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Institute for Energy Saving and Diversification

ANALYSIS OF THE POTENTIAL OF HIGH-EFFICIENCY COGENERATION IN SPAIN 2010 – 2015 – 2020

Energy Saving and Efficiency Division

Energy Conversion Department

CONTENTS

1. Introduction

Sustainable development of the energy sector in the EU as regards environmental aspects and security of supply is closely related to improving energy efficiency. In this context, cogeneration systems or total energy systems are recognised as one of the main tools for achieving the European energy efficiency improvement objectives, in view of their advantages in terms of saving of primary energy, prevention of losses and reduction of emissions, particularly those with "greenhouse" effects. Cogeneration also contributes positively to the security of supply and the competitiveness of EU Member States. For all these reasons, the promotion of high-efficiency cogeneration systems is a Community priority.

Accordingly, a study on existing cogeneration potential and its future prospects is deemed a key information tool for the effective development of new cogeneration plants and for government action to promote and support systems of this kind.

1.1. Justification for and objectives of the study

Directive 2004/8/EC concerning the promotion of cogeneration on the promotion of cogeneration based on a useful heat demand in the internal energy market, which was adopted on 11 February 2004 and came into force in March 2004, states in its Article 6 the need for each Member State to undertake a study on the potential for high-efficiency cogeneration[1], including high-efficiency micro-cogeneration.

The present study on high efficiency cogeneration potential, as well as meeting the Community requirements, is intended to help to set targets consistent with the possibilities for developing these systems in Spain.

1.2. Criteria of the study

The present study takes particularly into account Article 6 of the Directive – *national potentials for high efficiency cogeneration* – which lays down certain criteria for producing cogeneration potential studies. The study therefore covers the following aspects:

- It is based on well-documented scientific data and meets the criteria (set out below) of Annex IV of the Directive.
- It specifies all the useful heat[2] potential – *thermal or cooling* – that may be expected from high efficiency cogeneration, and the availability of fuels and other energy resources for use in cogeneration.

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[1] According to Directive 2004/8/EC, high-efficiency cogeneration is that defined by the following categories:
- That with output resulting in a primary energy saving of at least 10% relative to the reference data of separate production of heat and electricity
- Small-scale cogeneration units (electrical capacity below 1 MWe) and micro-cogenerations (electrical capacity below 50 kWe) that save primary energy

[2] Useful heat means that produced in a cogeneration process to meet an economically justifiable demand for heat or cooling.

- It includes an analysis of the barriers preventing the realisation of high efficiency cogeneration potential, particularly the obstacles in terms of the price and cost of fuels and access to them, the obstacles relating to the network, those relating to administrative procedures and those due to the failure to internalise external costs in energy prices

This study also takes into account the criteria indicated in Annex IV of the Directive – *Criteria for analysis of national high efficiency cogeneration potential* – requiring the study to take the following into account:

- Types of fuel likely to be used for achieving cogeneration potential, including specific consideration of the potential for increasing the use of renewable energy sources.
- Types of cogeneration technologies likely to be used for achieving national potential.
- Type of separate production of heat and electricity or mechanical energy that cogeneration replaces.
- Breakdown between the potential for modernisation of existing capacity and the construction of new capacity.

The same Annex IV also indicates two further criteria. One is the requirement for the study to include appropriate mechanisms for evaluating profitability in terms of saving primary energy and increasing the share of high efficiency cogeneration in national total energy production. This profitability analysis has also to take account of the national commitments to combat climate change undertaken by the Community under the Kyoto Protocol. It has also to specify the potential with respect to the horizons of 2010, 2015 and 2020.

1.3. Scope of the study

In accordance with the foregoing, the scope of this study is confined to the following:

Conceptual scope

The study refers to high efficiency cogeneration systems, including high-efficiency micro-cogenerations.

Geographical scope

It covers the whole of Spanish territory, both the mainland and the islands.

Sectoral scope

The sectoral scope is comprehensive, covering the secondary, tertiary and primary sectors of economic activity, although in Spain the development of cogeneration is focused mainly on the secondary sector.

With regard to the **secondary sector**, the study covers industry as a whole but only considers the areas with potential for use of cogeneration based on the demand for useful heat: consumers of steam, hot water, thermal oil, hot gases for drying and cold for cooling and processing.

The activities covered in the **tertiary sector** are as follows:

- Domestic and commercial activities. Cogeneration in the domestic sector means that involved in district heating and cooling, as detailed at an appropriate point in the chapter on results; commercial activities refer to hospitals, hotels, shopping and business centres, prisons and other activities not included in the domestic residential sector.
- Treatment of sludge arising from wastewater.

The **primary sector**, in which there is at present little penetration, has potential of various kinds. The study focuses on existing applications that are relatively well established, as follows:

- Treatment of livestock waste from pigs and cattle, including slurry treatment activities
- Processing and disposal of waste from the vegetable oil industry, e.g. the oilcake produced by olive oilmills.

Technological scope

The study covers all systems classifiable as cogeneration, meaning the simultaneous generation in a process of thermal and electrical and/or mechanical energy. These include, without being limited to, the following:

- Combined-cycle gas turbine with heat recovery
- Steam backpressure turbine
- Extracting and condensing steam turbine
- Gas turbine with heat recovery
- Internal combustion engine
- Microturbines
- Stirling engines
- Fuel cells
- Steam engines
- Organic fluid Rankine cycles

Timeframe

This study provides cogeneration potential data for the years 2010, 2015 and 2020 and for the present situation, meaning 2004 as the latest year for which complete data are available on the relevant sectors and activities. Any more recent figures, e.g. those for 2006, are quoted where available.

2. PRESENT COGENERATION SITUATION IN SPAIN AND IN THE EUROPEAN UNION

2.1. Legislative antecedents and present regulatory situation

The first regulatory act on cogeneration plants dates from 1980 in the form of Law 82/80 on Energy Conservation. Until then there had been no rules governing the connection of cogenerations to feed their surplus electrical energy into the public grid. That Law obliges electricity companies to acquire energy supplied to the grid by cogeneration plants. Significant development of plants of this kind dates from 1986, largely owing to the incipient growth of the network of gas pipelines, technological development and government encouragement.

The subsequent 1990 National Energy Plan and, more specifically, its Annex 1, Energy Saving and Efficiency Plan (PAEE), set targets for new cogeneration plants for the period 1991-2000. That Plan led to the publication of the Electricity Sector Control Law (LOSEN) and Royal Decree 2366/1994 on electricity production under a special regime, which already treated cogenerations as a distinct category.

The present regulatory position of cogeneration is characterised by the framework established by the Electricity Sector Act, Law 54/1997 (LSE), which has since been repeatedly amended. The LSE covers cogeneration plants within the so-called special regime, subject to their capacity not exceeding 50 MWe, and governs the following aspects:

- Need for regulated prior administrative authorisation
- Right of producers to feed their production to the electricity system
- Remuneration for electrical energy supplied to the regulated grid, supplemented by charging a premium.

The LSE was amplified as regards the special regime by the now repealed Royal Decree 2818/1998 and Royal Decree 436/2004, replaced by the present Royal Decree 661/2007 governing electricity energy production under the special regime and classifying cogeneration systems in the following groups and subgroups:

- Group a.1. Installations that include a cogeneration power station
    - Subgroup a.1.1. Cogenerations fuelled by natural gas
    - Subgroup a.1.2. Cogenerations fuelled by gasoil, fuel oil or liquefied petroleum gases(LPG)
    - Subgroup a.1.3. Cogenerations fuelled by biomass and/or biogas
    - Subgroup a.1.4. Other cogenerations possibly run on residual gases from refining or coke-making, process fuel, coal and other fuels not covered by the above subgroups

- Group a.2. Installations that include a power station using waste energy from any installation, machine or industrial process not intended to produce electrical and/or mechanical energy.

Royal Decree 661/2007 defines a remuneration framework for surplus electrical energy supplied to the grid from cogenerations on the basis of two alternatives freely adoptable by the plant owner:

- Disposal of electrical energy via the transmission or distribution grid, at a single regulated tariff for all scheduling periods

- Unrestricted sale of electrical energy on the market at the price arising from the organised market or a freely negotiated price, supplemented where applicable by a premium.

The recently published Royal Decree Law 7/2006 partly amending the LSE's regulatory framework for cogenerations and fostering their unrestricted operation on the market incorporates the following measures:

- Authorisation to sell freely the electrical energy produced

- Abolition of the concept of self-producer

- Abolition of "competition transition costs"(CTCs)

- Abolition of the obligation to consume heat and electricity internally

This abolition of the concept of self-producer and of the need for internal consumption expedites the administrative path for the development of energy service supply enterprises (commonly known as ESCOs[3]) which might, if introduced in Spain, cause a significant increase in installed capacity. This enactment at least partly transposes Directive 2004/8/EC on the promotion of cogeneration.

2.2. Production facilities and installed capacity in Spain

The data set out below on production facilities and installed capacity in Spain as regard cogeneration systems are broken down into two categories:

- Plants regarded as self-producers
- Waste treatment and utilisation plants

[3] Acronym of the English expression "*Energy Service Company*"

Plants regarded as self-producers

In December 2006, Spain had **5,875 MWe** installed in cogeneration systems regarded as self-production, spread over 860 plants[4]. The historical trend depicted in **Fig. 1** below shows the number of cogeneration plants installed annually in Spain, rising from 1987 to a maximum of new installations in 1999. The subsequent trend has been downwards, with no significant new plant activity in the last few years.

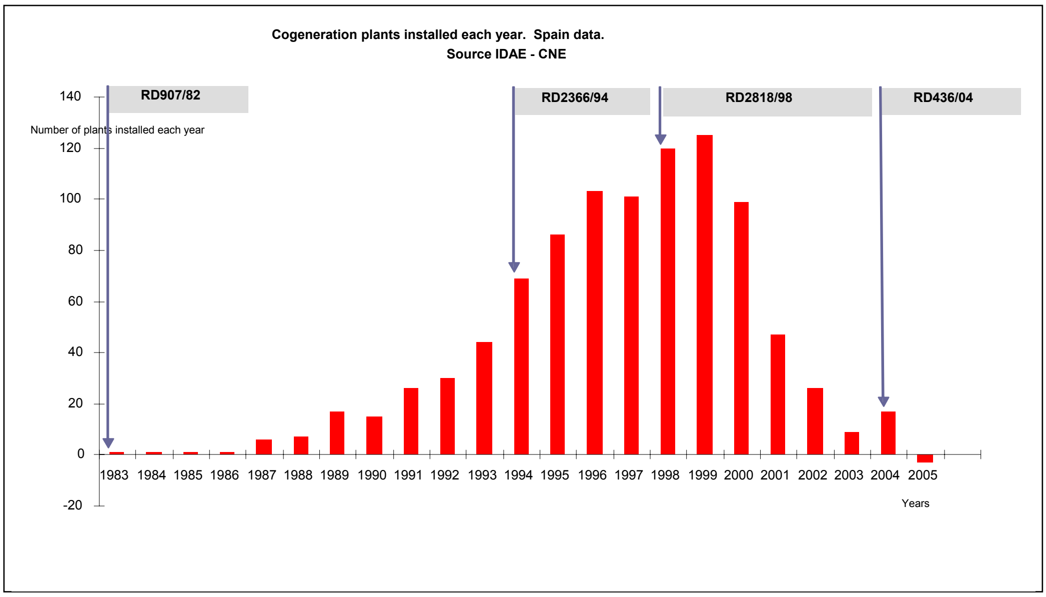


Fig. 1. Cogeneration plants regarded as self-producers installed per annum

The geographical distribution of the installed capacity is set out in **Table 1** and **Fig. 2**, showing a high concentration of cogeneration in Catalonia (1,169 MWe) and significant amounts in Valencia Region and Galicia (635 and 637 MWe respectively). **Fig. 3** shows the cumulative installed cogeneration capacity.

[4] CNE data at December 2006, based on categories "a" and "d" of the special regime for want of historical data on the other subsectors included in the study. The data are nevertheless representative of what is described in this section.

AUTONOMOUS REGION	POWER (MWe)
ANDALUSIA	**606**
ARAGON	**523**
ASTURIAS	**67**
BALEARICS	**6**
CANARIES	**33**
CANTABRIA	**288**
CASTILE LA MANCHA	**419**
CASTILE & LEON	**498**
CATALONIA	**1169**
VALENCIA REGION	**635**
EXTREMADURA	**9**
GALICIA	**637**
LA RIOJA	**50**
MADRID	**249**
MURCIA	**220**
NAVARRA	**111**
PAIS VASCO	**354**
SPAIN TOTAL	***5,875***

Table 1. Installed capacity of cogenerations regarded as self-producers per Autonomous Region in December 2006. Source: CNE

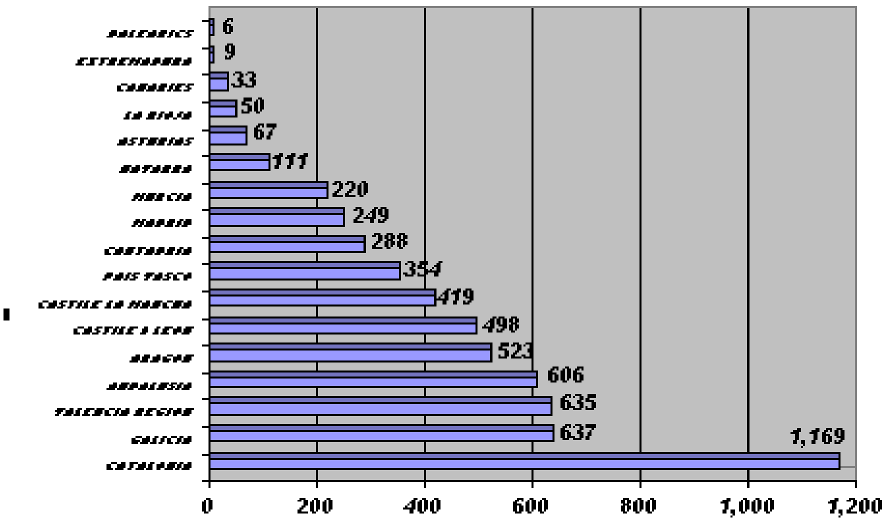


Fig. 2. Installed capacity of cogenerations regarded as self-producers per Autonomous Region in December 2006. Source: CNE

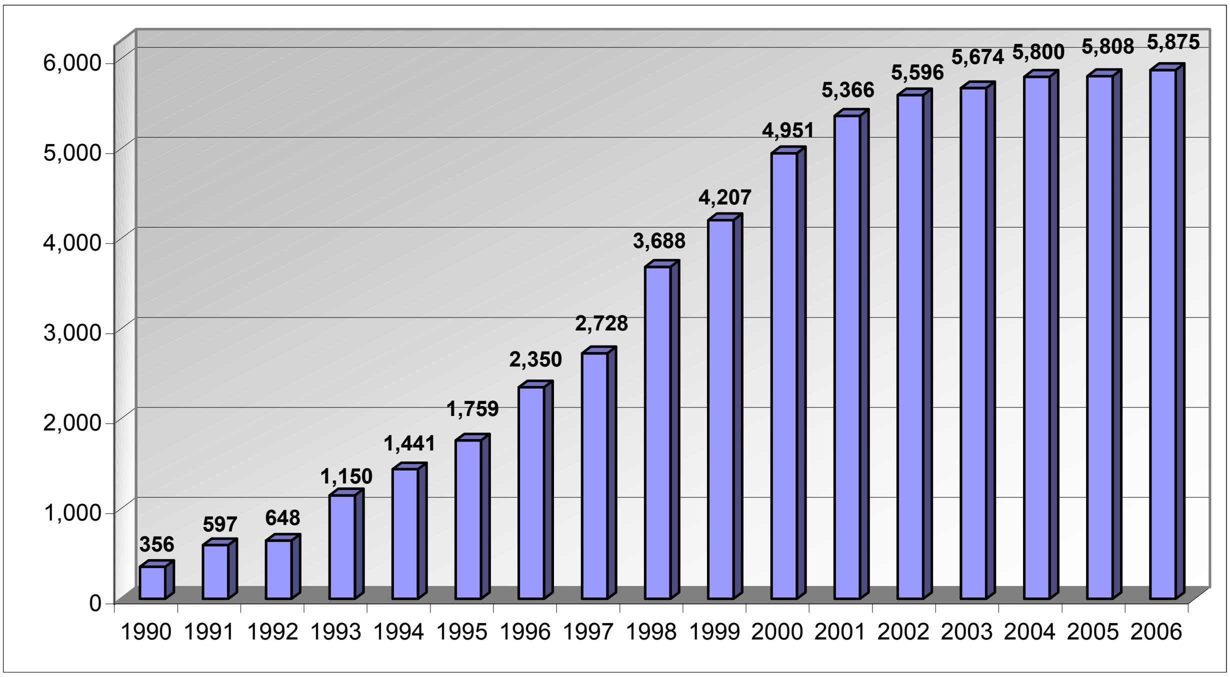
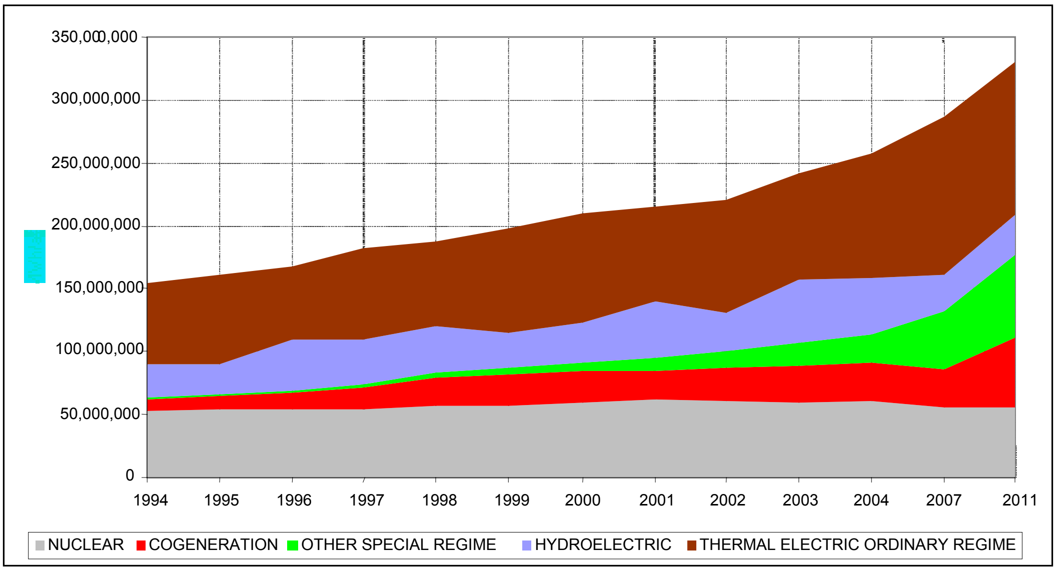


Fig. 3. Cumulative installed capacity of cogenerations regarded as self-producers. Source: CNE

The sectors of activity with the largest participation in terms of installed cogeneration capacity are food, chemicals and paper and board, accounting for about half of the national total.

Electrical energy produced by self-production cogeneration systems in 2005[5] covered 11.4% (about 31,400 GWh) of Spain's electricity demand. **Fig. 4** illustrates the sources of electrical energy produced from 1994 onwards and the production to 2011 according to the Ministry of Industry, Tourism and Commerce 2005-2011 Infrastructure Planning.

[5] Data from Ministry of Industry, Tourism and Commerce statistical documents.



MWh/year

Fig. 4. Net electricity production by type of plant. Compiled from the Ministry of Industry, Tourism and Commerce 2004 electricity balance and 2005-2011 infrastructure planning

As regards **efficiency**, the existing cogeneration facilities have an electrical efficiency of 29.7% and utilise 73.2% of the energy content of their fuels. The equivalent electrical yield (EEY) is 57.6% and the annual hours of use[6] average 6,113 for the industrial sector and 4,242 for the services sector. Hours for use for all sectors average 5,485. These figures are significantly better than the efficiencies of conventional electrical energy production systems.

Waste treatment plants

At December 2006, cogeneration systems treating pig farm slurry and those treating sludge (categories "d1" and "d2" of the special regime governed by Royal Decree 436/2004) totalled **592 MWe** installed[7], with the geographical breakdown shown in **Table 2** below.

[6] Hours of use calculated from the *Monthly Electrical Energy Statistics of the Ministry of Industry for the year 2000.*

[7] CNE data December 2006.

AUTONOMOUS REGION	Pig waste treatment	Sludge treatment
ANDALUSIA	**15**	**131**
ARAGON	**43**	**-**
ASTURIAS	**-**	**6**
BALEARICS	**-**	**-**
CANARIES	**-**	**-**
CANTABRIA	**-**	**-**
CASTILE & LEON	**78**	**32**
CASTILE LA MANCHA	**-**	**-**
CATALONIA	**74**	**70**
VALENCIA REGION	**1**	**1**
EXTREMADURA	**-**	**4**
GALICIA	**-**	**-**
MADRID	**-**	**42**
MURCIA	**45**	**25**
NAVARRA	**15**	**-**
PAIS VASCO	**-**	**10**
LA RIOJA	**-**	**-**
SPAIN TOTAL	***271***	***321***

Table 2. Installed capacity (MWe) of waste treatment cogenerations by Autonomous Regions in 2006. Source: CNE

2.3. Situation in the EU

Cogeneration has a long tradition in Europe both in industry type and in applications known as district heating or district energy, focused on the domestic and commercial useful heat market.

The penetration of cogeneration varies greatly from country to country. Its share of total energy produced reaches high levels in countries such as Denmark (49%), Finland (38%), Netherlands (30%) but also in countries with economies in transition such as Latvia (38%), Hungary (21%) and the Czech Republic (17%).

Fig. 5 illustrates for various EU countries the electrical energy generated by cogeneration systems and the proportion of each country's total energy demand covered by them. The electrical energy is broken down into that supplied by ESCOs (district energy) and that from self-producers.

The EU has a large number of "district energy" systems, a methodology that has not yet become significantly established in Spain. As indicated previously, however, the Electricity Sector Act amendments introduced by Royal Decree Law 7/2006 establish the appropriate administrative framework for encouraging the development of ESCOs in Spain.

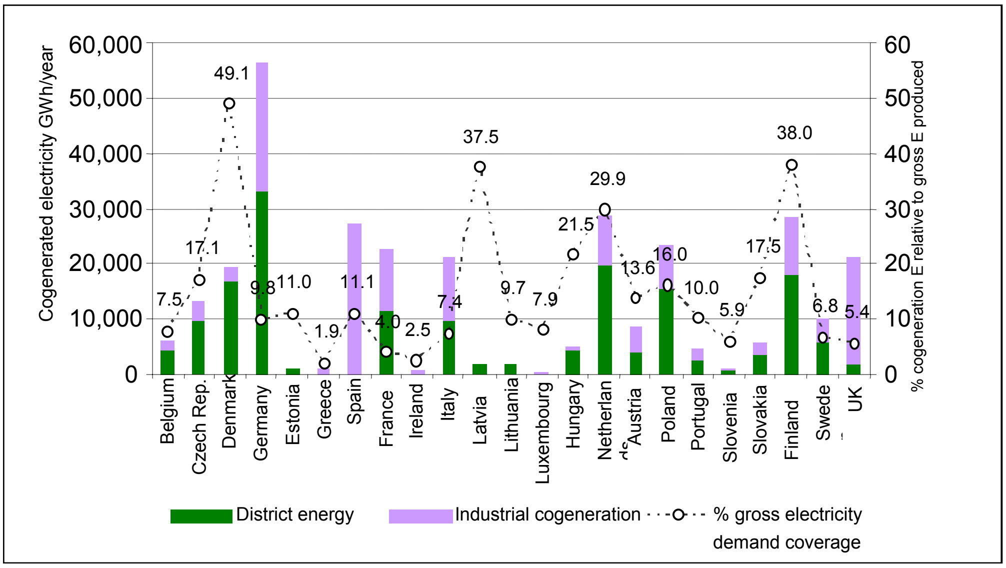


Fig. 5. Cogenerated electricity and its share of gross electricity produced by country. Compiled from EUROSTAT 2002 data

3. USEFUL HEAT POTENTIAL

3.1. Useful heat in the estimation of cogeneration potential. Calculation criteria

Calculation methodology

Directive 2004/8/EC governs the encouragement of cogeneration on the basis of the demand for useful heat. Its Article 3 defines useful heat as *heat produced in a cogeneration process to meet an economically justifiable demand for heat or cooling,* so the cogeneration potential has to be based on the heat of a useful kind that is required in a process.

