RESIDENTIAL WOOD-FIRED COGENERATION

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July 1996

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ABSTRACT

Wood-based electric and thermal cogeneration at the single household scale has conceptually widespread application in Canada and internationally; however, working examples are few. This report examines market opportunities and technologies for wood-fired cogeneration in the order of 2 kW electrical output.

Prime movers are Stirling or heat engines, steam engines utilizing wood-based steam generation and internal combustion engines fueled by wood gas from gasification processes. Electric generation options include conventional and linear induction generators, DC generators and switched reluctance technology.

Promising technologies for commercialization are identified and barriers discussed. Two embodiments, one for a typical household and one for a sustainable household, are presented for future development.

The report includes a contact list of organizations and persons active in small scale cogeneration and wood combustion.

Disclaimer

This study was conducted for Canada Mortgage and Housing Corporation under Part IX of the national Housing Act. The analysis, interpretations and recommendations are those of the consultant and do not necessarily reflect the views of Canada Mortgage and Housing Corporation or those divisions of the Corporation that assisted in the study and its publication.

EXECUTIVE SUMMARY

The potential for generating electricity and heat from wood at a household scale has attracted attention from various quarters both in Canada and internationally. The prevalence of wood heating, the large number of remote dwellings and the strength of the wood burning industry in Canada are favorable conditions for the development and commercialization of wood-fueled microcogeneration.

A majority of Canadian households burn some wood for heating and more than half a million houses use wood as their principal heating source. Between 200,000 and 400,000 dwellings are estimated to be in remote and off-grid locations which provide the most obvious market due to high costs for conventional transported fuels and electrical generation. This market segment may find an integrated wood-fired cogeneration system an attractive investment if affordability, efficiency and reliability can be demonstrated.

This study examines the status of technologies that are suitable for electrical generation, the market opportunities and configurations that may best suit residential applications. Candidate technologies include Stirling engines, steam boilers and engines, wood gasifiers and various electric generators. Canadian demographics and energy demands indicate wide potential applicability of cogeneration with two generic strategies, one for conventional construction and electrical usage and one for advanced efficiency design and sustainable lifestyle. Typical applications are considered to be either electrical grid connected or stand-alone with batteries. Photovoltaic generation complements supply when heating loads drop.

For houses requiring design space heating capacities greater than 5 kW and daily electrical usage greater than 5 kWh, the fuel loading requirements favour a continuous feed system using pellets or wood chips, with electrical power output of 2 kW and respective hot water thermal output. A steam boiler feeding a piston engine or turbine is considered the most promising configuration.

For a more advanced conserving house, the equipment may be incorporated into a combination fireplace/cookstove which is fired once a day. The driver would be a Stirling engine coupled to a generator with 2 kW electric output.

In order to accelerate development and encourage Canadian industries to pursue commercialization, public sector coordination and financial support is needed. More detailed analysis and design development is warranted leading up to laboratory testing of prototypes.

RÉSUMÉ

La possibilité de produire de l'électricité et de la chaleur à partir du bois dans un cadre domestique intéresse bien des secteurs au Canada et ailleurs dans le monde. La popularité du chauffage au bois, le grand nombre d'habitations éloignées et la vigueur de l'industrie du chauffage au bois au Canada constituent des conditions favorables à la mise en place et à la commercialisation de la cogénération à petite échelle axée sur le chauffage au bois.

Une majorité de ménages canadiens utilise parfois le bois pour se chauffer et plus d'un demi-million d'habitations ont le bois comme principale source de chauffage. On estime qu'entre 200 000 et 400 000 habitations sont construites en région éloignée ou dans des secteurs non desservis par les compagnies d'électricité, ce qui représente un marché logique en raison des coûts élevés de transport des combustibles traditionnels et de production d'électricité. Ce segment du marché pourrait être intéressé à investir dans un réseau intégré de cogénération axée sur le chauffage au bois si l'on arrivait à en démontrer l'abordabilité, l'efficacité et la fiabilité.

Cette étude examine l'état des technologies convenant à la production d'électricité, les débouchés commerciaux et les configurations pouvant le mieux se prêter aux applications résidentielles. Les technologies prometteuses sont les moteurs Stirling, les chaudières et moteurs à vapeur, les gazogènes à bois et diverses génératrices électriques. Les données démographiques et les demandes en énergie du Canada indiquent un vaste potentiel pour l'application de la cogénération selon deux stratégies génériques : l'une pour les bâtiments traditionnels et l'utilisation d'électricité, l'autre pour les bâtiments éconergétiques et les modes de vie écologiques. On considère que les principales applications seraient soit avec branchement au service d'électricité, soit en autonome avec usage de piles, l'énergie photovoltaïque complétant le tout lorsque les charges de chauffage diminuent.

Pour les habitations nécessitant des capacités de chauffage de calcul supérieures à 5 kW et dont la consommation quotidienne d'électricité dépasse les 5 kW, la charge en combustible exigée milite en faveur d'une installation à alimentation continue de granules ou de copeaux de bois doublée d'une puissance électrique de 2 kW et d'un rendement thermique respectif pour l'eau chaude. Une chaudière à vapeur alimentant un moteur à pistons ou une turbine est considérée comme la configuration la plus prometteuse.

Dans le cas d'une maison éconergétique, l'équipement peut être intégré au sein d'un groupe poêle à bois-cuisinière allumé une fois par jour. L'organe moteur serait un moteur Stirling raccordé à une génératrice d'une puissance de 2 kW.

Pour accélérer la mise au point de ce genre d'installation et inciter l'industrie canadienne à en poursuivre la commercialisation, la coordination et l'appui financier du secteur public est nécessaire. Une analyse plus détaillée et une mise au point conceptuelle plus approfondie devront être faites pour ensuite procéder à l'essai en laboratoire de prototypes.

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1.0 INTRODUCTION

1.1 Purpose of Study

This study is an investigation of the current potential for wood-fired household-scale cogeneration of electricity and heat, including market analysis, status and availability of equipment, appropriateness of application, and opportunities for development and commercialization.

The following synopsis gives an overview of the issues.

There are good reasons why wood-fired cogeneration at the household or community level is an attractive proposition.

- Wood is a renewable energy resource, so long as the woodlands are sustainably managed.
- Many remote communities are cash poor but rich in human resources, a condition which discourages importation of costly energy and encourages local wood harvesting employment.
- Many remote communities are located within reasonable distance of stocks and/or a continuous supply of otherwise waste wood from lumber operations.
- Most off-grid electrical generation is operated by the larger electrical utility companies and in many instances the electrical prices are subsidized. Removeal of these subsidies will drive prices even higher.
- A diesel engine generator, however well muffled, emits a persistent noise in communities which may be otherwise serenely quiet.
- Cogeneration squeezes the highest efficiency out of a fuel, producing both high grade energy in the form of electricity and lower temperature energy for space and water heating.
- Wood-fired cogeneration can complement other renewable energy sources: wind, microhydro, photovoltaics, passive solar thermal (space heating), active solar (water heating)
- Advancements in energy conversion technology, e.g. Stirling engines, opens up prospects that hitherto were not likely to be economically viable.

If there are so many benefits, why is small-scale wood cogeneration not already being used?

- Traditional complexity and cost of equipment.
- Relatively low cost of fuel, despite high transportation costs, and electricity.
- Availability of reliable diesel generator sets.
- Resistance to change.
- Lack of perceived large-scale market and business opportunity for equipment and fuel supply.
- Except in automatic feeding wood pellet systems, wood-fired systems require at least daily tending unless backed up by an auxiliary oil- or gas-fired burner.

Advantages and disadvantages of cogeneration at the household as opposed to the community level.

Advantages

- The majority of homes in remote areas are either not located densely enough to justify the high cost of piped lower grade (thermal) energy or so remote that neither central electrical or thermal supply is feasible.
- All buildings require electricity and low grade heat.

Disadvantages

- Decentralized and individual responsibility for operation and maintenance.
- There is a challenge to make equipment compact, simple and quiet enough to meet domestic circumstances.
- Higher initial cost for the homeowner

1.2 Context

There has been a strong emphasis in CMHC research policy towards sustainability initiatives in housing over the past several years.[1] Household energy consumption constitutes a primary concern, in that current emissions from conventional energy use are responsible for major local and global impacts. The growing consensus concerning a sustainable energy future is that high end use efficiency, conserving behaviour, and diverse renewable supply affords the solution. Early adoption occurs most rapidly in conditions of high energy costs paid by the user, remoteness or lack of supply alternatives, and raised awareness.

At present, most emphasis and success in reducing residential energy use has been in improved building and equipment efficiencies and passive solar techniques. With optimal economic application of current technologies, average household demand can be reduced by an order of magnitude.[5] Space and hot water heating can be readily provided by biomass, solar thermal, and ground source via heat pumps in most locales. Electrical services are, however, more challenging. Household scale systems employing photovoltaics, wind, and small hydro with battery storage are in usage, but typically require backup generation using fossil fuels for assured supply. High capital costs and maintenance limit application.

Some regional electrical utilities can tap water, wind, geothermal, tidal or other renewable sources but currently, most generation is by non-sustainable means, typically oil, gas, coal and nuclear. Arguably, with a comprehensive transformation to low energy usage, coupled with renewable source infrastructure, a utility-serviced household could be considered sustainable. Nonetheless, remote sites and low density habitation will still require autonomous sourcing. Self-generation, that is, power produced at the household, can also function as dispersed input to a grid distribution, thereby diversifying supply and demand and eliminating in-house storage. Even when a utility service is cheaper some people choose to deploy household-scale renewable energy supply on ethical grounds.

Using wood as a primary fuel source can be a sustainable, environmentally appropriate strategy, provided healthy forest regeneration and clean combustion is achieved. Combined with minimizing household demand, high-efficiency combustion and utilization of wood-fired devices make such a proposition feasible. Wood supply is plentiful in many regions of Canada, particularly in remote locations where autonomous energy systems are most attractive. The wood burning industry is developing alternatives to cord wood such as pellets and wood chips that permit automatic feeding and utilization of waste materials. Residentially, the use wood fuel has been almost entirely applied to space heating with wood-fired domestic hot water and cooking used in very few Canadian households. This represents a significant under-utilization of capital investment and renewable energy potential.

Since high temperatures are realized with efficient combustion, the concept of generating electric power with the thermodynamic losses applied to lower-grade thermal loads can further extend the utility and efficiency of wood consumption. Cogeneration with biomass fuel is not new, but has typically been exploited only for large-scale operations.

The development of a wood-fired microcogenerator suitable for application in an individual dwelling seems an attractive advancement with potentially wide appeal. Indeed, several initiatives to this end have been undertaken in recent years. To date, no commercially viable equipment has reached the market. Further, there has been no systematic appraisal of what an optimal configuration might encompass in the context of the potential applications. This study, is to determine the viability of pursuing the development of such a product.

2.0 MARKET ISSUES

2.1 Household Demographics in Canada

A majority of Canadian households burn some wood for heating.[2] Of the 5,823,000 detached houses, 619,000 houses use wood as their principal heating source, 68% of which employ wood stoves. An additional 970,000 households use wood stoves for supplementary heating, consuming on average 2.4 cords per year. As well, there are 2,230,000 wood-burning fireplaces, but only about 40% are used at least once a week (during the heating season).

Wood heating is prevalent in the Maritimes, constituting about a quarter of Canadian houses that are principally heated with wood but less than 10% of the Canadian population. High electrical and oil costs, absence of natural gas, plentiful wood supply and tradition account for this phenomenon. Alberta and Saskatchewan, due to wide availability of low cost natural gas and relative scarcity of wood, are virtually without wood heating. Quebec has the largest number of wood-heated houses with British Columbia and Manitoba at roughly the national average. In Ontario, although wood heating is common in rural and northern regions, it is below the national average.

