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ENERGY CASCADES IN CANADA

A.C. HAYDEN AND T.D. BROWN

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ENERGY CASCADES IN CANADA

by

A.C. Hayden* and T.D. Brown*

ABSTRACT

Combining energy uses in a cascade can result in significant overall reductions in fuel requirements. The simplest applications for a cascade are in the recovery of waste heat from existing processes using special boilers or turbines.

Specific applications of more complex energy cascades for Canada are discussed. A combined cycle plant at a chemical refinery in Ontario is a world leader in energy efficiency. Total energy systems for commercial buildings, such as one installed in a school in Western Canada, offer attractive energy and operating cost benefits. A cogeneration plant proposed for the National Capital Region, generating electricity as well as steam for district heating, allows the use of a low grade fossil fuel-coal, greatly improves energy transformation efficiency, and also utilizes an effectively renewable resource - municipal garbage.

Despite the widespread availability of equipment and technology of energy cascades, the sale of steam and electricity across plant boundaries presents a barrier. More widespread use of cascades will require increased cooperation among industry, electric utilities and the various levels of government if Canada is to realize the high levels of energy efficiency potentially available.

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LES CASCADES D'ENERGIE AU CANADA

par

A.C. Hayden* et T.D. Brown*

RESUME

Une combinaison de l'usage de l'énergie dans une cascade peut réduire de façon significative la consommation globale de combustibles. Les applications les plus simples pour une cascade impliquent la récupération de la chaleur résiduelle des procédés existants à l'aide de chaudières ou de turbines conçues à cet effet.

Des applications distinctes des cascades d'énergie plus complexes pour le Canada sont décrites dans ce rapport. Une usine à cycle combiné, faisant partie d'une raffinerie chimique en Ontario, domine en matière de consommation efficace d'énergie. Les systèmes d'énergie complets installés dans les immeubles commerciaux tel que celui qui est installé dans une école de l'ouest du Canada, offrent une réduction intéressante des coûts énergétiques et opérationels. Une usine de co-génération proposée pour la Région de la capitale nationale, susceptible de produire l'électricité ainsi que la vapeur pour le chauffage régional, peut utiliser un charbon carburant fossile à basse teneur, améliorer l'efficacité de la transformation de l'énergie et employer une source d'énergie renouvelable - les ordures municipales.

Quoique l'équipement et la technologie pour les cascades d'énergie soient facilement disponibles, la vente de la vapeur et de l'électricité au-delà des frontières de l'usine occasionnent des difficultés. Un plus grand usage de cascades doit engendrer une meilleure coopération entre les membres de l'industrie, des compagnies d'électricité et de certains niveaux de gouvernement si le Canada veut atteindre un haut niveau d'efficacité de consommation d'énergie.

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INTRODUCTION

The advent of an energy crisis with its consequent increase in fuel costs has brought about a flurry of activity in the optimization of energy use. Old techniques are being reapplied, and new technologies are being developed. Energy cascading is one of the established technologies which is being studied in a new light. An energy cascade can be created when the quality of energy rejected from one industrial process can meet the input energy specification of a second process. The two can be linked to produce the simplest form of cascade - a two-process series. Developments in new working materials have extended the temperature range within which an energy cascade can be used.

More than two processes can be linked in this way to create a series of processes in which the exhaust from one is input to the next. In this way the full potential of the energy input can be realized.

The inclusion of even a low efficiency process in an energy cascade can therefore improve overall fuel efficiency.

THE TERMINOLOGY OF ENERGY CASCADES

Development of this concept has introduced novel terminology. "Cogeneration", "total energy", "district heating" and "combined cycle systems" all refer to different groupings of energy cascading technologies.

Cogeneration refers to the process designed to simultaneously produce both heat and electricity from a fuel energy source. The relative amounts of heat and electricity produced will depend on demand at any given time. In many industries the technology of cogeneration is well established for use within a manufacturing plant itself but the sale of electricity and heat beyond the plant boundaries is less common.

Total energy systems simultaneously fulfill the electricity and heat requirement of a single building or a complex of buildings. The system may be designed to maintain the complex as a unit self-sufficient in energy; no energy is sold outside the complex, and the only input is the base fuel.

Combined cycle systems make use of more than one process to generate electricity. The processes may each use a different sequence of compression, heating, and expansion of either air or steam. Such sequences are known as thermodynamic cycles, by the far the most common of these being a combination of gas and steam turbines. These can be coupled to maximize the electricity output in a fuel-based power station.

District heating describes the heating of a multiple-building residential or commercial sector of a city from a single heat source. It is not an energy cascade in its own right. It is nevertheless a critically important component of many large-scale cogeneration energy cascades because it provides a large market for the low grade heat which is available after completion of electricity generation in a steam turbine.

The energy cascade saves fuel

When heat is required in an industrial process, the primary heat source is often a flame. Very few processes require the high temperatures that are generated in a flame; many now reject waste heat at very high temperatures.

The creation of a two-process energy cascade from a high temperature process is shown in Fig. 1. In this example the second process, which does not require the high temperature of a flame, has been attached to the exhaust from the first process. The energy cascade has been used to minimize the energy content of waste products emitted to the atmosphere.

An alternative method of using waste heat from any high temperature process is to use it in a waste heat boiler to generate steam. This steam can then be used for process heating or in a steam turbine to generate electricity.

The production of steam solely for the purpose of electricity generation is not an efficient use of either fuel or waste heat. The high pressure steam expands and cools in a steam turbine with the energy being recovered in rotational form as shaft power which is then used to drive an electric generator. The steam is not condensed in the system; the latent heat of condensation and a certain amount of heat energy cannot be recovered as work. This energy is lost to the atmosphere in downstream condenser units. The magnitude of these condenser losses can amount to over 50% of the energy potential of the input fuel.

The electric power consumed in Canadian industry is largely generated by provincial power utilities using the system outlined above. Despite efficient control and operation by the power utilities these condenser losses, which are illustrated in Fig. 2, typically represent 40% of the energy potential of the input fuel. The objective of most energy cascades incorporating electricity generation is to eliminate or minimize this loss.

Within an industrial plant, the use of a gas turbine to generate electricity from high temperature waste gases can be supplemented by a waste heat boiler producing process steam. This permits generation of electricity without incurring the penalty of a large condenser loss. When this type of cascade is employed it is possible to recover more than 70% of the input energy in the form of electricity, heat or work.

This has been recognized in many industrial applications where simultaneous demands for power, process heat, and work occur. When control of these demands is in one location, a "trade off" is usually possible. When one of the demands must be met at any expense, then trade-off potential is limited. This is one reason why electricity generating authorities do not encourage a commitment to simultaneous heat and electricity production.