The methodology adopted for determining useful heat in the sectors of activity covered by this study is as follows:

a. The starting point for each sector and activity was to take the fuel consumption as the basis for determining the **process heat** required, characterised by the following data:

   - Amount of thermal energy required
   - Characteristics of thermal energy required: steam, hot air, cold etc.
   - Work programme. On the basis of experience of the running of installations, the monthly, weekly and daily work programmes were defined to determine the thermal energy demand curve in the course of a year.

b. Once the process heat had been determined, the **cogenerable heat** was estimated, bearing in mind that not all heat demand can be met by a cogeneration system. High-temperature boiling processes, thermal processes involving very precise temperature regulation and control, and thermal processes requiring heat over 450 ºC or below 7 ºC cannot normally be catered for by cogeneration systems. Estimation was based on knowledge of processes or thermal demand according to type of user. In industry, this heat is related to the production process; in buildings, both domestic and commercial, all heat is cogenerable; in cogenerations for waste treatment processes, all heat may also be regarded as potentially cogenerable.

c. Finally, it was simply taken that **cogenerable heat** as defined in the previous paragraph represents the **useful heat potential**.

Time projection criteria

Directive 2004/8/EC states that the high efficiency cogeneration potential study must cover the *horizons 2010, 2015 and 2020*. The useful heat potential trend to the 2020 horizon depends on numerous factors including raw material prices, energy availability and both the macro-economic and the micro-economic situation. This study is based on the Ministry of Industry, Tourism and Commerce forecasts set out in its *2002-2011 Electricity and Gas Sector Planning, 2005-2011 revision,* which sees electricity energy demand increasing by an annual average of 3.46% up to 2011. To provide sectoral growth forecasts for the whole period covered by this study, i.e. up to 2020, those available were supplemented by extrapolation on the following criteria by sector and activity:

a. **Industry**. The Planning of the Ministry of Industry, Tourism and Commerce indicates annual average growth of 2.1% for the period 2004-2011. A figure of 1.8% has been taken for 2012-2020. It is assumed that all of the fuel consumption growth will be met by natural gas.

b. **Petroleum refining**. Annual average growth of 1.91% is adopted for the period 2004-2010 on the basis of the forecasts of the Spanish companies in petroleum refining sector. This means the petroleum processed increasing from 1,290 million barrels per day to 1,438 million. An annual average increase of 1.8% is adopted for 2011-2020.

c. **Bioethanol**. For the period 2004-2010, the targets of the 2005-2010 Renewable Energies Plan have been adopted, with bioethanol plants reaching a capacity of 2.2 MTOE in 2010.

d. **Domestic and commercial tertiary sector**. The growth in this sector's effective heat demand is proportional to the forecast increase in natural gas consumption in the period 2005-2011 (annual average 6.5%). Growth of 4.5% is supposed for 2012-2020. New buildings are taken to incorporate consumption efficiency leading to a 20% saving[8] in demand relative to existing buildings.

e. **Treatment and utilisation of waste.** Here it is considered that thermal demand will increase in line with population growth (annual average 1% to 2020); for pig waste treatment an increase in the degree of penetration of existing farms as forecast by their owners; for cattle an annual average increase of 2.7% and for the oil production sector zero annual growth because of EU guidelines for not increasing olive plantations in Spain.

Breakdown by sector and activity

Useful heat is defined above as the heat which arises from a cogeneration process for meeting an economically justifiable demand for heat or cooling. Accordingly, this study divides the data presented into two groups based on the nature of the heat or cooling provided by cogeneration:

- Activities in which cogeneration actually provides useful heat, i.e. on the basis of economically justifiable demand. These activities are referred to in this study as "**cogeneration systems that provide useful heat**" and are generally in the secondary sector and in heat supply in the domestic and commercial parts of the tertiary sector.

- Activities which in each particular case require analysis to see whether the cogeneration system provides useful heat. These mainly comprise waste treatment cogenerations in the primary and tertiary sectors: treatment of sewage sludge, treatment of pig waste, treatment of oilmill waste and cogenerations using biogas as fuel in sewage sludge treatment plants and cattle farms. In this study these cogenerations are called "**waste treatment and utilisation cogeneration systems**".

[8] This figure takes into account the estimated savings from applying the requirements of the Technical Building Code (CTE) except the solar contribution for domestic hot water, on the basis of its replacement by cogeneration.

This latter criterion is maintained throughout the study, including in determining the foreseeable trend in installed cogeneration capacity and in associated high efficiency cogenerated electricity.

3.2. Present situation and outlook

Table 3 shows the present useful heat potential situation and forecast demand to 2020. The secondary sector (industry, bioethanol and petroleum refining) is clearly the largest sector, representing nearly 70% of total useful heat potential, the bulk of it in activities such as paper and board, the chemical industry and the food industry. The tertiary sector's domestic and commercial activities account for 30% of the total potential. Present-day useful heat potential amounts to 145,889 GWh per annum, leading to a forecast for 2020 of 204,973 GWh per annum, an increase of 40% over the whole period 2004-2020 and an annual average increase of 2.1%.

ACTIVITY	2004 actual	2010 forecast	2015 forecast	2020 forecast
SECONDARY SECTOR				
INDUSTRIAL SECTOR				
Paper and board	14,351	16,159	17,494	19,407
Textiles	6,687	7,530	8,151	8,201
Chemicals	28,970	32,620	35,314	35,170
Food	15,305	17,233	18,657	23,056
Non-metallic minerals	9,804	11,039	11,951	10,335
Rest of industry	13,991	15,754	17,055	22,857
BIOETHANOL	870	3,498	3,655	3,820
PETROLEUM REFINING	11,280	12,573	13,716	14,621
SECONDARY SECTOR TOTAL	**101,258**	**116,406**	**125,993**	**137,467**
TERTIARY SECTOR: RESIDENTIAL AND COMMERCIAL				
Domestic activities	34,321	42,936	50,504	51,912
Commercial activities	10,310	12,898	15,171	15,594
RESIDENTIAL AND COMMERCIAL TOTAL	**44,631**	**55,834**	**65,675**	**67,506**
GRAND TOTAL	**145,889**	**172,240**	**191,668**	**204,973**

Table 3. Useful heat potential in GWh per annum for cogeneration systems

Table 4 gives possible useful heat figures for waste treatment and utilisation activities. There is substantial potential in pig waste treatment (5,616 GWh in 2004 and expected 2020 potential of 7,956 GWh) and in biogas from cattle waste digestion (5,870 GWh in 2004 and expected 2020 potential of 8,247 GWh). Waste treatment activities present a combined annual average growth in useful heat potential of 1.5% up to 2020.

ACTIVITY	2004 actual	2010 forecast	2015 forecast	2020 forecast
Pig waste treatment	5,616	6,526	7,284	7,956
Sewage sludge treatment	3,320	3,519	3,685	3,818
Oilmill waste treatment	3,011	3,011	3,011	3,011
Sewage sludge biogas	2,264	2,400	2,513	2,604
Cattle waste biogas	5,870	6,821	7,613	8,247
TOTAL	**20,081**	**22,277**	**24,106**	**25,636**

Table 4. Possible useful heat potential in GWh per annum for waste treatment and utilisation cogeneration systems

4. TECHNOLOGICAL POTENTIAL

4.1. Methodology and determination

Having estimated the useful heat potential as above, it is possible to design the most appropriate high efficiency cogeneration systems for meeting the demand, which involves converting the useful heat potential in GWh to installable capacity in electrical MW. This calculation is based on the criteria described below.

a. Available technologies

Calculating the installable capacity is based on the various available technologies, characterised by their electrical efficiency. **Table 5** shows the efficiencies adopted for the technologies most commonly used in cogeneration systems.

Cogeneration system	Electrical efficiency
Combustion engine	40%
Simple cycle gas turbine	33%
Combined cycle	40%
Steam turbine	20%

Table 5. Electrical efficiency of the most commonly used cogeneration system technologies

b. Technologies used at sector level

The calculation of technological potential was different for each sector. It involved taking the share of each technology in the various sectors in terms of installed capacity and applying that share to weighting the installable power. The result is a technological characterisation of each sector represented by its electrical efficiency.

c. Criterion of high efficiency

According to Directive 2004/8/EC, the study has to be based on **high-efficiency** cogeneration systems, a concept based, as mentioned previously, on saving at least 10% of primary energy compared with the reference situation. This introduces a condition which establishes a degree of freedom for calculating the technological potential, in terms of taking different equivalent hours of operation of cogeneration systems. The calculation method adopted for this study was as follows:

- The first step for each sector was to calculate the primary energy saving[9] resulting from cogeneration systems in terms of total capacity to be installed and average number of hours of operation of all cogenerations.

- The second step was to adopt the cogeneration potential and operating hours achieving the **maximum primary energy saving**. This criterion is consistent with the guidance of Directive 2004/8/EC, which gives priority to primary energy saving, thereby making it possible to quantify the potential on the basis of maximum economic saving, so it may be considered practical from the standpoint of the industrialist or operator making the investment.

- The final step for the purposes of this study was to check for each sector that the primary energy saving exceeds 10%, otherwise the cogeneration system could not be regarded as of high efficiency.

Fig. 6 illustrates the methodological process described in this and the previous chapter for calculating the useful heat potential and technological potential.

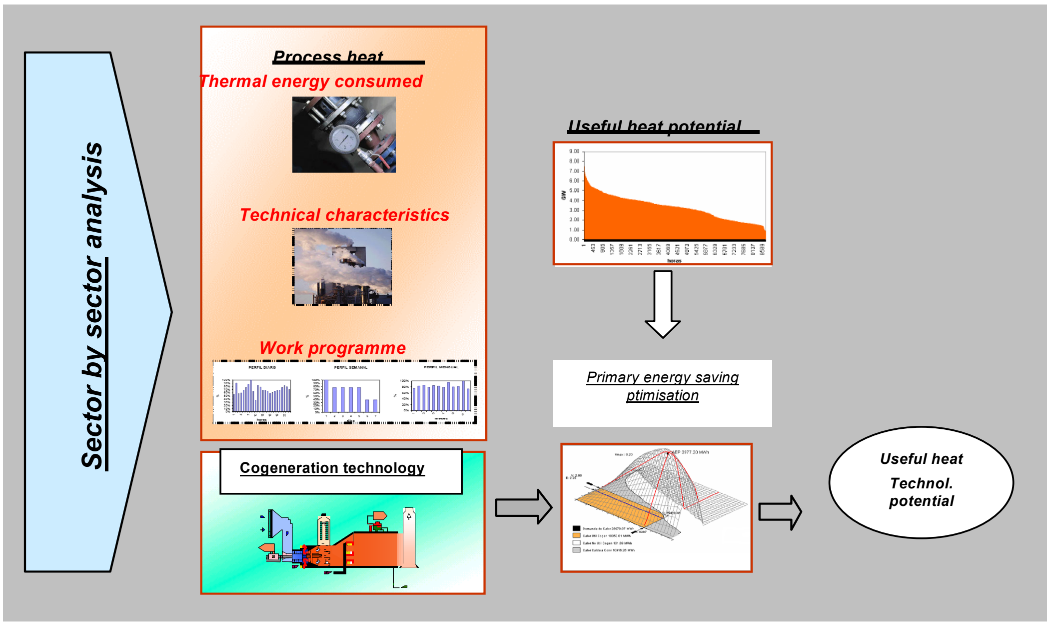


Fig. 6. Process of calculating the useful heat potential and technological potential

We now go on to consider the useful heat and technological potential results arising from the methodology described above.

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[9] The primary energy saving was calculated by the formula of Annex III to Directive 2004/8/EC, using the following reference values:

- Electricity production efficiency 52.5%, less losses at the 1-36 kV connection level (5.93%), i.e. 49.6%
- Heat production efficiency: 90%

Cogeneration systems that provide useful heat

Table 6 shows the high efficiency cogeneration potential technological potential arrived at for 2004, and **Table 7** the forecasts for 2010, 2015 and 2020. They show for each sector and activity the technological potential in electrical MW, the primary energy saving achieved, the useful heat covered by that technological potential, the electrical energy generated and the average hours of use of cogeneration.

These data show present-day technological potential of 17,237 electrical MW, comprising 62% and 38% in the secondary and tertiary sectors respectively, the tertiary sector, albeit in the minority, having a significant potential of 6,414 MWe. In the industrial sector the activities with greatest potential are paper and board and the food industries. The primary energy saving ranges between 13% and 23%, depending on the activity. The forecasts for 2020 are an increase in technological potential of 38% in the secondary sector and 51% in residential and commercial activities compared with 2004, with a forecast total high-efficiency technological potential of 24,606 MWe.

ACTIVITY	Techno-logical potential (MW)	Primary energy saving (%)	Useful heat (GWh per annum)	Cogenerated electricity (GWh)	Hours of use
SECONDARY SECTOR					
INDUSTRIAL SECTOR					
Paper and board	1,270	15%	13,814	10,674	8,404
Textiles	898	15%	4,910	4,311	4,800
Chemicals	2,255	13%	18,843	14,132	6,260
Food	1,427	13%	10,345	8,375	5,870
Non-metallic minerals	1,185	16%	7,786	7,202	6,080
Rest of industry	2,270	17%	10,829	10,552	4,648
BIOETHANOL	88	23%	798	709	8,095
PETROLEUM REFINING	1,430	21%	10,870	12,014	8,402
SECONDARY SECTOR TOTAL	**10,823**	**-**	**78,195**	**67,969**	**6,280**
TERTIARY SECTOR: RESIDENTIAL AND COMMERCIAL					
Domestic activities	5,220	16%	15,266	19,842	3,801
Commercial activities	1,194	16%	4,450	5,086	4,258
RESIDENTIAL AND COMMERCIAL TOTAL	**6,414**	**-**	**19,716**	**24,928**	**3,886**
GRAND TOTAL	**17,237**	**-**	**97,911**	**92,897**	**5,389**

Table 6. Technological potential in 2004 for cogeneration systems that provide useful heat

ACTIVITY	Year 2010			Year 2015			Year 2020		
	Useful heat (GWh)	Cogenerated electricity (GWh)	Technol. potential (MWe)	Useful heat (GWh)	Cogenerated electricity (GWh)	Technol. potential (MWe)	Useful heat (GWh)	Cogenerated electricity (GWh)	Technol. potential (MWe)
SECONDARY SECTOR									
INDUSTRIAL SECTOR									
Paper and board	15,555	12,019	1,430	16,839	13,012	1,548	18,681	14,435	1,718
Textiles	5,529	4,854	1,011	5,985	5,255	1,095	6,022	5,287	1,101
Chemicals	21,217	15,913	2,539	22,969	17,227	2,749	22,875	17,156	2,738
Food	11,648	9,430	1,607	12,611	10,209	1,740	15,584	12,616	2,150
Non-metallic minerals	8,767	8,110	1,334	9,491	8,779	1,444	8,208	7,592	1,249
Rest of industry	12,194	11,881	2,556	13,201	12,862	2,767	17,692	17,238	3,709
BIOETHANOL	3,209	2,853	352	3,353	2,981	368	3,504	3,115	385
PETROLEUM REFINING	12,116	13,391	1,594	13,218	14,609	1,739	14,090	15,573	1,853
SECONDARY SECTOR TOTAL	**90,235**	**78,451**	**12,423**	**97,667**	**84,934**	**13,450**	**106,656**	**93,012**	**14,903**
TERTIARY SECTOR: RESIDENTIAL AND COMMERCIAL									
Domestic activities	21,720	24,823	6,531	25,548	29,198	7,682	26,261	30,012	7,896
Commercial activities	5,567	6,362	1,494	6,548	7,484	1,758	6,731	7,692	1,807
RESIDENTIAL AND COMMERCIAL TOTAL	**27,287**	**31,185**	**8,025**	**32,096**	**36,682**	**9,440**	**32,992**	**37,704**	**9,703**
GRAND TOTAL	**117,522**	**109,636**	**20,448**	**129,763**	**121,616**	**22,890**	**139,648**	**130,716**	**24,606**

Table 7. Forecast technological potential in 2010, 2015 and 2020 for cogeneration systems that provide useful heat

Waste treatment and utilisation cogeneration systems

Tables 8 and 9 set out the data of 2004 and forecasts for 2010, 2015 and 2020 for waste treatment and utilisation cogenerations. A point to note is the significant possible potential for using biogas derived from cattle waste, currently 792 MWe and forecast to rise to 1,112 MWe by 2020.

It should be noted that the indicated amounts of useful heat potential and technological potential pertaining to waste treatment and utilisation depend on the cogeneration systems actually providing useful heat, since otherwise they could not be classified as potential. As this depends on the technical, economic and business characteristics of each plant, this study adopts joint recording covering "possible useful heat" and "possible technological potential"[10].

The primary energy saving ranges between 10% and 12% depending on the particular activity. The forecasts for 2020 expect an increase of 29% in technological potential relative to 2004, representing a prospective high-efficiency technological potential for these activities of 2,685 MWe.

ACTIVITY	Techno-logical potential (MW)	Primary energy saving (%)	Useful heat (GWh per annum)	Cogenerated electricity (GWh)	Hours of use
Pig waste treatment	498	10%	4,846	3,231	6,488
Sewage sludge treatment	199	12%	1,826	1,336	6,728
Oilmill waste treatment	301	10%	2,806	1,871	6,224
Sewage sludge biogas	294	-	2,264	1,981	6,728
Cattle waste biogas	792	-	5,870	5,136	6,488
TOTAL	**2,084**	**-**	**17,612**	**13,555**	**6,504**

Table 8. Possible technological potential in 2004 for waste treatment and utilisation cogeneration systems

[10] The inclusion or otherwise of potential is different for each activity. In the case of slurry treatment plants it will depend on whether the landfill fee payable by the livestock operator is high enough to justify a cogeneration system economically under the remuneration framework for plants of this kind. In the case of biogas, the cogeneration system's heat has to be used to meet an economically justifiable thermal demand.

ACTIVITY	Year 2010			Year 2015			Year 2020		
	Useful heat (GWh)	Cogenerated electricity (GWh)	Technol. potential (MWe)	Useful heat (GWh)	Cogenerated electricity (GWh)	Technol. potential (MWe)	Useful heat (GWh)	Cogenerated electricity (GWh)	Technol. potential (MWe)
Pig waste treatment	5,631	3,754	579	6,285	4,190	646	6,865	4,577	705
Sewage sludge treatment	2,101	1,416	210	2,200	1,483	220	2,279	1,536	228
Oilmill waste treatment	2,806	1,871	301	2,806	1,871	301	2,806	1,871	301
Sewage sludge biogas	2,400	2,100	312	2,513	2,199	327	2,604	2,278	339
Cattle waste biogas	6,821	5,968	920	7,613	6,662	1,027	8,247	7,216	1,112
TOTAL	**19,759**	**15,109**	**2,322**	**21,417**	**16,405**	**2,521**	**22,801**	**17,478**	**2,685**

Table 9. Possible technological potential forecast for waste treatment and utilisation cogeneration systems

4.2. Present degree of penetration

Spain's current cogeneration systems cover a wide range of applications, but the bulk of them are in the industrial and refining sectors. **Table 10** shows the sectoral penetration of cogeneration and the available potential in 2004.

ACTIVITY	Technol. potential (MWe)	Installed capacity (MWe)	Penetration (%)	Availability (%)
SECONDARY SECTOR				
INDUSTRIAL SECTOR				
Paper and board	1,270	877	69.1%	30.9%
Textiles	898	412	45.9%	54.1%
Chemicals	2,255	948	42.0%	58.0%
Food	1,427	1,057	74.1%	25.9%
Non-metallic minerals	1,185	536	45.2%	54.8%
Rest of industry	2,270	1,168	51.5%	48.5%
BIOETHANOL	88	50	56.8%	43.2%
PETROLEUM REFINING	1,430	577	40.3%	59.7%
SECONDARY SECTOR TOTAL	**10,823**	**5,625**	**52.0%**	**48.0%**
TERTIARY SECTOR: RESIDENTIAL AND COMMERCIAL				
Domestic activities	5,220	0	0.0%	100.0%
Commercial activities	1,194	175	14.7%	85.3%
RESIDENTIAL AND COMMERCIAL TOTAL	**6,414**	**175**	**2.7%**	**97.3%**
WASTE TREATMENT				
Pig waste treatment	498	233	46.8%	53.2%
Sewage sludge treatment	199	82	41.2%	58.8%
Oilmill waste treatment	301	97	32.2%	67.8%
Sewage sludge biogas	294	0	0.0%	100.0%
Cattle waste biogas	792	0	0.0%	100.0%
WASTE TREATMENT TOTAL	**2,084**	**412**	**19.8%**	**80.2%**

Table 10. Degree of penetration and current availability in 2004

A point to note is the still significant degree of availability in industrial sectors such as chemicals, non-metallic minerals and petroleum refining; we also find no cogenerations in domestic activities and few in commercial activities, but very significant potential in both. The degree of availability amounts to 48% in the secondary sector, 97.3% in domestic and commercial activities and 80% in waste treatment cogenerations. The respective unexploited potential is about 5,195 MWe in the secondary sector, 6,240 in domestic and commercial activities and 1,671 in waste treatment and utilisation.

5. TREND SCENARIOS

5.1. Methodology

This study estimates reasonable scenarios of change over time as regards cogeneration systems installed, which scenarios are limited upwards by the technological potential indicated in chapter 4 and downwards by the degree of penetration at the present time.

The scenarios used for determining the high efficiency cogeneration potential are based on the present degree of saturation of each activity concerned, giving rise to two scenarios:

a. *Vegetative growth scenario.* This supposes maintaining the present degree of saturation up to 2020, involving a certain growth of cogeneration owing to the growth in demand of the activities concerned. As indicated in previous chapters, the forecast for useful heat demand in general is moderate growth, which is reflected in the cogeneration systems installed. The only exception in this scenario is the forecast for pig slurry treatment plants, representing 322 MWe installed in 2008.

b. *Optimistic scenario backed by promotional policies.* This scenario supposes an increase in sectoral degrees of saturation and takes into account the objectives of Directive 2004/8/EC aimed at increasing the penetration of cogeneration systems. It is based on achieving the following targets for industrial, residential and commercial activity:

   - 63% saturation of the potential in industry, 70% in the petroleum refining sector and 78% in bioethanol production.
   - Raising penetration in the tertiary domestic/commercial sector to 3% in domestic activities and 20% in hospitals, offices, hotels, shopping and business centres and official buildings.

   In the case of waste treatment and utilisation cogenerations, this scenario is based on the following targets:

   - 5% more penetration in sewage sludge treatment applications
   - Total installed capacity of 322 MWe in pig slurry treatment plants
   - Installed capacity of the order of 300 MW in oilmill waste treatment plants in 2010
   - Utilisation of all biogas obtained by digestion, as a “homegrown” renewable resource

This scenario is also inspired by the European indicative target of covering 18% of electricity demand by cogeneration in 2010[11].

Table 11 shows the degree of penetration forecast for 2020 for each activity in each of the trend scenarios based on the criteria described above. A point to note is the forecast increase in petroleum refining, domestic activities and waste treatment and utilisation in the scenario, involving an increase in degrees of saturation.

