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# POSSIBILITIES FOR THE DEVELOPMENT OF COGENERATION IN HUNGARY

**CONTENTS**

## Outline

This lecture gives a brief overview of cogeneration in Hungary and the developments forecast for the period up to the end of the decade. The subject is divided into four areas:

- *the current role of cogeneration in Hungary's energy economy, or in other words, how much combined heat and power generation capacity is installed in Hungary (1);*

- *the main energetic aspects of cogeneration in Hungary (2);*

- *the role of cogeneration in reducing environmental load (3);*

- *the role power plants producing combined heat and power can play in the future development of the Hungarian power plant system (4).*

## 1. Present cogeneration capacity in Hungary
### 1.1. Cogeneration technologies in Hungary

The existing combined heat and power facilities in Hungary cover every major technology – back-pressure, extraction condensation generation, combined cycle (gas/steam) power plants where electricity production is fully or partly combined with heat production (combined cycle cogeneration power plants). Since the mid-nineteen nineties, a large number of gas engine cogeneration plants have been set up as heat sources for smaller district heating systems, in industrial plants and public buildings. Mini/micro cogeneration units (such as energy sources for larger private houses) have not yet, - to our knowledge -, been installed in Hungary.

### 1.2. Main producer groups involved in cogeneration

Cogeneration power plants can essentially be classed into five categories.

The first group comprises cogeneration units of public power plants whose primary purpose is electricity generation, and the second is made up of "urban" power plants, more correctly urban district-heating power plants. These two groups account for the bulk of combined heat and power production. The urban power plants are really heating power plants, since their primary purpose is heat supply. It is a notable feature of power plants in Hungary that nearly all of them supply heat. In most cases, they serve as heat sources for large district heating systems supplying industrial, residential or public buildings. Urban heating power plants include those of Budapest Power Plant Ltd (the Kelenföld, Újpest, Kispest and Kőbánya Power Plants), and those in other towns and cities (Tatabánya, Debrecen, Nyíregyháza, Szeged, Székesfehérvár, Győr, Sopron, Komló, Dorog, etc.). The third main group contains what used to be called "industrial" power plants, now known as independent power producers. These generally provide heat to particular industrial facilities, and only generate electricity on a secondary basis. In the vast majority of cases, some or all of the electricity generated is passed to the public transmission network. The fourth group comprises combined heat and power producers on a smaller scale than the power plants. The vast majority of the cogeneration units in the fourth group are gas engine units set up recently, mostly since the mid-nineteen nineties. This group has undergone major development in recent years, and now forms the fastest-growing area of cogeneration in Hungary in terms of the number of units installed. The first gas engine cogeneration unit was commissioned by the Budapest Sewage Works Company in 1989, with a 240 kW installed electrical and 312 kW installed heat production capacity. In the 15 years since then (up to the beginning of 2004), many gas engine units have been installed on a great many sites. By 2001, the total installed electrical capacity of these surpassed 35 MW and the total installed heat capacity, 47 MW. Most gas-engine cogeneration plants are set up to provide heat for district heating systems to meet industrial (internal) heat demand. However, they have also been employed to utilise biogas, mostly in sewage treatment plants. Many gas engine units are installed to serve the energy needs of large buildings, hospitals and health facilities. The energy output of such plants is steadily growing in both absolute terms and as a proportion of the total, and their number can be expected to rise even further in the near future.

## 1.3. The present position of cogeneration in Hungary

**Table 1** [1; p.25.] shows the electricity demand in Hungary's interconnected power system. The country's total electricity consumption in 2002 was 39,754 GWh, which corresponds to a rise in demand of 1.1% or 438.0 GWh over 2001. The peak load on the interconnected power system in 2002 was 5980 MW (17 December 2002, 17.00 hrs), against 5965 MW in 2001. Heat generation by public power plants fell by 4.3%, and was 44583 TJ in 2002 (2001: 46853 TJ).

Cogeneration made up 15.78% of total electricity generation in 2002, corresponding to 5600 GWh of electricity in absolute terms. Total net heat output from power plants was 46,335 TJ. The main figures for cogeneration are shown in **Table 2** [2; p.32.].