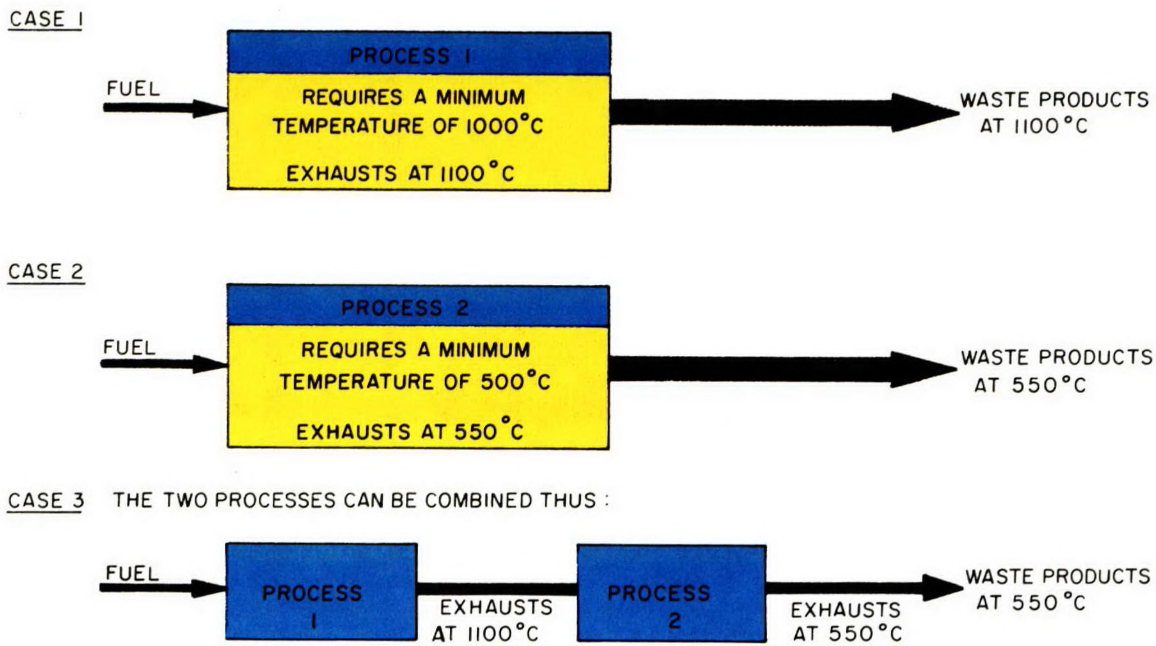
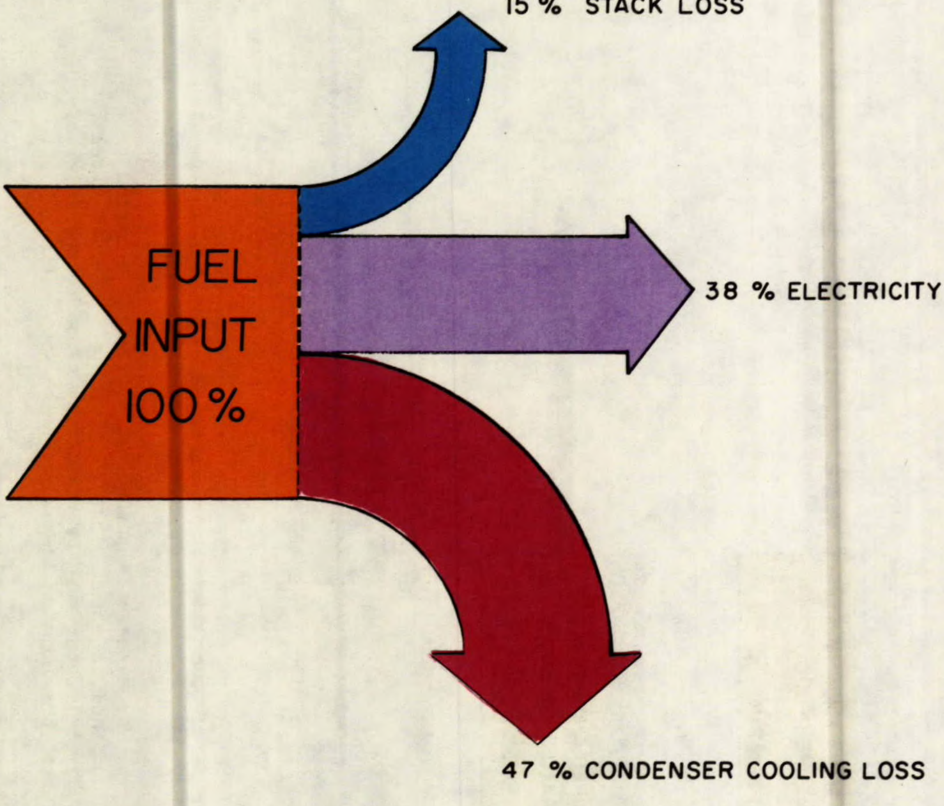


Fig. 1 - The combination of two thermal processes to form a two-process series.

When the waste heat from one process is sufficient to operate a second process the two can be combined as shown, thus eliminating one waste stream. The exhaust from the first process must be reasonably close to the inlet of the second process if heat transmission losses are to be kept small.



CONVENTIONAL THERMAL POWER GENERATION
38 % FUEL UTILIZATION EFFICIENCY

Fig. 2 - Conventional electricity generation only offers fuel utilization efficiency of up to 38%

In a conventional thermal power station the fuel may be coal, oil or gas which is burned with air and the heat is transferred to water. This produces steam at a high temperature and pressure which is expanded through a turbine to produce electricity. In doing this it cools. To maximize the work recovered in the turbine and hence the amount of electricity generated, the steam is condensed immediately after the turbine and water is returned to the boiler. The unit has a fuel utilization efficiency of 38%. Only 38% of the input energy appears in the useful form of electricity.

The waste heat boiler producing steam from waste heat in a high temperature process is undoubtedly the most common means of achieving a two-step cascade in Canadian industry. The use of the same waste heat to produce both steam and electricity is not so common, although it offers much greater overall benefits in terms of national fuel efficiency.

Figure 3 shows a hypothetical multistage cascade incorporating two manufacturing processes and electricity production. Some of the most practicable methods of increasing energy efficiency result from combinations of two or more of the elements shown in Fig. 3.

Industrial waste heat recovery

In discussing potential energy cascades in the process industries it must be recognized as unusual for one process stream to exhaust at precisely the desired temperature, purity and composition for direct use as feed to a second process. Proximity must also be added to these quality requirements if the energy and cost penalties attendant on energy transportation are to be avoided.

For these reasons a great deal of process heating uses steam. Steam purity is not affected by the fuel used in its generation, and its temperature and pressure can easily be controlled at both the generating location and point of use. In addition, steam is one of the cheapest and most plentiful heat-transport mediums available.

The waste heat boiler producing steam has therefore become an integral part of most industrial energy cascades. Alternatives which are encountered less often are the conventional gas turbine, the organic fluid gas turbine, and internal combustion engines.

The waste heat boiler

The steam produced in a waste heat boiler can be used directly for such purposes as heating the feeder streams for chemical reactors, providing heat to evaporate liquids, or heating buildings. It can also be used to generate electricity.

In these circumstances the rate at which steam or electricity is produced depends on the rate at which waste heat is produced. If the prime industrial process generating the waste heat is cyclic in nature, supplementary energy will be necessary to maintain a steady output of electricity or steam.

Industrial processes exhaust heat over a wide range of temperatures. This heat is chiefly in the form of hot gases; hot liquid streams are encountered less frequently. Streams have different impurity characteristics which produce different problems in implementing a waste heat recovery system.

For these reasons most waste heat boiler designs are custom-built to match a specific industrial process.

An example of this uniqueness of design and of other typical problems is waste heat recovery in a basic oxygen converter which is schematically illustrated in Fig. 4. In this batch process, molten pig iron is oxidized at high temperature and the chemical oxidation reactions liberate heat.