ACTIVITY	*Vegetative growth* scenario	Optimistic scenario with promotional policies
SECONDARY SECTOR		
Industry	53.7%	63.6%
Bioethanol production	56.8%	78.0%
Petroleum refining	40.3%	70.0%
SECONDARY SECTOR TOTAL	**52.1%**	**64.8%**
TERTIARY SECTOR: RESIDENTIAL AND COMMERCIAL		
Domestic activities	0.0%	3.0%
Commercial activities	14.7%	20.0%
RESIDENTIAL AND COMMERCIAL TOTAL	**2.7%**	**6.2%**
WASTE TREATMENT		
Pig waste treatment	45.7%	45.7%
Sewage sludge treatment	41.2%	46.2%
Oilmill waste treatment	32.2%	99.7%
Sewage sludge biogas	0.0%	100.0%
Cattle waste biogas	0.0%	100.0%
WASTE TREATMENT TOTAL	**19.1%**	**81.1%**

Table 11. Degree of penetration forecast for 2020 in the growth scenarios considered

5.2. Trend in new installations. Results

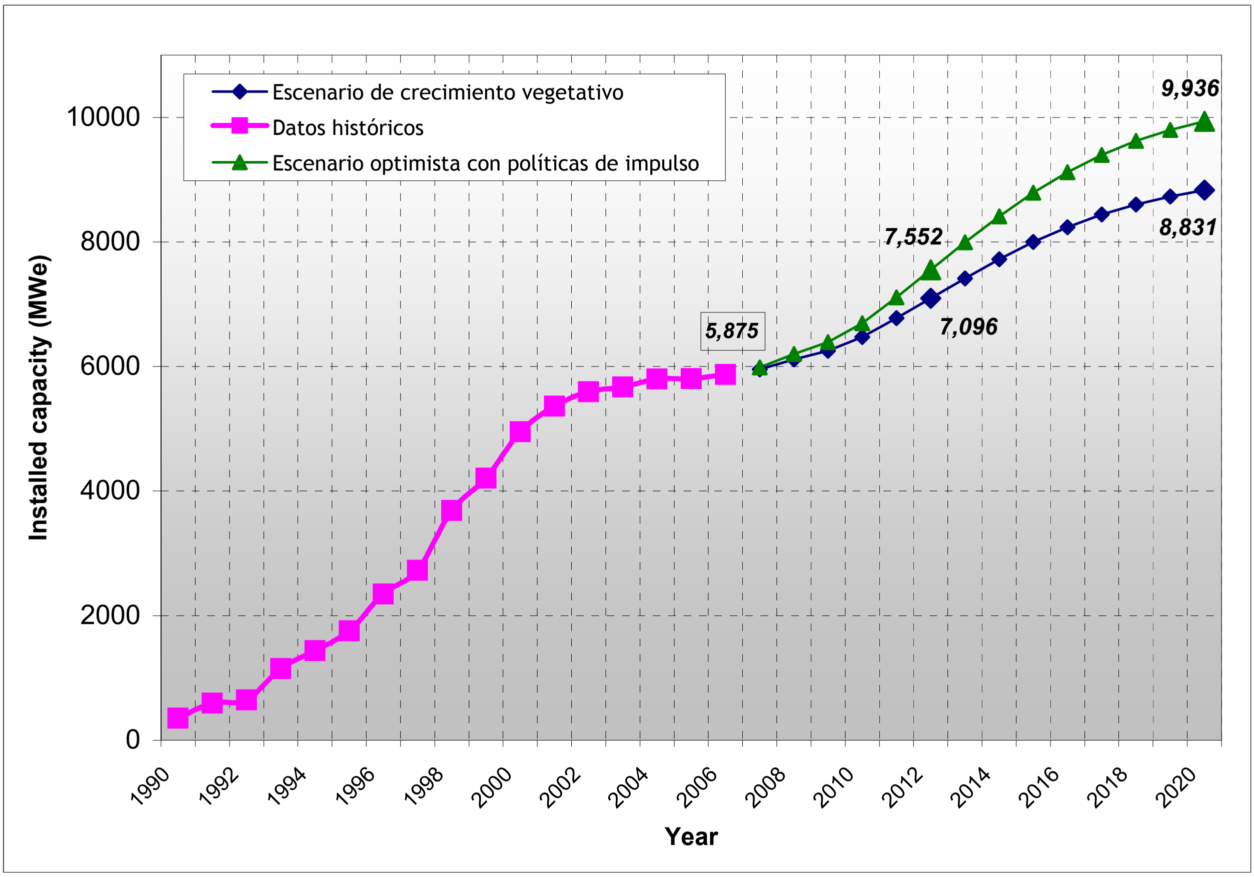
5.2.1. Installed capacity

The same criteria as in the foregoing section are used to present below the trend scenarios arrived at by separating cogeneration systems that provide useful heat and waste treatment and utilisation cogeneration systems.

[11] Target according to the Commission's Communication to the Council, the European Parliament, the Economic and Social Committee and the Committee of the Regions entitled "Community strategy for promoting the combined production of electricity and heat and for eliminating the obstacles to its development" dated 15 October 1997.

Cogeneration systems that provide useful heat

In **Figure 7**, the scenarios up to 2006 are based on actual capacity installed. The *natural growth* scenario reaches an installed capacity of 8,831 MW in 2020, the *optimistic* scenario *backed by promotional policies* 9,936 MW. It is reasonable to regard this scenario as a possible future maximum. It is therefore also reasonable to adopt a future projection between these two scenarios.

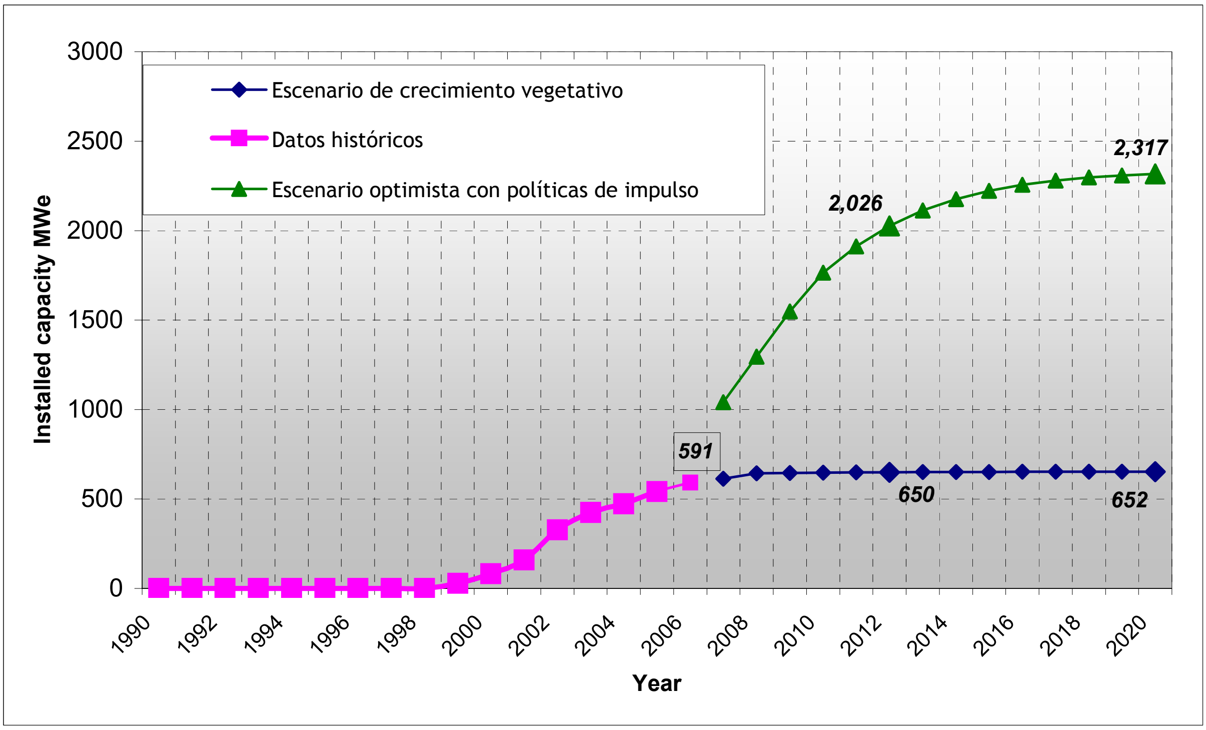


Natural growth scenario
Historical data
Optimistic scenario backed by promotional policies

Fig. 7. Trend scenarios for cogenerations that provide useful heat

Waste treatment and utilisation cogeneration systems

Figure 8 shows the growth scenarios for cogeneration systems based on the treatment and utilisation of waste. Here the *natural growth* scenario reaches an installed capacity of 652 in 2020, *optimistic* scenario *backed by promotional policies* 2317 MW. As in the case of cogenerations that provide useful heat, it is reasonable to adopt any projection between these two scenarios.

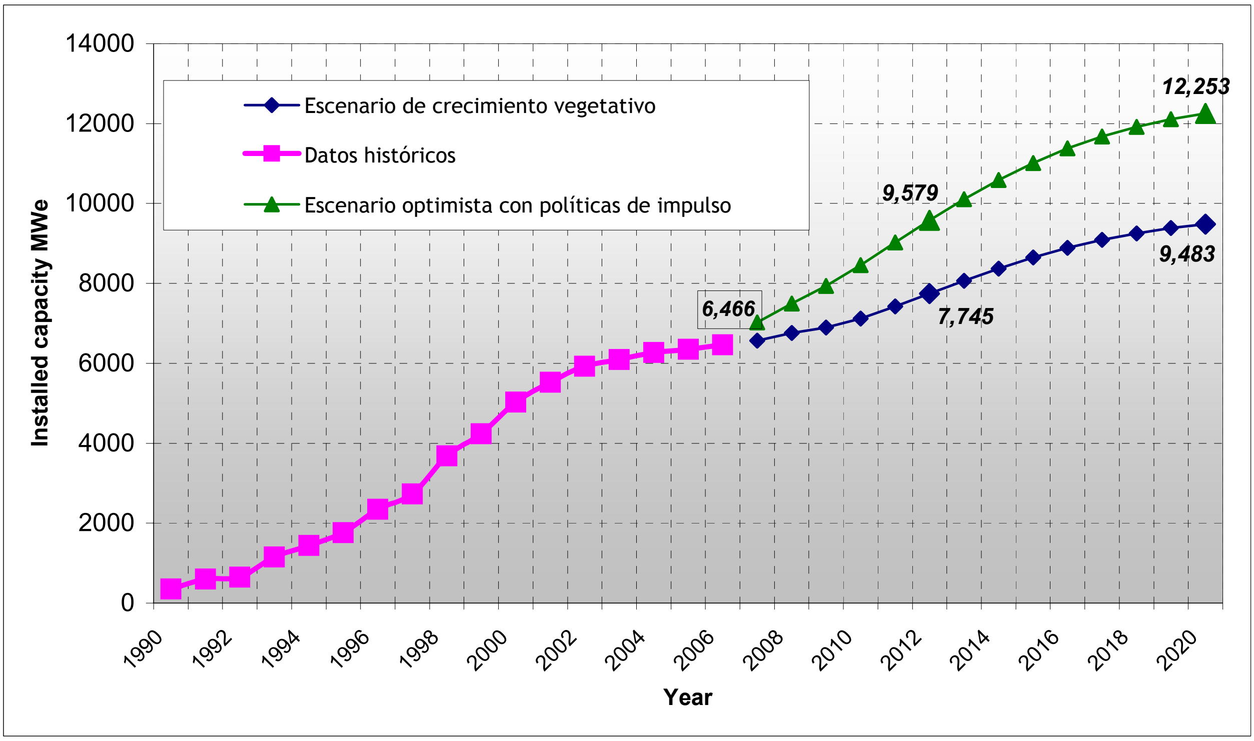


Vegetative growth scenario
Historical data
Optimistic scenario backed by promotional policies

Fig. 8. Trend scenarios for waste treatment and utilisation cogenerations

All cogeneration systems

Figure 9 combines Figures 7 and 8. The *optimistic* scenario *backed by promotional policies* reaches in 2012 an installed capacity of 9,579 MWe, which is more than the 9,215 MW target set in the 2005-2007 Action Plan of the *Energy Efficiency Strategy in Spain* (E4), which would not be achieved with the *natural growth* scenario.



Vegetative growth scenario
Historical data
Optimistic scenario backed by promotional policies

Fig. 9. Trend scenarios for all cogenerations

5.2.2. Electrical energy and coverage of electricity demand

The study shows the amount of electrical energy contributed by cogeneration systems that provide useful heat in 2020 is 54,854 GWh per annum under the *natural growth* scenario and 61,975 GWh under the *optimistic* scenario *backed by promotional policies*. The respective figures for waste treatment and utilisation cogenerations are 4,225 and 15,128 GWh. These figures nevertheless depend greatly on the sector in which new cogenerations are developed.

The proportion of total electricity production accounted for by cogeneration ranges in both scenarios between 12 and 14% for cogenerations that provide useful heat, depending on the year projected, and between 1% and 4% for waste treatment and utilisation cogenerations. The maximum total value arrived at in 2015 is 17.9% under the *optimistic* scenario *backed by promotional policies*.

The coverage of demand, on the basis of local production with consequently negligible losses, ranges between 13% and 16% for cogenerations that provide useful heat, depending on the year projected, and between 1% and 4.2% for waste treatment and utilisation cogenerations. The *optimistic* scenario *backed by promotional policies* achieves in 2015 a total coverage of 20%, fulfilling the EU’s 18% indicative target for that year.

Power use levels average about 6,250 hours per annum under the *natural growth* scenario and about 6,280 under the *optimistic* scenario *backed by promotional policies*.

Tables 12 and 13 set out the data discussed in this section.

Year	Power (MWe)	Electricity generated (GWh/year)	Proportion of production	Demand coverage
***VEGETATIVE GROWTH* SCENARIO**				
2010	6,471	39,680	11.9%	13.3%
2015	7,997	49,497	12.8%	14.3%
2020	8,831	54,854	12.5%	14.0%
OPTIMISTIC* SCENARIO *BACKED BY PROMOTIONAL POLICIES				
2010	6,694	41,095	12.3%	13.8%
2015	8,790	54,588	14.1%	15.8%
2020	9,936	61,975	14.1%	15.8%

Table 12. Forecasts for cogenerations that provide useful heat

Year	Power (MWe)	Electricity generated (GWh/year)	Proportion of production	Demand coverage
***VEGETATIVE GROWTH* SCENARIO**				
2010	647	4,196	1.3%	1.4%
2015	651	4,220	1.1%	1.2%
2020	652	4,225	1.0%	1.1%
OPTIMISTIC* SCENARIO *BACKED BY PROMOTIONAL POLICIES				
2010	1,765	11,504	3.4%	3.9%
2015	2,223	14,508	3.8%	4.2%
2020	2,317	15,128	3.5%	3.9%

Table 13. Forecasts for waste treatment and utilisation cogenerations

5.2.3. Saving of primary energy and fulfilment of the Kyoto Protocol

The potential saving in terms of primary energy was calculated with reference to the electricity produced by high-efficiency combined cycles. In the case of cogenerations that provide useful heat, the *natural growth* scenario leads to saving 2,661 kTOE in 2020, the *optimistic* scenario *backed by promotional policies* 2,994 kTOE. The corresponding figures for waste treatment and utilisation cogenerations are 196 and 698 kTOE of primary energy saving.

The contribution of cogenerations that provide useful heat to the fulfilment of the Kyoto Protocol is 6,216 kilotonnes of CO_2 per annum in 2020 under the natural growth and 6,994 under the *optimistic* scenario *backed by promotional policies*. The corresponding figures for waste treatment and utilisation cogenerations are 459 and 1,631 kt of CO_2. The total emissions prevented are equivalent to 4.7% of the rights assigned to Spain in the first National Allocation Plan 2005-2007.

Tables 14 and 15 set out the data discussed in this section.

Year	Primary energy saving (kTOE/year)	Thousands of tonnes of CO_2 prevented
***VEGETATIVE GROWTH* SCENARIO**		
2010	1,950	4,555
2015	2,410	5,629
2020	2,661	6,216
OPTIMISTIC* SCENARIO *BACKED BY PROMOTIONAL POLICIES		
2010	2,017	4,712
2015	2,649	6,188
2020	2,994	6,994

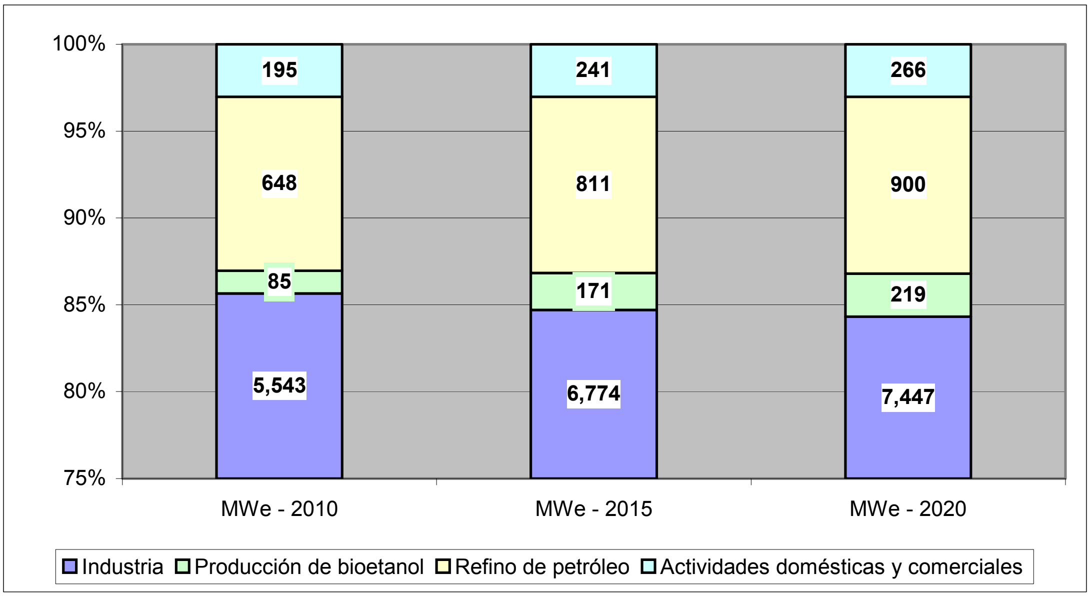
Table 14. Primary energy saving and prevented CO_2 emissions for cogenerations that provide useful heat

Year	Primary energy saving (kTOE/year)	Thousands of tonnes of CO_2 prevented
***VEGETATIVE GROWTH* SCENARIO**		
2010	195	456
2015	196	458
2020	196	459
OPTIMISTIC* SCENARIO *BACKED BY PROMOTIONAL POLICIES		
2010	532	1,242
2015	670	1,565
2020	698	1,631

Table 15. Primary energy saving and prevented CO_2 emissions for waste treatment and utilisation cogenerations

5.2.4. Participation by sector

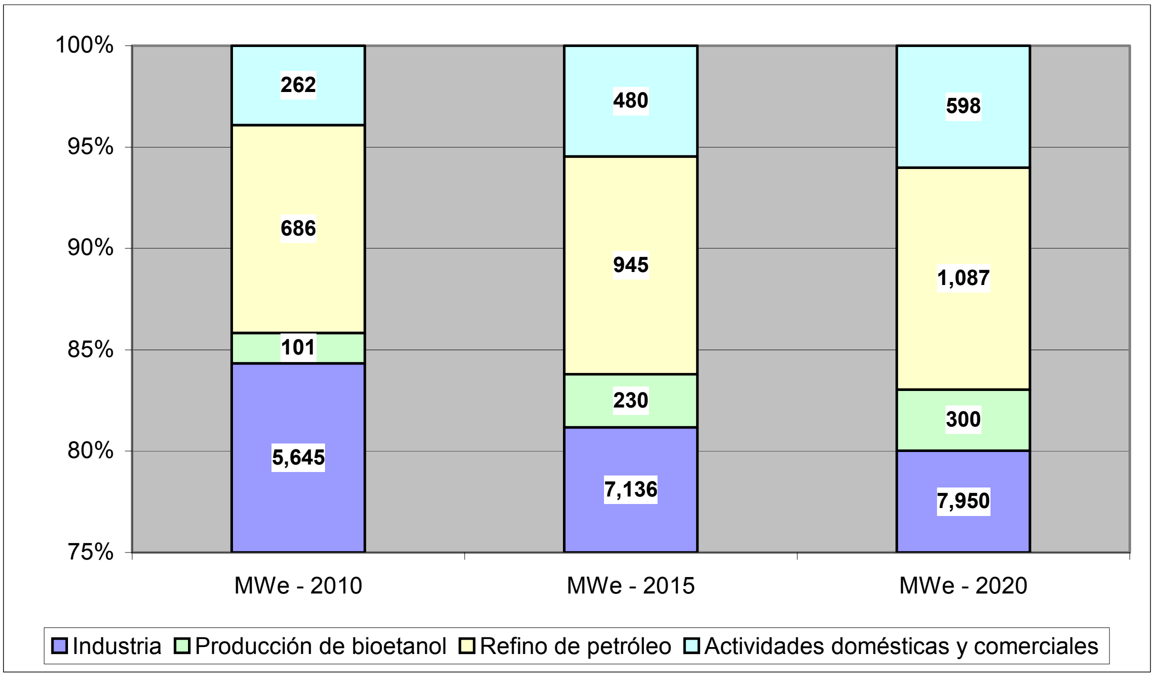
Under the natural growth, the sectoral breakdown of cogeneration potential remains virtually the same as at present, owing mainly to the very definition of the scenario. In 2020, industry is expected to account for about 84% of installed capacity, with the petroleum refining sector in second place with 11%. Bioethanol production accounts for a modest 2% and the remainder is spread over the applications in the domestic/commercial sector (3%). These data are illustrated in **Figure 10**.



Industry Bioethanol production Petroleum refining Domestic and commercial activities

Fig. 10. Relative weight of forecast installed capacity 2010-2015-2020. Vegetative growth scenario

The *optimistic* scenario *backed by promotional policies*, the breakdown of which appears in **Figure 11**, is based on an average increase in the degree of penetration of about five points, resulting in a significant amount of cogeneration of 6% in domestic and commercial activities in 2020, and bioethanol production of 3%.



Industry Bioethanol production Petroleum refining Domestic and commercial activities

Fig. 11. Relative weight of forecast installed capacity 2010-2015-2020. Optimistic scenario backed by promotional policies

Among cogeneration system for the treatment and utilisation of waste, the *optimistic* scenario *backed by promotional policies* forecasts for 2020 a significant participation of activities such as cattle biogas utilisation, with an installed capacity of 1,112 MW. The data appear in **Table 16**.

ACTIVITY	Forecast power (MWe)		
	2010	2015	2020
Pig waste treatment	322	322	322
Sewage sludge treatment	101	105	105
Oilmill waste treatment	300	300	300
Other waste treatment	139	139	139
Sewage sludge biogas	211	317	339
Cattle waste biogas	692	1,040	1,112
TOTAL	**1,765**	**2,223**	**2,317**

Table 16. Forecast power for waste treatment and utilisation cogenerations according to the scenario of increasing degree of saturation

The sections below explain the apportionment of potential among the various sectors of activity and the type of technologies and applications that will be used for developing it.

Secondary sector: industry, bioethanol and refining

The secondary sector accounts for 90% of the installed capacity in 2004, being the sector with the longest history of cogeneration systems in Spain, particularly in chemicals, paper, food and beverages, textiles and production of non-metallic minerals. The refining sector also accounts for a substantial proportion of the present cogeneration market. In this sector, the production of bioethanol, being a relatively recent economic activity - the first production plant came on stream in 1999 – comprises only two cogeneration plants, one in each production facility.

The maximum feasible installed capacity in 2020 of the secondary sector under the *optimistic* scenario *backed by promotional policies* is 9,337 MW, comprising 7,950 in industry, 1,087 in refining and 300 in the bioethanol production sector, as in **Table 17**.

