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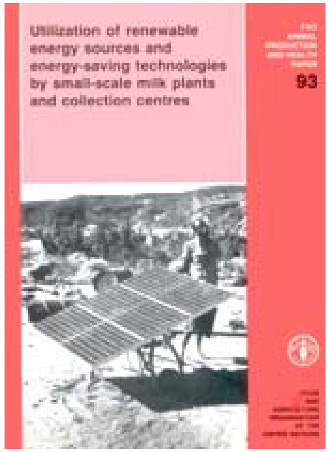

Utilization of renewable energy sources and energy-saving echnologies by small-scale milk plants and collection centres

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delimitation of its frontiers or boundaries.

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FOREWORD

This publication of the Meat and Dairy Service of the Animal Production and Health Division was prepared with the active cooperation of the Research and Technology Development Division. It gives the theoretical background to the use of renewable sources of energy in the

collection, storage and processing of milk and outlines some applications. It is hoped that future publications will develop and refine these applications to facilitate smallholder dairy development.

Acknowledgemts: The author would like to thank Gustavo Best for his comments on this report and Sharon Krenger for revising the text.

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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1. INTRODUCTION

This report is meant to be a brief guide to energy sources and technologies. The goal is to provide basic indications for an analysis of problems connected with the supply of energy (especially renewable sources) to small and medium-sized milk plants (500–2000 1/day).

In preparing this report, the requirements of the following users were taken into consideration:

a. **public sector researchers, whose task it is to identify those energy sources best suited for** employment by milk plants (and confirm their findings through subsequent studies by experts in the field) and evaluate plant proposals put forward by third parties;

b. extension service trainers, who must be supplied with practical data and information;

c. engineers in general, who are tackling the problem of energy supplied to milk plants for the first time.

The following subjects are discussed:

d. energy consumption in the production of the most important milk and cheese products;
e. renewable energy sources considered to be best suited to the processes under examination;
f. technologies designed for energy savings and employment of the sources mentioned in point e);

g. a method, currently under study at the Institute of Agricultural Engineering at the University of Milan, for the economic analysis of energy plants.

This discussion is followed by an example, which should clarify the concepts explained in the previous sections.

In addition, summaries are provided to simplify presentation of the various sources and technologies. The purpose of these summaries is to supply:

h. basic data for all types of evaluations;
i. the applicative limits of sources and technologies;
j. managerial problems;

k. the technological level of workshops that are suitable for the manufacture of various

k. the technological level of workshops that are suitable for the manufacture of various plants.

Special attention has been paid to problems that may arise as a result of the adoption of renewable energy sources. Indeed, one of the reasons why these sources are rarely employed today is the fact that farmers know little about their practical application.
Finally, the appendix provides information about the terminology used so that linguistic ambiguities are eliminated as much as possible.

It should be stressed that actual construction proposals that are recommendable for specific social and climatic contexts can only provided after further studies, in which the technological level of equipment used in milk processing can also considered with more attention.
It should also be noted that the costs of various technologies are not supplied here because of their extreme variability from one situation to another.
However, the aim has been to provide the reader with the necessary elements for an initial cost evaluation comparing those technologies with which he is familiar.

Thus, our hope is that this report proves to be a sufficiently flexible and valid work tool.

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2. ENERGY PRODUCTION AND ASPECTS CONCERNING THE USE OF RENEWABLE SOURCES

2.1 Basic Concepts (see Appendix 1 for definitions)

Energy is an essential element in all productive processes. In both the agricultural and transformation industries, however, its irreplaceable importance is often underrated. Indeed, in richer countries it may be observed that energy:

a. **often does not have a significant impact on production costs (generally 5–10%);**
b. **at present is easy to find;**
c. **does not pose important technical problems.**

On the other hand, energy becomes a priority when one of these conditions no longer holds, which is the typical situation in developing countries.

The question of energy supply and the choice of related technologies is generally tackled using quite different criteria, depending on the existence or absence of grids for the continuous supply of energy (e.g., electric grid, methane pipelines, etc.).
In the latter case, the main problem concerns the technical aspects connected with energy self-sufficiency (i.e., essential requirements will have to be met even at high costs).

In the former case, however, the following factors are determinant:

d. **the price of energy from the grid;**
e. **the convenience and reliability of the service;**
f. **the risks connected with individual energy production.**

In addition, situations which fall somewhere between these two extremes also exist. An

example which is particularly common in some countries is connection to the electric grid, with simultaneous individual production of thermal energy. The user is always willing to evaluate various plant designs for the latter type of energy, and his final choice is not always the most economical or rational plant (indeed, expensive features, such as increased functional reliability, may be considered useful).

In summary, when connection to a grid is possible, the supply of energy is usually based on strictly economical considerations, while in other cases a wide range of situations may exist, which have to be examined on a case by case basis.

This fact is extremely important when it comes to selecting energy conversion technologies.

In all cases, the supply and production of energy pose two types of problems:

g. **possible modification of existing energy plants;**

h. **choice of the most suitable source and energy plants (in case of absence or complete reconstruction of the plants themselves).**

2.2 Existing Plants: Criteria for Action

Existing plants are frequently the basis for operation.

This is the case when productive activities have been functioning for some time, and all of their technical aspects have been resolved (though perhaps temporarily or improperly).

In this context, the various energy plants could be re-examined for any one of the following reasons:

a. **the energy sources employed are no longer compatible with certain environmental aspects (e.g., the use of wood in areas subject to deforestation);**
b. **the produced energy is too expensive;**

c. **the negative influence of these plants on actual processing or the quantity of product obtained (e.g., a boiler which is too small to guarantee a consistent level of pasteurization).**

Experience has shown that:

d. **in case a), the energy source has to be replaced by one that is more suitable; in the majority of cases, this requires the choice of a new energy plant (see section 2.3);**
e. **in case b), the economic incidence of the energy may be related to the high cost of the source (e.g., small quantities of Diesel fuel that have to be transported long distances) or the excessive employment of labor. Cost reductions may be obtained:**
    - **by changing the energy source (again requiring a new plant; see section 2.3);**
    - **by increasing the efficiency (or level of automation) of the existing plant;**

f. **in case c), solution of the problem may require repair of a plant malfunction or, once again, a new plant.**

In all three cases, before formulating a work hypothesis, it is good practice to determine:

g. **the consumption levels of the technologies currently in use for the supply of energy, broken down by energy source (e.g., wood, Diesel fuel, etc.);**

h. **requirements (which, as noted in section 3, are proportional to the quantities of milk processed or transformed), broken down by type of energy (electric energy, low temperature thermal energy, etc.).**

The next step is to determine whether consumption levels and requirements are compatible (i.e., acceptable) in terms of:

i. **current energy costs (in other words, their incidence on the final product should be evaluated);**
j. **the quality of the sources employed (e.g., a Diesel fuel boiler may be considered inadequate for the type of fuel used; in fact this fuel is generally considered adequate just for engines);**
k. **conversion efficiencies (if they are too low, it is always worthwhile to consider alternative plants, at least from an economic standpoint);**

l. **environmental impact (generally based on the use of biomass or the elimination of refluents of some types of energy transformations).**

The proposed method of analysis can lead to two results:

m. **the existing plant (which may already employ renewable energy, as in the case of a wood boiler) merely requires limited modifications that do not alter its basic set-up. In this case, it is always a good idea to evaluate the benefits that could be provided by rationalizing the users (e.g., by modifying the time-table of daily operations), to obtain:**
   - **a reduction in the number of user points;**
   - **improved employment of labor;**

n. **the existing plant requires radical alteration. In this case, the situation is similar to the one described in section 2.3.**

2.3 Selection of the Most Suitable Sources and Energy Plants

Both renewable and conventional energy sources may be considered in the various hypotheses. At this point, two questions must be asked:

a. **what criterion should be adopted for selection of the most suitable source?**

b. **which of the available renewable sources should be preferred?**

Logically, choices a) and b) should be made solely on the basis of economic criteria. In other words, the most suitable source is the one that is the most advantageous and attractive from an economic standpoint. At most, a decision has to be made about whether the analysis should involve individual plants (microeconomic analysis in which the number of variables is generally limited) or entire regions or nations (macroeconomic analysis in which the number of variables is usually quite high).

When drawing up a list of the various energy sources to be considered in a technical-economic analysis, the following aspects should be included:

c. **traditional sources (i.e., common sources that are willingly accepted by the user). These sources may be renewable or conventional, and they are the "standard" solution in this case (one of these sources could be the "reference" solution for the method described in section 7);**

d. **available renewable sources. These sources should be determined by an analysis of the pedologic and climatic conditions of the site under examination (generally, they are connected with the presence of rivers, windiness, solar radiation, etc.). Since milk processing normally continues throughout the year, sources whose energy intensity remains fairly constant in every season should be preferred.**

Once the most suitable sources have been chosen, the right technologies for energy conversion must be selected. As mentioned above, this phase is influenced by the presence or absence of grids for the continuous supply of energy.
In the latter case, reduction, when possible, of the peaks of energy demand is especially important. This will limit the size of the generators and increase their use.
At this point it may be necessary to examine the possibility of carrying out rationalization operations aimed at increasing the compatibility of requirements and available energy. These operations may involve the adoption of energy-saving technologies (e.g., heat recovery from refrigeration, to be used for the production of sanitary hot water) or the drawing up of special time-tables for cheese production.

The choice of conversion technologies is mainly influenced by:

- **the availability of sources;**
- **their compatibility with requirements;**
- **energy costs;**
- **the availability of conversion technologies;**
- **investments and maintenance requirements;**
- **environmental impact;**
- **legislation in force (e.g., with reference to safety standards);**
- **the engineer's and user's opinions on the subject;**

- **the possibility of modifying milk processing or conservation plants in order to facilitate the introduction of a given source (as emphasized in section 3.1).**

In an attempt to provide objective data for evaluation, section 4 will discuss individual sources, and sections 5 and 6 will review various energy conversion technologies.

3. ENERGY REQUIREMENTS IN MILK PROCESSING

3.1 Introduction (see Appendix 1 for an explanation of the terminology used below)

This report considers only those energy requirements connected with milk processing. In fact, the following forms of energy consumption are not considered:

a. **indirect;**

b. **related to the production of milk on the farm and its transport to processing centers.**

It is not a simple matter to provide information which is valid for all situations. Indeed, practice has shown that energy requirements and the types of energy used are highly dependent on the technological level of the equipment used at the processing center. For example, in the case of home cheese production, the milk container is heated directly over the flame (using wood).

In this context, it may be observed that:

c. **the energy used is almost exclusively thermal;**
d. **the system's efficiency is limited (the ratio of energy requirements to energy consumption, in fact, is on the order of 10–15%);**

e. **electricity is used little or not at all (the milk is manually stirred and poured from one container to another).**

On the other hand, the following situation characterizes a modern cheese factory:

f. **thermal energy consumption is generally low, since high efficiency generators and heat recovery are used (unless particular, energy-intensive techniques are employed, such as the production of powdered milk);**

g. **electric energy consumption is significant as a result of milk chilling (using refrigeration equipment) and the widespread use of electric machinery (pumps, stirrers, etc.).**

In any case, it was impossible to consider anything other than <u>modern</u> <u>plants</u> (though of varying complexity and completeness) in this report. The reasons for this are obvious:

h. **only modern plants are capable of guaranteeing quality, hygienic final products and long-term uniformity in milk and cheese production;**
i. **milk refrigeration should be introduced in all rural settings, and this can only be made possible by the availability of plants which incorporate advanced technology. Under these conditions, both the necessary basis for a fresh milk market (highly requested in urban centers in poorer countries) and the opportunity for rural populations to finally leave behind the stage of familial self-sufficiency become possible;**
j. **the employment of rationally designed (i.e., modular) plants by individual countries may make it possible to plan the location of standardized processing centers in order to increase the probability of their successful introduction. In addition, standardization may lead to the development of local industrial activity based on the manufacture (at least partial) of the necessary plants;**

k. **all energy plants designed for the use of renewable sources have reached a certain**

k. all energy plants designed for the use of renewable sources have reached a certain technological level. This is true of even the simplest models.

In other words, the kind of engineering that goes into energy plants (e.g., solar collectors manufactured with locally produced components and used to heat water to 50°C) is decidedly more complicated than that required by simple milk-cheese plants (e.g., containers heated directly over wood fires).
Consequently, the possibility of using modern milk processing and transformation plants is implicit in any analysis of the possibility of producing energy. Indeed, it is logical to imagine a system in which energy and processing aspects are technologically compatible.

It should also be noted that the optimal use of energy sources would naturally lead to the modification of commercially available plants. For example, photovoltaic collectors would be better employed if the final users were direct-current electric motors (in order to do away with inverters and increase the plant's utilization factor). Another example concerns the use of 70–75°C water (instead of traditional steam) to heat milk, which would make it possible to employ relatively simple solar collectors.
It is clear, then, that the possible application of renewable sources is closely connected with the type and level of technology employed in the plants used to transform the milk.
Here, only brief mention is made of possible modifications of processing plants, since it is felt that the actual introduction of new technologies requires that their innovative impact be limited and spread out over time.

Finally, it should be observed that the use of modern technologies does not imply that poorer countries must be forced to import technologies; instead, this should be seen as an incentive to engage in semi-industrial activity (naturally in relation to available local labor), which could make it possible to create or consolidate commercial activities in rural areas.

3.2 Energy Requirements

In evaluating energy requirements, direct reference has been made to a study carried out by the FAO [49].
The results are provided below.
Here, reference is made to thermal and electric requirements (and not consumption). The former concern water-milk or steam-milk heat exchangers, while the latter relate to the electric motors found in normal milk-cheese plants (e.g., pumps, stirrers, refrigeration plant compressors and various servomechanisms).

<u>Requirements</u>, and not consumption, are examined for the following reasons:

a. **these plants should be viewed as equipment which has already been perfected and for which substantial modifications are not suggested (at least in principle and during the initial phase, as noted above). Attempting to modify the traditional set-up of these plants would, in fact, mean increasing their cost, since non-standard modifications would be required;**

b. **the energy consumption of electric motors (e.g., cooling plant compressors) and heat exchangers (e.g., to heat water and milk) has to coincide with the output of electric or thermal generators. Therefore, this output represents the share of energy that has to be provided.**

The analysis carried out in this section considers two basic operations:

c. **milk collection (refrigeration and supplementary treatments);**

d. **milk processing (milk packaging, production of cheese, yogurt, etc.).**

The energy consumption of centers whose plants are at varying levels of completeness are analyzed for each individual operation. In terms of point c), these include:

c1) modern collecting centers for chilling only;

c2) modern collecting centers for chilling and container washing.

For point d), they are:

d1) plants with modern equipment (complete or simplified);

d2) centers using electric energy only.

3.2.1 Milk Collection

Modern collecting centers for chilling only (medium-sized and large scale)

Refrigeration of one ton of product generally requires 100–120 MJ of electric energy. The energy is needed to remove heat (using icebank or direct expansion refrigeration systems), stir the milk and pump water to wash containers or equipment (approximately 150 l/t of milk).

Modern collecting centers for chilling and container washing (small scale)

Farmers bring their milk to these centers in small containers (quantities normally range from 1–2 to 100 1); the milk arrives at a temperature which is slightly lower than that of the freshly obtained product. Electricity consumption connected with refrigeration (including stirring and pumping) is higher than that noted above (120–145 MJ/t) because of the plants' increased energy losses and low utilization factors. In addition, approximately 25 MJ of thermal energy

per ton of milk should be added for container washing (water consumption may reach 300 l/t of milk in these types of plants).
By way of comparison, the consumption of electric energy is limited to approximately 65–85 MJ/t in large industrial plants (to which approximately 25–30 MJ/t of thermal energy must be added).

3.2.2 Milk Processing

Centers using modern equipment (complete or simplified)

Analysis has been restricted to small and medium-sized centers using electricity, low pressure steam boilers, simple filling and sealing machines and pasteurizers (usually batch type).

In the case of simple plants (with milk packaged in plastic containers), the following requirements have been estimated:

- pasteurization:	180 MJ of thermal and 90 MJ of electric energy;
- cheese and yogurt production:	180 MJ of thermal and 90 MJ of electric energy.

In the case of complete plants (the type that is generally used in Europe and produces bottled milk), the requirements are the following:

- pasteurization:	600 MJ of thermal and 200 MJ of electric energy;
- cheese and yogurt	450 MJ of thermal and 270 MJ of

production: electric energy.

Centers using electric energy only (without steam)

These plants have been created solely for the packaging of non-pasteurized milk. Their electricity consumption is estimated to be on the order of 120 MJ/t of final product.

3.2.3 Observations

The electric energy consumption and thermal requirements mentioned above are summarized in Table 1, which also contains data on the production of condensed milk. By way of comparison and in order to supply information about other products, Table 2 also provides typical values for complete modern plants (data obtained from developed countries). Based on the comments made earlier and with reference to the most important cheese products, only two kinds of plants have been considered in order to make summary evaluations possible:

a. **complete modern plants;**

b. **simplified plants.**

In both cases, milk cooling (plus equipment and container washing) and pasteurization are the operations carried out.

Using the following terms (quantities in t/day):

m_c: chilled milk;
m_p: milk packaged in small containers (i.e., pasteurized);

m_t: milk processed into yogurt or cheese (not including whey processing);
m_e: condensed milk.

As well as (values in MJ/t of processed milk):

E_e: electric energy requirements;
E_t: thermal energy requirements.

An initial approximation shows that for type a) plants:

$E_t = 25m_c + 600\ m_p + 450m_t + 1060\ m_e$

$E_e = 110m_c + 200\ m_p + 270m_t + 220m_e$ [MJ]

and for type b) plants:

$E_t = 25m_c + 180\ (m_p + m_t)$

$E_e = 145m_c + 90(m_p + m_t)$ [MJ]

For example, using a simplified plant working on the following quantities:

- **500 1/day of fresh milk (pasteurized);**
- **700 1/day processed into cheese.**

The related thermal and electric energy requirements are:

E_t = 25×0 + 180 (0.5+0.7) = 216 MJ/day
E_e = 145×0 + 90 (0.5+0.7) = 108 MJ/day

and using a complete plant:

E_t = 25×0 + 600×0.5 + 450×0.7 + 1060×0 = 615 MJ/day
E_e = 110×0 + 200×0.5 + 270×0.7 + 220×0 = 189 MJ/day

It may be observed that consumption largely depends on the final destination of the milk that comes into the center. To illustrate this aspect, Figures 1, 2, 3 and 4 show the maximum and minimum requirements of centers with a daily intake that ranges from 500 to 2000 1 (excluding the production of condensed milk).
In the case of both simplified and complex plants, the maximum and minimum thermal and electric requirements are measured for simple cooling and complete pasteurization (or processing) of all the available milk. For example, with reference to the figures provided above and with 1000 1/day of milk (simplified plant), the electric and thermal requirements would range from 90–140 and 24–180 MJ/t of fresh milk, respectively. In the case of complete plants, these figures would be 25–600 and 100–240 MJ/t, respectively. The energy plants will be dimensioned later on the basis of the variations illustrated by the figures.

Table 1 - Specific energy requirement in milk collection and processing (from [49], modified)

Final product	Plant type	Energy requirement [MJ/t of milk]

		Heat	Electricity
collected milk	A	-	100–130
	B	25–30	120–150
milk in bottles	C	600	200
	D (1)	-	120
	E	180	90
Cheese, yogurt (2)	C	450	270
	D	180	90
Condensed milk	C	1060	220

(1) unpasteurized
(2) without whey processing
A: collecting centres with chilling only
B: collecting centres with chilling and can washing
C: plants, large or small, with modern and compléte equipment
D: centres with electric power but without steam
E: centres with a varying degree of simple mechanization usingelectric power and steam (simplified plants)

Table 2 - Specific energy requirement in modern milk processing plants (from [49], modified)

Final product	Energy requirement [MJ/t of milk]	
	Heat	Electricity
Milk in bottles:		
- pasteurized	600	200
- sterilized	720	250
Milk in one-way containers:		
- pasteurized	250	180
- UHT	360	325
Skim milk powder and butter:	2100	325
Full cream milk powder:	1900	290
Ripened cheeses:		
- without whey processing	450	270
- with whey processing	1660	360
Evaporated and condensed milk:	1060	220

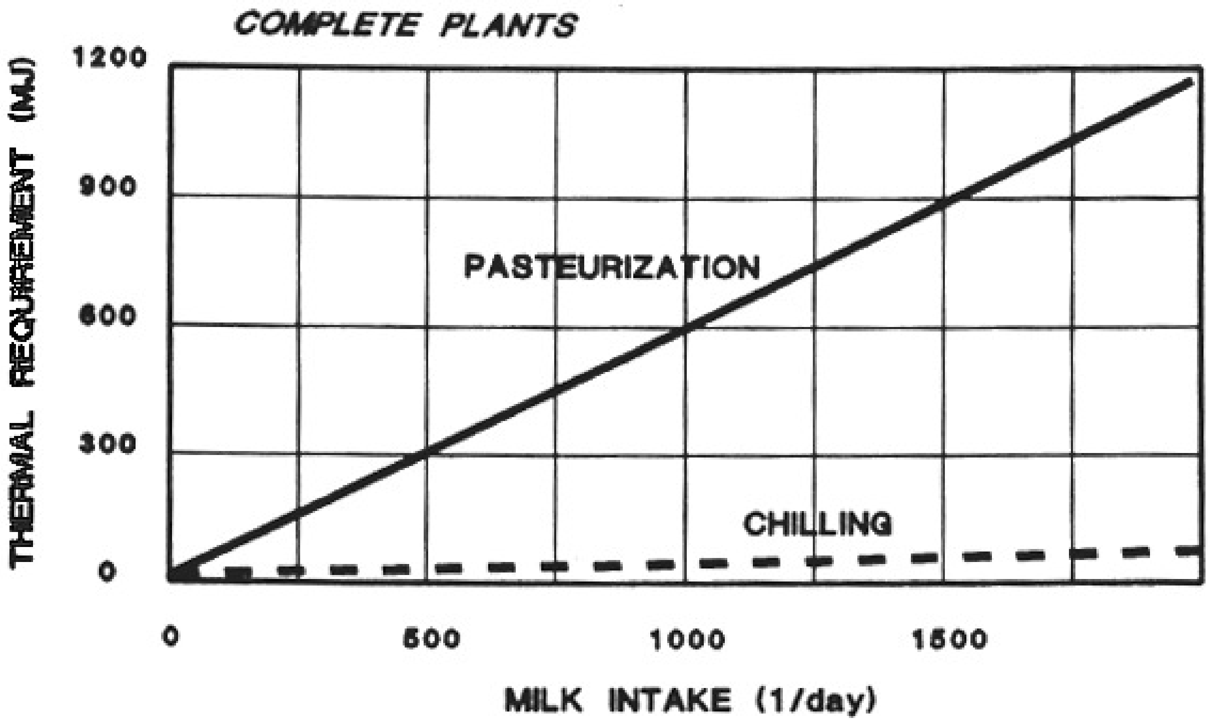

Figure 1 - Thermal requirements versus daily quantity of milk processed in complete plants. The lower line represents the energy requirements of chilling alone (sanitary hot water for washing), while the upper one represents pasteurization, which requires more energy.

