European Commission

Energy efficiency in Transmission & Distribution

The scope for energy saving in the EU

through the use of energy-efficient electricity distribution transformers

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Produced by
European Copper Institute
Avenue de Tervueren 168, b10
Belgium
Tel: +32 2 777 70 70
Fax: +32 2 777 70 79
E-Mail: eci@eurocopper.org

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The scope for energy saving in the EU through the use of energy-efficient electricity distribution transformers

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1 EXECUTIVE SUMMARY

The ultimate scope for saving energy in the EU through the use of energy-efficient distribution transformers, is approximately 22TWh/year, worth €1,171 million at 1999 prices. Despite the efficiency of individual units, up to 2% of total power generated is estimated to be lost in distribution transformers, nearly one-third of overall losses from the system. This is comparable in scope with the energy savings potential estimated for electric motors and domestic appliances. It is equivalent to the annual power consumption of over 5.1 million homes, or the electricity produced by three of the largest coal-burning power stations in Europe.

Because of the long life span of distribution transformers, ultimate market penetration will only be achieved gradually. However, we estimate that energy-efficient units could contribute 7.3TWh of savings by 2010, representing over 1% of the European commitment to reducing carbon emissions.

Europe has an urgent need to develop a strategy on existing and future global warming actions. As far as we have been able to ascertain, no European country has yet developed targets for the global warming savings potential which could result from distribution transformer programmes, nor has a formal estimate been made for the EU or Europe as a whole.

Europe has considerable potential to offer world-wide in transformer technology and experience. However, national governments and utilities appear to lag behind the US in terms of programmes and initiatives to encourage energy efficiency. There are no initiatives comparable to the US DOE/EPA programmes on utility commitments, information and software dissemination. This is despite the fact that most of the major European countries have a very poor position on energy self-sufficiency.

There is already considerable R&D and promotional effort within Europe aimed at reducing losses in small transformers, e.g. for domestic and office equipment, and some IEA/OECD work has been undertaken. Initiatives have included campaigns to urge consumers to switch off appliances, and the use of more efficient core materials. This could assist in focusing attention on the equally significant target of distribution transformers.

It is apparent that both utilities and private sector purchasers are difficult to influence. The transformer market is extremely competitive, and efforts to improve energy efficiency in the past have had limited success. However, the sector involves a limited number of professional buyers, already reasonably aware of the arguments for energy efficiency, and with well-established techniques for evaluating transformer performance. They are therefore likely to be receptive to rational arguments, provided that benefits are clearly demonstrated

We believe that distribution transformers represent an important focus for energy efficiency initiatives within the EU and a worthwhile area for R&D, demonstration and promotional effort. We therefore recommend the following:

- the potential for reducing losses from distribution transformers should be considered as one element of EU and national strategies on energy efficiency, global warming, and environmental impact

- an action plan should be developed to achieve these goals. The strategy and action plan need to be carefully co-ordinated, technically sound, and carry partners from all levels in the supply chain.

2 CONCLUSIONS AND RECOMMENDATIONS

2.1 Conclusions

The theoretical scope for energy savings through the use of energy-efficient distribution transformers in the EU is very substantial. Despite the efficiency of individual units, up to 2% of total power generated is estimated to be lost in distribution transformers, equivalent to nearly one-third of overall losses from the power system.

The savings potential is approximately 22TWh/year, worth €1,171 million at 1999 prices. This is comparable in scope with the energy savings potential estimated for electric motors in the EU (27TWh) and domestic appliances. It is equivalent to the annual energy consumption of over 5.1 million homes, or the electricity produced by three of the largest coal-burning power stations in Europe.

Because of the long life span of distribution transformers, ultimate market penetration will only be achieved gradually. However energy-efficient units could contribute 7.3TWh of savings by 2010, representing over 1% of the European commitment to reducing carbon emissions.

As far as we have been able to ascertain, no European country has developed targets for the global warming savings potential which could result from distribution transformer programmes, nor has a formal estimate yet been made for the EU or Europe as a whole.

European countries are currently developing strategies on existing and future global warming actions. As this happens, the potential for reducing losses from distribution transformers could be promoted, to ensure that they are incorporated as a component of the plan.

Europe has considerable potential to offer world-wide in transformer technology and experience. However, national governments and utilities lag behind the US in terms of programmes and initiatives to encourage energy efficiency.

There are no initiatives comparable to the US DOE/EPA programmes on voluntary utility agreements, or information and software dissemination. This is despite the fact that most European countries have a poor position on energy self-sufficiency. The US has also recently started a process to evaluate the role of regulation in transformer efficiency.

There is already considerable R&D and promotional effort within Europe aimed at reducing losses in small transformers, e.g. for domestic and office equipment, and some IEA/OECD work has been undertaken. Initiatives have included campaigns to urge consumers to switch off appliances when not in use, and the adoption of more efficient core materials. These are directed at domestic consumers, rather than utilities and professional buyers, but could assist in focusing attention on the equally significant target of distribution transformers.

It is apparent that both utilities and non-utility purchasers are difficult to influence. The transformer market is extremely competitive, and efforts to improve energy efficiency in the past have had limited success. However, the sector involves a limited number of professional buyers, already reasonably aware of the arguments for energy efficiency, and with well-established techniques for evaluating transformer performance. They are therefore likely to be receptive to rational arguments, provided that benefits are clearly demonstrated.

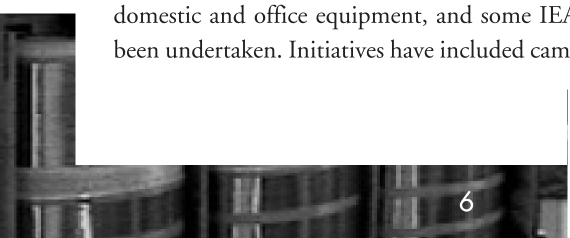
2.2 Recommendations

We consider that distribution transformers should be recognised as an important focus for energy efficiency initiatives within the EU, and that they represent a worthwhile area for R&D, demonstration and promotional effort. We therefore recommend the following:

- as EU and national strategies on energy efficiency, global warming, and environmental impact are developed, the potential for reducing losses from distribution transformers should be considered, to ensure that they are incorporated as a component

- a strategy should be developed to set and achieve goals for reducing losses from distribution transformers, or possibly from all power systems transformers in the EU. The strategy needs to be carefully co-ordinated and be both technically and commercially sound

- the main elements of an action plan to achieve the strategy should be identified and developed.



3 INTRODUCTION

3.1 Background

This project was undertaken to provide a detailed assessment of the scope for installing energy-efficient distribution transformers in both utility-operated and private electricity supply systems in the European Union.

An estimate has been made of the contribution which they could make to energy savings in the EU. The study has also identified the main technical, engineering and financial barriers to their application, and develops a suggested strategy to encourage their introduction.

The proposed strategy relates specifically to Europe, evaluating R&D and technical advances against factors such as the installed age and population of distribution transformers, replacement levels, utility ownership, distribution network design, operating voltages, purchasing criteria and financial constraints.

The study enables the European Commission, the governments of Member States, and regulators, to understand the current and future scope for energy saving which is associated with energy-efficient distribution transformers. It also allows to assess specific actions taking place or planned within the Community, and its priority compared with other sectors.

We believe that the study will also help electricity utilities and private electricity network operators to identify and specify energy-efficient equipment, based on a clearer understanding of available products and concepts, ways of evaluating financial pay-backs and life-time costs, and the use of concepts such as demand side management (DSM).

3.2 Project Components

The study has collected data from all EU countries. It takes account of national and regional priorities, installed electricity system networks, engineering practice. Some factors, for example the recent change in distribution operating voltages, affects various countries differently.

We have collected and analysed the limited amount of available statistical and marketing data to derive estimates of distribution transformer populations. We have also made estimates of pole/ground-mounted ratio, total capacity in GVA, operating voltages, unit size and rating profile, oil-filled/dry-type ratio, ownership, age profile, current and planned new installation rates.

The major technologies offering scope for energy efficiency in distribution transformers have been identified and appraised. These include transformer sizing, core/coil loss ratios, materials and components currently available and under development, such as amorphous iron, special magnetic steels etc.

We have also collected some technical and cost data, and operating experience, from existing energy-efficient transformer installations. Their success and relevance for wider application has been assessed, and a specific profile prepared for dissemination. An appraisal has been made of world-wide R&D developments likely to improve energy efficiency in distribution transformers, and the technical and commercial barriers which they face.

We have made an estimate of the potential impact on Europe of energy efficiency developments and initiatives in this sector, and identified strategic plan components for Europe in this sector. These are quantified as far as possible in terms of total energy savings, contribution to global warming goals, scope to delay or avoid new capital investments, demand side management, etc.

3.3 Methodology

The study is based on desk and telephone interviews, combined with a brief field programme in four key markets, France, Germany, Italy and the UK.

Our contacts included electricity utilities, specifying authorities such as consulting engineers, transformer manufacturers, the European Commission, national governments and energy agencies, raw materials producers and semi-fabricators, as well as individuals concerned with national and European transformer standards.

We also held discussions with the trade associations responsible for each point of the supply chain, including utilities, transformer manufacturers, raw materials producers and semi-fabricators.

A workshop has been organised to discuss the findings of the project was held at Harwell, UK, on 23d September 1999. This brought together delegates from all points of the supply chain, including raw material producers and semi-fabricators, transformer manufacturers, utilities, consultants and energy agencies, as well as a representative of the European Commission. Participants were provided in advance with a copy of our draft report. They confirmed the basic findings of the project, recognising the potential of energy-efficient transformers to contribute to global warming goals, and contributed specific additional initiatives to overcome the barriers to change,

4 THE ROLE OF TRANSFORMERS

4.1 Electricity Supply System Concepts

Modern electricity supply systems depend on a number of advances in electrical theory and engineering which were made in the late 19th century. These include the principle of AC generation, motors and transformers, the concept of creating interlinked high and low voltage networks, and the use of parallel rather than series connections to supply end-users. Their application enabled reliable electricity supply services to be provided to industry, commercial and domestic customers throughout Europe and the industrialised world.

Further developments resulted in electricity being generated in large efficient power stations, far from the point of use. Generating stations were then linked to each other, and to urban and industrial centres, through a country-wide network of overhead conductors and underground cables. This improved the balance between supply and demand, and further enhanced the quality of the service. Initially electricity in Europe was produced mainly from coal and hydro-electric power stations, but the national networks also proved ideal when nuclear power generation became feasible.

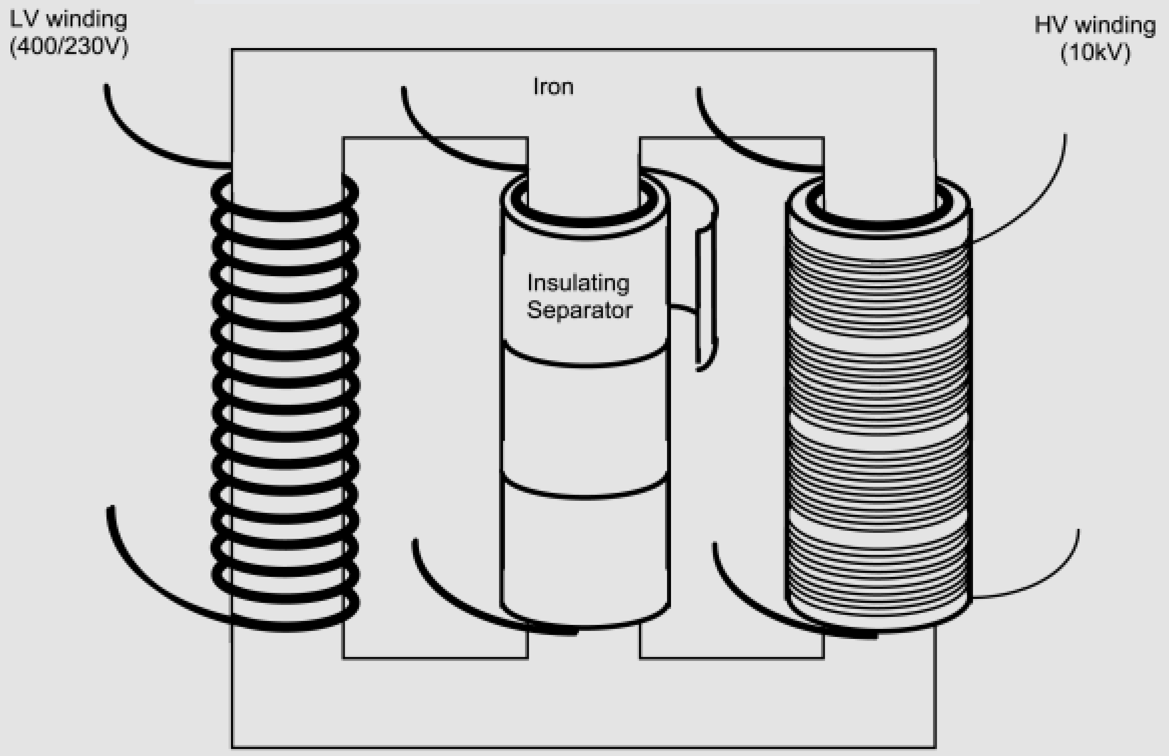
Losses in electricity supply systems depend on the voltage level. They are minimised by transmitting electricity at as high a voltage as possible, consistent with demand load levels, extent of urbanisation, etc. Transformers, which initially step up the generation voltage, and then reduce it to the level required by users, are therefore an essential component in transporting electricity economically from the power station to the final customer.

4.2 Distribution Transformers

In an electricity supply system, the high and low voltage power networks terminate within a transformer in wound coils, of copper or aluminium. The coils generate a magnetic flux, which is contained by an iron core. Energy is then transferred between the networks through this shared magnetic circuit.

The smallest transformers in an electricity supply system, which provide electricity to commercial and domestic customers, are described as **distribution transformers**. Figure 1 shows schematically the arrangement of the active components of a typical three-phase distribution transformer as used in Europe. It can be seen that the iron core of the transformer has three limbs, and that the

Figure 1 **Build-up of Three-phase Distribution Transformer**



Source: ECI

HV and LV coils of each phase are wound on the same limb, separated by insulating material.

4.3 Transformer Losses

The energy losses in electricity transformers fall into two categories:

- **no-load losses** or **iron losses**, which result from energising the iron core. These are incurred whenever the transformer is coupled to the network, even if no power is being drawn

- **load losses** which arise from the resistance of the windings, when the transformer is in use, and from the eddy currents which flow both in the windings and the transformer housing due to stray flux. Sometimes referred to as **copper losses**, or **short circuit losses**, as they are measured by shorting the windings.

The transformers installed in electricity supply systems are extremely efficient when compared with other machines. There are no moving parts, and large modern power station and transmission transformers typically have an efficiency above 99.75%. Distribution transformers are less efficient, but levels can still exceed 99%.

Despite the high efficiency of individual units, losses occur at each of transformation steps in an electricity supply network. Even in a modern network, the losses arising from power transmission and distribution can amount to as much as 10% of the total electricity generated. Losses are relatively higher when transformers are lightly or heavily loaded. This means that there is considerable potential for energy saving with efficient transformers.

5 ELECTRICITY SUPPLY AND DEMAND IN THE EU

5.1 Supply System Design

Electricity supply systems are similar throughout the world, although the voltages used for transmission and supply to the final customer may vary. In Europe electricity is typically generated at 10-20kV AC in a power station, and stepped up to transmission voltages of 275-400kV, for transportation by overhead transmission line or supertension power cable to regional load centres.

Within a region, electricity is transformed to lower voltages for supply at 110-150kV. This is often the stage at which power-generating companies sell electricity to local distribution utilities.

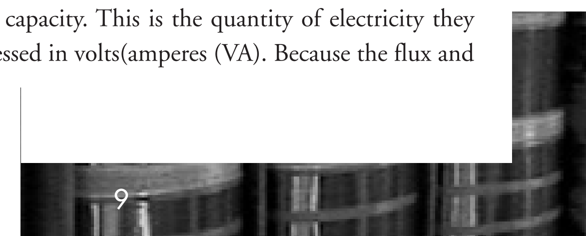
Power at 110-150kV is also supplied directly to major industrial customers, for example chemical works or steel producers, or carried into urban areas for further reduction at **system transformation points** to 10-20kV. Smaller industrial consumers as well as commercial offices, schools, hospitals and public sector buildings are supplied at this voltage, reducing levels within their own premises as necessary.

Finally the voltage is further reduced at **distribution sub-stations**, close to the point of use, for supplying smaller commercial and domestic customers at national consumer mains voltages, recently standardised in Europe at 400/230V. Figure 2 is a simplified representation of an electricity distribution system, showing the supply to industrial, commercial, rural and domestic customers, by either underground cable or overhead line.

The basic pattern of electricity network design, with four main operating voltage levels, is now used throughout Europe, irrespective of the relative utilisation of overhead and underground networks. It has been proven to provide a good balance between supply and demand, and reduce losses to a practical minimum.

The existing systems in most European countries are however rather more complex. They have been built up over a long period, and there are a variety of intermediate transmission voltages, such as 66kV, 50kV. These are slowly declining, but they represent a considerable proportion of existing networks, and can still provide the most economical option for system reinforcement and renovation.

A large number of different classes and sizes of transformers are therefore required in a modern electricity supply network, reflecting the wide range of operating voltages and currents. In addition to the four main operating voltages, and the intermediate voltages which have been described above, transformers are also specified in terms of their capacity. This is the quantity of electricity they can handle, expressed in volts(amperes (VA). Because the flux and



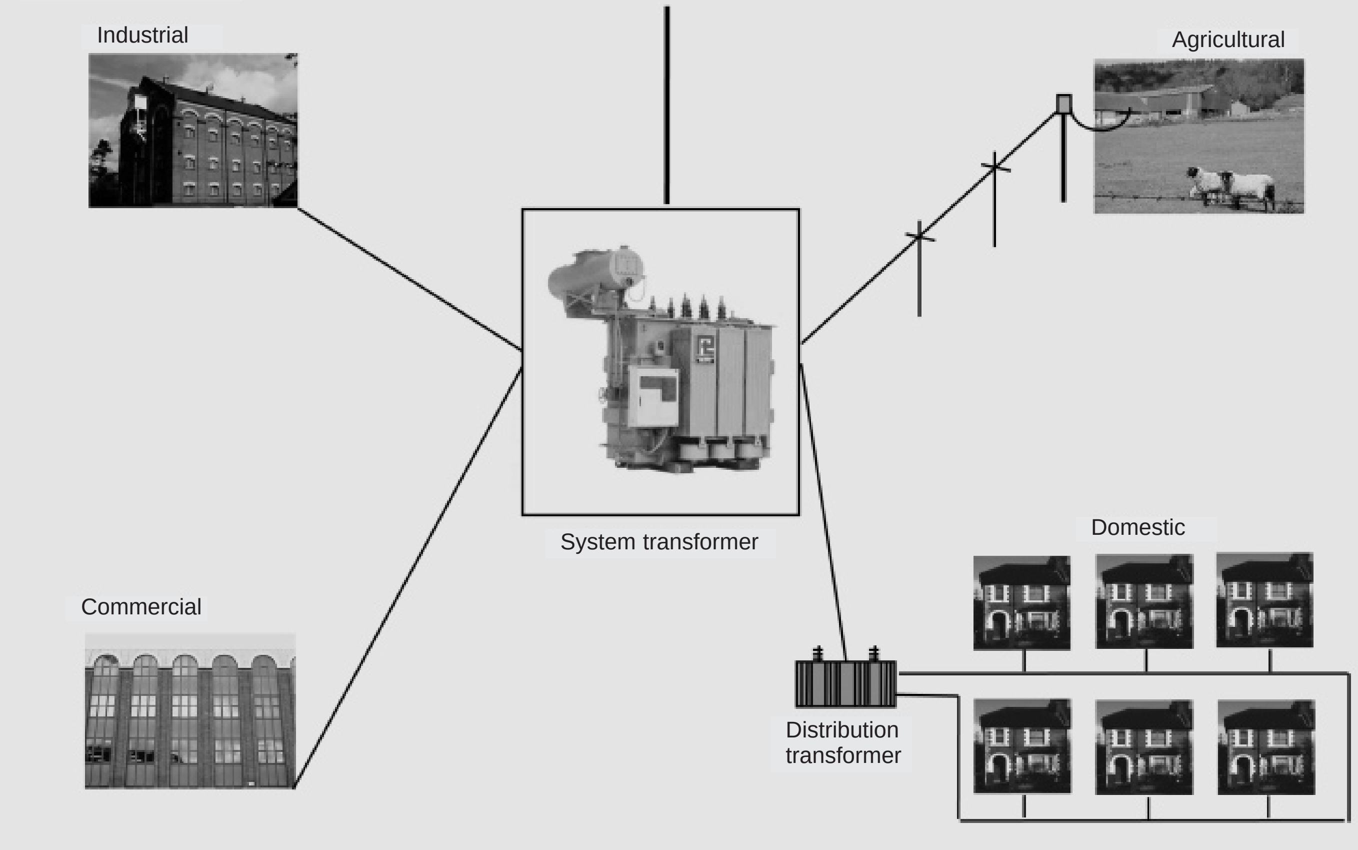


Figure 2 Electricity Distribution System

current-carrying capacities of the core and windings are limited, heavier currents require larger transformers.

made on investments in capital plant such as distribution transformers.

5.2 Power Generation and Distribution Utilities

Utilities produce and distribute over 90% of the total electricity generated in the European Union. There are approximately 2000 electricity utilities in the EU. They range in size from small town or rural area systems, controlled by municipal and local government, to very large state-owned bodies serving a whole country.

Considerable structural changes are now taking place in the sector, with a transfer to private ownership, joint ventures across national boundaries and new investments in power generation as main trends. Recent privatisation and decentralisation have left only France and Italy among the major countries in Western Europe following the traditional pattern of state ownership. Italy has already started a far-reaching privatisation plan for its national utility.

The Electricity Directive, which came into force in February 1999, is designed to create an open and competitive market for electricity in Europe. Member States are required to open up about 25% of their markets to free competition. These changes have important implications for the way in which decisions are

5.3 Non-utility Electricity Supply

Non-utility electricity supply systems include traction companies operating electrified railways, metros and tramway systems, large plants in the chemical, oil and gas and metals industry. Organisations in this category either generate their own requirements, or purchase electricity at high voltage from utilities and operate their own distribution networks. There is considerable mining and mineral extraction in Europe, often involving the distribution of power underground.

Private generation represents less than 10% of total capacity in the EU. However, generation of electricity on site for non-utility systems is growing rapidly, frequently using gas as a raw material. Overall, it is estimated that private generation could reach 20% of total capacity in the near future. Growth is being assisted by a number of special factors, including the development of renewable and combined heat and power technology, improved economics for gas-based generation, the liberation of tariff controls, and deregulation of electricity supply.

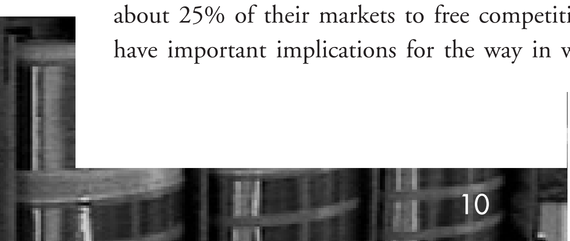


Figure 3 Maximum Net Generating Capacity at End Year, European Union (MW)

Type of origin	1980	1990	1995	1996	2000	2005	2010
Nuclear	40.106	114.837	119.581	120.710	122.427	121.062	119.232
Subtotal	40.106	114.837	119.581	120.710	122.427	121.062	119.232
Conventional thermal							
• coal	101.847	117.090	115.132	114.638	110.928	103.032	107.552
• brown coal	17.743	18.535	30.226	27.442	28.647	28.993	30.332
• oil	76.309	59.507	53.339	51.970	36.023	33.870	27.785
• natural gas	33.529	43.302	63.850	73.991	105.230	116.890	134.574
• derived gas	3.500	2.314	2.695	2.756	5.178	4.455	4.378
Subtotal	232.928	240.747	265.242	270.797	286.006	287.240	304.620
Hydro							
• gravity scheme	67.846	76.902	80.064	80.387	82.985	84.225	86.755
(of which run of river)	15.470	16.945	17.648	17.746	18.075	18.261	18.666
• pumped + mixed	20.284	32.303	34.586	34.597	34.909	36.109	37.290
Subtotal	88.130	109.205	114.649	114.983	117.893	120.334	124.045
Other renewables	1.830	4.602	6.734	6.815	13.958	20.561	25.747
Gas turbines, diesel, etc.	12.922	17.297	21.208	21.632	20.824	21.306	24.067
Not specified	6.186	7.865	6.579	9.335	12.330	18.547	22.054
Subtotal	20.938	29.764	34.521	27.782	47.112	60.414	71.868
TOTAL	382.102	494.553	533.993	544.272	573.438	589.050	619.765

While utilities generally rely on their own engineering staff to set standards for performance, including energy efficiency, private sector electricity supply systems are often designed with outside assistance. The pattern in Europe varies widely. In some countries, this work is undertaken mainly by firms of management contractors, or the design staff of a major electrical contractor. Elsewhere, independent professional consulting engineers are responsible for design and project management.