ACTIVITY	Installed capacity (MWe)
Industrial sectors	7,950
Bioethanol	300
Petroleum refining	1,087
TOTAL	**9,337**

Table 17. The secondary sector's share of installed capacity in 2020 according to the optimistic scenario backed by promotional policies

Domestic and commercial activity

The maximum feasible power installed in 2020 of the tertiary sector under the *optimistic* scenario *backed by promotional policies* is 598 MWe. This sector represents great potential for new applications of district energy and also of micro-cogeneration, along with what might be called conventional cogeneration, according to the Spanish industrial plant concept. The apportionment of the forecast installed capacity in the tertiary sector takes into account this differentiation of applications, which is consistent with the shares prevailing in countries with more tertiary sector saturation, such as the USA.

ACTIVITY	Installed capacity (MWe)
Public administration	100
District heating	300
Hospitals	75
Other buildings	123
TOTAL	**598**

Table 18. The tertiary sector's share of installed capacity in 2020 according to the optimistic scenario backed by promotional policies

Table 18 shows the breakdown of installed capacity in 2020 according to the *optimistic* scenario *backed by promotional policies*, taking technological factors into account as indicated previously. The sectors covered are as follows:

- Public administration. *Applications* in public establishments (regional parliaments, municipalities, sports centres, schools, universities etc.)
- District heat. *District heating and cooling* applications in various sectors, e.g. in new commercial, office and residential developments needing a thermal energy distribution network
- Hospitals. Cogenerations in hospitals not involving a network for distributing energies to various buildings
- Other buildings. Cogenerations and micro-cogenerations in buildings (offices, hotels, shopping and business centres, conference halls etc)

Waste treatment and energy utilisation

These activities afford the opportunity to utilise cogeneration technologies for saving primary energy. The cogeneration potential in this case is represented by both conventional cogeneration applications – normally in drying cycles – and micro-cogeneration applications. The estimated potential for each activity are as follows:

- Sewage waste treatment. Estimated potential of about 105 MWe in 2020 under the *increasing degree of saturation* scenario.
- Pig waste treatment. Known applications in Spain of 271 MWe registered under the special regime at the end of 2006. Forecast growth to 322 MW in 2020.

- Oilmill waste treatment. Another application known in Spain. Estimated to possibly reach 300 MW installed in 2020 under the *optimistic* scenario *backed by promotional policies*.

- Other waste treatment. Cogeneration applications in such sectors as food industry sludge treatment. Estimated at 139 MWe in 2020 under the *optimistic* scenario *backed by promotional policies*.

- Sewage sludge biogas utilisation. Estimated unstable power in 2020 of 339 MW according to the *increasing degree of saturation* scenario.

- Cattle waste biogas utilisation. This kind of application, as has been found in particular in the Principality of Asturias, would be valuable. In this case the fuel is renewable, so cogeneration is doubly efficient, there would even be primary energy saving without utilisation of heat, i.e. by using digestion biogas to generate electricity. Utilising all the potential, comprising about half of Spain's cattle, would mean a capacity of 1,112 MW in 2020.

5.2.5. Micro-cogeneration potential 2010 – 2015 – 2020

Micro-cogeneration as defined in Directive 2004/8/EC is cogeneration with a capacity of less than 50 kWe. This is comparable with the capacity usually contracted for by ten floors of a new building equipped with every kind of domestic electrical appliance (except cookers) and electric air conditioning. However, owing to the area of application and the available technology, this section is concerned with installations with less than 300 kWe installed and with equipment items not exceeding 100 kWe in *unit power*.

Micro-cogeneration is usually a type of plant normally intended for the tertiary sector, centres isolated from the electric grid and other applications with special gases such as landfill or anaerobic digestion biogas at treatment plants or farms.

In the tertiary sector its applications are in all centres where there is a large heat demand such as hotels, hospitals, sports clubs, air conditioned swimming pools, public buildings etc.

The potential as regards the use of renewable fuels such biogas is mainly in medium-sized landfill (up to 300 Nm^3/h of biogas) and anaerobic digestion plants with digester volumes of between 1,000 and 4,000 m^3. This second group includes both urban or industrial treatment plants and digestion facilities at farms.

Another very valuable area of application is in centres isolated from the electricity grid. With micro-cogeneration they can achieve energy savings and at the same time have high-availability equipment for producing electricity.

To sum up, micro-cogeneration is a *technologically mature* sector with numerous applications worldwide and is regarded as a *system for energy saving in buildings and a solution for the utilisation of biogas* at plants where the small amounts produced are at present flared off.

Like the scenarios defined, the micro-cogeneration potential has to be regarded as a reasonable objective on the basis of the technological potential. **Table 19** shows this potential as a function of the area of application.

Area of application	2010	2015	2020
Government buildings	1,500	5,000	10,000
Pig waste biogas	750	10,000	20,000
Water treatment biogas	1,000	2,500	5,000
Other buildings	2,000	10,000	20,000
TOTAL	**5,250**	**27,500**	**55,000**

Table 19. Micro-cogeneration potential in kWe

5.2.6. District heating and cooling cogeneration potential

We take *district heating and cooling cogeneration plants* to mean those with a distribution network for thermal energy - heat and/or cold – that supplies this energy to a number of consumers. Unlike other countries, especially in Eastern Europe, this type of application is not established in Spain to any significant extent.

The cogeneration potential study identifies the possibility of installing 300 MW, representing 43% of capacity in the *tertiary sector* (**Table 18**). Projects of this kind may be associated with redevelopment projects for urban areas that involve a variety of uses such as offices, shopping and business centres and residential accommodation.

5.3. Potential for renewal of existing facilities

The major part of the cogeneration capacity currently installed in Spain is in the secondary sector. 2007 is expected to see the installing of 3,310 MW to operate for ten or more years, spread over 594 sites. Of these, 794 MW spread over 115 plants will operate for fifteen years or longer. The renewal of this capacity may entail an increase or a decrease in installed capacity at the same sites, depending on efficiency improvements, changes in useful heat demand and hours of use of plants. **Figure 12** illustrates the age of existing cogeneration facilities.

The 3,310 MW operable for 10 or more years can be converted to 3,970 MW operating 6,150 hours per annum with electrical efficiency of 34.8% and overall efficiency of 77.0%; the remaining 2,148 MW currently installed will have been operating for at least ten years by 2015 and can be renewed to become 3,140 MW with the same operating and efficiency conditions.

On the above basis, the maximum renewal potential of the existing facilities is quantifiable at 660 MW in the period 2007-2015 and at 992 MW from 2015 onwards, making a total of 1,652 MW more than the installed capacity in 2004.

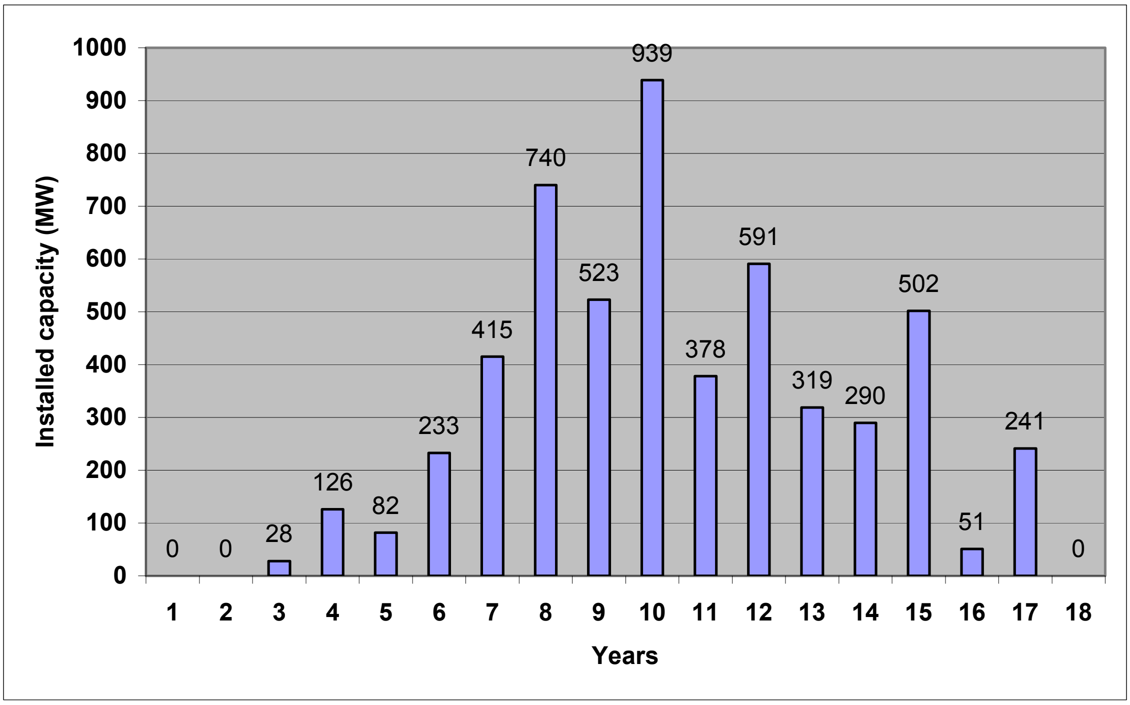


Fig. 12. Age of cogeneration facilities. It means that in 2007 there will be 939 MW that have been in operation for 10 years. Our compilation from CNE data.

6. CHARACTERISTICS OF NEW INSTALLATIONS THAT FORM PART OF THE POTENTIAL

6.1 Technologies

With a view to evaluating the technologies to be used for developing future cogeneration potential, it is important to bear in mind that existing installed potential covers a wide range of technologies, as illustrated in **Figure 13** based on 2004 data.

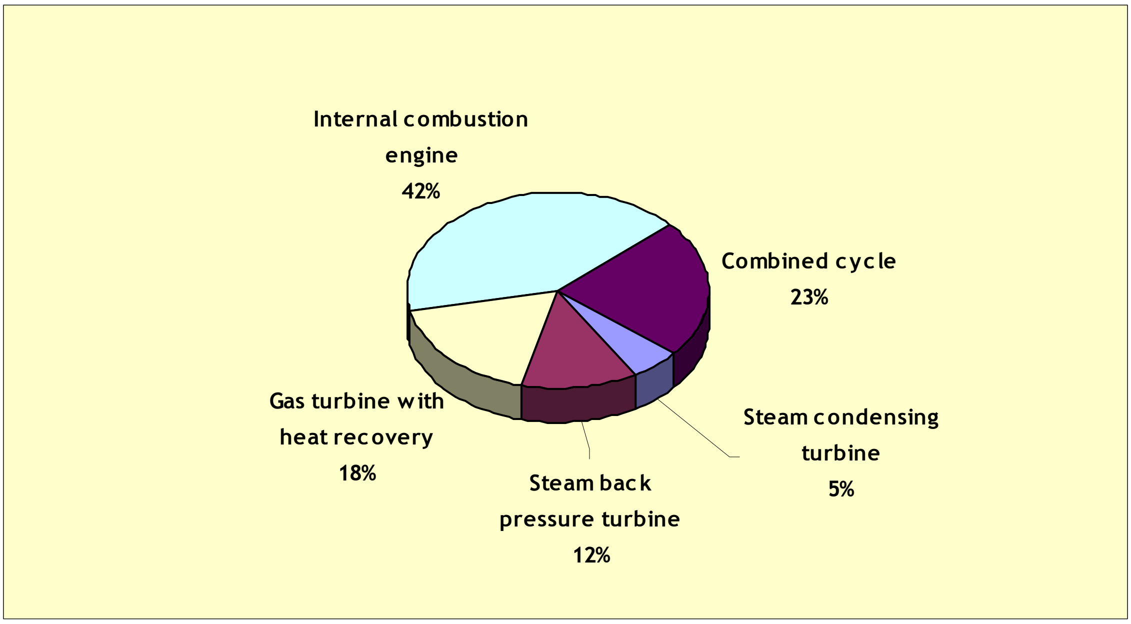


Fig. 13. Breakdown by technology of installed capacity in the autogenerator category. IDAE data for 2004

The current majority technologies are cycles based on gas engines and gas turbines, both simple cycle – 18% of current power – and combined cycle – 23% of installed capacity. Steam turbines have been steadily replaced by combined cycles and it is foreseeable that in the future they will only be used in cycles with renewable fuel as in oilmill waste combustion. For new installations it is also expected that the majority of cases will involve cycles with gas engines and combined cycles. **Figure 14** shows the share of each technology in the development of cogeneration potential.

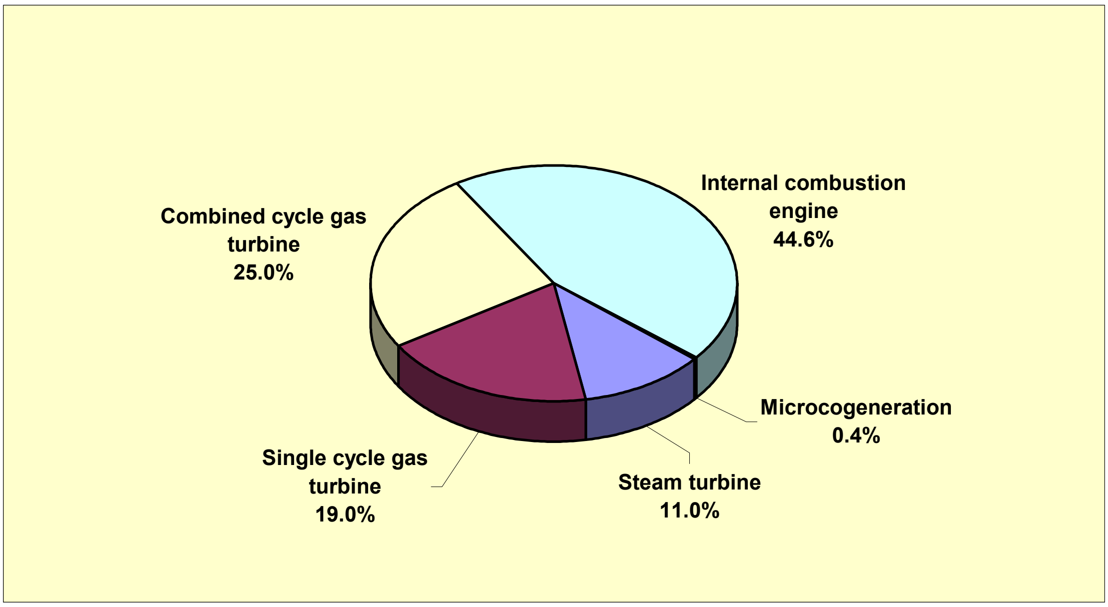


Fig. 14. Cogeneration potential by prospective technology

The range of technologies for developing the potential is expected to be similar to now except that steam turbines will increase in the renewable sector and in refining, whereas in other sectors they will be converted to combined cycles or be replaced by simple cycles.

Micro-cogenerations, despite the forecast potential, are of relatively little significance owing to the *different scale of power* of the equipment, which in absolute terms has to be construed as little penetration of this type of technology.

The industrial sector is expected to see a predominance of simple cycle gas engines (43%) and simple cycle turbines (20%), but steam turbines will give ground to combined cycles that will come to represent 19% of installed capacity in the industrial sector.

In waste treatment applications the bulk of capacity, between 80 and 90%, will be accounted for by internal combustion engines. Applications in buildings and district heating and cooling involve a greater variety of technologies (61% engines, 55% combined cycle turbines and 9% micro-cogenerations).

6.2. Fuels used

The development of cogeneration in Spain has been related to the country's gasification. The firm consumptions and long work programmes of cogeneration systems make them appropriate for the amortisation of gas infrastructures. In countries such as Colombia, Brazil and south-eastern Europe, the laying of pipelines is linked with the development of cogeneration. 82% of the electricity produced by cogeneration in the category known as self-producers is now based on natural gas, followed by 15% for fuel oil.

It is foreseeable that the growth of cogeneration will be based on natural gas, mainly because Spain is still undergoing gasification and this fuel has many advantages, including high availability and ease of handling in the tertiary sector, as well as lower emissions of pollutant gases.

Table 20 shows the cogeneration potential based on fuel of renewable origin currently representing 5.6% of the total. The *optimistic* scenario *backed by promotional policies*[12] is based on using 100% of resources that are renewable through being regarded as home-grown, with a forecast 2020 total installed capacity in biogas applications of 1,451 MWe, providing useful heat of 10,851 GWh per annum. We note the high potential in the cattle sector.

ACTIVITY	Year 2004		Year 2010		Year 2020	
	Techno-logical potential (MWe)	Useful heat (GWh/year)	Techno-logical potential (MWe)	Useful heat (GWh/year)	Techno-logical potential (MWe)	Useful heat (GWh/year)
Sewage sludge biogas	294	2,264	312	2,400	339	2,604
Cattle waste biogas	792	5,870	920	6,821	1,112	8,247
TOTAL	**1,086**	**8,134**	**1,232**	**9,221**	**1,451**	**10,851**

Table 20. Cogeneration potential from renewable fuel. Optimistic scenario backed by promotional policies.

[12] The *maintaining 2004 saturation* scenario provides no relevant data, since it is based on maintaining present levels, which are virtually nil.

7. BARRIERS TO THE DEVELOPMENT OF COGENERATION POTENTIAL

7.1. Legislative barriers

One of the main reasons why cogeneration has made no significant progress in recent years is the *transitoriness of the economic and legal regimes* published initially in Royal Decree 2818/1998 and subsequently replaced by Royal Decree 436/2004 which was itself replaced by the current Royal Decree RD 661/2007. There is an undoubted need for a stable legal framework to ensure reasonable long-term profitability for cogeneration plant promoters.

Another barrier is the complexity of the applicable legislation, which is liable to create confusion and conflicting interpretations.

There is also a regulatory barrier between cogenerations on either side of 50 MW, the figure which separates the special and ordinary regimes. There are thus less incentives for cogeneration systems over 50 MW, with consequent failure to utilise the efficiencies and economies of scale of larger projects.

7.2. Economic barriers

The main economic barrier is the failure of the tariff to reflect variation in fuel costs, resulting in many projects failing to achieve reasonable minimum profitability.

The present discrimination based on definite jumps of installed capacity also prompts the choice in some situations of a technical solution leading to economics that are not always optimistic as regards saving primary energy. This applies particularly at the jump from less than to more than 10 MW.

With regard to the provision of economic support, the letter of the law states that it is granted on the basis of saving primary energy and emissions to the atmosphere and taking into account the interconnection voltage, but the quantification of these effects is not transparent and it is therefore difficult to distinguish the portion of support that promotes cogeneration from the portion that internalises the external costs of distributed production and the saving of primary energy. Distinguishing the external costs would give investors security by acknowledging remunerative and non-remunerative portions of transitional or arbitrary support.

7.3. Administrative barriers

An important aspect for the viability of any project is the availability of *grid connection*. The fact that the electricity companies operating the grid are sometimes the very companies competing with cogeneration projects as suppliers of electrical energy has led to situations of no competition. It is necessary to set up administrative control mechanisms to supervise the fulfilment of the right of access to the grid.

7.4. Technical barriers

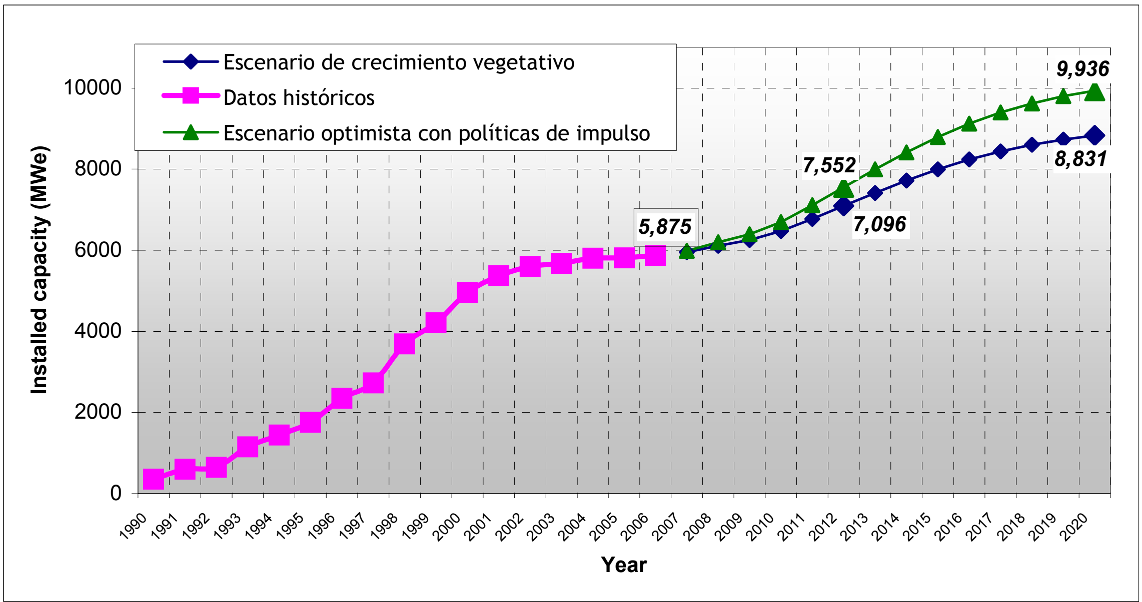
Shortage of natural gas supply continues to be an important barrier, particularly for low-power cogeneration systems.

8. CONCLUSIONS

The first important result established by the cogeneration potential study is that there is a large potential market for systems of this kind, quantified at 24,606 MWe in 2020 for cogenerations that provide useful heat and 2,685 MWe for waste treatment and utilisation cogenerations. 14,903 MWe of the total technological potential forecast for 2020 are in the industrial and petroleum refining sector and the other 9,703 MW are in applications in the domestic and commercial sector.

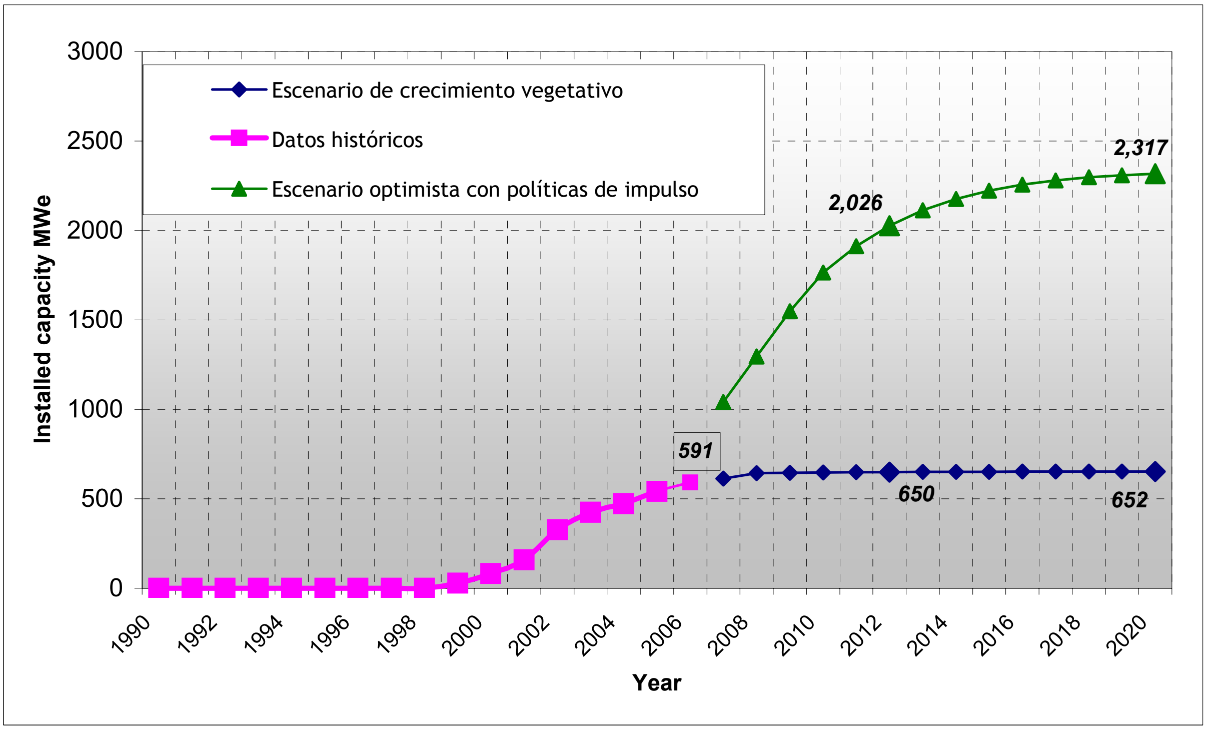
The greatest currently unexploited potential is in the tertiary sector, with more than 97% availability, and the treatment and utilisation of waste, with more than 80% of potential not yet realised. Cogenerations installed that provide useful heat currently amount to 5,800 MWe, with a 33.6% penetration of the potential, leaving 66.4% of cogeneration potential still available. The maximum potential for renewal of existing cogeneration facilities by 2020 is 1,652 MWe more than the installed capacity in 2004.