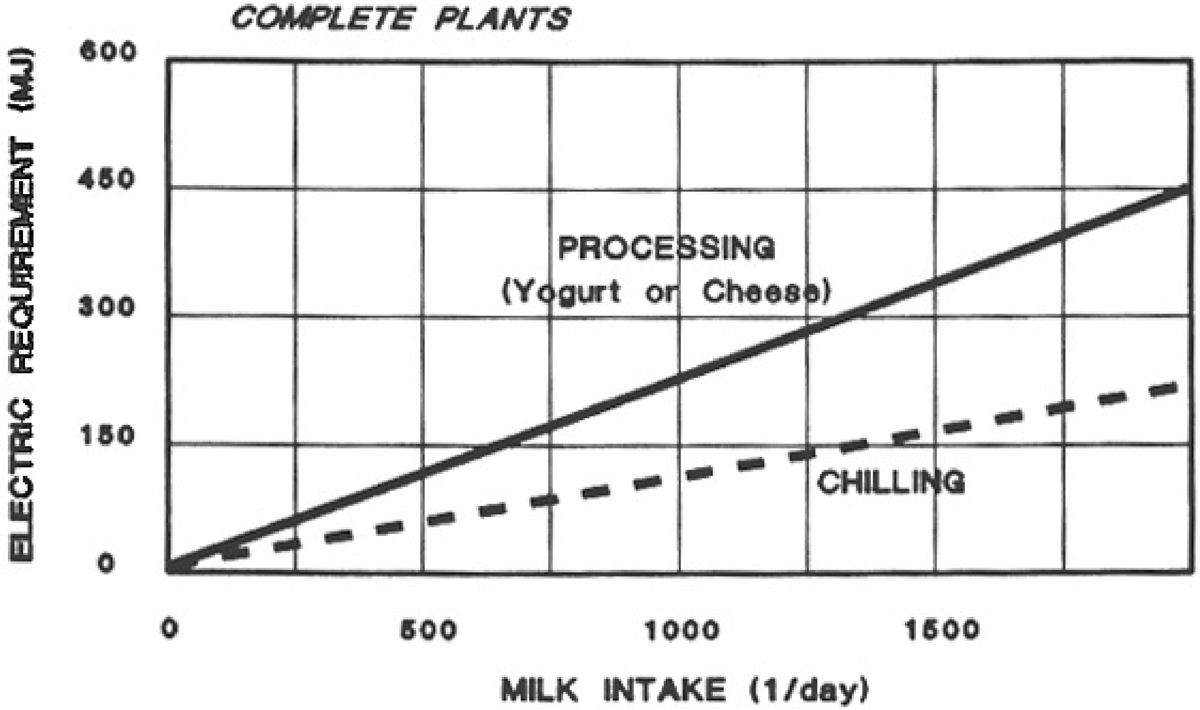

Figure 2 - Electric requirements versus daily quantity of milk processed in complete plants. The lower line represents the energy requirements of chilling alone, while the upper one represents the production of yogurt and cheese, which requires more energy.

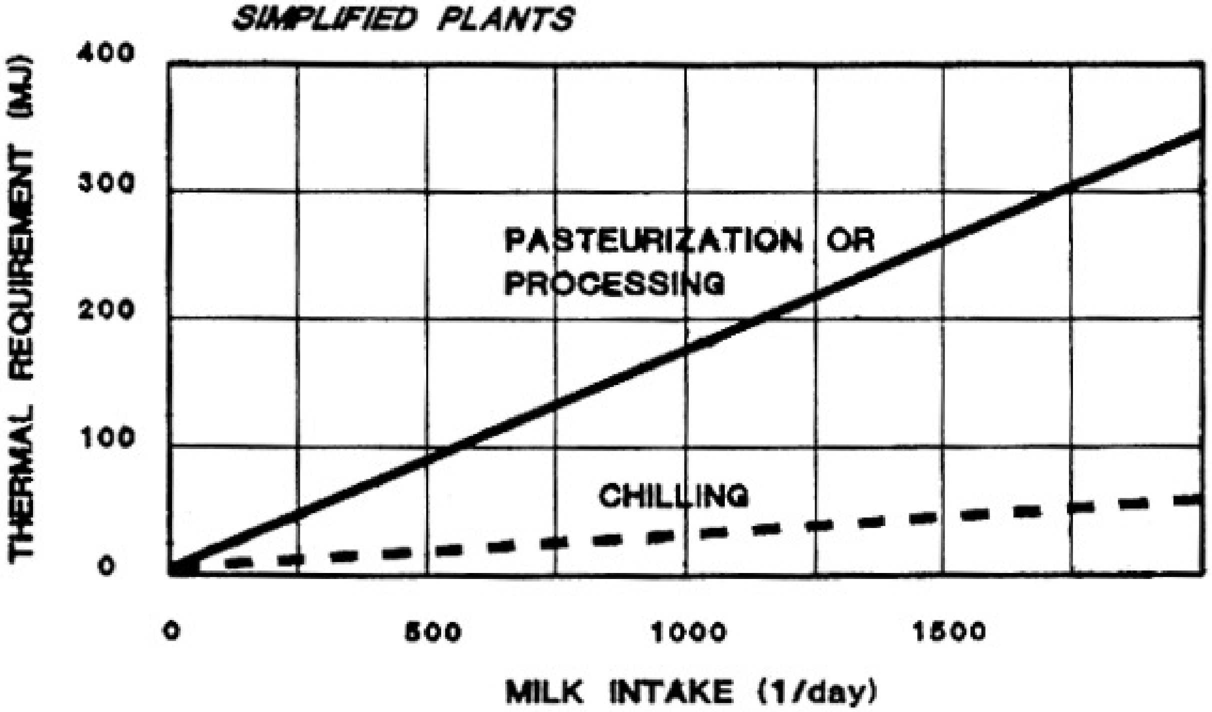

Figure 3 - Thermal requirements versus daily quantity of milk processed in simplified plants. The lower line represents the energy requirements of chilling alone (sanitary hot water for washing), while the upper one represents the pasteurization or the production of yogurt and cheese, which require more energy.

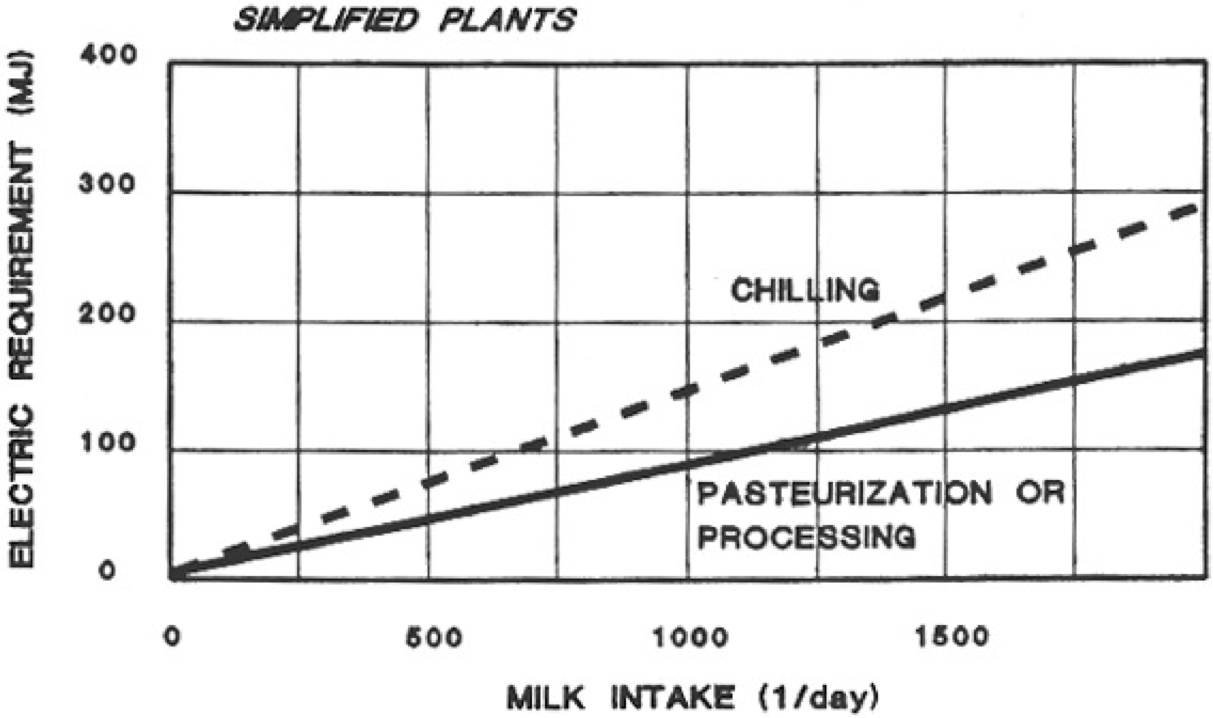

Figure 4 - Electric requirements versus daily quantity of milk processed in simplified plants. The lower line represents the energy requirements of the pasteurization and of the production of yogurt and cheese, while the upper one represents the chilling, which require more energy.

3.3 Comments on Renewable Sources in Relation to Their Use in Milk Treatment and Processing Centers

Energy is used on three qualitative levels at milk treatment and processing centers.

Specifically, energy is used in the form of:

a. **hot water, heated to temperatures under 80°C (low temperature washing and processes);**
b. **steam at various temperatures and pressures (the traditional energy medium for all**

treatments and processes). As mentioned above, steam may be replaced (with slight plant modifications) by water heated to 80–90°C;

c. **electricity (220 or 380 V).**

It should be observed that the availability of a heat-carrying fluid and electricity is essential.
Low-temperature water could be generated (at least partially) from process waste.
If our analysis is limited to actual practice, this type of situation would lead us to consider only a small number of sources and, most importantly, a limited number of energy conversion technologies.

In fact, for the production of low-temperature hot water, the following technologies may be considered:

- **flat solar collectors made with locally produced components;**
- **recuperators to be installed on electricity generator sets (cogeneration);**
- **recuperators to be installed on refrigeration equipment condensers (to transform them into heat pumps);**
- **exchangers operating on geothermal fluids (when available).**

For the production of steam (or average-temperature water at 80–90°C), these technologies may be evaluated:

- **boilers fed by gasification or biological gas (produced by the anaerobic fermentation of animal waste);**
- **boilers fed by biomass;**
- **electricity, which voltage and frequency are not regulated, produced by wind generators, wheels or water turbines.**

Consideration of unusual technologies for the production of thermal energy (i.e., electric generators) is justified by the very real possibility of discovering significant water resources quite near treatment and processing centers. Naturally, this solution would only be useful (since it would simplify plant design considerably) in the case of reduced thermal power requirements or if special kinds of thermal storage were employed.
In addition, it is obvious that technologies that are suitable for average-temperature energy production can also be used for low-temperature production.

The following technologies may be considered for electricity production:

- **generators combined with Otto engines fed by gasification or biological gas (the use of Diesel engines is also possible with the dualfuel system);**
- **generators combined with steam or Stirling engines fed by any kind of fuel (including solid);**
- **generators combined with wind or water mills;**
- **photovoltaic solar collectors.**

Naturally, it would be logical to concentrate on technologies that offer the possibility of meeting all the user's energy requirements with a single, easily obtainable source. An example of this type of technology is the steam engine.

Technologies which are considered to be experimental or impractical are not analyzed here for obvious reasons. For example, focusing collectors (for generating average-temperature thermal energy or even electricity) require significant maintenance, meticulous plant design and efficient heat storage and are not easy to find on the market. Their on-site construction (in significant quantities and with a high level of quality and completeness) may pose problems. Similarly, steam or organic fluid turbines are not discussed.

Sections 5 and 6 contain information about the considerations that have led to selection of the technologies listed above.

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4. RENEWABLE SOURCES: CHARACTERISTICS AND AVAILABILITY

4.1 Introduction and Definitions

The basic characteristics of each source, methods for evaluation of its energy potential and the extent of its availability are discussed below.
A summary table containing all the characteristics required for a clear understanding of the most important aspects connected with the source's use in milk processing is also presented.
The following is an outline of the table, including definitions of the headings used:

Summary Source Table:	identification

a. **operative flexibility: flexibility means the possibility of using the source as desired. For example, biomass is a very flexible source, since it can be obtained when needed, is easy to accumulate and can generate as much energy as required. On the other hand, solar energy is highly inflexible.**

b. **availability: information is provided about areas in which the source under examination**

may be considered relatively abundant.

c. **essential data for preliminary evaluation: that is, the minimum information to be provided to an expert for the design of energy conversion plants.**

d. **typical energy intensity values: data that would enable anyone to make preliminary evaluations.**

e. **share (%) recoverable for the production of energy in the form of:**

1 - water at 40–70°C	2 - steam(*)	3 - electricity
______	______	______

Positions 1, 2 and 3 give the percentage of energy recoverable using common energy conversion technologies (on the source under examination) for the production of hot water, steam and electricity. The values are averages and refer to actual situations.

f. **figure calculated from the characteristics of the source, needed to meet the energy requirements of a center with a daily milk intake of 1000 l/day** (**)
(unit of measure:____________):

Simplif. Proc. Plants		Complete Proc. Plants	
Thermal req.	Electric req.	Thermal req.	Electric req.
______	______	______	______

This section gives an indication of the degree to which the source may be utilized to meet the processing and treatment requirements of 1000 1/day of milk. Values relating to

thermal energy tend to vary widely as a function of the type of process; minimum values refer to plant washing alone (necessary if refrigeration is the only process involved), while maximum values refer to pasteurization of all the milk. In practice, minimum and maximum values reflect the two extremes (lowest and highest, respectively) of the energy requirements of 1000 1 of milk, shown in Figures 1 and 3. Naturally, a more precise value can be calculated using these figures and simple ratios. The same is true of electric energy (Figures 2 and 4).

g. remarks: miscellaneous information.

(*) low-pressure, or in some cases water heated to 80–90°C
(**) with different intake levels, use proportional values

4.2 SOLAR ENERGY

4.2.1 Basic Characteristics

Solar energy is the perturbation emitted by the sun following the thermonuclear reactions that occur in its interior (the resultant power having an effect on the earth is estimated at 1.8×10^{17} W). There are two interpretations of this phenomenon, which are called the corpuscular and undulatory theories. The former involves a flow of particles (photons), while the latter is based on electromagnetic radiation. These interpretations explain the photoelectric effect and optic phenomena, respectively.

Outside the earth's atmosphere, radiation is practically constant over time, but on the earth it is highly variable. The reason for this is:

- the position of the earth's axis with respect to the sun;

- **the latitude of the receiving surface;**
- **the time of day.**

These factors affect the thickness, s, of the air which the radiation passes through. This in turn determines the amount of energy lost, which is mainly due to air molecules and the presence of steam and atmospheric dust. In other words, the larger the value of s, the more the radiation is weakened.

The following distinctions are generally made: direct radiation (coming from the sun without any deflection) and diffuse radiation (subjected to deflection and scattering). The former casts distinct shadows, while the latter uniformly illuminates an object. The sum of these two types of radiation is the total radiation.
On clear days, scattered radiation represents 20–22% of the total, while it represents 100% on cloudy days.
Insolation (or sunshine or duration of the sun) represents the number of hours per day, month or year in which there is direct radiation.

4.2.2 Measurement and Evaluation Methods

The term solar radiation can represent both the thermal power supplied by the sun and the energy made available to one m^2 of surface area during relatively long periods of time (day, month or year). Consequently, it is important to clearly specify the unit of measure adopted.

Total radiation is measured by pyranometers. These instruments link radiated energy to the difference in temperature between a black surface and a light colored surface, both of which are exposed to radiation (or the difference between a black surface and the environment). Scattered radiation can be evaluated by screening the pyranometer's sensor (so that it is only

illuminated by light from the sky and the reflection from the surrounding objects), while direct radiation can be measured through difference (in this case, two instruments are needed). Sensors based on the photoelectric effect or the sensitivity of some solar energy resistors are also available.

4.2.3 Availability

Outside the earth's atmosphere, the power of radiation is 1.35 kW/m^2 (solar constant). Seasonal variations are limited.

On the earth's surface, its power varies from 0 to 1 kW/m^2. The energy produced by radiation is influenced by the latitude, the local climatic conditions and the position of the receiving surface (orientation and slope with respect to a horizontal plane).

Average daily radiation on a horizontal plane is usually available for each month (see summary table).
It is always important to determine whether these values have been measured or calculated (by simulation models).
The validity of the latter data is closely connected with the programmer's skill (since the must also be aware of the site's climatic characteristics), and these data are acceptable for comparative evaluations only.

References: [9], [13], [17], [21], [29], [37], [40], [43], [44] [49], [50].

Summary Source Table:	**SOLAR RADIATION**
a) operative flexibility:	very poor

b) availability: generally good at sites whose latitude is between 35°N and 35°S

c) essential data for preliminary evaluation: average monthly radiation values on a horizontal surface

d) typical energy intensity values:

• maximum power:	1 kW/m^2
• maximum daily radiation:	25–30 MJ/m^2
• average annual radiation in the Tropics:	17–22 MJ/(m^2.day)

e) share (%) recoverable for the production of energy in the form of:

1 - water at 40–70 fC	2 - steam (*)	3 - electricity
40–60	15–20	5–10

f) figure calculated from the characteristics of the source, needed to meet the energy requirements of a center with a daily milk intake of 1000 1/day (**)

(unit of measure: m^2 of receiving surface):

Simplif. Proc. Plants		Complete Proc. Plants	
Thermal req.	Electric req.	Thermal req.	Electric req.
4.30	60–90	4–100	80–160

g) remarks:

Reference is made to average Tropical conditions (results are also valid for summers in many other locations).

(*) low-pressure, or in some cases water heated to 80–90°C

(**) with different intake levels, use proportional values

4.3 WIND ENERGY

4.3.1 Basic Characteristics

Solar energy absorbed by the earth produces the upward motion and expansion of air which create areas of high and low pressure.
The latter contain air currents (winds) whose direction is influenced by the earth's rotation and the force of gravity.
The kinetic energy in these currents is called wind energy.
The horizontal component of wind speed is generally larger than the vertical component. There is a negative and positive correlation, respectively, between the two components and the ambient temperature. The vertical component always generates weather disturbances (gusts or blasts of wind, etc.).
The horizontal component, V, equals zero at ground level (z=0) and varies according to an undefined law until it reaches the top of any obstacles it encounters (trees, buildings, hills, etc.). It then follows a curve represented by the expression:

$$V = V'^{*}\ 1n[(z-d)/z'],$$

where:

V′ is the speed at $z \rightarrow \infty$;
d is a value which is slightly lower than the height of the obstacles;
z′ is a coefficient that depends on the irregularity of the contour of the land.
Standard meteorological data refer to the wind speed measured at a height of 10 m (Vs).

The speed V can be evaluated at height z by using the equation:

$$V = Vs^*(z/10)^n$$

where n = 0.143 for open spaces. This equation is used to obtain an initial orientation (n varies during the course of the day and according to the season) and when z < 50 m.

In addition, the behavior of the wind speed over time (on an annual basis) is an essential element.
Experience shows that the distribution of the probability φ_V that a given V will occur can be estimated by using Weibull's function:

$$\Phi_V = \frac{k}{c} * \left(\frac{V}{c}\right) * \exp\left[-\left(\frac{V}{c}\right)\right]$$

and that the probability φv of there being a V > V′ is equal to:

$$\Phi_{V>V'} = \exp\left[-\left(\frac{V'}{c}\right)\right]$$

where:
k may vary from 1.6 to 3;
$c \simeq 2V_m / \sqrt{\Pi}$
V_m is the average speed at the site.

When k=2 (an acceptable value in the majority of cases), Weibull's function is the same as

Rayleigh's function:

$$\Phi_V = \frac{\Pi V}{2 V_m^2} \exp\left[-\frac{\Pi}{4}\left(\frac{V}{V_m}\right)^2\right]$$

$$\Phi_{V>V'} = \exp\left[-\frac{\Pi}{4}\left(\frac{V'}{V_m}\right)^2\right]$$

In addition, the maximum value of φ_V is reached when V=0, 8*V_m. Therefore, knowing V_m is sufficient for obtaining preliminary values. The directional distribution of the wind is also important.

4.3.2 Measurement and Evaluation Methods

Wind energy is calculated on the basis of knowledge of the wind speed, V. Anemometers placed at a height of 10 m are normally used to obtain this value. These instruments provide a signal (usually an impulse) which is proportional to the number of rotations.
Readings should be taken continuously so that fluctuations in wind speed and direction (which have a significant impact on, processing efficiency and the machine's endurance strength) can be evaluated.

The power P_V of wind with a speed V is equal to:

$$P_V = A\mu V^2/2 = 1.24{*}AV^2/2 = 0.62{*}AV^2 \qquad [W]$$

where:
μ is the mass of a unit volume of air;

A is the area of the section under consideration (perpendicular to the wind's flux lines).

In the usual case of circular sections with a diametre D:

$$P_V = 0.487 * V^2 D^2 \qquad [W]$$

The average power P_m may be calculated by considering the average speed V_m during the time period under examination. In fact, it can be shown that:

$$P_m \simeq \mu A(V_m)^3 = 1.24 * A(V_m)^3 \qquad [W]$$

Going back to the distribution of Weibull's and Rayleigh's functions, the product P $*\Phi_V$ represents the distribution of the various wind powers as a function of V.
The maximum value of $P_V * \varphi_V$ is obtained when $V=1.6*V_m$.

Evaluation of the duration of periods in which $V \simeq 0$ is also very useful. In actuality, when V_m>12 m/s, some P_V is always present. When $5<V_m<8$ m/s, periods of $P_V \simeq 0$ are brief; when V_m<5 m/s, the duration of periods in which $p_V \simeq 0$ may be unacceptable.

4.3.3 Availability

It is estimated that approximately 1% of the solar energy that reaches the earth is transformed

into the kinetic energy of wind ($1.2*10^{15}$ W). Wind energy is generally available along the coast.

References: [9], [20], [27], [36], [50].