5.4 Production Capacity

The installed generating capacity for electricity in the European Union is about 550GW (Figure 3). Germany and France are by far the largest producers, accounting for approximately 35% of the total.

It is estimated that about 60GW of new generating capacity will be added in the period to 2010, during which time about 15GW will be decommissioned. Two-thirds of new investment is planned to be based upon gas, particularly in Italy, France and the Netherlands. Much of this will be installed by independent generators for their own use and resale, or for the co-generation of heat and power. The remainder of the predicted capacity increase is mostly new nuclear power stations, in France and Finland.

5.5 Demand and Growth Rate

Electricity consumption in the European Union is nearly 2,500TWh per year. Four countries, Germany, France, the UK and Italy, account for approximately two-thirds of the total (Figure 4). Population levels, size of economy, degree of industrialisation, the volume of heavy industry, climate, prices and competition from other fuels all contribute to the pattern of consumption in individual countries.

The demand for electricity in Europe grew rapidly in the 1960s and 1970s, in line with increasing industrialisation, rapid economic growth rates, the completion of national networks and the development of nuclear power. The rate of increase in consumption has slowed dramatically in the 1990s. The current annual growth rate is 1.7%, compared with 4.3% in the 1970s and 2.7% in the 1980s.

The power industry has found it difficult in the past to forecast demand, but the International Union of Producers and Distributors of Electrical Energy (UNIPEDE), the international utilities' industry association, predicts that growth in the EUR-21 (those shown in Figure 4 together with the Czech Republic, Hungary, Norway, Poland, Slovakia and Switzerland) will be 1.7% per year over the next 15 years.

The fastest growing end-use sector is expected to be services, averaging 2.4% per year, and transport, growing at 1.6% per year.

Figure 4 Electricity Consumption, European Union, 1980-2010 (TWh)

	Actual				Forecast			Implied Average Annual Increase (%)						
Year	**1980**	**1990**	**1995**	**1996**	**2000**	**2005**	**2010**	**1980-1990**	**1990-1995**	**1995-1996**	**1996-2000**	**2000-2005**	**2005-2010**	**1996-2010**
Austria	36,3	46,9	51,0	52,3	56,6	62,1	67,3	2,60	1,69	2,55	1,99	1,87	1,62	1,82
Belgium	47,7	62,6	73,5	75,3	81,2	89,0	94,5	2,76	3,26	2,45	1,90	1,85	1,21	1,64
Germany	351,0	415,0	493,0	500,0	512,0	531,0	547,0	1,69	3,50	1,42	0,59	0,73	0,60	0,64
Denmark	23,9	30,8	33,7	34,8	35,8	36,8	37,7	2,57	1,82	3,26	0,71	0,55	0,48	0,57
Spain	102,0	145,4	164,0	169,0	188,2	218,2	246,7	3,61	2,44	3,05	2,73	3,00	2,49	2,74
Finland	39,9	62,3	69,0	70,1	78,0	85,4	92,1	4,56	2,06	1,59	2,71	1,83	1,52	1,97
France	248,7	349,5	397,3	415,2	444,0	479,0	516,0	3,46	2,60	4,51	1,69	1,53	1,50	1,56
Greece	21,9	32,5	38,8	40,5	47,2	54,2	63,4	4,03	3,61	4,38	3,90	2,80	3,19	3,25
Ireland	9,5	13,0	16,4	17,6	21,7	26,8	32,1	3,19	4,76	7,32	5,37	4,31	3,68	4,39
Italy	179,5	235,1	261,0	262,9	296,0	330,0	360,0	2,74	2,11	0,73	3,01	2,20	1,76	2,27
Luxembourg	3,7	4,4	5,1	5,1	5,6	5,9	6,3	1,75	3,00	0,00	2,37	1,05	1,32	1,52
Netherlands	59,7	78,0	89,6	93,5	101,2	110,9	121,5	2,71	2,81	4,35	2,00	1,85	1,84	1,89
Portugal	15,3	25,1	29,3	30,9	36,5	42,8	49,0	5,07	3,14	5,46	4,25	3,24	2,74	3,35
Sweden	94,1	139,9	142,4	142,7	145,5	147,8	152,3	4,05	0,35	0,21	0,49	0,31	0,60	0,47
UK	264,8	309,4	330,7	343,9	360,8	393,0	425,7	1,57	1,34	3,99	1,21	1,72	1,61	1,54
EUR 15	1.498,0	1.949,9	2.194,8	2.253,8	2.410,3	2.612,9	2.811,6	2,67	2,39	2,69	1,69	1,63	1,48	1,59

Major planned investments include a US$1.3 billion HVDC power bridge to link Western and Eastern Europe.

A number of countries in Western Europe have published formal plans for their electricity industry. Some utilities have also prepared detailed forward plans. Typically, these address issues such as electricity consumption, maximum demand, regional trends and growth rates, major planned generation and transmission investments.

Increasingly, national and utility plans also cover energy efficiency. As far as we have been able to ascertain, there have been no statements by organisations in the EU of targets to reduce losses through the use of energy-efficient distribution transformers. In practice there are considerable problems in estimating the potential for savings, discussed in Sections 10.5 and 11.

5.6 Representation

The electricity utilities in most European countries are represented by one or more industry associations. These are co-ordinated at European level by EURELECTRIC, which was created in 1989. EURELECTRIC has recently formed a joint secretariat with UNIPEDE.

Technical issues, and other developments associated with the operation of electricity supply systems, are handled by a number of international representative bodies. These include the International Conference of High Tension Networks (CIGRE) and the International Conference of Distribution Networks (CIRED). A further body, the Union for the Co-ordination of the Production and Transport of Electricity (UCPTE) helps co-ordinate power transmission in Continental Western and Central Europe.

The organisations directly responsible for the technical specifications of distribution transformers are described in Section 7.4.

5.7 Regulation

The decentralisation and privatisation of utilities in EU countries has resulted in the creation of independent regulatory bodies at national level. These cover issues such as price control, investment levels for new plant and equipment, safety, environmental impact. These responsibilities can be undertaken by a government department, usually the ministry responsible for energy policy, or by the creation of an independent agency.

The regulatory bodies have varying degrees of control over energy efficiency. Some allow utilities to levy their customers to help fund for environmental spending. Others can reward utilities with rebates or capital allowances for energy efficiency or environmental improvements and investments.

The Electricity Directive, described above, establishes rules for the generation, transmission and distribution of electricity. The implementation of the Directive is contributing to the growth of the regulating process. A further item of European Community legislation, the Utilities Directive, covers certain aspects of the electric power industry operations. Energy efficiency is not included.

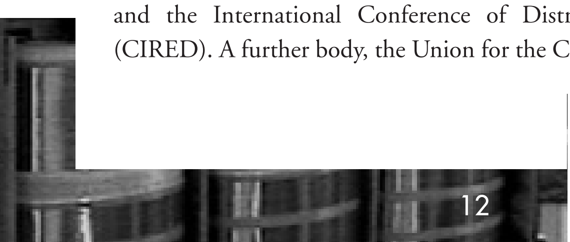


Figure 5 System Losses - European Utilities (%)

5.8 Environmental Impact

Power generation is the largest contributor to toxic emissions and global warming in Europe. Carbon dioxide emissions are forecast to increase rapidly in the period to 2010, particularly in Italy, where they are expected to rise by one-third, with investment in gas generation plant a major contributor. Releases of sulphur and nitrogen oxides in Europe are forecast to fall.

Initiatives to reduce toxic emissions, and meet agreed climate change and global warming targets, are often similar to those aimed at improving energy efficiency. There has been considerable discussion in EU countries about the use, by the either European Commission or national governments, of economic instruments, e.g. taxes or levies, to regulate emissions and global warming. These include the imposition of a carbon tax to increase the cost of burning fossil fuels.

5.9 Energy Losses

Detailed figures of estimated and forecast energy losses for EU countries in the period 1970-2010 are provided in Appendix A. Total losses for the EU are running at about 150TWh, representing approximately 6.5% of total power generated, or the output of 15 large power stations. However, losses have fallen steadily, from about 7.5% in 1970.

Some examples of the losses in the power systems of a number of Western European countries are shown in Figure 5. There is a significant variation between countries in reported electricity system losses, ranging between 4-11%. Obviously, distribution losses could be expected to be higher in small lightly populated rural countries than in major industrialised countries. There is some doubt about whether losses are always measured on a consistent and comparable basis.

Among major countries, Germany reports exceptionally low loss levels, has made significant progress in the period since 1970, and set ambitious targets for the next 15 years. In contrast the UK, France and Italy are showing persistently high loss levels, and with no foreseen or planned improvement.

In Central Europe, losses in the system are reported to be much higher, up to twice the average for Western Europe. Some indication of this is provided by data from Germany, where losses in the former DDR were reported at 10.0% in 1992, compared with 4.7% for West Germany, but had improved to 9.0% by 1995.

5.10 Distribution System Losses

It is estimated that over 40% of the total losses in an electricity distribution network are attributable to transformers (See Section 11.1). The remainder is mainly in the cable and overhead conductor system.

Modern electricity supply grid networks are extremely complex. Transformers may operate at close to full load for most of the year, or else be very lightly loaded, either to provide spare capacity or as a result of lower than expected growth in demand. Distribution transformer losses are discussed in more detail in Sections 10.1-10.4.

Figure 6 Distribution Losses for LV and HV Customers, United Kingdom Ditribution Utilities (%)

Utility	1990/1991	1991/1992	1992/1993	1993/1994	1994/1995	1995/1996	1996/1997	1997/1998
Eastern	7,0	7,0	6,8	6,5	6,7	6,9	7,1	7,0
East Midlands	6,6	6,5	6,7	6,8	6,0	6,1	6,1	6,1
London	7,8	7,2	7,0	7,0	7,1	6,7	7,1	6,8
Manweb	9,8	9,1	8,7	8,7	8,1	8,8	8,8	9,0
Midlands	6,2	5,9	5,7	5,5	5,5	5,5	5,6	5,5
Northern	7,5	7,6	6,8	7,2	6,1	6,8	6,9	6,7
Norweb	7,1	7,1	6,3	6,3	6,4	4,8	5,0	5,7
Seeboard	7,9	7,7	7,6	7,5	7,5	7,1	7,6	7,7
Southern	7,1	7,2	7,1	7,0	7,0	7,2	7,2	7,2
Swalec	8,9	8,4	8,1	7,0	7,0	6,7	8,0	6,9
Sweb	8,6	8,5	8,5	8,3	7,3	7,2	7,9	7,3
Yorkshire	6,3	6,3	6,2	6,2	6,5	6,5	6,5	6,5
Scottish Power	8,5	7,2	7,7	8,1	8,0	6,7	7,2	7,2
Hydro-electric	9,5	8,9	9,0	9,1	9,1	9,0	9,0	9,1
Average	7,6	7,2	7,1	7,0	6,9	6,7	6,9	6,8

There is also a need to balance the loading of the network as far as possible, and provide alternative routes to the major points of demand. Transformers are sometimes moved between sites to meet changed load demands. Some techniques now used in network management, for example deliberately running transformers at above their rated capacity, can be expensive in terms of losses.

The lack of reliable data also applies to individual utility losses, as well as the national loss statistics described in Section 5.9. Some utilities produce figures for distribution system losses (See Figure 6). Utilities may be rewarded by a regulator or national government for reducing losses, for example by environmental subsidies or tax concessions.

Unfortunately, these loss figures are produced by various empirical calculations, and not directly by metering or data logging. They cannot be reconciled with generation or engineering data, or by comparing energy purchases with sales. For this reason, it is not possible to demonstrate, for example, the incremental savings which a utility would achieve by the installation of a single energy-efficient transformer.

6 DISTRIBUTION TRANSFORMER INSTALLATIONS

6.1 Ownership

Electricity utilities are estimated to own and operate about 70% of the total population of distribution transformers in the EU, and represent a similar proportion of the market for new units. Major utilities also control most of the larger items of installed generation and transmission plant in Europe, but the distribution transformers can be owned by the host of regional and municipal distribution utilities. Changes in utility ownership, for example as a result of privatisation, usually result in changes in the ownership of the transformers installed in the network.

Transformer ownership outside the utility sector is shared between the non-utility electricity supply systems, described in Section 5.3, and the medium-sized customers for electricity. These include the proprietors of small factories, office blocks, supermarkets, schools, hospitals, apartments, hotels etc. They typically purchase power from a utility at 10-20kV, and own the distribution transformer and associated switchgear which undertakes the final step in reducing the voltage to 400/230V.

6.2 Population

The population of distribution transformers installed in European electricity utility and private sector networks is estimated to be about four million units. Statistical records are poor, particularly for privately owned installations, but the data which is available suggests that the total is broken down by size and type of construction approximately as follows:

Table A

Distribution transformer population, European Union

Category	Primary Voltage (kV)	No of Transformers	Total Capacity (GVA)
Liquid-cooled, <250kVA	20,10 etc	2,000,000	
Liquid-cooled, 250kVA and above	20,10 etc	1,600,000	1,600
Dry-type, cast-resin	20,10 etc	400,000	

Source: Utility statistics, ECI estimates

Non-utility distribution transformers account for about 30% of the total population, but a much higher proportion, possibly around 50%, of the total installed capacity. Non-utility transformers tend on average to be larger than those operated by electricity utilities.

6.3 Transformer Age Profile

The distribution transformers which have been installed in the EU in the post-War period, have shown great reliability. They have no moving parts, and are designed for a lifetime of 20-30 years, but have successfully operated for much longer. A rough indication from comparing the distribution transformer annual sales estimates in the EU, (approximately 150,000) with the transformer population (approximately 4 million) suggests a lifetime for each unit, in a market which is relatively static, of 30-40 years.

Life spans have also been extended by the fact that many transformers installed in the 1960s, when the growth of demand for electricity was at a peak, were lightly loaded to allow for future expansion, thus reducing the effects of heating, cooling stresses and insulation ageing. Combined with lower investment levels to meet new demand, the result is a skewed age profile for the population of distribution transformers currently installed in Europe.

Although modern transformers can be more efficient in terms of energy losses, older transformers have a reasonable performance. Their costs are completely written off, they are compatible in engineering terms with the associated circuit breakers and fuse-gear, and provide little incentive for replacement. Cases of transformer damage and failure, major network redesign schemes, and excessive transformer noise levels, represent the main opportunities for reinvestment.

6.4 Failures

Only limited information is available about the transformer failure pattern in Europe. Several studies have been undertaken, but the results are rather inconclusive. A 1983 survey based on 47,000 transformer-years of service in 13 European countries estimated the mean-lifetime-between-failures (MLBF) of installed transformers to be 50 years, and showed design defects, manufacturing problems and material defects to be the main causes of failure.

The same project identified windings and terminals to be the components most likely to cause failure in service. Failures in coils using jointed conductors, built in earlier years, have caused some problems. A high proportion of failures in pole-mounted distribution transformers result from lightning strikes.

Unacceptable noise levels, and incompatibility with more modern circuit breakers and fuse-gear, are often cited as being more important influences on renewal programmes than complete breakdown. One source reports the failure rate for installed distribution transformers at approximately 0.2% per year.

6.5 Investment Programmes

There is evidence of considerable remaining spare capacity in the existing population of distribution transformers in the EU. Load diversity factors, load monitoring and overload characteristics are now much more sophisticated than in the past. These factors tend to depress further the installation rates for new transformers.

A number of new electronic control technologies for power supply systems are being introduced to optimise the use of existing hardware, as an alternative to installing new plant, although these mainly apply to the HV system rather than the distribution network. Condition monitoring of transformers, to provide warnings of overload and failure, is contributing to transformer lifetimes. Some utilities are introducing demand side management (DSM) techniques, to reduce the load on the generation and distribution system. These trends tend to work against investment in new transformers.

However, the existing population of distribution transformers is ageing, with many transformers over 40 years old. The age profile of the power transformer population in Europe is widely regarded as giving cause for concern.

Some EU Member States have made attempts to direct utility funds to distribution network renovation, but these have not been generally successful. Newly privatised utilities are reported to show less interest in longer-term problems, and demand more rapid paybacks, than the public sector network operators they have replaced. However older transformer installations are being gradually renewed, and possibly 60-70% of current spending is associated with replacement.

7 THE EU DISTRIBUTION TRANSFORMER MARKET

7.1 Market Size

Figure 7 shows the estimated breakdown of 1997 sales of distribution and smaller systems transformers in the EU by number of units, size and sales value. Smaller transformers, below 650kVA, account for about 85% of sales and 55% of value.

There is a sharp contrast in size and sophistication between conventional distribution transformers and the larger units, between 1,600-10,000kVA, used in the primary distribution network and for supplying larger consumers. Distribution transformers account for about two-thirds of sales value, but represent 95% of total numbers.

7.2 Growth Rates

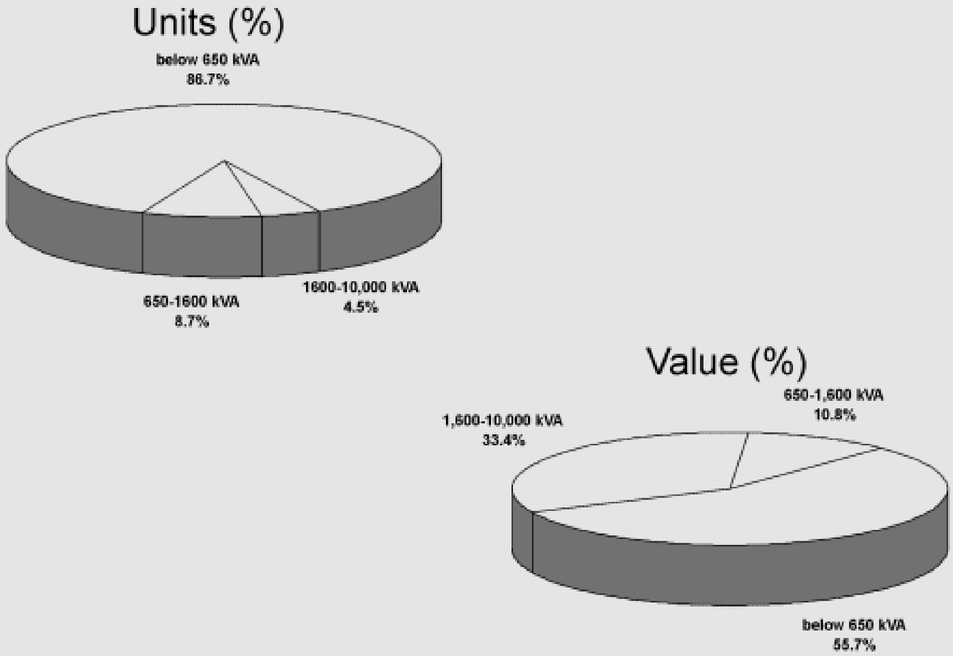
The European market for distribution transformers has been depressed since the early 1980s, and at present, the size of the market is reported to be approximately static. This reflects the age profile and investment levels discussed in Section 6.

The future impact of power industry development on distribution transformer volumes is difficult to assess. The spare capacity in the installed population of distribution transformers is considerable. Electricity generation based upon natural gas or renewables, including combined heat and power installations, at sites close to the point of use, suggests a reducing need for transmission across long distances, but will increase the volume of smaller transformers in the network.

The age of the installed population, and the replacement of units contaminated with toxic coolants, represents a possible opportunity. Some specific programmes to replace distribution plant more frequently have been mentioned.

On balance, we forecast that distribution transformer sales will remain constant in Europe in the next 10 years. The increase in private generation and the need for replacement of older units is likely to be balanced by continuing overall low growth rates in electricity demand, and the more sophisticated operating techniques for managing the low-voltage network.

Figure 7 **European Distribution Transformer Production**



Source : ECI estimates

7.3 Purchasing Policies and Procedures

Distribution transformers are usually built against a specific customer order. The large number of operating voltages and capacities in grid networks means that it is quite common in Europe for a single utility to be buying 50 or more different types and sizes of power systems transformer.Electricity utilities may place contracts for their transformer purchases for a year or more in advance. A typical requirement would be several hundred units. In this case, a contract is negotiated, based on tenders received from a short-list of approved suppliers. Public sector utilities in the European Community must advertise major contracts Europe-wide.

In the tender, utilities either specify maximum levels for load and no-load losses, or use loss capitalisation, leaving it to the transformer manufacturer to design the optimum transformer in terms of minimum total cost (purchase price + cost of losses). The former is common practice in France, Belgium and Germany. Loss capitalisation, on the other hand, is commonly used in UK, Scandinavia and Switzerland, among others. The use of loss capitalisation tends to lead to higher efficiency transformers (cf Scandinavia, Switzerland) but not necessarily (cf UK). These practices are further explained in sections 10.5 and 10.6.

7.4 Standards and Designs

There are European specifications for power systems transformers, which set standards for performance, including power losses. These have consolidated earlier national standards, and are compatible with International Electrotechnical Commission (IEC) world standards. They have been developed by the European Committee for Electrotechnical Standardisation (CENELEC), in consultation with UNIPEDE.

The distribution transformer standards applicable within the EU are described in detail in Section 10.1. Non-utility outdoor distribution transformers are superficially very similar to utility transformers, but the specifications and sizes may be different. For example, many European railways are supplied at 15kV, 162/3Hz, single phase. Mining transformers are often flameproof.

Distribution transformers with conventional oil cooling and installed on indoor sites, for example the basement of a large commercial building, are considered to pose a possible fire risk. They are required by the building regulations in many EU countries either to use non-flammable coolants, or to be dry-type, without coolants. Polychlorinated biphenyls (PCBs), the principal coolant used in the past, have been linked with the production of highly toxic chlorine compounds, mainly dioxins, at high temperatures. Non-toxic coolants are now available, and cast resin clad transformers offer an alternative to dry-type construction.

Reliability is reported to be the main factor influencing the way in which distribution transformers are chosen by consulting engineers and non-utility sector customers. Their installations are relatively small in scale, and unlike utility networks may have only limited back-up in the case of transformer failure.

8 TRANSFORMER MANUFACTURE IN THE EU

8.1 Industry Overview

The EU electricity systems transformer industry is an important component of the electrical engineering sector, with an output valued at approximately €3 billion per year. The European transformer manufacturers are major exporters of transformers worldwide, and the leading producers have established a number of overseas manufacturing operations. These factories mainly supply local markets, and replace earlier export business, but in some cases are capable of building transformers for sale world-wide, complementing the resources of the parent company. EU manufacturers have moved rapidly to establish a position in Central Europe, mainly by the acquisition of existing companies.

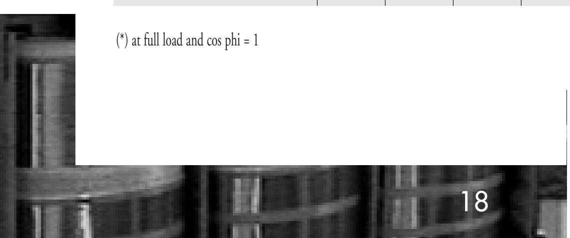
Following substantial growth in post-war years, the industry has been forced to contract and rationalise in the period since 1980, in the face of slowing growth rates in electricity demand, the completion of national electricity supply grid networks, and the long installed life span of transformers in service.

Since 1990 transformer demand in Europe has stabilised and remained reasonably steady, although at lower levels, and competition is still intense. This is reflected in selling prices, continuing losses by some companies, further closures and mergers, and a

Figure 8 Typical Distribution Transformer Parameters

RATING	kVA	100				400						1600					
HV	kV	20				10						20					
LV	V	400				400						690					
LOSS-LEVEL	HD428	A-A'	C-C'	A-AMDT	C-AMDT	A-A'	A-A'	C-C'	C-C'	A-AMDT	C-AMDT	A-A'	A-A'	C-C'	C-C'	A-AMDT	C-AMDT
NO-LOAD LOSSES	W	320	210	60	60	930	930	610	610	150	160	2.600	2.600	1.700	1.700	380	420
LOAD LOSSES	W	1.750	1.475	1.750	1.475	4.600	4.600	3.850	3.850	4.600	3.850	14.000	14.000	17.000	17.000	17.000	14.000
TOTAL MASS	kg	520	650	740	770	1.190	1.200	1.300	1.400	1.590	1.750	3.300	3.240	3.370	3.680	4.310	4.550
CORE MASS	kg	150	220	220	225	435	440	450	540	570	600	1.100	1.210	1.200	1.460	1.400	1.550
FLUX DENSITY	T	1,83	1,45	1,35	1,35	1,83	1,84	1,65	1,6	1,35	1,35	1,84	1,84	1,7	1,6	1,35	1,35
CONDUCTOR MATERIAL	Cu/Al	Cu	Cu	Cu	Cu	Cu	Al	Cu	Al	Cu	Cu	Cu	Al	Cu	Al	Cu	Cu
WINDING MASS	kg	85	115	130	155	203	145	350	220	360	450	505	295	725	465	1.120	1.225
CURRENT DENSITY	A/mm2	2,9	2,3	2,35	2	2,9	1,55	2,1	1,1	2,3	1,85	3,65	2	2,75	1,4	2,45	2,1
HEIGHT	mm	1.300	1.300	1.300	1.300	1.330	1.420	1.350	1.550	1.400	1.400	1.890	1.820	1.860	2.000	1.870	1.900
LENGTH	mm	890	830	1.050	1.100	1.320	1.100	1.010	1.130	1.340	1.240	1.820	2.000	1.710	1.850	1.770	1.770
WIDTH	mm	600	560	620	620	800	840	800	780	770	800	1.180	1.280	1.100	1.020	1.320	1.200
EFFICIENCY (*)	%	97,94	98,32	98,19	98,46	98,62	98,62	98,89	98,89	98,81	99,00	98,78	98,78	99,02	99,02	98,91	99,10
SOUND POWER	dB(A)	57	36	59	59	61	68	56	58	68	68	68	72	63	63	76	76
UNIT COST	BEF	102.400	112.900	139.400	143.900	176.900	172.900	196.900	189.800	257.100	274.200	391.000	373.200	415.800	408.200	607.100	626.500
UNIT COST	%	90,7	**100**	123,5	127,5	93,2	91,1	103,7	**100**	135,5	144,5	95,8	91,4	101,9	**100**	148,7	153,5

(*) at full load and cos phi = 1



determination on the part of companies to secure orders, even at very low margins, in order to survive.