Most cogenerated power came from public power plants. These generated 3,411,168 MWh of electricity in cogeneration mode in 2002, implying a cogeneration rate (cogenerated electricity as a proportion of electricity generation as a whole) of $e_E = 0.106$, the corresponding figure for heat being $e_Q = 0.789$. Cogenerated heat in these power plants was thus 30,214,183 GJ in 2002.

| DESCRIPTION | | | 2001 | 2002 |
|---|---|---|---|---|
| | | | GWh | |
| | | | | |
| Total national electricity consumption | | | 39316 | 39754 |
| | | | | |
| Import-export balance | | | 3171 | 4256 |
| | | | | |
| Electricity generated by independent power producers | | | 457 | 570 |
| | | | | |
| Public power plants | | | 35688 | 34928 |
| | Nuclear | | 14126 | 13953 |
| | Hydro | | 186 | 195 |
| | Thermal | | 21376 | 20780 |
| | | | | |
| | Coal-based power plants | | 9185 | 8927 |
| | Hydrocarbon-based power plants | | 12191 | 11853 |
| | | Gas turbines | 5637 | 6182 |
| | | | | |

**Table 1**
Sources of electricity consumed in Hungary [1; p.25]

| DESCRIPTION | unit | YEAR | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1990 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 |
| | | | | | | | | | | |
| Total net heat | TJ | 83 514 | 73 405 | 67 618 | 66 067 | 62 256 | 61 354 | 56 477 | 58649 | |
| Cogenerated electricity | GWh | 2 227 | 2 869 | 3 464 | 3 100 | 3 577 | 3 333 | 3 386 | 5294 | 5600 |
| Cogeneration rate | % | 5.68 | 7.94 | 9.36 | 8.33 | 9.52 | 8.80 | 8.86 | 14.9 | 15.56 |
| | | | | | | | | | | |

**Table 2**
Overall figures for cogenerated electricity in Hungary [2; p.32]

## 1.4. The development of cogeneration in Hungary in the last fifteen years

Great changes have taken place in the installed capacity of cogeneration power plants in Hungary over the last decade and a half. In addition to the growth of cogenerated electrical power as a proportion of the total, there have been changes in the energy indicators and the trend of development. We will now look at what the main changes have been. Several new, very high-efficiency combined cycle cogeneration power plant units have been commissioned in public power plants (Dunamenti Power Plant Unit G1, 145 MW, Dunamenti Power Plant Unit G2, 241 MW, Kelenföld Power Plant’s combined-cycle cogeneration unit, 136 MW, Debrecen Power Plant’s combined-cycle cogeneration unit, 95 MW, Újpest Power Plant’s combined-cycle cogeneration unit, 110 MW, and Csepel Power Plant, 396 MW). A 110 MW combined-cycle cogeneration unit is under construction at Kispest Power Plant. A new combined-cycle cogeneration unit has also been installed in the independent power producer category in BorsodChem (48.4 MW). Figures for the main producers are given in **Table 3**.