Summary Source Table:	**WIND**

a. **operative flexibility: average only in “windy” places**

b. **areas of acceptable use: anywhere, as long as the average wind speed is equal to or greater than 5 m/s**

c. **essential data for preliminary evaluation: average annual speed; information about the duration of periods in which there is no wind**

d. **typical energy intensity values:**

- **annual energy available at an average speed of 5 m/s: 490 MJ/m^2 of surface perpendicular to the wind flux**

e. **share (%) recoverable for the production of energy in the form of:**

1 - water at 40–70°C	2 - steam (*)	3 - electricity
10–15	10–15	10–15

f. **figure calculated from the characteristics of the source, needed to meet the energy requirements of a center with a daily milk intake of 1000 1/day (**)**

(unit of measure: m^2 of surface receiving the wind at 5 m/s):

Simplif. Proc. Plants	
Thermal req.	Electric req.
60–450	250–450

Complete Proc. Plants	
Thermal req.	Electric req.
60–1500	250–700

g. **remarks:**
The contributions made by wind energy are highly dependent on the average speed at the site.

(*) low-pressure, or in some cases water heated to 80–90°C
(**) with different intake levels, use proportional values

4.4 HYDRO ENERGY

4.4.1 Basic Characteristics

The term hydro energy is used to indicate the potential energy that a stream loses (turning into kinetic energy) as a result of a head or sloping course.

The following aspects are important for the utilization of this source:

a. **the water's flow rate and how it changes over time;**

b. **the usable head.**

The flow rate of natural streams generally depends on:

a. **the surface of the catchment basin (i.e., of the entire area from which water flows as a result of a natural slope);**
b. **soil permeability;**
c. **existing vegetation;**
d. **extent of rain and snow.**

If the stream is only fed by rain, the maximum flow rate occurs during rainy seasons (normally the spring and autumn); if, on the other hand, the stream is fed by glaciers or snow fields, the maximum flow rate occurs at the start of the summer, and the minimum flow rate is observed in the winter.

The volume of water that crosses a given section of the stream during a certain period of time (a month or a year) is called the discharge flow. Information on the discharge flow is generally available from national agencies; when data is lacking, however, direct measurements must be taken.
Official or measured data should make it possible to construct an average duration curve for the flow rate, which is essential for evaluation of the usefulness of energy transformation of this source.

The gross or geodetic head (H_O) represents the difference between the height of the water surface above and below the head. The latter value is usually considered to be small (low head) when $2<H_O<12$ m; it is considered average when $12<H_O<100$ m and large when $H_O>100$ m.

4.4.2 Measurement and Evaluation Methods

The power P generated by a water flow rate Q [m^3/s] with a head of H_O [m] is equal to:

$P=\mu QgH_o=1000*9.81*Q*H_o=9810*Q*H_o$ [W]

where μ is the mass of a$_2$ unit volume of water [kg/m^3] and g is the acceleration of gravity [m/s^2].

In the absence of official data, Q may be calculated in the following manner:

a. **for low Q's, by directing the entire flow rate into a container of known volume and measuring filling times;**

b. **for average Q's, by measuring the speed V_s of a floating object, two-thirds of which are submerged (e.g., a half-full bottle), in a part of the stream (e.g., 50 m long) which is sufficiently straight and has a constant cross-section. Assume that the stream's average speed V_m is around $0.8*V_s$ (the operation should be repeated several times in order to obtain a reliable figure). Then it is necessary to calculate the area A of that part of the bed by measuring the depth Z_n at various points which are Y_n from one bank:**

$$A \simeq Y_1Z^*{}_12+(Y_2-Y_1)^*(Z_1+Z_2)/2+(Y_3-Y_2)^*(Z_2+Z_3)/2+\ldots.$$

When the bed is irregular, the number of reading points should be increased. Therefore, $Q \simeq V_m*A$;

c. **for average and high Q's, through the use of a grate and a speedometer, or a standard size weir. In the latter case, Q is a function of the height of the stream through the section under examination (see specific manuals on the subject).**

All these methods provide an instantaneous value for the flow rate. The analysis should be continued for at least one year to determine the minimum and maximum values of Q. Calculation of H_O, on the other hand, is easier, and that value may be obtained by using normal topographic methods.

4.4.3 Availability

Calculation (and related energy evaluation) of heads that generate less power is practically impossible. This estimate is, especially complex since only heads that are an acceptable distance from potential users should be considered.

References: [3], [9], [15], [23], [24], [30].

Summary Source Table:	**HYDRO**
a) operative flexibility:	generally very high

b) areas of acceptable use: anywhere that a head with the required characteristics is available near a processing center (preferable distance < 500 m)

c) essential data for preliminary evaluation: changes in the water's flow rate over the course of the year

d) typical energy intensity values:

- power generated by 1 l/s that falls from 1 m:	9.8 W
- energy generated annually by 1 l/s that falls from 1 m:	309 MJ

e) share (%) recoverable for the production of energy in the form of:

1 - water at 40–70°C 70–80	2 - steam (*) 70–80	3 - electricity 70–80

f) figure calculated from the characteristics of the source, needed to meet the energy requirements of a center with a daily milk intake of 1000 l/day (**) (unit of measure: product flow rate*head in m^3/S):

Simplif. Proc. Plants		Complete Proc. Plants	
Thermal req.	Electric req.	Thermal req.	Electric req.
0.3-2.5	1.2-2.0	0.3-8.0	1.3-3-1

g) remarks:
It is assumed that the necessary energy can be supplied in three hours of generator functioning.

(*) low-pressure, or in some cases water heated to 80–90fC
(**) with different intake levels, use proportional values

4.5 GEOTHERMAL ENERGY

4.5.1 Basic Characteristics

In the innermost parts of the earth, temperatures of 4,000°C are reached and maintained by nuclear reactions (radioactive decay of uranium, thorium, potassium, etc.). This produces a gradient of less than 30°C/km (e.g., at a depth of 35 km, it is normal to observe a temperature equal to 500°C) and a thermal energy flux, calculated on the earth's surface, of 0.06 W/m^2.

Therefore, the average energy intensity of this source is negligible.

At some sites, however, 10–20 W/m^2 are reached at a depth of 5 km for sufficiently long periods of time (over 20 years). In these cases, 100 MW/km^2 are available in the form of a 50–70°C aquifer or, more rarely, a steam bed with a temperature ≥ 150°C.

The term geothermal energy is generally used to indicate the thermal energy available at a depth of less than 6 km.
From an energy standpoint, a temperature gradients G≥80°C/km (along the borders of tectonic plates, for example) is considered to be high. If 40<G<80°C/km, the temperature is average (the origin is due to irregularities in the earth's crust), and if G<40°C/km, the temperature is normal.

Fluids (liquids and steam) coming from geothermal basins almost always have a complex composition. This is because they contain a high number of minerals (alkali, sulfates, bicarbonates, etc.) and/or dissolved gas (CO_2, H_2S, CH_4, H_2, NH_3, Ar, Rn, etc.), which always pose problems for the plant (corrosion, encrustation, etc.).

4.5.2 Measurement and Evaluation Methods

At least two kinds of analyses are required:

a. **hydrogeological, for a determination of the flow rates of the available fluids, their operating temperature (i.e., in case of extraction) and any side effects (possible lowering of the aquifer, etc.);**

b. **chemical-physical, of the geothermal fluid for design of the user plant.**

Evaluation of the source's thermal power P (i.e., of the energy producible) is carried out on the

basis of:

c. **the maximum flow rate Q_{max} extractable (kg/s);**

d. **the maximum temperature head δT obtainable.**

Indeed:

$$P=c_sQ\delta T$$

where c_s is the fluid's specific heat (when liquid, consider the c_s of the water).

The value δT depends on the temperature T_s of the source and the temperature T_f to which the geothermal fluid is cooled ($\delta T=T_s-T_f$). T_s is a characteristic (not modifiable) of the site; T_f, on the other hand, is a function of the type of plant and user considered.
If $25<T_f<35$, only space heating is possible. If $80<T_f<120$, the generation of thermal energy and refrigeration is also possible. Finally, if $T_f>150$, electric energy can be generated.

4.5.3 Availability and Methods for Utilization

Geothermal energy is rare at high temperatures and relatively widespread at average and low temperatures.
The majority of uses involves the extraction of hot water, its cooling by an exchanger and its replacement in the aquifer.
The exchanger and the pump (often submergible) operating on the source must be suitable for the temperature and the chemical composition of the fluid.

Replacement of the fluid is required to prevent lowering of the aquifer and to solve the problem of disposal of the refluent (which is usually considered to be a pollutant).

Wells for extraction and replacement must be sufficiently far away from each other and correctly laid out; naturally, replacement water must not cool extraction water.
The economic impact of these wells (including any geological studies) should always be carefully analyzed and confirmed. It should also be remembered that wells tend to age; that is, they loose their initial characteristics (in terms of flow rate).

References: [34], [50].

Summary Source Table:	**GEOTHERMAL ENERGY**
a) **operative flexibility:**	high where available

b) **areas of acceptable use:** anywhere geothermal fluids are available with a temperature of approximately 80°C

c) **essential data for preliminary evaluation:** analysis and temperature of geothermal fluid; available flow rates.

d) **typical energy intensity values:**

- power generated by 1 l/s extracted at 80°C: 170 W [1]

e) **share (%) recoverable for the production of energy in the form of:**

1 - water at 40–70 fC	2 - steam (*)	3 - electricity
70–90	70–90 [2]	5–10 [3]

f) **figure calculated from the characteristics of the source, needed to meet the energy requirements of a center with a daily milk intake of 1000 l/day (**) (unit of measure: liquid flow rate in l/s):**

Simplif. Proc. Plants		Complete Proc. Plants	
Thermal req.	Electric req.	Thermal req.	Electric req.
0.04–0.3[4]	0.7–1.0 [3]	0.04–0.9 [4]	0.7–1.7 [3]

g) remarks:

It is assumed that the necessary energy can be supplied in three hours.

[1] For calculation of d), it is assumed that the fluid will be cooled to 40°C.

[2]–[3] Possible when the fluid's temperature is on the order of 150°C.

[4] Hot fluid at $\simeq$100°C.

(*) low-pressure, or in some cases water heated to 80–90°C
(**) with different intake levels, use proportional values

4.6 BIOMASS

4.6.1 Basic Characteristics

The term biomass is used to describe organic substances that are directly (vegetable) or indirectly (animal) derived from photosynthetic activity. The two types of biomass generally considered for energy purposes are vegetable substances and animal waste.
In order to characterize the various materials from an energy standpoint, certain physical (moisture content, heat value of the dry substance, mass of a unit volume) and chemical properties (composition of the dry substance, C/N ratio, total solid content) must be known.

Physical Characteristics

The moisture content U (here evaluated on wet basis) gives an indication of the difficulty

involved in conservation of the substance as it is and its suitability for fermentation processes. In the case of vegetable substances, $10<U<90\%$; in animal wastes, $60<U<99\%$.

The apparent mass of a unit volume m_a is connected with the state of fragmentation, collection and packing methods and the product's energy intensity.
The following are some indicative values (kg/m^3):
loose vegetable substances, $40<m_a<80$ (straw, pruning residues); baled vegetable substances, $150<m_a<250$ (straw); densified vegetable substances, $600<m_a<800$; manure with a considerable amount of straw and just removed from the stable, $180<m_a<250$; ripe manure, $550<m_a<800$; waste in general, $900<m_a<1050$.

The heat value is the quantity of thermal energy produced by the complete combustion of 1 kg of liquid or solid fuel (1 Sm^3 in the case of gases; “S” indicates that reference is being made to a temperature of 0°C and to atmospheric pressure).
The gross heat value (GHV) includes the latent heat of the steam that is formed during the process by combination of the hydrogen and oxygen contained in the fuel and in the air. The latent heat is not considered in the low heat value (LHV). GHV and LHV are determined by the “calorimetric bomb” method, and they always refer to 1 kg of anhydrous substance. LHV is generally 90–95% of GHV.
The energy content (EC) is also evaluated in the case of products containing moisture (e.g., wood). EC takes into account the energy absorbed by evaporation of the water incorporated into the material's structure:

$$EC = \frac{LHV * (100 - U)}{100} - 0.025 * U \qquad \text{[MJ/kg of substance as is]}$$

Chemical Characteristics

The composition of the dry substance makes it possible to evaluate the C/N ratio, which, together with the moisture content U, is determinant for selection of the right energy conversion process. If C/N>30 and U<30, the product may be used as solid fuel suitable for thermochemical transformations (e.g., sufficiently dry vegetable substances).
If C/N<30 and U>30, the product is acceptable for biochemical transformations (e.g., wet vegetable substances and animal waste). In the case of animal waste, the content of the following substances is important: total solids (TS), volatile solids (VS), N (organic and mineral content), P and K.

4.6.2 Measurement and Evaluation Methods

The following aspects must be evaluated for a calculation of the potential energy supplied by the biomass:

a. **the quantity of product that may be collected from a unit of surface area (vegetable) or per animal (waste);**
b. **the most important physical characteristics as a function of the transformation process in which the product is to be used;**

c. **the costs of collection and possible transport to a user point:**

For a), reference may be made to average subproduct/product ratios in the case of secondary agricultural products. The procedure is approximate and should be employed with caution, especially in the case of wood residues. Quantities of animal waste are evaluated with reference to the species, the type of breeding and the average weight of the animals. For b), the type of energy process in which the product will be utilized must be clearly defined.

When thermochemical processes are involved, the dry substance's LHV and the moisture content U at the time of use are always required for a calculation of the energy content. This value is needed to determine the amount of energy that is actually available.
In the case of anaerobic processes, the content of volatile substances (VS) must be known. One kg of VS can theoretically be transformed into $\simeq$ 0.8 Sm^3 of gas. In actuality, this value is limited to 0.1–0.4 Sm^3/kg of VS (depending on the type of process involved).

Evaluation of the costs of collection and transport c) makes it possible to obtain an initial parameter for analysis of the feasibility of the product's use as energy.

4.6.3 Availability

The availability of biomass varies widely as a function of the location under consideration. It is virtually impossible to provide general indications.

References: [9], [11], [12], [14], [25], [35], [50].

Summary Source Table:	**DRY BIOMASS** [C/N>30]
a) operative flexibility:	high

b) areas suitable for its use: anywhere dry wood-pulp products and residues are available

c) essential data for preliminary evaluation: type of biomass, its moisture contect and available quantities

d) typical energy intensity values:

- material with 10–20% moisture: 13–16 MJ/kg

e) share (%) recoverable for the production of energy in the form of:

1 - water at 40–70 fC	2 - steam (*)	3 - electricity
40–60	40–60	5–25

f) figure calculated from the characteristics of the source, needed to meet the energy requirements of a center with a daily milk intake of 1000 l/day (**) (unit of measure: kg/day of wood residue):

Simplif. Proc. Plants		Complete Proc. Plants	
Thermal req.	Electric req.	Thermal req.	Electric req.
4–30	100–150	4–100	110–250

g) remarks:

(*) low-pressure, or in some cases water, heated to 80–90°C
(**) with different intake levels, use proportional values

- Summary Source Table:	**WET BIOMASS** [animal waste]
- **a) operative flexibility:**	poor

b) areas suitable for its use: anywhere there are animal breeding farms near a processing center

c) essential data for preliminary evaluation: quantity of waste; volatile solid content; chemical analysis

d) typical energy intensity values:

- 100 kg of live weight provide 25–35 MJ/day

e) share (%) recoverable for the production of energy in the form of:

1 - water at 40–70 fC	2 - steam (*)	3 - electricity
70–80	70–80	5–20

f) figure calculated from the characteristics of the source, needed to meet the energy requirements of a center with a daily milk intake of 1000 l/day (**) (unit of measure: live animal weight in t):

Simplif. Proc. Plants		Complete Proc. Plants	
Thermal req.	Electric req.	Thermal req.	Electric req.
0.12–0.80	3–5	0.12–3	4–8

g) remarks:

A chemical analysis of the waste is always necessary to confirm the possibility of energy production (in the form of biological gas)

(*) low-pressure, or in some cases water heated to 80–90°C
(**) with different intake levels, use proportional values

5. ENERGY CONVERSION PROCESSES AND RELATED TECHNOLOGIES

5.1 Introduction

Some energy conversion processes transform an energy source into a second source with different characteristics.

Two examples are combustion (fuel - > hot gases) and gasification (biomass - > combustible gas). Naturally, the products of these processes have to be transformed, with the use of other technologies, into their final form: hot water, steam or electricity (for example, with the use of boilers, engines, generators, etc., in the cases mentioned above).

Given the basic characteristics of small and medium-sized milk processing centers, the following technologies may reasonably be proposed: combustion, gasification and anaerobic fermentation.

These processes can be carried out by small plants and do not require expert assistance. On the other hand, alcoholic fermentation and the production of oils and charcoal should usually only be undertaken by companies or specialized organizations.
Section 6 considers the use of alcohol and oils for the operation of engines, but the assumption is that these products are found on the market.

As in the case of energy sources, a summary table is presented for each of the proposed conversion processes (with the exception of combustion, for which the reader is referred to section 6.2.1).
A standard outline is not included here, since the specific examples are considered to be sufficiently clear.

5.2 Combustion

Combustion consists of the oxidation of a substance (the fuel) through a comburent (oxygen or air). The combustion process has been completed when the related products (high-temperature gas) are incombustible (e.g., CO_2, H_2O).

The process is exothermal and takes place at temperatures on the order of 1,000-2, 000°C; it

requires initial energy input. For example, solid and liquid fuels require that part of the material be heated to 200–300°C in order to start the phase of distillation of volatile substances.
The stoichiometric ratio V_a is the weight of air theoretically necessary, per unit of weight or volume of fuel, to obtain complete combustion.
This value is calculated by knowing the content, in weight P_i, of the various elements (C, H_2, S).
By way of approximation:

$$V_a = (8C/3 + 8H + S - O)/0.23$$

In practice, an excess of air E is supplied to assure complete oxidation of all fuels. E is determined by the equation:

$$E = (\text{Weight air used} - V_a)/V_a$$

In the case of gases (good miscibility between fuel and air), low values of E are employed; the opposite is true for coarse fuels (e.g., large pieces of wood).

Combustion involves the use of burners, which, when they exist, are an integral part of boilers (see section 6.1.1).

5.3 Gasification

Gasification is the transformation of a liquid or solid fuel into a gaseous fuel.
This process may be desirable when the operative characteristics of a gas are required (feeding endothermal engines, combustion with low excesses of air, etc.), despite the fact that low-quality fuels (biomass, coal, etc.) are available.

In the case of solids, high-temperature (900–1500°C), incomplete oxidation is employed to generate combustible gases. In this situation, typical reactions are:

$C+O_2$	$\rightarrow CO_2$	$C+CO_2$	- (for t>1000°C) $\rightarrow$	$2CO$
$C+O_2/2$	$\rightarrow CO$	$CO+H_2O$	------------------------- $\rightarrow$	CO_2+H_2O
$H_2+O_2/2$	$\rightarrow H_2O$	$C+H_2O$	- (for t>800°C) -$\rightarrow$	$CO+H_2$

This is obtained by using a quantity of comburent air equal to 10–15% of the stoichiometric air. The moisture content of the original material may be beneficial if it is < 20% (wet basis).

The process normally involves fixed- or fluid-bed gasifiers. The former, which are easy to set up and are adapted to small plants, can either be equi- or counterflow; the distinction is based on the movement of the material and the gas. The latter are only used in medium-sized and large plants and require substances broken down into small pieces (which can be kept in suspension).
In the case of fixed-bed gasifiers, the gas produced should contain approximately 60–70% of the chemical energy of the original material (assuming the moisture, content is 10–15%).

Typical production levels in terms of Sm^3 of gas (LHV: 3.6–4.7 MJ/m^3) per kg of transformed material are:

- wood residues:	**2.9;**
- rice straw and corn cobs:	**2.5;**
- wheat straw and maize stalks:	**2.7.**

References: [9], [14], [22], [39], [41], [42], [48].

Summary Technology Table:	**GASIFIERS**
a) operative flexibility:	high

b) operation: relatively problem-free with the simplest versions (fixedbed gasifiers), as long as fuels with consistent piece size and physical characteristics are utilized.

c) most obvious limitations: i) automatic gasifier feeding may be complicated; ii) use in milk processing centers would led to frequent start-ups and shut-downs (presumably once or twice a day) with consequent increase in labor requirements; iii) engine feeding requires purification of the gas and greater care in terms of management; iv) the fuel has to be prepared.

d) auxiliary machinery needed: saw for preparation of the fuel.

e) recommended technical solution and its technological level:

- type:	fixed-bed gasifiers;
- suggested fuel:	small, prism-shaped pieces of wood (size of a pack of cigarettes);
- production:	2.5–3 m3 of gas/kg of wood. 10–11 m^3 is needed to obtain the same energy potential of 1 kg of Diesel fuel;
- labor required:	approximately 1 man-hour for start-up; operation must then be checked on (not constantly, however) and fuel must be added (depending on consumption). Total: 3–6 man-hours/day;
- workshop required	for construction: any place in which solid-fuel stoves with power over 100 kW are produced. The plate must be bent and welded, and simple kinematic motions and gas circuits are necessary.

f) final conversion technologies to be added: i) boilers for the production of hot water and steam; ii) Otto engines. In case i), the gas may be used as is; in case ii), it has to be cooled (to eliminate condensable substances) and filtered (to eliminate particles). The engines' feed systems should be completely modified, and use of the original fuel will no longer be possible.

5.4 Anaerobic Fermentation

This is a biochemical process resulting in the breakdown of organic substances (proteins, lipids, glucides and their polymers, such as cellulose), starting from biomass with a high moisture content (>60%) and utilizing various groups of anaerobic bacteria.
The products obtained include a gas with useful energy properties (biogas or biological gas) and a biomass whose volatile solid (VS) content is lower than that of the original material.
In the absence of O_2, the process takes place in three phases. For example, the following reactions occur with the use of cellulose (simplified illustration):

$(C_6H_{10}O_5)n + nH_2O$ →	→ (hydrolysis) →	$nC_6H_{12}O_6$
$nC_6H_{10}O_6$ →	(acidification) →	$3nCH_3CO_2H$
$3nCH_3CO_2H$ →	(methanization) →	$3nCH_4 + 3nCO_2$

In practice, complex organic compounds are transformed by hydrolytic bacteria into soluble

compounds with a simpler molecular structure (hydrolysis). These compounds in their turn are transformed into volatile carboxyl acids by the acetic and homo-acetic bacteria (acidification), and subsequently into CH_4 and CO_2 by the methane bacteria (methanization).

Below, the influence of various chemical and physical parameters is described:

Temperature: determines the predominant bacterial group and hence the rate of the chemical reactions. The process is difficult to start below 10 or above 80°C. Temperatures of 25 to 35°C are considered to be an adequate compromise between desired gas production and energy requirements. It is important to keep the temperature constant; variations of 5°C have an impact on microbial activity.

pH: values of 5.6-6 are optimal for hydrolysis and acidification, while neutral values (6.8–7.2) are better for methanization. Neutrality is also preferred when the entire process takes place in a single environment.