Market opportunities exist most obviously in remote communities and off-grid communities and properties where there is ample access to wood. High electrical costs for conventional transported fuels and off-grid electrical generation compel a search for alternatives and the use of local wood supply. In Ontario off-grid connected electrical costs range from $0.13/kWh to $0.50/kWh (including subsidies) as compared to $0.08/kWh to $0.15/kWh for properties connected to the grid. The number of dwellings in the off-grid category are estimated at between 200,000 and 400,000, many of which are recreational residences. Where natural gas is not available and electrical rates are high, there are economic motivations to use wood, at least as supplementary heat. This large market segment may find an integrated wood-fired cogeneration system an attractive investment if affordability, efficiency and reliability can be demonstrated. The rest of the market in cities, towns, and gas-serviced rural areas are not likely micro-cogeneration economic, but may find the technology attractive for reasons of environmental responsibility, security of supply, access to free fuel, aesthetics, etc.

2.2 Global Markets

Wood is the primary fuel for most of the world's population. Concern for the sustainability of wood harvest in many locales coupled with a growing demand for electricity in unserviced communities suggests very extensive application for biomass cogeneration. More direct applicability of a Canadian product may be found in similar climatic regions including Russia, the Balkans, Scandinavia, Argentina, New Zealand and, of course, the northern USA. Export potential may exist for a complete appliance or components that could be tailored to locally produced wood fuel devices. The technology may also be marketed as part of a total Canadian housing package, an export product currently enjoying some success.

2.3 Fuel Availability and Cost

For most of the Canadian population, fuel wood is in plentiful supply at costs competitive with alternatives. Table 2.1 gives a typical spread of costs of conventional and wood fuel for heat output, i.e. after efficiency of heating device is taken into account (from Ref. 4).

Fuel Type	Fuel Cost ¢/kWh
Electric Resistance	
Off-grid	13 - 50
Rural	12.5
Urban	8.2
Ground Source Heat Pump	
Off-grid	
Rural	4.6
Urban	3.0
Oil	4.2 - 4.9
Nat. Gas	2.4 - 2.7
Propane	6 - 7
Pellets	5.3 - 6
Cord Wood	2.5 -3.5

Note: The ranges in fuel cost relate to differences in efficiency of combustion devices. The spread of costs for off-grid communities reflects the different costs for transporting fuel for diesel generation.

Table 2.1 Comparative Fuel Costs for Different Fuels

The use of wood chips and wood pellets is growing in Canada, enabling equipment to be hopper and auger-fed. Source material is typically diverted waste wood thus improving on the efficient usage of wood resources. The ability to control feed rates to combustion offers advantages for microcogeneration including automated operation and controlled combustion. Availability of fuel in these forms will likely be restricted to regions where high density usage prevails.

In rural communities, the household scale application will compete with community systems; however, many of the houses are separated by significant distances, making it uneconomic for hook-up to district energy systems. For the off-grid case, clearly any reliable self-generation, including PV and wind, is attractive and integration with thermal functions should be a winner. Grid-connection has the attraction of back-up, export and not requiring electric storage if the meter can spin forward and backward. Ontario Hydro is just embarking on a pilot project of this type.

Hybrid community systems, that is, central community plants combined with household scale cogeneration, may have application.

An off-grid electric miniutility may supply a community which is too spread out to warrant piped thermal distribution. Each house would have a wood-fired cogenerator supplemented with a central cogenerator (supplying thermal loads of community buildings) and battery storage. Such diversity of sharable electrical generation makes for reliability of service and meeting individual peak demands.

Another hybrid system could consist of an automated central wood gasifier that allows gas to be piped to each house which would have an engine-based cogenerator. The advantage is that wood combustion is centralized and fuel is available on-demand. With only supply piping required it has less piping than a hot water district heating system. However, the system would require pressurized gas storage and would likely have lower overall efficiency with two separate combustion processes, one centrally and one at the house. Without electrical integration, this system is not able to benefit from community diversity.

Similarly liquid biofuel is a possibility for piping to individual oil-fired residential cogenerators.

3.0 TECHNOLOGY OVERVIEW

The attraction of wood-fired electric cogeneration is the utilization of high grade heat to produce high-grade electrical energy as well as thermal output for lower temperature demands.

Typically the cogenerator consists of an energy source, a mechanical converter and an electric generator. A different technology using the thermionic principle, can convert heat directly to electricity.

3.1 Primary and Derived Fuel

The primary fuel source is assumed to be wood-based: pellets, chips or cord wood.

A related renewable fuel source is organic solid wet waste (compostables) which can be conditioned with wood chips, sawdust or straw for maximum methane output. This is attractive in agricultural applications. Other agricultural waste, such as rice husks (and perhaps soon hemp stalks), may be feed stock for such appliances. Dual fuel combustion units with propane back-up may also have applications.

The derived energy for input to the mechanical driver can be in the form of heat, steam, wood gas, liquid biofuel or methane.

3.1.1 Heat

Heat from cord wood is the most difficult to maintain at elevated temperatures consistently. With well-designed, highly-efficient fire boxes such as contra-flow masonry heaters or high performance wood stoves or fireplaces, the temperatures can be kept high for significant periods of time. In Reference 6, the throat temperature of a masonry heater stayed between 500°C and 800°C for one hour of a two-hour fire. A fire of any length should be able to maintain these temperatures except for the last hour.

More automated chip and pellet stoves would be able to have more controlled, optimum temperatures with fires of any duration.

3.1.2 Steam

Steam is conventionally produced in small boilers operating at pressures around 80 psi to 100 psi.

Steam systems can store enormous amounts of energy in a highly pressurized form, creating the potential of personal injury in case of malfunction. These are systems that can not be run unattended for long periods of time. In addition, fire tube boilers can be very inefficient because the water lowers the combustion temperature. The large volume of water also makes them slow to start.

Water tube boilers can be designed to allow higher temperature combustion; however they require even closer attention than fire tube boilers.

Water quality is an issue even with smaller systems and therefore chemical treatment would be required to run any high pressure steam system. Oxygen and water hardness are two issues which must be addressed.

3.1.3 Wood Gas and Biofuel

Conventional wood combustion is more chemically complex than gasification since the wood must first pyrolyze then be partially combusted or gasified before it is fully combusted. Complete combustion is achieved by providing the appropriate or stoichiometric amount of oxygen to yield a maximum amount of heat and mainly CO_2 and water. Pyrolysis is conversion of wood to charcoal, oil and gas only in the presence of heat. Gasification is the partial combustion of wood, i.e. with limited oxygen, to maximize gas production.

Gasifiers were developed during the Second World War when gasoline was in short supply.[3] The devices are bulky and the fuel supply, wood gas, is "dirty" requiring special cleaning for use in conventional internal combustion engines.

A number of biomass feed stocks can be turned into “liquid wood” by adding heat in the absence of air (pyrolysis). This biofuel can be used as a diesel fuel without depleting fossil fuel reserves. Small diesel cogeneration packages, such as the residential-scale unit from Intelligen Energy Systems, can easily be run on biofuel.

3.1.4 Methane

Methane, the major component in natural gas, can be produced by anaerobic digestion of compostables. Some cleaning is also required but digesters exist that produce sufficiently clean biogas for conventional cogenerator engines, as well as a high grade compost for agricultural purposes.

3.2 Mechanical Converters

3.2.1 Stirling Cycle Engines

Direct heat-based mechanical drivers are Stirling engines (Ref. 4). This device is a piston-based engine utilizing a low pressure working fluid, typically helium or air. Heat is applied to one end, expanding the working fluid thereby moving a piston. The working fluid is then cooled (or “regenerated”) to allow the piston to return. The heat source can range from 500°C for cord wood to 1600°C for natural gas. Note that the metallurgical limit of stainless steel is around 750°C and more expensive materials would be required the higher the temperature range. The working fluid is then regenerated with ambient air or low temperature hot water (40°C). The output and efficiency is primarily proportional to the temperature of the available heat source and secondarily to the cooling source.

Efficient wood combustion devices such as masonry heaters have high outputs over short duration. The instantaneous fire box output might be 25 kW while the average external output over time is 5 kW. To maximize the heat utilization for electricity while keeping the Stirling engine as small as possible thermal storage of energy at 500°C or higher is required. A soapstone slab is a candidate but a lithium bromide solution has also been used, which allows for even temperatures and flexibility of Stirling engine location.

Low efficiency units have a long tradition in the third world, particularly in India. Although many functional Stirling cycle engines have been made and some are in operation today around the world, this engine has always been the second choice to both the internal combustion engine and the steam engine because its power output was less.

Modern designs have mechanical efficiencies over 20% which makes them the highest mechanical efficiency from a thermal source. However, these units have been typically natural gas fired and availability and costs are a concern.

Its many advantages over steam engines for this application include the quietness, safety (although this must be qualified because the lubricant can catch fire in certain types of systems), and the fact that it would have a less detrimental effect on combustion allowing a wood stove to meet the EPA requirements.

Some of the disadvantages include its size, the sophistication of the available technology and, depending on the drive, its robustness. A major technical hurdle is the development of high pressure seals for the working fluid. If the working fluid is air, replenishment is fairly straight forward and seal design is not as critical. There are working Stirling engines in third world countries which use biomass fuel for pumping water and driving fans. These are simple devices with air as the working fluid and low overall efficiencies. In addition, there are many other individual efforts around the world which have successfully built small Stirling engines that could be used for electrical power generation (refer to Appendix A2).

Many companies including Ford, General Motors and Japanese engine producers have made investments in the Stirling technology. Philips of the Netherlands actually produced a few hundred prototypes of a 1 kW Stirling generator in the 1950's. For a detailed description of Philips' Stirling program refer to "The Philips Stirling Engine" by C.M. Hargreaves, 1991. One of these prototypes is probably still available for testing.

In recent years some notable work on Stirling engines has been completed by Sunpower Inc. under William Beale. They have developed a free piston engine and have tested prototypes on solar systems. One challenging aspect of the Stirling engine design is the converting the reciprocating motion to rotation to drive an electric generator. With the development of a linear induction generator this can be avoided. The Sunpower unit uses such a generator and eliminates some of the tricky kinematic linkages required for a drive shaft. They are currently working towards a multi-fuel 5 kW engine. The development costs are approximately $500,000.

A small company, Tamin Enterprises, has recently developed a 1 kW Stirling engine, but reliability and performance needs to be established.

However, no small-scale Stirling engines exist in North America or Europe which will produce between 500 W and 3000 W and run off a wood stove. The development costs have been hard to justify without a defined large-scale market. But it is interesting to note that a small market has been created for a 5 kW diesel cogenerator.

From a user point of view the Stirling engine has distinct advantages for home power generation because these systems are quiet, reliable and not as susceptible to catastrophic failure as a steam engine and its boiler. Furthermore, they can operate for long periods between servicing since no oil change is required.

The failure of Stirlings to come to the forefront of engine research has been largely because of timing and not technical obstacles, although concerted efforts are required to refine the Stirling engine so that it is competitive with existing technologies as a prime mover. The Stirling could very easily have replaced the steam engine in many applications in the early part of this century had not the internal combustion engine become successful due to the low cost and high energy density of fossil fuels. And although the automotive industry made modest investments in Stirling research to date no one has made any commitment to commercialize this engine.