As regards future development of installed capacity, this study traces two kinds of trend, one based on maintaining the degree of sectoral penetration, the other on increasing degrees of penetration on the basis of policies that encourage cogeneration. Any trend scenario between the two is feasible as a future objective. The following repeat of **Fig. 7** shows two scenarios considered, the "*natural growth* scenario" and the "*optimistic* scenario *backed by promotional policies*" for cogenerations that provide useful heat. **Fig. 8** shows the same scenarios for waste treatment and utilisation cogenerations.



Vegetative growth scenario
Historical data
Optimistic scenario backed by promotional policies

Fig. 7. Trend scenarios for cogenerations that provide useful heat



Vegetative growth scenario
Historical data
Optimistic scenario backed by promotional policies

Fig. 8. Trend scenarios for waste treatment and utilisation cogenerations

These diagrams show that the installed capacity in 2020 would range between 8,831 and 9,936 MWe for cogenerations that provide useful heat and between 652 and 2,317 for waste treatment and utilisation cogenerations. The "*optimistic* scenario *backed by promotional policies*" forecasts an installed capacity of all cogenerations in 2012 of 9,579 MWe, which is more than the 9,215 MWe set for that year in the 2005-2007 Action Plan of the Strategy for Energy Efficiency in Spain (E4).

A final point to note is the reference in this study to the potential in the development of new applications and technologies such as *district heating and cooling,* quantified at some 300 MW, and micro-cogeneration, at 55 MW.

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ANNEX I. SECTORAL CHARACTERISATION OF USEFUL HEAT DEMAND

This annex contains an analysis of fuel consumptions for the sectors covered by this study and a quantification of the heat that might be generated by cogeneration and therefore be regarded as potential useful heat. It also presents for each sector the design of cogeneration systems (technological potential) that optimises the saving of primary energy.

A. Industrial sector. Paper and board subsector

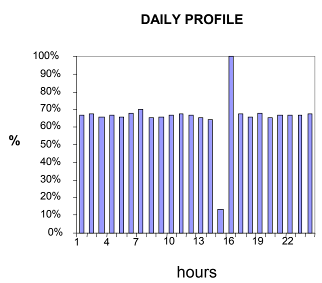
A.1. Energy consumed

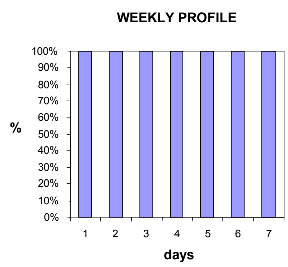
- Consumption at end of 2004: 2,236 kTOE
- Fuel consumptions 2004: 1,412 kTOE
    - Natural gas 1,158 kTOE
    - Petroleum products 254 kTOE
    - Coal 0 kTOE
- Useful heat demand: 1,234 kTOE (14,351 GWh)
    - Natural gas 1,019 kTOE
    - Petroleum products 216 kTOE
    - Coal 0 kTOE

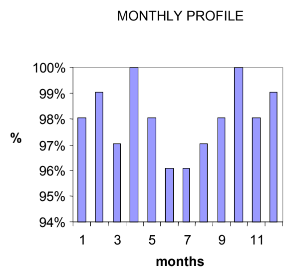
The usual heat demand is in the form of steam which can be generated entirely by cogeneration.

A.2. Work programme

Production 24 hours per day, 7 days per week with insignificantly slight monthly variation. The following diagrams illustrate the commonest standard profiles.



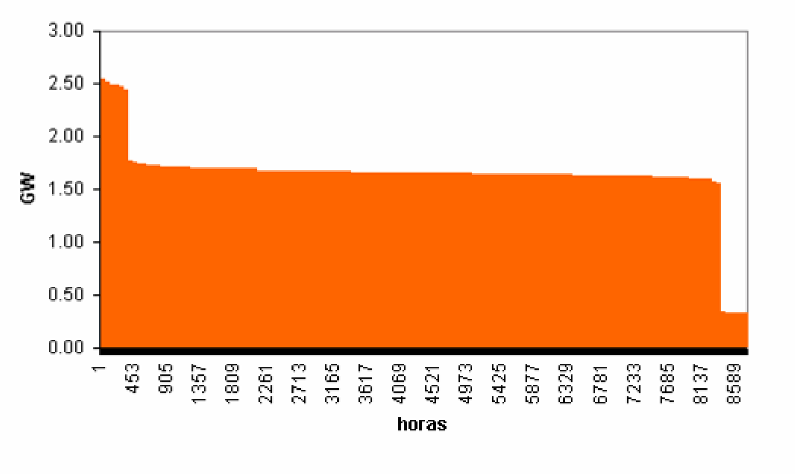




A.3. Useful heat demand

Cogenerable heat coefficient / useful heat: 1

Useful heat potential: 14,351 GWh/year.



hours

Useful heat consumption is constant and uniform over most of the year. This is due to an extensive work programme with hardly any interruptions and a process steam consumption that is fairly constant all day long.

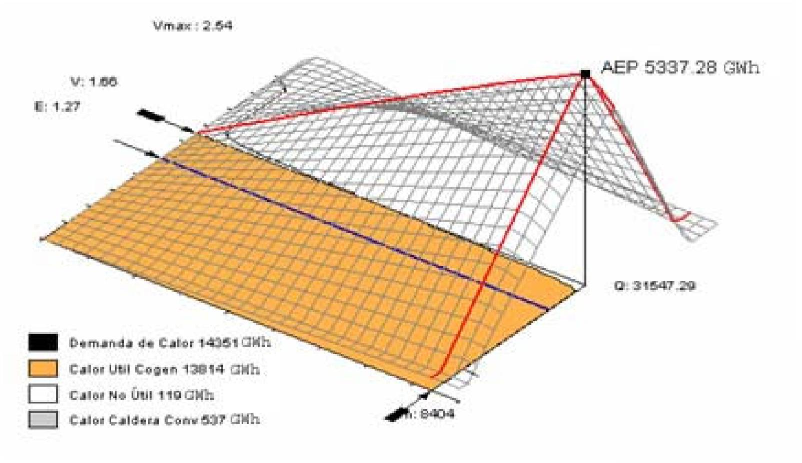
A.4. Cogeneration technologies

Majority combined cycles and gas turbines.

Characterisation of cogeneration system as a function of technological mix:

- Electrical efficiency: 34%
- Overall efficiency: 78%

A.5. Design of technological potential



- **High efficiency cogeneration potential:** **1,270 MWe**
- Associated useful heat: 13,814 GWh (96.2% of total)
- Annual operating hours: 8,404 h

B. Industrial sector. Textile subsector

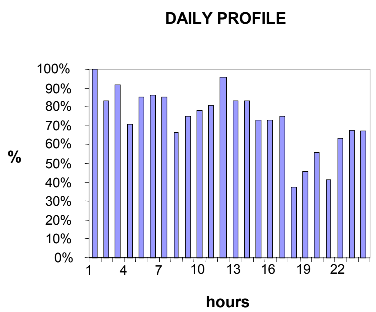
B.1. Energy consumed

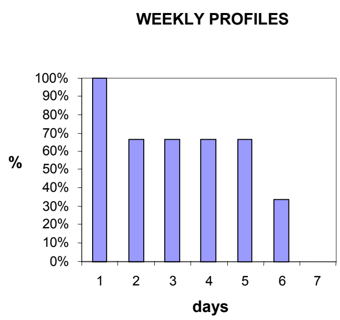
- Consumption at end of 2004: 1,299 kTOE
- Fuel consumptions 2004: 875 kTOE
  - Natural gas 736 kTOE
  - Petroleum products 139 kTOE

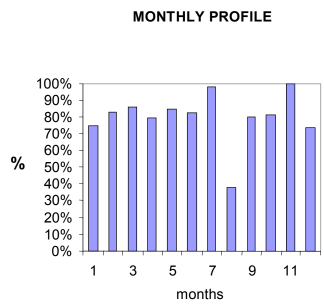
- Coal 0 kTOE
- Useful heat demand: 766 kTOE (8,902 GWh)
  - Natural gas 648 kTOE
  - Petroleum products 118 kTOE
  - Coal 0 kTOE

B.2. Work programme

Production 24 hours per day Monday to Saturday. The daily programme varies because there are several steam consumption points. In the weekly programme, Monday consumes more because of machines starting up and Saturday consumes less because of only one shift. The monthly programme presents no significant variations except the August holiday period. The following diagrams show the commonest standard profiles.



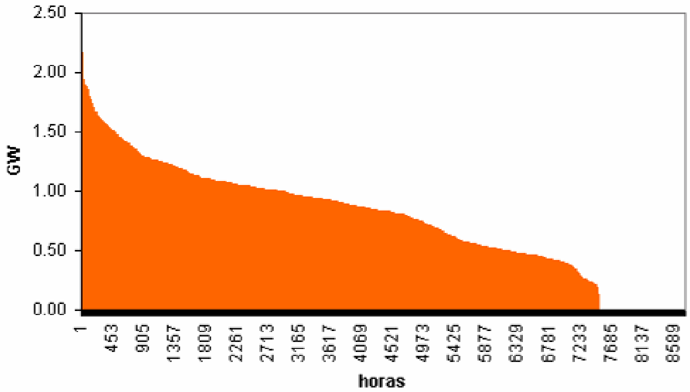




B.3. Useful heat demand

Cogenerable heat coefficient / useful heat: 0,75

Useful heat potential: 6,687 GWh/year.



Useful heat consumption is not constant because of daily variations in consumption and the decreasing profile over the working week.

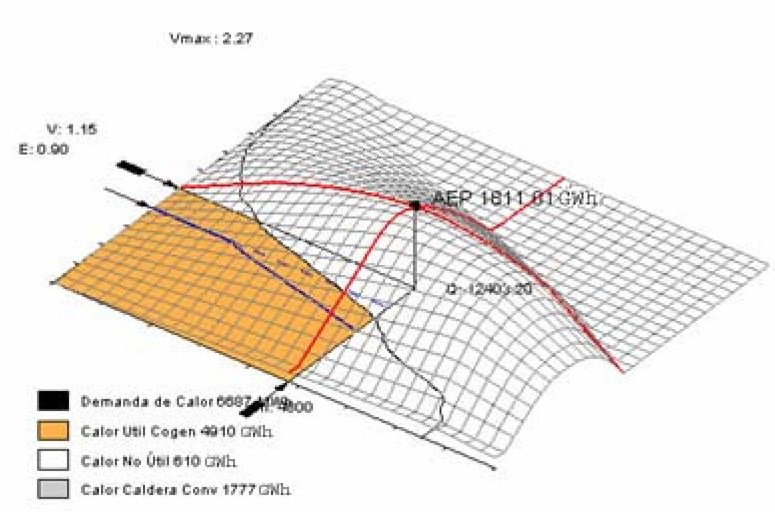
B.4. Cogeneration technologies

Majority internal combustion engines and combined cycles.

Characterisation of cogeneration system as a function of technological mix:

- Electrical efficiency: 36%
- Overall efficiency: 77%

B.5. Design of technological potential



- **High efficiency cogeneration potential: 898 MWe**
- Associated useful heat: 4,910 GWh (73.4% of total)
- Annual operating hours: 4,800 h

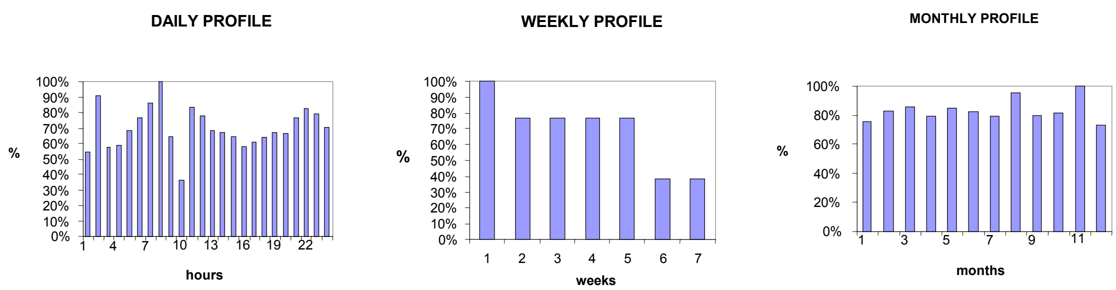
C. Industrial sector. Chemical subsector

C.1. Energy consumed

- Consumption at end of 2004: 4,153 kTOE
- Fuel consumptions 2004: 2,865 kTOE
    - Natural gas 2,042 kTOE
    - Petroleum products 702 kTOE
    - Coal 121 kTOE
- Useful heat demand: 2,491 kTOE (28,950 GWh)
    - Natural gas 648 kTOE
    - Petroleum products 118 kTOE
    - Coal 0 kTOE

C.2. Work programme

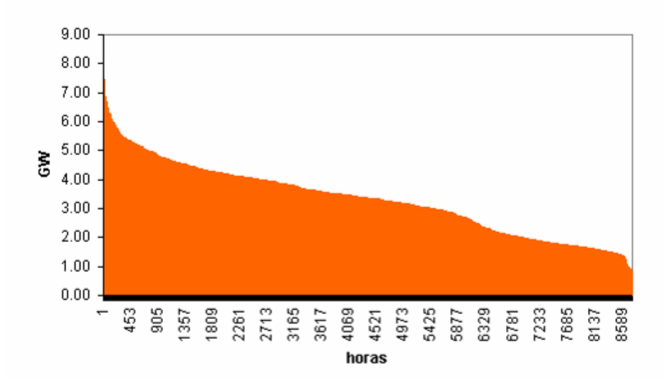
Production 24 hours per day Monday to Sunday. The daily programme is variable owing to the manufacture of different products in the same factory with different steam requirements. In the weekly programme, Saturday consumes less because of only one shift. The monthly programme presents no significant variations. The following diagrams show the commonest standard profiles.



C.3. Useful heat demand

Cogenerable heat coefficient / useful heat: 1

Useful heat potential: 28,970 GWh/year.



hours

Useful heat consumption is not constant because of variable work with a downward trend.

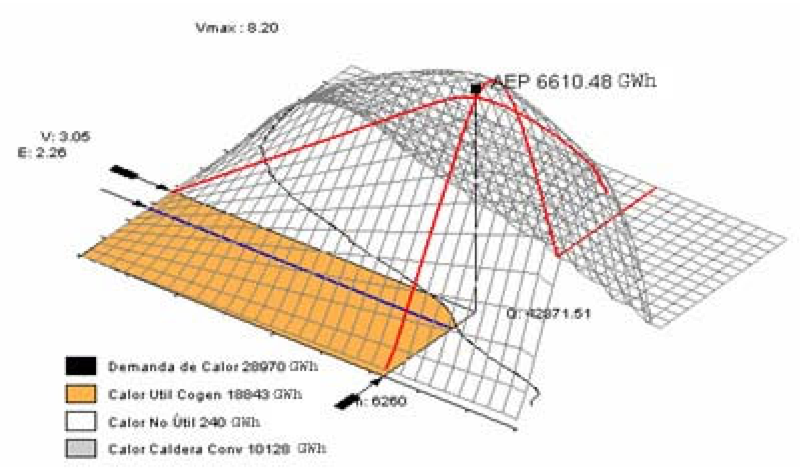
C.4. Cogeneration technologies

Significant representation of all technologies: engines, gas turbines, combined cycles and steam turbines.

Characterisation of cogeneration system as a function of technological mix:

- Electrical efficiency: 33%
- Overall efficiency: 77%

C.5. Design of technological potential



- **High efficiency cogeneration potential: 2,255 MWe**
- Associated useful heat: 18,843 GWh (65% of total)
- Annual operating hours: 6,260 h

D. Industrial sector. Food subsector

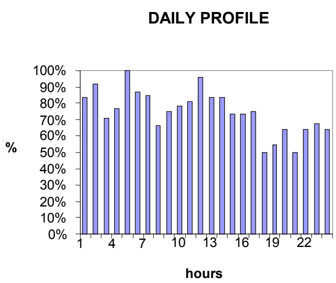
D.1. Energy consumed

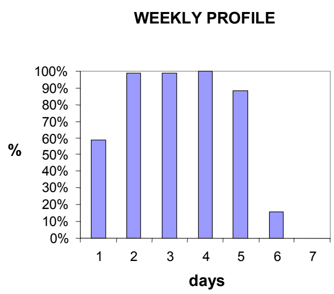
- Consumption at end of 2004: 2,682 kTOE
- Fuel consumptions 2004: 1,512 kTOE

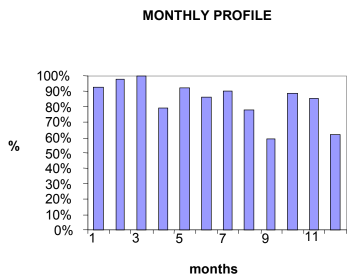
  - Natural gas 1,047 kTOE
  - Petroleum products 458 kTOE
  - Coal 7 kTOE
- Useful heat demand: 1,316 kTOE (15,305 GWh)
  - Natural gas 921 kTOE
  - Petroleum products 389 kTOE
  - Coal 5 kTOE

D.2. Work programme

Production 24 hours per day Monday to Saturday. The daily programme is variable owing to the manufacture of different products in the same factory with different steam requirements. In the weekly programme, Saturday consumes less because of only one shift. The monthly programme presents no significant variations. The following diagrams show the commonest standard profiles.

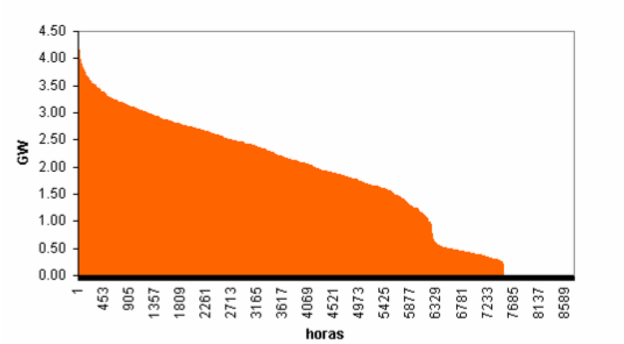






D.3. Useful heat demand

Cogenerable heat coefficient / useful heat: 1
Useful heat potential: 15,305 GWh/year.



Useful heat consumption is not constant because of variable work with a downward trend.

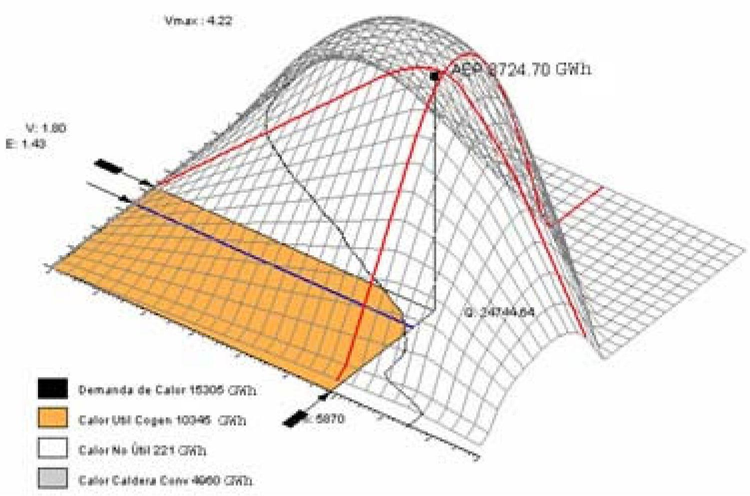
D.4. Cogeneration technologies

Predominantly internal combustion engines but there are also gas turbines and steam turbines.

Characterisation of cogeneration system as a function of technological mix:

- Electrical efficiency: 34%
- Overall efficiency: 76%

D.5. Design of technological potential



- **High efficiency cogeneration potential: 1,427 MWe**
- Associated useful heat: 10,345 GWh (67.5% of total)
- Annual operating hours: 5,870 h

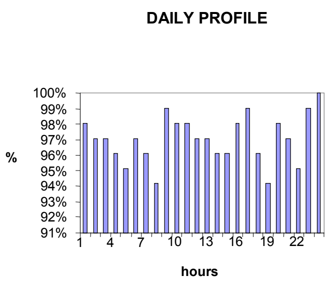
E. Industrial sector. Non-metallic minerals subsector (ceramics, glass, cement)

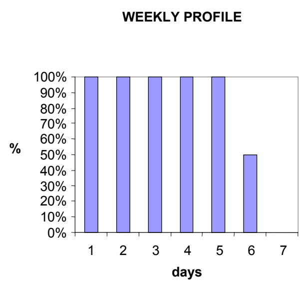
E.1. Energy consumed

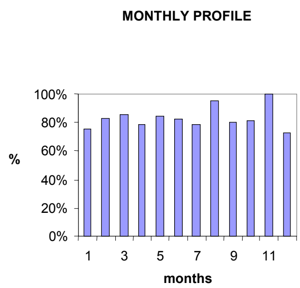
- Consumption at end of 2004: 6,673 kTOE
- Fuel consumptions 2004: 5,583 kTOE
  - Natural gas 3,191 kTOE
  - Petroleum products 2,202 kTOE
  - Coal 190 kTOE
- Useful heat demand: 4,832 kTOE (56,160 GWh)
  - Natural gas 2,809 kTOE
  - Petroleum products 1,871 kTOE
  - Coal 152 kTOE

E.2. Work programme

Production 24 hours per day Monday to Saturday. The daily programme is variable owing to the manufacture of different products in the same factory with different drying requirements. In the weekly programme, Saturday consumes less because of only one shift. The monthly programme presents no significant variations. The following diagrams show the commonest standard profiles.



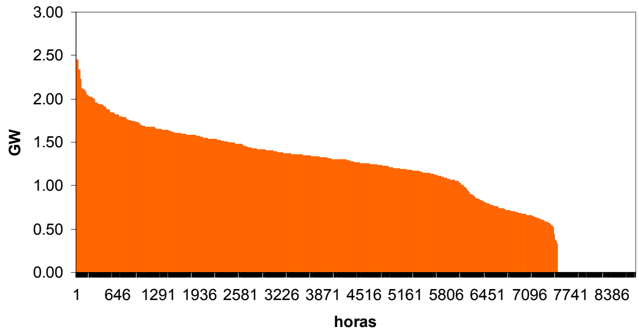




E.3. Useful heat demand

Cogenerable heat coefficient / useful heat: 0.18

Useful heat potential: 9,804 GWh/year.



Useful heat consumption is not constant because of the daily and monthly work profile presenting variability.