Competition from companies in Central, Eastern and Southern Europe, where labour costs are lower and home markets are depressed, is adding to the pressure, as is the business in second-hand and refurbished transformers. There are however some signs that volumes may be beginning to improve.

8.2 Industry Structure

Distribution transformers, together with special transformers of similar size used for applications such as power rectification, electric furnaces, electrolytic refineries etc, are produced by about 200 companies in the Europe. A considerable number of additional companies work only on transformer repair and refurbishment, although they have the skills to build new units.

We estimate that over 200 transformer factories have closed since the mid-1960s. Increased productivity, combined with pressure from imports and moderate forecasts for growth, mean that further rationalisation can be expected.

Following a major merger in 1999, creating a clear leader in the sector, the European market is now dominated by 6 producers. Two of these are part of major electrical engineering groups, organisations manufacturing a comprehensive range of products and systems for power supply and heavy electrical engineering, including steam and gas turbines, generators, transformers and motors, switchgear and transmission equipment.

Together the major producers account for over 50% of the total EU output of distribution transformers. Additional three companies, all capable of building both distribution transformers and larger units, are responsible for a further 10% of output.

8.3 Manufacturing Investment

Sophisticated mechanised or flow-line production is not usual in distribution transformer factories, except for the smallest sizes of pole-mounted units. There are, however, some examples in Europe of high levels of investment and automation. Ground-mounted distribution and larger transformers are mostly built in bays or on stands, reflecting the very wide range of standards and sizes involved.

Utility customers often let an annual contract for a number of distribution transformers, typically several hundred units. Labour content and skill levels are high, with a great deal of specialised knowledge and experience associated with design and testing.

This pattern of manufacture and ordering is reflected in the structure of the industry. The larger companies, which dominate the sector, have been built up partially by acquisition and rationalisation, but they continue to operate a number of separate transformer factories. Each of these will have its own product range, specialist skills and customer base. Typically an independent power systems transformer producer, or a transformer factory within a large group, has a volume of output in the range €20-100 million per year.

8.4 Product Ranges

An example of the product range of a typical major European transformer manufacturer is as follows:

- oil-filled distribution transformers from 15kVA to 3,150kVA/36kV
- cast resin transformers up to 10MVA/36kV
- power transformers from 4MVA to 500MVA/500kV
- autotransformers up to 400MVA/500kV
- HVDC transformers up to 275MVA/500kV.

An overview of typical parameters for the distribution transformers used in European electricity supply networks is shown in Figure 8. This provides a further indication of the wide range of products manufactured, in terms of physical size, use of materials and price.

A standard ground-mounted distribution transformer costs about €10,000 and weighs four tonnes. A typical distribution transformer factory could build a few thousand of these units per year.

Distribution transformers factories are usually dedicated to manufacturing these products for electricity supply industry and non-utility customers. Manufacturers do not normally build other equipment, such as large power systems transformers or small transformers, on the same site. Some smaller companies produce only pole-mounted transformers. Non-standard power transformers, such as flameproof units, electric locomotive transformers or marine power supplies are often produced in specialist facilities.

8.5 Exports

Exports by European transformer manufacturers are running at about €1000 million per year. Export volumes help to balance the workload of transformer factories, and are particularly important when domestic demand is depressed.

Trade within Europe is increasing as the power supply industry is progressively deregulated. This new competition is often not welcomed by those manufacturers who have had to face the decline in industry size, but were previously protected in their home markets by utility purchasing policies and national specifications.

Exports to non-European destinations account for over one-quarter of the total output. The main overseas markets for power systems transformers manufactured in Europe are the United States, India, Saudi Arabia, Indonesia and China. A proportion of this is associated with turnkey projects undertaken by major electrical engineering groups.

8.6 Repair and Maintenance

Repair and maintenance now represent a considerable proportion, up to 20%, of the activities of some transformer manufacturers. This ratio is increasing as the population ages. Rebuilding provides an opportunity to improve efficiency at a lower cost than purchasing new machines.

Special skills are required to deal with the PCB contamination which affects many older transformers installed in the EU, even those using mineral oil as the coolant. It is not clear in some cases how this contamination has occurred, but it may result from poor housekeeping in past manufacturing or maintenance routines.

8.7 Representation

There are national trade associations representing the transformer manufacturers in larger European countries, usually linked to the national electrical engineering trade body. The trade association for the European transformer industry is the Committee of Associations of European Transformer Manufacturers (COTREL), which links the national trade associations. The members of COTREL are shown in Appendix B.

Non-members of COTREL could represent a further 20-30% of total production volume. COTREL also takes responsibility for transformer industry relationships with the European Commission, through the national association in Belgium (Fabrimetal).

COTREL meets three times per year, when an agenda of issues is discussed by the executive and members. Statistics are also collected on transformer production. COTREL report that 2-3 years ago a working group was set up to consider the problem of older transformers and possible replacement initiatives. It was however abandoned.

9 DISTRIBUTION TRANSFORMER TECHNOLOGY

9.1 Design Concepts

Transformer design is extremely specialised, and requires a capable and experienced design team. Transformers are manufactured against specific customer invitations to tender, taking into account the following basic parameters:

- **flux density (or induction)**, a measure of the loading of the iron core. Each magnetic steel has its typical inherent core loss, directly related to its flux density. Once above the saturation induction of the steel, the flux will leave the core and no-load losses are no longer under control. Maximum flux density should therefore be limited to well below this saturation point. Energy-efficiency can be improved by selecting better performing, lower core loss steels, or by reducing flux density in a specific core by increasing the core size

- **current density** in the copper windings. Increasing conductor cross-section reduces the current density. This will improve energy efficiency, but also result in higher cost. Because copper losses are dependent on the loading of the transformer, it is necessary to consider how the unit is to be installed and used in practice

- **iron/copper balance**. The balance between the relative quantities of iron and copper in the core and windings. A "copper-rich" unit has a high efficiency across a wide range of load currents. An "iron-rich" unit has a lower initial cost price, and may be more economical when transformers are expected to be lightly loaded.

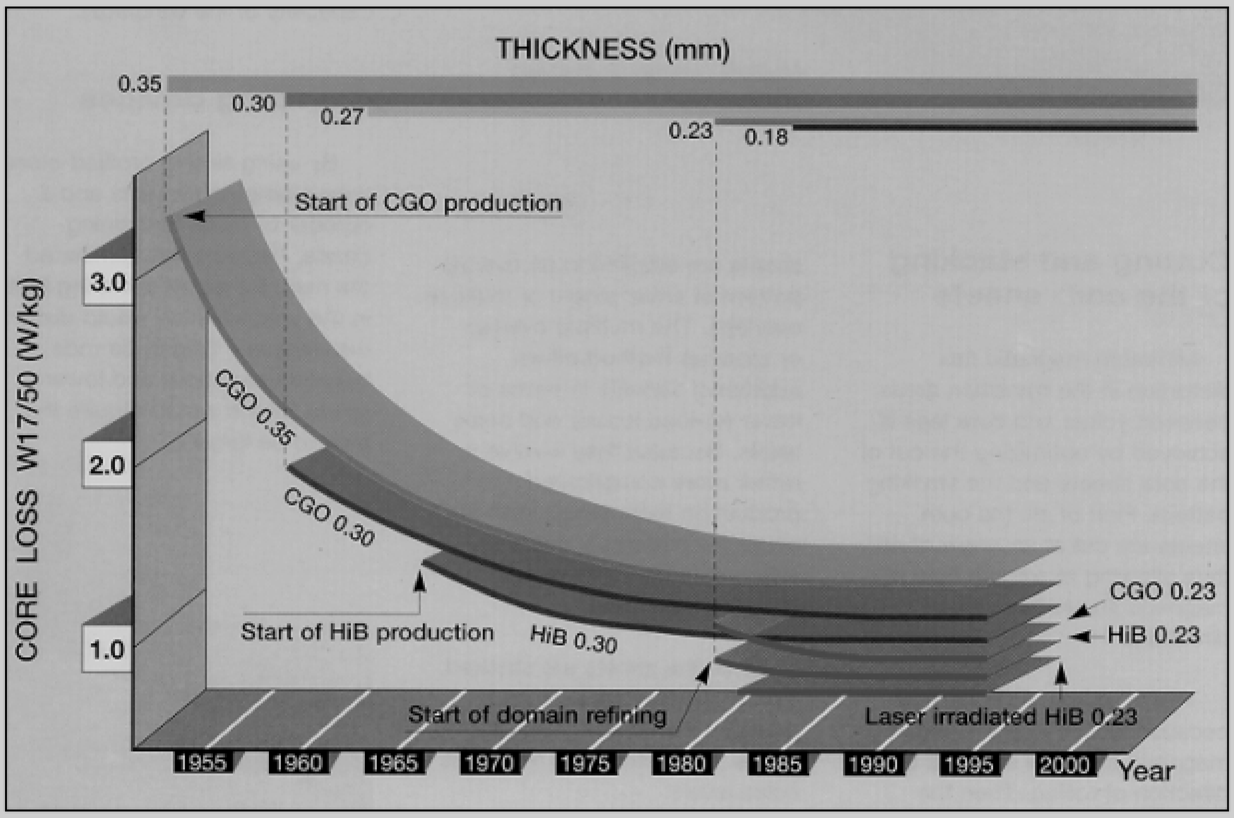
These basic considerations must then be combined with a wide range of other factors, to enable a competitive tender to be submitted to the customer. Copper and iron prices are continually changing, and this can affect the balance between the two materials.

A variety of proprietary steels are available for building the core, and the techniques to be used for the construction of the transformer core, windings, insulation and housing need to be decided. Alternative materials, such as aluminium coils or pre-formed copper windings, could be considered.

The energy efficiency of a distribution transformer, in terms of losses, is usually specified by the customer. These, and other factors directly associated with energy efficiency, are discussed in Sections 10.1-10.4.

Figure 9

Development Stages, Transformer Steels



Source: Pauwels

9.2 Transformer Steels

The energy efficiency of distribution transformers is fundamentally dependent on the type of steel used for building the transformer core. More specialised steels, particularly suitable for distribution and larger transformers, have developed in a number of stages. (Figure 9).

Thin **hot-rolled steel sheet**, with a silicon content of about 3%, became the basic material for fabricating electromagnetic cores in about 1900. Individual sheets were separated by insulating layers to combine low hysteresis losses with high resistivity. **Cold rolling** and more sophisticated insulation techniques were progressively developed.

Grain-oriented silicon steels, in which the magnetic properties of transformer steels are improved by rolling and annealing, to align the orientation of the grains, became available in the mid-1950s.

Various processing and coating techniques, combined with a reduced silicon content, were incorporated into **high permeability grain-oriented steels**, about 10 years later. During the 1980s, techniques were introduced for **domain** refinement, reducing domain width by mechanical processes, principally laser-etching.

A recently developed core material, **amorphous iron**, represents a significant new advance in transformer steels. Amorphous iron is produced by rapidly cooling molten metal into a very thin ribbon with a non-crystalline structure.

At the same time other technology advances have progressively improved the performance of the steel used in distribution transformer manufacture. These include rolling and coating technology, reduced gauge (thickness), material purity, dimensional tolerances, internal and surface stresses and tension. The various materials, their properties, and the extent to which they are used, are described in more detail in Sections 9.3-9.6.

9.3 Grain-oriented Steels

Conventional grain-orientated (CGO) steels are rolled from silicon-iron slabstock, and coated on both sides with a thin layer of oxide insulating material to reduce eddy-currents. They are supplied in Europe in about 10 standard thickness. The European standard, EN10107, reflects the international IEC 60404 standard, and describes a range of gauges from 0.23-0.50mm (previously M3-M7, a nomenclature which is recognised world-wide).

CGO steels remain the standard raw material for distribution transformer manufacture in Europe. They are estimated to account for over 70% of the total steel consumption in distribution transformer production, estimated at about 100,000 tonnes per year.

Demand is still very much skewed to the thicker gauges. Thinner gauge CGO and other more sophisticated raw materials are considerably more expensive, reflecting higher capital investment and technology levels, as well as additional processing steps. Core production costs are also higher.

High permeability steels are manufactured to the same European Standard as CGO, and are available in about five gauges ranging from 0.23-0.30mm. They account for about 20% of total consumption in transformer manufacture.

9.4 Domain Refined Steels

A further reduction of losses is achieved by domain limitation. Domain refined steels are produced mainly by proprietary laser etching processes. Together with grain-oriented steel, they offer material with specific losses ranging from about 0.85-1.75W/kg at 1.7T/50Hz for distribution transformer manufacture.

Commercially available domain-refined steel is typically 0.23mm thick. Together with amorphous iron, see below, it has a market share in Europe for transformer manufacture of about 10%.

9.5 Amorphous Iron

Distribution transformers built with amorphous iron cores can have more than 70% reduction in no-load losses compared to the best conventional designs. There is only one known producer world-wide of amorphous iron material suitable for distribution transformer manufacture.

Amorphous iron became commercially available in the early 1980s. It is reported to have been used in the construction of several hundred thousand distribution transformers in the US, Japan, India and China.

European experience of manufacturing and installing amorphous iron distribution transformers in the EU has been very limited (See Section 10.5) This is partly due to network design characteristics which differ from US and Japanese practice. However a very large (1,600kVA) amorphous iron three-phase distribution transformer has recently been built and installed in the EU.

9.6 Future Developments

Research and development on magnetic steels is vigorously pursued world-wide. The licensing of new processes has been extremely prevalent in this sector for many years.

Distribution transformers appear to represent a poor return on recent development effort, with the possible exception of amorphous iron, because of the competitive nature of the market. However new magnetic steel developments also benefit from other applications, notably electric motors and small transformers. Future emphasis on energy efficiency and environmental impact could change this picture.

Among areas of interest are:

- the ending of certain patents on amorphous iron processes, which could encourage other producers to enter the market

- the adoption of the design of amorphous iron transformers to European practice (i.e. use a three legged Evans-core design for Dy-connected transformers, resulting in reduced length, cost and noise)

- mechanical or thermal processes other than laser etching for domain limitation

- the use of thinner steels. Magnetic steels with gauges as low as 0.05mm are being offered in narrow strip for small transformers and coils. For larger transformers 0.18mm steel is available, but both raw material and core fabrication costs rise very rapidly as the gauge is reduced.

9.7 Conductor Developments

The conductor materials for winding the coils of distribution transformers are supplied in the form of wire, narrow strip or sheet. They have not experienced the same significant step changes in recent years as core steels. The main developments have been:

- the availability of copper and aluminium wire-rod produced by continuous casting and rolling (CCR) processes, combined with mechanised handling techniques. This has enabled semi-fabricators to offer wire and strip in much longer lengths than was previously possible, increasing transformer reliability. The welded or brazed joints in strip, which were inevitable in rod produced from wire-bar, created weak points in the finished coils

- both copper and aluminium are now available in wide sheet and foil form with high dimensional tolerances. Sheet has extensively replaced strip for the LV windings of distribution transformers

- continuous cold rolling processes are now being introduced for conductor strip production. This potentially offers better availability, and more consistent quality, than is available from drawn strip.

Potential developments include the shaping of conductors to improve the mechanical strength of the completed coil, and more compact fabrication of coils.

9.8 Other Materials

Developments have also taken place in the other components used in distribution transformer manufacture. The most significant are the development of flame-proof coolants to replace PCBs, and the use of cast resin encapsulation as an alternative to dry construction in non-liquid cooled transformers (See Section 7.4)

More sophisticated insulating papers and boards, including synthetic and self-bonding papers, are also available.

9.9 Core Fabrication and Assembly

The way in which distribution transformer cores are designed, cut, fabricated and assembled, plays an important part in energy efficiency. The cost of a completed core is also affected by these factors. Various levels of mechanisation and automation are available for the cutting and stacking processes.

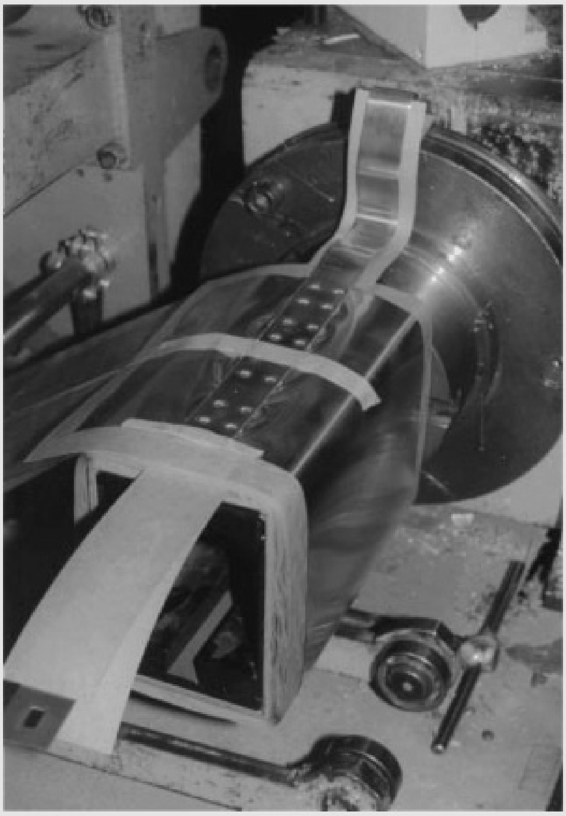
There is a specific problem of the capacity of European transformer manufacturers to handle and process magnetic steel at gauges below 0.23mm, and to fabricate amorphous iron in-house. It seems likely that the steel suppliers will attempt to extend their capability to supply built cores and semi-fabricated components.

9.10 Coil Winding and Assembly

The processes of winding the conductor coils and then fitting them onto the assembled core are labour-intensive, and require skilled workers. Again the performance and energy efficiency of a distribution transformer greatly depends on these steps. Mechanised winding, under operator control, is increasingly used

Figure 10

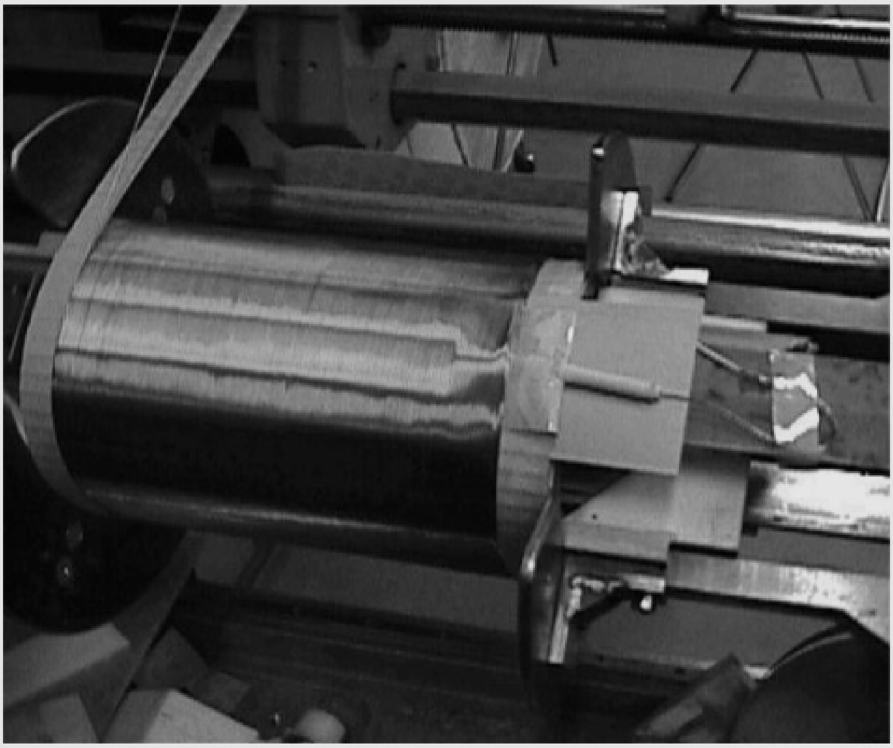
Spiral Sheet Low-voltage Winding



Source: Pauwels

Figure 11

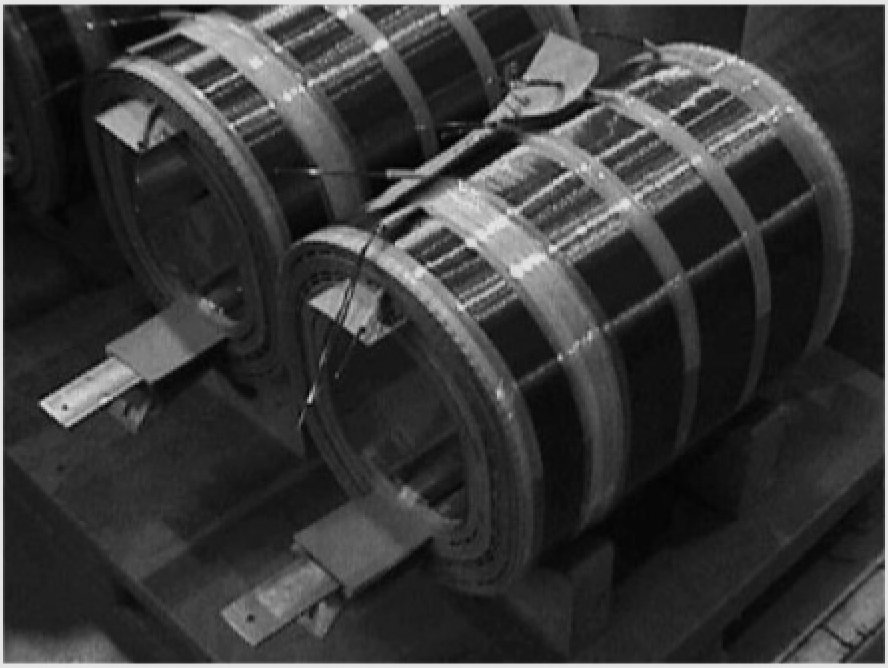
Multilayer Coil High-voltage Winding



Source: Pauwels

Figure 12

Disc Coil High-voltage Winding



Source: Pauwels

for producing coils based upon copper wire, wide strip and aluminium foil.

The main types of coil which are now used in distribution transformers are:

- **spiral sheet** windings, using wide copper strip or aluminium foil (Figure 10). A relatively recent development, used in place of helical coils for the LV windings of distribution transformers, particularly where there are only a small number of turns required in the coil

- **multilayer coils** for HV windings (Figure 11). The complete winding is a single unit, wound in wire, consisting of several layers and a number of turns per layer

- **disc coils**, particularly for the HV windings of dry-type transformers (Figure 12). A number of radially wound discs produced from a single length of conductor, separated from one another by insulating spacers.

There is also an established coil-winding industry in the EU, which mainly offers windings for smaller transformers, and specialist products such as current transformers. These companies frequently have encapsulation capabilities, and are able to supply ready-built coils for dry-type transformers.

9.11 Superconducting Transformers

A number of superconducting distribution transformers have been built. One company has developed a nitrogen-cooled 630kVA high temperature superconductor (HTS) transformer, which was installed in the Swiss electricity supply network in 1997. This is a single-phase transformer, and considerable engineering problems are reported in producing three-phase versions.

It is widely agreed that superconductivity will always remain much more expensive for power distribution transformers than conventional technology. The most promising areas appear to be in specialist applications, particularly traction transformers, where increasingly large transformers are required for train motors in railway networks.

9.12 Technology Sources

Power systems transformers are very specialised products, and R&D activities outside the major transformer manufacturing companies are limited. Even here most effort is centred on practical product development, together with the testing and evaluation of new materials. Only a few distribution transformer manufacturers in Europe have significant fundamental R&D capabilities dedicated to transformer research.