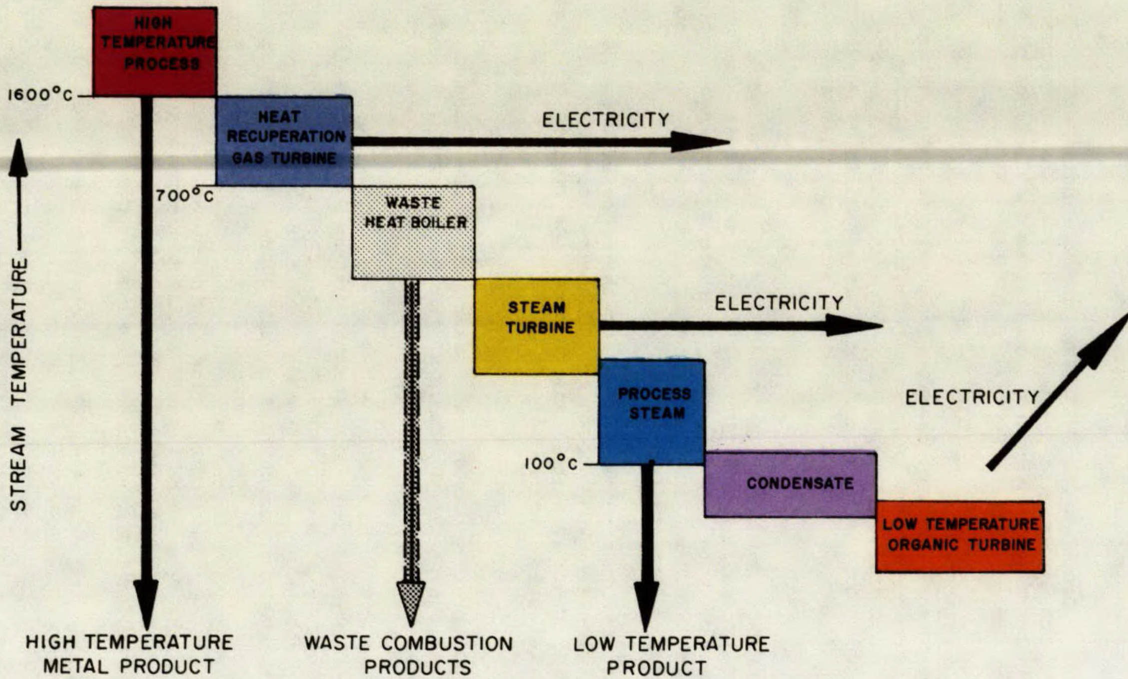


Fig. 3 - Schematic diagram of an energy cascade

As its energy level decreases, waste heat from the high temperature process is used to generate electricity in a gas turbine and then to generate steam in a waste heat boiler. The combustion products are sufficiently cool to be rejected. The steam from the waste heat boiler generates electricity in an industrial process. The condensed steam then drives a low temperature organic turbine and produces still more electricity.

ERRATA SHEET FOR CANMET REPORT 79-12

Page 2, paragraph 6, approx. line 4 - should read:

" ..... typically represent 47% of the energy ...."

instead of:

" ..... typically represent 40% of the energy ...."

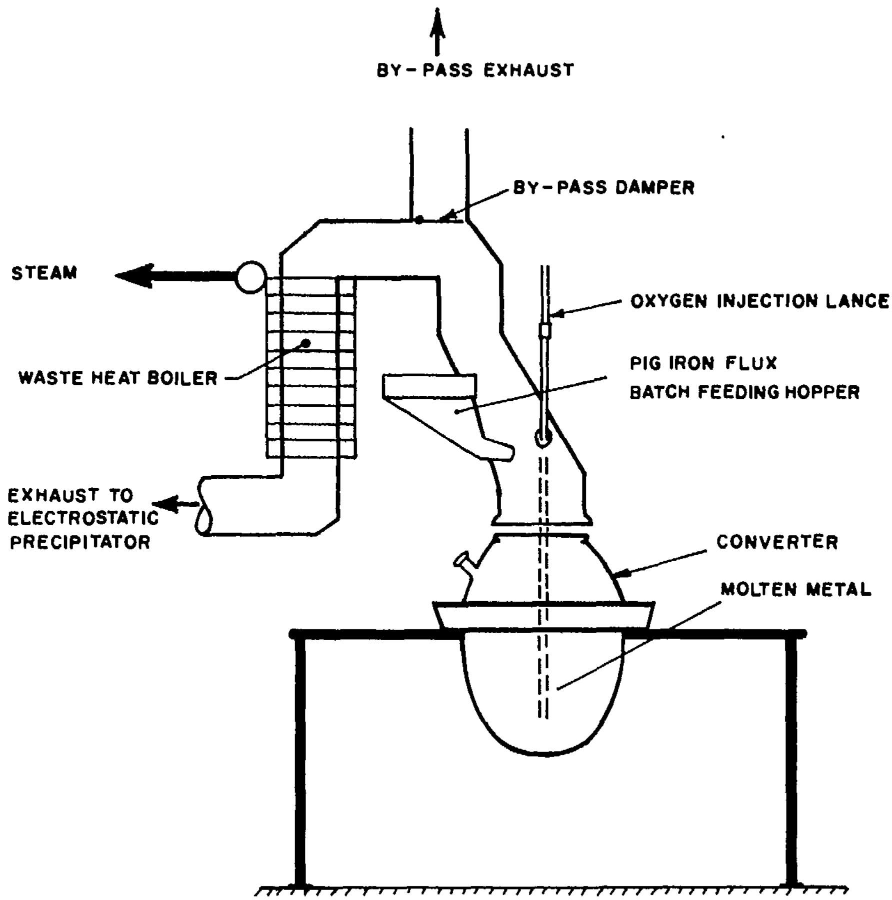


Fig. 4 - Waste heat boiler on an oxygen blown converter used in making steel

Impurities in pig iron from a blast furnace are removed during treatment of molten metal with oxygen. The heat generated by the chemical reactions is removed in a waste heat boiler. Steam is generated intermittently during periods when the oxygen treatment occurs.

The 1800°C effluent is a flue gas containing 80% carbon monoxide and variable amounts of slag, lime and iron which have been entrained in the gas blown through the converter.

The dust content of the waste gases is high. Environmental considerations demand that it not be emitted to the atmosphere. It is normally cleaned by electrostatic precipitation, which is restricted to temperatures below 400°C.

The waste gases could be cooled to this temperature by quenching with water. The use of a waste heat boiler allows the technologies for both energy and environmental conservation to go hand in hand; the waste heat boiler cools down the exhaust gases, allows that energy to be utilized, and then passes the gases to a precipitator to be cleaned.

One basic premise in installing waste heat recovery units is that they should not interfere with the production a saleable commodity. In this example, the steel is produced in batches and the "blowing time" during which steam can be produced is about 60 hours a week. Steam is produced at a high rate during each "blow" which may last for 20 minutes in a 75-ton unit. The steam supply must therefore be smoothed out before it can be used in the plant steam system or to generate electricity.

One typical smoothing method is to install auxiliary burners in the recovery unit to provide 60% of the maximum load. The remaining 40% can be smoothed by steam accumulators. If the steam is to be used to generate electricity, the control system must eliminate surging during the transition between full waste heat recovery and full support firing over the period of a blowing cycle. It is not usually economic to introduce a separate boiler plant dedicated to output smoothing.