"The Stirling Alternative" by G. Walker of the University of Calgary[4] provides detailed information on the operation of Stirling machines; however, for our purposes all that is required are the system inputs, outputs and basic configuration.

Stirling machines require a heat source, a heat sink (or device for extracting heat) and some means for converting the thermodynamic potential into useful mechanical energy (such as for driving a pump or an electric generator). From the information available a wood fired stove will provide sufficient heat to drive a Stirling engine and a domestic hot water system could be used as the heat sink giving an approximate temperature difference between the heat source and heat sink of 400°C.

Unlike the fire tube boiler (with steam systems), the Stirling system would allow combustion to be maintained at high temperatures which reduces emissions.

A Stirling engine could be driven by combustion of wood gas produced by a gasifier, but overall efficiency would be low. More traditionally, wood gas has been used to drive internal combustion piston engines. While mechanical efficiency may be reasonable, the gasifier is bulky, complex and often costly.

3.2.2 Steam Engines and Turbines

For small steam drivers there is a range of options available. Low-output piston steam engines are typically produced for historic markets where authentic appearance are as important as operating characteristics. There also exist low RPM paddle-wheel steam turbines. These technologies are typically no higher than 15% mechanical efficiency. There is some development in small high performance steam piston engines and turbines; however, there seems to be no commercialization for lack of a defined market. Safety concerns about operating steam devices in a residential setting is also a perceived barrier.

There are many working models of steam systems being used in North America today. For anywhere between $10,000 and $15,000 it would be possible to set up a system to produce electric power. Typically these use reciprocating engines and a fire tube boiler, however more exotic equipment such as low volume water tube boilers and steam turbines have been developed.

With fire tube boilers and either steam turbine or reciprocating engines the typical operating pressures are around 80 to 100 psi. Canadian Registration Numbers (CRN) and Ontario Insurance Numbers (OIN) numbers, provided by the Ministry of Consumer and Commercial Relations for high pressure steam systems, would not be necessary for most home sized systems. However, the requirements of the Boiler and Pressure Vessels Act should all be met regardless of the regulatory obligations.

Steam turbines match the efficiency of reciprocating engines: the typical overall efficiency of this kind of system would be 10% to 18% for the thermal to electrical conversion. Simple steam turbines can be considerably less expensive than piston engines, however they are not as robust. A good reciprocating engine will easily run for 10,000 to 15,000 hours before new bearings are required and virtually no other maintenance will be necessary. It is possible to either modify the head of a gasoline or diesel engine to run on steam or to use a reciprocating engine designed expressly to run off steam. Steam turbines do not take accidental water injection very well because the blades will be damaged which is a concern if the system is not operated properly. However, the bearings on a steam turbine should last as long as those on a reciprocating engine.

Because they rotate at a much higher speed the size and mass of the steam turbines is considerably less than that of a reciprocating engines capable of producing the same output. At present, there is only one known supplier of steam turbines that are suitable for in home use. A commercial grade steam turbine would be far too expensive to justify the investment ($5,000 to $10,000).

Clearly, the reciprocating technology is much more common.

3.3 Electrical Generators

Availability of small electrical generators does not appear to be a barrier. Conceptually they are simply electric motors run in reverse: a mechanical input results in electrical output. As with motors, efficiencies can be high at over 80%.

There are four different kinds of electrical generators that can be used with small scale cogeneration systems: single phase rotating induction generator, alternator, DC generator and linear induction generator. Of these the most common is the alternator. A relatively new technology is the switched reluctance generator which shows promise of high efficiency.

3.3.1 Single Phase Induction Generator

Any induction machine can be run as a generator when it is driven past synchronous speed by mechanical means. The synchronous speed is the maximum speed that a motor typically runs at, minus the slip speed, or typically 1150, 1750 or 3550 rpm for six, four and two pole machines. Over its normal operating range it has an efficiency of about 75%.

Advantages:
- Low cost
- Inherent over-speed protection because of the generator efficiency characteristics
- Produces synchronous power. There is no need for voltage or frequency correction.
- Can also be used as a motor and therefore it could be used as a starting motor.

Disadvantages
- Can not be self-excited therefore power must be available to provide the excitation to the stator. This can come from the grid or from an inverter.
- The generator's efficiency is dramatically affected by speed. Although a variable speed input is permissible the actual effective speed range is quite narrow.
- The motor/generator will only produce past the synchronous speed.

3.3.2 Alternator or AC Generator

This is a common type of generator found in most automobiles and in many industrial applications. It is available in variety of sizes and configurations. It has an efficiency of 80% to 85%.

Advantages
- It is a common, inexpensive and robust generator.
- Does not require any input power for starting (it can have either permanent magnets or be self excited or have the DC field current come from an external source like a battery or DC power supply).

- In sophisticated applications it is possible to vary the voltage output by changing the DC field current.

Disadvantages
- It is more difficult to synchronize with an AC distribution grid (a synchronizing relay is required).
- The voltage and frequency of the output power is dependent on the mechanical input, thus strict control over the mechanical input is required for good quality AC power.

3.3.3 DC Generator

This type of generator is available in a number of different configurations with a compound wound type generator being the most suitable. The efficiency is high at 90% to 95%.

Advantages
- High efficiency.
- Good over-speed protection inherent in a shunt wound machine.
- Can be used as motor as well as a generator.
- Relatively good voltage regulation.

Disadvantages
- Brushes require maintenance.
- Brushes produce radio frequency (RF) signals which may interfere with other electrical devices in the buildings.
- More expensive than the alternator or induction generator.

3.3.4 Linear Induction Generator

This is really just an induction generation with different winding geometry from the rotating induction machine. Theoretically it is a very good approach to AC power generation from reciprocating machines because the linear motion of the reciprocation cylinder can be used can drive the generator directly without having to use a drive shaft to provide a rotating input.

The problem is in building this kind of generator because the magnetic air gap must be strictly maintained or the efficiency will be reduced.

Although there are working industrial linear induction motors driving trains which use regenerative braking (induction generation), linear induction machines in a size suitable for this kind of generation are not common.

3.3.5 Switched Reluctance Technology

A smart, efficient motor technology is the switched reluctance motor. There is no current supplied to the rotor; instead the stator is supplied with a magnetic field which changes polarity with high-frequency electronic switching, resulting in significantly lower losses. Similarly, as a generator the RPM provided from the mechanical driver would be used to electronically control the switching rate of the stator magnetic field.

3.3.6 Choice of Generator

For independent power production (i.e. where there is no grid power) the most robust and simple generator is the AC alternator. It's prime drawback is that it produces wild AC or variable voltage and variable frequency power unless the speed is controlled (or some control is provided for the field current). Therefore, typically the output would be converted to DC and used to charge batteries which in turn would power an inverter to run AC loads.

When grid power is available or in situations where battery charging is not required, an induction generator could be considered. When grid connected, it has good inherent speed control characteristics and no special electronic hardware is required to directly feed the grid. The limitation is that the efficiency will change dramatically if the speed control is not kept within 10 to 20% of the rated speed (this depends of the number of poles in the motor). This would be the most inexpensive way to feed power to the grid with the added advantage of providing a starting motor for any reciprocating device.

3.3.7 Electrical Load Management

Batteries are a necessary component of any independent system because it would be impractical to run the generator continually to meet all the daily loads and the daily load profile changes. If grid connection is required with a battery system, then a synchronous inverter must be used.

A future storage medium may be flywheel technology. This is essentially a high density disk spinning at very high RPM in a low friction medium (e.g. a vacuum). Energy is stored in the form of momentum and the RPM increases and decreases as mechanical energy is added by generation or energy is removed by electrical loads. The speed at the perimeter is so high that extremely high strength materials are required and any imperfections or vibrations can cause explosive failure of the flywheel. However, flywheels have been used successfully and new materials are being developed.[7]

3.3.8 Thermionics

Electricity can be generated by the thermionic effect, that is, the use of dissimilar metals can cause electrons to flow in the presence of heat. This effect is used in thermocouples which measure temperature based upon small changes in electric current flow.

Thermionic generation devices consist of hundreds of thermocouples wired in series and parallel to produce DC power. A collection of thermocouples is called a thermopile. The technology has the attraction of being a device that simply located on top of a hot surface, e.g. wood stove; however, electrical production efficiency from heat is very low at less than 5%.

The advantages are that there are no moving parts and that the combustion temperature will not be adversely affected by this kind of device. The main disadvantages are low efficiency, cost, availability, and capacity. This kind of device is not in commercial production and so only prototypes are available. There is also some questions as to whether large power outputs of two to three kilowatts could be developed with this kind of device.

4.0 APPLICATION

4.1 Energy Loads

A typical new Canadian household of 135 m^2 requires about 50 MWh per year with 35 MWh for space heating and cooling, 5 MWh for domestic hot water, the remaining 10 MWh for lighting and appliances. Advanced housing standards, high efficiency end-use technology and a conserving lifestyle can reduce the demand to 6.5 MWh per year, 2.5 MWh for space heating, 1.5 MWh for hot water, and 2.5 MWh for lighting and appliances. Since 1 MWh is typically used for cooking with an electric range and oven, yet is a thermal load, one possibility is to break it out of lighting and appliances, leaving the remaining 1.5 MWh as electrical load. These two cases, typical vs. sustainable household, may be taken as a market range for capacity sizing and configuration.

4.2 Fuel Consumption Rates

A cord of hardwood (e.g. sugar maple) has and energy content of about 8 MWh. If we assume an overall efficiency of conversion for the cogeneration device of 70% with a maximum 20% producing electricity and the remaining as thermal, and all delivered energy can be utilized, the typical household would consume 9 cords of wood per year. For the sustainable household, 0.5 to 1.5 cords per year would be required, depending on renewable energy supplement. It requires only 0.4 hectares to sustainably grow 1 cord of hardwood per annum.

4.3 Complementary Technologies

For the warmer half of the year, when wood burning may be displaced by direct solar power, electrical loads may be served primarily with photovoltaic (PV) cells, domestic water heating and space heating by solar thermal panels and space heating by passive solar means. Cooking via PV power during summer when solar input is plentiful complements wood cooking with cogeneration during winter's low solar availability.

Wind power combines less well as availability is greatest in winter and least in summer. Nonetheless, a wood-fueled cogenerator being deployable as required, would function to maintain available power for independent systems and export power on thermal demand for grid-connected systems.

Energy storage, both thermal and electric, are practically essential for good performance. With wood heating, operation requires occupant participation so that maximum convenience is achieved when firing can be intermittent. In addition, best combustion and thermodynamic efficiency corresponds with high temperature and burning rates which require storage for extended use. Typical storage technologies include hot water tanks, building mass, masonry wood heaters, soapstone cook surfaces, solution separation (e.g. ammonium/water for cooling), phase change, electrochemical batteries, and avoided fuel combustion on electrical grids. Automatic and controlled hopper feed systems for wood pellets and chips can, to some extent, displace storage requirements but are accompanied with some sophistication of controls apparatus.

4.4 Thermodynamic Considerations

Second law efficiencies are optimally achieved when the thermal degradation process serves end uses at their required temperatures. The generation of kinetic or electric energy is achieved at, say, 500°C supply temperature. The next highest requirement is for cooking at 100°C to 200°C which may be derived from the flue gasses. The next level of 70°C to 100°C could be used to operate absorption cooling with lower temperature heat rejected to space, make-up air, or hot water preheat. Domestic water heating at 50 to 70°C may be extracted from the heat rejection of the generator engine. Space heating at 25°C could be supplied largely by cooking losses, refrigeration heat rejection, excess heat to domestic hot water and flue gasses.