Type of biomass: the volatile solid (VS) and total solid (TS) content and the ratio of the two values (VS/TS) are related to the production of biological gas.

C/N ratio: to encourage the development of bacteria, the chemical composition of the substrate must meet the following condition: 20<C/N<30.

Oxidation-reduction potential: -300<rH←350 mV to encourage microbial activity.

Retention time (RT): this is the amount of time the biomass remains in the processing environment (reactor). When the biomass is not homogeneous (as frequently happens), RT is distinguished from the solid fraction (RT_S ; that is, from the part that tends to be deposited in

the reactor) and the liquid fraction (RT_1). The ratio between reactor volume and the volume of biomass added daily is defined as the hydraulic retention time (RT_i; sometimes also abbreviated as HRT). Depending on the type of plant: $10<RT_i<30$ days.

Specific load (L_s): is the quantity of VS/day added to the reactor per unit volume. Under mesophylic environment (20<process temperature<40°C): $1<L_s<5$–6 kg/day of VS per m^3 of reactor (depending on the type of plant). Higher values favor the acidification phase, with inhibition of methanization (the pH is lowered).

Plants are classified according to the type of feeding involved and the organization of the process. There are two basic types:

a. **full cycle loading plants, in which the biomass is loaded in one single solution and remains in the reactor for the entire RT;**

b. **continuous loading plants, in which loading (and generally unloading as well) is a continuous process.**

The following plant models (with indications as to the complexity of their construction and management) may be classified as type b):
plug-flow: there is only one reactor, and motion is obtained through the introduction of waste (construction and management: relatively simple).
variable volume digesters: loading is continuous throughout the RT, but unloading is not (construction and management: simple).

References: [9], [10], [18], [31], [46], [47], [52], [53].

Summary Technology Table:	**DIGESTERS**
a) operative flexibility:	average to poor

b) operation: not simple when a fairly consistent level of gas production is desired.

c) most obvious limitations: i) the process must be kept going at all times, and when it stops, it takes several days to start up again; ii) high-level production can only obtained by heating the waste; iii) the gas has to be stored.

d) auxiliary machinery needed: all the equipment required for loading and unloading the waste.

e) recommended technical solutions and their technological level:

- type:	batch (intermittent loading and unloading); single-stage (plug-flow or the like);
- suggested substrates:	animal waste with total solid content between 8 and 15%;
- quantity of waste:	the addition of 100 kg/day of undiluted material produces 1–2 m^3 of gas/day. 2m^3 of gas is needed to obtain the same energy potential as 1 kg of Diesel fuel;
- labor required:	variable for loading and unloading (depending on the level of mechanization);constant attention is required, especially in the case of continuous digesters;
- workshop required for construction:	facility capable of doing construction work, (masonry, tanks, etc.);(the plate must be bent and welded; hydraulic circuits must be set up and boilers have to be installed for the production of hot water.

f) **final conversion technologies to be added:** i) boilers for the production of hot water and steam; ii) Otto engines.
In the latter case, the gas has to be dehumidified, and the machinery cannot contain any copper parts whatsoever. The engines' feed systems should be modified slightly.

6. TECHNOLOGIES FOR FINAL ENERGY CONVERSION

6.1 Introduction

These technologies are classified on the basis of their final product: thermal or electric energy. As in the case of energy sources and conversion processes, summary tables are provided in this section as well.
A standard outline is not presented here, since the specific examples are considered to be sufficiently clear.

6.2 Final Product: Thermal Energy

6.2.1 Combustion Systems

These systems convert the chemical energy contained in fuels into thermal energy (in the form of hot fluids: steam, water, oil or air).

In general, these systems are composed of:

a. **a burner or a feed system (often both together);**
b. **a boiler shell:**

The components listed in a) may be absent (e.g., wood-fired boiler with intermittent loading).

Classification is based on the physical state of the fuels used (gas, liquid or solid).

Burners

Burners mix comburent air with fuel to facilitate the process of oxidation. Solids are generally placed in contact with a flow of air, liquids are atomized in the comburent, and gases are simply mixed. Burners may contain a feed system (e.g., a gas blower), whose size and cost can be significant (especially in the case of solid fuels).
The comburent air can be sucked in by the boiler's natural draught (atmospheric burners), or it can be forced in by a blower (blown air burners).
In the case of solid fuels, a distinction is made between burners designed for coarse fuels and those that use powdery fuels (or fine-grained fuels, such as powdered coal or biomass, which can be transported in suspension by the air).
Combustors are a particular kind of burner. In this case, the fuel is gasified (with an air flow rate that is 30% that of normal), and the gas is immediately burned (with the addition of the remaining quantity of comburent air).
When the pieces of fuel are large (prisms whose longest side is over 50–60 mm), burners are replaced by a feed mechanism.
The proper regulation of the burners (or of the feed system) is extremely important in terms of process efficiency.

The following forms of regulation should be mentioned:

a. **"all or nothing", in which the burner delivers only the maximum fuel flow rate ($Q=Q_{max}$);**
b. **"two rates", when two values of Q are possible;**
c. **"modulated", in which Q may vary over a sufficiently wide range (generally between $0.3*Q_{max}$ and Q_{max}).**

Boiler Shell

This is where combustion and thermal exchange take place between hot gases and heat-carrying fluids (water, steam, diathermic oil or air; type and operating pressure should always be specified). The fluid may circulate inside the tubes (tube boilers), outside them (fire-tube boilers), or in proper air spaces.
Boilers are further distinguished on the basis of how the comburent air is transported (depression boilers or presurized boilers; see also burners). In the latter case, the flue gases can be forced to lick more complicated (and hence more efficient) finning.
Condensation boilers are characterized by a large exchange surface, which makes it possible to bring the temperature of the flue gases down to 55–60°C (the maximum temperature of the circulating fluid is thus limited to these values). These boilers are only used for pure gases, since the condensates of some fuels (e.g., biological gas, oil and coal) are corrosive or create operating problems (soot or tar deposits, etc.).

The following equation provides the system efficiency μ:

$$\mu = \text{thermal power produced } (P_p) / \text{thermal combustion power } (P_c)$$

P_c is the product of the fuel load Q and its heat value HV. It is always important to specify

whether this is gross or low HV (generally the latter). Defined in this way, the efficiency is instantaneous and refers to very precise operating conditions (value of Q, temperature of heat-carrier, etc.).
The efficiency may also be calculated as the ratio between energies during relatively long periods of time (one hour, one day, an entire season, etc.). In this case, the value obtained is the average efficiency during the time period under consideration.

The following factors have an effect on the efficiency:

a. **the excess of air (E). If this is insufficient, there will be unburned substances in the flue gases; if it is too high, the hot gases will be overly diluted;**
b. **extent of the exchange surface. Insufficient surface produce flue gas temperatures over 200–250°C;**
c. **intermittent functioning of the burner or the feed system (the on-off transistors lower μ);**
d. **encrustations on the exchange surfaces;**
e. **the chimney draught when the burner (or feeder) is off;**
f. **various forms of dispersion (e.g., through the boiler's outer walls);**

g. **incorrect system dimensioning or design (whether too large or too small).**

Efficiency can be measured directly or indirectly. In the former case, the power supplied to the heat carrier P_p and the combustion power P_c are measured. Specifically:

$$P_p=h_s G\delta T;\qquad P_c=Q^{*}HV;$$

where, in addition to the terms defined above, h_s is the specific heat of the fluid under consideration, G is the fluid flow rate and δT is the temperature increase in the heat carrier. Power measurement can pose some practical problems because of the inevitable operating instability. Consequently, energy totals over sufficiently long periods of time, t, are preferred. It should be noted that the direct method requires installation of numerous instruments (flow rate meters, etc.).
The indirect method, on the other hand, is based on measurement of the temperature T_f and the concentration of O_2 and CO_2 in the flue gases (in some cases, CO is also calculated). This information makes it possible to determine whether combustion is taking place in an optimal fashion, and if the boiler is operating properly. Indeed, when the concentrations of O_2 and CO_2 are normal, E is correct. When T_f is lower than 250–300°C, the thermal exchange is satisfactory.
It is also possible to estimate the value of μ using graphs and empirical formulas. The method is fast and economical (it requires an outlet in the flue and inexpensive instruments). The result provided, however, is not an absolute value, but merely an indication of proper system functioning.

Values of μ (with respect to GHV) are always under one (this is also true with respect to LHV, except, sometimes, in the case of condensation boilers).

References: [9], [14], [15], [42].

Thermal Energy Production
Final Technology - Summary Table: **BOILERS**

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a) operative flexibility:	high

b) operation: simple with boilers that produce hot water; less simple with boilers that produce steam (the consumed water has to be treated).

c) most obvious limitations:1) liquid and gaseous fossil fuel and gasification and biological gas boilers: none in particular; **2)** solidfuel boilers: i) cost of automatic feed systems; ii) low mass of unit volume of wood residues (large storage volumes); iii) particles in the flue gases (maintenance, safety and pollution problems).

d) auxiliary machinery needed: machinery to chip the wood.

e) recommended versions and their technological level:

1) Liquid and gaseous fuel boilers:
When gasification and biological gas are used, always be ready to feed the boiler with other kinds of fuel that are readily available;

2) Solid fuel boilers: Automatic feed systems are hard to justify with thermal power of less than 150 kW. Therefore, it is best to use “gasifier” boilers that do not need to be reloaded for 4–5 hours;

3) For all types:
Models with very simple means of checking the combustion process can only be produced by workshops with a complete series of machine tools, heavy plate bending and welding capabilities and the possibility of obtaining cast pieces. The production of high-efficiency boilers (with adequate combustion control) is only feasible in high level factories located in rich countries.

f) energy transformation yields:

- gaseous and liquid fuels:	> 70%;
- solid fuels:	> 45% (generally no more than 70%).

g) can this technology be considered self-sufficient?(*)

- used together with gasifier	YES
- used together with digester	NO
- solid fuels in general	YES

(*) NO/YES: frequent replacement of the source by another, more readily available source is/is not suggested.

6.2.2 Solar Collectors

There are two different kinds of solar collectors: flat-plate (operating temperature: ≃30–80°C) and focusing (≃80–300°C).
In the former models, solar radiation heats a surface (the absorber), which contains a fluid (normally water or air). Other collector components include a transparent cover, thermal insulation and a container.
The absorber must be highly absorbent (capable of transforming radiation into thermal energy) and should emit (or loose) little heat through radiation.
The transparent cover should produce an intense greenhouse effect, while the insulation should not absorb water and should be able to operate under temperatures ≃100–140°C.

Focusing collectors can be fixed or mobile; they use optic systems to concentrate solar radiation on their small absorbers. The most complete versions contain an optic system (reflecting surfaces or lenses), a receiver (absorber), a tracking system (to determine the position of the sun and follow it) and a support structure. The ratio of the receiver's front surface to the optic system's surface is called the concentration ratio.

The main difference between flat-plate and focusing collectors is that the former use total radiation, while the latter employ only the direct component. Indeed, focusing collectors

convert a lower degree of potential energy into thermal energy and require clear skies.

The efficiency (µ) is the ratio of the collector's thermal power to the power of the solar radiation incident on the receiving surface (in the case of flat-plate collectors, this coincides with the dimensions of the collector itself; in the case of focusing collectors, the front surface of the optic system has to be considered). It may be observed that:

$$\mu = C_1 - C_2 * (T_i - T_{amb})/I$$

where:

- **C_1, C_2 are constants which have been experimentally determined (C_1 depends on the collector's optic characteristics and coincides with µ when T_i=T_{amb});**
- **T_i is the inlet temperature of the collector's heat-carrying fluid.**

Consequently, µ increases as T_i approaches T_{amb}.

The fact that availability of the solar source and the user's requirements are almost never in tune with each other necessitates the use of some form of storage (generally tanks of water at a temperature T_s).

The operative rationale is the following: when the collector is capable of supplying water with T_u>T_s, the solar plant starts to work, and the temperature T_s increases over time. When T_u>T_s, the plant stops working. This simple form of control can be activated by a differential thermostat.
Each time a user takes H_2O out of the tank, cold H_2O is added (and T_s decreases).

Consequently, the storage tank's specific volume V_S (1 per m^2 of collector) influences the temperature range T_i and hence μ. In order not to have a negative effect on the latter value, V_S is selected so that T_i (and consequentely T_S) remains below the desired temperature.

When energy production must be guaranteed, the solar plant is always combined with a system whose production is continuous (e.g., fuel oil or biomass boiler).
The two plants are connected after the storage tank so that T_S may be kept as low as possible.
Finally, it should be remembered that the insertion of exchangers into the circuit will result in an increase in T_i and thus a decrease in μ.

References: [17], [40], [44], [54].

Thermal Energy Production

Final Technology - Summary Table: **SOLAR COLLECTORS**

---

a)	**operative flexibility**:	limited
b)	**operation:** simple with flat-plate collectors (hot water production); less simple with focusing collectors (steam production)	
c)	**most obvious limitations:** i) processing plants would have to be redesigned (e.g., to use water heated to 60°C in cheese-making), and the processes themselves would probably have to be modified to make the best use of the solar source; ii) the source is not dependable; iii) flat-plate collectors can only be relied on to supply hot water for washing and energy for processes that do not require high temperatures; iv) focusing collectors require clear skies and a certain level of plant complexity; they are not usually recommended.	
d)	**auxiliary machinery needed:**	none

e) recommended models and their technological level:

1) Flat-plate collectors: produced with components manufactured locally and capable of being incorporated directly into processing center roofs (as an integral part). The traditional 1–2 m^2 models are not recommended.

2) Focusing collectors: only parabolic-cylinder or fixed (e.g., Winston) versions. It should be kept in mind that maintaining operating temperatures of even 100°C, with reasonable yields, can be difficult.

3) For all types: production of flat-plate collectors can only be handled by workshops that are able to work on thin sheet metal, weld and put together simple hydraulic plants. This type of workshop could also produce focusing collectors (simple parabolic-cylinders with absorbers that are not insulated). The following are also required for the support structure and moving parts of focusing collectors: carpentry, electric motors, reducers, gears and low level electronics.

f) energy transformation efficiencies:

- flat-plate collectors that operate at temperatures < 70°C: 40–60%;
- focusing collectors that operate at temperatures of $\simeq$150°C for 4–6 h/day: 10–20%.

g) can this technology be considered self-sufficient? (*)

- All types of plants: NO

Solar plants always have to be combined with other energy systems (generally boilers).

(*) NO/YES: frequent replacement of the source by another, more readily available source is/is not suggested.

6.2.3 Heat Pumps (Refrigerating Machines)

These machines draw heat from one environment at a temperature of T_1 and transfer it to another environment at a temperature of T_2 ($T_1 < T_2$).
Compression heat pumps make use of a fluid (generally freon) that boils at a low temperature (-20/-40°C) and circulates in a closed circuit made up of:

a. **two exchangers to draw and give out thermal energy (evaporator and condenser):**
b. **a compressor (usually electric);**
c. **an expansion valve.**

The fluid is liquid at the condenser outlet (at a pressure p_1 and a temperature T_1, generally > 30–40°C).
As it passes through the expansion valve (which is a capillary with Φ ~1–2 mm), it reaches p_2 (< p_1 because of the narrow neck) and T_2 (< T_1 because of the evaporation of 10–20% of the fluid).
In the evaporator, the fluid boils at a low temperature, drawing heating from the outside and turning it into steam.
The steam is sucked in by the compressor, which brings it up to $p_3 = p_1$ and $T_3 > T_1$. The fluid then cools down in the condenser and returns to the liquid state. At that point the cycle starts again. Temperature and pressure levels depend on the refrigerating fluid.
These machines are equipped with numerous auxiliary devices designed to optimize the cycle and guarantee safe operation.

In the case of absorption heat pumps, the refrigerating fluid (e.g., NH_3) is sucked in by a fluid capable of absorbing it (a solvent; e.g., H_2O). The fluid is extracted from the latter substance by heating the mixture.

The advantage in this case is the use of thermal energy (85–200°C) rather than mechanical energy. The most interesting aspect of the machine is the fact that it does not have the compressor.

Generally, if the machine's primary function is to generate thermal energy (by drawing it from any source), it is called a heat pump. If, on the other hand, the goal is to draw thermal energy (dissipating it into the environment), it is called a refrigerating machine.
These two operations may also coexist (e.g., a system that cools milk while heating sanitary H_2O).
Indeed, differences in construction are limited, and the two machines are considered to be basically identical.

Models

Compression machines are classified on the basis of: the path followed by the heat, the type of compressor and its operation.
Generally, the term “x-y” heat pump is used to described machines that draw thermal energy from source x and transfer it to y.
Examples include air-air, air-water, water-air and water-water heat pumps. The best sources are those that maintain a constant and sufficiently high temperature throughout the entire period of their use.
When adjustments can be made to an x-y machine to turn it into a y-x machine (that is, the evaporator will function as a condenser and vice versa), it is reversible. Reversibility can be achieved with simple hydraulic circuits, especially in the case of water-water models.

Performance

Performance is defined by:

- **thermal power;**
- **refrigerating capacity;**
- **coefficient of performance (COP);**
- **refrigerating efficiency (ε).**

Specifically:

COP = thermal power supplied (Q_u)/mechanical power absorbed (L).

When nothing is lost:

$$COP = Q_u/L = 1+\varepsilon.$$

The machine's performance depends on the temperatures of the hot (T_c) and cold (T_f) source. The lower the value of $\delta T=T_c-T_f$ (although $\delta T>\delta T_{min}\simeq 5\text{-}10°C$), the better the performance. In addition, performance always has to be analyzed in relation to the value of δT.

References: [5].

Thermal Energy Production
Final Technology - Summary Table: **HEAT PUMPS**

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a) operative flexibility: high

b) operation: simple when the cold source is the milk (or even whey) to be cooled.

c) most obvious limitations: i) the maximum temperatures that can be reached are

≃60°C, which is approximately the same as the limits posed by flat-plate solar collectors (see related table); ii) recovery is applicable only to electric machines; iii) refrigerating fluids (type R500) that limit the machine's refrigerating capacity (with respect to the traditional type, (R22) must be used to reach high temperatures at the condenser.

d) auxiliary machinery needed: none.

e) recommended models and their technological level:

Machines whose evaporator and condenser are connected to refrigerating tanks (as in normal plants) and thermal storage tanks, respectively. For the sake of safety, the normal heat elimination procedure employing fans should be maintained. Production of heat pumps requires advanced technology. If compressors and regulating components are not supplied in-house, assembling workshops equipped with all machine tools are adequate.

f) energy transformation efficiencies:

A quantity of energy is recovered that is 30–50% greater than the heat drawn from the fluid to be cooled.

g) can this technology be considered self-sufficient? (*)

- All types of plant: YES

as far as the production of hot water (≃50°C) is concerned.

(*) NO/YES: frequent replacement of the source by another, more readily available source is/is not suggested.

6.2.4 Wind- and Water-Powered Machines

The mechanical energy generated with wind and water power may be transformed directly (by

friction) or indirectly (through the use of electric generators and resistors) into thermal energy. The latter possibility is used most often (and is recommendable); in this case, the frequency of the electricity produced does not have to be checked.

Thermal Energy Production	
Final Technology - Summary Table:	see **WIND TURBINES**
and **WATER WHEELS AND TURBINES** for electric energy production	

6.2.5 Heat Exchangers

The purpose of this equipment is to exchange thermal energy between two fluids (e.g., air and water) while keeping them physically separated. Heat exchangers are normally made of metal (Al, Cu, etc.) because of its excellent conductivity (when limited thickness is a requirement, however, poor conductors, such as plastic, are also acceptable).
Heat exchangers are classified according to efficiency (ε_S), which is defined by the ratio Q/Q_∞, where Q is the thermal energy actually exchanged and Q_∞ is the thermal energy exchanged with a surface → ∞ under the same conditions.

The simplest exchanger is composed of two coaxial pipes in which flow two different fluids. When the fluids circulate in the same direction, the exchanger is in equiflow; otherwise, it is in counterflow.

When δT_1 and δT_2 indicate the differences in temperature at the two ends, then:

$$Q = kS\delta T_{ml}$$

where Q is the thermal power exchanged, k is the overall heat transfer coefficient, and δT_{ml} is defined by:

$$\delta T_{ml} = (\delta T_1 - \delta T_2)/\ln(\delta T_1/\delta T_2)$$

It should be noted that:

a. **the subscript 1 indicates the end in which the hotter fluid enters;**
b. **the overall transfer coefficient is equal to:**

$$k=1/(1/\alpha_a+1/\alpha_b+s/\Gamma),$$

where α_a and α_b are the convective thermal resistivities of the fluids (which depend on the type of fluid, its speed and on the type of wall), and s and Γ are the thickness and the thermal conductivity of the material.

Crossed currents exist when the two fluids move at right angles to each other. We can assume that:

$$\delta T_{ml} \simeq (T_{i1}-T_{i2}+T_{u1}-T_{u2})/2$$

where T_{i1}, T_{i2}, T_{u2} are the inlet and outlet temperatures. The subscript 1 always indicates the hotter fluid. More complicated situations should be compared with equicurrent and countercurrent exchangers for approximate evaluations. Whenever possible, ask the manufacturer for information about the exchanger's features.

The influence of any encrustations, oxidation or other deposits on the surface have to be

evaluated in order to take the time effect into account.

References: [34].

Thermal Energy Production

Final Technology - Summary Table:

for thermal recovery and to reduce refrigeration requirements	**HEAT EXCHANGERS**

a) **operative flexibility**: high

b) **operation:** simple

c) **most obvious limitations:** i) milk precooling requires well water at temperatures under 15°C and in quantities equal to or greater than those of the milk; ii) the temperature of the heated water is at least 3–5°C lower than that of the cooled fluid (i.e., 25–28°C). The production of water for washing is the only feasible final use.

d) **auxiliary machinery needed:** none

e) **recommended models and their technological level:**

Countercurrent exchangers. Exchangers not produced by sheet metal forming (e.g., plate exchangers) require workshops that are capable of welding stainless steel pieces (in addition to working on sheet metal and pipes).

f) **energy transformation efficiencies:**

By cooling 1 1 of milk from 30 to 15°C, 1.1–1.2 1 of water can be heated to 25°C. With whey at 40°C, the same quantity of water can be heated to 35–37°C.

g) **can this technology be considered self-sufficient?** (*)

- All types of plants: NO

The result is the preheating of water for washing, which saves a small amount of energy.

(*) NO/YES: frequent replacement of the source by another, more readily available source is/is not suggested.