<u>The waste heat recovery gas turbine</u>

The gas turbine for producing electricity from waste heat has the advantage that an intermediate steam stage is not used. The irrecoverable latent heat of evaporation loss is therefore avoided. A typical system is illustrated in Fig. 5.

An intermediate heat exchanger must be used if problems due to impurities in the high temperature waste gas steam are to be avoided. In this case air is expanded through the turbine after being heated in the heat exchanger. The higher the turbine inlet temperature the greater the efficiency of electricity generation.

This electricity generating process operates at the high temperatures which occur at the top of an energy cascade. In these circumstances it is sometimes called a "topping cycle".

The major problem with this system is that it requires a heat exchanger for high temperatures. The turbine inlet currently is limited to about 700°C with a consequent restriction on conversion efficiency.

Waste heat recovery systems incorporating gas turbines and waste heat boilers feeding steam turbines have already been installed. The cascade is illustrated in Fig. 6. In some of these instances the combined system has been found to yield higher energy recoveries than an all-steam system.

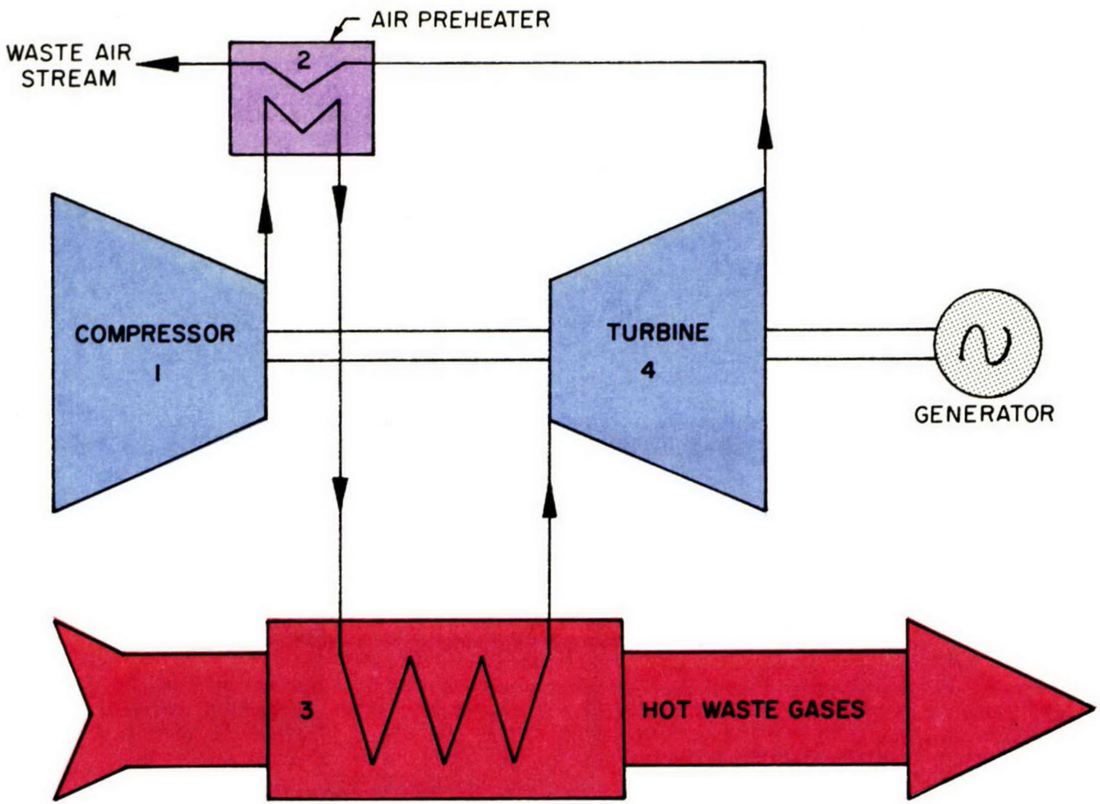


Fig. 5 - A gas turbine cycle generating electricity from hot waste gases

The turbine working fluid is air. It is compressed and preheated before passing through a heat exchanger; then it is expanded through a turbine to generate electricity. The air cools on expansion and is exhausted to atmosphere. The efficiency of such turbines increases with increasing turbine inlet temperature.

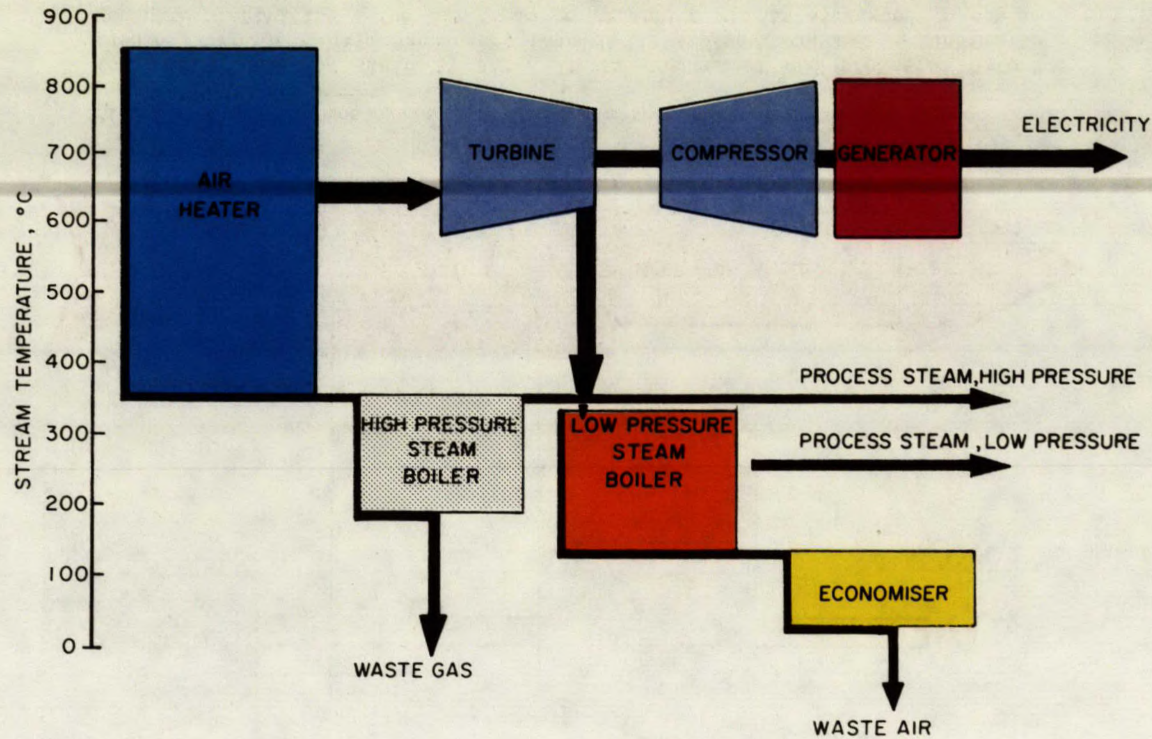


Fig. 6 - The use of a gas turbine in a waste heat recovery cascade

Hot waste gases pass through a heat exchanger and a waste heat boiler where high pressure steam is generated. The heated air from the heat exchanger drives a turbine to generate electricity and then passes through a different waste heat boiler to generate low pressure steam and an economizer to preheat boiler feed water. The waste heat boilers supply steam to different parts of an industrial process.