Much of the recent work on the steels used in distribution transformers has originated from Japan and the United States, although European companies have a world reputation for the steels and non-ferrous alloys used in smaller transformers. Some of the technology for adding value to conductors and coils, such as the continuous cold rolling of narrow strip, has also been imported.

However there are a number of centres of excellence in Europe, with a capability for R&D and demonstration of distribution transformers or component materials. Many European universities have a capability in magnetic materials within their electrical engineering or materials departments.

10 TECHNICAL AND ENGINEERING APPRAISAL

10.1 Distribution Transformer Standards

Most of the characteristics of distribution transformers are specified in national or international product standards. The application of standards can be legally require, or by specific reference in the purchase contract.

Generally, the purpose of standards is to facilitate the exchange of products in both home and overseas markets, and to improve product quality, health, safety and the environment. International standards are also of importance in reducing trade barriers.

For distribution transformers purchased in the European Union, three levels of standards are applicable:

• world-wide standards (ISO, IEC)

• European standards and regulations (EN, HD)

• national standards (e.g. BSI, NF, DIN, NEN, UNE, OTEL).

European Harmonisation Documents are initiated if there is a need for a European standard. The draft HD is a compilation of the different national standards on the subject. The HD is finalised by eliminating as many national differences as possible. When a harmonisation document (HD) has been issued, conflicting national standards have to be withdrawn within a specified period of time, or modified to be compatible with the HD. Usually, the HD is the predecessor of an European standard (EN), which must be adopted as a national standard in the EU member countries. Thus, purchase orders which refer to national standards are compatible with European standards (EN) and/or harmonisation documents (HD).

Among the many international standards for distribution transformers, two main European Harmonisation Documents specify energy efficiency levels:

• HD428: Three-phase oil-immersed distribution transformers 50Hz, from 50 to 2,500kVA with highest voltage for equipment not exceeding 36kV

• HD538: Three-phase dry-type distribution transformers 50Hz, from 100 to 2,500kVA, with highest voltage for equipment not exceeding 36 kV.

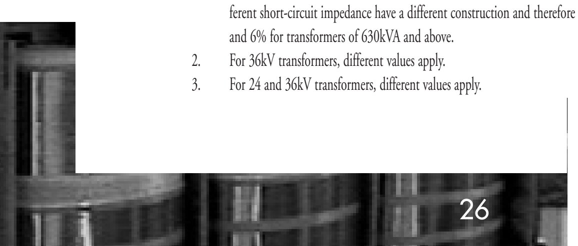
A separate HD is under consideration for pole-mounted transformers.

In the next Section, the efficiency limits defined in these standards are discussed. The standards however leave considerable freedom for local deviations in energy efficiency, which implies that energy loss levels may (and do) still vary across European countries. This is also discussed in the next Section.

Figure 13 Distribution Transformer Loss Standards

	Load Losses for Distribution Transformers				No-Load Losses for Distribution Transformers			
RATED POWER	OIL-FILLED (HD428) UP TO 24kV2)			DRY TYPE (HD538)	OIL-FILLED (HD428) UP TO 24kV2)			DRY TYPE (HD538)
	LIST A	LIST B	LIST C	12kV PRIMARY 3)	LIST A'	LIST B'	LIST C'	12kV PRIMARY 3)
kVA	W	W	W	W	W	W	W	W
50	1,100	1,350	875	N/A	190	145	125	N/A
100	1,750	2,150	1,475	2,000	320	260	210	440
160	2,350	3,100	2,000	2,700	460	375	300	610
250	3,250	4,200	2,750	3,500	650	530	425	820
400	4,600	6,000	3,850	4,900	930	750	610	1,150
630 /4%1)	6,500	8,400	5,400	7,300	1,300	1,030	860	1,500
630 /6%	6,750	8,700	5,600	7,600	1,200	940	800	1,370
1000	10,500	13,000	9,500	10,000	1,700	1,400	1,100	2,000
1600	17,000	20,000	14,000	14,000	2,600	2,200	1,700	2,800
2500	26,500	32,000	22,000	21,000	3,800	3,200	2,500	4,300

Notes:
1. The short-circuit impedance of the transformers is 4% or 6%, in most cases. This technical parameter is of importance to a utility for designing and dimensioning the low-voltage network fed by the transformer. Transformers with the same rated power but with different short-circuit impedance have a different construction and therefore slightly different losses. For HD428 / HD538 compliant distribution transformers, the preferred values for the short-circuit impedance are 4% for transformers up to and including 630kVA, and 6% for transformers of 630kVA and above.
2. For 36kV transformers, different values apply.
3. For 24 and 36kV transformers, different values apply.



10.2 Rated loss levels of Standard Distribution Transformers

Distribution transformers built to HD428 and HD538 have a limited number of preferred values for rated power (50, 100, 160, 250, 400, 630, 1,000, 1,600 and 2,500kVA). Intermediate values are also allowed. The two key figures for energy efficiency, the load losses and the no-load losses, are specified for each rated power.

Figure10 gives the limits for load losses (often called "copper losses") for some important types of oil-filled and dry-type distribution transformers according to HD428.1 and HD538.1 for the preferred rated power range of the transformers. For oil-filled distribution transformers, the HD allows a choice of energy efficiency levels, A, B and C.

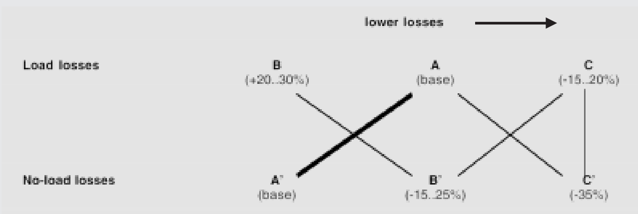
Loss values for transformers are usually, declared as maximum values with a specified tolerance. If higher losses are found at the factory acceptance test, the transformer may be rejected or a financial compensation for exceeding the loss limit may be agreed between client and manufacturer. In the same way, a bonus may be awarded to the manufacturer, mainly for large transformers, for a transformer with losses lower than the limits agreed.

The no-load losses (iron losses) for the same range of transformers are given below. For oil-filled distribution transformers, the HD offers a choice between three efficiency levels, A', B' and C' (Figure 13).

HD428 therefore allows customers to choose between three levels of no-load losses and three levels of load losses. In principle, there are 9 possible combinations, ranging from the lowest efficiency, (B-A') to the highest, (C-C'), which may be regarded as providing a high practical standard of energy efficiency for a distribution transformer.

HD428 defines five preferred combinations of these losses. These combinations are shown below in Table B, where the combination A-A' is chosen as the base case (shown as a bold line - the percentages refer to this combination).

Table B



There is a significant difference in total no-load and load losses between A-A' and C-C' distribution transformers, approximately 1.5kW for a 630kVA unit.

The freedom for choosing different levels of energy efficiency is increased by the fact that transformer buyers can comply with HD428/538 through the use of a capitalisation formula, rather than the tabulated losses shown in the standard. In this, they are free to insert their own capitalisation values, to which no restrictions are imposed. This process of loss capitalisation is described in Section 10.6.

If high capitalisation values for losses are chosen, transformers with low losses but with higher investment cost tend to be favoured. If however capitalisation values are set to zero, a purchaser effectively eliminates energy loss evaluation from the purchase decision, which favours the cheapest transformer.

HD428.1 (part 1: general requirements and requirements for transformers with highest voltage for equipment not exceeding 24 kV) as well as other HD sections also contain phrases such as "(...) in the case of established practice in the market (...) the transformers can be requested and, by consequence, offered, with losses differing from the tabled losses", which indicates some freedom to national or local deviations.

As stated before, HD428 and HD538 represent a compilation and/or compromise on the various old standards which were used in European countries. It appears to be rather unambitious in terms of the standards set, and by allowing capitalisation formulas to be used.

10.3 Loss levels of Standard Distribution Transformers when Loaded

The losses of a transformer show considerable dependence on the actual load. At no-load, the no-load losses are still present. At full load, the load losses are added to the no-load losses. For less than full load, the load losses decrease proportional to the square of the load.

For example, the total losses of a 400kVA oil-insulated transformer are shown opposite as a function of the transformer load, for the different loss combinations mentioned above.

The transformer efficiency can be calculated by dividing the losses by the power transferred. Here, the effects of reactive power should be accounted for, as reactive power causes current to flow, with its associated losses. This causes the efficiency of the transformer to decrease. By multiplying the transformer load (in kVA) by the so-called power factor (usually designated cos (), this effect is accounted for, showing the net power transformed.

Figure 14 shows the relative transformer loss as a function of the load. The relative transformer loss is equal to 100% minus transformer efficiency. Clearly, the relative losses follow a U-shaped curve, and transformers are typically at maximum efficiency when

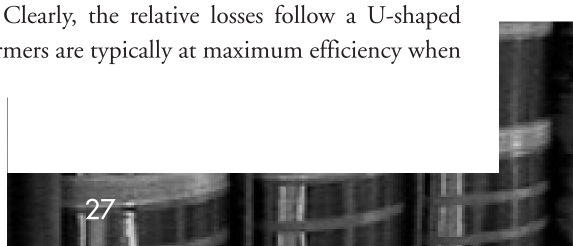
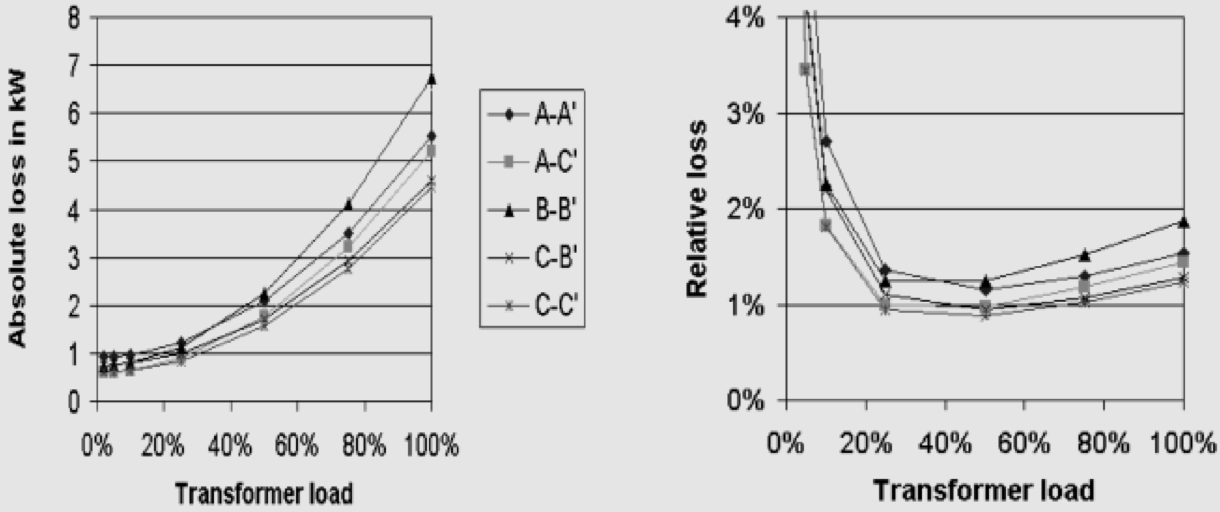


Figure 14

Total Losses of a 400 kVA Transformer as a Function of the Load (12kV and 24 kV Transformers



Source: European Harmonisation Documents

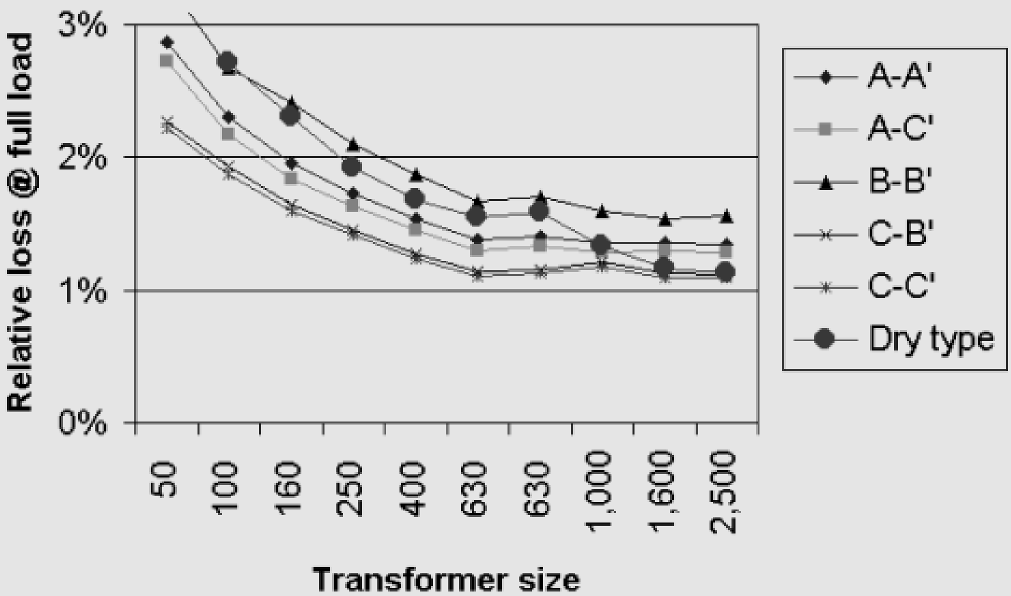
50% loaded. The figure also shows that B-B' transformers have less loss than A-A' transformers in the lower load region, while the A-A' transformers show lower loss in the region above 40% load. Which transformer is best with regard to energy efficiency thus depends on the application. C-C' transformers have 20-30% lower loss than the A-A' and the B-B' types.

Figure 15 shows how efficiency at full load varies with the size of the transformer, and includes dry-type transformers. The graph shows efficiency of the transformers of various sizes at full load. Clearly, economies of scale apply to the oil-filled distribution transformer and, to a stronger extent, to the dry-type transformer.

Because energy efficiency varies with load, the calculation of the net efficiency of a transformer over a year or over its lifetime is rather complex. Due to the square relationship between losses and load, the average load of a transformer is not an adequate parameter to calculate the annual energy losses or the average efficiency directly. There are, however, some empirical formulae available to estimate the annual transformer losses from the average annual load.

Figure 15

Dependendy of Transformer Losses on Size (kVA) for 12kV and 24kV transformers



Source: European Harmonisation Documents

10.4 Achievable Loss Levels

The HD428 C-C' loss level for oil-filled distribution transformers may, as mentioned before, be regarded as providing a high practical standard of energy efficiency for a distribution transformer.

There is no internationally agreed definition of an "energy-efficient" transformer. It is proposed to use the term "energy-efficient" transformer for the following transformers:

- oil-filled transformers: range C-C' (HD428.1) and D-E' (HD428.3)

- dry-type transformers up to and including 24kV: 20% lower than specified in HD538.1. HD538 mentions one list of preferred values, but explicitly allows the possibility for national standards to specify a second series with load and/or no-load losses at least 15% lower. Some transformer manufacturers offer dry-type transformers in normal and low-loss versions

- dry-type transformers 36kV: 20% better than specified in HD538.2, analogous to the previous category.

An important reason for choosing the values suggested above is the fact that these levels are entirely feasible within the current "state of the art" of nearly all transformer manufacturers. In the remainder of this report, the class of energy-efficient transformers is often referred to as C-C', as the oil-filled transformers form the majority of the transformers, and, among these, units up to 24kV are the most numerous.

An alternative way of defining "energy-efficient transformers" would be to by considering the energy-efficiency levels of the transformers sold on the market. This is be analogous to the concept of the US "energy star" transformer program (see Section 11). Here transformers with energy efficiency equal to or above that of the most efficient 35% being currently sold meet the requirement for Energy Star rating.

Figure 16 gives an impression of the way in which the distribution transformer population varies in Europe. It can be seen that reference to the population per country or for the European Union as a whole will produce different results. However, it seems preferable to address losses more absolutely.

Another way to define "energy-efficient transformers" would be the application of special windings, advanced steels or amorphous iron. An argument against this definition is that there are a number of practical considerations involved in deciding on the optimum choice of transformer for installation into a network. Moreover, the energy loss level is the key performance indicator of each transformer design with respect to energy efficiency and would consequently the fairest benchmark.

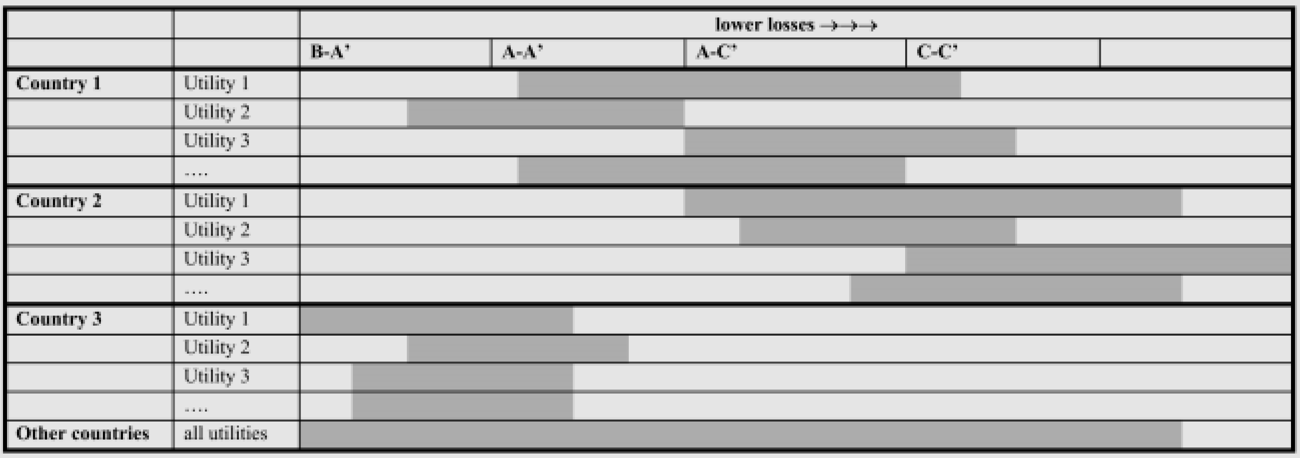
As expected, the loss level of "energy-efficient transformers" as defined above does not represent the maximum efficiency which is technically possible. Both load and no-load losses may be reduced significantly.

Load losses may be reduced beyond the levels mentioned above by following technical design measures:

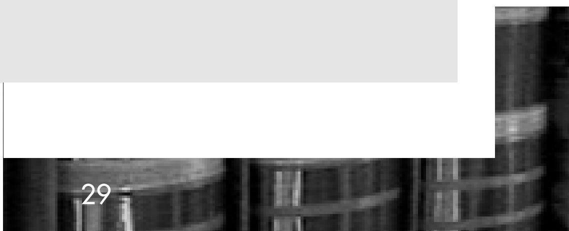
- increasing the conductor section of the transformer windings, which reduces conductor resistance and thus load losses. To a lesser extent, the application of ribbon or sheet conductors also contributes to reducing load losses. The disadvantage of increasing the conductor section is the higher investment cost. Another disadvantage is the larger size of the transformer, which may exceed the maximum sizes specified by the purchaser. This is

Figure 16

Fictitious Example of Different European Transformer Standards



Source: KEMA



partially offset by the reduction of heat production in the transformer, which lowers the need for cooling

- application of superconductor material for the windings, eliminating load losses. This technology is not yet mature and still very expensive. The main application will lie in larger transformers. Another drawback of superconducting transformers is the inability to withstand short-circuit currents of the level that are common in medium-voltage networks. These problems need to be solved before the superconducting transformer will become a viable option.

No-load losses may be reduced beyond the levels mentioned above by following technical design measures:

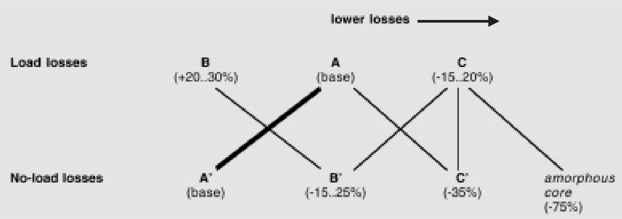
- increasing the core section, which reduces the magnetic field in the transformer core and thus the no-load losses. However, this results in higher investment cost. Another disadvantage is the larger size of the transformer, which may exceed the maximum sizes specified by the purchaser

- application of high-grade modern transformer core steel, see Section 9. It should be noted that the C-C' level can be reached without applying laser-etched transformer steel, the latter being regularly used in large transformers

- reduction of the thickness of the core laminations, see Section 9

- application of amorphous core material, see Section 9. The saving potential with respect to no-load losses is high, as shown in the table below, where the amorphous transformer is compared to the conventional types according to HD428.

Table C



The conclusion is that transformer efficiency may be raised well beyond the current level of energy-efficient transformers by using existing technology.

There are, however, some other important technical aspects that are essential to the adoption of energy-efficient distribution transformers and critical to some technologies:

- dimensions. Distribution transformers need to be aligned to switchgear, fit into enclosures or go through doorways. For larger transformers, the mass may also be a critical parameter. Many dimensional features are still defined at national level or even utility level

- noise level. Distribution transformers are often sited in buildings or residential areas, where strict limits on acoustic noise emission apply

- absence of technological risk. The distribution transformers currently in use are extremely reliable. Furthermore, the consequences of failure are severe, as most distribution networks are operated in radial configurations. Many networks have no back-up for a distribution transformer failure, with the consequence that a transformer outage will affect customers until the transformer has been replaced. For this reason, utilities tend to be very careful when adopting new technologies (see Section 11) unless a new design has unequivocally proven its reliability (preferably at another utility).

The options are compared qualitatively in Figure 17 (+ indicates a favourable score).

10.5 Loss Levels in Practice

(source: EDON)

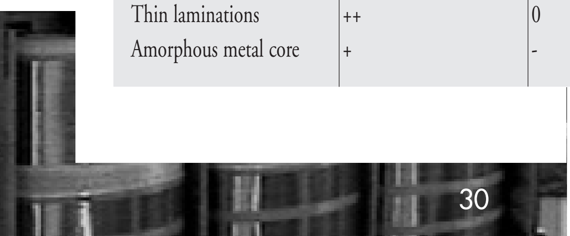
In practical installations, the loss levels of transformers are determined by three factors, the efficiency class specified, the load profile of the transformer and deviations from the standard loss values. The three factors will each be discussed below.

The efficiency class specified

There appears to be a "league table" of standards for distribution transformer losses specified by the electricity utilities of the various European countries. Switzerland, Scandinavian countries are said to set the highest standards, with France and Italy amongst the lowest (A-A') with France particularly keen to reduce no-load

Figure 17 Comparison of Technologies to Improve Energy Efficiency

	Absence of technological risk	Dimensions	Noise	Cost compared to C-C'	Energy saving @ light load	Energy saving @ heavy load
Increased conductor section	++	0/-	0	-	0	+
Superconducting windings	--	variable	0	---	-	+
Increased core section	++	0/-	0	-	+	0/+
Modern core material, Thin laminations	++	0	+	-	++	0/+
Amorphous metal core	+	-	-	--	+++	0/+



losses rather than load losses. Others are somewhere in the middle. Among values reported in the project were (oil-filled transformers):

Table D

Utility Distribution Transformer Loss Levels in Europe

Country	Utility Distribution Transformer Loss Levels
Belgium	C-C'
France	A-A' and B-B' and B-C'
Germany	A-C' and B-A' and C-C'
Netherlands	C-C'
Spain	50% meet C-C'
UK	Uses capitalisation values

As indicated above, the UK does not apply the HD428/538 losses table. Each utility uses its own values to capitalise losses, in accordance with the alternative approach permitted by HD428. The capital value of losses is normally assessed annually.

There is quite a lot of movement at present in the loss standards which are currently being applied. Newly decentralised and privatised utilities are changing earlier procurement standards for distribution transformers, and placing first cost above energy efficiency, either as a conscious action or as the result of reducing payback periods. German utilities are said to be reducing previous higher standards. However Belgium has recently raised its national procurement standard to C-C'.

Energy-efficient transformers are generally regarded by European customers as technically sound but uneconomic (but see Section 10.7 and Section 11). The number of extremely energy-efficient transformers (beyond the C-C' level) operating in Europe is quite low, compared with a.o. the United States. We estimate that about 200 amorphous distribution iron transformers have so far been installed, many of which are very small, and probably a slightly larger number using laser-etched domain-refined steel. The amorphous iron installations we have identified are as follows:

Table E

Amorphous Iron Distribution Transformers, Europe

Location	Number	Total kVA
Belgium	10	4,000
Germany	1	500
Ireland	101	3,100
Netherlands	3	1,200
Slovakia	2	800
Spain	14	8,330
Switzerland	5	1,540
UK	25	2,390
Total	161	21,860

The load profile of the transformer

Although transformer efficiencies can be measured accurately in the test house, the load profile and hence the efficiency differs for every transformer in the field. The dependency of the efficiency of the transformer on the load profile was mentioned in Section 10.4.