Thermal Energy Production	
Final Technology - Summary Table:	**HEAT EXCHANGERS for geothermal media**

a) operative flexibility: high

b) operation: simple when exchanger is made with the right material and used with fluids that are not overly saline.

c) most obvious limitations:

1 For exchangers alone: i) chemical composition of the geothermal fluids; ii) temperatures reached by the fluids themselves (when < 80°C, which is very common, the problems encountered are similar to those observed with flat-plate solar collectors; see related table).

2 For geothermal plants: iii) two wells are usually necessary; iv) cost of the wells; v) use of high quality pumps, when required; vi) thermal storage tanks are needed when low-capacity sources (or small plants) are used.

d) auxiliary machinery needed: none

e) recommended models and their technological level:

1 For exchangers alone: countercurrent exchangers. Exchangers produced without sheet metal forming (e.g., plate exchangers) require workshops that are capable of welding stainless steel pieces (in addition to working on sheet metal and pipes).

For geothermal plants: the level of plant design depends on the temperature T. T<80°C

2 does not present any particular problems (the same components and contractors involved in drilling drinking-water wells are also acceptable in this case); T>80°C requires a certain degree of specialization in terms of components (e.g., water-cooled pumps) and contractors.

f) **energy transformation efficiencies:**

See table on geothermal sources.

g) **can this technology be considered self-sufficient? (*)**

- All types of plants: NO

The result is the preheating of water for washing, which saves a small amount of energy.

(*) NO/YES: frequent replacement of the source by another, more readily available source is/is not suggested.

6.3 Final Product: Electric Energy

6.3.1 Internal Combustion Engines Combined with Generators

This is the classic solution for the production of electricity in isolated areas. Diesel engines are usually used because of their low level of consumption.

Generally, with machines whose capacity is:

- **under 10 kW: 400–410 g of Diesel oil are needed per electric kWh generated;**
- **between 10 and 50 kW: 340–360 g/kWh;**
- **above 50 kW: 310–320 g/kWh.**

Specific consumption is higher in small machines, since smaller engines and generators tend

to be less efficient (mainly for economic reasons).
This aspect is more evident in generators (see Appendix 3 for general characteristics) than in engines.

Endothermal engines use part of the energy freed by fuel combustion; these include Diesel and Otto engines.
The consumption levels of the latter type of engine are generally 20–25% higher than those of Diesel engines.
It should be noted that specific consumption increases for all engines as the load decreases.
For more complete information about performance, the following values have to be known:

a. **behaviour of the power and torque curves as a function of the number of revolutions;**
b. **maximum power that can be continually supplied;**
c. **engine performance map.**

Parameters a) and c) make it possible to identify the machine's basic features and determine whether it is suitable for use. Map c) makes it possible to evaluate the behaviour of the specific consumption curve as a function of the load and the related efficiencies.

The following fuels can be used:

d. **traditional fuels (gas, kerosene, natural gas, Diesel oil, etc.);**
e. **renewable liquid fuels: ethanol, methanol and vegetable oils;**
f. **renewable gaseous fuels: gasification and biological gas.**

As mentioned above, renewable liquid fuels are not treated as potential energy sources since their small-scale production for self-consumption (i.e., as part of the processing center's activities) is not recommended, at least initially.

It is felt that the problems connected with their production should be handled on the macroeconomic level (and thus are beyond the scope of this report).
However, Appendix 4 contains information on the general characteristics of these fuels.

The summary tables presented below consider the practical performance of engine-generator sets in relation to type of feeding. It is assumed that no information is necessary with regard to feeding with traditional fuels. It should be emphasized that Otto engines can be gas-, ethanol- and methanol-fed.
Diesel engines can be fed with vegetable oils, or with any of the renewable sources listed above with the aid of the "dual-fuel" system.

References: [1], [2], [19], [32], [38], [41], [48], [55], [56].

Electric Energy Production Final Technology - Summary Table:	**GENERATOR SETS FED BY GASIFICATION GAS**

a) **operative flexibility:** high

b) operation: fairly simple when the gasification gas (see related intermediate technology table) is cooled (so that all condensables are eliminated) and filtered (to eliminate all particles). But operation is more difficult than in the case of similar engines fed with standard quality fossil fuels. The lubricating oil has to be changed more frequently, and various components have to be checked more often.

c) most obvious limitations: (with respect to standard models)

1) Otto engines: i) the feed system has to be modified substantially and the ignition system has to be adjusted; ii) the use of fossil fuels is no longer possible; iii) although high energy transformation efficiencies can be obtained, the maximum power that can be developed is approximately 50% that generated by fossil fuels (thus, bigger engines are

needed);

2) Dual-fuel Diesel engines (where the gas is mixed with comburent air): i) the feed system has to be modified substantially (in terms of both air intake and injection equipment); ii) a fairly sophisticated governing system is required; iii) at maximum load, approximately 15% of the energy requirement has to be supplied by Diesel fuel; with variable loads (which is almost always the case), this percentage can reach 50%;

3) For all types of engines: i) the cleanness of the components has to be checked continually (especially the valves); ii) the noise level should be considered (this problem also exists in standard models).

d) auxiliary machinery needed: none

e) recommended models and their technological level:

1000–1500 rpm engines with water cooling to make use of thermal recovery (see cogeneration table); electronic ignition (Otto engine). Self-exciting generators without brushes.

The technological level required for construction of these engines is well known. Simple transformation (for the use of renewable fuels) does not require special equipment, but a good understanding of this field is still necessary.

f) efficiencies (%) (*):

element	30% of load	max. load	average real values
otto engine	10–15	20–25	15–20
diesel engine	18–22	30–35	25–30
5 kW generator	-	-	70–75
20 kW generator	-	-	80–85
100 kW generator	-	-	>90

5 kW otto set	7–12	10–15	≃10
5 kW diesel set	12–16	20–25	≃18
20 kW otto set	10–14	17–22	≃14
20 kW diesel set	15–19	24–30	≃22
100 kW otto set	10–15	20–25	≃18
100 kW diesel set	18–22	27–33	≃24

g) can this technology be considered self-sufficient? (**)

YES

Since the gasifier can provide a constant supply of gas.

(*) Calculated in relation to the fuel. Multiply these values by ≃0.7 to take the gasification process into consideration as well (in which case, efficiency will refer to the chemical energy of the biomass).

(**) NO/YES: frequent replacement of the source by another, more readily available source is/is not suggested. Here, reference is to the gasifier-engine-generator.

Electric Energy Production Final Technology - Summary Table:	**GENERATOR SETS FED BY BIOGAS**

a) operative flexibility: average

b) operation: fairly simple when the engine does not contain copper parts (e.g., all the bearings must be made of white metal), and the biological gas (see related intermediate technology table) has been sufficiently cooled (so that all the vapour is eliminated). But operation is more difficult than in the case of similar engines fed with standard quality fossil fuels. The lubricating oil has to be changed more frequently.

c) **most obvious limitations** (with respect to standard models):

1) Otto engines: i) the feed system has to be modified and the ignition system has to be adjusted; ii) although high energy transformation efficiencies can be obtained, the maximum power that can be developed is approximately 60–80% that generated by fossil fuels (thus, bigger engines are needed);
2) Dual-fuel Diesel engines (where the gas is mixed with comburent air): i) the feed system has to be modified substantially (in terms of both air intake and injection equipment); ii) a fairly sophisticated governing system is required; iii) at maximum load, approximately 15% of the energy requirement has to be supplied by Diesel fuel; with variable loads (which is almost always the case), this percentage can reach 50%;
3) For all types of engines: i) the cleanness of the components has to be checked continually (especially the valves); ii) the noise level should be considered (this problem also exists in standard models).

d) **auxiliary machinery needed:** none

e) **recommended models and their technological level:**

1000–1500 rpm engines with water cooling to make use of thermal recovery (see cogeneration table); electronic ignition (Otto engine). Self-exciting generators without brushes.

The technological level required for construction of these engines is well known. Simple transformation (for the use of renewable fuels) does not require special equipment, but a good understanding of this field is still necessary. The transformation procedure for biological gas is simpler than that for gasification gas.

f) **efficiencies (%) (*):**

See values for gasification gas.

g) can this technology be considered self-sufficient? (**)

NO

Since digesters (especially smaller models) may vary or stop gas production for numerous reasons. Normalization or restarting can take days (3–10). However, biological gas-fed engines can also operate with other fuels.

(*) **Calculated in relation to the fuel.**

(**) **NO/YES: frequent replacement of the source by another, more readily available source is/is not suggested.**

Electric Energy Production Final Technology - Summary Table:	**GENERATOR SETS FED BY ALCOHOL**

a) operative flexibility: high

b) operation: similar to fossil fuel-fed models.

c) most obvious limitations: (with respect to standard models)

1) Otto engines operating on gasoline-alcohol mixtures (generally 5–25% ethanol or methanol): i) possible problems connected with the mixture's instability;

2) Otto engines operating on alcohol alone: i) the engines have to be modified substantially; ii) the use of fossil fuels is no longer possible;

3) Dual-fuel Diesel engines (alcohol is added to the comburent air): i) the feed system has to be modified substantially (in terms of both air intake and injection equipment); ii) a fairly sophisticated governing system is required; iii) at maximum load, approximately 15% of the energy requirement has to be supplied by Diesel fuel; with variable loads (which is almost always the case), this percentage can reach 30–50%.

d) auxiliary machinery needed: none

e) recommended models and their technological level:

1000–1500 rpm engines with water cooling to make use of thermal recovery (see cogeneration table); electronic ignition (Otto). Selfexciting generators without brushes.

The technological level required for construction of these engines is well known. Transformation for the use of mixtures (Otto engines) does not require special equipment or experience. However, this is not the case with transformation for the use of alcohol alone.

f) energy efficiencies (%) (*)

See values for gasification gas.

g) can this technology be considered self-sufficient? (**)

YES

As long as the fuel is constantly supplied.

(*) Calculated in relation to the fuel. See Appendix 4 for information concerning the fuel production process.
(**) NO/YES: frequent replacement of the source by another, more readily available source is/is not suggested.

Electric Energy Production Final Technology - Summary Table:	**GENERATOR SETS FED BY VEGETABLE OILS**

a) operative flexibility: high

b) operation: fairly simple when the oil has been carefully filtered and degummed, but operation is more difficult than in the case of similar, standard quality, Diesel-oil-fed engines. The various components have to be checked more frequently.

c) most obvious limitations: (with respect to standard models)

1) Feeding with Diesel-vegetable oil mixture vv (generally 20% vegetable oil): none;

2) Feeding with vegetable oil alone: i) precombustion Diesel engines have to be used (although these engines are being phased out in agriculture); ii) possible paraffin formation at temperatures as low as OfC; iii) the components' condition must be checked constantly; iv) the noise level should be considered (this problem also exists in standard models).

d) auxiliary machinery needed: none

e) recommended models and their technological level:

1000–1500 rpm/l engines with water cooling to make use of thermal recovery (see cogeneration table) and good fuel filtering. Selfexciting generators without brushes.

The technological level required for construction of these engines is well known. Simple transformation (for the use of vegetable oils) does not require special equipment, but a good understanding of this field is still necessary.

f) efficiency (%) (*):

element	30% of load	max.load	average real values
diesel engine	18–22	30–35	25–28
5 kW generator	-	-	70–75
20 kW generator	-	-	80–85
100 kW generator	-	-	>90
5 kW set	12–16	20–25	$\simeq$18
20 kW set	15–19	24–30	$\simeq$22

100 kW set	18–22	27–33	≃24

g) can this technology be considered self-sufficient? (**)

YES

As long as the fuel is continuously supplied.

(*) Calculated in relation to the fuel. See Appendix 4 for information concerning the fuel production process.
(**) NO/YES: frequent replacement of the source by another, more readily available source is/is not suggested.

6.3.2 External Combustion Engines Combined with Generators

The most interesting models to consider are steam and Stirling engines. The basic feature of these engines is external combustion. Therefore, they can hypothetically use <u>any type of fuel whatsoever</u> (including solids).

Steam engines are already in use in some developing countries. When less power is needed, they provide some advantages over steam turbines, which are not recommended for the applications discussed here (because of the limited power required). Steam engines naturally have to be combined with steam boilers (adapted to operate at 10 bar and ≃350°C).

Stirling engines are operated by the expansion and contraction of a gas (usually air or helium) through a hot and cold source, both of which are located outside the machine. Engines with small capacities (4–5 kW) are currently available, but they are expensive and difficult to find (for commercial reasons).

References: [4], [5], [9], [26], [51].

Electric Energy Production
Final Technology - Summary Table:

STEAM SETS FED BY VARIOUS FUELS

a) operative flexibility: high

b) operation: fairly simple. Considerable amount of labor required to load the fuel into non-automatic systems (10–12 hours/day for continuous function systems).

c) most obvious limitations: none that are particularly serious. However, it should be noted that: i) water consumption is high (water must be filtered and chemically treated); ii) the simplest models have a limited number of revolutions (200–300 rpm), which necessitates the use of multipliers for connection with generators.

d) auxiliary machinery needed: none

e) recommended models and their technological level:

Existing models are available in small numbers, and consequently it is difficult to recommend a specific version. The technological level required for construction of the simplest models (manual fuel loading and release of exhaust steam into atmosphere) is not high, and it is feasible for manufacturers located in underdeveloped countries. It is similar to the level required for production of simple, single-cylinder Otto engines.

f) efficiencies (*):

- simple models: 5%;
- improved models: 5–10%.

g) can this technology be considered self-sufficient? (**)

YES

As long as the required fuel is available (e.g., wood).

(*) Calculated as the ratio of the electric energy produced to the energy of the fuel employed (usually solid).

(**) NO/YES: frequent replacement of the source by another, more readily available source is/is not suggested. Here, reference is made to a steam boiler-engine-generator set.

Electric Energy Production Final Technology - Summary Table:	**STIRLING SETS FED BY VARIOUS FUELS**
a) operative flexibility:	high
b) operation: fairly simple, except in the case of fuel loading.	
c) most obvious limitations: none, except the fact that commercial models are hard to find.	
d) auxiliary machinery needed:	none
e) recommended models and their technological level:	

Existing models are available in small numbers, and consequently it is difficult to recommend a specific version.

The technological level required for construction of modern Stirling engines suitable for operation at a fixed site is high. In fact, research into these engines is currently being conducted in developed countries only.

f) efficiencies (*):

- mechanical efficiençies with modern versions operating at full load:

i) using helium as working gas:	20–25%;
ii) using air as working gas:	$\simeq$6%;

- corresponding overall efficiencies (electric energy production) at full load:

i) with small capacities (< 5 kW): 5–15%;

ii) with highly efficient generators and engines: 18–23%.

g) can this technology be considered self-sufficient? (**)

YES

As long as the fuel is continuously supplied.

(*) **Calculated in relation to the fuel, and considering a heat generatorengine-generator set.**

(**) **NO/YES: frequent replacement of the source by another, more readily available source is/is not suggested.**

6.3.3 Hydraulic Engines Combined with Generators

These machines are divided into two groups: water wheels and water turbines. The former are used for the production of mechanical energy (low power with a small number of revolutions), while the latter are normally combined with generators for the production of electric energy.

Water Wheels

Wheels that convert the potential energy of a head are equipped with boxes (overshot wheels), while those that convert the kinetic energy of streams have paddles (undershot wheels).
The power P obtainable with overshot wheels is calculated as follows:

$$p = 10 * QH\mu \qquad [kW]$$

where Q is the flow rate [m^3/s], H is the available head, and μ is the wheel's overall efficiency (0.5–0.7).
For example, if Q=20 l/s and the wheel's diameter and width are 3 and 0.17 m, respectively, then p= 0.4 kW (at 9.5 rpm).
For undershot wheels:

$$p=0.25*AV^3\mu \qquad [kW]$$

where A is the submerged section measured perpendicularly to the flow [m^2], V is the speed of the current [m/s], and μ is the overall efficiency (0.5– 0.7).
Given the low number of revolutions (6–20 rpm), wheels are not highly recommended for the production of electric energy (a velocity ratio of ≃1/100 is required).

Water Turbines

Water turbines are basically composed of a nozzle (or stationary guide vanes) and a runner (or rotor, or propeller).
The purpose of the nozzle (or stationary guide vanes) is to direct the water to the runner and transform (completely or partially) its pressure energy into kinetic energy. The runner is composed of vanes that convert the energy of the water E_a into mechanical energy E_m (rotation around a fixed axis; machine efficiency: $\mu=E_m/E_a$).
When all the energy at the runner's inlet is kinetic, the machine is called an impulse turbine; when the energy is mixed (i.e., in the form of pressure and velocity), it is called a reaction turbine. The latter are also equipped with a diffuser, which connects the rotor's outlet to the tailrace. Its purpose is to suck in the water (this is important for low heads). Each kind of turbine is suitable for different values of available head.

Propeller or Kaplan Turbines (reaction turbines)

These turbines operate with low heads (2–20 m) and high flow rates. The runner is composed of a bulb-shaped hub and 4–6 adjustable vanes, which guarantees high efficiencies μ (defined as the ratio of the mechanical energy produced to the total energy of the flowing water) even with variable flow rates ($0.8<\mu<0.9$).

Francis Turbine (reaction turbine)

Suitable for average heads (15–150 m); composed of a rotor (rotation speed: 250–1000 rpm) with stationary guide vanes. ($0.8<\mu<0.9$).

Pelton Turbine (impulse turbine)

Requires large heads (> 100 m) and the runner (rotation speed: 500–1000 rpm) is composed of a disk around which a set of vanes (in the shape of a double spoon) are placed. Injectors (1–6) direct an equal number of jets towards the paddles, thereby generating torque ($0.8<\mu<0.9$).

Other kinds of turbines also exist, including the Banki turbine which is suitable for heads between 1 and 200 m; in this case, the water passes through the rotor.

To calculate the amount of power that can be produced, it is necessary to evaluate:

a. **the head's potential;**
b. **the plant's total efficiency, μ_t. This value is equal:**

$$\mu_t=\mu\mu_c\mu_g$$

where μ is the water machine's efficiency (defined above), μ_c is the water pipe's efficiency (if this exists; ≃ 0.93–0.98), and μ_g the electric generator's efficiency (0.9–0.98 with average and high capacities).

When the plant has been well constructed, μ_t=0.65–0.88.

References: [3], [23], [24], [30].

Electric Energy Production Final Technology - Summary Table:	**WATER WHEELS**
a) operative flexibility:	high

b) operation: fairly simple.

c) most obvious limitations: i) requires the presence of a stream with the right characteristics near the processing center; ii) the number of revolutions is low: therefore, overgears are needed for connection with generators; iii) when thermal energy is desired, heat storage is required to limit the amount of installed power.

d) auxiliary machinery needed: none in particular, except that related to water intake and conveyance.

e) recommended models and their technological level:

Versions are based on the type of stream under consideration. Naturally, the most efficient paddle design should be selected.

The technological level required for construction of water wheels is not high. Workshops must be capable of working with and welding sheet metal, or working with wood.

f) efficiencies (*):

- electricity generation (regulated electricity): 20–25%;
- electricity generation (unregulated electricity for heat production): 30–35%.

g) can this technology be considered self-sufficient? (**)

YES

As long as the flow rate is constant.

(*) Calculated in relation to the energy of the stream.
(**) NO/YES: frequent replacement of the source by another, more readily available source is/is not suggested.

Electric Energy Production Final Technology - Summary Table:	**WATER TURBINES**
a) operative flexibility:	high

b) operation: fairly simple.

c) most obvious limitations: i) requires the presence of a stream with the right characteristics near the processing center; ii) operations connected with water conveyance are generally laborious and sometimes complex; iii) when thermal energy is desired, heat storage is required to limit the amount of installed power.

d) auxiliary machinery needed: none in particular, except that related to water intake and conveyance.

e) recommended models and their technological level:

Versions are based on available head. The Michell-Banki model is recommended for use in poor countries because of its operative flexibility.

The technological level required for construction of Pelton, Francis and Kaplan turbines is fairly high when satisfactory efficiencies are desired. Workshops must be able to carry out all mechanical and foundry operations. However, Michell-Banki turbines can be produced in simpler workshops (capable of working with and welding sheet metal and doing basic work on metal parts), but adequate technical back-up is required.

f) efficiencies (*):

- electricity generation (regulated electricity): 60–90%;

- electricity generation (unregulated electricity for heat production): 70–90%.

g) can this technology be considered self-sufficient? (**)

YES

As long as the flow rate is constant.

(*) Calculated in relation to the energy of the head.
(**) NO/YES: frequent replacement of the source by another, more readily available source is/is not suggested.

6.3.4 Photovoltaic Flat-Plate Collectors

When certain materials are reached by solar radiation, they generate an electromotive force (photovoltaic effect). Examples include silicon crystal wafers (thickness: 0.2–0.4 mm) cut from bars and contaminated by impurities in order to turn the two sides into positive and negative semiconductors, respectively.

When solar radiation is present, electric energy is supplied by connecting the bottom surface (metalized) to the top (to which a metal grate is applied).

Other materials can be used in addition to silicon. Examples include indium phosphorus (InP), gallium arsenide (AsGa) and cadmium sulfide combined with copper sulfide (CdS-Cu2S).

Amorphous silicon can be very useful (because of its low cost), but its duration is limited.

The cells are characterized by peak power (P_p), which is the electric power supplied with 1000 W/m^2 of radiation.

A complete photovoltaic plant is composed of:

a. **solar modules made up of several cells protected by a transparent cover and connected in series to obtain voltages of 12 or 24 V);**
b. **electric storage (see Appendix 5);**
c. **a charge controller (this prevents the current's return from the storage to the collectors in the case of weak radiation and overcharging of the storage in the case of intense radiation);**
d. **a converter and transformer (to supply users in alternate current).**

References: [9], [21], [43].

Electric Energy Production Final Technology - Summary Table:	**PV SYSTEMS**
a) operative flexibility:	low

b) operation: fairly simple.

c) most obvious limitations: i) solar energy varies over time, and hence photovoltaic collectors have to be connected with other systems to ensure continuous service; ii) complete plants (i.e., with storage and inverter for the production of alternate current) are required for application to processing plants; to simplify the system, existing milk processing plants would have to be modified (changeover to direct current motors, etc.);

iii) high construction costs.

d) auxiliary machinery needed: none

e) recommended models and their technological level:

The characteristics of existing milk processing plants require systems composed of: collectors, regulating equipment, electric storage and inverter.

The technological level required for their construction is very high, and only developed countries are currently in a position to produce these systems.

f) efficiencies (*):

- complete systems: 5–10%.

g) can this technology be considered self-sufficient? (**)

NO

Since a solar source cannot be relied on to power a continuous process, unless the system is highly oversized.