Low-temperature, organic turbine engines

At low power levels, mechanical and electrical machinery losses can be large. Further, steam cannot be contemplated as a suitable heat recovery medium for temperatures below 100°C. This has led to the development of organic fluids with low boiling points for use in turbine systems. A representative scheme is illustrated in Fig. 7.

The organic fluid turbine operates at a higher efficiency than a steam turbine and is simpler in construction. So far it has only been developed for low power levels. Increases in size and subsequent use in an electricity generating mode would allow the use of condensate or cooling water from a power station to generate further electricity.

In this way heat recovery at the lower temperature end of the system would be increased markedly. This system and others which operate at the low temperature end of a heating or electricity generating process are frequently called "bottoming cycles".

Bottoming cycles for electricity production merit special attention because of the massive amount of heat throughout the country which is rejected at temperatures below 100°C.

ENERGY CASCADE SYSTEMS IN USE IN CANADA

The technologies used in energy cascades are not new. However, energy cascade systems are often unique and may not readily be transferred to other plants or commerical developments. To this extent, cascaded energy systems are often site-specific.

The following examples show three major applications where the cascade principle has offered advantages in both fuel conservation and costs over more conventional systems. It is noticeable that all three systems involve an electricity production stage.

A combined cycle energy cascade

In this type of system, the high temperature exhaust gas from a combustion turbine is used as input to a steam boiler. The steam produced can be used both in processes and to generate electricity. This example is taken from the Dow Chemical plant in Sarnia.

The cascade shown in Fig. 8 consists of:

1 - a natural gas-fired combustion turbine generating electricity and exhausting into 2,
2 - steam boiler generating 90,000 kg/h of high pressure steam with waste gases exhausting into 3,
3 - steam boiler generating 12,000 kg/h of low pressure steam with waste gases exhaust into 4,
4 - feed water heater which produces boiler feed water at 270°F.

This cascade feeds its high pressure steam to a turbine to generate electricity. Intermediate take-off locations exist in the turbine to extract steam at the conditions required for plant use.

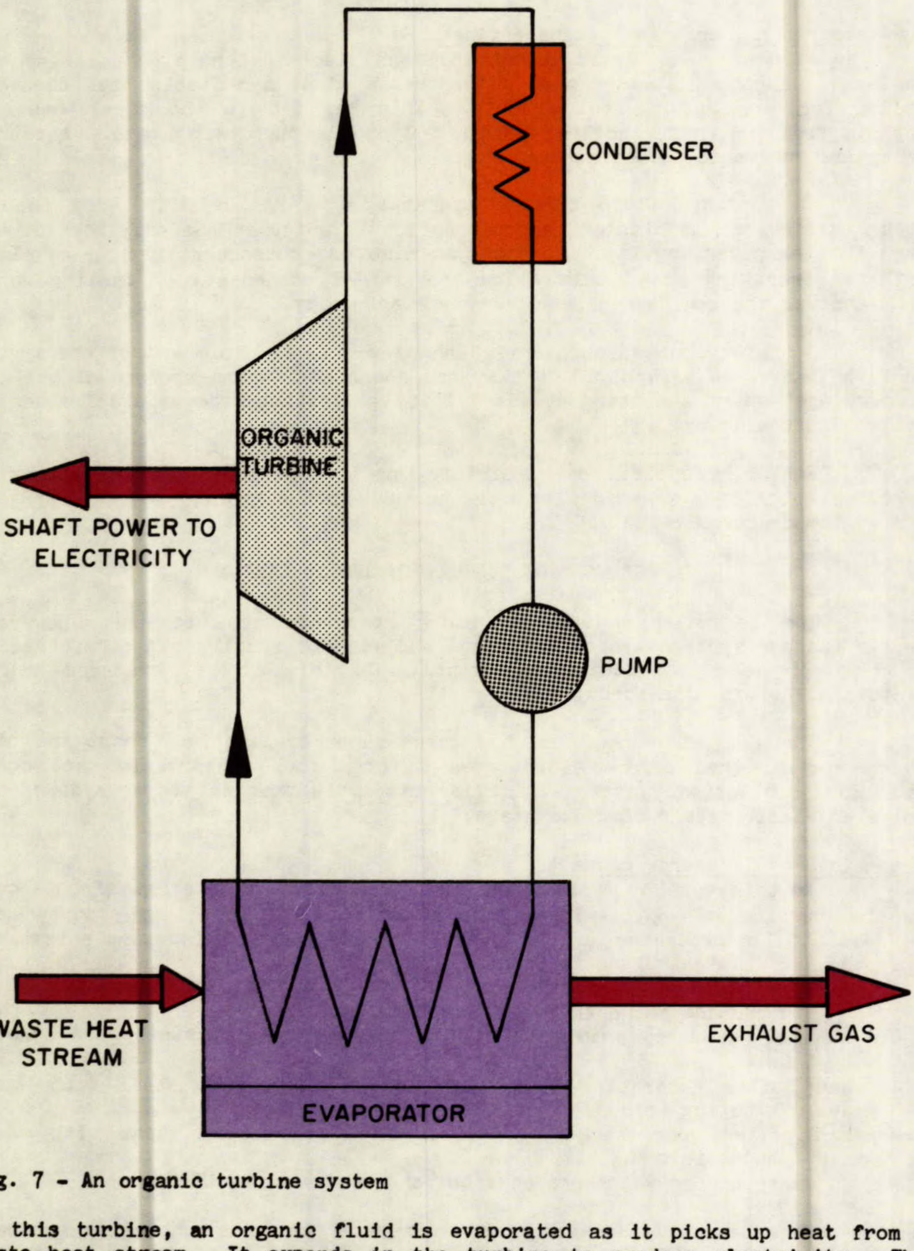


Fig. 7 - An organic turbine system

In this turbine, an organic fluid is evaporated as it picks up heat from a waste heat stream. It expands in the turbine to produce electricity. The outlet vapour from the turbine is condensed before returning to the pump. By careful selection of the organic liquid it is possible to generate electricity from waste heat streams at temperatures of 50°C or lower.

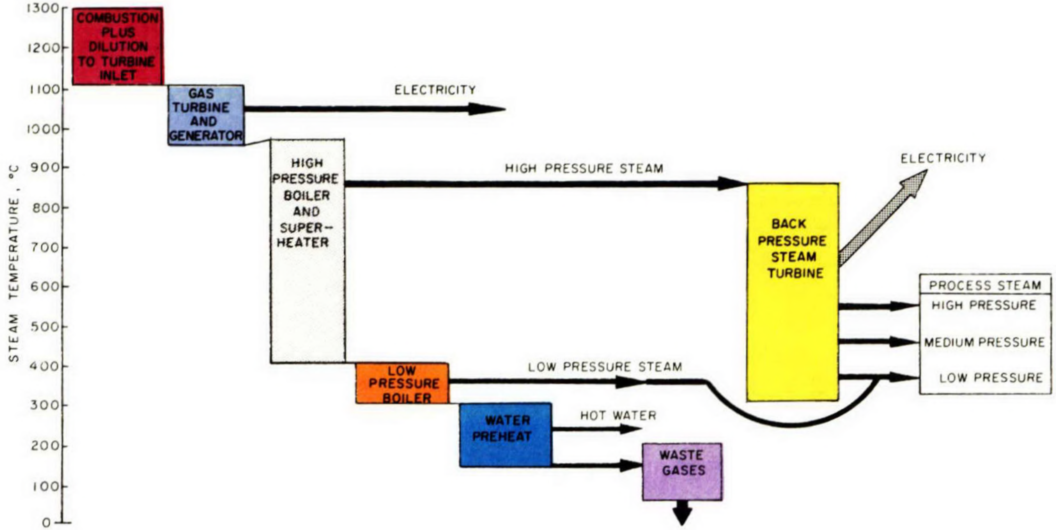


Fig. 8 - A cascade diagram for the energy system at Dow Chemical Corporation, Sarnia, Canada