The table below gives an idea of the load profiles involved:

Table F

Typical Load profiles, Distribution Transformers, Europe

Transformer	Yearly peak load	Running time, average load	Loss time	Power factor (cos j)
100kVA (small, rural)		1,500 h	750 h	0.95
• lightly loaded	10%	1.6%		
• average loaded	40%	6.5%		
• heavily loaded	120%	20%		
400kVA (average)		2,500 h	1,500 h	0.95
• lightly loaded	20%	5.5%		
• average loaded	55%	15%		
• heavily loaded	110%	30%		
1,600kVA (industrial)		3,500 h	2,500 h	0.8
• lightly loaded	30%	9.5%		
• average loaded	50%	16%		
• heavily loaded	110%	32%		

The terms in the table are defined as follows:

- yearly peak load: the highest load of the transformer as a percentage of its rated power. This load is only present for a small part of the year

- running time: the ratio of energy transmitted during a year [kWh] and the yearly peak load [kW] - physically, this figure indicates how much time it would take to transmit the yearly energy at a power equal to the yearly peak load. A low value indicates strong fluctuations of the load, a high value a relatively constant load. The average transformer load is the yearly peak load, multiplied by the running time over 8760 hours

- loss time: the ratio of the yearly energy loss [kWh] and the maximum losses occurring in a year [kW] - this figure indicates how much time it would take for the transformer to lose the yearly energy loss when loaded at the maximum load occurring in the year.

The data above result into the following data for an A-A' and a C-C' transformer with an "average" load profile as indicated above:

Table G

Average load profiles - Distribution Transformer				
Transformer rating (kVA)		100	400	1,600
Yearly energy transmitted (MWh)		57	523	2,240
A-A' transformer	Energy loss (kWh) Efficiency (%)	3,013 94.71	10,234 98.04	33,401 98.51
C-C' transformer	Energy loss (kWh) Efficiency (%)	2,017 96.46	7,091 98.64	23,642 98.94
A-AMDT transformer	Energy loss (kWh) Efficiency (%)	736 98.71	3,401 99.35	13,954 99.38
C-AMDT transformer	Energy loss (kWh) Efficiency (%)	703 98.77	3,149 99.40	12,429 99.45

The no-load (iron) losses account for 95% of the yearly losses in the case of a 100kVA transformer, and 66% of the no-load losses in a 1,600kVA transformer.

For very lightly loaded transformers, the efficiency falls rapidly. There are several reasons why some transformers are so lightly loaded. Often a limited number of transformer types used by a utility (advantages of lower stock) is the cause, or allowing for a load increase. Usually, the distribution network is dimensioned with certain expectations of load growth, in order to postpone upgrading of the infrastructure as long as possible. A final factor is the usual technical practice to apply safety margins to electrical equipment. This is good for the load losses, but increases the no-load losses.

The extremely low loads encountered at some transformers seem to suggest the need for smaller distribution transformer sizes, or cores with extremely low losses.

Although the figures used are based on empirical rules validated by measurements, there is a wide spread in the average transformer loading and the running time. Although some utilities keep track of the maximum loads of transformers, there are no representative transformer load data available for the European Union. The figures given above should therefore be considered an example.

Deviations from the standard loss values

Apart from the efficiency class and the load profile, many other factors may influence transformer losses:

- medium-voltage (MV) network voltage - the core (iron) losses are dependent on the network voltage. A higher network voltage leads to higher core (iron) losses. For instance, 5% increase of the network voltage may cause 10-20% higher core losses, depending on the type of core material and the design of the transformer.

The loss levels of individual transformers are, therefore, always specified for a defined network voltage. For an individual transformer, the effect can easily be measured. In an electrical network, the voltage at each substation varies according to the electrical distance to the feeding point and the load situation. A special case is the gradual change (between 1989 and 2004) of the network voltage within Europe from 220V or 240V to 230V as defined in IEC60038. In some cases, the increase from 220V to 230V is realised by increasing the voltage level in the medium-voltage network, which leads to increased losses in the distribution transformers. On the other hand, the decrease from 240V to 230V may be achieved by decreasing the voltage level in the medium-voltage network, which leads to lower losses in the distribution transformers

- operating temperature of the transformer. Conductor losses slightly increase with the operating temperature of the transformer. The loss levels of individual transformers are, therefore, always specified for a defined operating temperature

- production deviations of the transformer. This is a quality assurance aspect, which will normally not yield large deviations from the contracted loss values

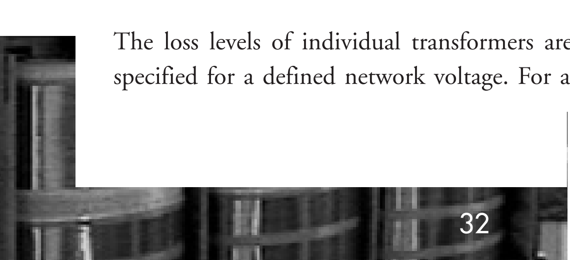
- ageing of the transformer. Older transformers may deteriorate in several modes, one of which is a loss increase. Normally, this effect is neglected. There are, however, some concerns about ageing of amorphous cores

- poor power quality. The presence of non-linear loads in the network will lead to harmonic current components in the transformer. These harmonic currents tend to heat the transformer, but normally the transformer design allows for some harmonic contents of the load current. Normally, this effect is not taken into account, except in industrial or comparable installations with many distorting loads.

Accounting for these factors for a network would require a detailed knowledge of operating conditions, Usually, efficiency class and transformer loading are the two dominant factors, the other factors are not taken into account when assessing transformer losses.

10.6 Loss Evaluation

A transformer purchaser aims to buy the cheapest transformer, i.e. with the lowest total owning cost, which complies with the requirements for a given application. The total owning cost of a transformer consists of several components, including purchase price, the value of energy losses, maintenance and repair costs over the lifetime, and decommissioning cost. The purchase price and the energy losses are the two key factors for comparison of the different transformers. Installation, maintenance, repair and decommission costs are seldom taken into account for choosing between transformers as they are relatively insensitive to transformer design.



In cases where transformers of different technologies are compared, e.g. dry-type and oil-immersed, installation costs (a.o. fire protection, oil containment provisions) will be considerably different and do need to be taken into account.

When comparing two transformers with different purchase prices and/or different losses, one must take into account that the purchase price is paid at the moment of purchase, while the cost of losses come into effect during the lifetime of the transformer. Usually the costs are converted to the moment of purchase by assigning capital values. When transformers are compared with respect to energy losses, the process is called loss evaluation.

In the basic process of loss evaluation, three transformer figures are needed:

- purchase price
- load loss
- no-load loss.

For the specified load loss of a transformer, the purchaser can assign a cost figure per kW of loss representing the capitalised value (net present value) of the load losses over the lifetime of the transformer or a shorter time scale e.g. 5 or 10 years. This cost figure is based on the expected transformer load over time, the average cost per kWh and the interest rate chosen by the purchaser.

Similarly, for the no-load loss of a transformer, the purchaser can assign a cost figure per kW of no-load loss representing the capitalised value of the no-load losses. This cost figure is also based on the average cost per kWh and the interest rate chosen by the purchaser. As nearly all transformers are connected to the grid for 100% of the time, and the no-load losses are independent on the load, the load curve is not relevant. The average cost per kWh will tend to be lower than for the load losses, as the latter will tend to coincide with peak loads, at which time energy is very expensive.

Thus, the capitalised cost (CC) of a transformer can be expressed as the sum of the purchase price (Ct), the cost of no-load losses and the cost of the load losses, or as a formula:

$$CC = Ct + A \times Po + B \times Pk$$

where A represents the assigned cost of no-load losses per watt, Po the value of the no-load losses per watt, B the assigned cost of load losses per watt and Pk the value of the load losses per watt. This formula can also be found in the HD428 and HD538.

An example of application of the formula to the transformers of Figure 8 gives the capitalised cost values in Figure 18. In this example, A and B have been chosen as 4 and 1.2 Euro/W respectively. It is obvious that there is a significant discrepancy between the cheapest transformer at purchase and the cheapest transformer in the long term. Even the expensive amorphous transformer may be cheapest option.

The formula is simple, but the choice of the factors A and B is very complicated (see Section 10.5 for difficulties in determining load patterns). Medium-size and large utilities use standard values for loss evaluation, based on average values for energy cost and loads.

Usually, the loss evaluation figures A and B are submitted to the transformer manufacturers in the request for quotation. They can in turn start the complicated process of transformer design, to obtain a transformer design which performs best using the same formula. The result of this open process should be the cheapest transformer, i.e. with the lowest total owning cost, optimised for a given application.

Drawbacks of this process are its extreme complexity and the uncertainty of the purchaser with the exact load profiles of the transformers and energy prices in the future. Tariff structures are very complex.

For large transformers, above a few MVA, the cost of losses are so high, that transformers are custom-built, tailored to the loss evaluation figures specified in the request for quotation for a specific project.

For distribution transformers, often bought by large batches, the process is undertaken infrequently, e.g. once every 5 years. This yields an optimum transformer design, which is then kept for several years until energy prices or load profiles have changed dramatically. In fact, the loss levels established in HD428, HD538 and national standards reflect established practice of preferred designs with respect to loss evaluation values. It is then usual to select one category e.g. C-C' as the most appropriate, and omit the

Figure 18 Cost comparison of typical Distribution Transformers according to figure 8

RATING	kVA	100				400						1600					
HV	kV	20				10						20					
LV	V	400				400						400					
LOSS-LEVEL	HD428	A-A'	C-C'	A-AMDT	C-AMDT	A-A'	A-A'	C-C'	C-C'	A-AMDT	C-AMDT	A-A'	A-A'	C-C'	C-C'	A-AMDT	C-AMDT
NO-LOAD LOSSES	W	320	210	60	60	930	930	610	610	150	160	2600	2600	1700	1700	380	420
LOAD LOSSES	W	1750	1475	1750	1475	4600	4600	3850	3850	4600	3850	14000	14000	17000	17000	17000	14000
CONDUCTOR MATERIAL	Cu/Al	Cu	Cu	Cu	Cu	Cu	Al	Cu	Al	Cu	Cu	Cu	Al	Cu	Al	Cu	Cu
Investment costs	Euro	2598	2790	3456	3567	4385	4286	4481	4705	[illegible]	[illegible]	9663	9241	10087	10416	[illegible]	[illegible]
NLL cost	Euro	1280	840	240	240	3720	3720	2440	2440	600	640	10400	10400	6800	6800	1520	1680
LL cost	Euro	2100	1770	2100	1770	5520	5520	4620	4620	5520	4620	16800	16800	20400	20400	20400	16800
Total owning costs	Euro	5978	5400	5796	5577	13625	13526	11541	11765	[illegible]	[illegible]	36863	36441	37287	37616	[illegible]	[illegible]
Cost Savings																	
Comparison of investment costs (base C-C')		93%	100%	123%	127%	98%	96%	100%	105%	131%	139%	96%	92%	100%	98%	148%	151%
Comparison of total owning costs (base C-C')		111%	100%	107%	103%	114%	113%	100%	99%	105%	101%	99%	97%	100%	99%	99%	91%

The cheapest transformers are indicated bold and shaded

Source: Pauwels (see figure 8)
The evaluation figures are typical values used in e.g. Belgium and the Netherlands

tedious evaluation process by purchasing the cheapest C-C' compliant transformer.

It can be concluded that the efficiency of transformers purchased is, directly or indirectly, controlled by the choice of loss evaluation figures:

- if high loss evaluation figures A and B are used, energy-efficient transformers tend to be favoured. A and/or B will be higher if a value is assigned to energy saving, an allowance is made for taxes on usage of natural resources. A low interest rate will yield high A and B values, by valuing future energy savings to a greater extent

- low loss evaluation figures A and B, the result of a high rate of return required, lead to cheap but relatively inefficient transformers

- merely evaluating the purchase price will lead to the cheapest transformers being chosen, which may be very inefficient. This policy corresponds to A and B equal to zero, and is regularly found with turn-key contracting firms or the project departments of utilities that are concerned only with direct project costs.

The chosen values for A and B are also the key factor in the application of new technologies.

10.7 Case Study 1: Replacement of Old Transformers

Groningen saves 1.2 million kWh per year - Overview

In 1983 the municipal electricity utility of Groningen, a town of 165,000 inhabitants in the north of the Netherlands, decided to replace 146 of the oldest of its stock of 613 10/0.4kV distribution transformers by 75 new modern units. The total network load was about 100MW, and annual consumption 450 million kWh. The transformers to be replaced ranged in size from 100-400kVA. They were all installed before 1955 and characterised by large dimensions, heavy weights, and relatively poor annual efficiencies of 97.5-98%. A typical transformer replaced under the Groningen project is shown in Figure 19.

The 75 replacements, ranging between 250-400kVA, have an efficiency of 99%. By optimising the load and no-load losses of the 400kVA units, a balance was made between the highest practical level of efficiency and acceptable cost. It was estimated that the project could achieve energy saving of 0.5 cubic metres of natural gas per Dutch guilder of investment. (1kWh=0.34m3 gas). A Government grant was awarded to the project, under a scheme to promote industrial investment.

Figure 19

Distribution transformer, replaced under the Groningen project

To achieve the planned goal, it was necessary to increase the rated load from 0.65 to 0.80 without overloading. The work was carried out by means of a carefully prepared schedule for exchanging the transformer units. The project, which was completed in 1984, has resulted in an annual saving of 1.2 million kWh. The total energy losses in the HV and LV networks have been reduced by 0.25% to 3.8%.

Definition of Old transformers

The introduction of cold-rolled steel in about 1956 marked a revolution in transformer design. In Groningen, as elsewhere, only lower loss transformers with cold-rolled iron cores have since been purchased. From 1956 to 1968, transformer losses were further improved. Since1968, losses have been standardised, using the capital value method.

All the old distribution transformers replaced in the Groningen project were built before 1955. With respect to losses they fell into three clear categories:

- constructed before 1940

- constructed between 1948 and 1951

- constructed between 1951 and 1955.

In the period 1920 to 1940, transformer losses were gradually reduced. After the war high quality raw materials were not available, and loss levels rose. Between 1951 and 1955 the quality of transformers was slightly better than those manufactured in the late thirties. It was found that transformers installed in 1953-1955 represented the critical point in deciding where replacements were necessary.

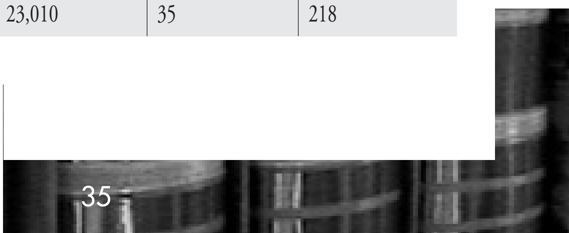
Transformers manufactured before 1950 were difficult to exchange, and adapt for new loads, because the high risk of damage during transportation. They were constructed for lifting and had no transport rolls. Spare parts such as isolators and oil packing were not obtainable from the manufacturer. The cost of repair was expensive. These transformers were therefore taken out of service and discarded.

Table H

Groningen transformer replacement schedule

OLD (replaced and converted into scrap) 3-phase 10,000/380V				NEW (purchased) 3-phase 10,500/400V				
Number	Power (kVA)	No-Load (W)*	Load losses (W)**	Number	Name	Power (kVA)	No- Load (W)	Load losses (W)
				1	N76	50	150	900
1	75	634	1,451					
6	100	684	2,000	3	N76	100	210	1,415
2	125	798	2,500					
2	150	513	2,314					
3	150	656	2,960					
20	150	798	2,800					
				1	N76	160	310	2,050
5	200	684	2,850					
12	200	969	3,900					
13	200	741	3,917					
14	200	1,208	3,596					
15	200	741	3,922					
				34	N76	250	450	2,815
4	300	1,368	4,700					
7	300	1,630	4,590					
16	300	1,089	5,215					
19	300	1,094	5,200					
1	400	1,539	5,600	35	C	400	540	3,300
6	400	1,300	6,520					
Total								
	(kVA)	(kW)	(kW)			(kVA)	(kW)	(kW)
146	33,075	142	587	74		23,010	35	218

• calculated at 400V ** calculated at 75 oC



Low voltage grid network

In Groningen the low voltage system is entirely constructed as a grid network. Depending on the locality, between 4 and 12 transformers feed a completely meshed cable grid. The cable forms closed loops between the transformer sites and the low voltage interconnection and switch cabinets along the streets. In this way, the cables are double fed, and the transformers and cables are in parallel operation. This has been found to be attractive both in respect of investment levels and network losses.

Until 1965, transformer housings were constructed for two transformers, for reasons of reliability and maintenance. After a period of fast growth in prosperity and electricity consumption, it became less expensive to design and construct these housings for a single transformer. The average standard unit size was increased from 200kVA to 400kVA to optimise costs and energy efficiency.

The mean peak loading before conversion was 0.65. Most transformers were running at between 0.4 and 1.1 peak load in respect of the rated load. The project was undertaken by exchanging transformers and adapting then to their loads. Overloading was not practicable, because of risk and a lack of experience in this area. A summary of the replacement schedule is shown in Table H:

All the three-phase distribution transformers installed Groningen before 1961 are of rated voltage 380V. To make a comparison with the new units, the no-load losses from the old data-sheets are multiplied by 1.14 to obtain the losses under 400V operating conditions. The load losses of the old sheets were recalculated at 75oC, because previously load losses were stated at room temperature. These recalculations enabled the criteria for government support to be met.

However, the main gain in cost efficiency was achieved by improving the peak load of the new transformers. This resulted in savings in both investment and energy. A further gain was obtained by improving the balance between the transformer power rating and the network loads. In practice, this meant that for Groningen it was better to have a lower number of 400kVA units in place of a greater number of lower powered units.

Process for choosing the Groningen 400kVA transformer

In 1982 Groningen were offered the normal type N76 (type F in the figures), with losses of 640/4,000W, and a number of special designs (K,L,I,J,G and H). The utility undertook financial and economic evaluations, using the well-known method of capitalising the future loss cost over a period of 30 years. Energy cost figures are shown in Table I:

Table I

Energy Cost Figures A and B in Dutch Guilders NLG / Watt

Year	Project	Legend (TOC)	No-Load (A)	Load losses (B)	
				Peak / rated load	
				0.60	0.80
1982	Groningen	1982-Normal	13.80	1.60	2.80
1982	Groningen	1982-High	16.40	2.05	3.65
1982	The Netherlands	1982-Top (N84)	21.00	4.70	4.70
1999	The Netherlands	1999 (N95)	10.00	1.50	2.65

The transformer types were evaluated at 1982 prices of NLG13.80/2.80, at peak load of 0.80. Subsequently transformers F,E,D,B,C and A were offered. Transformer F was the Dutch standard (N76) at that time. Type C was chosen because the better energy saving performance. Energy saving was of great interest throughout the Netherlands at this time, as oil prices were growing rapidly. Transformer efficiencies were calculated under the following operational conditions. Efficiency is output kWh divided by (output+losses) kWh:

Table J

Operational Conditions for year based energy efficiency calculation

Capacity factor (= peak load / rated load)	0.60 (for project Groningen 0.80)
Mean power factor	0.90
Load time	3,500 hours / year
Loss time	2,000 hours / year
No-Load time	8,760 hours / year

A summary of the decision-making process is shown in table K:

Table K

Groningen 1982-1983 Optimising Process Special Transformer 400kVA					
Trans-former Name	Price (1982)		No-Load Losses (W)	Load Losses (W)	Remark
	Dutch Guilder	Euro (rate 2.20)			
First round 1982					
K	10,300	4,682	720	4,600	
L	10,300	4,682	510	5,800	
I	12,300	5,591	650	3,300	
J	12,300	5,591	490	4,100	
G	14,600	6,636	550	3,000	
H	14,600	6,636	682	2,700	
Second round 1983					
A	13,720	6,236	545	3,160	
B	13,100	5,955	530	3,560	
C	13,300	6,045	540	3,300	
D	13,000	5,909	665	3,000	
E	11,850	5,386	663	3,250	
F=N76	10,912	4,960	640	4,000	Dutch Spec.1976
Final Decision 1983					
E	11,850	5,386	663	3,250	
C	13,300	6,045	540	3,300	Option

10.8 Case Study 2: Evolution of Dutch Transformer Specification

The 400kVA transformer type described above is an example of the level of the normalised range 50-100-160-250-400-630-1,000-1,600kVA transformers in the Netherlands. In 1984, the Dutch utilities decided to limit the price of the new transformer (N84) at 110% of the price of the existing N76 transformer (type F in the diagrams). The N84 was therefore not adopted. In 1991 a new type (N91) was developed. The low voltage was changed from 400-420V. The efficiency was improved. Minimum load losses were set at 3,100W.

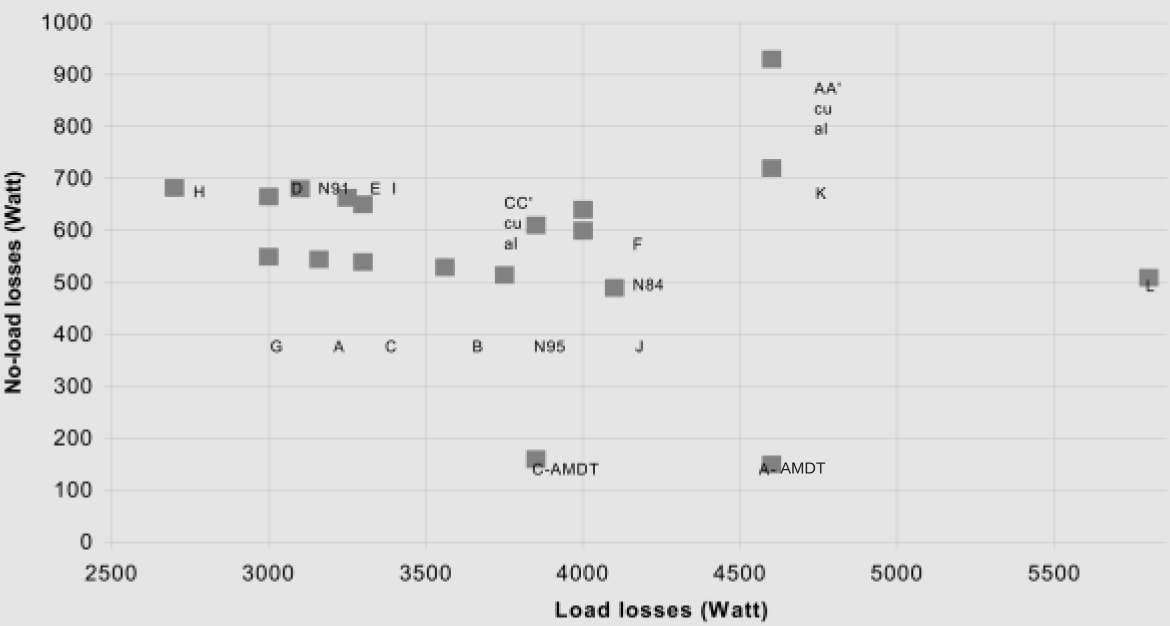
The loss evaluation of types N84, N91, and the newly developed N95, were extensively discussed by the Dutch utilities in 1993-1994, because the popularity of the N84 type. One factor was the N91 transformer was not optimised for the universally applied capacity factor of 0.60. Almost none of the Dutch utilities permit transformers to be in overload condition. An exceptional loading of between 100-120% is allowed in some years. An additional argument is not to load a transformer too highly on environmental grounds.

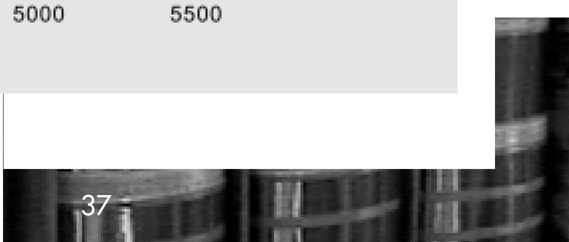
The new standard type N95 is more efficient than the C-C' losses specified in CENELEC HD428. Figure 20 illustrates the no-load and load losses of 21 types of 400kVA distribution transformer evaluated at Groningen in the period 1982-1999.