(*) **Calculated as a ratio of electric energy produced (A.C.) to incident solar energy.**

(**) **NO/YES: frequent replacement of the source by another, more readily available source is/is not suggested.**

6.3.5 Wind Generators

Wind generators can be divided into two groups: those with horizontal axes and those with vertical axes. The former (unlike the latter) do not have moving parts that are faster than the wind, and they must rotate around a vertical axis for the rotor to be in operating position. Machines with 1–3 blades are generally used for electricity production.
The most complete versions include:

a. **a rotor with a device for regulating the blades' pitch (to keep the rotation speed constant when wind speed varies);**
b. **a brake (generally disc) to stop the machine for maintenance or when wind speed is excessive;**
c. **an overgear;**
d. **an electric generator;**
e. **an orientation system (not included in vertical machines).**
   The rotor is the most important component; the blades must have a special shape, and their fatigue strength and resistance to stress have to be high (wind speed varies constantly, and this causes the structure to vibrate).

The supply of electric energy is dependent on the wind speed v. Once three typical values of v (v1, v2, v3, where v1 <v2 <v3) have been established, the machine will operate in the following manner:

- when $v<v_1$,	the machine will not start;
- when $v_1<v<v_2$,	variable power is supplied;
- when $v_2<v<v_3$,	constant power is supplied,
- when $v>v_3$,	the machine stops working to prevent damage.
Generally:	$v_1 \simeq$ 5 m/s; $v_2 \simeq$ 12 m/s; and $v_3 \simeq$ 25–30 m/s.

Between v_1 and v_2, electric energy is not regulated (variable frequency).

Theoretically, the transformation efficiency μ (defined as the ratio of energy produced to wind

energy) can reach 59% (Betz's criterion), but it generally ranges from 10 to 40%.

In brief:

a. **direct or alternate current is generated, at variable frequency or voltage, for resistive loads (heating) or storage (possibly with transformation into direct current), from which it is then drawn and transformed into alternate current, if necessary. The machine operates when $v>v_1$;**
b. **only regulated alternate current is generated. The machine functions only when $v>v_2$;**
c. **production of unregulated alternate current and energy management with a controller that supplies resistive-load power when $v<v_2$, or power at any load when $v>v_2$.**

   Procedures a) and c) are more efficient than b).

When the machine is connected to the national grid, speed can be controlled by a generator excited by the grid itself (hence, the machine is forced to rotate at a fixed number of revolutions).

References: [9], [20], [27], [36], [50].

Electric (and Thermal) Energy Production Final Technology - Summary Table:	**WIND TURBINES**

a) **operative flexibility:** low

b) **operation:** fairly simple when the machine has been designed well

c) **most obvious limitations:** i) wind energy is extremely variable over time, and the production of regulated electricity is always a problem; the procedure can be simplified by equipping milk processing plants with direct current motors; ii) storage is always necessary in order to avoid oversized plants; iii) possible operation in parallel with other generators requires fairly complex energy plants.

d) **auxiliary machinery needed:** none

e) **recommended models and their technological level:**

The need to store energy (see Appendix 5) means that direct current machines have to be chosen.

The technological level required for construction of a good wind system is high. A clear understanding of the basic problems encountered in this field is the most important requirement.

f) **efficiencies (*):**

Average operating efficiencies are closely connected with the average wind speed v.

In places where average annual v > 5 m/s:

- electricity generation (regulated electricity): 8–10%;
- electricity generation (unregulated electricity for heat production): $\simeq$15%.

g) **can this technology be considered self-sufficient? (**)**

NO

Since wind speed is extremely variable over time.

(*) calculated as the ratio of electric energy to the wind's kinetic energy. Set considered: wind generator-storage-inverter.

(**) NO/YES: frequent replacement of the source by another, more readily available source is/is not suggested.

6.4 Combined Production of Electric and Thermal Energy: Cogenerators

As we have seen, processing centers require electric and thermal energy. Consequently, a plant capable of the simultaneous generation of these two types of energy certainly merits discussion here.

Cogenerators are based on the recovery of waste heat from an engine (internal or external combustion) connected to a generator. For example, with generators based on Otto (fed with any kind of fuel) or Diesel engines, 10–30% of the fuel's energy is transformed into electric energy, and the remaining portion is dispersed as heat by the exhaust gas (30–35%) and engine and lubricating oil cooling (30–40%). Thus, it is possible to recover (using simple exchangers) thermal power that is 1.2–2.5 times greater than electric power (total efficiency: 75–95%).

Positive results can only be obtained with water-cooled engines. When all the exchangers (operating on the exhaust gas and engine, respectively) are in series, thermal energy at ≃80°C can be produced.

Cogeneration can also be applied to steam and Stirling engines.

Steam engines, unlike all other types of engines, can produce thermal energy independently from electric energy. Indeed, in addition to recovering steam from the engine's exhaust, desired quantities of this product can also be drawn directly from the boiler.

References: see section 6.

Cogeneration Final Technology - Summary Table: (**Internal and External Combustion Engines**)	**GENERATOR SETS**

a) **operative flexibility:** average

b) **operation (apart from the engines' requirements):** no problem when the plants have been designed well.

c) **most obvious limitations** (apart from those connected with the engines): i) the thermal power supplied (except in the case of steam engines) is closely connected with the electric power by precise ratios that vary from 1.5 to 2.5; however, at processing centers, the ratios of thermal to electric requirements very from 0.3 to 2.7; therefore, cogeneration is not always suitable for the center's production requirements; ii) production of thermal and electric energy is simultaneous, but related requirements are not; thus, thermal storage is necessary; iii) steam (except in the case of engines fed with this medium) can only be produced with exhaust gas (which supplies slightly less than half the thermal energy recoverable).

d) **auxiliary machinery needed (in addition to that required for the engines):** none

e) **recommended models and their technological level:**

Water-cooled engines are recommended because of the ease of thermal recovery. Steam engines (and their related boilers) are best suited for these purposes.

The technological level required for transformation of engines and cogenerators is quite high.

f) **energy efficiencies (*):**

- Otto, Diesel and Stirling engines: 60–80%.

g) **can this technology be considered self-sufficient? (**)**

YES

As long as the processing center has ratios of thermal to electric requirements that are similar to the cogenerator's production.

(*) Calculated as the ratio of total energy produced (electric + thermal) to that of the fuel used.
(**) NO/YES: frequent replacement of the source by another, more readily available source is/is not suggested.

7. ECONOMIC EVALUATION OF ENERGY PLANTS

7.1 Introduction

A method has been designed to provide engineers with a tool for synthetic evaluation of the competitiveness of a given technology (e.g., a high-efficiency, gas-fed boiler) with respect to a reference plant (e.g., standard gas-fed boiler).
The need for a practical, analytical tool emerged between 1975 and 1980 in developed countries, following increases in the price of fossil fuels and the resultant spread of "energy-saving" technologies. Indeed, numerous innovative energy proposals were made at that time, and this created some confusion.
Consequently, engineers and final users had to be able to analyze the economic soundness of the options being offered to them.

7.2 The Main Aspects of Energy Investments

a. **Economic analysis of energy plants is always based on the comparison of two plant solutions and their satisfaction of a given energy requirement. Therefore, the data necessary concern variations in a number of parameters (investments, maintenance costs, etc.).**

b. **Normally, as we switch from an inefficient to a more efficient solution (from an energy standpoint), investment and operating and/or maintenance costs increase (since more efficient solutions are usually more complicated), while the incidence of the energy source decreases. The same thing happens when we switch from a solution employing conventional sources (fossil fuels, electricity from the national grid, etc.) to solutions that make use of renewable sources. This “energy saving trend” is almost always observed.**

   Example no. 1: the consumption of an electric, thermal-energy generator is certainly higher than that of a solution involving its combination with a solar collector. In the latter case, however, investments are higher, and routine and special maintenance are more expensive (the number of components is larger, and thus inspection requirements and the probability of accidental breakdowns increase).

   Example no. 2: the cost of wood is generally lower than that of any liquid or gaseous fossil fuel (needed to produce the same amount of energy). But plants designed to use wood (especially those with high capacities), are sometimes more expensive and difficult to operate (because of the type of feeding, the cleaning necessary, etc.) than plants that employ other types of fuel.

c. **Even when a certain degree of energy coverage must be guaranteed, savings on energy production costs can be obtained:**

- **by reducing consumption. For example, by switching from a standard electric motor to a high-efficiency motor;**
- **by completely or partially replacing some of the energy consumed with a source whose cost is zero. For example, use of a wind turbine together with a Diesel generator, employment of solar collectors to reduce the consumption of an electric boiler, etc.;**

- **replacement of the source used in the standard solution by one which costs less. For example, switching from a Diesel fuel-fed boiler to a coal-fed boiler.**

  In the first case, the goal is energy savings, in the second it is a reduction in consumption, and in the third it is a reduction in the cost of the source.

7.3 Basis of the Method and Important Concepts

The method is based on pro-rating the cash flow and hence on calculation of the Net Present Value (NPV).
This makes it possible to quantify, in monetary terms, most of the aspects that distinguish the two technologies being compared.

Generally speaking, when an energy requirement must be met (e.g., home heating), the problem concerns evaluation of the profitability of adopting a more expensive, energy-saving technology, as opposed to the reference solution (the example of the high-efficiency and standard gas-fed boilers also applies here). In other words, the main question is: is it worthwhile to make an additional investment in order to later obtain a reduction in operating costs?
An answer can certainly be provided by calculating the NPV.

For this purpose, the following parameters must be estimated for <u>each year of the plant's useful life</u> (Lu):

a. **the <u>gross benefits</u> obtained from the lower cost of the energy produced;**
b. **the difference (positive or negative) in routine and special maintenance costs (variation in <u>operating costs</u>);**
c. **the algebraic sum of the gross benefits and the increase (or decrease) in operating costs (<u>net annual benefits</u>, NB). On the basis of the established interest rate (i), the annual net benefits are then "shifted" (PNB) to the time of the investment (year zero).**
   Their sum (TNB), less the increase in the initial investment (δI), gives the NPV, or the monetary gain (or loss) that the technology will provide during its useful life, when compared with the reference technology.

Using the terminology mentioned above, the following is a summary of the procedure:

$$TNB = \sum_{n=1}^{Lu} PNB_n = \sum_{n=1}^{Lu} NB_n/(1+i)^n$$

$$NPV = TNB - \delta I$$

The ratio of NPV to the initial increase in investment (δI) is called the <u>profitability index</u>:

$$Pi = NPV/\delta I$$

which is probably easier to use in some situations.

7.4 An Example Applying These Basic Concepts

Let's assume that we have to analyze the profitability of a wood-fed boiler used to heat milk, as compared with similar equipment fed with Diesel fuel. The technical-economic hypotheses contained in Table 3 are assumed to hold true.
The problem is quite simple, since the net benefit is constant throughout all the years of the plant's useful life. The following calculations have to be made:

a) <u>Evaluation of annual savings on energy production</u> (gross benefit):

Where:

- **HP_w and HP_d are the wood's and Diesel fuel's heat value, respectively;**
- **μ_w and μ_d are the efficiency of the wood-fed and Diesel fuel-fed boilers, respectively;**
- **EC_w and EC_d are the costs of the energy produced with the two fuels, respectively;**

It is observed that (Table 3):

EC_w = biomass cost/(HP_w*μ_w)	= 0.07/(16*0.5) = 0.009 U.S.$/MJ
EC_d = Diesel fuel cost/(HP_d*μ_d)	=0.50/(42*0.7) = 0.017 U.S.$/MJ

Therefore:

Gross benefit (GB) = (EC_d-EC_w)*annual energy requirement =
= (0.017-0.009)*36,000=U.S. $288/year

b) <u>Evaluation of annual operating costs</u>:

It is assumed that analysis of the two plants', maintenance requirements (which are not discussed here, in order not to complicate presentation of the economic concepts) would lead to the following conclusions:

- **zero costs of labor needed to load the wood and for routine maintenance of the Diesel fuel-fed boiler (family-run plants);**
- **annual visit by an engineer to check on plant operation.**

Related costs are estimated at U.S. \$80 and \$50 (two hours of work and various materials), for the wood-fed and Diesel oil-fed boilers, respectively.
Consequently, the <u>increase in operating costs</u> of a Diesel fuel-fed boiler, as opposed to a wood-fed model, is U.S. \$30/year (this value does not change throughout the plant's useful life).

c) <u>Evaluation of the net annual benefits</u>:

During every year “n” of the plant's useful life:

NB_n = Gross Benefit (GB) - annual operating costs = = 288 - 30 = U.S. \$258/year

d) <u>Calculation of NPV</u>:

All the annual net benefits are updated to year “O” (i.e., the time at which the investment is made). In other words, the following calculation should be made for <u>each year of the plant's useful life</u> (considering an interest rate of 15% by way of example):

$$PNB_n = NB_n/(1+i)^n$$

Thus, for the first year:

$$PNB_1 = 258/(1+0.15)^1 = \text{U.S. } \$224.30$$

whereas, for the fifth year:

$$PNB_5 = 258/(1+0.15)^5 = \text{U.S. } \$128.30$$

It can be observed that the present value of the benefits decreases as n increases. In other words, future savings are worth “less” at the time when the cash outlay is made than short-term savings.
The results of each individual operation are then added together to obtain the TNB. In this specific case, all the NBs are the same throughout the plant's useful life. Therefore (see Table 4, initial summation), TNB can be calculated by the following expression:

$$TNB = [(1+i)^{Lu}-1]*NB/(i*(1+i)^{Lu}) = [(1.15)^{10}-1]*258/(0.15*1.15^{10}) = \\ = \text{U.S. } \$1,295$$

This figure is the “value” at year “O” of the total savings (which are actually distributed over the course of the useful life).
Finally, if we consider that the additional investment (δI) to switch from a Diesel fuel-fed to a wood-fed boiler is U.S. $1,500:

$$NPV = TNB - \delta I = 1,295 - 1,100 = \text{U.S. } \$195$$

In other words, NPV represents what's "left in the user's pocket" when he switches from the reference solution to the solution under consideration here.

e) <u>Evaluation of the profitability index</u>:

Pi = NPV/δI = 195/1,100 = 0.18 (18%)

The economic performance of the wood-fed boiler can be considered satisfactory (although, this is still a subjective judgment).

7.5 Comments on the Basic Procedure

a. **The method requires estimation of numerous technical and economic parameters (e.g., the useful life of the plants, their average efficiencies, the users' energy requirements, the maintenance schedule, the duration of components that have to be replaced during the plants' useful life, etc.). Naturally, the reliability of the analysis largely depends on the reliability of the estimates. Therefore, the analyst must have considerable experience with the plants under examination. The problem becomes particularly complicated when innovative or experimental plants are considered, since all the necessary data cannot always be found.**

b. **Uncertainties of the data can be lessened by calculating NPV and Pi in relation to their maximum and minimum values (obviously estimated). This provides a measure of the sensitivity of the economic results to the parameters under consideration.**

   For example, let's assume that we are not sure whether to estimate the annual number of hours required for a given plant's routine maintenance at 50 or 100 hours. The use of an average value (75) is the most logical solution, but doubts remain about the reliability of

this evaluation. Indeed, the effect produced by uncertainty becomes immediately apparent if we calculate NPV using the highest and lowest values (100 and 50). When the results obtained differ only slightly, the average value can be readily accepted. But when this is not the case, the problem has to be analyzed more deeply (by referring to specific documentation, consultants, etc.).

c. **In order for the proposed plant to be preferable to the standard version, its NPV (and hence its Pi) must be positive. This is a necessary, but insufficient, condition. In some cases, for example, the user may feel that the NPV (or Pi) calculated does not justify the inevitable risks that go hand-in-hand with more complex plants (e.g., a Pi of 10% may be considered too low);**

d. **The user is sometimes forced to reject sound operative proposals because he cannot come up with the required capital. For example, let's assume that a complete overhaul of the energy plants at a milk processing center would reduce consumption by 50% and that Pi is estimated at 30% (based on improved product quality, as well), but the capital required is U.S. $2,000. This figure may be prohibitively high if it is impossible to get a mortgage, negotiate extensions on payments, etc. Therefore, plant solutions requiring lower investments are naturally more competitive (even when these plants save less energy);**

e. **More complex cases have to be analyzed carefully. For example, when evaluating gross revenue, the profits deriving from the use or sale of the following products can sometimes be added to the benefits provided by energy savings:**

   - **byproducts of the proposed technology (e.g., the ash produced by the combustion of husks, the increased nitrogen content of sewage treated in anaerobic fermentation** plants, etc.);

- surplus energy (e.g., an electric generator that supplies part of its energy to another user).

In highly complicated analyses, values of NB can vary from one year to the next because of the company's production schedule, presumed price variations over time, etc.

7.6 The Complete Method

NPV and Pi are closely connected with the net price of the energy saved or replaced (P_S) and the interest rate adopted, i. Therefore, analysis of the sensitivity of these values to the two parameters will show:

a. the influence of variations in the price of the energy source employed by the reference plant (usually a fossil fuel);
b. the “critical” prices of the source at which the technologies are or are not profitable;
c. the influence of financial limitations (generally linked to i).

For example, the following equation shows how Pi is connected with the price of the replaced source:

$$Pi = a + b^* p_S$$

where a and b are constants that depend on the plant's technical and economic characteristics. The connection between Pi and P_S is linear.

If, in addition to P_s, the rate of interest i also varies, a sheaf of straight lines passing through a set of coordinates (x_a, -1) is plotted on a cartesian plane P_s -Pi.
In practical terms, it is useful to consider a sheaf formed by three straight lines calculated using the following rates (Figure 5):

- **i=O;**
- **i=the cost of money (i_b, that is, the rate on bank loans);**
- **i=interest desired by the user (i_u, that is, the rate of return on capital that would make the investment attractive to the user).**

In principle, i_u>i_b, since it is assumed that the user is only interested in a plant whose yield is higher than the interest rate to be paid to third parties for loans.
On the abscissa (i.e., Pi=0 or NPV=0, which is implicit), the three lines identify four energy prices (x_a, x_b, x_c and x_d) to which particular conditions correspond.

In fact, when:

$P_s = x_a$:	the proposed plant's annual net benefits equal the variations in operating costs: in other words, the annual net benefits are always zero;
$P_s = x_b$:	over the course of the plant's useful life, the annual net benefits are able to “cover” (at an interest rate of zero) the additional investment; in other words, this is the payback price, where the payback period is equal to the presumed life of the plant;
$P_s = x_c$:	there is no difference between the reference and the proposed solution from an economic standpoint;
$P_s =$	the proposed solution makes sense for the user, since the plant returns i_u, with

x_d: respect to the reference solution.

The method is simple to use: equations for three straight lines on the plane P_s-Pi are determined (e.g., by calculating two values of Pi for each line in correspondence with two prices P_s) for a given combination (consisting of the reference plant and the proposed plant). Once the graph has been completed, the current price P_a of the energy saved or replaced is located with respect to prices x_a, x_b, x_c and x_d.

Five situations are possible:

$P_a<x_a$:	the proposed technology is not economical at all, since its operating costs are higher than its gross benefits (Pi<-1; Figure 6);
$x_a<P_a<x_b$:	annual balances are positive, but not sufficient to guarantee a full return on the capital invested (even when i=0; Figure 7);
$x_b<P_a<x_c$:	the capital has not yet been recovered (indeed, Pv<0; Figure 8);
$x_c<P_a<x_d$:	the economic balance is positive, but lower than that desired by the user (Figure 9);
$P_a>x_d$:	economic performance is equal to or higher than the minimum desired by the user (Figure 10).

In conclusion, the graph can be used to evaluate the “°” of profitability of the proposed solution in comparison to the reference solution.
If we assume that the <u>gross benefits are constant throughout the plant's useful life Lu</u> (which is almost always the case), the values of x_a, x_b, x_c and x_d can be supplied by the following equations:

$$x_a = \frac{ST(0)}{Vu*E}$$

$$x_b = \frac{[ST(0) + I]}{Vu*E}$$

$$x_c = \frac{[ST(i_b) + I]}{A(i_b)*E}$$

$$x_d = \frac{[ST(i_u) + I]}{A(i_u)*E}$$

Where:

E is the energy saved (net) when the goal is <u>energy savings or decreases in consumption</u>, whereas it is the user's thermal requirement <u>in the case of reduced source costs</u>.
ST(x) is the variation in routine and special maintenance costs, pro-rated at rate x, when the goal is <u>energy savings or decreases in consumption</u>; it is the variation in maintenance costs (routine and special) plus the costs relating to the supply of energy for the <u>proposed solution</u> (pro-rated at rate x), <u>in the case of reduced source costs</u>.

A(x) is a financial operator defined by the equation:

$$A(x) = \frac{(1+x)^{Lu} - 1}{x * (1-x)^{Lu}}$$

When difficulties connected with estimation of the various parameters (see points a and b in section 7.2) can be overcome, application of this method is fairly rapid.
In fact, once values have been determined for the four points, the three straight lines can be traced and a final judgment can be made.

Calculation of ST(x) can be difficult in more complicated cases and when manual methods are used. However, this problem can be solved by using work sheets and programmable calculators (even those with few functions). Standard programs, which make rapid calculation possible, are available for these machines.

7.7 Additional Information Provided by This Method

An economic index that is frequently used is the internal rate of return (IRR). This index is, by definition, the rate of interest that reduces NPV to zero. With reference to the terminology used above:

$$TNB(IRR) - \delta I = 0$$

Calculation of NPV and IRR gives a fairly precise idea of the economic performance of an investment. The former value provides the amount of savings obtained and the latter the rate of interest that would make the reference and proposed plants economically equivalent. Consequently, the information obtained may be considered complementary.

IRR is usually determined through iterative calculations. The rate of interest is varied until NPV=0. Therefore, this procedure requires the use of a computer.
The proposed method provides an approximate evaluation of IRR, which is sufficient to reach some initial conclusions.

Indeed, in correspondence with points x_b, x_c and x_d, Pv is zero and hence NPV=0.

Thus, it is clear that:

for $P_a=x_b$ → $IRR=0$;

for $P_a=x_c$ → $IRR=i_b$;

for $P_a=x_d$ → $IRR=i_u$;

and

for $P_a<x_b$ → $IRR<0$;

for $x_b<P_a<x_c$ → $0<IRR<i_b$;

for $x_c<P_a<x_d$ → $i_b<IRR<i_b$;

for $P_a>x_d$ → $IRR>i_u$.

By comparing P_a with the values of x_b, x_c and x_d, the corresponding value of IRR can be estimated.

7.8 An Applicative Example

Phase 1: Definition of the problem. The advisability of installing a solar water collector on a 30-m^2 surface to be used by a milk processing center (for washing containers) to limit the consumption of Diesel fuel by an existing boiler equipped with storage.