| | NET HEAT OUTPUT | EFFICI-ENCY | σ | COGENERATED ELECTRICITY | TOTAL ELECTRICITY GENERATED | PROPORTION |
|---|---|---|---|---|---|---|
| | TJ/a | % | - | GWh | GWh | % |
| | | | | | | |
| Ajka Power Plant | 2 754 | 46.9 | 0.30 | 230 | 400 | 57.38 |
| Alfen Kft. Power Plant | 61 | 71.8 | 0.00 | 0 | 0 | - |
| Bánhida Power Plant | 48 | 31.1 | 0.45 | 6 | 556 | 1.08 |
| BorsodChem Power Plant | 1 848 | 77.2 | 0.62 | 319 | 319 | 100.00 |
| Borsod Power Plant | 1 145 | 31.0 | 0.30 | 95 | 407 | 23.44 |
| Industrial power plants | 348 | 84.5 | 0.70 | 68 | 68 | 100.00 |
| Csepel Power Plant | 1 368 | 53.3 | 0.95 | 361 | 2 134 | 16.92 |
| Debrecen Power Plant | 1 060 | 82.4 | 0.08 | 25 | 25 | 100.00 |
| Debrecen Power Plant (KCE) | 990 | 67.4 | 2.27 | 623 | 623 | 100.00 |
| Dorog Power Plant | 618 | 67.8 | 0.33 | 57 | 57 | 100.00 |
| Dunamenti P. P. Unit G1 | 5 047 | 78.7 | 0.75 | 1 045 | 1 045 | 100.00 |
| Dunamenti P. P. Unit G2 | 397 | 49.7 | 0.45 | 50 | 1 474 | 3.37 |
| Dunapack Power Plant | 693 | 78.1 | 0.16 | 30 | 30 | 100.00 |
| Egyesült Vegyiművek Power Plant | 355 | 88.8 | 0.12 | 12 | 12 | 100.00 |
| EMA Power Kft. Power Plant | 5 237 | 74.0 | 0.12 | 173 | 173 | 100.00 |
| Gas engines | 1 496 | 82.6 | 0.79 | 327 | 327 | 100.00 |
| Steam turbines | 471 | 84.8 | 0.70 | 92 | 92 | 100.00 |
| Győr Power Plant | 578 | 84.6 | 0.09 | 15 | 15 | 100.00 |
| HUHA Budapest | 329 | 24.9 | 0.45 | 41 | 59 | 69.70 |
| Hungrana Power Plant | 1 069 | 65.2 | 0.33 | 99 | 99 | 100.00 |
| ICN Tiszavasvár Power Plant | 330 | 79.5 | 0.07 | 6 | 6 | 100.00 |
| Kelenföld Power Plant | 2 982 | 73.0 | 0.74 | 613 | 613 | 100.00 |
| Kispest Power Plant | 1 984 | 79.5 | 0.19 | 106 | 106 | 100.00 |
| Komló Power Plant | 325 | 76.3 | 0.24 | 22 | 22 | 100.00 |
| Kőbánya Power Plant | 1 641 | 78.2 | 0.18 | 81 | 81 | 100.00 |
| Mátra Power Plant | 266 | 29.5 | 0.30 | 22 | 5 059 | 0.44 |
| Neusiedler Szolnok Power Plant | 1 046 | 83.9 | 0.09 | 27 | 27 | 100.00 |
| Nitrokémia Fűzfő Power Plant | 552 | 76.1 | 0.12 | 18 | 18 | 100.00 |
| Nyíregyháza Power Plant | 1 510 | 82.1 | 0.15 | 63 | 63 | 100.00 |
| Oroszlány Power Plant | 352 | 28.9 | 0.45 | 44 | 1 304 | 3.37 |
| Paks Nuclear Power Plant | 603 | 34.3 | 0.45 | 75 | 13 953 | 0.54 |
| Pécs Power Plant | 2 135 | 44.2 | 0.45 | 267 | 654 | 40.81 |
| Sopron Power Plant | 482 | 81.7 | 0.13 | 17 | 17 | 100.00 |
| Székesfehérvár Power Plant | 821 | 87.8 | 0.04 | 9 | 9 | 100.00 |
| Tatabánya Power Plant | 1 399 | 71.7 | 0.22 | 86 | 86 | 100.00 |
| Tiszapalkonya Power Plant | 885 | 31.7 | 0.30 | 74 | 461 | 16.00 |
| TVK Power Plant | 256 | 58.2 | 0.00 | 0 | 0 | - |
| Újpest Power Plant | 2 854 | 81.1 | 0.51 | 402 | 402 | 100.00 |
| All power plants | 46 335 | | 0.44 | 5 600 | 30 796 | 18.18 |
| | | | | | | |

**Table 3**
Main production figures for cogeneration power plants in 2002

Since the mid-nineteen nineties, gas engine generating units have been installed at a quickening pace. This trend is still continuing, due in large part to the availability of subsidies.

## 2. Energetic aspects of cogeneration in Hungary

### 2.1. Problems in determining energy efficiency

Before discussing the energetic aspects of cogeneration in Hungary, we should consider some general issues. The energy efficiency of combined heat and power is ultimately expressed as the savings it delivers in primary energy carriers. However, the interpretation of primary energy saving is somewhat complicated, and there is no universally accepted definition.

There is no problem in the definition of cogeneration. It is the production of heat and electricity from some primary energy carrier by means of common technology. Its essential attributes are (1) it has two “energy products”, heat and electricity; (2) these are produced by the same technological process; and (3) they originate from the same primary energy carrier(s). The quantitative definition of cogenerated energy is much more problematic. To begin with, there is no single indicator that characterises cogeneration in energetic terms. Since heat and electricity are produced by transformation of the same energy carrier, the question arises of how the energy content of the transformed energy carrier is to be divided between the two energy end-products. Here it must be stressed that there is no thermodynamic basis for this sharing: every “theory” of sharing is to a certain extent based on an arbitrary convention, and so the issue has no unambiguous solution from a scientific standpoint. The problem of sharing is one of the main difficulties in the energetic evaluation of cogeneration.