There is at present a good balance between energy saving and total owing cost, because the pay-back time of the higher purchase price

Figure 20

21 Transformers 400 kVA Evaluated Project Groningen 1983 - 1999



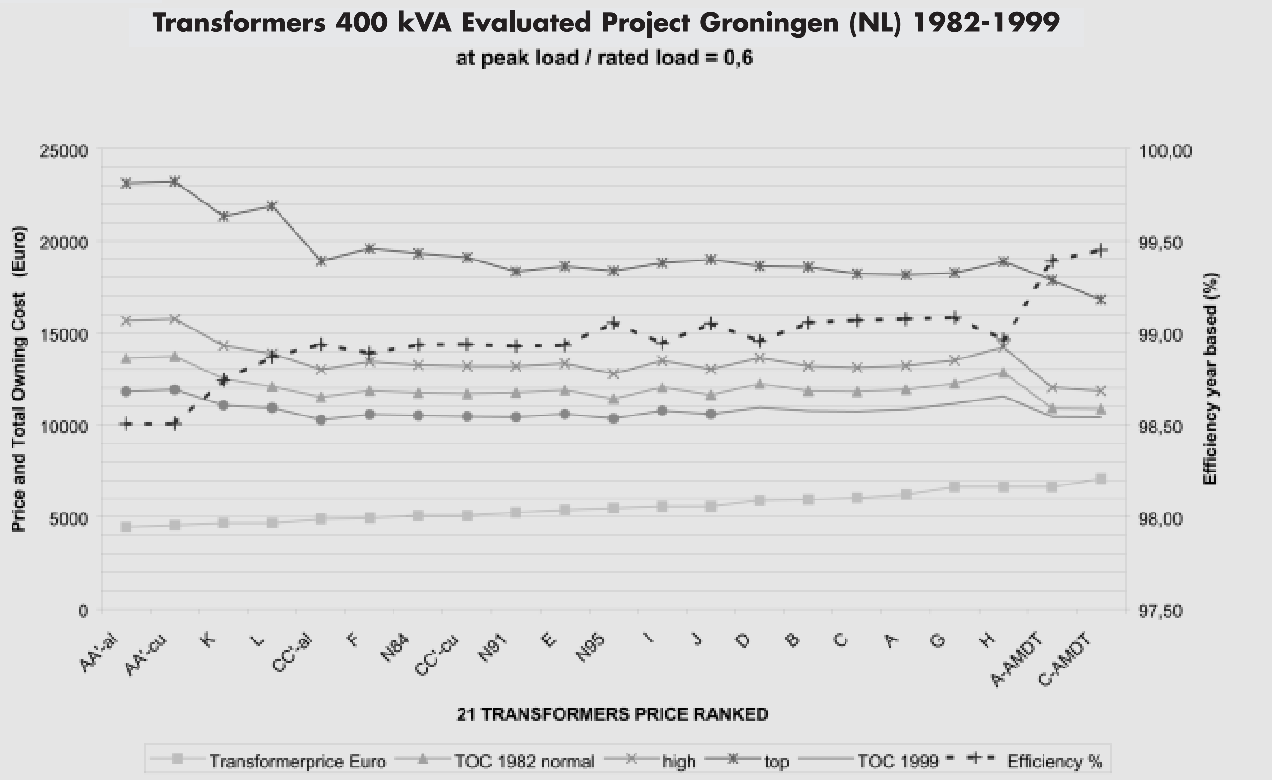


is within the calculated period of 30 years. A summary of the way in which the Dutch specification has evolved is shown in Table L:

Table L

Dutch Loss Specification Transformer 400 kVA (10/0.4 kV)				
Year	Name	No-Load Losses (W)	Load Losses (W)	Voltage (V)
1968	N68	680	4,000	400
1972	N72	680	4,000	400
1976	N76	640	4,000	400
1984	N84	600	4,000	400
1991	N91	680	3,100	420
1995	N95	515	3,750	420

Figure 21



The purchase prices of the transformers shown in Figure 21 give an overview of the relationship between price and performance of the 21 400kVA distribution transformers evaluated at Groningen in the period 1982-1999. These prices are not the actual market prices. It provides a comparison between groups of lower priced transformers, with normal no-load losses, and a higher priced group with reduced no-load losses. The types between these groups could be also of interest. See for example options C-E and N84-N91-N95. From a practical point of view, the most economical option has to be decided in co-operation with transformer manufacturers.

10.9 Case Study 3: Large AMDT in Europe

History

In Section 9, amorphous steel was introduced as a low-loss core material. Since the introduction of amorphous core material in the early eighties, hundreds of thousands of amorphous metal distribution transformers (AMDTs) have been installed in the US, Japan, India and China. Application of these units in Europe has, so far, been very limited.

However, a very large amorphous iron three-phase distribution transformer has recently been built and installed in the EU at an engine plant at Waterford in Ireland in 1998. The 1.6MVA transformer is the first to be designed specifically for the European industrial market. The load losses are 18.2kW, the no-load losses are as low as 384W, compared to 1,700W for a HD 428 C-C' transformer.

With no-load losses up to 80% lower than a conventional silicon-core transformer, it should recoup its extra cost in about three years, says Allied-Signal, which owns the Irish factory. 'By going with the amorphous core transformer, we managed to resolve several major issues in one action,' reports the electrical engineer at the Waterford plant. 'The transformer has increased the site's power capacity by 40%, while providing dramatically lower losses than a conventional transformer.'

At an average loading of 70%, the AMDT will use 13.3GWh less energy a year than a conventional transformer.

With a price premium of £2,500 over a standard transformer, the AMDT should pay for itself in about three years at current Irish power prices - and continue to make savings over its 20-30-year life. The transformer manufacturer reports that although the 1.6MVA AMDT has been bought by part of the AlliedSignal group (an amorphous iron producer), the deal was done on a commercial basis.

The 20kV/400V transformer, completed by Pauwels International, is the first AMDT to target European industrial customers. Previously, Pauwels has focused on utility users with AMDTs rated at up to 630kVA. The Irish transformer required new construction techniques, which could now be applied to build AMDTs up to 2.5MVA.

Discussion

Some material properties of the amorphous metal have proven to be a major obstacle for development of European amorphous-cored transformers. Amongst others, the transformer core can not be stacked from sheets but must be wound. In addition, the material properties require a more complicated transformer design. In the US, with a large number of single-phase wound-core transformers, this did not cause problems. In Europe, however, all conventional three-phase distribution transformers are built with stacked cores. Production of amorphous cores therefore requires major changes in the transformer production process. Some European transformer manufacturers have taken the plunge to develop a new transformer production process. Three-phase distribution transformers may now be considered proven technology.

However, the success of the amorphous transformer in the US and Japan has not yet been replicated in Europe. The main drawback has been, and continues to be, the AMDT's higher initial cost. The premium over a conventional transformer was previously around 40% or more, but this has now fallen to 30-35%, cutting the time it takes to recover the extra cost.

At present (1999), there seem to be three important issues preventing large-scale adoption of amorphous distribution transformers in Europe:

- reluctance of transformer users to make the higher initial investment (e.g. 35%) of an energy efficient transformer, even in cases where, on basis of the chosen values of A and B, the total costs (purchase price plus cost of energy losses) are significantly lower (Figure 18). This is caused by the fact that the purchase cost of a transformer takes only a small share, say one-quarter or one-third, of the total owning cost. The loss costs may, however, hardly be visible or traceable within a utility, whereas the investment costs are clearly visible at the moment of investment, this very important aspect is discussed in Section 10.6 and Section 12
- energy prices tend to be lowering, yielding lower loss evaluation values (see Section 10.6)
- the presently high $/€ exchange rate is unfavourable for amorphous core material in comparison to conventional core steels, as it is produced in the US. At present (1999), the cost benefits acquired by advances in transformer production technology seem to be more than offset by the cost rise of the amorphous material.

The future for the amorphous transformer in Europe does not seem very bright. However, the above factors may in time be reversed. The first will be addressed in Section 12, the latter two fall outside the scope of influence of the EU.

11 ECONOMIC AND MARKET ANALYSIS

11.1 Assessment of Energy-Saving Potential

Earlier Sections of this report provide some background information on the role of transformers in the transmission and distribution of electricity through the European Union. The European Community (EUR 15) consumption of electricity for 1996 is 2,253TWh with forecast growth to 2010 to 2,811TWh (1.6%) by 2010.

There is significant energy loss on the total 'system', estimated to be 146TWh (1996) or 6.5%. This is slightly more than the demand for electrical power in Sweden in 1999.

An assessment has been made to establish the contribution that distribution transformers make to the current level of energy loss on the European electrical transmission and distribution system. It is important to get a good understanding of the major contributors to this system loss.

To develop a simple European model, ETSU has used data available from an UK model developed under another project. The data that has been introduced in to the model is summarised below.

Figure 22

Distribution System Losses

Type of Loss	Losses (%)			
	Company A	Company B	Company C	Average
132kV line losses	5	12	7	
132kV – 33kV transformer losses	9	10	10	
33kV line losses	14	6	6	
33kV – 11kV transformer losses	12	11	9	
11kV line losses	13	15	15	
11kV – 414V transformer losses	25	24	20	
LV line loss	19	20	33	
Services	1	-	-	
Meters	2	3	-	
Total	100	100	100	
Total line losses	51	53	61	57
Total transformer losses	46	45	39	43

Source: ETSU

Total Losses on the European Distribution System

By assuming that the ratio of transmission losses to distribution losses in Europe is broadly similar to that in the UK model, distribution loss for EUR15 will be 4.8%, equivalent to 116TWh. (This is based on the total loss in the UK of 24.6TWh. From published national statistics in 1994, this loss is made up of 6.8TWh from the national transmission system and 17.8TWh from the local distribution. This data is also identified in Appendix A.)

Total Losses from Distribution Transformers

Transformers make up a large proportion of the loss. Again taking the UK as an example Figure 22 provides information on what level of distribution loss can be attributed to transformers. It should be noted however, that there may be some loss due to theft that is not declared. In addition, loss data is produced by various empirical calculations, and not by metering, making the data questionable.

By using the average transformer system loss of 43% and applying it to the European model, it is estimated that transformers make up 2.8% of total consumption.

Consideration of Figure 22 and the average load tables shown in Table G (Section 10.5) suggests that distribution transformers are responsible for losing approximately 2% of total electricity generated in Europe.

Other Factors Which Contribute to the Calculation of Energy Loss

Using estimated production data for distribution transformers, Table A, replacement is approximately 150,000 units a year within a total population of 4 million. This gives a replacement rate of 3.75% per year.

To establish the 'base case' for estimated savings it is unclear what efficiency can be applied to those transformers currently installed within the system. Transformer life can be as long as 40 years and standards have improved over the years. However it is clear that any future installation is likely to be to a minimum A-A' standard in line with European Harmonisation Documents. Therefore, to assess energy saving potential, A-A' is used in the model as the 'base case'. Savings can then be identified from the more 'energy-efficient' units.

Table M

Improvements From Energy-efficient Transformers

	Base Case %	Efficiency Improvement % Over Base Case		
Transformer Rating	A-A'	C-C'	A-AMDT	C-AMDT
100kVA	94.71	33.0	75.6	76.7
400kVA	98.04	30.7	66.8	69.2
1,600kVA	98.51	29.2	58.2	62.8

In Table G, Section 10.5, the reduction in losses from using energy-efficient transformers are identified. Table M identifies the energy savings possible for a single unit over and above the 'base case'. This data has been applied to the European model.

The population of transformers at different kVA rating has been estimated from sales data. The contribution that each makes toward the total loss within the European model, due only to transformers, has been estimated in Table N.

Table N

Contribution Towards Total Loss On European Distribution System

Transformer Rating	Contribution Towards Energy Loss %
100kVA	45
400kVA	45
1,600kVA	10
Total	100

Figure 23 has been produced by installing the above data into a simple spreadsheet model. It can be seen that the introduction of energy-efficient transformers on to the distribution system has the potential of saving up to 22.3TWh/year, worth €1,171 million (1999 prices).

This is equivalent to a 35% reduction in transformer losses and represents an 12% saving of all losses on the European electrical distribution system. The technology to provide these savings is already available today and therefore does not represent a large R&D investment. However, there are many barriers toward the integration of energy-efficient transformers and these are discussed in the following Sections.

Payback on Investment

Figure 24 provides an indication of the savings possible per unit and the payback period from fitting energy-efficient transformers, compared with the 'base case' A-A' standard.

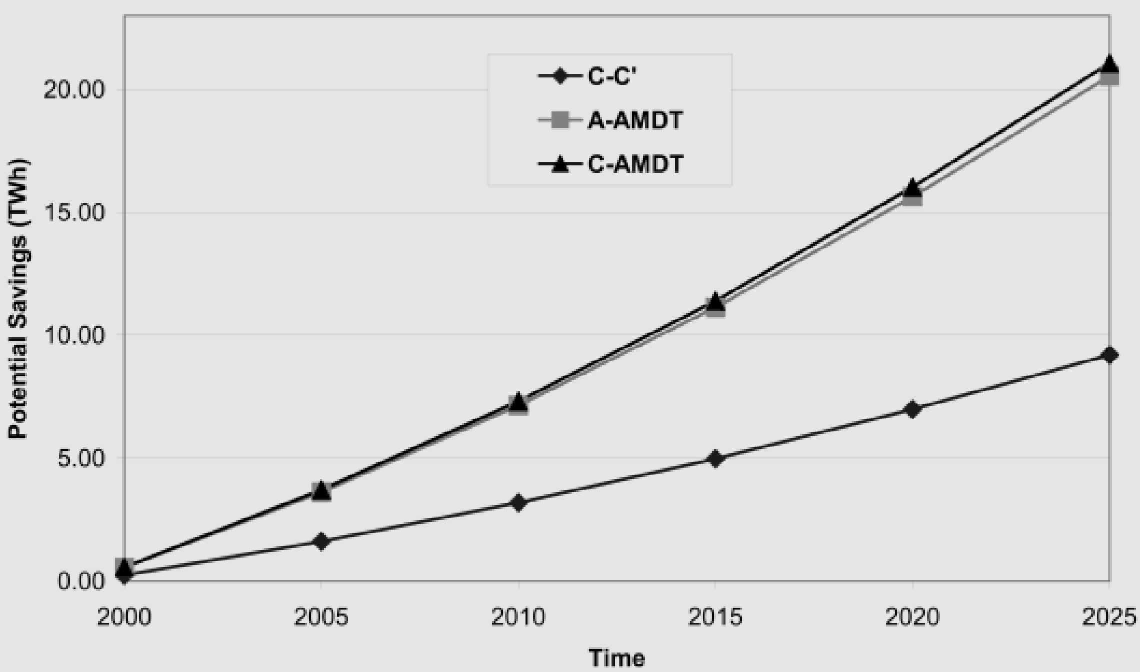
It is clear from Figure 24 that the payback periods for C-C' type transformers are very short. With the help of some of the promotional measures identified in Section 13, C-C' type units could start to make a valuable contribution to energy saving. The economics for the purchase of this standard of transformer make it very attractive and an effective awareness campaign would help to stimulate increased sales.

Figure 24 gives also the internal rate of return for investment in efficient transformers, which is consistently above 10%, and sometimes as high as 70% per year. Considering the low risk of the investment, and market capital rate of returns, this should make efficient transformers attractive to distribution utilities.

The total possible contribution that C-C' transformers can make to saving can be seen from Figure 23 to be 9.7TWh. Savings could be increased through the adoption of amorphous core transformers.

Figure 23

Savings Potential Through Installing Energy Efficient Transformers. Europe



Source: ETSU

Figure 24 Energy Saving Potential and Payback-Energy-efficient Transformers

Transformer Rating	100kVA					400kVA					1,600kVA				
	Efficiency	Savings		Unit Cost	Payback	Efficiency	Savings		Unit Cost	Payback	Efficiency	Savings		Unit Cost	Payback
	(%)	(kWh)	(E)	(E)	(Years)	(%)	(kWh)	(E)	(E)	(Years)	(%)	(kWh)	(E)	(E)	(Years)
A-A’	94,71	-	-	2.538	-	98,04	-		4.307	-	98,51	-	-	9.434	-
C-C’	96,46	996	52	2.799	5,0	98,64	3.143	163	4.762	2,8	98,99	9.759	507	10.147	1,4
A-AMDT	98,71	2.277	118	3.456	7,7	99,35	6.833	355	6.332	5,7	99,38	19.447	1.011	14.953	5,5
C-AMDT	98,77	2.310	120	3.567	8,6	99,40	7.085	368	6.753	6,6	99,45	20.972	1.091	15.469	5,5

Note 1. Savings in kWh compared to ‘base case’ – losses for type A-A’

Transformer Rating	100kVA					400kVA					1,600kVA				
	Efficiency	Savings		Premium	IRR	Efficiency	Savings		Premium	IRR	Efficiency	Savings		Premium	IRR
	(%)	(kWh)	(E)	(E)	(25 Years)	(%)	(kWh)	(E)	(E)	(25 Years)	(%)	(kWh)	(E)	(E)	(25 Years)
A-A	’ Baseline					Baseline					Baseline				
C-C’	96,46	996	52	260	20%	98,64	3.143	163	455	36%	98,99	9.759	507	713	71
A-AMDT	98,71	2.277	118	917	12%	99,35	6.833	355	2.025	17%	99,38	19.447	1.011	5.519	18
C-AMDT	98,77	2.310	120	1.029	11%	99,40	7.085	368	2.446	15%	99,45	20.972	1.091	6.035	18

Source: ETSU-ECI

However the long payback period makes this standard of transformer difficult to justify at the current first cost. Clearly manufacturing costs need to be reduced to make these very high efficiency transformers attractive to the market place. If reduced to provide a reasonable payback period then the potential savings could increase by a further 12.6TWh.

11.2 Contribution to Energy Efficiency and Global Warming Goals

Emissions data suggested by the International Institute for Energy Conservation (IIEC) for Europe is 0.4kg CO2/kWh. Electrical energy savings of 22.3TWh will provide emissions savings of 8.9 million tonnes of CO2. The European Union is committed to a reduction of 8 per cent on 1990 levels (266 million tonnes) by 2008-2012.

From Figure 23, potential savings from energy-efficient distribution transformers could reach 7.3TWh by 2010. This is equivalent to 2.9 million tonnes of CO2, or approximately 1% of the total European commitment.

To put the overall potential saving of 22.3TWh into perspective, this is equivalent to the annual energy use of over 5.1 million homes or the electricity produced by three of the largest coal burning power stations in Europe.

Distribution transformers have not yet been the focus of energy saving measures and could, if developed, contribute significantly to European targets for reduction.

11.3 Characterisation of the Utility Market

Utility markets account for approximately half the installed transformer capacity in Europe. Throughout Europe, the purchasing of transformers seems to be reasonably standardised, with the utilities having open tender practices in line with European Purchasing Directives. In almost all cases, losses (iron and copper) are factored into the specification, with minimum standards in line with internationally accepted standards. However, the specifications in each country differ in relation to the load characteristics (rural/urban), the network being served or the requirements for low noise emission (e.g. in German urban areas).

Selection of the supplier is usually made on the “first cost” principle, i.e. the supplier providing the lowest cost offer that meets the specification wins the business. Few exceptions are made where a supplier offers a more efficient transformer (i.e. lower life-time cost), but at a slightly higher price. The one exception to this is the Nordic countries, where the efficiency of the transformer in specific applications is given a high priority, with the specification giving the efficiency of the transformer a very high rating.

In almost all EU countries, first cost is the driving principle. Where the utility is state owned, limitations on capital expenditure are paramount to assist in meeting the ever tightening budgets brought about by the strict monetary requirements associated with the €. Where the utility is in private ownership, the availability of capital for efficient transformer purchases always competes against more attractive (i.e. quicker payback) investments that can be made by the utility in other areas.

In both cases, the lack of interest in efficient transformers is compounded by the electricity suppliers' inability to pass the cost of any losses on to the consumer, hence removing any incentive to overall system, and consequentially transformer, performance.

Example: *A utility buys transformers under 'framework' contracts that are competitively tendered approximately every two years. They specify the number and type of transformers that are likely to be required by the utility over the following two year period along with the technical specification. This technical specification includes copper and iron losses that are expressed using a capitalisation formula (i.e. a comparison between efficiency gains and the depreciation of capital).*

Contracts are always awarded to the lowest tender that meets the specification. Although partnerships are being established between utilities and transformer manufacturers, these are developed within these 'framework' contracts subsequent to the initial tendering exercise. These partnerships facilitate increased dialogue between the two parties and allow refinement of the original specification, a process that sometimes leads to increased energy efficiency.

However, a counter to this has been the move towards the installation of a limited range of transformers to minimise the stock of spare parts and rationalise service requirements. This means that there are few transformer sizes to select from and consequential matching to load characteristics is likely to decrease.

The cost of distribution losses is passed from the utility to their customers. In the UK the acceptable distribution losses are calculated according a Distribution Price Control Formula, issued by the electricity regulator. The Distribution Price Control Formula includes factors that relate to energy efficiency. At present, there is no financial incentive for utilities to improve their efficiency beyond that specified by this formula.

Since privatisation, it appears that utilities are under greater pressure to reduce capital expenditure. This tends to reinforce the 'lowest first cost' policy that is prevalent. Even when the marginal capital is available to meet the higher cost of a more efficient transformer, there must also be a straight payback of under five years.

The environmental policies of some utilities are driving them towards increased energy efficiency. East Midlands Electricity, UK, has an initiative in this area, although this is the exception rather than the normal situation.

11.4 Characterisation of the Non-Utility Market

The non-utility market consists of three distinct groupings, each with different characteristics and priorities:

- major energy users (e.g. large industrial plants (chemicals, oil, gas and steel), traction companies etc)
- large energy users (e.g. supermarkets, hospitals)
- smaller energy users.

The **major energy users** are aware of the issues and tend to make rational purchasing decisions. These companies retain sufficient expertise to be able to derive their own transformer specifications. Although energy efficiency and life-time cost of ownership will form an important part of these specification, other factors are also considered, e.g. the competitive cost of capital, life-time maintenance costs, potential growth capacity, etc. The overall result will be the purchase of the most cost-effective transformer to the business. This will not always be the most efficient transformer.

This group will only be influenced to buy transformers that are more efficient by external factors that change the business case. For example, rebate schemes.

Increasingly, **large energy users** are becoming more aware of the concept of transformer life time cost and its influence on operating profits. In particular, supermarkets have a high 24-hour base load, which encourages the selection of more efficient units. However, these customers rarely have the required in-house skill to specify suitable transformers effectively, often relying on a turn-key package from a contractor to an agreed overall specification. This group would therefore benefit from increased information that would allow them to make better initial specifications to the contractors. For example, labelling schemes or specification tool kits.

Smaller energy users tend to use contractors on a turn-key basis to provide premises that meet the requirements of their particular business. Specification will concentrate on meeting the business requirements, e.g. floor space available for the installation, adequate provision of utilities, infrastructure etc. The overall price of the package, perceived competence of the contractor and service levels are the key issues with the type of transformer installed being of little consequence. These customers do not have sufficient knowledge to be able to specify transformers in detail, and will be unaware of the business benefits of reduced life time costs.

As a corollary to this, contractors (including utility company contracting departments) will specify whatever the customer asks for. However, in most cases, no detailed specification will be received, because of lack of knowledge, and the contractor will simply specify the cheapest transformer available. Consequently, the provision of information on the advantages of specifying more efficient transformers and specification tool kits will allow these customers to make more informed choices.

11.5 National/International Policies and Initiatives

Across Europe, transformers are manufactured to individual national standards. These are broadly compatible with the European specification, Harmonisation Document 428. This in turn is based on the International Electro-technical Commission World Standard IEC60076. Through this harmonisation of standards, a mechanism is in place for communicating and enforcing more rigorous requirements for energy efficiency. However at present, compliance with HD428 is purely voluntary. For this mechanism to be effective in increasing the overall level of transformer efficiency across Europe, the specification would have to be formally adopted by CENELEC as a standard and compliance (via the provisions of any national standard) would have to be compulsory.

Despite this apparent standardisation, national standards can vary significantly. Each country has its own specific issues related to distribution system strength, capacity considerations, etc. Other differences result from variations in particular circumstances within countries. In France, the majority of generation is by nuclear power station. The marginal cost of generation is therefore very low and the environmental impact is negligible because emissions are minimal. French utilities are therefore under no pressure to purchase energy-efficient transformers and lowest first cost transformers are specified as standard. In Germany, where many transformers are based in the centre of residential areas, there are very stringent noise regulations. There are also often size restrictions. Harmonising the East/West supply systems and standardising the equipment are also causing problems.

The situation is further confused with the regulators in each country setting varying goals for the utility companies. In almost all cases, continuity of supply is the key factor. However, variations on other priorities are profuse and cover cost of electricity to the customer, voltage tolerances, safety, noise, overall environmental impact of the system, etc.

There appears to be little overall attempt to encourage the uptake of energy-efficient transformers by any national government or regulator. In the UK, the regulator includes an efficiency incentive in the pricing formula for supply, but this is marginal compared with other considerations. The following example describes how one electricity supply company assessed the value of fitting amorphous core transformers into its network.

Example: *Discussions with a utility company in the UK suggest that the level of investment in these very low loss transformers cannot be supported because of the low incentives provided by the UK Government electricity supply regulator (OFFER). The company explained that under the current distribution supply formula (which is said by OFFER to provide incentive to reduce system loss) the lifetime value of continuous losses to the company is approximately £1,110 per kW. The cost benefits for the use of amorphous core transformers compared to low loss transformers are as follows:*

The example chosen was for a 630kVA, ground mounted transformer which was said to have a loss load factor of 0.21. For a new transformer the utilisation for the transformer was suggested to be 70% (company average 57%) therefore the copper loss factor of 0.72 =0.49.

Table O

Example of Utility Assessment of Amorphous Core Transformers

	No-load loss	Load loss	Total Watts Continuous equivalent
Low -loss (C-C')	824	5,320	824 + (0.21 x 0.49 x 5,320) = 1,371
Amorphous	230	8,150	230 + (0.21 x 0.49 x 8,150) = 1,069
Loss difference			302 watts

Using 302 watts the lifetime value of the savings from using amorphous core transformers compared to C-C' standard transformers is therefore 0.302 x £1,110 = £335 (€532).