Natural gas is burned and the products of combustion are expanded in the turbine to generate electricity. The waste products are used successively to generate high pressure steam, low pressure steam, and preheated boiler feedwater. Finally, at the low waste gas temperature of 80°C they are exhausted into the atmosphere. The high pressure steam is used in a steam turbine to generate electricity. Steam extraction points are provided in the turbine where steam can be withdrawn at various conditions for use in different chemical processes.

The overall operational system efficiency is above 86%, possibly the most efficient in the world. The heat rate, a measure of thermal energy required to produce 1 kW of electricity, is noticeably low. This energy cascade supplies the chemical plant with 145 MW of electricity using 4220 kJ (4000 Btu) of fuel for every kW of electricity produced. The plant must purchase 25 MW of electricity from local utilities which use approximately 9495 kJ (9000 Btu) of fuel for every kW of electricity they produce which represents an efficiency below 40%.

The total cycle efficiency of 86% presents a major financial advantage in a plant operation where energy costs are 40% of the total operating costs.

A combined cycle of this sort involving an extraction turbine, allows considerable flexibility in the use of steam. Importantly, the total control of the electricity and process heat lies within the same plant. The conservation of fuel energy has been achieved with good reliability in operation.

<u>The total energy gas engine cascade</u>

In another system, the high temperature exhaust from an internal combustion engine is used to generate steam which can be used directly in heating or indirectly in air conditioning within a single building. The name "total energy" reflects the fact that a single internal mechanical system is responsible for all the electric power and heat requirements throughout the building.

The cascade, illustrated in Fig. 9, is installed in a school in Edmonton. The exhaust gases from a gas-fired engine-generator produce steam in a waste heat boiler. This steam is then used to generate hot tap water and hot water for building heating and air conditioning. Any internal combustion engine could be substituted for the gas engine used in this particular example.

The system was installed in the school in the 1960's, before the energy crisis. Despite high installation costs due to the requirement for a duplicate stand-by unit, the capital and operating costs shown in Fig. 10 are attractive.

Clearly, in such systems provision should be made to interlock the heating and lighting systems and also to dissipate excess heat in a cooling tower. However, the good design practice of recovering the heat in the engine coolant and condensed steam all combine to give a high overall system efficiency.

<u>Cogeneration in a district heating scheme</u>

Fuel costs are a significant component of the cost of electricity generation. The transformation efficiency from fuel to electricity was seen in Fig. 2 to be below 40%. At this efficiency the use of a renewable fuel such as municipal garbage looks attractive. In addition, sanitary land fill is becoming expensive as acceptable sites move farther away from centres of population. Sanitary land fill makes no use of the significant energy content of the waste, which can be as high as that of a low quality coal.

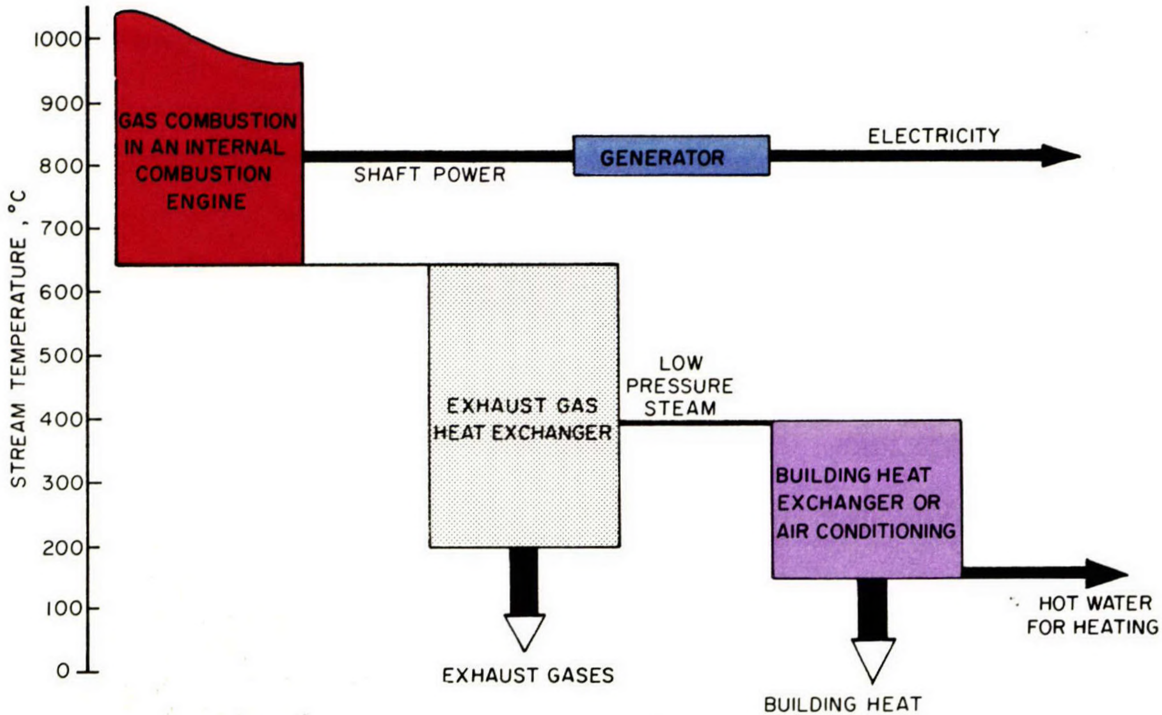


Fig. 9 - A cascade diagram for a simple total energy scheme

A gas engine is used to generate electricity. The hot exhaust gases are used to produce steam which provides heating, cooling, and service hot water. This system is installed in a school in Edmonton. The school is energy self-sufficient and the single unit services all the power, heating and cooling requirements.