A further problem is the choice of reference point for assessing primary energy saving in cogeneration, or in other words, what principle should be used for calculating the saving. The basic principle is to determine the different amounts of primary energy carrier consumed by separate generation and cogeneration in producing the same quantities of electrical and heat energy. The difference between these figures is the primary energy saving. After accepting this principle, we are left with the crucial question of what reference level of primary energy consumption to apply in assessing cogeneration. The saving will appear very high if compared with inefficient separate generation, and vice versa. Indeed, separate electricity generation with modern technology can be more efficient in energetic terms than cogeneration with obsolete technology. This gives rise to the third basic problem of evaluating energy consumption in combined heat and power systems: ensuring that the comparison is made against a form of electricity generation that uses the same primary energy carrier, the same or not greatly different technology, and a similar level of technical advancement. Finally, the fourth basic problem is the impossibility of finding a single energetic indicator to characterise cogeneration processes, making it difficult to establish a straightforward and categorical comparison.

### 2.2. Energetic characterisation of cogeneration power plants

We will compare and assess the energy efficiency of cogeneration in different power plant types using energy characteristic curves.

If we look at the energetic performance of specific public power plants, we find that Ajka Power Plant, Borsod Power Plant and Tiszapalkonya Power Plant, even using very low reference values, effectively fail to provide any primary energy carrier saving compared with separate generation. Generation at Kőbánya Power Plant, Kispest Power Plant, Tatabánya Power Plant, Nyíregyháza Power Plant and the power plant at EMA Power Kft. are much more energy-efficient, but owing to the generally low $\sigma$ value (heat-to-power ratio), their contribution to saving primary energy carrier is not highly significant. (**Figure 1.**) [2; p.35.] On the figure: $g_Q = 1/\mu_Q$ and $g_E = 1/\mu_E$. See **Table 6**, regarding the terms.

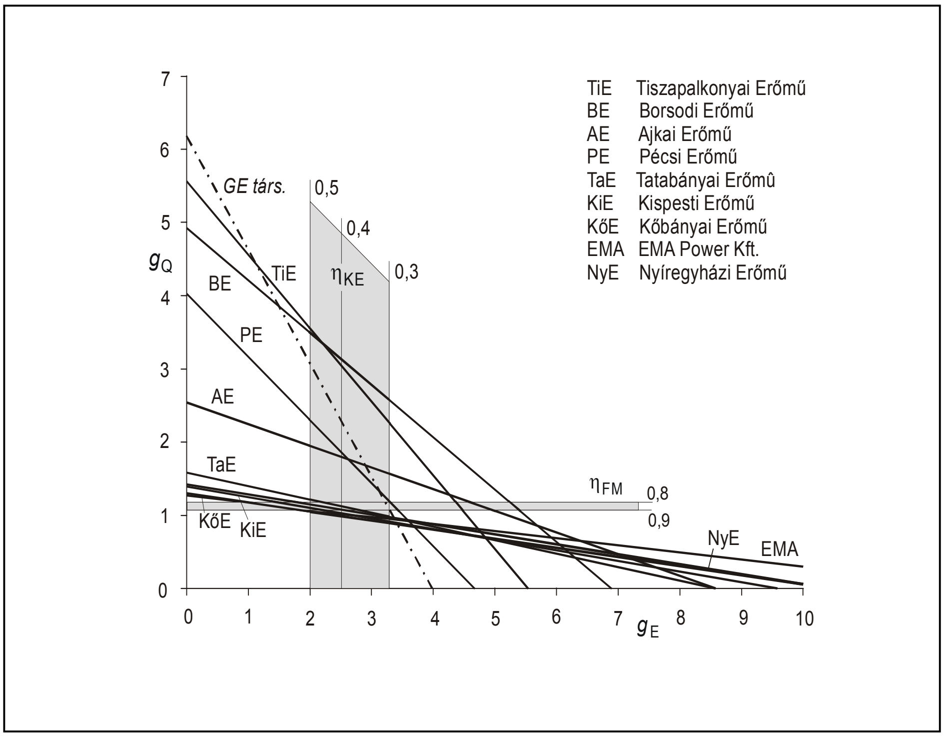


**Figure 1** Energetic characteristics of some public power plants in Hungary I. [2; p.35]

Against stricter reference values, there is not a single Hungarian public power station, apart from the combined-cycle cogeneration plants and plant units, where cogeneration is more efficient that high-efficiency separate generation. A few plants do achieve a level of primary energy use similar to that of efficient separate heat and power generation, but do not produce any actual savings.