Make-up air heating, domestic water preheat and auxiliary uses such as greenhouses and snow melting can extend utility to temperatures below 20° C. If thermal cascading can be applied to the appropriate energy services to a greater extent, overall utilization efficiency is increased.

4.5 Configurations

For the more consumptive typical household, wood consumption quantities and rates are not conveniently achieved in a living area appliance using cord wood. A utility room or remote cogenerator with hydronic supply of space and domestic water heating is most apt with a large, controlled combustion chamber for cordwood or auger-fed pellets or chips. A capacity of about 10 kW thermal and 2 kW electrical would adequately service most newer houses. Operation for electrical demand during a period of off-peak thermal demand would require heat rejection to the environment and reduced utilization efficiency. Another strategy might be to install a smaller capacity cogenerator, say 5 kW thermal and 1 kW electric. Such a unit would run continuously through much of the heating season and employ an auxiliary wood cookstove to reduce electrical demand and supplement space heating as required.

For the sustainable household the configuration of appliances would reflect the greatly reduced loads and combustion requirements. Since space heating becomes a minor concern, served adequately by losses from cooking and a central convecting or radiating heater, the cogenerator may be integral with a heater in the living space fed with cord wood or pellets via a hopper. The heater could serve for both fireplace and cook stove. Note that if cooking is not integrated but is part of the electrical load, electrical generation and the resultant wood consumption could double in the absence of electrical source alternatives.

For most convenient use and highest performance, the firebox, cooking surfaces and oven would embody thermal storage and be insulated both to extend usage beyond times of burn and to allow regulation of space heating.

Thermal storage may also benefit the generator interface permitting downsizing the generator for extended operation and optimization for a narrower temperature band. For a 2-hour burn, a 2 kW electric cogenerator would produce sufficient power and domestic hot water for one day's use in the sustainable household.

The cogenerator heat rejection is ideally suited to water heating, both in terms of heat transfer and principal end use. A storage tank for domestic hot water situated above the unit could operate on thermosyphon and reject heat to air via convectors as overheat protection.

The foregoing commentary provides some concepts to guide the design of a domestic wood-fired cogenerator and what functions it might serve. Many other elements will need consideration to best suit the market including economics, safety, ease of operation and flexibility.

4.6 System Designs

Two system designs, one for typical new housing and one for the sustainable household, are presented below.

A potential system design for application to typical new housing is described as follows. An auger-fed pellet steam generator, located in a mechanical room, provides 100 psi steam to a 3.5 horsepower piston engine. The engine operates a 2 kW induction generator which is used as a grid interconnect under a net billing arrangement with the electrical utility. The low pressure steam leaving the engine is condensed in a heat exchanger connected to an oversized domestic hot water tank. Space heating is delivered via a fan-coil through which domestic hot water is circulated. The firing period is regulated off a tank aquastat to maintain 70°C water. Space cooling is generated by cooling the high pressure steam from the boiler through an outdoor heat exchanger, then dropping its pressure through the steam engine providing direct expansion cooling to the fan-coil. A 2 kW photovoltaic array makes up the remainder of the annual electrical generation.

A quite different system configuration is conceptualized for the sustainable household. A high-efficiency masonry heater, a kit-built contra-flow design, is located between the kitchen and living area providing both a fireplace and a cookstove. On days requiring heating and/or power, the occupant loads about 20 kg of cordwood into the firebox for a two hour burn. Driving a 2 kW generator, a Stirling engine housed over the fire chamber produces 4 kWh of electricity to charge up the batteries (or reverse the meter) and 10 kWh of hot water heating. Another 40 kWh charges up the thermal mass of the insulated cooktop, the bake oven and the remaining heater masonry. The balance or 20 kWh is lost up the stack. Over the next 24 hours, heat is released to the house through radiation and natural convection. On sunny days and throughout most of the summer, the 1 kW photovoltaic array and solar hot water heater provide the required energy services allowing cooking to be done with high efficiency electric appliances. When supplementary or domestic hot water is needed, the wood heater may be fired with the contra-flow channels bypassed, thereby limiting heat delivery to the house when it is not desired. A system similar to this was conceptualized for the CMHC Toronto Healthy House, see Figs. 4.1 and 4.2.

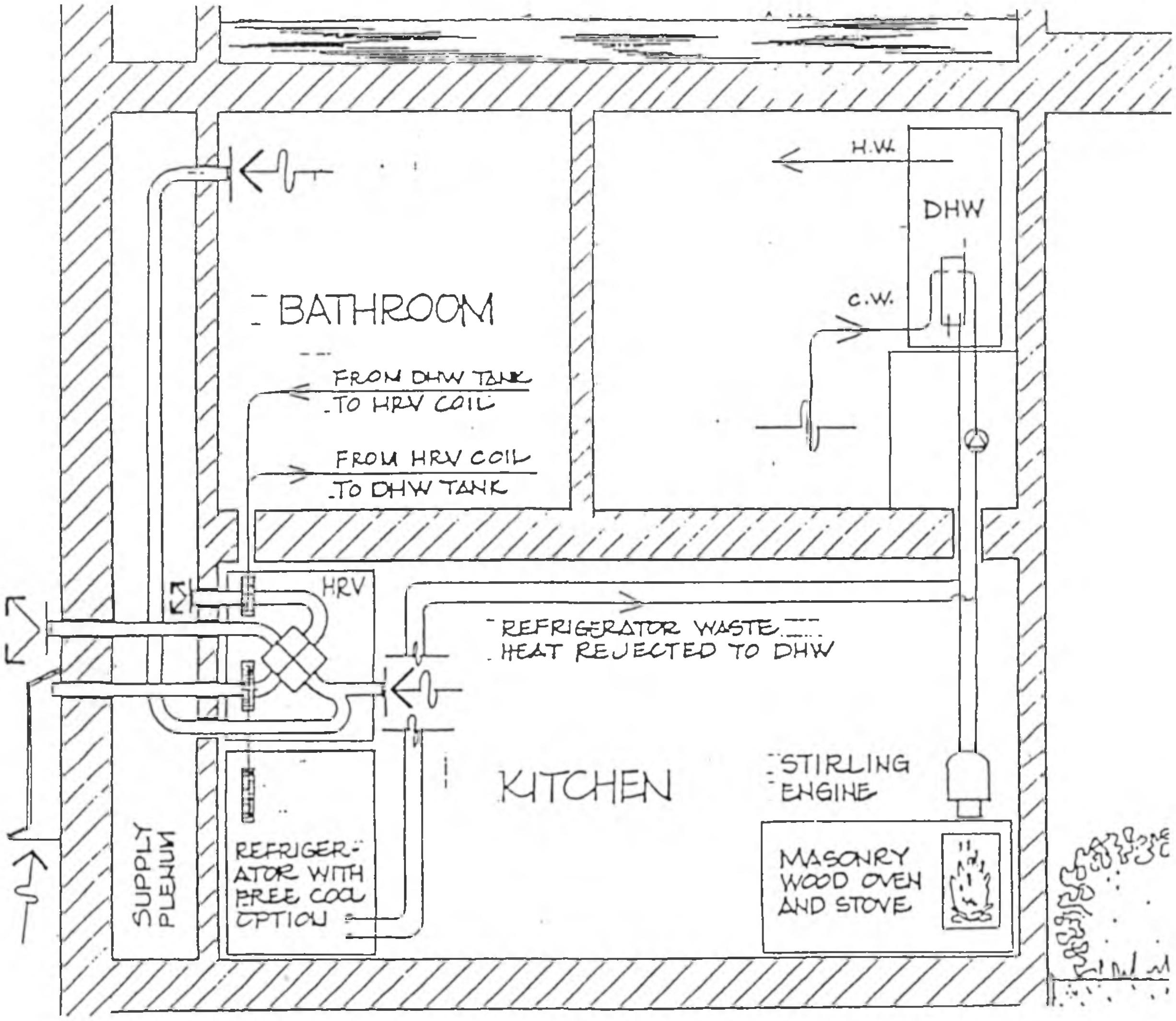


Figure 4.1 Wood-fired Cogenerator Concept for the Sustainable Household

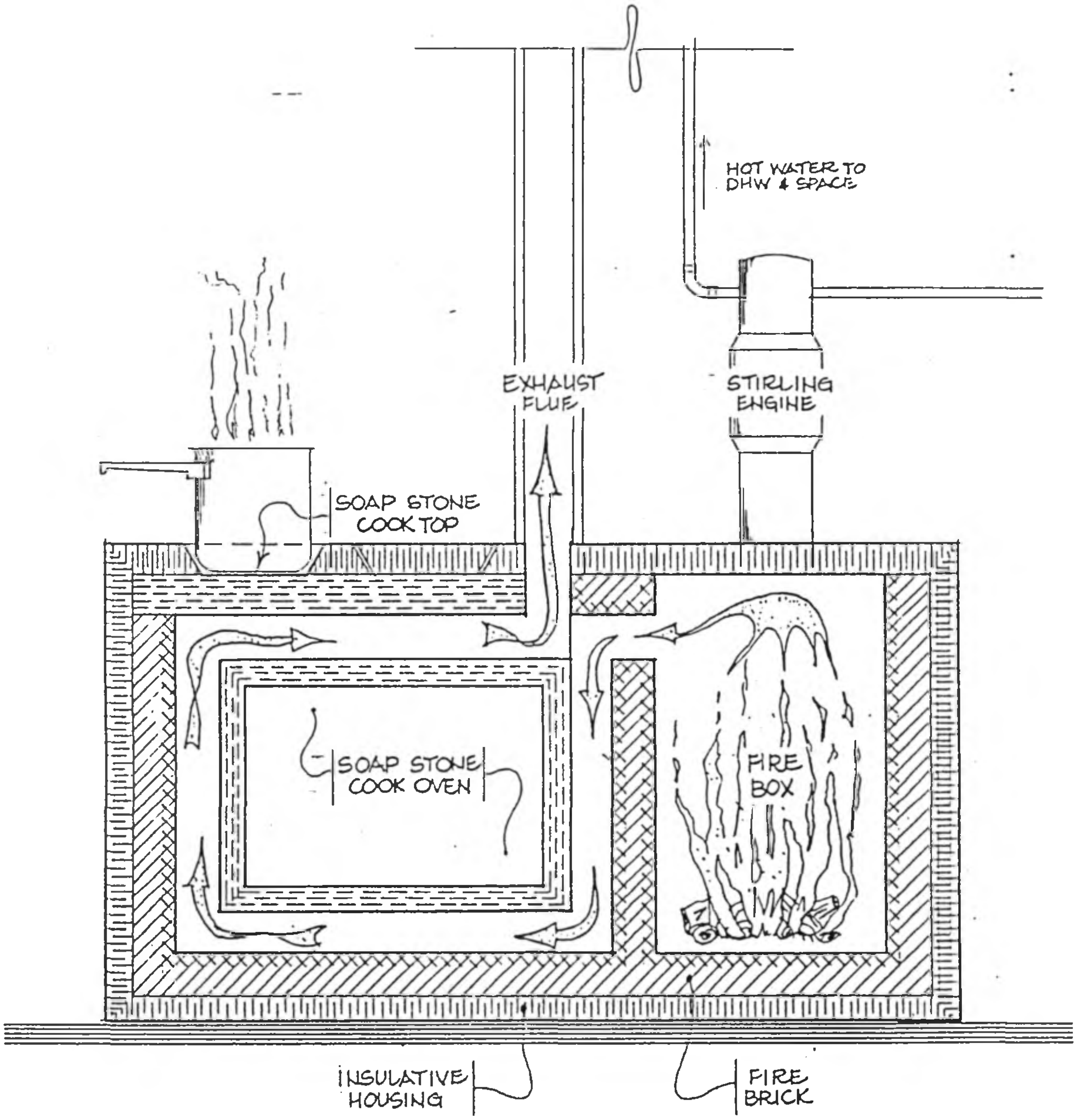


Figure 4.2 Stirling-based Wood-fired Cogenerator System Configuration

5.0 COMMERCIALIZATION

5.1 General Requirements

The absence of a product available in the marketplace may seem evidence of lack of consumer need, industry interest, or feasibility. On the other hand, market analysis indicates a large market opportunity for wood microcogeneration; many inventors, product developers and wood energy equipment suppliers are actively investigating the potential and the technology is fairly well understood. What then is needed to advance the technology to commercialization?