Phase 2: Definition of the reference and proposed plants. The reference plant consists of a Diesel fuel-fed boiler; the proposed plant is a combination of this boiler and the solar collector. The goal is a reduction in consumption (solar energy, whose source costs nothing, is employed so as to limit the consumption of Diesel fuel).

Phase 3: Estimation of technical and economic parameters. The increased investment concerns installation of the solar plant; the proposed plant also requires additional maintenance. An initial analysis of the two plants demonstrates the following:

- **net energy contribution of the solar plant: 2,000 MJ/year per m^2 of collector;**
- **investment required for the solar portion alone: U.S. $150/$m^2$;**
- **the useful life of the plants: 8 years;**
- **annual routine maintenance costs for the solar section (including the costs of electric energy for circulation of fluid in the collector): U.S. $8/$m^2$. During the fourth year, the plastic cover has to be replaced (special maintenance), and the cost of this operation is U.S. $15/$m^2$;**
- **cost of Diesel fuel: U.S. $0.50/kg (heating power: 42 MJ);**
- **average boiler efficiency: 0.6;**
- **interest rates under consideration: i_b=10; i_u=15%.**

In conclusion, it must be determined whether an investment of U.S. $150 (for simplicity's sake, reference is made to unit of surface area) is justified to obtain an energy savings of 2,000 MJ.

Phase 4: Determination of routine and special maintenance. Let's assume that the gross benefit is constant throughout the plant's useful life (which is an essential hypothesis for application of the calculation formulas). In addition, since the goal here is a reduction in

consumption, it is necessary to calculate the discounted values of the costs of routine and special maintenance.

Annual maint. costs (years: 1, 2, 3, 5, 6, 7, 8)	= U.S. $ 8/m^2
Annual maint. costs (year: 4) = 8 + 15	= U.S. $23/$m^2$

Discounting these costs at an interest rate of 0% coincides with their algebraic sum. That is:

ST(0) = 8 * 7 + 15 = U.S. $71/$m^2$

For rates of 10 and 15%, however:

$$ST(10) = 8 * \frac{(1+0,1)^8 - 1}{0,1 * (1+0,1)^8} + \frac{15}{(1+0,1)^4} = U.S.\ \$52.9$$

$$ST(15) = 8 * \frac{(1+0,15)^8 - 1}{0,15 * (1+0,15)^8} + \frac{15}{(1+0,15)^4} = U.S.\ \$44.5$$

<u>Phase 5: Plotting the graph</u>.
Calculation of characteristic points:
for the various rates (0, 10 and 15%):

$$A(i_b) = \frac{(1+0,1)^8 - 1}{0,1 * (1+0,1)^8} = 5,3 \quad A(i_u) = \frac{(1+0,15)^8 - 1}{0,15 * (1+0,15)^8} = 4,5$$

$$x_a = \frac{ST(0)}{Vu*E} = \frac{71}{8*2000} = U.S.\$0.0044/MJ$$

$$x_b = \frac{[ST(0\%) + \delta I]}{Vu*E} = \frac{[71 + 150]}{8*2.000} = U.S.\ \$0.014/MJ$$

$$x_c = \frac{[ST(i_b) + \delta I]}{A(i_b)*E} = \frac{[52.9 + 150]}{5,3*2.000} = U.S.\ \$0.019/MJ$$

$$x_d = \frac{[ST(i_u) + \delta I]}{A(i_u)*E} = \frac{[44.5 + 150]}{4,5*2.000} = U.S.\ \$0.022/MJ$$

Since we are concerned with a reduction in consumption, E represents the energy supplied by the solar plant (energy saved).
At this point, the characteristic points can be plotted on the graph, and the three straight lines can be traced.
In our specific case, all the lines will pass through the same coordinates (0.0044, -1), with each one passing through the points (0.014, 0), (0.019, 0) and (0.022, 0).

Phase 6: Reaching a final conclusion. The current cost of energy is equal to:

P_a = (0.5/kg)/(42 MJ/kg*0.6) = U.S. $0.02/MJ

Then P_a is located between points c and d.

Thus, it is clear that although the proposal is economically profitable, it does not fully meet our expectations.
IRR, which falls somewhere between 10 and 15%, is positive.
To improve the situation, the proposal would have to be revised in order to obtain:

- **an increase in the plant's useful life;**
- **an increase in the amount of energy saved;**
- **a reduction in operating and investment costs.**

7.9 Application of the Method to Feasibility Studies

When an operative hypothesis and an element for comparison exist, this method may be useful for an initial evaluation of a proposal's level of competitiveness, which may be defined as good, improvable or non-existent depending on the situation.
The level of competitiveness may be defined as good (Figure 10) when the current price P_a of the energy that is replaced or saved is higher than x_d. As we noted above, under these conditions the alternative proposal guarantees better results than those desired by the user.
The level of competitiveness becomes improvable when P_a is between x_b and x_d. In this case, economic performance is modest and does not meet the user's expectations. However, revision of the proposal may provide a result that can be classified as “good”.
Finally, the level of competitiveness is defined as non-existent when P_a is lower than x_b. When P_a<x_a, economic performance is extremely negative.

7.10 Application of the Method in the Study of Financial Subsidies

The “design” or analysis of various forms of assistance is often under consideration to encourage the spread of technologies that are felt to be highly sound for different reasons. In this context, the three levels of competitiveness described above may be interpreted as follows:

Level of competitiveness - Good: the final user already considers the seconomic performance satisfactory, and assistance is not necessary. Consequently, activity can concentrate on the spread of these technologies and various forms of monetary assistance.

Level of competitiveness - Improvable: modest economic performance justifies an analysis of subsidies that could make these technologies more acceptable to the user. The objective should be to encourage the moderate spread of these technologies in order to examine all their technical and economic aspects. In the most unfavorable cases ($x_b<P_a<x_c$), the possibility of financing exemplary plants (together with research institutes) may be considered.

Level of competitiveness - Non-existent: there is no reason to encourage the spread of these technologies (especially when $P_a<x_a$). These technologies require further research aimed at increasing their level of competitiveness. Exemplary plants would only be useful in certain cases (when P_a approaches x_b).

References: [6], [7], [8].

Table 3 - Technical and economic data used in comparison of a manual, woodfed boiler (proposed plant) and a standard Diesel fuel-fed boiler (reference plant; see text).

Parameter	Wood-fed	Diesel fuel-fed
Thermal power (kw)	40	40

Energy requirement (MJ/Y)	36000	36000
Investment (U.S. $)	3100	2000
Maintenance cost ($/year)	80	50
Interest rate (%)	15	15
Useful life (years)	10	10
Avg. fuel efficiency (%)	50	70
Fuel's heat value (MJ/kg)	16	42
Fuel cost ($/kg)	0.07	0.5

Table 4 - Useful Financial Formulas

Purpose of the Formula	Equation [1]
shift from year “n” to year “O”	$S/(1+i)^n$
shift from year “O” to year “n”	$S*(1+i)^n$
initial accrual of constant annuities (for N years)	$A*[(1+i)^N-1]/[i*(1+i)^N]$
Final accrual (during year “N”) of constant annuities	$A*[(1+i)^N-1]/i$

[1] All the equations refer to deferred annuities (i.e., available at the end of each year taken into consideration, which is usually the actual case).

Terminology: S - sum of money; A- annual share; i - interest rate; n -year between O and N; N - number of years taken into consideration.

Table 5 - List of Symbols Used in the Text

Parameter	Symbol
Net annual benefits during year n (U.S. $)	NB_n
Pro-rated net annual benefits during year n (U.S. $)	PNB_n
Financial operator to accrue at rate x (-)	A(x)
Energy saved or energy requirement (MJ/year)	E [1]
Investment (U.S. $)	I
Profitability index	P_i
Price of energy saved or replaced (U.S. $/MJ)	P_s
Current price of energy saved or replaced (U.S. $/MJ)	P_a
Generic interest rate (%)	i
Bank interest rate (%)	i_b
Interest rate desired by investor (%)	i_u
Operating costs for year n discounted at rate x (U.S. $)	$SA_n(x)$ [2]
Summation of all the $SA_n(x)$	ST(x) [2]
Internal Rate of Return	IRR
Net Present Value (U.S. $)	NPV
Plant's Useful Life (years)	

Lu

[1] E represents the energy saved when the goal is energy savings or a reduction in consumption; it represents the energy requirement when a reduction in source costs is desired (see section 7.6).
[2] Operating costs also include energy costs only when a reduction in the cost of the source is desired (see section 7.6).

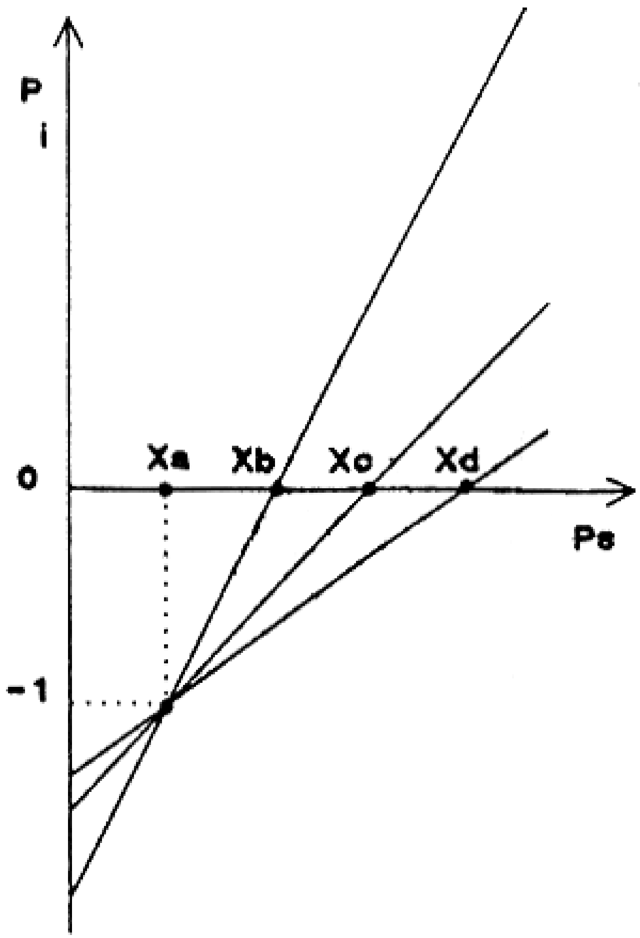

Figure 5 - Profitability index Pi (ratio of NPV to the increase in the initial investment) versus the

price P_s of the energy saved or replaced. The three lines are related to the following interest rates: i=0; i=cost of money (i_b; i.e., bank rate on loans); i=the interest desired by the user (i_u; i.e., the rate of return on the capital that would make the investment attractive). The three lines define the points x_a, x_b, x_c and x_d, which are described in the text.

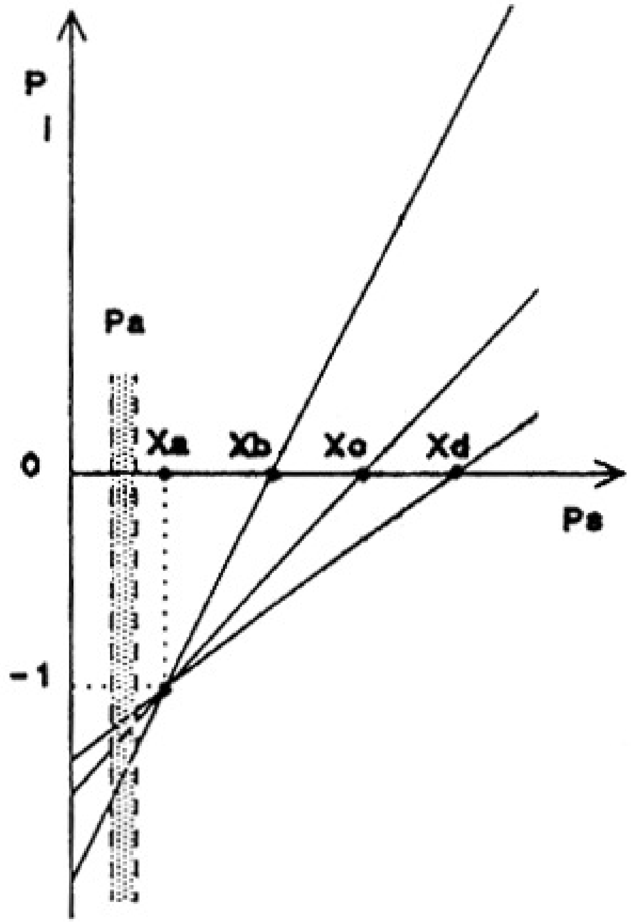

Figure 6 - When the price (or the variation in prices) of the energy saved or replaced (P_a) is less than x_a, the technology is not economical from any standpoint, since the annual net

benefits are always negative (costs > benefits). In this case, the degree of competitiveness is non-existent.

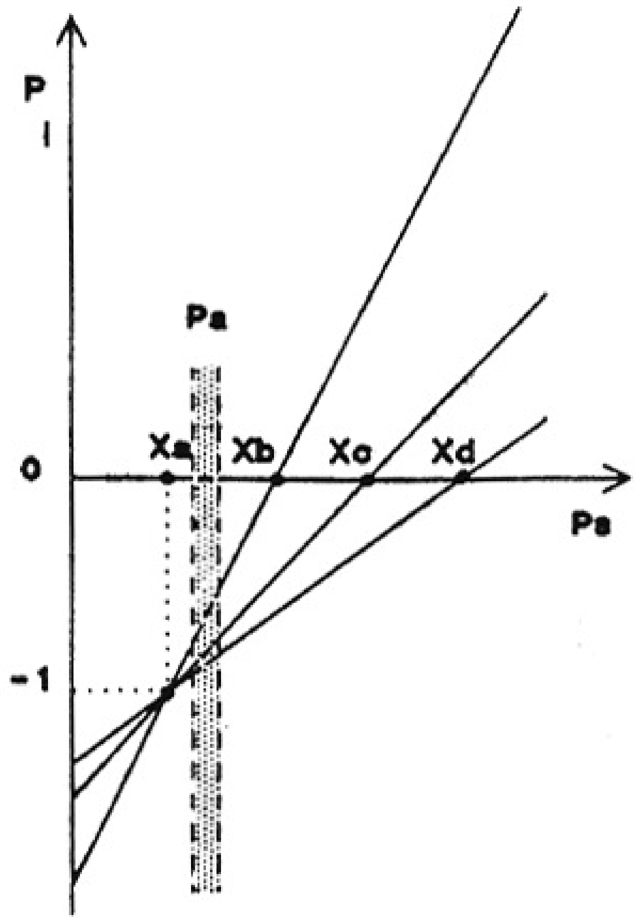

Figure 7 - When the price (or the variation in prices) of the energy saved or replaced (P_a) is between x_a and x_b, the technology is not economical, since the annual net benefits are positive but do not compensate (even with an interest rate of zero) for the initial investments. As in the case in Figure 6, the degree of competitiveness is non-existent.

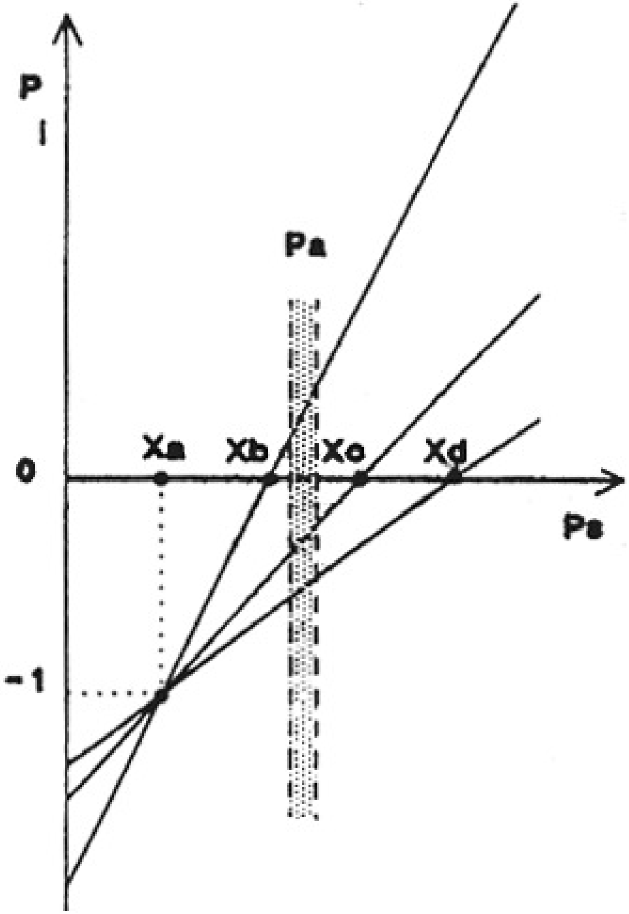

Figure 8 - When price P_a is between x_c and x_b, the technology is only economical when the interest rate is zero. This type of situation is defined as “improvable”, since revision of the project may improve its economic performance.

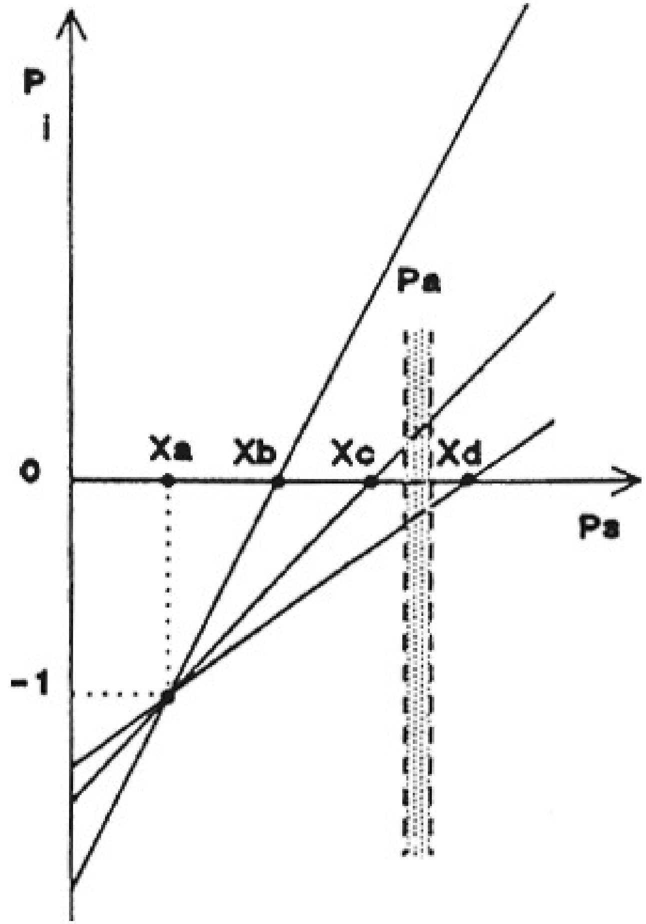

Figure 9 - When price P_a is between x_d and x_c, the technology is economical. Indeed, the initial investment is recovered even when the bank's interest rate is used. However, the user does not consider overall performance adequate (i.e., he feels that it does not compensate for the risks inherent in the proposed technology). As in Figure 8, this situation is defined as "improvable" in terms of economic competitiveness.

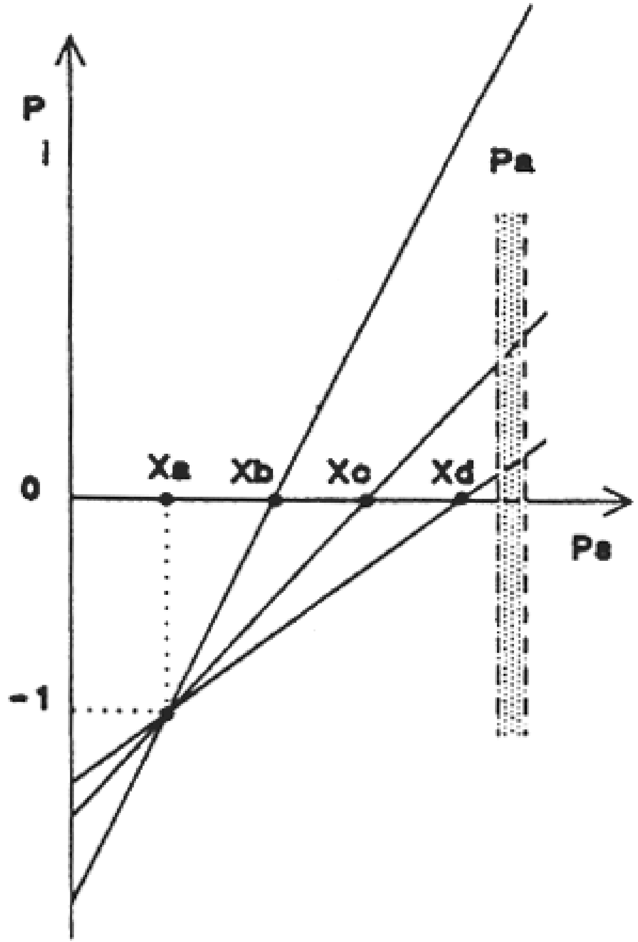

Figure 10 - When P_a is greater than x_d, the technology is economical and profitable. The level of competitiveness is good.

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8. CASE STUDY

8.1 Introduction

The following analysis of a practical case is designed to clarify the concepts discussed in previous sections and provide a better example of the objectives of this study.
The information contained in the following pages should be viewed as an illustration of a hypothetical analyst's possible conclusions, if that analyst were provided with the information contained in the various summary tables.

The following conditions are assumed to hold:

Analyst's identity: employee of the Ministry of Agriculture without any special training in the field of energy and plant design.
Country under consideration: Tropical.
Pedologic and climatic characteristics: dry climate, average annual wind speed: 4 m/s; no specific data on solar radiation; availability of wellwater.
Other information: electric energy from the grid is not available; biomass (wood with a moisture content of 25% w.b.) is available at a cost of U.S. $0.02/kg; Diesel fuel at a cost of $0.60/kg (including transport) may also be available.
Processing center: currently does not exist. Expected quantities of milk to be processed: 1500 1/day; final products: pasteurized milk in plastic containers (1000 1/day); yogurt (500 1/day). Milk will be collected daily in metal cans. The products will be sold in a nearby city (30 km) by another organization.
Personnel: are not available, and it is not possible (for economic reasons) to have full-time engineers supervising the processing center's plants. There is an abundant supply of unskilled labor.

Purpose of the analysis: identification of several technical solutions for the supply of energy to the processing center on the basis of the information contained in this study.

8.2 Evaluation of Energy Consumption and Selection of Possible Energy Sources

Energy consumption is the first aspect that has to be evaluated. Indeed, this value makes it possible to analyze various technical possibilities with more confidence.