By contrast, advanced combined cycle cogeneration power plants show significant primary energy carrier savings compared with separate generation **Figure 2** [2; p.35.].

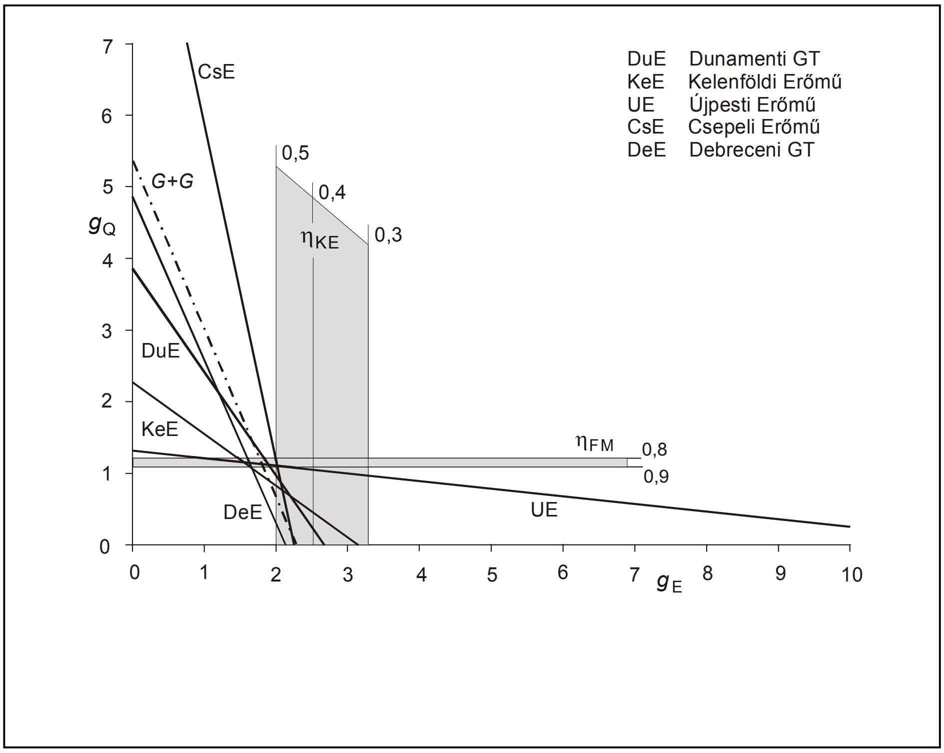


**Figure 2** Energetic characteristics of some public power plants II. [2; p.35.]

## 3. The potential role of cogeneration power plant units in the development of power plant capacity in Hungary

### 3.1. System power demand and peak power demand

Total national electricity consumption on national level is forecast to be 42.0-42.4 TWh in the middle of the decade and 45.0-45.4 TWh at the end. Peak system demand is estimated at 6250-6300 MW in mid-decade and 6700-6900 MW at the end. This corresponds to an annual average rate of growth of 1.3-1.5% for electricity demand, and somewhat higher – 1.8% – for peak demand. Major improvements in transmission loss are expected compared with past practices. The transmission loss rate is forecast to decrease from the present figure of around 6.3% to 5.8% in 2005 and to 1% less than the present level (about 5.2%) by the end of the decade. This implies that net electric energy consumption will rise somewhat faster than total demand, at the estimated annual rate of 1.9 % up to the end of the decade. These figures correspond to the "basic version" of possible demand scenarios.