The absence of product in the market place is a barrier itself to further development. The demands for developing sustainable energy technologies and deterioration of capacity to subsidize marginal energy supply conventionally is accelerating. The rate at which this is happening often exceeds traditional development rates for new products. The integration of traditionally disparate technologies also means there is no singular lead industry segment. Another significant barrier is that standards approval for a product without precedent can be lengthy, if not unpredictable.

Canada is not only a prime marketplace for the technology but could translate its boreal forest/cold climate conditions into international competitive advantage. A public/private development initiative seems warranted.

5.2 Product Development Strategy

In order to overcome inertia in advancing the technology, it would be valuable to have a lead agency, such as NRCan Combustion Research Laboratory, champion the research and development phase. Steps to be taken could include:

1. hosting a wood microcogeneration workshop with prospective developers, users, industry associations and researchers to explore opportunities;
2. undertake more detailed research and analysis of applications and technology;
3. design, fabricate and test a number of alternative test lab prototypes;
4. demonstrate a number of field prototypes;
5. provide procurement for early production runs;
6. develop standards for safety and performance accreditation.

6.0 CONCLUSIONS

There is both a need and a technological capacity to bring forward commercial hardware that can generate electricity and low-grade heat from wood at the household scale. A small wood-fired micro cogenerator can complement photovoltaic and solar thermal applications to provide a resource efficient solution for many Canadian houses and international markets

In order to accelerate development and encourage Canadian industries to pursue commercialization, public sector coordination and financial support is needed. More detailed analysis and design development is warranted leading to laboratory testing of prototypes.

References

1. Canada Mortgage and Housing Corporation. CMHC's Healthy Housing Competition: Guide and Technical Requirements. Ottawa, 1993.

2. National Resources Canada. 1993 Survey of Household Energy Use. Ottawa, 1994.

3. Solar Energy Research Institute. Handbook of Biomass Downdraft Gasifier Engine Systems. SERI/SP-271-3022, DE 8800 1135. Golden, Colorado, 1988.

4. Walker, G. et al. The Stirling Alternative. University of Calgary, Calgary, Alberta, 1990.

5. Canada Mortgage and Housing Corporation. Energy and Power Availability in Housing. Ottawa 1992.

6. Canada Mortgage and Housing Corporation. Air Requirements and Related Parameters for Masonry Heating Systems. Ottawa, 1994.

7. Cutter Information Corporation. Flywheel Energy Storage Systems: Poised for Growth. Technologies for Energy Management, June 1996.

Additional Resource

Ross, Brad A., Ed. Directory of the Stirling Machine Industry. Stirling Machine World Magazine. West Richland, Washington.

APPENDICES

A1. End Use Thermal and Electric Loads

A1.1 Environmentally Sustainable Housing
A1.2 Conventional Household Energy Profile
A1.3 Sustainable Household Energy Profile

A2. Contact List

A2.1 Wood Heating Organizations
A2.2 Derived Fuel Generators
A2.3 Mechanical Converters
A2.3 Mechanical Converters

A3. Related Information

1. High performance masonry wood heating with cook oven and hot water heating (3 pages)
2. External boiler strategy could be used for steam systems (2 pages)
3. Gasifier fundamentals from Reference 3 (3 pages)
4. S-Series wood gasifier literature (5 pages)
5. Paper on biomass pyrolysis oil from Wartsila Diesel Int. Ltd. (3 pages)
6. Paper on liquid biofuel from Ensyn Technologies Inc. (4 pages)
7. Residential 5 kW oil-fired cogenerator from Intelligen Energy Systems Inc. (4 pages)
5. Schematic of Stirling engine (1 page)
6. Sunpower paper on 10 kW Stirling engine (4 pages)
7. Description of 1 kW Stirling engine from Tamin Enterprises (1 page)
8. Description of 25 kW Biostirling from Stirling Thermal Motors (1page)
9. Low pressure steam turbine (2 pages)

APPENDIX A1. END USE THERMAL AND ELECTRIC LOADS

A1.1 Environmentally Sustainable Housing

Housing development that is environmentally sustainable should have no negative environmental impact in terms of global and local bioregions or ecosystems. Very simply, the resource inputs and outflows crossing the site boundaries should be benign or balanced whether they be energy, water or air emissions. The site itself should be life sustaining as an ecosystem. Healthful indoor conditions are part of sustainable design.

Some new building projects, typically single and multi-unit family housing (Toronto Healthy House) and small commercial (Body Shop) and small institutional (Boyne Ecology Centre, Kitchener/Waterloo YMCA Environmental Learning Centre) have been moving toward environmentally sustainable building design. These projects have the following characteristics.

- high insulation levels
- low air leakage envelope
- high performance glazing
- passive solar design
- controlled ventilation with heat recovery
- high efficiency lights, appliances, fans
- renewable energy resources
- passive, non ozone depleting cooling
- low-tox materials
- appropriate, low embodied energy construction
- severe water conservation
- benign waste water management
- site and building greening

These projects were primarily designed to minimize environmental impact of resource consumption balanced with measures to mend the ecosystem support structure. However, the cumulative effect of executing these projects is that we now have the technology and design principles to make new and retrofit building developments, whether a single house or a community, become "environmental clean-up modules". Each construction of a housing unit is an opportunity to export renewable power, to clarify water and to consume emissions by increased greening.

A1.2 Conventional Household Energy Profile

On a fundamental level thermal loads include space heating, space cooling domestic water heating, cooking and refrigeration. Typically space cooling and refrigeration are powered by electricity, even though gas fired absorption exist for both. In Canada over 95% of households use electricity for cooking while wood is only used in 0.2% of households (Ref. 2). Nevertheless, major wood cooking perhaps coupled with limited use of a microwave oven is a rational expectation for the markets being addressed.

A conventional household for an assumed conditioned floor area of 135 m^2 is profiled below.

THERMAL LOAD		kWh/yr
Space Heating		32,000
Space Cooling	Thermal	5,500
	Elec.	2,800
Dom. Water Heating		5,000
APPLIANCE LOAD		
Cooking		1,100
Lighting		1,200
Refrigeration		800
Television/Computer		800
Clothes drying		1,000
Fans		4,000
Other		1,100
		10,000

A1.3 Sustainable Household Energy Profile

A sustainable building design results in severely reduced energy budgets. By definition, sustainability also does not allow for waste and a wasteful energy lifestyle. For the CMHC Toronto Healthy House a 100% renewable energy system was conceptualized. However, renewable energy is not sustainable if it is used to power inefficient end uses. To make this proposition economically viable and sustainable, the following energy budgets were developed.

Space Heating	2,500 kWh
Domestic Hot Water	1,500 kWh
Cooking	1,000 kWh
Electricity	1,500 kWh
Total	6,500 kWh

The 6500 kWh is to be supplied by external renewable resources. The energy system consisted of photovoltaic (PV) electricity production, solar thermal domestic water heating and integrated wood-fired space heat, cooking, hot water and electricity. The rationale for wood electricity production recognizes the poorer solar potential in winter but when space heat is required.

The PV system is responsible for 1000 kWh of electricity and the solar hot water for 1000 kWh thermal output. The remaining 4500 kWh (3500 kWh for space heat and cooking, 500 kWh for DHW and 500 kWh for electricity) is supplied by wood heat. If overall efficiency is a minimum of 70% the required wood fuel is equivalent to 6500 kWh (1000 kg air-dried) or one full cord which is equivalent to a 0.4 hectare woodlot, assuming sustainable forest practices.

APPENDIX A2. CONTACT LIST

A2.1 Wood Heating Organizations

Masonry Heaters Association of North America

Contact: Norbert Senf Tel. 819 647 5092
Fax 819 647 6082

Hearth Products Association of Canada

Contact: Tex McLoed Tel. 416 921 5501
Fax 416 921 0743

A2.2 Derived Fuel Generators

Longhill Wood/Electric Co.
1220 South Drive
Socorro, NM 87801

Contact: Mark Taylor

Developing monotube (low-water) boiler for 3 kW reciprocating steam engine.

Humphries and Associates Inc.
33 Parkwood Drive, Suite 2
Augusta, MN 04330

Contact: Jack Humphries Tel. 207 622 5336

Suppliers of relatively small-scale wood chip gasifiers.

R & R Wood Products
Route 3
California, MO 65018

Contact: Raymond Rissler Tel. 816 458 6511

Suppliers of wood gasifiers for driving engines as low as 7 kW or for supplementing propane supply.

System Johansson Gas
P.O.Box 295, Halfway House 1685
Midrand, South Africa

Contact: Tel. 011 310 1008
Fax 011 805 1138

A2.3 Mechanical Converters

Sunpower, Inc.
6 Byard Street
Athens, OH 45701

Contact: William Beale Tel. 614 594 2221
Fax 614 593 7531

One of the leading firms in stirling technology and can develop 1 kW unit.

Stirling Thermal Motors, Inc.
275 Metty drive
Ann Arbor, MI 48103-9444

Contact: Lennart Johannsson Tel. 313 995 1755
Fax 313 995 0610

Can develop 1 kW unit based on new rhombic drive.

Tamin Enterprises
311 Grove Street,
Half Moon bay, CA 94019-2005

Contact: Donald Isaac Tel. 415 726 2338

Developed 1 kW stirling engine at reasonable cost.

Clever Fellows Innovation Consortium, Inc.
302 10th Street
Troy, NY 12180

Contact: John Corey Tel. 518 272 3565
Fax 518 272 3582

Have 3 kW stirling unit developed for solar applications which can be downsized.

ESD Engines
51 Artesian Road
London W2 5DB
United Kingdom

Contact: Drummond Hislop Tel. 071 792 2241
Fax 071 792 2543

Have been developing 2 kW stirling engine.

Tem-Mai Mo Forskningscentrum
Agnesfridsvagen 220
Malmo, Sweden

Contact: Curt Schroder Tel. 011 46 40 34 3401
Fax 011 46 40 94 8960

Suppliers of 1 kW to 3 kW stirling engines.

Tiny Power Steam Engines
P.O.Box 1605
Branson, Missouri 65615

Reciprocating steam engines are available through steam hobbyist supply houses, but often historic authenticity, rather than performance is stressed

A2.4 Electric Generators

Clever Fellows Innovation Consortium, Inc.
302 10th Street
Troy, NY 12180

Contact: John Corey Tel. 518 272 3565
Fax 518 272 3582

Use the Star linear Alternator with the stirling above.