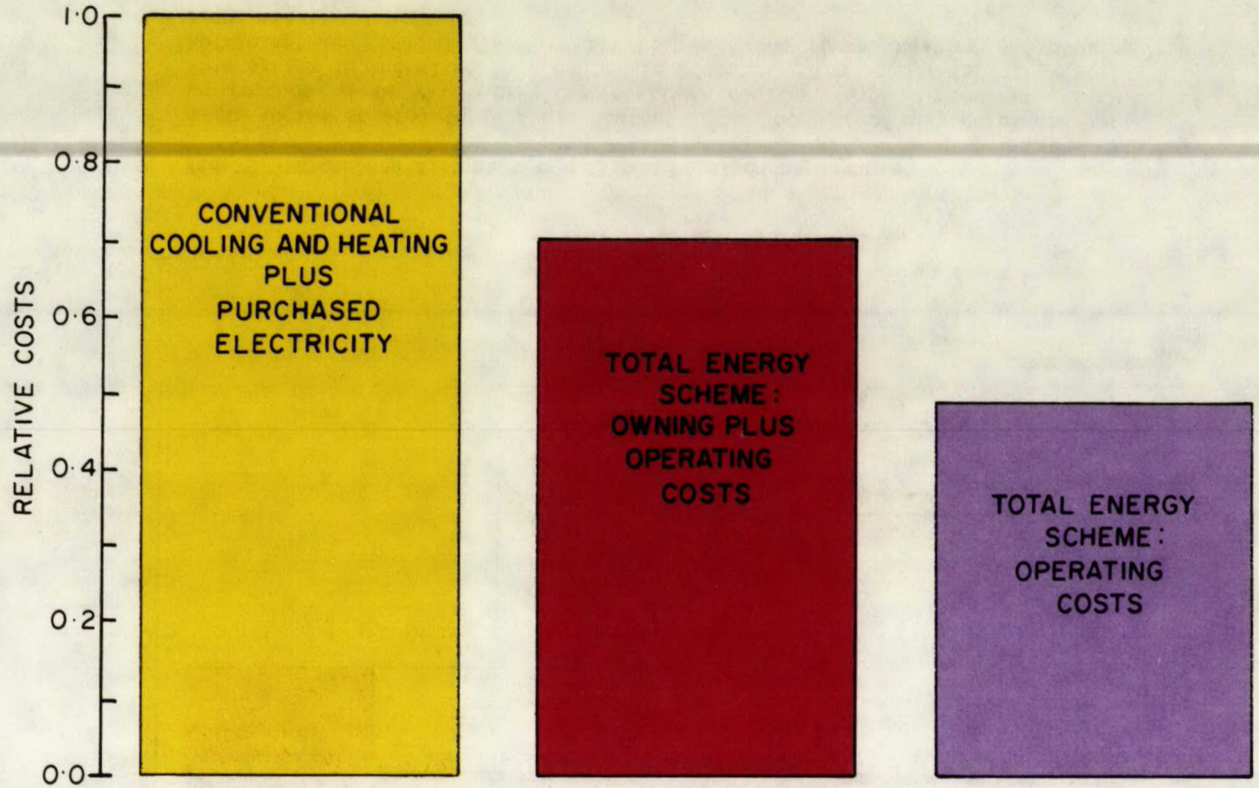


Fig. 10 - Owning and operating costs for the total energy scheme in the Edmonton school

Government buildings in downtown Ottawa offer a concentrated market for waste heat for both winter heating and summer air conditioning. Heat and electricity could be supplied simultaneously via a steam turbine in a cogeneration system. In this way the electricity production efficiency would be twice that of electricity production alone. This level of fuel utilization efficiency makes equipment which has historically been considered too small for power generation look more attractive.

This concept has been developed in design studies variously described as the "Ottawa Master Plan" and the "Nepean Bay District Heating Project".

Municipal garbage is available at a constant rate throughout the year. Its use in a cogeneration system must allow for a supplementary fuel input during periods when the electricity and heat demands are both high. This occurs at the peak of winter heat and summer air conditioning peak. The annual steam load follows the pattern shown in Fig. 11, where the year is divided into four sectors which are either identical or mirror images of each other. In considering the district heating-cogeneration options that are available, it is convenient to consider only one of these sectors.

The three schemes illustrated in Fig. 12 and 13 are available. All meet the essential requirement that the steam demand be matched at all times; they all require supplementary fuel firing.

Figure 12 represents simple district heating with no electricity generation. The peak steam demand must be met by a combination of garbage and supplementary energy supply. The garbage supply remains essentially constant and must be burnt. Outside the period of peak steam demand, garbage energy must be wasted.

Cogeneration routes are illustrated in Fig. 13. In option 1, waste energy from garbage is used to generate electricity during periods when the steam energy market is less than the garbage energy supply. This type of cogeneration system can operate at fuel utilization efficiencies of about 80%. The electricity generating equipment will only be used for less than one half of the year and cannot produce an income when not in use.

This low "use factor" can be increased with the cogeneration scheme illustrated as option 2. In this case the electricity generating equipment is oversized and must be supplied with steam in excess of that used in the maximum steam market. To achieve this, supplementary fossil energy must be supplied. This option requires the biggest steam and turbo generators of the three schemes considered. The equipment, however, will be in continuous use throughout the year, generating electricity as a source of revenue, whereas steam will be an intermittent revenue source. Overall fuel utilization efficiency will be about 60%.

These fossil fuel-garbage combinations in cogeneration schemes are both attractive ways for many municipalities to supply a downtown core with heat and electricity. Simultaneously, the efficiency of fuel utilization in the generation of electricity is markedly increased.

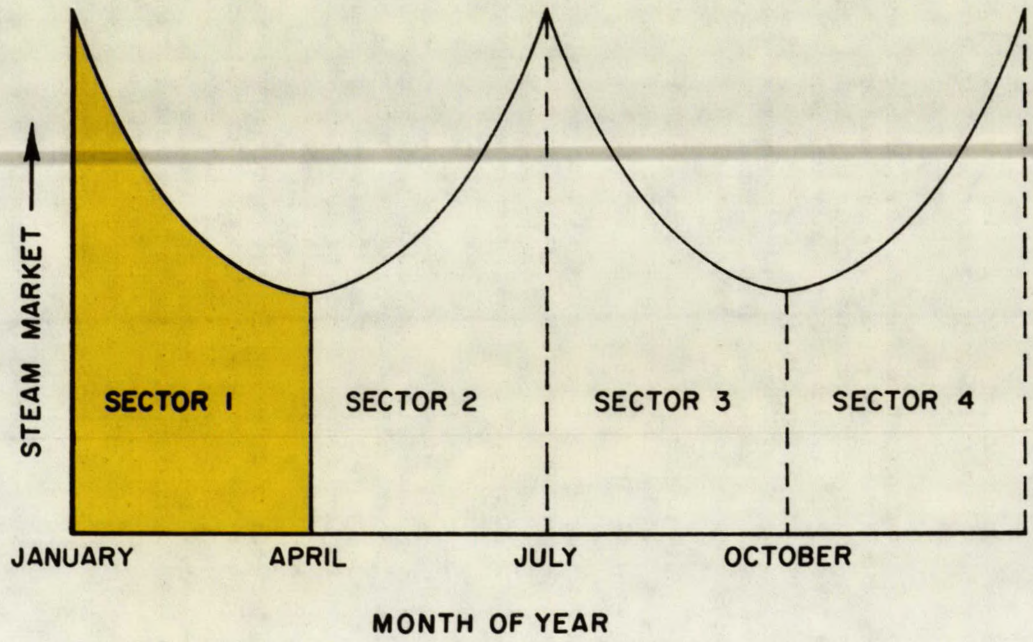


Fig. 11 - Seasonal variation in the steam market in downtown Ottawa

Steam demand is at a maximum in Ottawa during the coldest and the hottest months of the year for winter heating and summer air conditioning. The year can be divided into four steam market sectors which are either identical or mirror images of each other. Sector 1 shows a decrease in heating load as winter progresses into spring; sector 2 shows the gradual increase in the air conditioning load as summer passes. Sectors 3 and 4 show the reduced air conditioning load and increased heating load which occur during fall and winter respectively. Quadrupling of sector 1 therefore represents the annual steam market variation..