The following comments therefore can be made:

- the company has assessed the benefits of amorphous core transformers

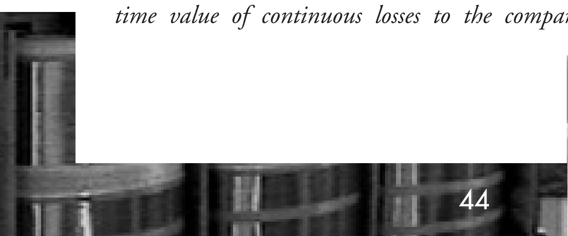
- the company has no incentive to use amorphous core transformers from the formula used by UK government electricity regulator

- these savings have to be weighed against the price premium of the amorphous core transformer. Increasing the load loss by 50% reduced the cost of the amorphous unit, with negative effect on the loss-savings. Since generally high capitalisation of no-load losses will go together with considerable evaluation of load losses, amorphous transformers will tend to have also reduced load losses (C, not B). This example should therefore not be generalised.

- the evaluation factor used for no-load loss of £1,110/kW is very low, which means a high discount factor is being used for future energy savings. Factors being reported in Germany and Switzerland prove to be at least 5 times higher, making a much stronger case for the investment in amorphous iron transformers.

11.6 Potential Mechanisms for Change

There appears to be several potential mechanisms that could change the buying behaviour of transformer purchasers. Each potential mechanism is briefly examined below.



No Change Scenario

It is possible that no action at the EU level will be required, as national governments begin to realise the implications of international commitments on CO2 and act at national level to improve the efficiency of transformers purchased. However, realistically this is unlikely to occur, due to the long term nature of savings from transformers and the complex nature of specification and the purchasing cycle. National governments are much more likely to concentrate on simpler targets, e.g. improvements in the performance of domestic appliances, etc.

Enforceable Minimum Standards

Discussions have already taken place between EC DGXVII, COTREL and EURELECTRIC to discuss the possibility of voluntary agreements or a European Directive to initiate reduced losses from distribution transformers through a minimum standard.

A minimum standard of sorts already exists in the Harmonisation Document 428. This standard could be made more prescriptive and specify improved minimum losses for all types of transformer. Such a standard could then be made mandatory through an EU Directive.

Unfortunately, such an approach is likely to be strongly resisted at national level, due to the specific needs of each national distribution system and local political considerations. Further, the imposition of overall standards for efficiency higher than those already in force would cause problems, due to the variations in demand profiles from the various end use applications, e.g. rural/urban uses.

An alternative approach would be for the EU to place obligatory requirements on national regulators to include efficiency as one of their key elements when forming regulatory policy. It is unlikely that such an approach would work as, without specific guidelines, regulators are likely to simply pay lip-service to the issue. Further, the preparation of specific guidelines may impose on the principles of subsidiarity and would be difficult to draft in any case.

Financial Incentives

The major cause of purchases of "less efficient" transformers is the requirement of many purchasers for the lowest first cost. If some financial mechanism could be introduced, that would make the purchase of efficient transformers more attractive, it is likely to have a major impact on the marketplace. Such financial incentives appear to fall into three categories:

• rebates

• tax incentives

• increasing responsibility for cost of losses.

If a mechanism was in place to define efficient transformers (e.g. transformer labels described below), it would be possible to offer **rebates on purchases of higher efficiency units**, hence lowering the purchase cost differential between the more and less efficient units. Unfortunately, the rebate would be extremely expensive, given the number of transformers purchased across the EU annually. Further, such a scheme could only be sustained for a short period and following withdrawal, the marketplace would almost certainly revert to the original situation with no lasting market transformation.

Changing national taxation systems to make the capitalisation of transformers more attractive, e.g. shortening the allowable assets write- off period, is likely to have a major impact on the purchases made by utility buyers (other buyers are unlikely to purchase enough transformers for this to have any significant impact relative to other considerations). However, this would have to be made a national issue, as the EU is specifically excluded from direct interference with national taxation issues. As such, it is unlikely that individual member states would adopt such a policy, due to the complex requirements in drafting the required legislation and policing claims under the system.

Increasing responsibility for cost of losses. Obviously, financial costs associated with losses from transformers owned by end users are already borne by the end user. However, losses accruing from transformers owned by utilities are currently almost universally transferred to the end user as part of the cost of electricity.

This situation is difficult to change where the utility is state owned. However, where the utility is privatised, there is an opportunity to use this "cost of losses" as an incentive to improve the system. At present, if the utility improves the efficiency of the system, then the amount of "cost of losses" is adjusted accordingly, hence the utility makes little improvement in profit.

A realignment of the pricing structure , to allow a fixed amount of "cost for losses" to be passed to the consumer, with the savings from any reduction in losses split between the consumer and the utility (say on a 50:50 basis), would improve the business case for examining lifetime costing. Such a system would allow investments in efficient transformers to be more competitive against other demands on the capital budgets of the utilities. However, this is again a national issue, with the individual pricing regimes coming under the control of the national regulators.

Labelling system

Lack of knowledge is a significant barrier to the purchase of energy-efficient transformers. This is particularly true of large energy users, where there is a desire to use efficient transformers, but not the technical ability to specify them effectively.

A labelling system that indicated the efficiency of transformers under specific load profiles would assist this group considerably, and is likely to cause a significant movement in the market. While there are obvious difficulties in creating a labelling system for transformers, given the variability of losses depending upon application, it is possible to develop a labelling system that provides the user with appropriate guidance in most instances. Such a system is currently under development for electric motors, a product with similar difficulties in efficiency definition.

The introduction of a labelling system also provides a framework from which future minimum standards may be derived (if deemed appropriate). The framework could also be used for financial incentives, should they be required at a national level.

Buyer Clubs

If a number of purchasers combine, they will receive direct benefits in bulk purchasing, hence receiving lower prices from manufacturers. This in itself would not necessarily induce the purchase of more efficient transformers, but it would increase the combined knowledge of the purchasing group, and is likely to result in the more effective specification. Such groups are however unlikely to form, as buyers remain unaware of the potential.

A possible method of inducing the formation of such groups would be the funding of some demonstration activity by the EU, e.g. the funding of the establishment and promotion of a buying group by the SAVE programme.

Specification tool kit

Smaller users are large in number, but individually buy small numbers of transformers. However, collectively they account for a significant part of the market. Education of these users, through promotional campaigns to purchase efficient transformers, would not be cost effective. However, it would be possible to develop a simple Specification Tool Kit (or buyer's guide) that would assist them in asking the right questions of the turnkey contractors.

Such a guide could include information on ensuring that the transformer is correctly sized and has been specified to likely load characteristics. Further, if combined with a labelling scheme, recommendations could be made on the type of transformer to be specified to the contractor. If manufactures/contractors could be persuaded to distribute this guide to potential buyers, costs would remain at a manageable level, and the user would have at least the basic knowledge to make a rational purchasing decision.

11.7 International Perspective

US and Canada

The US DOE is in the process of implementing a test standard for distribution transformers, following a report from Oak Ridge that supports a DOE determination that minimum performance requirements for distribution transformers can be justified. Following on from the test standard, formal analysis and legislation will be implemented. The standard is not expected to be issued until after 2000.

The transformer industry opposes the prospect of a mandatory minimum and would prefer a voluntary standard (NEMA TP1). The Oak Ridge study concluded that the TP1 levels of energy efficiency do not meet the DOE criteria. A US 'Energy Star' programme which provides energy efficiency labelling, currently promotes the TP1 levels of energy efficiency.

Canada is in the midst of consultation to implement mandatory levels equivalent to TP1, with a view to revising them once the US legislation has been implemented.

China

Shanghai Zhixin Electrical Industry Co Ltd. have been developing a relationship with GE under a licence agreement to produce amorphous core transformers since June 1997. The contract was signed in February 1998. Currently they are importing most of the components and assembling them in Shanghai. A core winding machine has been purchased, to be installed in mid-July 1999. Average transformer size is 400kVA. Shanghai Urban Power Distribution Bureau have installed 116 sets of amorphous core transformers, saved 770,000kWh power per year, worth about 27,900,000 RMB (€3.2 million).

Information from the company identifies the no load losses as 20% of those in a conventional transformer. The incremental cost is 30% over that of a conventional transformer. They have a target to reduce this to 20% when more components are manufactured in China. Currently the estimated payback is 2.5 years.

Transformer sales in China are estimated to be 350,000 per year. The company has a production target of 2,000/year, which will rise to 3,000/year, and can see no technical barriers to more transformers being manufactured in China if the market can be stimulated. The main barrier to uptake is the increased cost over the conventional product.

12 ANALYSIS, RECOMMENDATIONS, STRATEGY, ACTION PLAN

12.1 Analysis

Europe has considerable potential to offer world-wide in transformer technology and experience. However, national governments and utilities lag behind the US in terms of programmes and initiatives to encourage energy efficiency.

No European country has yet developed targets for the global warming savings potential which could result from distribution transformer programmes, nor has a formal estimate been made for the EC or Europe as a whole.

There are no initiatives in Europe comparable to the US DOE/EPA programmes on utility commitments, information and software dissemination. This is despite the fact that most of the major European countries have a very poor position on energy self-sufficiency.

Europe has an urgent need to develop a strategy on existing and future global warming actions. As this happens, the potential for reducing losses from distribution transformers could be promoted, to ensure that they are incorporated as a component of the plan.

There is already considerable R&D and promotional effort within Europe aimed at reducing losses in small transformers, e.g. for domestic and office equipment, and some IEA/OECD work has been undertaken. To date this has mostly focused on the use of more efficient core materials and campaigns to urge consumers to switch off appliances when not in use.

It is of course relatively easy to obtain industry compacts on small components and to exhort domestic consumers, compared with influencing or coercing utilities and professional buyers in connection with major items of capital plant. The work on small transformers could nevertheless assist in focusing attention on the very significant target of distribution transformers.

It is apparent that both the utilities and private sector purchasers are difficult to influence. The transformer market is extremely competitive, and efforts to improve energy efficiency in the past have had limited success.

The utility sector involves a limited number of professional buyers, already reasonably aware of the arguments for energy efficiency, and with well-established techniques for evaluating transformer performance. They are therefore likely to be receptive to rational arguments, provided that benefits are clearly demonstrated. We believe however that rapid change is unlikely without support, the use of economic instruments, or legislation.

Devising an effective approach to the private sector, which is growing steadily in terms of new investment, is very challenging. There are a limited number of larger distribution transformer buyers to target directly, but even these are quite dispersed. There are also consulting engineering and energy efficiency professional and trade associations to address, as well as energy clubs at European and national level. Other than the setting of minimum product standards, any approach to the bulk of the market, would require a ‘macro’ approach, involving the use of media, labelling, buying clubs etc.

The impact of the current European transformer standard, HD428, is very complex. Obviously product standards, in the electrical engineering sector as elsewhere, are directed at reducing barriers to trade by standardising minimum operating performance, dimensions, capacity and engineering practice, as well as setting high levels for health, safety, and reliability. Other CENELEC product standards, for example TC 20(SEC)456e, covering building wires, provide data on energy efficiency. As far as we have been able to ascertain, however, there is no treatment of energy efficiency similar to that of HD428 in other product standards.

Although HD428 sets a choice of specific energy efficiency levels, ranging from B-A’ to C-C’ levels, the option to use a capitalisation formula means that no effective minimum exists at present.

12.2 Recommendations

We consider that distribution transformers represent a worthwhile area for R&D, demonstration and promotional effort within the EU, with distribution transformers recognised as an important focus for energy efficiency initiatives. To optimise energy saving, an ideal way forward would be to raise standards EU-wide to the best current practice in Europe, from A-A’ to C-C’ using conventional materials and technology. Subsequently this standard could be raised to the cost-benefit balancing point, preferably with a formula that recognises the total cost of ownership.

Our recommendations are as follows:

- as EU and national strategies on energy efficiency, global warming, and environmental impact are developed, the potential for reducing losses from distribution transformers should be considered as a component

- a strategy should be developed to set and achieve goals for reducing losses from distribution transformers, or possibly from all power systems transformers in the EU. The strategy needs to be carefully co-ordinated and be both technically and commercially sound

- the main elements of an action plan to achieve the strategy should be identified and developed.

12.3 Strategy Development

The steps in preparing a strategy to set and achieve goals for reducing losses from distribution transformers in the EU will have the following elements:

- identify and convene a steering group, ideally representative of all levels in the supply chain, to manage the initiative

- agree or revise the estimates for energy saving and global warming which have been made in this project. Reliable data is difficult to obtain, and there is a need to recognise that electricity distribution networks are extremely complex. It is therefore possible to oversimplify the potential for operational efficiencies and cost savings, for example by simply considering the no-load and load losses in single transformers

- undertake any further work necessary to confirm the scope for energy savings. In particular there is a need for more detailed information on distribution transformer populations, ages, loading and efficiency

- seek the agreements necessary to prepare a formal strategy. The aim would be to carry all representative parties, including EU and national governments, utilities, transformer manufacturers, raw material suppliers

- agree set targets for the strategy, including quantified savings levels, time-scales, monitoring

- identify and agree the action plan components necessary to achieve the strategy.

12.4 Strategy Components

The main components of an appropriate strategy are likely to be:

- goal-setting. In particular the current position and future position of the European transformer standard, HD428, should be examined in detail. However there is little point in setting low standards for energy efficiency

- legislation, probably only appropriate if it is agreed that distribution transformers should form a component of EU global warming strategies. It should be subject to a formal Compliance Cost Assessment (CCA)

- incentives, investment grants. If high standards are set, the initial costs to the utility sector will be very substantial. There could be adverse reactions, for example the postponement of distribution transformer investment programmes

- monitoring of the implementation of standards and the benefits in terms of energy saving. Whether a new standard is recognised in the non-utility sector through national building codes etc

- the impact of regulation e.g. how a Framework Directive is enforced at national level, whether regulation is appropriate.

12.5 Action Plan

The mechanisms and activities which could be included as components of the action plan to achieve the agreed strategy, are:

- utility compacts on transformer standards, replacement programmes etc

- regulation, for example the introduction of mandatory minimum distribution transformer efficiency standards

- initiatives to involve all representative parties, such as conferences, seminars, workshops

- demonstration, software, pay-back and lifetime cost assessments. A specific example would be to undertake more pilot installation programmes (such as the Groningen project described in Section 10.7) to generate realistic operational and cost data for energy-efficient distribution transformers

- benchmarking to understand the differences between the loss evaluation factors used in various countries and categories of non-utility customer

- labelling, publicity, promotion, dissemination, investment grants etc

- support for new technical developments, for example new steel core materials, both at the R&D stage and as they reach commercialisation

- examination of the cost of new materials and manufacturing technology, to identify mechanisms by which it could be reduced and establish the longer-term pattern, advantages of scale etc

- replacement of older transformers in Europe through planned investment programmes, in which the best technology is used

- investigation of whether there is scope to use PCB elimination plans to promote energy-efficient practices

- development of an effective approach to the non-utility sector

- collaboration with partners and facilitators world-wide

- encouraging utilities and private sector customers to employ demand side management (DSM) and other network management tools to their installations. Highlighting the contribution

which energy-efficient distribution transformers can make to optimising utility operations or reducing maximum demand tariffs.

13 ACTIONS, PARTNERS

13.1 Examples of Proposals, Actions and Impact

Given the possible alternative market transformation measures available, and the costs/barriers associated with each, it is recommended that the EU consider the following specific actions:

Create a Mandatory Labelling System for Transformers:

Such a system would ensure that end users with minimal knowledge of transformers can make rational purchasing decisions. Further, it produces a framework for the future introduction of financial incentives for the purchase of more efficient transformers and/or the introduction of minimum standards should these be deemed appropriate.

It is estimated that such a labelling scheme would cost approximately €2-300,000 in development costs. It has the potential to save 850GWh/year, valued at €45 million (340,000 tonnes of CO2) per annum within 20 years.

Production of a Specification Tool Kit for Buyers:

This tool kit would provide basic guidance on the issues relating to the purchase of transformers, and would allow the purchaser to better specify their transformer needs to the manufacturer/contractor. Such a tool kit should be developed in conjunction with the manufacturer and contractor trade bodies, to ensure their commitment to the project and increase the likelihood of dissemination to the end user at the point of specification. Further, the act of seeking co-operation from both the manufacturer and contractor trade bodies will aid in understanding between both bodies and may lead to concerted actions by the two groups in the future.

It is estimated that the development of a Specification Tool Kit tailored to national situations would cost approximately €60-80,000 to develop, and €60,000 to print and distribute. The potential savings are of 8.5GWh, worth €1.8 million (3,400 tonnes of CO2) per annum within 20 years. The Specification Tool kit has the added benefit that the package could be developed and distribution begun very quickly.

Funding of a Demonstration Buyer Group:

While the principles of buyer groups are well understood throughout Europe, group purchasing of transformers has not yet occurred. The establishment and consequential promotion of such a buyer group would demonstrate the practicality of groups in this area, particularly to large users.

It is estimated that the cost of establishing such a group would be €40,000, and the promotion across Europe to targeted large users would be a further €40,000. This should result in savings of 340GWh/year worth €18 million (136,000 tonnes of CO2) per annum within 20 years.

The Active Promotion by the EU of Financial Incentives at the National Level:

While it is recognised that the EU cannot have direct control over financial incentives at the national level, every effort should be made to encourage national governments to offer financial incentives for the purchase of efficient transformers. This is particularly true of countries with privatised utilities, where the sharing of any improvement in the “cost of losses” could be used as an incentive the utilities to reduce losses, while simultaneously reducing the cost to the consumer.

13.2 Approach to the Non-utility Sector

The main problems with the non-utility sector are the fragmentation of the market and the difficulty of identifying decision-makers.

There is a need to target larger distribution transformer buyers such as railways, metros and rapid transit, chemicals and steelworks. The industry energy efficiency trade associations and energy clubs at European and national level can be addressed.

Smaller non-utility customers should be regarded mainly as an opportunity to demonstrate good practice, because of their small individual size and the effort required to convert them.

13.3 Partners for Collaboration, Facilitators

Potential partners we have identified for collaboration in R&D, demonstration and promotional initiatives on energy-efficient power systems transformers in Europe include the following:

- national European government energy departments and energy agencies, where the main goals would be demonstrating the energy saving potential for distribution transformers, and encouraging the implementation of national targets and initiatives

- the International Energy Agency (IEA), an OECD agency which operates mainly through a series of inter-country agreements (chapters) supporting the development of specific energy technologies. The IEA appears to be showing some interest in energy-efficient small transformers. It may be possible to persuade IEA to extend initiatives to distribution transformers

- the European Organisations for the Promotion of Energy Technology (OPET) network, funded by the EC. The OPET network has recently been relaunched, and is particularly useful for collaborative efforts in Central Europe

- utility trade associations at European (Eurelectric) and national level, with the objective of securing a Europe-wide utility platform for energy efficiency issues

- industry energy efficiency trade associations and energy clubs at European and national level

- European and national transformer trade associations, to promote energy efficiency and good practice

- distribution transformer manufacturers. At this stage there is the need to identify and start to work with champions for energy efficiency in transformer manufacturers and utilities

- private sector buyers of distribution transformers with an interest in energy efficiency

- international collaboration, with countries able to both share experience and to learn. The European transformer manufacturers are manufacturing world-wide, and are also major exporters, particularly interested in business development in China, South East Asia, India and the Middle East

- transfer of US experience and concepts. The US Environment Protection Agency (EPA) has developed a software programme on transformer sizing for energy efficiency, which has been adapted for European practice in one country, and is reported to have received considerable interest

- other countries working on similar issues. These include Canada, India and China.

13.4 Sources of Funding

There has been very little funded work undertaken in Europe on energy efficiency in distribution transformers, or related areas, undertaken in Europe. Sources of financial support for R&D, promotion and dissemination, in addition to the partners described in Section 13.3, include:

- the 5th Framework ENERGIE Programme, the successor of Joule/Thermie within the EC Science, Research and Development Directorate, which undertakes research and development projects in the energy sector

- • the EC PHARE and TACIS programmes, working together with the European Bank for Reconstruction and Development (EBRD), to assist in the restructuring of the economies of Central and Eastern Europe

- technology transfer of US experience and software. Creation of software and financial models applicable to the European market

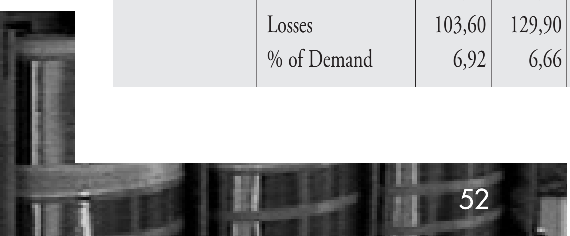
- trade associations, particularly the transformer trade associations at national and European level (COTREL). The secretary of the German trade association has agreed to inform his members about EC interest in energy efficiency initiatives in power systems transformers

- the utilities' trade associations, including UNIPEDE and CIRED, the technical association for electricity distribution.

Appendix A

Power Systems Losses - European Union, 1980-2010 (TWh)

Country		Actual				Forecast			Implied Average Annual Increase (%)						
	Year	1980	1990	1995	1996	2000	2005	2010	1980-1990	1990-1995	1995-1996	1996-2000	2000-2005	2005-2010	1994-2010
Austria	Demand	36,30	46,90	51,00	52,30	56,60	62,10	67,30	2,60	1,69	2,55	1,99	1,87	1,62	1,82
	Losses	2,60	3,00	3,30	3,30	3,40	3,60	3,80	1,44	1,92	0,00	0,75	1,15	1,09	1,01
	% of Demand	7,16	6,40	6,47	6,31	6,01	5,80	5,65	-1,12	0,23	-2,49	-1,22	-0,71	-0,53	-0,79
Belgium	Demand	47,70	62,60	73,50	75,30	81,20	89,00	94,50	2,76	3,26	2,45	1,90	1,85	1,21	1,64
	Losses	2,70	3,40	3,70	3,80	4,10	4,50	4,80	2,33	1,71	2,70	1,92	1,88	1,30	1,68
	% of Demand	5,66	5,43	5,03	5,05	5,05	5,06	5,08	-0,41	-1,51	0,25	0,01	0,03	0,09	0,05
Germany	Demand	351,00	415,00	493,00	500,00	512,00	531,00	547,00	1,69	3,50	1,42	0,59	0,73	0,60	0,64
	Losses	14,00	17,00	21,00	20,00	21,00	21,00	21,00	1,96	4,32	-4,76	1,23	0,00	0,00	0,35
	% of Demand	3,99	4,10	4,26	4,00	4,10	3,95	3,84	0,27	0,78	-6,10	0,63	-0,73	-0,59	-0,29
Denmark	Demand	23,90	30,80	33,70	34,80	35,80	36,80	37,70	2,57	1,82	3,26	0,71	0,55	0,48	0,57
	Losses	2,10	2,20	2,20	2,40	2,30	2,40	2,50	0,47	0,00	9,09	-1,06	0,85	0,82	0,29
	% of Demand	8,79	7,14	6,53	6,90	6,42	6,52	6,63	-2,05	-1,78	5,64	-1,76	0,30	0,33	-0,28
Spain	Demand	102,00	145,40	164,00	169,00	188,20	218,20	246,70	3,61	2,44	3,05	2,73	3,00	2,49	2,74
	Losses	9,90	13,70	13,80	14,10	17,50	19,90	23,20	3,30	0,15	2,17	5,55	2,60	3,12	3,62
	% of Demand	9,71	9,42	8,41	8,34	9,30	9,12	9,40	-0,30	-2,24	-0,85	2,75	-0,39	0,62	0,86
Finland	Demand	39,90	62,30	69,00	70,10	78,00	85,40	92,10	4,56	2,06	1,59	2,71	1,83	1,52	1,97
	Losses	2,30	2,90	3,00	3,00	3,10	3,30	3,40	2,35	0,68	0,00	0,82	1,26	0,60	0,90
	% of Demand	5,76	4,65	4,35	4,28	3,97	3,86	3,69	-2,12	-1,36	-1,57	-1,83	-0,56	-0,91	-1,05
France	Demand	248,70	349,50	397,30	415,20	444,00	479,00	516,00	3,46	2,60	4,51	1,69	1,53	1,50	1,56
	Losses	17,20	26,60	29,40	31,00	33,00	36,00	38,00	4,46	2,02	5,44	1,58	1,76	1,09	1,46
	% of Demand	6,92	7,61	7,40	7,47	7,43	7,52	7,36	0,96	-0,56	0,90	-0,11	0,22	-0,41	-0,10
Greece	Demand	21,90	32,50	38,80	40,50	47,20	54,20	63,40	4,03	3,61	4,38	3,90	2,80	3,19	3,25
	Losses	1,60	2,90	3,20	3,30	3,90	4,60	5,40	6,13	1,99	3,12	4,26	3,36	3,26	3,58
	% of Demand	7,31	8,92	8,25	8,15	8,26	8,49	8,52	2,02	-1,56	-1,20	0,35	0,54	0,07	0,32
Ireland	Demand	9,50	13,00	16,40	17,60	21,70	26,80	32,10	3,19	4,76	7,32	5,37	4,31	3,68	4,39
	Losses	1,10	1,20	1,50	1,70	2,00	2,50	3,00	0,87	4,56	13,33	4,15	4,56	3,71	4,14
	% of Demand	11,58	9,23	9,15	9,66	9,22	9,33	9,35	-2,24	-0,18	5,61	-1,17	0,24	0,04	-0,24
Italy	Demand	179,50	235,10	261,00	262,90	296,00	330,00	360,00	2,74	2,11	0,73	3,01	2,20	1,76	2,27
	Losses	15,90	16,40	17,60	16,90	20,70	23,10	25,20	0,31	1,42	-3,98	5,20	2,22	1,76	2,89
	% of Demand	8,86	6,98	6,74	6,43	6,99	7,00	7,00	-2,36	-0,68	-4,67	2,13	0,02	0,00	0,61
Luxembourg	Demand	3,70	4,40	5,10	5,10	5,60	5,90	6,30	1,75	3,00	0,00	2,37	1,05	1,32	1,52
	Losses	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	% of Demand	2,70	2,27	1,96	1,96	1,79	1,69	1,59	-1,72	-2,91	0,00	-2,31	-1,04	-1,30	-1,50
Netherlands	Demand	59,70	78,00	89,60	93,50	101,20	110,90	121,50	2,71	2,81	4,35	2,00	1,85	1,84	1,89
	Losses	2,50	3,10	3,50	3,60	3,50	3,80	4,10	2,17	2,46	2,86	-0,70	1,66	1,53	0,93
	% of Demand	4,19	3,97	3,91	3,85	3,46	3,43	3,37	-0,52	-0,35	-1,43	-2,65	-0,19	-0,31	-0,94
Portugal	Demand	15,30	25,10	29,30	30,90	36,50	42,80	49,00	5,07	3,14	5,46	4,25	3,24	2,74	3,35
	Losses	1,80	3,20	3,30	3,50	4,00	4,70	5,10	5,92	0,62	6,06	3,39	3,28	1,65	2,73
	% of Demand	11,76	12,75	11,26	11,33	10,96	10,98	10,41	0,81	-2,45	0,57	-0,82	0,04	-1,07	-0,60
Sweden	Demand	94,10	139,90	142,40	142,70	145,50	147,80	152,30	4,05	0,35	0,21	0,49	0,31	0,60	0,47
	Losses	8,20	9,30	10,10	10,10	7,60	7,60	7,70	1,27	1,66	0,00	-6,86	0,00	0,26	-1,92
	% of Demand	8,71	6,65	7,09	7,08	5,22	5,14	5,06	-2,67	1,30	-0,21	-7,31	-0,31	-0,34	-2,37
UK	Demand	264,80	309,40	330,70	343,90	360,80	393,00	425,70	1,57	1,34	3,99	1,21	1,72	1,61	1,54
	Losses	21,60	24,90	28,50	29,60	31,50	34,30	36,20	1,43	2,74	3,86	1,57	1,72	1,08	1,45
	% of Demand	8,16	8,05	8,62	8,61	8,73	8,73	8,50	-0,13	1,38	-0,13	0,36	-0,01	-0,52	-0,09
EUR 15	Demand	1.498,00	1.949,90	2.194,80	2.253,80	2.410,30	2.612,90	2.811,60	2,67	2,39	2,69	1,69	1,63	1,48	1,59
	Losses	103,60	129,90	144,20	146,40	157,70	171,40	183,50	2,29	2,11	1,53	1,88	1,68	1,37	1,63
	% of Demand	6,92	6,66	6,57	6,50	6,54	6,56	6,53	-0,37	-0,28	-1,13	0,18	0,05	-0,10	0,03