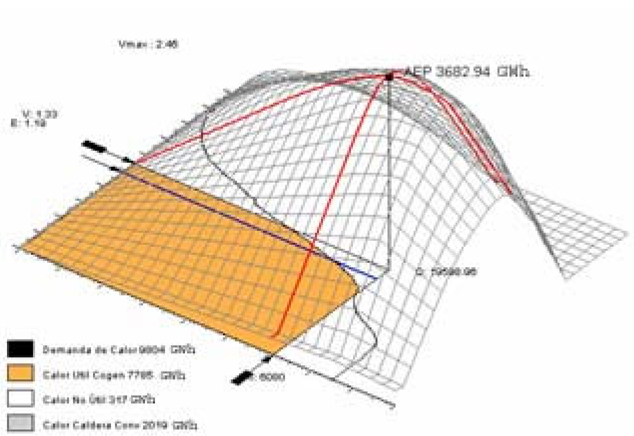
E.4. Cogeneration technologies

Significant presence of gas turbines and engines.

Characterisation of cogeneration system as a function of technological mix:

- Electrical efficiency: 37%
- Overall efficiency: 77%

E.5. Design of technological potential



- **High efficiency cogeneration potential: 1,185 MWe**
- Associated useful heat: 7,786 GWh (79.4% of total)
- Annual operating hours: 6,080 h

F. Industrial sector. Rest of industry

This section includes non-energy extractive industries, ferrous metallurgy and casting, non-ferrous metallurgy, metal processing, transport equipment, construction, wood, cork, furniture etc.

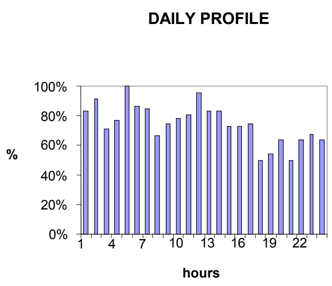
F.1. Energy consumed

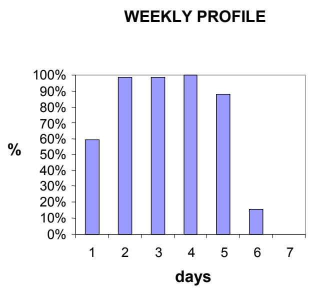
- Consumption at end of 2004: 10,734 kTOE

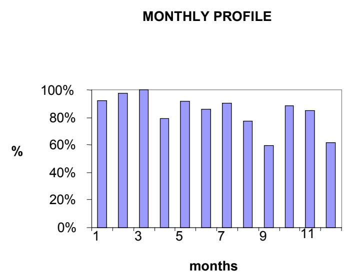
- Fuel consumptions 2004: 5,659 kTOE
    - Natural gas 2,121 kTOE
    - Petroleum products 1,390 kTOE
    - Coal 2,148 kTOE
- Useful heat demand: 4,766 kTOE (55,391 GWh)
    - Natural gas 1,867 kTOE
    - Petroleum products 1,181 kTOE
    - Coal 1,718 kTOE

F.2. Work programme

Production 24 hours per day Monday to Saturday. Daily programme not uniform and weekly programme with single shift on Saturdays and 6.00 a.m. start on Mondays. The following diagrams show the commonest standard profiles.



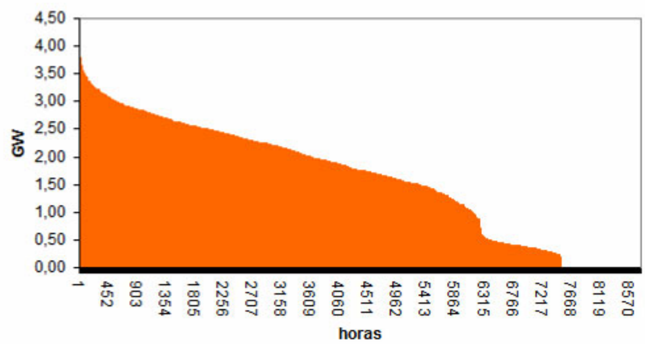




F.3. Useful heat demand

Cogenerable heat coefficient / useful heat: 0.25

Useful heat potential: 13,991 GWh/year.



Decreasing useful heat consumption with some 6,300 hours of significant heat demand.

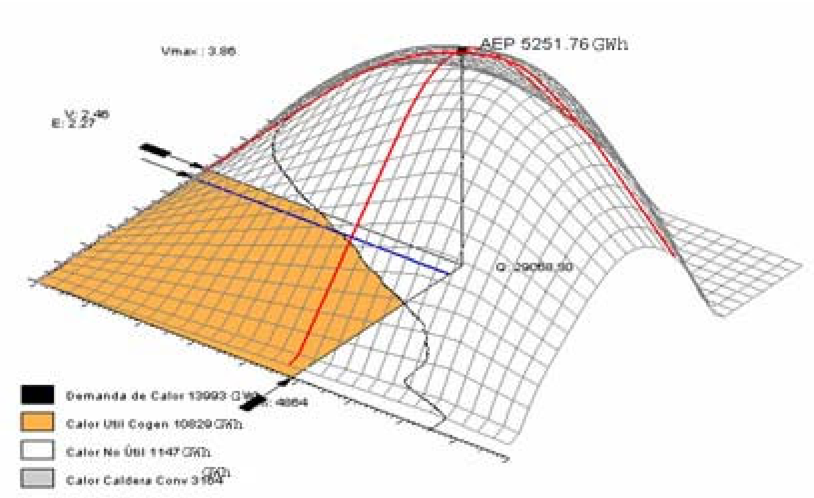
F.4. Cogeneration technologies

Majority combustion engines and combined cycles.

Characterisation of cogeneration system as a function of technological mix:

- Electrical efficiency: 38%
- Overall efficiency: 77%

F.5. Design of technological potential



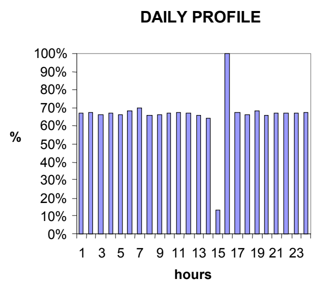
- **High efficiency cogeneration potential: 2,270 MWe**
- Associated useful heat: 10,829 GWh (77.4% of total)
- Annual operating hours: 4,648 h

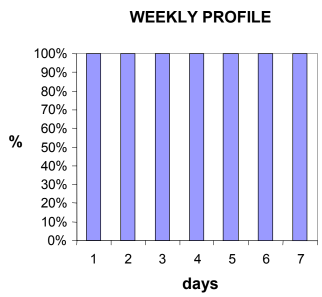
G. Bioethanol

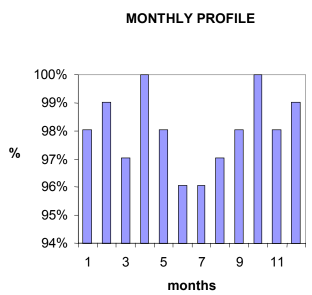
In response to the petroleum crises of 1973 and 1978, energy policies in the 1980s encouraged the search for alternatives to dependence on fossil fuels, particularly in the USA and Brazil. The current perception is that biofuels cannot entirely replace fossil fuels but can be used in various blends with them to reduce petroleum dependence, unlike other alternatives that are exclusive (e.g. liquefied petroleum gases) and involve some system duplication. Moreover, biofuels can use the same logistic distribution network as fossil fuels. All these reasons combine with Spain's biofuel targets to indicate the bioethanol sector growing in the years ahead.

G.1. Work programme

Production 24 hours per day Monday to Sunday. Daily programme virtually uniform and monthly profile with reduced production in summer months. The following diagrams show the commonest standard profiles.



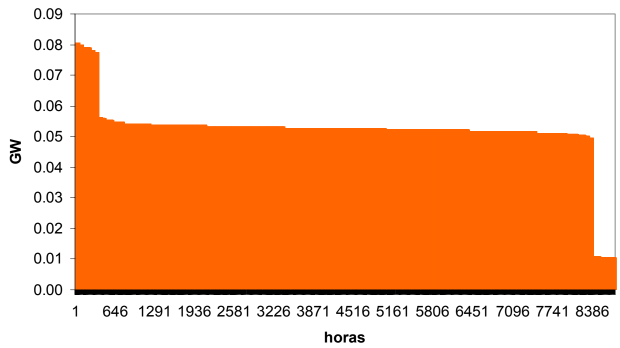




G.2. Useful heat demand

Cogenerable heat coefficient / useful heat: 1

Useful heat potential: 870 GWh/year.



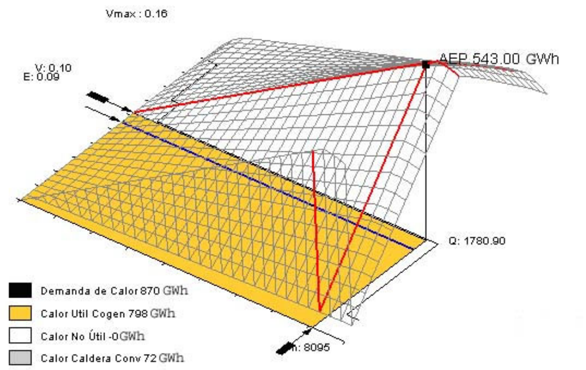
G.3. Cogeneration technologies

The only current technology in this sector is simple cycle gas turbines.

Characterisation of cogeneration system as a function of technological mix:

- Electrical efficiency: 40%
- Overall efficiency: 85%

G.4. Design of technological potential



- **High efficiency cogeneration potential: 88 MWe**
- Associated useful heat: 798 GWh (91% of total)
- Annual operating hours: 8,095 h

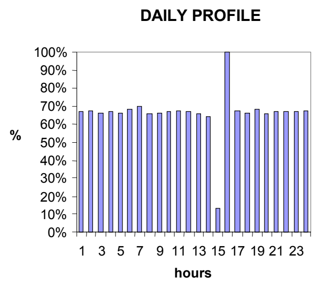
H. Petroleum refining

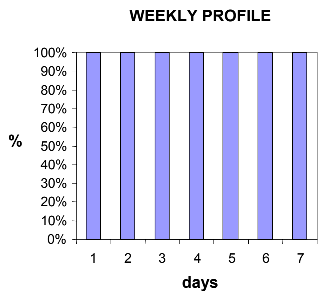
The petroleum refining industry is an intensive energy consumer both in the form of fuel directly applied in the numerous heaters and boilers and in the form of electrical energy used substantially for powering of motors and to a lesser extent for lighting of plants. A peculiarity of this activity is that raw material and fuels are virtually indistinguishable, so this activity is included in the energy conversion sector with a differentiated treatment.

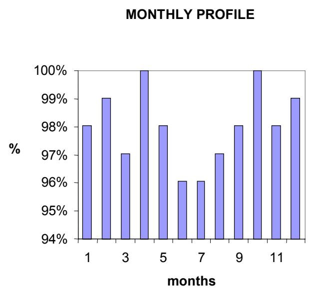
The refinery capacity installed in Spain in 2004 was 1,290,000 barrels per day (64.5 million tonnes per annum). According to the expansion plans of the various companies, this capacity will increase.

H.1. Work programme

Production 24 hours per day Monday to Sunday. Daily programme and monthly profile virtually uniform. The following diagrams show the commonest standard profiles.



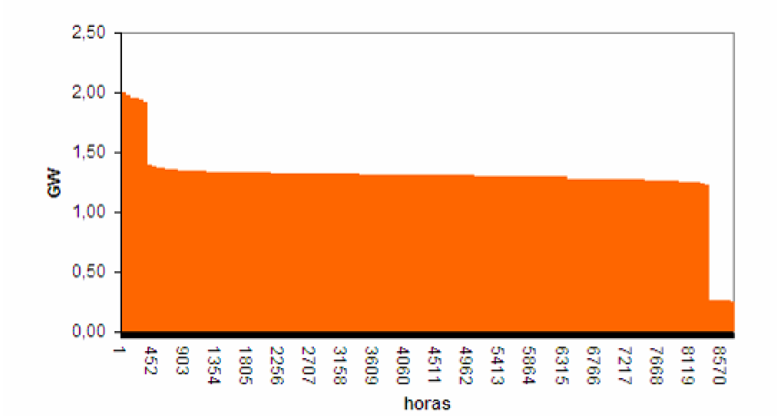




H.2. Useful heat demand

Cogenerable heat coefficient / useful heat: 0.96

Useful heat potential: 11,280 GWh/year.



Useful heat consumption is very constant owing to an extensive and uniform daily work programme 24 hours per day throughout the year.

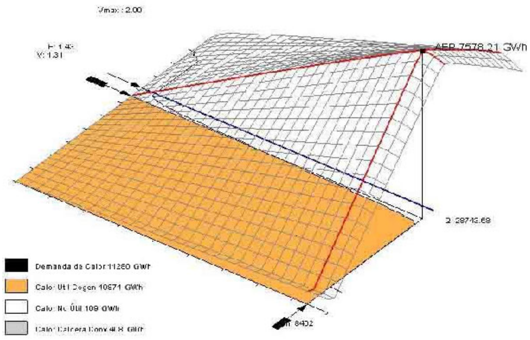
H.3. Cogeneration technologies

Significant presence of gas turbines, combined cycles and steam turbines.

Characterisation of cogeneration system as a function of technological mix:

- Electrical efficiency: 40%
- Overall efficiency: 85%

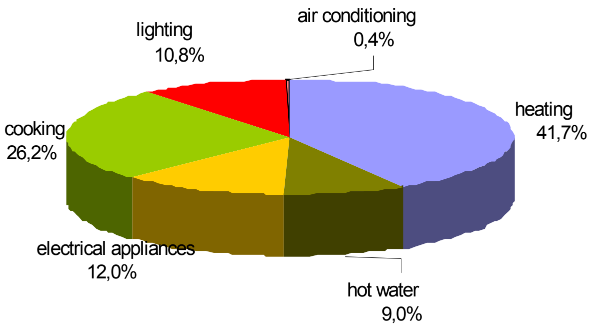
H.4. Design of technological potential



- **High efficiency cogeneration potential: 1,430 MWe**
- Associated useful heat: 10,870 GWh (96% of total)
- Annual operating hours: 8,402 h

I. Tertiary sector. Domestic activities

The residential sector's final energy consumption in 2004 amounted to 16,287 kTOE (16.8% of national total), as per the following diagram:



The uses concerned are such that the only three types of consumption that can be met by cogeneration heat are:

- Heating
- Hot water
- Air conditioning

These consumptions amount to 51.1% of the residential sector's final energy total in 2004.

Of the residential sector's final energy uses that might be cogenerated, air conditioning is almost negligible relative to heating and hot water.

As regard the technical characteristics of the heat, all of the thermal demand may be regarded as cogenerable as being of low temperature profile, but the long life of buildings and their fixed installations and their relatively small individual consumptions cause technical measures with a view to saving in existing buildings to be of low profitability and difficult to implement. The table below shows the forecast natural gas demand in the domestic sector according to the Infrastructure Planning of the Ministry of Industry, Tourism and Commerce:

Year	2005	2007	2010	2011
Forecast consumption (GWh/year)	42,372	48,062	56,291	58,905

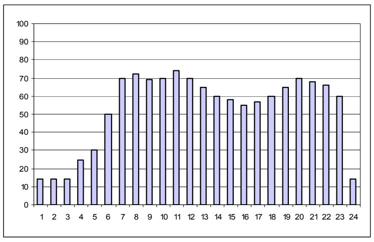
I.1. Work programme

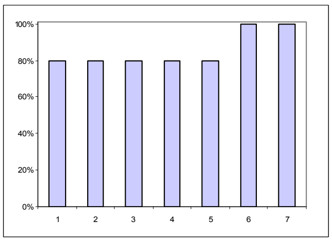
The work programme of a dwelling is related primarily to its occupancy and secondarily to the local weather.

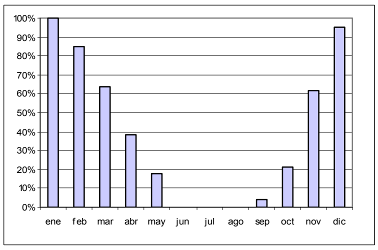
The predominant prime factor, the occupancy involving a particular use, has not been systematised, as it would give rise to erroneous figures; each case has therefore to be examined to see whether the occupants are, for example, a family household whose members all work, a single-parent household or a sharing household of adults. Each situation gives rise to a different kind of programme that crucially affects the viability of a cogeneration. It should in any case be noted that social habits in major cities are tending towards ever shorter programmes and to concentrating the use of energy consuming appliances in less hours, i.e. the actual power required is tending to increase.

The following graphs illustrate the behaviour of a group of dwellings in a continental climate.

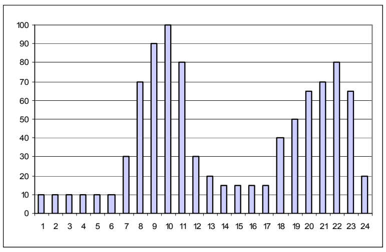
Heating consumption:

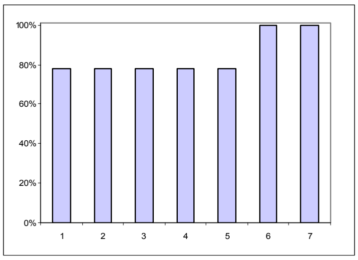


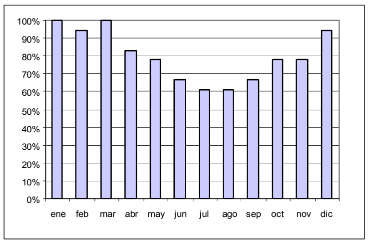




Domestic hot water consumption:



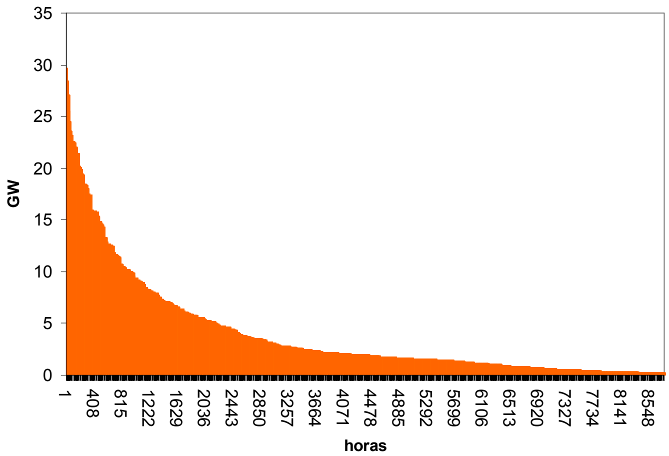




I.2. Useful heat demand

Cogenerable heat coefficient / useful heat: 1

Useful heat potential: 34,321 GWh/year.



hours

Useful heat consumption is decreasing, with some 3,600 hours per annum of significant heat demand.

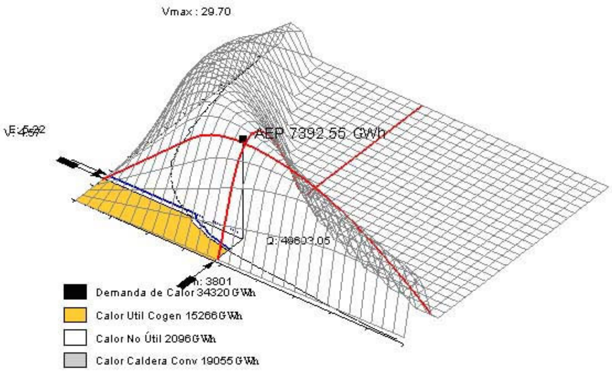
I.3. Cogeneration technologies

Almost entirely internal combustion engines.

Characterisation of cogeneration system as a function of technological mix:

- Electrical efficiency: 40%
- Overall efficiency: 75%

I.4. Design of technological potential

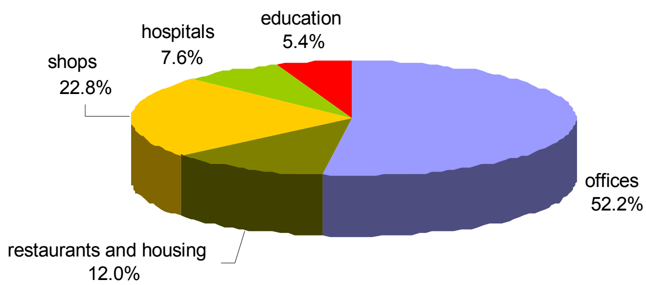


Heat demand Cogen useful heat Non-useful heat Conv. boiler heat

- **High efficiency cogeneration potential: 5,220 MWe**
- Associated useful heat: 15,266 GWh (44.4% of total)
- Annual operating hours: 3,801 h

J. Tertiary sector. Commercial activities

The services sector's final energy consumption in 2004 amounted to 9,340 kTOE, as per the following diagram:



The office segment is thus the largest consumer, followed by restaurants and housing.

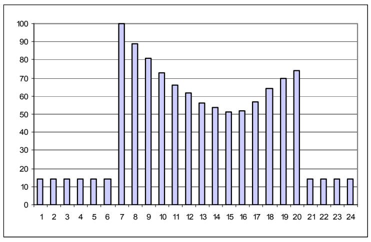
As in domestic activities, the whole thermal demand may be regarded as cogenerable heat being of low temperature profile, but the relatively small consumptions make economic profitability of cogeneration systems difficult to achieve. The table below shows the forecast natural gas demand in the commercial sector according to the Infrastructure Planning of the Ministry of Industry, Tourism and Commerce:

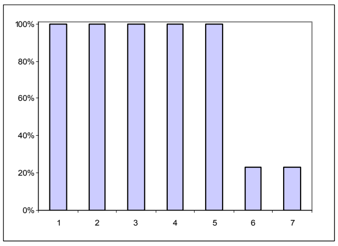
Year	2005	2007	2010	2011
Forecast consumption (GWh/year)	12.728	14.438	16.909	17.695

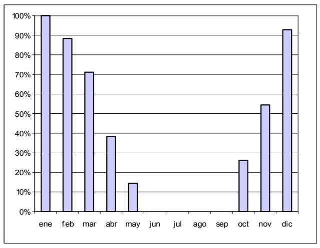
J.1. Work programme

Work programme for offices:

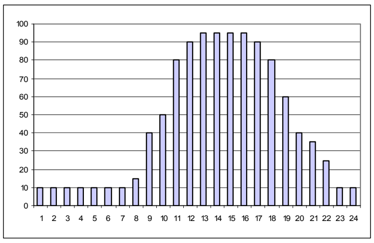
Heating consumption

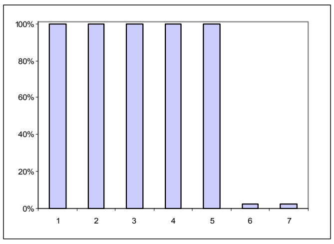


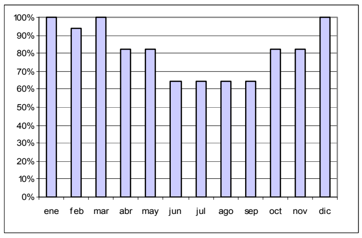




Domestic hot water consumption

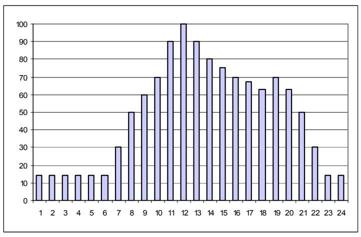


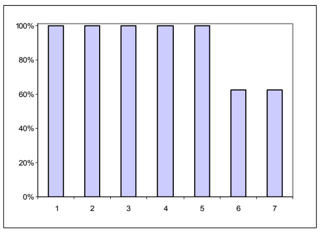


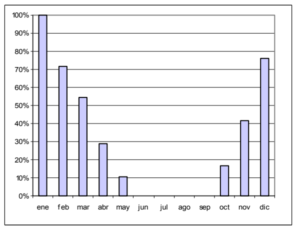


Work programme for shops:

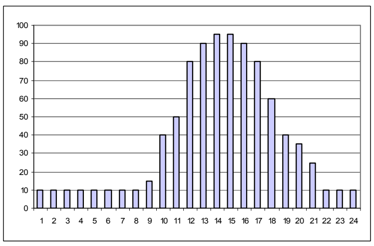
Heating consumption

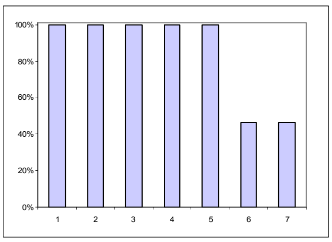


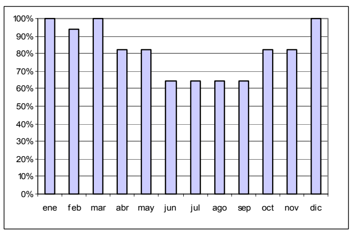




Domestic hot water consumption

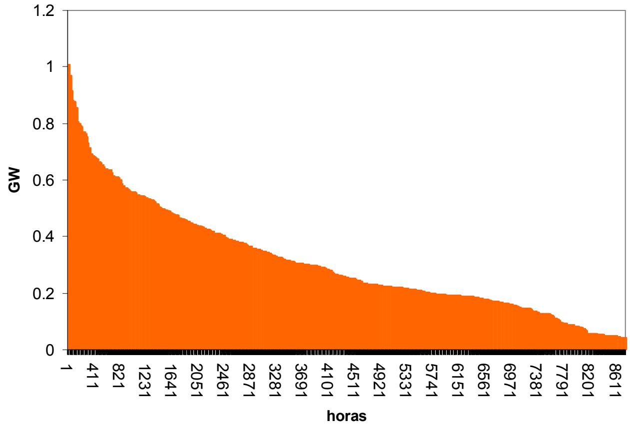






J.2. Useful heat demand

Cogenerable heat coefficient / useful heat: 1
Useful heat potential: 10,310 GWh/year.



