District heating for Piqua, Ohio

Conference on Energy Use Issues: Conservation

Cogeneration in Europe
Present status in the United Kingdom
Danish island plant serves mainland by undersea pipeline
Combined Heat and Power: The Present Position

by G. T. Shepherd
Chairman, Midlands Electricity Board
United Kingdom

A great deal has been written and spoken about total energy. In its strictest interpretation total energy is taken to imply a situation such as a factory, a housing estate or a town where the total electrical requirements are produced by engine-driven generators, and the total heat requirements are provided by waste heat from the engines. In this definition the power plant operates in complete isolation; I hope to demonstrate that such schemes are rarely viable. Modified systems, however, particularly when integrated with the public electricity system can, in favourable circumstances, be economically justified.

Much of the literature on the subject of total energy suffers from being over enthusiastic, with the result that for some people the total energy concept has been discredited. Little attention has been paid to the possibility of reducing or completely removing technical and financial uncertainties, and at the same time producing real economies.

My talk today is intended to go some way towards remedying this situation.

It comes to two conclusions, which are interrelated. The first is that an isolated total energy scheme would in many cases prove to be unsatisfactory both financially and technically. The second conclusion is that there are some situations in which on-site generators connected to the public electricity distribution system, and heat exchangers using exhaust gases from the prime movers, would provide all energy requirements both cheaply and reliably.

Review of Present Situation

So far as industrial applications are concerned, the concept of total energy is as old as the use of electricity for motive power, and there are obvious advantages in the use of on-site generation when large quantities of process steam are needed. Successive generations of factory managers and engineers have applied the principles concerned with great success; and in the early days of the electricity supply industry some of the more enterprising among them used their surplus generating capacity to give an electricity supply to the village or town in which the factory was situated. In general they found this to be a lucrative proposition, and of mutual benefit to their customers in the town, and the factory.

Nowadays, however, industry is turning more and more to the public electricity system for power, and raising steam from a normal boilerhouse.

(We wish to thank the District Heating Association of the United Kingdom for permission to print Mr. Shepherd’s paper, which appeared in the DHA Journal No. 24.)

An important factor in this matter has been the high degree of security of the public electricity supply system. This country has a very good record in this respect with an average shutdown time per customer of 90 minutes per annum, from all causes, including planned shutdowns.

The total energy method has been examined for many commercial and housing projects in recent years, but few appraisals have resulted in action. Nevertheless, there are some who foresee its adoption on a big scale over the next decade or so, and it is instructive to consider what evidence there is for this prophecy.

Reasons for Total Energy Rejection

The basic argument in favour of total energy is that it should be possible to obtain a worthwhile overall advantage by local generation of electricity, and at the same time putting to good use some of the two thirds or so of the fuel’s energy which is usually wasted in power stations.

This is such an attractive proposition in theory that one may be forgiven for expecting to find every large new commercial or housing estate development supplied in this way, but there are so many pitfalls in practice that the benefits turn out to be illusory in all but a few instances.

Some of the difficulties and uncertainties which must be faced when considering total energy are:

1. A decision to install a total energy plant commits the company (or as it may be, the local authority or say hospital board) to a course of action and continuing expenditure which is irreversible for many years. A large number of assumptions relating to costs, taxes and allowances, energy
needs, availability of fuel, spare parts and skilled labour, and many other factors, have to be made. Even if these are correctly calculated for the short term, it is a bold man who will guarantee the full cost for many years ahead, especially in view of the present unstable wage, price, and interest rate conditions. The company may consequently be faced with serious expenses additional of its budget, and may in the last resort be forced to cut its losses and revert to buying its energy from the local Electricity Board.

2. A further change which may not be foreseeable but one which could cause considerable extra expense, would be a decision at a later date to extend the energy requirements, necessitating increased generation and/or heat supplies. It might well be necessary to provide this extra capacity at a much higher cost than the original installation, and this could make the combined scheme uneconomic. It could also upset the balance of generation and heat supplies, which might lower the overall efficiency. The fact of the matter is that a total energy scheme must be tailor-made for a given set of circumstances, and it has little built-in flexibility to adjust to changes.