Given the context outlined above, simplified milk processing plants will no doubt be chosen for the processing center.

With reference to the equations contained in section 2.2.3:

$$E_t = 25m_c + 180(m_p + m_t)$$

$$E_e = 145m_c + 90(m_p + m_t) \qquad [MJ]$$

where: E_t and E_e are the electric and thermal energy requirements; m_c, m_p and m_t are the quantities (t) of milk that are cooled, pasteurized and processed (into milk or yogurt).
In the case under examination, 1000 1 of milk are pasteurized and 500 1 are processed into yogurt.

$$E_t = 25*0 + 180(1.0 + 0.5) = 270 \text{ MJ/day}$$

$$E_e = 145*0 + 90(1.0 + 0.5) = 135 \text{ MJ/day}$$

By referring to <u>graphs 3 and 4</u> (section 2), it may be observed that the <u>thermal energy requirements are equal to the maximum values</u> and the <u>electric energy requirements are halfway between the maximum and minimum values</u>.

This observation is important for analysis based on the summary tables contained in the text.

For the sake of information, it should be remembered that the chemical energy contained in 1 kg of Diesel fuel is 42 MJ (80% of which is transformable into thermal energy and 15–20% into electric energy with the use of normal energy conversion technologies).

The complete absence of a grid for the supply of energy means that selfsufficient solutions should be considered. Therefore, the profitability of employment of traditional sources (e.g., Diesel fuel for the generation of electric and thermal energy) and renewable sources has to be evaluated. Since the site under examination does not have any special resources (streams, geothermal sources, etc.), the only possible sources are the sun, wind and biomass (dry).

Solar Source

The summary table concerning solar radiation states that from 4 to 30 m^2 of receiving surface are needed to satisfy thermal requirements and from 60 to 90 m^2 are needed for electric requirements in the case of simplified plants and a daily intake of 1000 l. This means that the following surface areas are needed in the case under examination:

For thermal requirements	$\rightarrow 30\ m^2 * 1.5 \simeq 45\ m^2$
For electric requirements	$\rightarrow 75\ m^2 * 1.5 \simeq 110\ m^2$

1.5 is the multiplication factor used to take into account the larger quantity of milk considered here (1500 l/1000 1 = 1.5); 30 is the maximum value between 4 and 30 (as noted above, the thermal requirements equal the maximum values shown in Figure 3); and 75 is the intermediate

value between 60 and 90 (the electric requirements fall halfway between the maximum and minimum values shown in Figure 4).

Wind Source

The summary table on wind energy (section 4.3) states that the employment of wind energy is only useful in areas in which annual wind speed is at least 5 m/s. In the case discussed here, wind energy appears to be excluded.

Use of Biomass

The summary table concerning dry biomass (section 4.6) suggests that consumption of this material (as in the case of solar radiation) is equal to:

For thermal requirements	→ 30 kg * 1.5 ≃	45 kg
For electric requirements	→ 125 kg * 1.5 ≃	190 kg.

8.3 Evaluation of Conversion Technologies

Solar Energy

The summary table regarding the production of thermal energy from a solar source (section 6.2.2) states that the production of hot water is not a significant technological problem as long as flat-plate collectors are used (thus, milk processing plants that are capable of operating at low temperatures have to be employed).
The most serious problem is the fact that the source is not self-sufficient and hence requires

the installation, in parallel, of a thermal energy generator. In this particular case, the generator could be a biomass-fed boiler.
Generation of electric energy could be handled by photovoltaic plants (section 6.3.4), but this equipment is very expensive and hard to manufacture in underdeveloped countries. In addition, the application of this technology would require the redesign of current processing plants. It should be remembered, however, that the consumption of electricity for cooling (and hence the surface area of the required photovoltaic collectors) could be reduced considerably if the available well-water were cold enough (under 15–20 fC) and the heat exchangers were instantaneous (summary table in section 6.2.5).

Wind Energy

As noted above, wind energy does not appear to be applicable here. However, this source could be considered for pumping water (using water pumps that operate satisfactorily with wind speeds between 3 and 4 m/s).

Biomass

The required thermal energy could easily be produced (in the form of hot water or steam) by the right kind of boilers (section 6.2.1). These boilers could be manufactured on the semi-industrial level in numerous countries with varying socioeconomic levels.
The production of electric energy could be handled by reciprocating steam engines (see related summary table, section 6.3.2), which could also produce the necessary thermal energy with the aid of steam-water exchangers.
In addition, these technologies can be considered self-sufficient.

Other Technologies

Thermal energy requirements could be reduced through the adoption of refrigerating machines for milk cooling with heat recovery (section 6.2.3). Electric energy could also be produced by gasification of the biomass and use of suitable electric generators (section 6.3.1).
The use of generators (with possible heat recovery) fed by alcohol or vegetable oils (sections 6.3.1 and 6.4) is a special case. These solutions are naturally only applicable when these fuels are available (at least on the regional level).

8.4 Initial Observations

Given the discussion of sources and technologies in the previous section, the use of biomass seems to be the most rational choice for the following reasons:

- **this is the only self-sufficient, renewable source; that is, it does not require emergency plants, and hence the investment should be lower than that required by non self-sufficient technologies:**
- **the quantity of biomass needed is approximately 235 kg/day, which should be consistent with the site's resources;**
- **technologies for the production of electric energy from biomass appear to be better suited to the situation in developing countries than solar or wind technologies (both in terms of maintenance and production of these plants on the semi-industrial level);**
- **investments should be lower than those required for solar and wind technologies, since biomass technologies are simpler.**

8.5 Economic Analysis

Once the most suitable energy source has been preliminarily identified (more detailed studies can be carried out later by energy experts), the economic aspect has to be tackled.

The objective here is to compare the classic technological solution (a liquid or solid fuel-fed boiler and Diesel generator) with what appears to be the most promising solution from a practical standpoint, based on the analysis carried out in the previous sections (i.e., the steam generator with heat recovery). Naturally, two solutions that employ renewable sources can also be compared.

Even an approximate economic analysis requires a certain amount of data and, as we saw in section 7, some familiarity with the technologies and their general problems. Therefore, the analyst has to gather enough information to make it possible for him to evaluate the following parameters (which are defined more precisely in section 7.8):

- **the technologies' investment costs and technical features;**
- **their useful life and maintenance requirements (the latter aspect in terms of costs);**
- **the quantities of energy required annually;**
- **the costs of the energy produced by the various plants;**
- **the interest rate to be considered.**

For the sake of simplicity, in the case at hand electric energy production alone is analyzed, and it is assumed that requests for estimates (from specialized companies) and technical information (from specialists) would make it possible to fill in the following table:

Parameter		Diesel Generator	Steam Generator
Investment	(U.S.$)	4000	15000
Maintenance cost	($/year)	100	1000
Interest rate	(%)	15	15
“Desired” rate	(%)	20	20

Useful life	(years)	10	10
Energy to produce	(GJ/yr)	50	50
Fuel type		Diesel oil	wood
Fuel cost	($/kg)	0.6	0.02

The amount of energy to be produced has been evaluated on the basis of the daily electric requirement (section 8.2). The maintenance cost includes all routine expenses (including labor for manual fuel feeding).

At this point, the question becomes: is it profitable to invest U.S. $11,000 more and spend $900 a year more for maintenance in order to use a less expensive fuel?

With reference to the symbols used in section 7, and keeping in mind that in this case the goal is a <u>reduction in the cost of the energy source</u>, the following values can be calculated:

a. **δI = U.S. $11,000;**
b. **Difference in annual maintenance costs: $900/year;**
c. **Cost of electric MJ produced with the traditional solution (Diesel generator): $0.60/kg/(42*0.10) ≃ $0.14/MJ; where 42 is the Diesel oil's heating power (MJ/kg), and 0.10 is the generator's presumed efficiency (see the summary table, Generator Sets Fed by Gasification Gas);**
d. **Cost of electric MJ produced with the proposed solution (steam engine): $0.02/kg/(15* 0.05) ≃ $0.03/MJ; where 16 is the wood's heating power (MJ/kg), and 0.05 the steam generator's presumed efficiency (see related summary table);**

e. **Annual fuel costs with the proposed solution: 50,000 [MJ/year]*$0.03/MJ≃$1500/year.**

In addition:

ST(0)=(900+1500)*10 = U.S. $24,000

$$ST(10) = 2400 * \frac{(1+0.15)^{10} - 1}{0.15 * (1+0.15)^{10}} \approx \text{U.S. } \$12,000$$

$$ST(20) = 2400 * \frac{(1+0.20)^{10} - 1}{0.20 * (1+0.20)^{10}} \approx \text{U.S. } \$10,000$$

$$A(15) = \frac{(1+0.15)^{10} - 1}{0.15*(1+0.15)^{10}} = 5,0$$

$$A(20) = \frac{(1+0.20)^{10} - 1}{0.20*(1+0.20)^{10}} = 4,2$$

$$x_a \frac{ST(0)}{Vu*E} = \frac{24,000}{10*50,000} \approx \text{U.S. } \$0.050/MJ$$

$$x_b = \frac{[ST(0) + \delta I]}{Vu*E} = \frac{[24,000+11,000]}{10*50,000} \approx \text{U.S. } \$0.070/MJ$$

$$x_c = \frac{[ST(15) + \delta I]}{A(15)*E} = \frac{[12,000 + 11,000]}{5.0*50,000} \approx \text{U.S. } \$0.090/MJ$$

$$x_d = \frac{[ST(20) + \delta I]}{A(20)*E} = \frac{[10,000 + 11,000]}{4.5*50,000} \geq \text{U.S. } \$0.093/MJ$$

It may be observed that the current energy cost ($0.14/MJ) is higher than x_d.

In conclusion, the steam engine appears to be suitable for the production of electric energy,

and its economic performance exceeds expectations. Indeed, IRR is over 20%.
In order to complete the analysis, the problem of thermal energy production also has to be tackled (thermal energy can be recovered by the engine itself, as shown by more detailed studies).

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9. CONCLUSIONS AND RECOMMENDATIONS

a. **The information contained in this report makes it possible for the user to carry out an initial screening of applicative possibilities for the use of renewable sources in milk processing. Indeed, special attention was paid to the requirements of government analysts and/or agencies for agricultural development which are interested in identifying the energy carriers best suited to their countries' needs. Nonetheless, the results obtained with the methods outlined here should be considered approximate and valid only as a preliminary orientation. While the recommended evaluation methods and various information are based on experience with numerous experimental plant, they naturally do not take into account the peculiarities of each individual situation.**

   Within this context, one of the main goals of this report is to make possible for users to initially select one or two possible technical solutions without having to commission special studies. Later, these solutions can be more carefully evaluated by experts in the field.

b. **Technologies for the use of renewable energy sources require a more advanced milk processing plants, since the autoproduction of energy requires equipment which (even in its simplest versions) is more complicated than normal processing plants. Consequently, it make sense to consider plant solution in which the energy-producing and milk-processing aspects are consistent with each other.**

c. **The energy currently required for the transformation of 1 t of milk varies from 30–600 thermal MJ and from 100–200 electric MJ (if condensed milk is not included). Consequently, total requirements (considering normal efficiencies for the production of electric energy) range from 400 to 1300 MJ/t of milk.**

   In other words, processing requires from 9.5 to 31 kg of oil equivalent per t of milk.

d. **The present evaluation of the energy requirements of milk processing is based on the standard features of currently available plants. This decision was motivated by practical considerations connected with the difficulties involved in modifying commercial plants that are readily available on the market.**

   It should be emphasized, however, that commercial plants are not optimal from an energy standpoint. Consequently, their "redesign" (e.g., to limit electric energy requirements and allow for the use of hot water instead of steam) could facilitate the employment of renewable sources. In this light, studies on the various modifications that could be made to these plants would be enlightening.

e. **Specifically, studies whose goals are the following should be undertaken to clarify possibilities for the use of renewable sources and encourage the development of milk processing centers in developing countries:**

i. identification of various types of processing plants designed to reduce energy requirements to a minimum;

ii. construction indications on the energy technologies to be employed;

iii. detailed information about the possible combination of technologies related to i) and the various solutions in ii), in order to provide users with applicative examples for every climatic and social condition considered to be significant.

Consequently, the goal is to harmonize processing plant characteristics and requirements with energy supply while providing construction models for plant design.

f. Under present conditions, the most promising technologies that make use of renewable sources are those which:

i. rely on one single plant to meet thermal and electric requirements (so as to limit maintenance and investment costs);

ii. can be produced on the semi-industrial level in developing countries (which would favor their development);

iii. do not require a second plant in parallel to guarantee energy supply over time (again, to reduce investment costs).

Consequently, the following technologies are of interest: reciprocating steam engines, endothermal engines fed with renewable fuels (gasification gas, vegetable oils, etc.), all technologies for the recovery and limitation of energy consumption (e.g., plate-type exchangers for milk precooling, etc.).

g. Giving up the use of steam and electric energy (or their drastic reduction) would simplify plants considerably. The use of solar energy would also become a valid proposal if the milk containers utilized could be heated by hot water. The use of hot water (as opposed to steam or direct flame), however, requires different work schedules, since there is less thermal power available, and the plants' thermal inertia is increased.

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APPENDIX 1: The Basic Characteristics of Energy

1. Main Definitions

Energy is the capacity to perform work. Power is the work carried out during a unit of time. Equipment for the conversion of a given energy source into final energy is employed to meet the needs of a user (e.g., boiler for the transformation of the chemical energy of Diesel fuel into thermal energy).
The energy that enters the equipment is defined as consumption (C), while the energy that leaves it directed towards the user is called the energy requirement (R). C is always higher than R, and it can be observed that:

$$R=\mu C$$

where μ is the process efficiency (first law).

In a given operation (e.g., milk collection), a distinction is made between direct and indirect consumption. The former refers to the energy consumed during the operation (e.g., Diesel fuel to power the truck), while the latter concerns the energy consumed to make the necessary technical equipment available (e.g., for production of the truck, the milk containers, etc.).

2. Energy Sources and Forms

The basic energy source is the sun. On the sun, matter is transformed into energy (E), by using up its mass m, according to the equation $E=mc^2$, where c is the speed of light in a vacuum ($\simeq 3*10^8$ m/s).
With the exception of the gravitational field, the renewable and non-renewable energy sources present on the earth in various forms originate either directly or indirectly from the sun's energy.

3. Energy Quality and Operative Flexibility

Energy may be superior or inferior (i.e., its qualitative level varies). Forms of energy that are able to create mechanical energy (with which it is possible to meet any type of requirement) are considered to be “superior”; the term “inferior”, on the other hand, is used to denote all the lower forms of energy.
For example, a water supply placed at a certain height with respect to a water turbine is a superior form of energy (gravitational), since it can be conserved over time, does not create environmental impact problems, and can be converted into mechanical, electric or thermal energy at any time. However, a tank of water heated to 60°C is an inferior form of energy; one of its few uses is home heating.

In general, it is incorrect to add together forms of energy of different qualities (since each of these forms provides different results).

Energy tends to deteriorate from superior to inferior forms. For example, in an Otto engine, gasoline (superior chemical energy) explodes thereby creating mechanical and thermal energy at various temperatures (exhaust gas: 500–700°C; cooling air: 80–100°C). Once the former energy is supplied it turns into thermal energy, while the latter is diluted into the environment at lower and lower temperatures.

Edible energy (which is chemical in nature) should also be noted here. Its qualitative level is significantly different from that of other forms of energy. Consequently, from a conceptual standpoint, comparisons between these forms of energy should be avoided.

4. Energy conversions and their efficiencies

The basic forms of energy conversion are photosynthesis and combustion. The former transforms solar energy (and substances found in nature; e.g., CO_2 and H_2O) into chemical energy stored in C- and H-based compounds. The latter produces thermal and mechanical energy from chemical energy.
In addition, the following "transformers" convert energy: mechanical converters (e.g., wind machines), electric generators, and biochemical and nuclear reactions.
The efficiency μ_1 (first law) of a conversion process is defined by the equation:

$$\mu_1 = E_p/E_c$$

where E_p and E_c are, respectively, the energy produced and the energy consumed by the process itself (through a given technology). μ_1 is always less than 1 because of the inevitable

energy losses involved in transformation processes and related equipment. This type of efficiency is commonly used in practice, and it is repeatedly referred to in this report.

The efficiency μ_2 (second law) is defined by the equation:

$$\mu_2=f/(E_1/E_2)$$

where E_1 and E_2 are energy expressed in terms of capacity to carry out mechanical work at the exit and entrance to the conversion process, respectively (according to the laws of thermodynamics).
When μ_2 assumes low values (<20–40%), this means that a high quality source is being used to produce low quality energy (e.g., Diesel fuel used to produce water heated to 50°C).
When the two levels are similar, μ_2>50–60% (e.g., 80°C geothermal water to produce 50°C air).
In summary, μ_2 demonstrates whether the source and user are compatible from an energy standpoint.

5. Energy Features and Units of Measure

The main features are:

a. **source of origin;**
b. **form of energy;**
c. **cost.**

These features are generally sufficient (otherwise, this is specified) for a definition of:

d. qualitative level;
e. operative flexibility (or lack thereof);
f. simplicity of storage and transport;

g. environmental impact.

Energy is measured in J (Joules) and power in W (Watts). Electric energy is generally measured in kWh. However, numerous measurement systems may be used in practice.

APPENDIX 2: Useful Formulas (Thermodynamics)

a. Thermal power P_t produced by a circulating fluid with a flow rate q [kg/s], whose temperature increases from T_1 to T_2:

$$P_t=c_s q(T_2-T1) \qquad [W]$$

where c_s is the specific heat of the fluid under consideration ($Jkg^{-1}{}^\circ C^{-1}$); the problem is exactly the same when the opposite situation is considered (a fluid that cools down, thereby changing its temperature from T_2 to T_1).

b. **Calculating the thermal energy E_t created in a period of time t:**

$$E_t = P_t t \qquad [J]$$

c. **The thermal energy E_t of a fluid or solid of mass m [kg] at a temperature T with respect to a reference temperature T_r [°C]:**

$$E_t = c_s m(T - T_r) \qquad [J]$$

For c_s, see point a).

d. **Thermal power P_t transmitted by an environment at temperature T_1 to an environment at temperature T_2>T (the two environments are separated by a wall with a surface area of S [m^2] and thermal conductivity k [$Wm^{-2}°C^{-1}$]):**

$$P_t = kS(T_2 - T_1) \qquad [W]$$

for calculation of the energy see point b).

APPENDIX 3: Generators

Generators may be divided into two groups: dynamos (direct-current generators) and alternators (alternate-current generators).

Dynamos

Their scheme of work is based on a rotating turn (rotor) in a magnetic field (generated by permanent magnets that compose the stator). Movement can only be obtained through an external, mechanical energy source (e.g., a water turbine).
A positive voltage V=F(t) can be measured (at the ends of two immobile brushes) by commutator segments (two separate conductors that are integrated with the turn itself and that offer the possibility of sliding contact).
By increasing the number of turns and closing the circuit with a utilizer, a voltage V (and hence also a current I) can be obtained which becomes increasingly uniform to the point that it may be considered continuous over time.
It possible to use windings, in place of the permanent magnets, which create a magnetic field when crossed by direct current (according to the excitation, and supplied by external batteries or the machine itself). The operation of generators in direct current is defined by characteristic curves of the type V=f(I).
The dynamo is reversible and thus can also function as an engine (with current I sent to the rotor).

Alternators

Alternators are similar to dynamos, but the, difference between them consists of the fact that the ends of the turn are connected to two sliding slip rings on two immobile brushes.

The same result can be obtained by making the magnetic field rotate and by keeping the coil immobile. In this case, it is possible to avoid sliding contacts.
The model described generates single-phase currents.
Multiphase currents (normally three-phase) are obtained with the use of several coild and pairs of poles.
Alternators are also characterized by V=f(I) curves.

Generator efficiency

Efficiencies greater than 0.95 can be obtained.
In practice, performance is connected with machine size; with small, medium and large capacities, μ is ≃0.70–0.80, 0.80–0.95 and 0.95–0.98, respectively.

APPENDIX 4: Renewable Liquid Fuels

These fuels are derived from the treatment of biomass. They belong to the alcohol and oil families.

The most important liquid fuels are:

a. **ethanol, which is obtained from alcohol fermentation of amylaceous or sacchariferous**

substances;
b. methanol, when produced for distillation of ligno-cellulose substances;

c. oils obtained from oleaginous cultures.

Alcohols, which are used in explosion engines, decrease CO operating temperatures and emissions. Specific consumption (in volume) increases by 40–50%.
Their use as a gasoline additive causes an increase in the octane number (e.g., the addition of 25% ethanol volume increases the index from 90 to 98).
Carburetors require modifications; for example, with 20% mixtures, flow rates have to be increased by approximately 10% (increase in specific consumption: 9%).
There may be problems related to miscibility (and stability of the mixture) because of the alcohol's water content (generally 2–5%). Its use in Diesel engines as a supplementary fuel is also possible (e.g., with the dual-fuel system).

Oils of vegetables origin are characterized by heating powers approaching those of light oils for Diesel engines. Their use does not present problems, as long as precombustion engines are employed. The most serious problems are connected with:

a. gum (e.g., soy oil) or paraffin (e.g., sunflower oil) content;
b. viscosity higher than that of normal fuels;

c. clouding at relatively high temperatures (from -5 to -10°C).

Possible consequences are:

a. jamming of mechnical parts, obstruction of nozzles, increases in their operating temperature;

b. **difficulty of feeding;**

c. **increased sensitivity to climatic conditions. The quality of the oils should make it possible to use 3–µm filters.**

APPENDIX 5: Storage of Electric Energy

This energy is stored in cells, which transform electrical energy (direct current) into chemical energy (charging phase) and vice versa (discharge).

Cells consist of two electrodes (one negative and one positive) immersed in a liquid conductor (electrolyte) and enclosed in a container (the cell). Several cells in series form a battery. Various types of cells are classified on the basis of the materials of which the electrodes are made. Thus, there are lead batteries, nickel batteries, etc.
A charged lead battery supplies a voltage (open circuit) V_a of 2–2.1 V (voltages of 6, 12 and 24 V can be obtained with 3, 6 and 12 cells, respectively).

The capacity (unit of measure: Ah, ampere-hour) is defined by the product of the current I and the output time t.
Nominal capacities generally refer to t=10 h; the capacity decreases with lower times (i.e., discharging is more violent). Under these conditions, specific graphs should be consulted.

In addition to capacity, other parameters to be considered when selecting a battery are:

- **useful life in terms of charge-discharge cycles;**
- **maintenance requirements;**
- **functioning under various climatic conditions and weight.**

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