APPENDIX A3. Related Information

1. High performance masonry wood heating with cook oven and hot water heating (3 pages)
2. External boiler strategy could be used for steam systems (2 pages)
3. Gasifier fundamentals (3 pages)
4. S-Series wood gasifier literature (3 pages)
5. Schematic of stirling engine (1 page)
6. Sunpower paper of 10 kW stirling engine (4 pages)
7. Description of 1 kW stirling engine from Tamin Enterprises (1 page)
8. Low pressure steam turbine (2 pages)
9. Masonry wood heater integrated with stirling engine conceptualized by Allen Associates for the Toronto CMHC Healthy House (2 pages)

The Heat-Kit System

Introduction

Traditionally, building a good masonry heater has required craftspeople with considerable skill and training. The heater is not only required to perform well in terms of efficiency and emissions, but also to be able to stand up to many thousand cycles of rapid heating and cooling. This severe thermal cycling places tremendous stresses on refractory materials, with which the stovemason must be intimately familiar.

Our philosophy

We have been designing and building heaters for 17 years. We are also founding members of the Masonry Heater Association and produce the newsletter (MHA News) for the association. As a result, we have been able to leverage our know-how by networking with a very capable group of heater masons all over North America, trading tips, and making sure that we learn from everyone's mistakes, including our own.

The Heat-Kit was the first heater core developed in North America and some of its more innovative features can now be found throughout the industry.

We are committed to masonry heater research and development because it is a worthwhile endeavor with consequence. We feel that the results speak for themselves and are the best form of advertising (our advertising budget is zero).

We developed the Heat-Kit system in 1985 to better address both our own needs and those of our clients. It is a system of precast refractory components that has allowed us to reduce the amount of expensive on-site time required to build a heater core by 90% . Our main innovation was to retain about 50% of the firebrick construction in the core, including all critical areas such as the firebox. Firebrick are unsurpassed, in our opinion, for taking the heavy abuse of thermal cycling.

For example, we have developed the first all-masonry white bakeoven (i.e., the flames do not pass through the oven) and believe that it is the best oven in the business. At home, we now use one to bake all of our own sourdough bread - R&D can be fun!

Description

A complete system includes a foundation, heater and chimney.

The heater consists of a core and a facing. The masonry facing has a minimum thickness of 4" and is part of the active thermal mass. It is typically installed by a local mason, and you have a wide choice of finish options.

Components

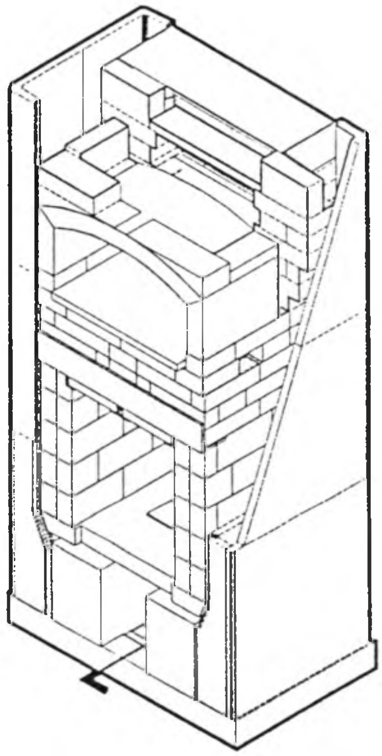


Figure 3. Cutaway of Heat-Kit2 core with front bakeoven

The heater core consists of precast refractory components that are assembled on site in conjunction with standard firebricks that are usually obtained locally. Included with the core is all of the necessary hardware for a complete installation, including firebox doors, clean outs, dampers, etc.

Some of this hardware is installed into the facing, i.e., it will be done by the local mason. In the northeast we offer a delivered and installed price for the core, set up ready for facing.

Gas flow

Figure 4. illustrates the gas flow through the Heat-Kit 2. It is shown with the bakeoven option.

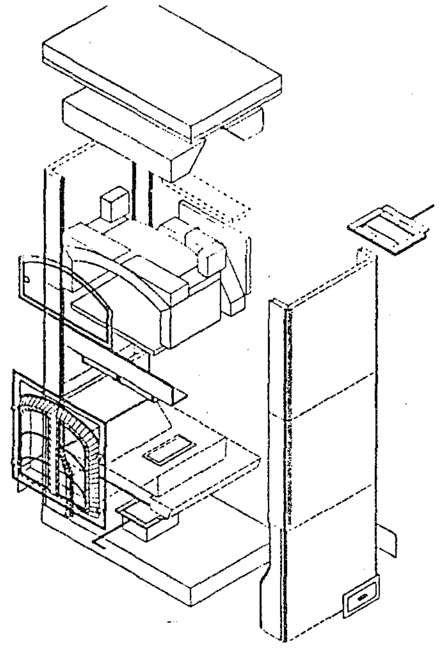


Figure 2. Kit components, exploded view

Outside combustion air enters at a lower level through the foundation. It passes through the air damper (2) and then into the firebox (3). Rapid combustion of the fuel charge results in long flames, which are directed around the bakeoven (7) and then burn out in the secondary combustion chamber. The hot gases are cooled in two downdraft heat exchange channels (8) and enter a connecting plenum (9) under the firebox. From there the cooled exhaust gases enter the chimney at floor level. The design of the connecting plenum allows the chimney to be connected anywhere at the back or side of the heater without unbalancing the downdraft channels.

A shutoff damper (11) in the chimney is closed once the fire is completely out, after about two hours. This interrupts the chimney draft and prevents the large amount of energy now stored in the masonry from bleeding out through the flue.

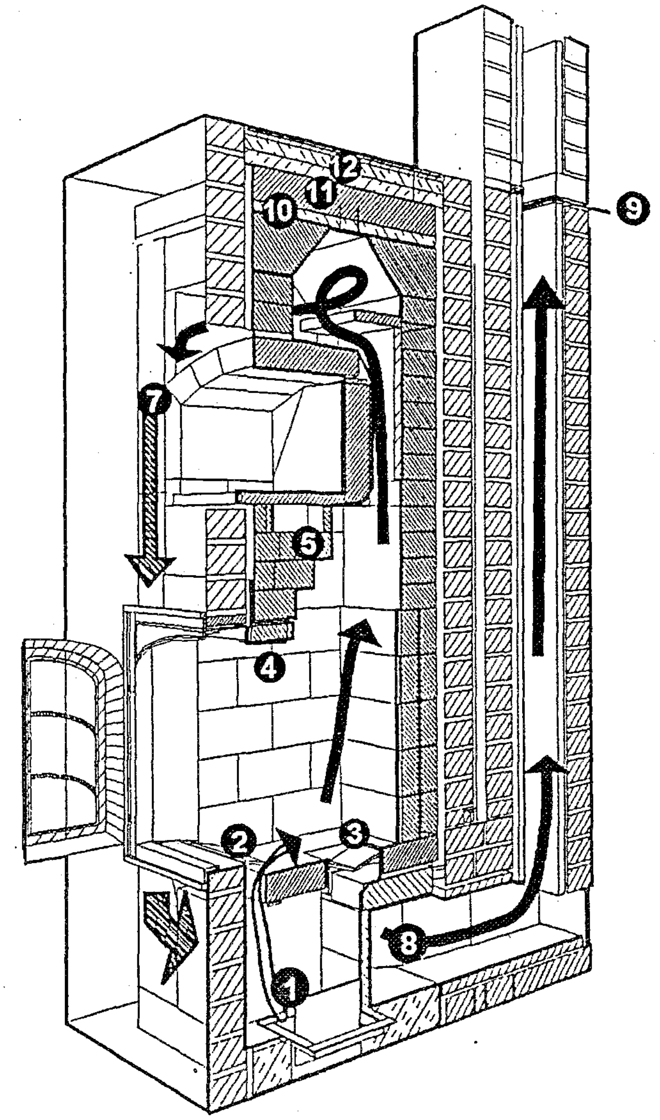


Figure 4. Gas flow in a Heat-Kit2 with front bakeoven

1. Insulating Base Slab with Outside Air Damper
2. Combustion Air Inlet
3. Ash Drop
4. Firebox Lintel w. Heat Shield
5. Bakeoven Floor Heat Bypass
7. Heat Exchange Channel
8. Exhaust Gas (to Chimney)
9. Chimney Damper
10. Hi-Temp Insulating Board
11. Refractory Capping Slab
12. Insulating Concrete

Domestic Hot Water

Introduction

An electric domestic hot water heater usually accounts for the largest portion of a household's electricity bill, assuming that electricity is not used for space heating. Natural gas, where available, is less costly. However, it is still a non-renewable resource that contributes to global warming.

Part of the heat output of a contraflow heater can be used to heat water. The water can be domestic hot water or water used for space heating (i.e., in a radiant floor system).

A heat exchanger consisting of one or more loops of stainless steel high pressure boiler tubing is located against the back of the firebox, in the hottest part of the fire.

It is very important to install the proper safety devices when adding a hot water coil. If water in the coil is allowed to turn to steam, an explosion could result. Also, the water in the tank can reach scalding temperatures, so that a tempering valve may need to be used. Never take any shortcuts when designing or installing a domestic hot water loop into a wood fired appliance.

Thermosyphon Method

The heat transfer can take place in two ways, by thermosyphoning, using natural convection, or by means of a small circulation pump.

A thermosyphon system is the simplest, but also has some drawbacks. It requires that the storage tank be located higher than the coil. Best efficiency is obtained when horizontal distance to the tank is 4 ft. (1.2 m) or less and the vertical distance is 6 feet (1.8m) or more.

This arrangement is often not convenient because the domestic hot water tank is usually located in the basement. Sometimes you can get around this by adding a preheat tank. The preheat tank is located for good thermosyhoning and is plumbed to feed into the cold water inlet of the primary tank.

Heat transfer is lower with the thermosyphon method due to the slower water flow through the stainless loop(s). In order to achieve good efficiency, both lines from the coil to the tank should be insulated. A minimum of 3/4" dia. pipe must be used to ensure adequate flow.