3. A very important consideration, and one which might prove crucial in deciding against a total energy scheme, is the question of security of supply of electricity and heat. Obviously, the greater the number of generators and the higher the proportion of spare capacity, the greater the security of supply. For many applications there is an unenviable choice between buying a reasonable security of supply at an unwarrantable increase in capital cost, or running unwarrantable risks in order to make the project financially viable.

4. It is difficult in many cases to obtain the correct mix of the use of generation and heat, and to ensure a high annual load factor of both.

5. There is a tendency to allot too small a charge for overhead expense; for example an allowance for the use of land occupied by the generator and other plant is often omitted, the possibility that the local authority rates will be increased is sometimes overlooked, and the cost of management overheads often ignored.

6. Recent estimates of the cost of heat mains are very high (between £2,000-£3,000 per metre) which could easily make the cost of the distribution system half the total capital cost of the project.

7. Lastly, but not least in importance, there are the problems of noise, vibration and pollution of the atmosphere. These factors can often be largely discounted for industrial applications, but increasing attention is being paid to them in town planning requirements for other situations. Site limitations can make compliance with stringent conditions very difficult.

These are the main problems to be taken into account in assessing the viability of any proposed total energy scheme. While few projects will encounter all the possible drawbacks described, in most instances a true appraisal of costs would include heavy expenditure on a number of them, resulting in a DCF basis yield of well below the 16-20% which would probably be obtainable by alternative investment in the company's own field. The calculation is made even more unfavourable by the changes in company taxation which may occur from time to time. This situation may have been marginally alleviated to some extent by the introduction of a scheme by the Department of Industry whereby a cash grant of 25% may be made in certain cases. Even if the financial calculations are satisfactory, the risks and uncertainties have to be faced, and these as already indicated are often formidable, sufficiently so in most cases to daunt all but the most speculative of investors, who would expect an even higher yield in order to offset the risk.

Electricity Board On-Site Generation and Heat Supply

The preceding section of the Paper argues that in all but a very few instances, total energy is not a commercial proposition when promoted by the company which will own the proposed development. This section of the Paper is devoted to demonstrating that an alternative approach is possible by which the improvement in thermal efficiency by recovering the waste heat is retained, and at the same time most of the disadvantages are avoided; so that, in suitable circumstances, schemes which are acceptable both financially and technically can be devised.

The essential features of this concept are that on-site generation of electricity and supply of low-grade heat would be run so as to be completely integrated into the public supply system. The circumstances would be that the on-site generation would be established with heat-recovery equipment sufficient to meet all or part of the requirement of the development, and would be operated to meet the demand for heat and not the demand for electricity. The supplies of electricity would be at the normal tariff, but the benefits of the relatively cheap production of heat would be shared on an agreed basis with the consumer.

In order for the benefits to be real, the circumstances must be right and a most careful examination of the heat requirements, site facilities, amenity problems, and alternative schemes is required, with a full cost appraisal to demonstrate an adequate return on investment.

The problems of providing for site limitations, and for satisfactory noise, vibration, and air pollution levels, are just as serious for the Boards as for any other developer, and when a Board-owned generator scheme is contemplated, it is vital that adequate provision be made in the very early stages of planning. The advantages of Board proprietorship are as follows:
1. Since the Board becomes the main contractor, the consumer is not involved in any capital expenditure and in these days, when capital is increasingly hard to come by, most consumers would be glad of an opportunity to apply their slender investment resources in other directions. For the consumer to embark on a total energy project would be pointless anyway, because the same object, obtaining cheap supplies of heat, is achieved by means of the advantageous terms the Board’s generation scheme would be able to offer.

2. The consumer is relieved of the risk of a serious failure of his generators, causing loss of supplies of electricity and heat for days and even weeks. As already indicated, this is a real possibility even if he goes to the considerable extra expense of providing spare generating capacity.

In the case of Board’s proprietorship, the generators would be running in parallel with the Board’s supply network, and the security of supply would rise to the very high level of the public system. In fact it would be even better because the generators would probably keep running on the rare occasions when the public supply system failed.