### 3.2. Changes in power plant capacity

In the next few years, old power plant capacity in Hungary is likely to be decommissioned faster than new capacity is connected to the system. The installed electrical capacity of the country's five large public power plants, Paks Nuclear Power Plant (1866 MW), Dunamenti Power Plant (2143 MW), a Tisza Power Plant (860 MW), Mátra Power Plant (836 MW) and Csepel Power Plant (396 MW) will not essentially change. The Paks Nuclear Power Plant is planned to run on full capacity from 2005. At Mátra Power Plant, desulphurisation capacity constraints will mean that only one of the two units each of installed electrical power one hundred megawatts will be usable at full plant load. The coal-fired power plants at Bánhida and

Tiszapalkonya will be decommissioned at the end of 2004. The other coal-based power plants will be converted to comply with the environmental requirements. Also in late 2004, the Kispest combined-cycle cogeneration power plant unit is expected to enter operation with installed electrical capacity of 110 MW.

Major developments are expected in small power plants by the end of the decade, and this includes cogeneration power plants and generating units. Their total installed electrical capacity will increase substantially over the period. The installed electrical capacity of gas engine generating units will continue to rise, although perhaps at a lesser pace after the expected reduction of subsidies. The installed electrical capacity of gas engine cogeneration generating units is estimated to reach 200-220 MW by the end of 2004. By mid-decade, there is expected to be 300-350 MW of such capacity at system level, and by the end of the decade the total installed electrical capacity of gas engine cogeneration units is forecast to reach 480 MW, to which will be added about 200-250 MW of other cogeneration capacity in small power plants. Construction of new large combined cycle cogeneration power plant units is, in our judgement, unlikely.

### 3.3. Total cogeneration capacity forecast

By the end of the decade, cogenerated electrical energy is expected to reach a national total of 9-9.5 TWh. This means that cogenerated electricity will continue to rise as a proportion of the system as a whole, from around 15% today to 20-22%.

### 3.4. Development potential for cogenerated electricity

In Hungary, the heat consumer base for cogenerated heat fundamentally comprises district heating systems (**Table 4 [2; p.67.]** and **Table 5 [2; p.67.]**). At the turn of the millennium there were about 270 district heating systems in operation, with a total net heat demand of 61.2 PJ. The average load factor of Hungarian district systems is 2778 h/a. This large number of district heating systems presents a very mixed picture in terms of technical and energetic characteristics, and there are many different ways by which cogeneration could be installed, extended or modernised in these systems

| | District heat category by annual net heat consumption | Number of district heating systems | Total net heat consumption in category | | District heating systems average | |
|---|---|---|---|---|---|---|
| | | | TJ | % | net heat, TJ/a | output, MW |
| | | | | | | |
| 1 | Q < 25 | 121 | 1259.9 | 2 | 10.4 | 1.0 |
| 2 | 25 < Q < 50 | 36 | 1354.5 | 2 | 37.6 | 3.8 |
| 3 | 50 < Q < 100 | 38 | 2568.9 | 4 | 67.6 | 6.8 |
| 4 | 100 < Q < 500 | 44 | 11242.0 | 18 | 255.5 | 25.6 |
| 5 | 500 < Q <1 000 | 14 | 10390.0 | 17 | 742.1 | 74.2 |
| 6 | 1000 < Q < 2500 | 13 | 21819.3 | 36 | 1678.4 | 167.8 |
| 7 | 2500 < Q < 5000 | 2 | 5718.2 | 9 | 2859.1 | 285.9 |
| 8 | 5000 < Q | 1 | 6890.3 | 11 | 6890.3 | 689.0 |
| Total/average | | 269 | 61242.9 | 100 | 227.7 | 22.8 |

**Table 4**
Main energy characteristics of Hungarian district heating systems at the turn of the millennium [2; p.67.]

| | Public power plants | | | Whole system | | |
|---|---|---|---|---|---|---|
| | PJ | % | % | PJ | % | % |
| | | | | | | |
| Cogenerated heat | *28.1* | *72.1* | 100.0 | *34.4* | *73.5* | |
| hot water heat carrier | 14.2 | | 64.8 | 14.5 | | 64.7 |
| steam heat carrier | 13.9 | | 81.3 | 19.9 | | 81.6 |
| Direct generated heat | *10.9* | *27.9* | 100.0 | *12.4* | *26.5* | |
| hot water heat carrier | 7.7 | | 35.2 | 7.9 | | 35.3 |
| steam heat carrier | 3.2 | | 18.7 | 4.5 | | 18.4 |
| Total heat generated | *39.0* | *100* | | *46.8* | *100* | |
| hot water heat carrier | 21.9 | | | 22.4 | | |
| steam heat carrier | 17.1 | | | 24.4 | | |
| | | | | | | |

**Table 5**
Main figures for cogenerated heat [2; p.67.]

Existing district heating systems offer major potential for development of cogeneration in Hungary. The possibilities divide into five main groups:

- install cogeneration in systems where there is no cogeneration at present;
- expand existing cogeneration;
- modernise existing cogeneration;
- implement cogeneration in for other heat consumer bases (such as industrial heat demand, space heating, or in connection with cooling demand).