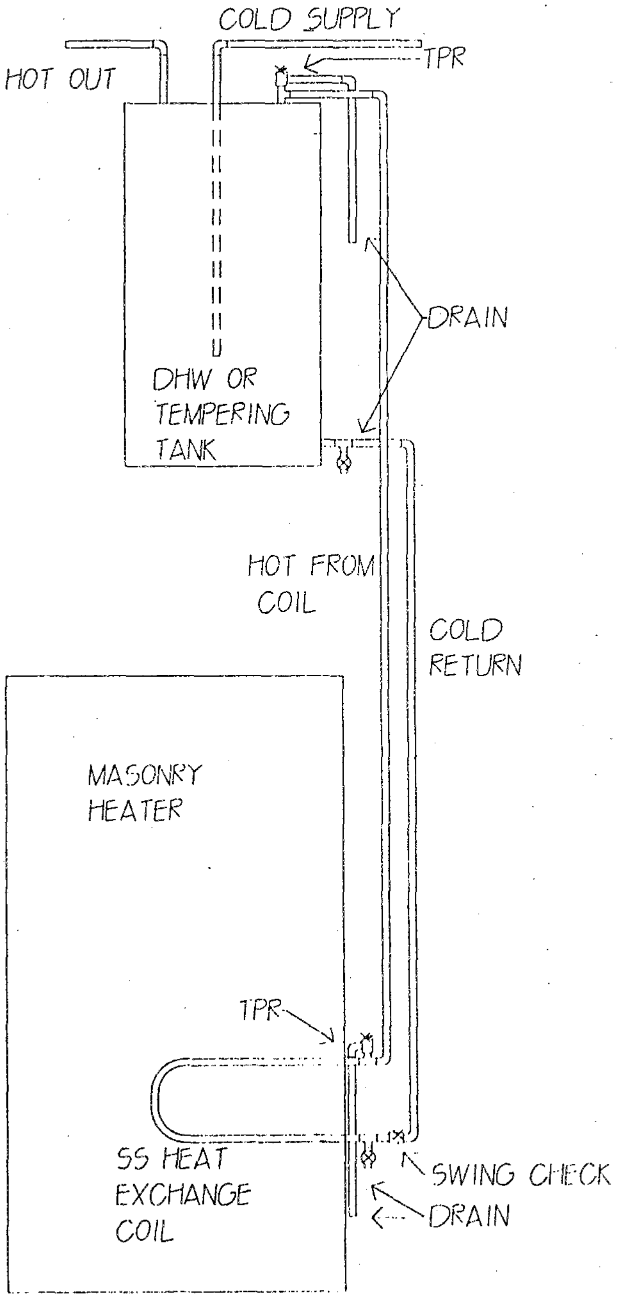
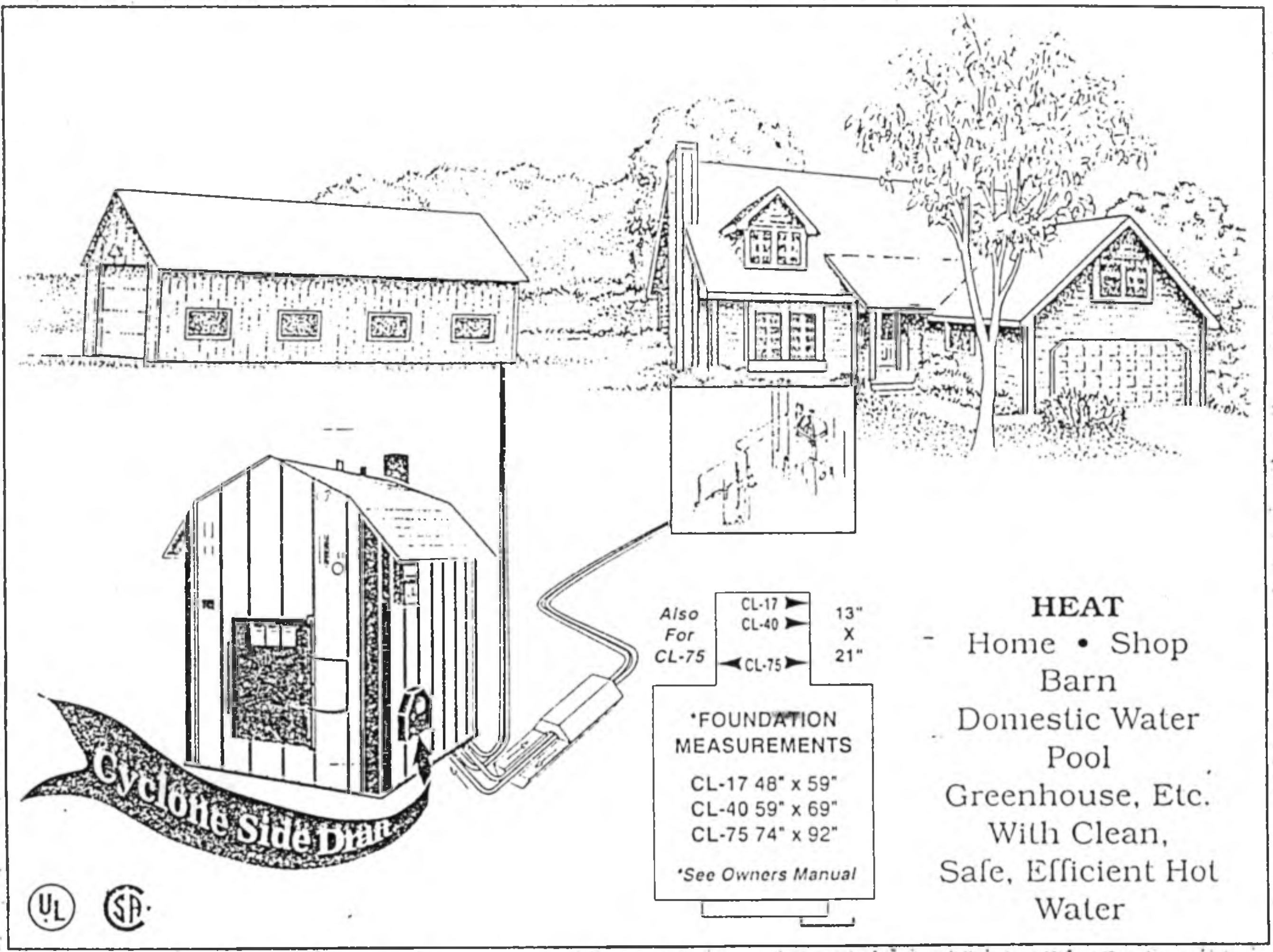


Figure 3. Hot water system -thermosyphon method

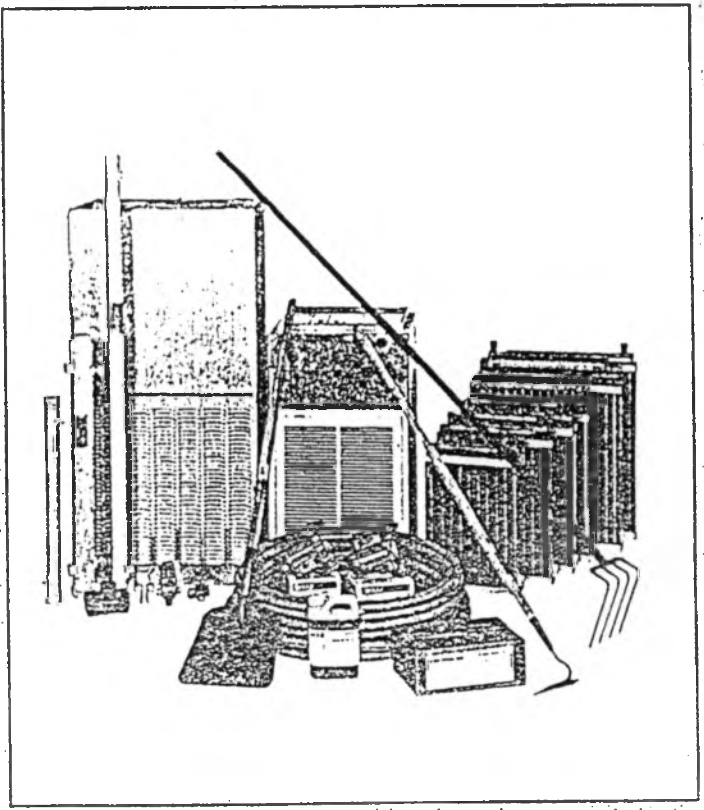


*FOUNDATION MEASUREMENTS
CL-17 48" x 59"
CL-40 59" x 69"
CL-75 74" x 92"
*See Owners Manual

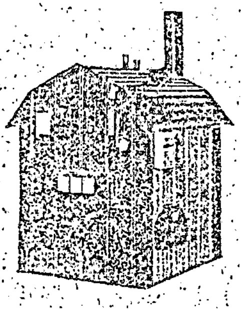
HEAT
Home • Shop
Barn
Domestic Water
Pool
Greenhouse, Etc.
With Clean,
Safe, Efficient Hot
Water

Accessories Available

- Water-to-Water Heat Exchanger (Existing Boilers, Heat Swimming Pools, Spas, etc.)
- Baseboard Heaters
- Water-to-Air Heat Exchangers (Forced Air Heating)
- Domestic Water Heaters
- Circulation Pumps
- Poly Fittings and Underground Tubing
- Spark Arrester Chimney Caps
- Water Treatments
- Rust Inhibitors
- Many More Not Pictured or Listed



▼ SPECIFICATIONS ▼



Model CL 17

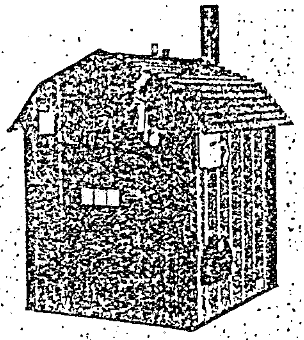
Door	22" x 22"
Water Capacity	170 Gallons
Draft Control	Thermal Electric
Firebox	30 x 36 x 42
Steel Thickness	3/8", 1/4" & 7-Gauge
Heat Transfer Area	64 Sq. Ft.
Weight	1,500 Lbs.

Will Replace Up To:

- 1,500 gallons of fuel oil annually
- 3 to 15 cords of wood burned indoors
- Up to $250 per month heating bill
- Will heat most normal 3 to 4 bedroom homes with 12 to 36 hour burn times

Current Applications:
House; House and Garage; House and Spa; Pools, etc.

The Central Boiler Classic furnaces Models CL 17, CL 40, and CL 75 are UL and CSA Listed.



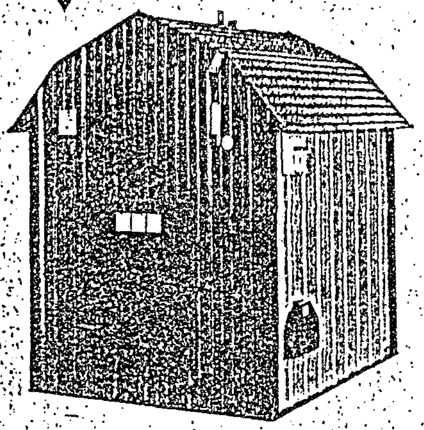
Model CL 40

Door	22" x 30"
Water Capacity	400 Gallons
Draft Control	Thermal Electric
Firebox	36 x 48 x 54
Steel Thickness	3/8", 1/4" & 7-Gauge
Heat Transfer Area	114 Sq. Ft.
Weight	2,150 Lbs.

Will Replace Up To:

- 1,300 to 3,000 gallons of fuel oil annually
- 3 to 25 cords of wood burned indoors
- Up to $500 per month heating bill
- Will heat large homes, 2 or 3 buildings with 12 to 36 hour burn times. If installed to heat a single 3 or 4 bedroom home, burn times can be as high at 48 to 72 hours.

Current Applications:
2 and 3 Houses; Laundromat and Store; House and Hog Barn; House, Swimming Pool and Shop, etc.



Model CL 75

Door	30" x 40"
Water Capacity	750 Gallons
Draft Control	Thermal Electric
Firebox	40 x 60 x 72
Steel Thickness	3/8", 1/4" & 7-Gauge
Heat Transfer Area	170 Sq. Ft.
Weight	3,200 Lbs.

Will Replace Up To:

- 1,500 to 5,000 gallons of fuel oil annually
- Applications currently using 20 or more cords of wood
- $400 to $1,500 per month heating bill

Current Applications:
20-Unit Motel and Apartment; Antique Shop, Warehouse and Large House; 18-Unit Motel; Supper Club and Ballroom with Approximately 10,000 Sq. Ft.; Factory Assembly Building for Central Boiler with 24,000 Sq. Ft.; Greenhouses, Houses and Shop; Door Factory.
Pallet Burner heating applications are the same as the CL-75.

6-YEAR WARRANTY

Ratings are based upon actual performance from working applications in northern climates with 12 to 36 hour burn time. Actual performance for your application will vary with the condition of the building, the insulation, shelter from wind and the geographical location.

*Test reulsts available from Central Boiler to authorized regulatory bodies.

Greenbush, MN 56726
(218) 782-2575

CENTRAL
BOILER, INC.

U.S. Patent # 5,329,920 Brochure #37 Printed in U.S.A.