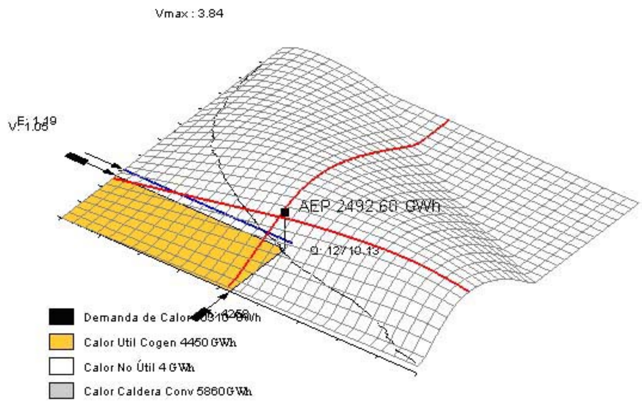
J.3. Cogeneration technologies

Almost entirely internal combustion engines.

Characterisation of cogeneration system as a function of technological mix:

- Electrical efficiency: 40%
- Overall efficiency: 75%

J.4. Design of technological potential



- **High efficiency cogeneration potential: 1,194 MWe**
- Associated useful heat: 4,450 GWh (43% of total)
- Annual operating hours: 4,258 h

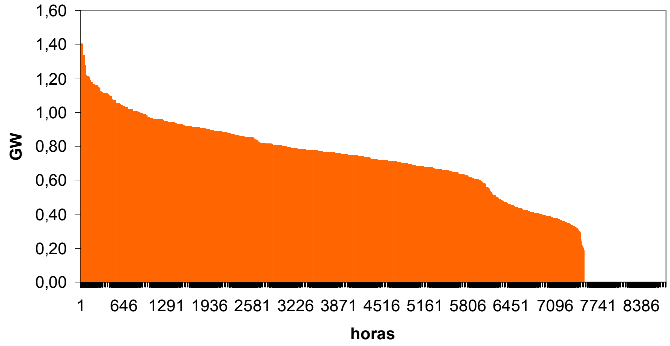
K. Pig waste treatment sector

K.1. Work programme

The work programme is continuous and relatively constant and similar to that of the non-metallic materials sector, since it basically comprises drying processes.

K.2. Useful heat demand

Cogenerable heat coefficient / useful heat: between 86% and 100%
Useful heat potential: 5,616 GWh/year.



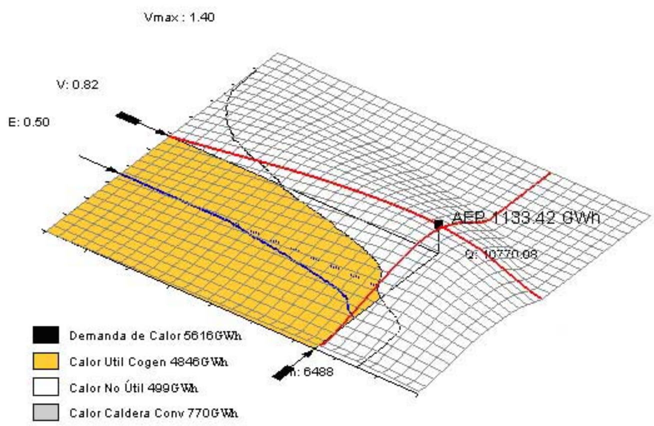
K.3. Cogeneration technologies

Almost entirely internal combustion engines.

Characterisation of cogeneration system as a function of technological mix:

- Electrical efficiency: 30%
- Overall efficiency: 75%

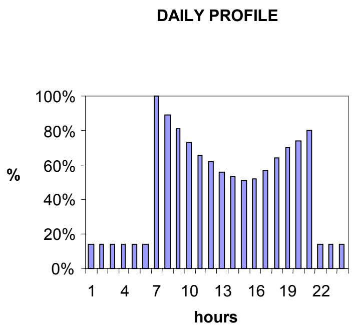
K.4. Design of technological potential

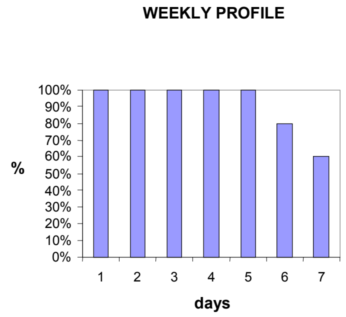


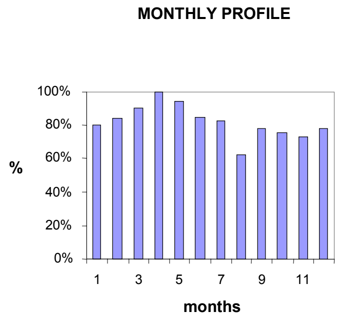
- **High efficiency cogeneration potential: 498 MWe**
- Associated useful heat: 4,846 GWh (86% of total)
- Annual operating hours: 6,488 h

L. Sewage sludge treatment sector

L.1. Work programme





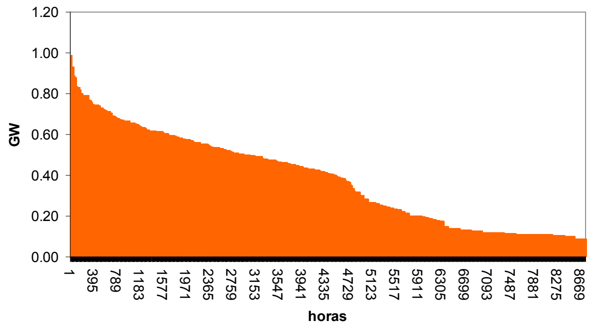


The greatest sludge output is on working days, hence the decrease in activity at weekends. August is likewise a month of low activity.

L.2. Useful heat demand

Cogenerable heat coefficient / useful heat: 1

Useful heat potential: 3,320 GWh/year.



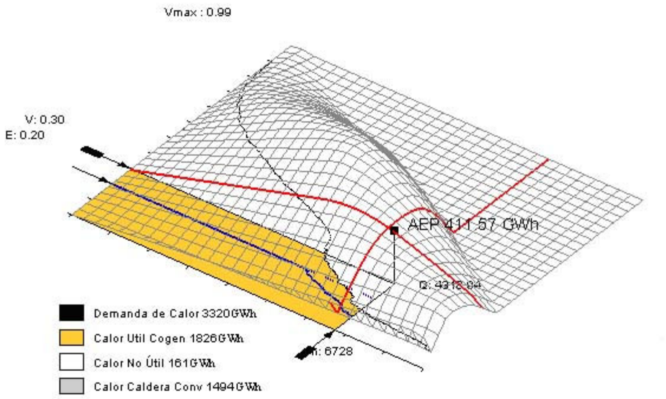
L.3. Cogeneration technologies

Gas and steam turbines and internal combustion engines.

Characterisation of cogeneration system as a function of technological mix:

- Electrical efficiency: 31%
- Overall efficiency: 77%

L.4. Design of technological potential



- **High efficiency cogeneration potential: 199 MWe**
- Associated useful heat: 1,826 GWh (55% of total)
- Annual operating hours: 6,728 h

M. Oilmill waste treatment sector

M.1. Work programme

The work programme of these installations is continuous and usually begins with the olive gathering season, ending months later.

M.2. Useful heat demand

Cogenerable heat coefficient / useful heat: 0.93
Useful heat potential: 3,011 GWh/year.

The monotone curve is comparable with similar curves of sectors with drying applications.

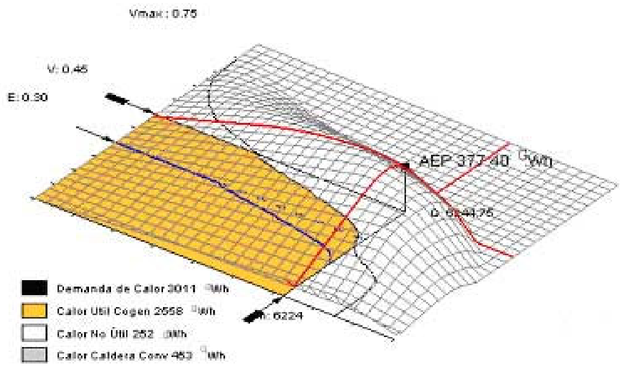
M.3. Cogeneration technologies

Drying cycles based on gas turbines.

Characterisation of cogeneration system as a function of technological mix:

- Electrical efficiency: 30%
- Overall efficiency: 75%

M.4. Design of technological potential



- **High efficiency cogeneration potential: 301 MWe**
- Associated useful heat: 2,806 GWh (93% of total)
- Annual operating hours: 6,224 h

N. Sewage sludge biogas sector

The inclusion of cogeneration in the municipal services sector is in line with utilising digestion biogas. In this case, the cogeneration is regarded as performing two services: production of electricity and utilisation of biogas, a renewable source. There are of course possible applications for residual heat from exhaust gases, such as the heating of the respective anaerobic digesters, but the definition of useful heat in this case is considered economically justifiable by the fact of utilising a renewable resource rather than by the use that might be made of residual heat.

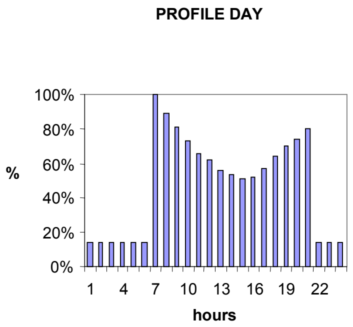
The cogeneration applications in this sector are:

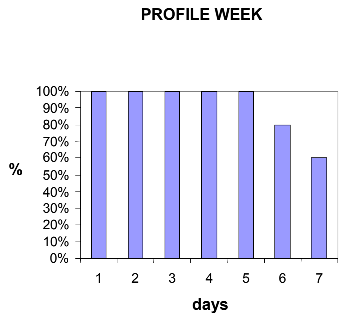
- Utilisation of anaerobic treatment biogas with or without application of heat to maintain appropriate digestor temperatures

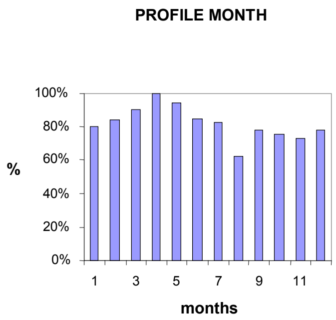
- Utilisation of landfill gas with or without application of heat from exhaust gases to dry concentrate from leachate treatment plants

N.1. Work programme

The programme is continuous all the year round with no breaks. Depending on the location of the treatment plant, sludge output is greater on working days (as in urban treatment plants) or at weekends (as in treatment plants in small localities where there are many second homes). This study is based on a work programme that reflects the proximity of an industrial estate, a certain decrease in activity at weekends and less activity in August.

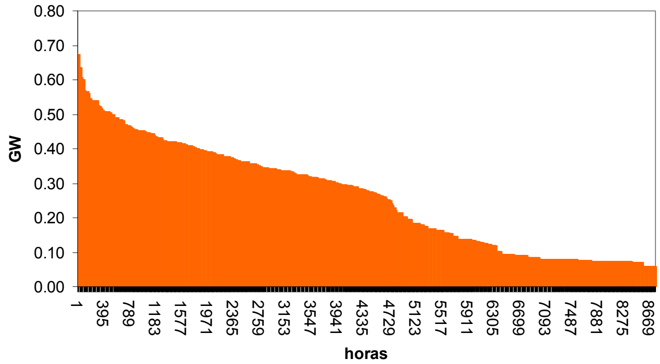






N.2. Useful heat demand

Useful heat potential: 2,264 GWh/year.



N.3. Cogeneration technologies

Internal combustion engines only.

Characterisation of cogeneration system as a function of technological mix:

- Electrical efficiency: 28%
- Overall efficiency: 60%

N.4. Design of technological potential

The technological potential of this sector corresponds to the whole of its useful heat potential in that the gasholder facilities (i.e. biogas accumulation systems) make it possible for the generating equipment (engines/microturbines) to run at full load, but not all the year round, since only when there is a certain amount of biogas stored will the plant start up. Otherwise, at times of little biogas production, the plant will remain shut down while the gas accumulates.

- **High efficiency cogeneration potential: 294 MWe**
- Associated useful heat: 2,264 GWh (100% of total)
- Annual operating hours: 6,728 h

O. Cattle waste biogas sector

The best or most efficient treatment for all agricultural and livestock waste is anaerobic digestion, which degrades about 70% of the volatile organic matter, producing a biogas that can be utilised to cover the energy needs of the digestion process and any surplus can be applied to other process uses. Utilisation of the biogas produced by anaerobic digestion processes from agriculture and livestock waste thus represents substantial renewable fuel potential.

The use of this biogas is considered useful as a whole in that there are numerous applications on cattle farms that require thermal and cooling energy: cleaning system using water at 70°C on dairy farms, raising the temperature of drinking troughs in cold weather, keeping milk at 4°C pending processing (absorption applications).

O.1. Work programme

The programme is continuous all the year round, with no breaks. The modulation varies slightly with livestock cycles and weather.

O.2. Useful heat demand

Useful heat potential: 5,870 GWh/year.

The monotone curve of biogas production is similar to that of the sewage sludge sector.

O.3. Cogeneration technologies

Internal combustion engines only.

Characterisation of cogeneration system as a function of technological mix:

- Electrical efficiency: 28%
- Overall efficiency: 60%

O.4. Design of technological potential

As in the sewage sludge biogas sector, the technological potential of this sector corresponds to the whole of its useful heat potential. This is because gasholders are likewise installed as biogas accumulation systems.

- **High efficiency cogeneration potential: 792 MWe**
- Associated useful heat: 5,870 GWh (100% of total)
- Annual operating hours: 6,488 h

ANNEX II. Technological description of cogeneration systems

Annex IV to the Cogeneration Directive indicates that the cogeneration potential study should indicate the cogeneration technologies likely to be used for realising the potential, which it lists as follows:

A. Combined cycle gas turbine with heat recovery

B. Non-condensing backpressure turbine

C. Steam condensing extraction turbine

D. Gas turbine with heat recovery

E. Internal combustion engine

F. Microturbines

G. Stirling engines

H. Fuel cells

I. Steam engines

J. Organic fluid Rankine cycles

K. Other technologies

Each cogeneration plant should be configured as a function of the characteristics of the useful heat user establishment and the characteristics of that heat, particularly the level of its temperature of use and its modulation. The various prime movers that may be adopted (steam or gas turbines and alternative prime movers) also dictate different processes.

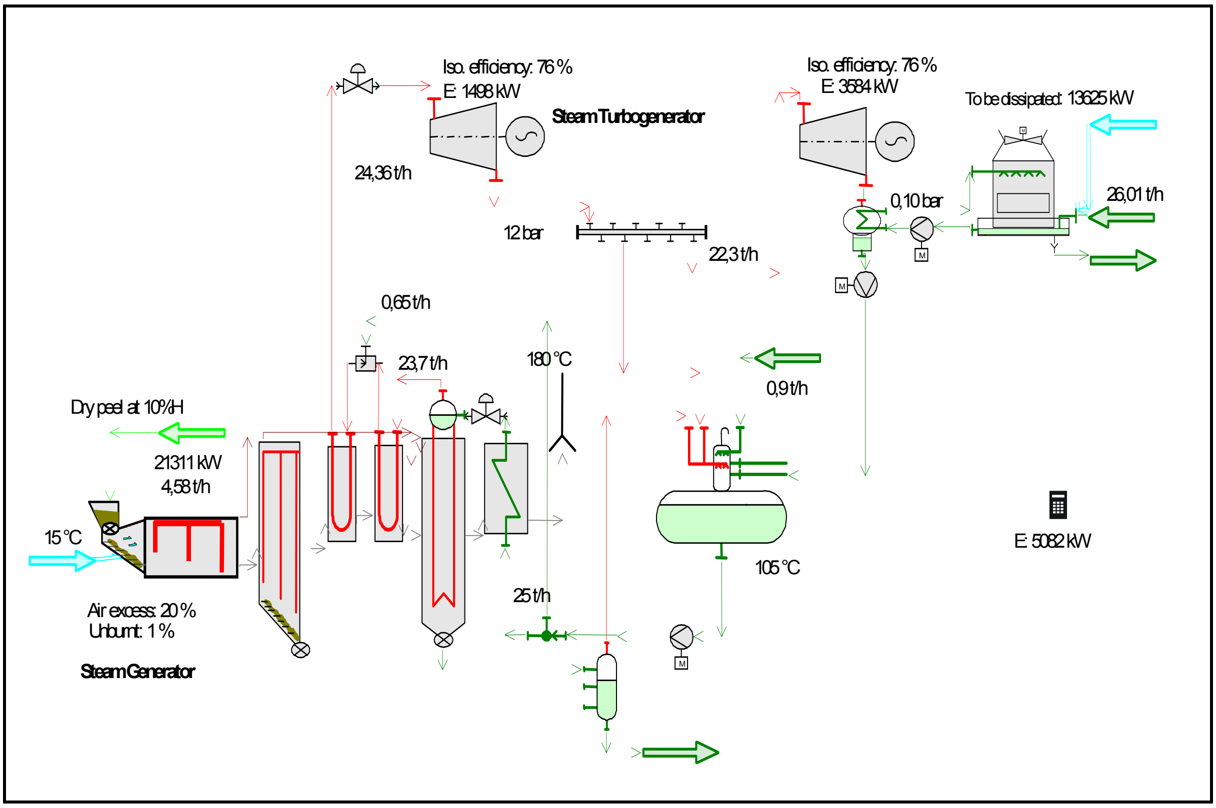
This annex describes the productive cycles using the technologies listed above that will be used in the development of cogeneration in Spain. It also includes comments about the commonest type of application for each technology.

1. Simple cycle with steam turbine (CSTV). Letters B, C and J

This is the cycle most widely known and used, although it is no longer regarded as a modern cogeneration system, since its electricity production is very limited. This view is so representative that a substantial number of paper concerns that previously used this cycle have installed gas turbines, thus converting it to a combined cycle.

The simple cycle is now used only in waste disposal incineration systems and old fuel oil/gas power stations of the electricity system. Its electrical efficiency is very limited (20-25% on waste and up to 40% in large power stations) and its application is only effective with very low priced fuels. It is at present the process used in plants for eliminating agricultural waste and urban solid waste.

The following diagram illustrates the process for an agricultural biomass plant.

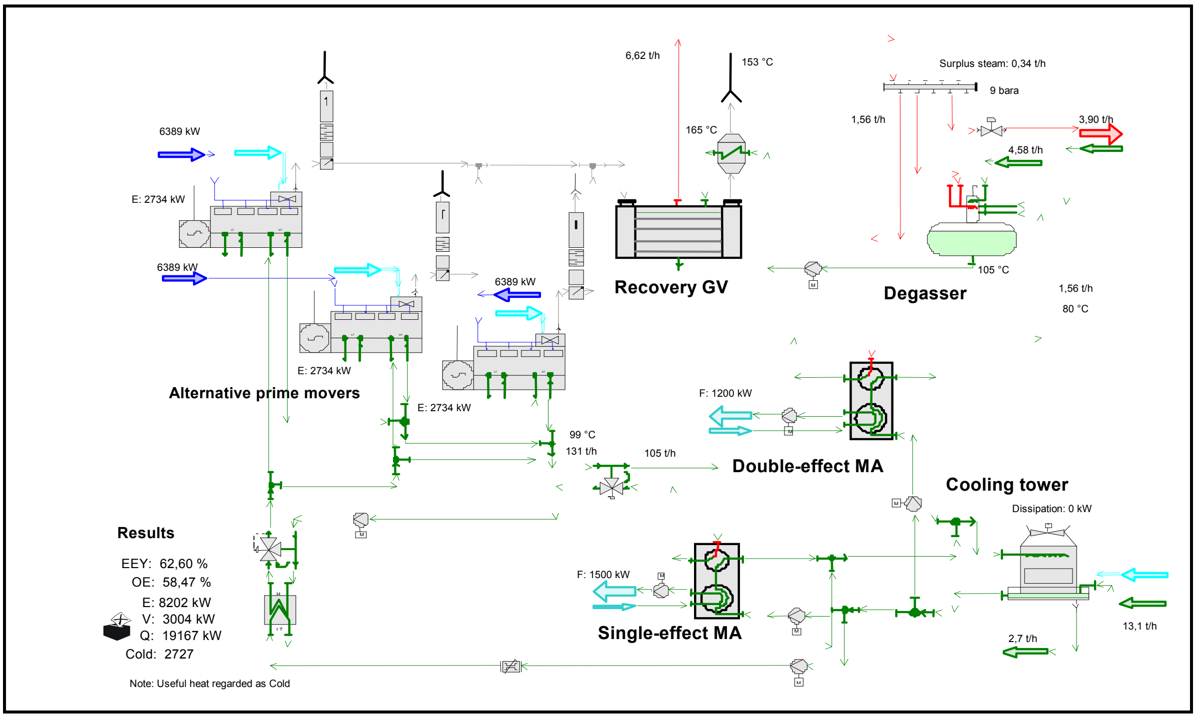


It is thus a system applicable to organic fluid Rankine cycles. The main difference is that the delivery of heat to the process is not by steam from the turbine but via a heat exchanger.

2. Simple cycle with alternative prime movers (CSMG, CSMF) and trigeneration cycles. Letter E

The commonest applications of this cycle are in the textile industry, the tertiary sector (heating) and some food sector plants. It is also applied in sludge drying and slurry disposal plants.

Its most suitable area of application is in an electrical power range of 1 to 10 MW, although plants of up to 25 MW have been set up with fuel oil engines, using only the heat from the exhaust gases, resulting in maximum equivalent electrical efficiencies of 55-56%.