3. There are difficult problems of matching heat and power loads at all times. Any mismatch lowers the overall efficiency of the scheme.

4. There would be no difficulties in the control of electrical frequency and voltage, because the generators would automatically synchronise with the public supply, the frequency of which is kept within fine limits.

The points listed above in favour of the Board’s proprietorship, when considered together, have the effect that in many cases the Board can obtain a satisfactory return on its investment, while being able at the same time to offer attractive terms to the consumer for supply of his total energy requirement.

Midlands Electricity Board Approach

In 1966, when the cost of primary fuel was around 1p per therm, a combined investigation with the CEGB resulted in an offer to supply heat to consumers in Telford New Town from the new Ironbridge B power station. The scheme was uneconomic mainly due to the immense capital investment necessary for the distribution pipework system and the low annual heat load factor.

In 1973 an offer to provide a CHP scheme, integrated into the public electricity system, was made to supply heat to approximately 3000 dwellings, six schools and a shopping precinct in a section of Redditch New Town. Following agreement with local officials, it was planned to construct a small diesel station and sell (Continued on 27)
heat at the station boundary at a price equal to the cost of primary fuel plus 10%. There would have been no capital contribution. The scheme was finally turned down by the Redditch Development Corporation on the grounds that there would be a loss of freedom of choice for cooking, since no gas pipes would be laid around the estate.

In 1974 further efforts were made to build a similarly integrated station at Telford where it was proposed to supply heat in the form of hot water, again at the station boundary to 3000 dwellings and a swimming pool complex. This scheme was abandoned for the following reasons:

1. During negotiations the housing density was changed from 20/22 per acre to 11/12 per acre, thus increasing the distribution costs.
2. Commercial tenants in the second stage of the city development were not prepared to accept a supply of heat from a district heating scheme.
3. There was massive escalation in capital cost of pipework, etc.
4. The Gas Board, although declining to supply a central power station, was prepared to supply individual boilers throughout the housing development.

In view of the uncertain demand on the lengthy payback period associated with district heating schemes, the MEB has since concentrated its efforts on specialised CHP systems. In each case, the proposals have involved the integration of electrical output for the public supply system.

The break-through came by radically reappraising the basic principles. The requirements are:

1. Substantial heat load with high annual load factor.
2. A relatively small and simple heat distribution system.
3. The generating plant to be sized for the base-load heat requirement, and topping-up to be carried out by package boilers.
4. The generators to be run in parallel with the public supply system.

The most attractive applications are for industrial demand which can be accurately predicted, and which have high heat load factors on smaller distribution systems.

Some of the industrial schemes investigated have involved paper mills, dye factories and rubber manufacturers; and potential commercial schemes have included the NEC, a county council complex and a university—all of which for various reasons have had to be abandoned.

**Plant Choice**

The choice of plant is probably the most important factor in evaluating a potential scheme, and some appreciation of the available plant options may be obtained by comparing heat balances for various prime-movers under ideal conditions.

Three different prime-movers have been evaluated:

Firstly, the gas turbine, whose capital costs are low compared with, say, a steam turbine, has an overall efficiency of about 80%, although only 21% of the fuel energy is converted into electrical power. The disadvantage is that a high-grade distillate fuel is required.

Secondly, the back pressure steam turbine where approximately 20% of the fuel energy is obtained as electrical power, and 66% as useful heat energy.

Thirdly, diesel engines which produce a relatively high electrical output of up to 40% of the fuel energy, and about 36% can be recovered as useful heat via waste heat boilers and heat exchangers associated with the cooling systems.

An appreciation of the significance of the plant selection can be obtained from the comparisons of capital cost to supply 40 megawatts (h) heat load.

Superficial examination indicates that the diesel is expensive in terms of capital costs. On the other hand the boiler-only case has the cheapest capital, fuel and maintenance costs which should give it the best financial performance.
When the energy outputs are examined, however, it is obvious that the diesel installation has the highest percentage of electricity and hot water output, and the valuable revenue from this alters the initial merit order of financial performance.

Fig. 7—Capital costs comparison, industrial total energy schemes.

Hereford Scheme

In the Hereford scheme which is now in course of construction, diesel engines have been selected for the reasons given.