Appendix B

LIST OF COTREL MEMBERS

COMMITTEE OF ASSOCIATIONS OF EUR0PEAN TRANSFORMER MANUFACTURERS
SECRETARIAT - Ing Tomasso Genova (ANIE)

AUSTRIA
Fachverband der Elektro und Electronikindustrie (FEEI)
Mariahilfer Strasse 37-39
1060 Vienna
Austria
Tel: +43 588 39 21
Fax: +43 1 586 69 71

BELGIUM
Federation des Entreprises de I'Industrie des Fabrications Metalliques (FABRIMETAL)
Rue des Drapiers 21
1050 Bruxelles
Belgium
Tel: +32 2 510 2540
Fax: +32 2 510 2561

FRANCE
Groupement des lndustries de Materiels d'Equipement Electrique et de I'Electronique lndustrielle Associee (GIMELEC)
11 Rue Hamelin
75783 Paris - Cedex 16
France
Tel: +33 1 45 05 70 70
Fax: +33 1 47 04 68 57

GERMANY
ZVEI/Fachverband Transformatoren
Zentralverband Elektrotechnik und Elektronikindustrie e.v.
Stresemannallee 19
POSTFACH 70 12 61
60591 Frankfurt/Main 70
Germany
Tel: +49 69/6302 256
Fax: +49 69/6302 317

IRELAND
Irish Transformer Manufacturers' Association (ITMA)
(Irish Business & Employers Confederation) Confederation House
84/86 Lower Baggot Street
Republic of Ireland
Tel: +353 1 660 1011
Fax: +353 1 660 1717

ITALY
Associazione Nazionale lndustrie Elettrotecniche (ed Elettroniche) (ANIE)
Via Alessandro Algardi 2
20148 Milan
Italy
Tel: +39 2 326 4242
Fax: +39 2 326 4212

NETHERLANDS
FME HOLTRAM - Holland Transformer Manufacturers
Vereniging voor de Metaal - en de Elektronische industrie
Postbus 190
40 Boerhaavelaan
2700 AD Zoetermeer
Netherlands
Tel: +31 79 353 11 00
Fax: +31 79 353 13 65

PORTUGAL
Associacao Nacional des Industriais de Material Electrico e Electronico (ANIMEE)
Av. Guerra Junqueiro, 11-20
1000 Lisbon
Portugal
Tel: +351 01 849 4521
Fax: +351 01 840 7525

UNITED KINGDOM
Westminster Towers
3 Albert Embankment
London SE1 7SL
Tel: +49 69/6302 256
Fax: +49 69/6302 317

Appendix C

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OPET NETWORK:
ORGANISATIONS FOR THE PROMOTION OF ENERGY TECHNOLOGIES

The network of Organisations for the Promotion of Energy Technologies (OPET), supported by the European Commission, helps to disseminate new, clean and efficient energy technology solutions emerging from the research, development and demonstration activities of ENERGIE and its predecessor programmes. The activities of OPET Members across all member states, and of OPET Associates covering key world regions, include conferences, seminars, workshops, exhibitions, publications and other information and promotional actions aimed at stimulating the transfer and exploitation of improved energy technologies. Full details can be obtained through the OPET internet website address http://www.cordis.lu/opet/home.html

OPET

ADEME
27, rue Louis Vicat
75737 Paris, France
Manager: Mr Yves Lambert
Contact:
Ms Florence Clement
Telephone: +33 1 47 65 20 41
Facsimile: +33 1 46 45 52 36
E-mail:
florence.clement@ademe.fr

ASTER-CESEN
Via Morgagni 4
40122 Bologna, Italy
Manager: Ms Leda Bologni
Contact: Ms Verdiana Bandini
Telephone: +39 051 236242
Facsimile: +39 051 227803
E-mail: opet@aster.it

BEO
BEO c/o Projekttraeger Biologie, Energie, Umwelt
Forschungszentrum
Juelich GmbH
52425 Julich
Germany
Manager: Mr Norbert Schacht
Contact: Mrs Gillian Glaze
Telephone: +49 2461 615928
Facsimile: +49 2461 61 2880
E-mail:
g.glaze@fz-juelich.de

BRECSU
Bucknalls Lane, Garston
WD2 7JR Watford
United Kingdom
Manager: Mr Mike Trim
Contact: Mr Mike Trim
Telephone: +44 1923 664754
Facsimile: +44 1923 664097
E-mail: trimm@bre.co.uk

CCE
Estrada de Alfragide, Praceta 1
2720 Alfragide
Portugal
Manager: Mr Luis Silva
Contact: Mr Diogo Beirao
Telephone: +351 1 4722818
Facsimile: +351 14722898
E-mail:
dmre.cce@mail.telepac.pt

CLER
28 rue Basfroi
75011 Paris
France
Manager: Ms Liliane Battais
Contact: Mr Richard Loyen
Telephone: +33 1 46590444
Facsimile: +33 1 46590392
E-mail: cler@worldnet.fr

CMPT
Exploration House
Offshore Technology Park
Aberdeen AB23 8GX
United Kingdom
Manager:
Mr Jonathan Shackleton
Contact Ms Jane Kennedy
Telephone: +44 870 608 3440
Facsimile: +44 870 608 3480
E-mail: j.kennedy@cmpt.com

CORA
Altenkesselerstrasse 17
66115 Saarbrucken
Germany
Manager: Mr Michael Brand
Contact: Mr Nicola Sacca
Telephone: +49 681 9762 174
Facsimile: +49 681 9762 175
E-mail: sacca@sea.sb.uunet.de

CRES
19 km Marathonos Ave
190 09 Pikermi, Greece
Manager: Ms Maria Kontoni
Contact: Ms Maria Kontoni
Telephone: +30 1 60 39 900
Facsimile: +30 1 60 39 911
E-mail: mkontoni@cres.gr

Cross Border OPET- Bavaria-Austria
Wieshuberstr. 3
93059 Regensburg
Germany
Manager: Mr Johann Fenzl
Contact: Mr Toni Lautenschlaeger
Telephone: +49 941 46419-0
Facsimile: +49 941 46419-10
E-mail: fenzl.zreu@t-online.de

ENEA-ISNOVA
CR Casaccia
S Maria di Galeria
00060 Roma, Italy
Manager:
Mr Francesco Ciampa
Contact: Ms Wen Guo
Telephone: +39 06 3048 4118
Facsimile: +39 06 3048 4447
E-mail:
enea_opet@casaccia.enea.it

Energy Centre Denmark
DTI
P.O. Box 141
2630 Taastrup, Denmark
Manager: Mr Poul Kristensen
Contact: Cross Border OPET
Bavaria Mr Nils Daugaard
Telephone: +45 43 50 70 80
Facsimile: +45 43 50 70 88
E-mail: ecd@teknolgisk.dk

ETSU
Harwell
Didcot
OX11 0RA Oxfordshire
United Kingdom
Manager: Ms Cathy Durston
Contact: Ms Lorraine Watling
Telephone: +44 1235 432014
Facsimile: +44 1235 433434
E-mail:
lorraine.watling@aeat.co.uk

EVE
Edificio Albia I planta 14,
C. San Vicente, 8
48001 Bilbao, Spain
Manager: Mr Juan Reig Giner
Contact:
Mr Guillermo Basanez
Telephone: +34 94 423 50 50
Facsimile: + 34 94 435 56 00
E-mail: jreig@eve.es

FAST
2, P. le R. Morandi
20121 Milan
Italy
Manager: Ms Paola Gabaldi
Contact: Ms Debora Barone
Telephone: +39 02 76 01 56 72
Facsimile: +39 02 78 24 85
E-mail: paola.gabaldi@fast.mi.it

ICAEN
Avinguda Diagonal, 453 bis, atic
08036 Barcelona
Spain
Manager:
Mr Joan Josep Escobar
Contact:
Mr Joan Josep Escobar
Telephone: +34 93 4392800
Facsimile: +34 93 4197253
E-mail: edificis@icaen.es

ICEU
Auenstrasse 25
04105 Leipzig
Germany
Manager: Mr Jörg Matthies
Contact: Mrs Petra Seidler / Mrs Sabine Märker
Telephone: +49 341 9804969
Facsimile: +49 341 9803486
E-mail: krause@iceu.manner.de

ICIE
Via Velletri, 35
00198 Roma, Italy
Manager: Mariella Melchiorri
Contact: Rossella Ceccarelli
Telephone:
+39 06 8549141-8543467
Facsimile: +39 06 8550250
E-mail: icie.rm@rm.icie.it

IDAE
Paseo de la Castellana 95, planta 21
28046 Madrid, Spain
Manager:
Mr José Donoso Alonso
Contact:
Ms Virginia Vivanco Cohn
Telephone: +34 91 456 5024
Facsimile: +34 91 555 1389
E-mail: vvivanco@idae.es

IMPIVA
Plaza Ayuntamiento, 6
46002 Valencia
Spain
Manager: José-Carlos Garcia
Contact: Joaquin Ortola
Telephone: +34 96 398 6336
Facsimile: +34 96 398 6201
E-mail:
ximo.ortola@impiva.m400.gva.es

Institut Wallon
Boulevard Frère Orban 4
5000 Namur
Belgium
Manager: Mr Francis Ghigny
Contact: Mr Xavier Dubuisson
Telephone: +32 81 25 04 80
Facsimile: +32 81 25 04 90
E-mail:
xavier.dubuisson@iwallon.be

Irish Energy Centre
Glasnevin
9 Dublin
Ireland
Manager: Ms Rita Ward
Contact: Ms Rita Ward
Telephone: +353 1 8082073
Facsimile: +353 1 8372848
E-mail: opetiec@irish-energy.ie

LDK
7, Sp. Triantafyllou St.
113 61 Athens, Greece
Manager:
Mr Leonidas Damianidis
Contact:
Ms Marianna Kondilidou
Telephone: +30 1 8563181
Facsimile: +30 1 8563180
E-mail: ldkopet@mail.hol.gr

NIFES
8 Woodside Terrace
G3 7UY Glasgow
United Kingdom
Manager: Mr Andrew Hannah
Contact: Mr John Smith
Telephone: +44 141 332 4140
Facsimile: +44 141 332 4255
E-mail: glasgow@nifes.co.uk.

Novem
Swentiboldstraat 21
P.O. Box 17
6130 AA Sittard
Netherlands
Manager: Mr Theo Haanen
Contact:
Mrs Antoinette Deckers
Telephone: +31 46 42 02 326
Facsimile: +31 46 45 28 260
E-mail: A.Deckers@Novem.nl
T.Haanen@Novem.nl

NVE
P.O. Box 5091, Majorstua
0301 Oslo, Norway
Manager: Mr Roar W. Fjeld
Contact: Mr Roar W. Fjeld
Telephone: +47 22 95 90 83
Facsimile: +47 22 95 90 99
E-mail: rwf@nve.no

OPET Austria
Linke Wienzeile 18
1060 Vienna, Austria
Manager: Mr Günter Simader
Contact: Mr Günter Simader
Telephone:
+43 1 586 15 24 ext 21
Facsimile: +43 1 586 94 88
E-mail: simader@eva.wsr.at

OPET EM
Swedish National Energy Administration
c/o Institutet för framtidsstudier
Box 591
S- 101 31 Stockholm
Manager: Ms Sonja Ewerstein
Contact: Mr Anders Haaker
Telephone: +46 70 648 69 19/
+46 85 452 03 88
Facsimile: +46 8 24 50 14
E-mail:
sonja.ewerstein@stem.se.

These data are subject to possible change. For further information, please contact the above internet website address or Fax +32 2 2966016

OPET Finland
Technology Development Centre Tekes
P.O. Box 69,
Malminkatu 34
0101 Helsinki, Finland
Manager: Ms Marjatta Aarniala
Contact: Ms Marjatta Aarniala
Telephone: +358 105215736
Facsimile: +358 105215908
E-mail:
marjatta.aarniala@tekes.fi

OPET Israel
Tel-Aviv University
69978 Tel Aviv
Israel
Manager: Mr Yair Sharan
Contact: Mr Yair Sharan
Telephone: +972 3 6407573
Facsimile: +972 3 6410193
E-mail: sharany@post.tau.ac.il

OPET Luxembourg
Avenue des Terres Rouges 1
4004 Esch-sur-Alzette
Luxembourg
Manager: Mr Jean Offermann (Agence de l'Energie)
Contact: Mr Ralf Goldmann (Luxcontrol)
Telephone: +352 547 711 282
Facsimile: +352 54 77 11 266
E-mail:
goldmann@luxcontrol.com

OPET Bothnia
Norrlandsgatan 13, Box 443
901 09 Umea - Sweden
Blaviksskolan
910 60 Asele -Sweden
Manager: Ms France Goulet
Telephone: +46 90 16 37 09
Facsimile: +46 90 19 37 19
Contact: Mr Anders Lidholm
Telephone: +46 941 108 33
Facsimile: +46 70 632 5588
E-mail: opet.venet@swipnet.se

Orkustofnun
Grensasvegi 9
IS-108 Reykjavik
Iceland
Manager:
Mr Einar Tjörvi Eliasson
Contact:
Mr Einar Tjörvi Eliasson
Telephone: +354 569 6105
Facsimile: +354 568 8896
E-mail: ete@os.is

CEEETA-PARTEX
Rua Gustavo de Matos Sequeira, 28 - 1 . Dt .
1200-215 Lisboa
Portugal
Manager: Mr Aníbal Fernandes
Contact: Mr Aníbal Fernandes
Telephone: +351 1 395 6019
Facsimile: +351 1 395 2490
E-mail: ceeeta@ceeeta.pt

RARE
50 rue Gustave Delory
59800 Lille, France
Manager: Mr Pierre Sachse
Contact:
Mr Jean-Michel Poupart
Telephone: +33 3 20 88 64 30
Facsimile: +33 3 20 88 64 40
E-mail: are@nordnet.fr

SODEAN
Isaac Newton s/n
Pabellón de Portugal - Edifico SODEAN
41092 Sevilla
Spain
Manager:
Mr Juan Antonio Barragán Rico
Contact:
Ms Maria Luisa Borra Marcos
Telephone: +34 95 4460966
Facsimile: +34 95 4460628
E-mail:
mailto:mborra.sodean@sadiel.es

SOGES
Corso Turati 49
10128 Turin, Italy
Manager:
Mr Antonio Maria Barbero
Contact: Mr Fernando Garzello
Telephone: +39 0 11 3190833/3186492
Facsimile: +39 0 11 3190292
E-mail: opet@grupposoges.it

VTC
Boeretang 200
2400 Mol
Belgium
Manager:
Mr Hubert van den Bergh
Contact: Ms Greet Vanuytsel
Telephone: +32 14 335822
Facsimile: +32 14 321185
E-mail: opetvtc@vito.be

Wales OPET Cymru
Dyfi EcoParc
Machynlleth
SY20 8AX Powys
United Kingdom
Manager: Ms Janet Sanders
Contact: Mr Rod Edwards
Telephone: +44 1654 705000
Facsimile: +44 1654 703000
E-mail: opetdulas@gn.apc.org

FEMOPET

Black Sea Regional Energy Centre — (BSREC)
8, Triaditza Str.
1040 Sofia
Bulgaria
Manager: Dr L. Radulov
Contact: Dr L. Radulov
Telephone: +359 2 980 6854
Facsimile: +359 2 980 6855
E-mail: ecsynkk@bsrec.bg

EC BREC - LEI FEMOPET c/o EC BREC/IBMER
Warsaw Office
ul. Rakowiecka 32
02-532 Warsaw, Poland
Manager: Mr Krzysztof Gierulski
Contact: Mr Krzysztof Gierulski
Telephone: +48 22 484832
Facsimile: +48 22 484832
E-mail: grewis@ibmer.waw.pl

Energy Centre Bratislava
c/o SEI-EA
Bajkalská 27
82799 Bratislava, Slovakia
Manager: Mr Michael Wild
Contact: Mr Michael Wild
Telephone: +421 7 582 48 472
Facsimile: +421 7 582 48 470
E-mail: ecbratislava@ibm.net

Energy Centre Hungary
Könyves Kálmán Körút 76
H-1087 Budapest
Hungary
Manager: Mr Andras Szalóki
Contact: Mr Zoltan Csepiga
Telephone: +36 1 313 4824/ 313 7837
Facsimile: +36 1 303 9065
E-mail:
Andras.szalóki @energycentre.hu

Estonia FEMOPET
Estonian Energy Research Institute
Paldiski mnt.1
EE0001 Tallinn, Estonia
Manager: Mr Villu Vares
Contact: Mr Rene Tonnisson
Telephone: +372 245 0303
Facsimile: +372 631 1570
E-mail: femopet@femopet.ee

FEMOPET LEI - Lithuania
Lithuanian Energy Institute
3 Breslaujos Str.
3035 Kaunas, Lithuania
Manager: Mr Romualdas Skemas
Contact: Mr Sigitas Bartkus
Telephone: +370 7 35 14 03
Facsimile: +370 7 35 12 71
E-mail: bartkus@isag.lei.lt

FEMOPET Poland KAPE-BAPE-GRAPE
c/o KAPE
ul. Nowogrodzka 35/41 XII p.
PL-00-950 Warsaw
Poland
Manager: Ms Marina Coey
Contact: Ms Marina Coey
Telephone: +48 22 62 22 794
Facsimile: +48 22 62 24 392
E-mail: kape4@pol.pl

FEMOPET Slovenia
Jozef Stefan Institute
Energy Efficiency Centre
Jamova 39
SLO-1000 Ljubljana
Slovenia
Manager: Mr Boris Selan
Contact: Mr Tomaz Fatur
Telephone: +386 61 1885 210
Facsimile: +386 61 1612 335
E-mail: tomaz.fatur@ijs.si

Latvia FEMOPET c/o B.V. EKODOMA Ltd
Zentenes Street 12-49
1069 Riga
Latvia
Manager: Ms Dagnija Blumberga
Contact: Ms Dagnija Blumberga
Telephone: +371 721 05 97/ 241 98 53
Facsimile: +371 721 05 97/ 241 98 53
E-mail: ekodoma@mail.bkc.lv

OMIKK
National Technical Information Centre and Library
Muzeum Utca 17
H-1088 Budapest
Hungary
Manager: Mr Gyula Nyerges
Contact: Mr Gyula Nyerges
Telephone: +36 1 2663123
Facsimile: +36 1 3382702
E-mail: nyerges@omk.omikk.hu

FEMOPET Romania ENERO
8, Energeticienilor Blvd.
3, Bucharest 79619
Romania
Manager: Mr Alexandru Florescu
Contact: Mr Christian Tintareanu
Telephone: +401 322 0917
Facsimile: +401 322 27 90
E-mail: crit@mail.gsci.vsat.ro

Sofia Energy Centre Ltd
51, James Boucher Blvd.
1407 Sofia
Bulgaria
Manager: Ms Violetta Groseva
Contact: Ms Violetta Groseva
Telephone: +359 2 96 25158
Facsimile: +359 2 681 461
E-mail: ecencentre@enpro.bg

Technology Centre AS CR
Rozvojova 135
165 02 Prague 6
Czech Republic
Manager: Mr Karel Klusacek
Contact: Mr Radan Panacek
Telephone: +420 2 203 90203
Facsimile: +420 2 325 630
E-mail: klusacek@tc.cas.cz

FEMOPET Cyprus
Andreas Araouzos, 6
1421 Nicosia
Cyprus
Manager: Mr. Solon Kassinis
Contact: Mr. Solon Kassinis
Telephone: +357 2 867140/ 305797
Facsimile: +357 2 375120/ 305159
E-mail:
mcienerg@cytanet.com.cy

NOTICE TO THE READER

Extensive information on the European Union is available through the EUROPA service at internet website address http://europa.eu.int/

The overall objective of the European Union's energy policy is to help ensure a sustainable energy system for Europe's citizens and businesses, by supporting and promoting secure energy supplies of high service quality at competitive prices and in an environmentally compatible way. European Commission DGXVII initiates, coordinates and manages energy policy actions at transnational level in the fields of solid fuels, oil & gas, electricity, nuclear energy, renewable energy sources and the efficient use of energy. The most important actions concern maintaining and enhancing security of energy supply and international cooperation, strengthening the integrity of energy markets and promoting sustainable development in the energy field.

A central policy instrument is its support and promotion of energy research, technological development and demonstration (RTD), principally through the ENERGIE sub-programme (jointly managed with DGXII) within the theme "Energy, Environment & Sustainable Development" under the European Union's Fifth Framework Programme for RTD. This contributes to sustainable development by focusing on key activities crucial for social well-being and economic competitiveness in Europe.

Other DGXVII managed programmes such as SAVE, ALTENER and SYNERGY focus on accelerating the market uptake of cleaner and more efficient energy systems through legal, administrative, promotional and structural change measures on a trans-regional basis. As part of the wider Energy Framework Programme, they logically complement and reinforce the impacts of ENERGIE.

The internet website address for the Fifth Framework Programme is
http://www.cordis.lu/fp5/home.html

Further information on DGXVII activities is available at the internet website address
http://europa.eu.int/en/comm/dg17/dg17home.htm

The European Commission
Directorate-General for Energy DGXVII
200 Rue de la Loi
B-1049 Brussels
Belgium

Fax +32 2 2950577
E-mail: info@bxl.dg17.cec.be