DISTRICT HEATING WITH GARBAGE AND FOSSIL FUEL

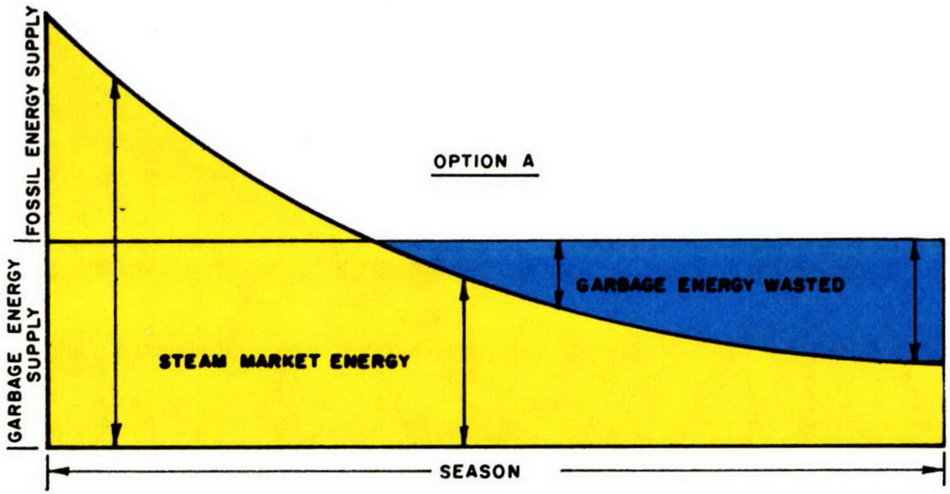


Fig. 12 - Seasonal district heating in Ottawa, burning garbage and fossil fuel

In this case the constant garbage energy supply is insufficient to fill the maximum steam market and supplementary fossil energy must be provided. No electricity is generated, but revenue can be obtained from the steam market. Size of the equipment must be sufficient to fill the maximum steam market.

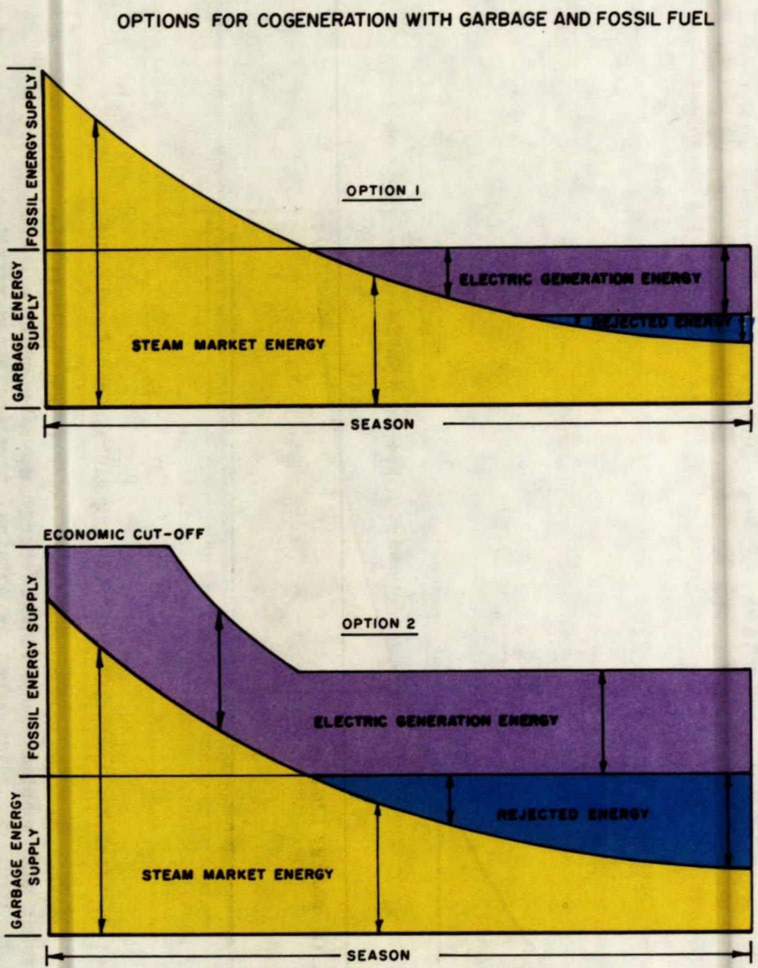


Fig. 13 - Cogeneration in Ottawa burning garbage and fossil fuel

Option 1 is cogeneration using garbage energy to produce electricity during periods of low steam market demand. Supplementary fossil energy must be supplied to fill the maximum steam market. The steam generating equipment must be sufficiently large to fill the maximum steam market. The electricity generating equipment will be in use and generate revenue only when excess garbage energy is available.

Option 2 is cogeneration using both garbage energy and supplementary fossil energy at all times. In this case the steam generating equipment must be sufficiently large to fill the maximum steam market and provide some steam for electricity generation. When the steam market is low, some garbage energy is wasted. The electricity generating equipment and the steam boiler are in use and generate revenue continuously.

SUMMARY

The energy cascades described in this report are examples of the technology of improved fuel use from industrial, commercial and government sectors.

These examples had one feature in common - the technologies were all well established. No novel engineering was employed and any ingenuity or innovation lay only in the selection of processes which could be combined in the cascade.

While capital investment is usually higher than for uncascaded systems, the cascades all show high fuel utilization factors; hence operating costs are low. In the case of the school near Edmonton, the total cost of owning and operating the combined energy scheme adopted was more attractive than for a more conventional scheme. Each case must be considered individually in establishing relative costs and return on capital investment.

Barriers to the use of energy cascades

If the technology of energy cascading is well established and the benefits so great, why is it not in widespread use in Canada?

The answers to this question are critical to the extension of cascading technology in the future.

The answer lies in an historically cheap fuel supply which emphasized productivity without regard to energy requirements. Even after accepting the fact that fuel supplies are not infinite, this same attitude persists. Industries still demand high rates of return on investments. Fuel savings to industry must be unrealistically large - both in energy content and in cost - to justify the increased capital investment of cascaded systems. Many industries require a return on investment of more than 20%. At that rate it is difficult to justify investment in an energy cascade involving electricity production when the electricity generating companies themselves require return rates of only 10 to 15%.

Another reason for the restricted use of energy cascades is the independent attitude of both industry and electric power utilities. Both groups maintain high levels of fuel efficiency within their own operating plants. Neither group has yet considered it sufficiently attractive to interact with the other and with commercial and residental sectors of the community to produce integrated heat and electric power.

The sale of electricity by a manufacturing firm or the sale of heat by an electricity generating station are both attractive economically as well as in terms of fuel efficiency. A contract for the continuous supply of either commodity over a long period of time at fixed rates imposes an additional constraint on the flexibility inherent in uncascaded systems maintained within the plant boundary.

In an analogous manner the terms of reference of many electricity generating authorities require that electricity be generated at the lowest cost compatible with specified levels of reliability. The emphasis is thus not on the most efficient use of national fuel reserves.

These institutional barriers are now supporting attitudes created in an era of low priced fuel.

Widespread application of cascading technology of the types described will require increased cooperation and compromise among industry, utilities and various levels of government. All must be willing to become joint users and suppliers of energy as heat and electricity.

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