## 4. The role of cogeneration in reducing environmental load in Hungary
### 4.1. Calculation principle

In advanced societies, energy consumption is very high. Supplying this energy results puts a very heavy load on the environment. The pursuit of sustainable development has made the reduction of primary energy carrier use and environmental load into become fundamental social objectives, with an interrelationship that needs no explanation. It has been clearly demonstrated that combined heat and power generation is one of the most effective means of achieving these objectives.

**Table 6** shows the primary energy carrier savings achieved in public power plants in 2002 (calculation does not apply for the whole system!).

The fuel heat saving ($S_f$ [kJ]) attainable by cogeneration in relation to direct (separate) heat and power generation is given by the following formula:

$$S_f = (Qq_{Q,n,hp} + Eq_{E,n,cond}) - (Qq_Q + Eq_E) = \\ = Q(q_{Q,n,hp} - q_Q) + E(q_{E,n,cond} - q_E).$$

The specific fuel saving ($s_f$ [kJ/kJ]) relative to the fuel consumption of separate generation is:

$$s_f = S_f / (Q_{f,Q,sep} + Q_{f,E,sep}) = S_f/Q_{f,sep}.$$

The specific fuel saving ($s_f$* [kJ/kJ]) relative to net cogenerated heat is:

$$s_f{}^* = \frac{S_f}{Q} = \frac{(Qq_{Q,n,hp} + Eq_{E,n,cond}) - (Qq_Q + Eq_E)}{Q} =$$
$$= (q_{Q,n,hp} - q_Q) + \sigma(q_{E,n,cond} - q_E).$$

The key to the terms in the formula is given in **Table 6.**

## 4.2. Primary energy carrier saving achieved by cogeneration in public power plants

The primary energy carrier saving achieved by cogeneration in public power plants is calculated based on two different reference values (**Table 6**).

In the first case, the heat rate of separate electricity generation was equal to the average heat rate of condensation electricity generation ($q_{E,n,cond,nat}$ = 11089 kJ/kWh, equivalent to an efficiency of $\eta$ = 32.46 %), and the heat rate of separate heat generation was equal to the system average ($q_{Q,n,sep,nat}$ = 1,218 kJ/kJ, equivalent to an efficiency of $\eta$ = 82.10 %). With these reference values, the primary energy carrier saving achieved by cogeneration in public power plants was $S_{f,nat}$ = 18,993,383 GJ (~ 19 PJ). The primary energy carrier saving relative to separate energy generation in 2002 was thus $s_{f,nat}$ = 25.45 %.

For the sake of completeness, the calculation was also made taking the efficiency of the most advanced direct energy production as the reference. This gives $q_{E,n,cond,EU}$ = 6545 kJ/kWh, equivalent to an efficiency of $\eta$ = 55.00 %. The figure for heat production is $q_{Q,n,sep,EU}$ = 1,111, and the efficiency $\eta$ = 90.00 %. The primary energy carrier saving by cogeneration in public power plants in this case is $S_{f,EU}$ = 260 118 GJ (~ 0.3 PJ). The primary energy carrier saving relative to separate energy production in 2002 was $s_{f,nat}$ = 0.47 %. This result is not surprising in the circumstances.

Under the EU proposal, the system average value must be taken as the reference for system-level calculations and comparative studies. The fact that cogeneration in public power plants alone delivers equivalent primary energy carrier savings of some 19 PJ, equivalent to 2% of unaccumulated primary energy consumption of Hungary, indicates very clearly the environmental significance of cogeneration in Hungary. It may be confidently stated that no other energy production technology can deliver a reduction of environmental load of comparable magnitude. Combined heat and power is thus of enormous environmental significance in Hungary, since 19 PJ primary energy carrier saving greatly reduces harmful emissions and therefore reduces environmental load. The environmental benefit is actually much greater than this, since the calculations only apply to a subset of combined heat and power generation (instead of the total production of 5600 GWh/a, only 3700 GWh/a were taken into account in the calculations.)

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