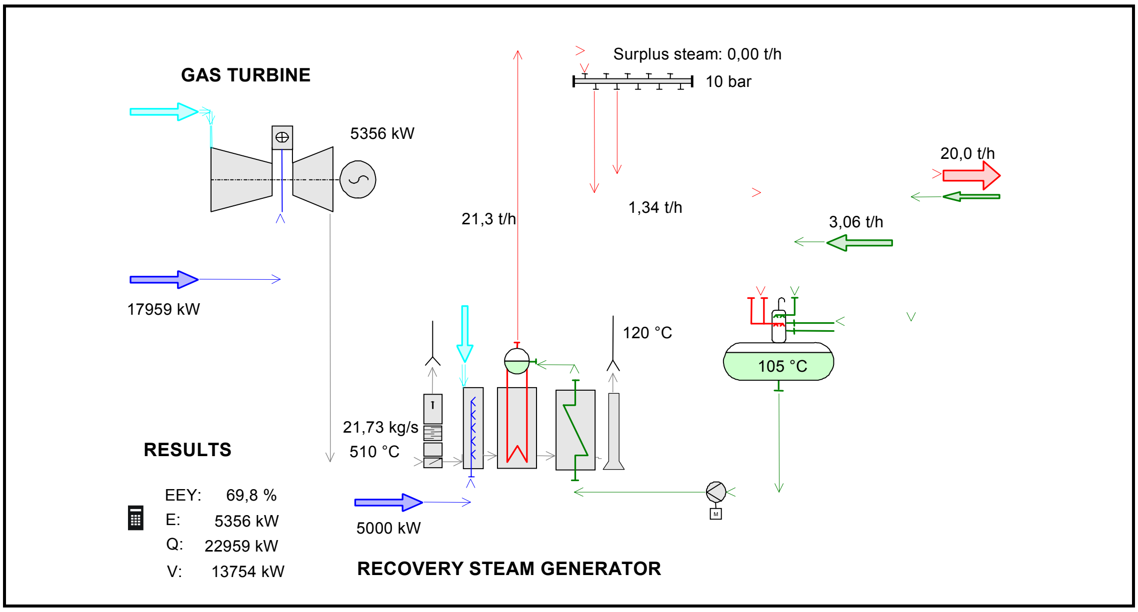
Some plants with alternative prime movers use hot water for generating cold in absorption machines. Although such trigeneration processes improve the EEY, they involve about 15% more investment.

3. Simple cycle with gas turbines (CSTG). Letter D

This cycle is appropriate for meeting heat demand in the form of steam or hot gas of 7-8 MW (10 t/h of steam) or more, with a range of application from 4 MW to more than 50 MW installed electrical capacity.

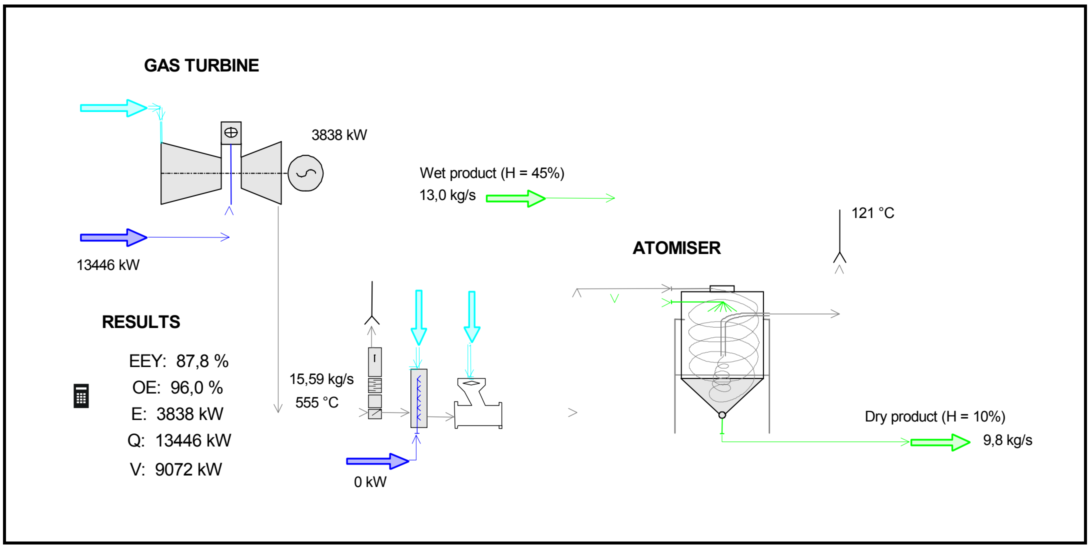
It is the commonest cycle for medium-sized steam consumer installations and is usually regulated by an afterburn system for adjusting steam production to demand.

The following diagram illustrates the process of a plant of this kind for about 5 MW.



Gas turbines have the great advantage of providing heat in the form of gases at about 500°C which are well suited to non-food product drying processes. The gas turbine drying cycle has therefore been extensively adopted in the stoneware ceramic industry (clay atomisation processes). It is simple to install and more economic than processes intended to produce steam, resulting in large equivalent electrical efficiencies if the turbine is adjusted to the drying heat requirements.

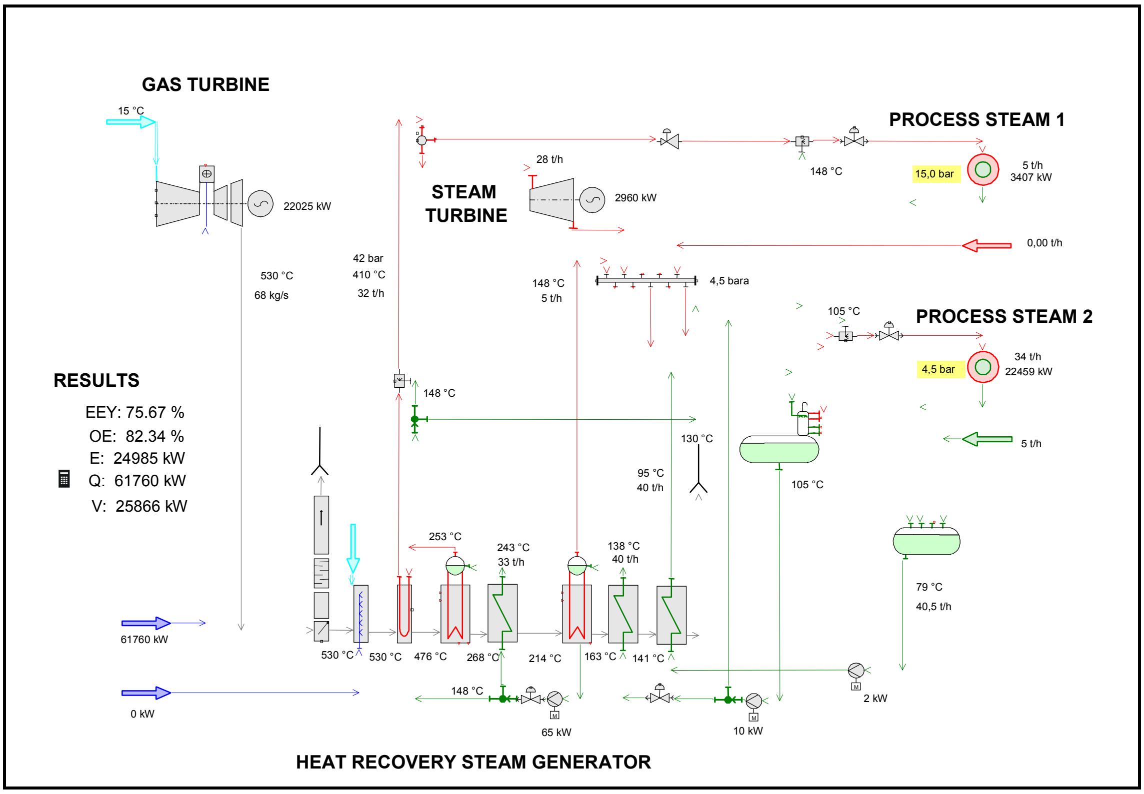
The following diagram illustrates a simple gas turbine and atomiser drying cycle.



4. Combined cycle backpressure gas turbine (CCTG). Letter A

This extension of the simple cycle involves the difference of generating high pressure steam to make it possible to include a steam backpressure turbine and thereby increase the electricity produced from the same amount of process heat. Its EEY is higher than the simple cycle, although its overall efficiency is substantially similar. It is applicable to small powers (upwards of 5 MWe) and its installations maximise the advantages of cogeneration with increasing investment virtually proportional to the increase in capacity of the steam turbine.

The diagram below illustrates this cycle, in which thermal generation is conducted in a two-vessel boiler to increase its production capacity.



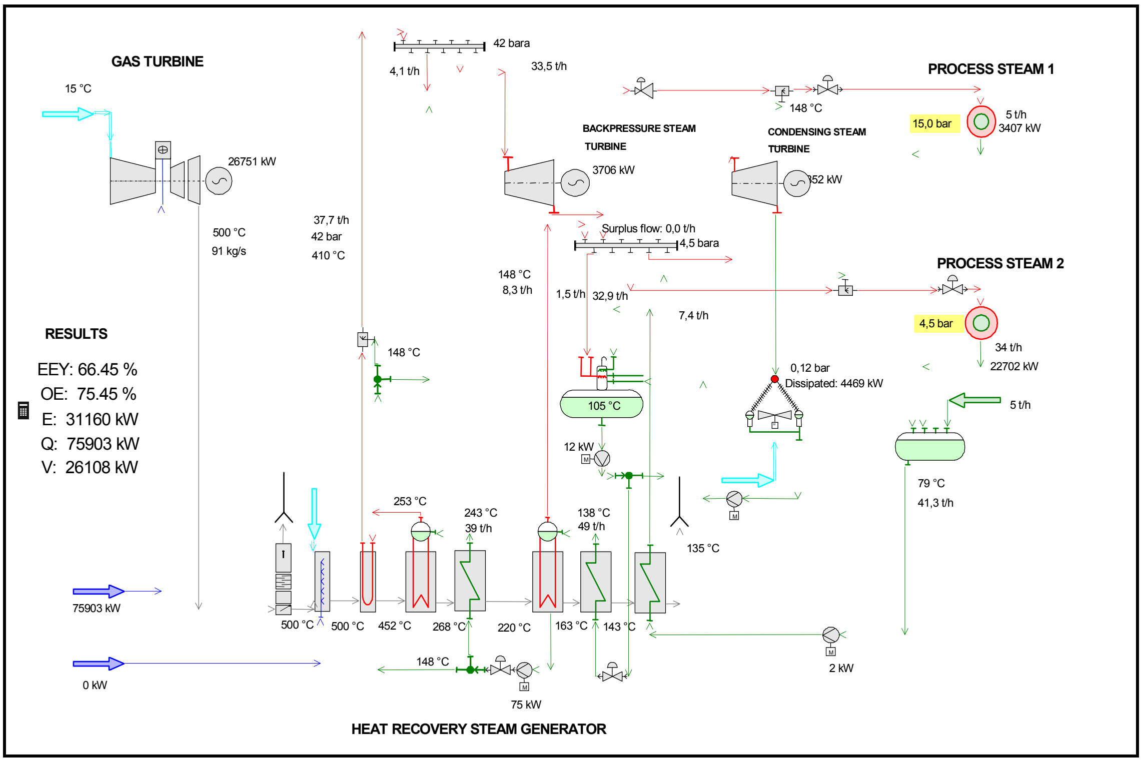
5. Condensing and extracting combined cycle (CCCTG). Letters A and C

This extension of a simple cycle involves the difference of generating high pressure steam to make it possible to include a steam backpressure turbine and thereby increase the electricity produced from the same amount of process heat. Its EEY is higher than the simple cycle, although its overall efficiency is substantially similar.

In large plants this cycle has enormous efficiency and operating advantages, since the previous cycle allows more effective regulation if a steam condensing turbine is added.

Whenever there is surplus steam, the previous cycles have to eliminate part of the gases to the atmosphere via the bypass stack, but in this cycle the surplus is condensed in the condensing turbine, producing extra electricity.

This cycle is appropriate for establishments with variable demands and powers of more than 20 MW and should not be confused with a conventional combined cycle, since it normally operates with backpressure and only condenses spot steam surpluses. The following diagram illustrates this process for a plant that requires steam at various pressure levels.



6. Microturbines and Stirling engines. Letter F

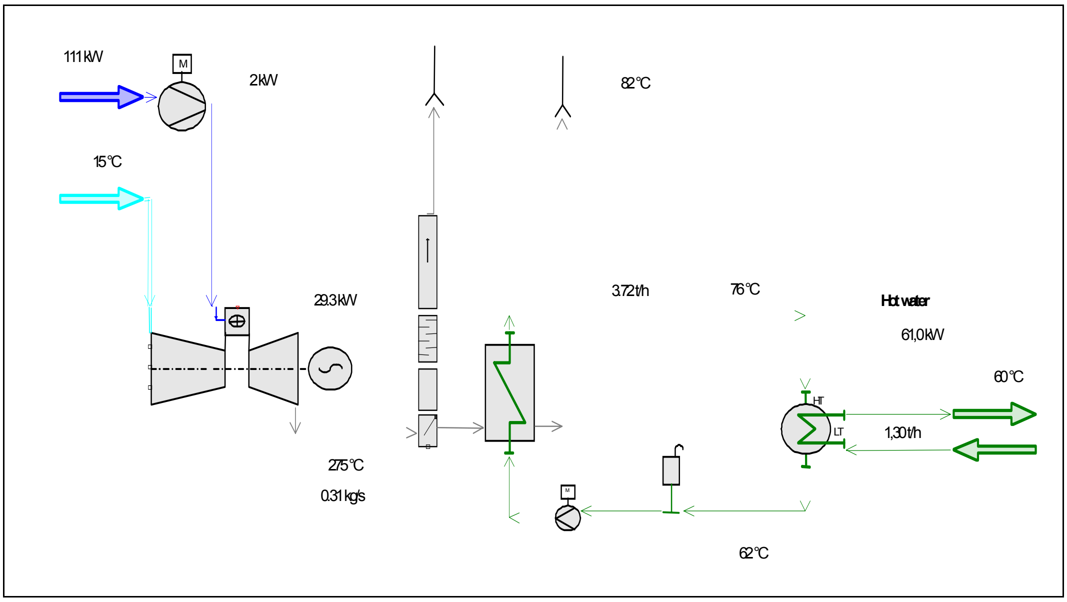
These are small capacity facilities not usually adaptable to the demands of industry and their use is largely restricted to the service sector (hotels, gymnasiums etc.) and even to isolated private houses. The heat utilised is normally in the form of domestic hot water and heating.

Microturbines comprise all gas turbines with a power of less than 1 MW. They operate in much the same way as larger turbines but their size makes it necessary to change the design of the main components in order to improve efficiency and they run at higher speeds.

Microturbines usually utilise part of the heat of the exhaust gases to preheat the air entering the combustion space, in which case they are called heat recovery microturbines.

Microturbines are beginning to be used for utilisation of the biogas produced by wastewater and slurry treatment plants, which is too little to justify installing larger facilities. The following photograph illustrates the application of a microturbine system on the flat roof of a hotel.

The following is the flowchart of a microturbine.



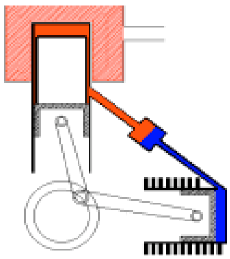
Stirling engines are alternative external combustion and closed cycle machines. Unlike alternative internal combustion engines, the working fluid is not the fuel and the oxidant but a gas (helium or hydrogen) confined in a hermetic enclosure. One or two pistons and a displacer cause the gas fluid to pass through every point of the cycle until it is closed, moving it between a cold zone and a hot zone. A regenerator is usually placed between the two zones to recover part of the heat and improve the efficiency of the cycle.

The process involves an isothermal compression at the coldest temperature, an isochoric temperature and pressure increase process followed by an isothermal expansion, and the cycle closes with an isochoric temperature and pressure decrease process. In theory the piston and displacer movements are discontinuous, which is impossible from the dynamic point of view.

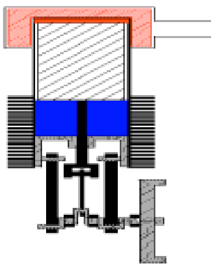
In reality, a connecting rod/crank combination is used, which approximates the movements of the components.

The main types of Stirling engine are alpha, beta and gamma.

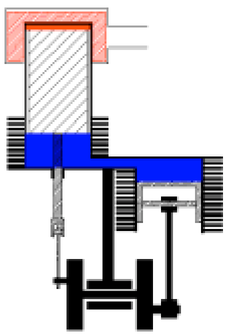
- **Alpha type engine**: comprises two independent cylinders, no displacer and two pistons offset 90º. One of the cylinders is heated by a gas or alcohol burner and the other is cooled by fins or water, as in the following diagram:



- **Beta type engine**: the original Stirling engine, comprising one cylinder with a hot zone and a cold zone. The displacer is inside the cylinder. Small engines usually have no regenerator but a clearance of a few tenths of a millimetre between the displacer and the cylinder to allow gas to pass, as in the following diagram:



- **Gamma type engine**: a simpler design derived from the beta type. Comprises two separate cylinders, one of which contains the displacer and the other the power piston, as in the following diagram:



7. Fuel cells. Letter H

A fuel cell may be defined as an electrochemical device which converts the chemical energy stored in a fuel to electrical energy directly and, more important, continuously. Its operating principle is the reverse of electrolysis.

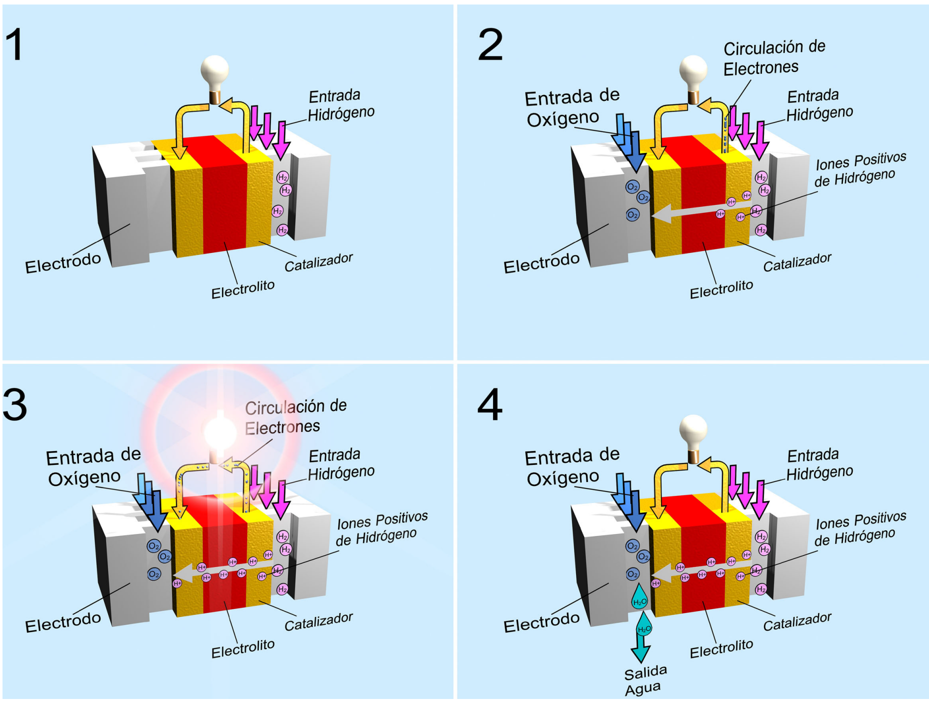
It is not a thermal machine, so it is not limited by the Carnot cycle and can achieve efficiencies very close to 100%. Achieving 100% is only prevented by limitations in the utilisation of energy generated and in the materials used in its construction.

Fuel cells comprise an assembly of stacked unit cells, each of which has a negative electrode (anode) and a positive electrode (cathode) separated by an electrolyte that facilitates the ion transfer between the electrodes.

Each of the substances involved in the reaction is supplied to a different electrode. Thus the fuel, generally rich in hydrogen, is fed continuously to the anode, and the oxidant, normally oxygen from the air, to the cathode. There the reagents are transformed electrochemically. In the case of fuel cells operating with hydrogen, which involves the following semireactions:

- Anode: $H_2 \rightarrow 2H^+ + 2e^-$
- Cathode: $\frac{1}{2} O_2 + 2H^+ + 2e^- \rightarrow H_2O$
- Overall reaction: $H_2 + \frac{1}{2} O_2 \rightarrow H_2O$

The following diagram illustrates the electricity generating process in a fuel cell:



Key: Electrodo = Electrode Electrolito = Electrolyte Catalizador = Catalyst
Entrada Hidrógeno = Hydrogen Input Entrada de Oxígeno = Oxygen Input
Iones Positivos de Hidrógeno = Positive Hydrogen Ions Salida Agua = Water Output
Circulación de Electrones = Electron Circulation

In a fuel cell, an electric current is generated between the two electrodes, but unlike what happens in a conventional battery, it is not exhausted over the operating time but continues for as long as the supply of the reagents continues.

The various ways of obtaining hydrogen include steam reforming, partial oxidation of fuels with oxygen shortage, electrolysis of water, gasification of biomass, pyrolysis, ion ***[TRANSLATOR'S NOTE: READING "iónico" RATHER THAN "cónico"]*** exchange or solid polymer ***[READING "polimérico" RATHER THAN "polémico"]*** electrolyte membranes and photobiological production. Fuel cells that incorporate a system for converting fuel gas (e.g. natural gas) to hydrogen and by-products are also on the market.

The fundamental unit, also called unit cell, is not sufficient for practical applications, so a number of them are linked up to achieve suitable power and voltage, thereby forming a single fuel cell. The unit cells are connected electrically in series. A device for extracting the heat generated by the electrical reaction is inserted at each certain number of unit cells, thereby keeping the temperature within the optimum margins for each type of unit cell. The heat extracted via the internal cooling circuit is gathered by a series of heat exchangers which deliver it to an external circuit, producing therein hot water or steam, depending on the operating temperature of the composite cell. The resulting thermal energy may be used as such or to generate an additional amount of electrical energy, thus increasing the efficiency of the system.

The direct current provided by a fuel cell has to be transformed to alternating current appropriate to consumers, with particular attention to the electrical parameters (voltage, frequency, harmonics etc.) of the grid. The electrical facility which performs this transformation is called an energy conditioning system, and its most important component is the inverter that transforms the direct current produced by the fuel cell to alternating current.

The commonest of the various ways of classifying types of fuel cells is by the type of electrolyte they use, which gives them their name. On this criterion we have fuel cells that operate at different temperatures, need greater or lesser purity of hydrogen supplied and are more or less suited to certain applications. The following table lists various fuel cell technologies.

Type	Electrolyte	Operating temperature (ºC)	Uses	Advantages	Disadvantages
Polymer membrane (PEMFC)	Solid polymer	60 - 100	• Stationary generation • Portable computers • Vehicles	• Solid electrolyte reducing corrosion and maintenance • Low temperature • Rapid starting	• Expensive catalyst • Sensitive to impurities in hydrogen or other fuel
Alkaline (AFC)	Aqueous solution of potassium hydroxide	90 - 100	• Space • Military applications	• Quicker cathodic reaction in alkaline electrolyte • Greater efficiency	• Sensitive to impurities
Phosphoric acid (PAFC)	Liquid phosphoric acid	175 - 200	• Stationary generation • Portable computers	• 85 % efficiency in cogeneration of electricity and heat • Accepts impure hydrogen	• Pt catalyst • Low current and power • Great weight and volume
Fused carbonates (MCFC)	Liquid solution of lithium, sodium and potassium	600 - 1000	• Stationary generation	• Greater efficiency • Inexpensive catalyst	• Corrosion due to high temperatures • Short service life
Solid oxides (SOFC)	Solid Zr oxide with lithium additions	600 - 1000	• Stationary generation	• Greater efficiency • Inexpensive catalyst • Solid electrolyte	• Corrosion due to high temperatures • Short service life

The most attractive fuel cells for cogeneration technologies are those that work at higher temperatures. Using the heat may reach overall efficiencies of 90%. These installations utilise cooling heat for the industrial process, so their use when the fuel cell operates at high temperature is valuable. The heat may be used in various forms (hot water, steam, hot air or thermal oil).