The two 10,000 hp diesel engines are fitted with waste heat boilers and economisers, each driving 7.5 MW 11 kw alternators.

The engines will be operated for approximately 6400 hr/yr. Approximately 47% of annual heat requirement will be obtained from the prime-movers which will be run on full load at all times.

During peak heat load periods, and when the diesel engines are shut down, steam will be supplied from four 40,000 lb/hr boilers operating at 300 psig.

Heat is recovered from the exhaust gas in two stages.

Firstly, the gas at 840 F, enters the waste heat boiler where it generates dry saturated steam. The steam is then passed through a superheater, where it is superheated to 450 F (300 psig) before entering the station steam range.

Secondly, the exhaust gas gives up heat to an economiser where it is cooled to 350 F before passing up the stack to atmosphere. The economiser circuit heats a calorifier (heat exchanger filled with a thermal fluid) which in turn heats offices and the boilers and facilitates a reduction in capital costs. Another major source of heat is the output from the valve cage, engine jacket and lubrication oil coolers. This supplies the hot water process at 165 F and also feeds the economiser calorifier. The overall thermal efficiency of the scheme is estimated to be approximately 76%.

A number of other interesting problems had to be overcome such as obtaining ministerial consent, negotiating wayleaves and designing an environmentally acceptable enclosure for the rather noisy diesel engines.

We appreciate the help we have received from those who assisted us in overcoming these problems.

Potential Schemes

Other schemes under consideration include one which involves the supply of heat to a very large industrial consumer in Birmingham.

It is proposed to install two diesel generators of 12 MW capacity approximately to produce power for about 6400 hr/yr at 11,000 volts. Each engine will be equipped with a supplementary fired waste heat steam boiler and economisers, together with heat recovery systems to enable heat to be recovered from the engines’ cooling systems. The steam so produced would augment steam produced from 2 x 25,000 lb chain-grate package boilers.

The maximum steam produced would be 100,000 lb/hr and would be delivered to the customer’s boiler-house together with hot water for boiler feed and for an industrial process.

As an alternative to the chain-grate boiler, consideration is being given to the installation of a fluidised-bed boiler which, for a small additional cost, will provide increased flexibility in fuel use and also participation for the diesel exhaust fumes.

Heat Boards

Before I conclude my talk I would like to comment on the possible formation of heat boards. While at the present time I do not have knowledge of the powers and terms of reference that may be invested in these boards, I do not consider that their formation would
assist in advancing the cause of fuel conservation in this country. By and large it is the electricity distribution boards and the gas industry which have knowledge of the requirements of integrating with their systems. It is organisations such as these, having underground mains and services in roadways, which would be presented with a major problem resulting from the introduction of heat mains on a large scale. I would have preferred that closer cooperation be encouraged between local authorities and the existing fuel industries.

Conclusion
And now in conclusion I would re-emphasise our conviction that the potential for schemes such as Hereford is great. However, it is evident that the more conventional district heating schemes are difficult to justify in the present politico-economic climate. If the UK Government takes action to dictate consumers' choice of fuel or finance consumers' capital costs, or subsidise the undertaking's capital costs, then this present unfavourable situation might improve.

Until this happens, the MEB will place its faith in industrial applications integrated with the public electricity system which save energy, and are commercially viable and are not subsidised financially by electricity consumers or anyone else.

**THE FUEL EFFICIENCY QUIZ.**

Should stack temperature be high or low?
Should CO₂ readings be high or low?

The answers to these and other combustion efficiency questions are readily available in Bacharach Combustion Testing Bulletins.

Hardly surprising since Bacharach Combustion Testing Kits have been helping maintenance people obtain greater fuel efficiency in oil, gas, and coal for over forty years.

Quiz answers: low stack temperature and high CO₂ readings are essential for both heating efficiency and fuel conservation.

For information on our Combustion Testing Kits, contact the T&M Sales Group, Bacharach Instrument Company, 625 Alpha Drive, Pittsburgh, Pennsylvania 15238. (412) 782-3500

**Ambac • Bacharach**

A Division of AMBAC Industries, Inc.