Chapter 5
Gasifier Designs

5.1 Introduction

Many different designs of gasifiers have been built and are described in the extensive literature on this subject (see especially Gengas 1950; Skov 1974; Foley 1983; Kjellstrom 1983, 1985; Kaupp 1984a; NAS 1983). Much of this material has been collected by A. Kaupp of the University of California at Davis. (Copies of these papers are also at SERI and the German Appropriate Technology Exchange [GATE] in Eschborn, West Germany.) Anyone interested in design modification and improvement would be well-advised to become acquainted with this material before repeating tried and tested techniques. However, many of the documented design variations are minor.

We believe that future improvements to gasifiers will be based on a better understanding of the basic processes, combined with improved measurements of gasifier behavior and better regulation of fuel properties. Work is under way at various private and public centers to increase our understanding of the gasification process. Consequently, gasifier design is in a state of flux. This makes it difficult to organize a "handbook of gasifier design" without having it out of date before the ink is dry.

To avoid this problem, we will first describe the construction and operation of a number of historical gasifiers described in the literature to aid in understanding various tradeoffs still under development. The reader must remember that the choice of gasifier is dictated both by the fuels that will be used and the use to which the gas will be put. We will then describe some gasifiers currently under development.

5.2 Basic Gasifier Types

Fixed bed (sometimes called **moving bed**) gasifiers use a bed of solid fuel particles through which air and gas pass either up or down. They are the simplest type of gasifiers and are the only ones suitable for small-scale application.

The **downdraft gasifier** (Figs. 4-5(b), 5-1, and 5-2) was developed to convert high volatile fuels (wood, biomass) to low tar gas and therefore has proven to be the most successful design for power generation. We concern ourselves primarily with several forms of downdraft gasifiers in this chapter.

The **updraft gasifier** (Figs. 4-5(a), 5-3, and 5-4) is widely used for coal gasification and nonvolatile fuels such as charcoal. However, the high rate of tar production

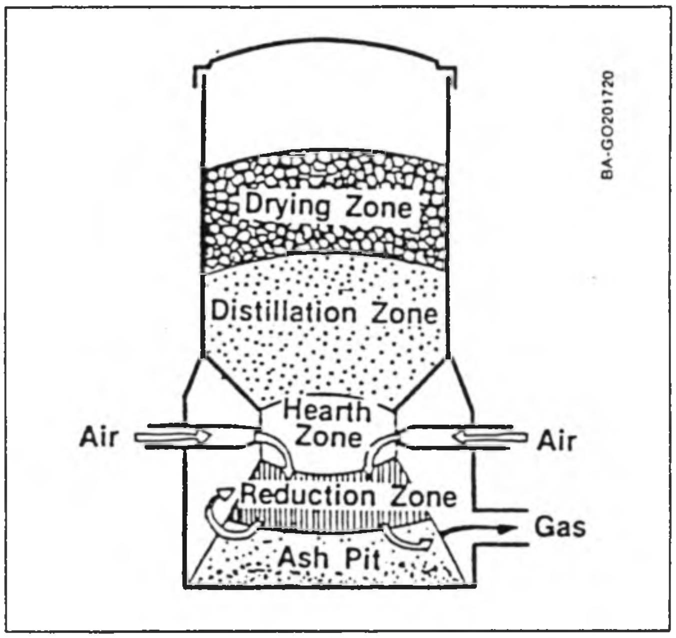


Fig. 5-1. Diagram of downdraft gasification (Source: Skov 1974, Fig. 14. © 1974. Used with permission of Biomass Energy Foundation, Inc.)

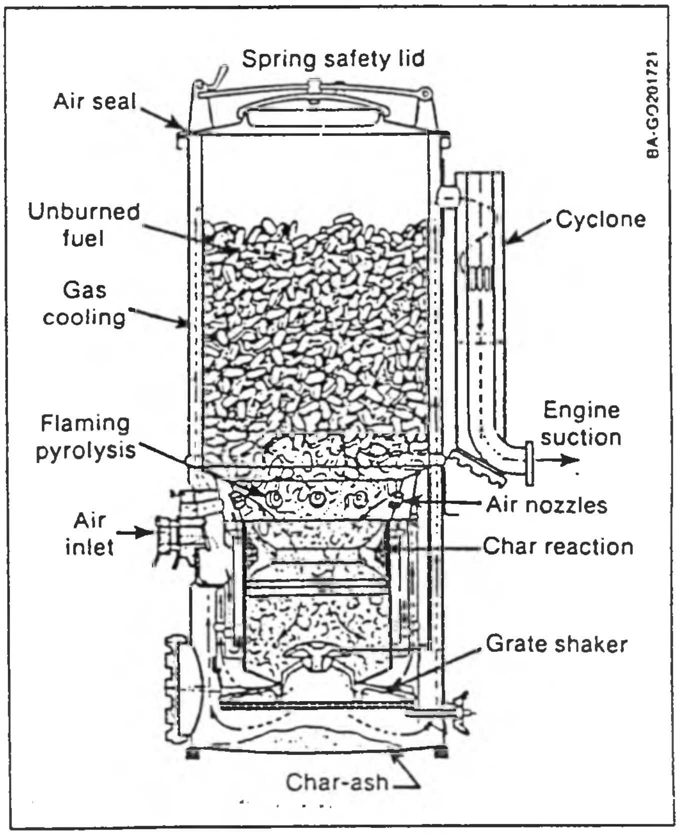


Fig. 5-2. Imbert (nozzle and constricted hearth) gasifier (Source: Gengas 1950, Fig. 75)

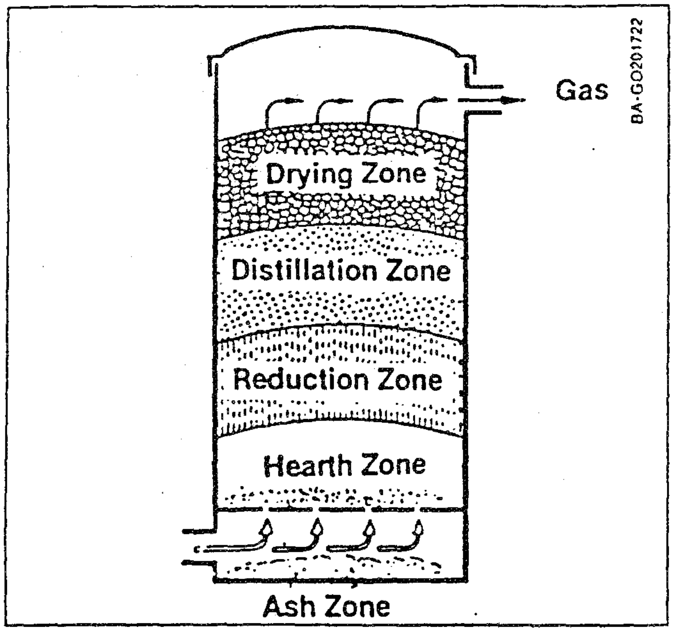


Fig. 5-3. Diagram of updraft gasification (Source: Skov 1974 Fig. 9. © 1974. Used with permission of Biomass Energy Foundation, Inc.)

(5%-20%) (Desrosiers 1982) makes them impractical for high volatile fuels where a clean gas is required.

Fluidized beds are favored by many designers for gasifiers producing more than 40 GJ(th)/h* [40 MBtu(th)/h] and for gasifiers using smaller particle feedstock sizes. In a fluidized bed, air rises through a grate at high enough velocity to levitate the particles above the grate, thus forming a "fluidized bed." Above the bed itself the vessel increases in diameter, lowering the gas velocity and causing particles to recirculate within the bed itself. The recirculation results in high heat and mass transfer between particle and gas stream.

Suspended particle gasifiers move a suspension of biomass particles through a hot furnace, causing pyrolysis, combustion, and reduction to give producer gas. Neither fluidized bed nor suspended particle gasifiers have been developed for small-scale engine use.

We have already mentioned that gasifier designs will differ for different feedstocks, and special gasifiers have been developed to handle specific forms of biomass feedstocks, such as municipal solid wastes (MSW) and rice hulls.

The manner in which ash is removed determines whether the gasifier is classified as either a dry ash (ash is removed as a powder) or slagging (ash is removed as a molten slag) gasifier. Slagging updraft gasifiers for biomass and coal have been operated at only a very large scale.

5.3 Charcoal Gasifiers

Updraft charcoal gasifiers were the first to be developed for vehicle operation. They are suitable only for low-tar fuels such as charcoal and coke. Figure 5-4 shows an updraft charcoal gasifier that was used in the early part of World War II. Air enters the updraft gasifier from below the grate and flows upward through the bed to produce a combustible gas (Kaupp 1984a). High temperatures at the air inlet can easily cause slagging or destruction of the grate, and often some steam or CO_2 is added to the inlet air to moderate the grate temperature. Charcoal updraft gasifiers are characterized by comparatively long starting times and poor response because of the large thermal mass of the hearth and fuel zone.

Charcoal manufacture is relatively simple and is carried on in most countries. However, it requires tight controls on manufacturing conditions to produce a charcoal low in volatile content that is suitable for use in charcoal gasifiers.

5.4 Charcoal versus Biomass Fuels

High-grade charcoal is an attractive fuel for gasifiers because producer gas from charcoal, which contains very little tar and condensate, is the simplest gas to clean. Charcoal gasifiers were restricted over much of Europe during the later years of World War II because charcoal

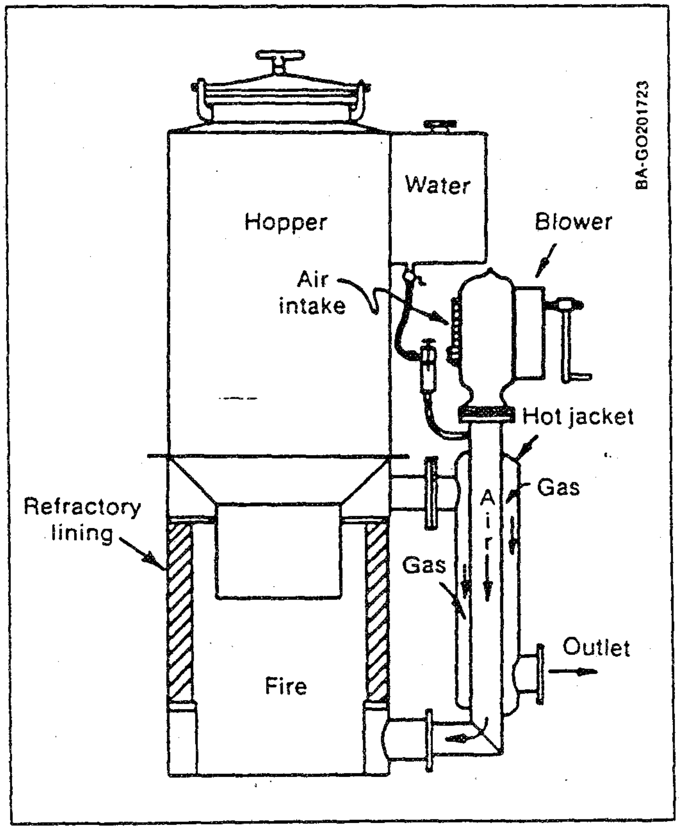


Fig. 5-4. Updraft coke and charcoal gasifier, early World War II (Source: Kaupp 1984a, Fig. 27)

---

*The units J(th) and Btu(th) refer to the thermal or chemical energy produced. This can be converted to electricity with an efficiency of 10% to 40%, so the electrical energy content (J or Btu) will be proportionally lower.

level of particle separation down to the Stokes' limit of about 1 µm. In fact, many of the earliest gasworks used gigantic settling chambers. However, even though it is effective, this method tends to be a bit cumbersome.

Strauss (1975). Unfortunately, the small cyclones required for small gasifiers are not available commercially, so they must be custom designed and fabricated.

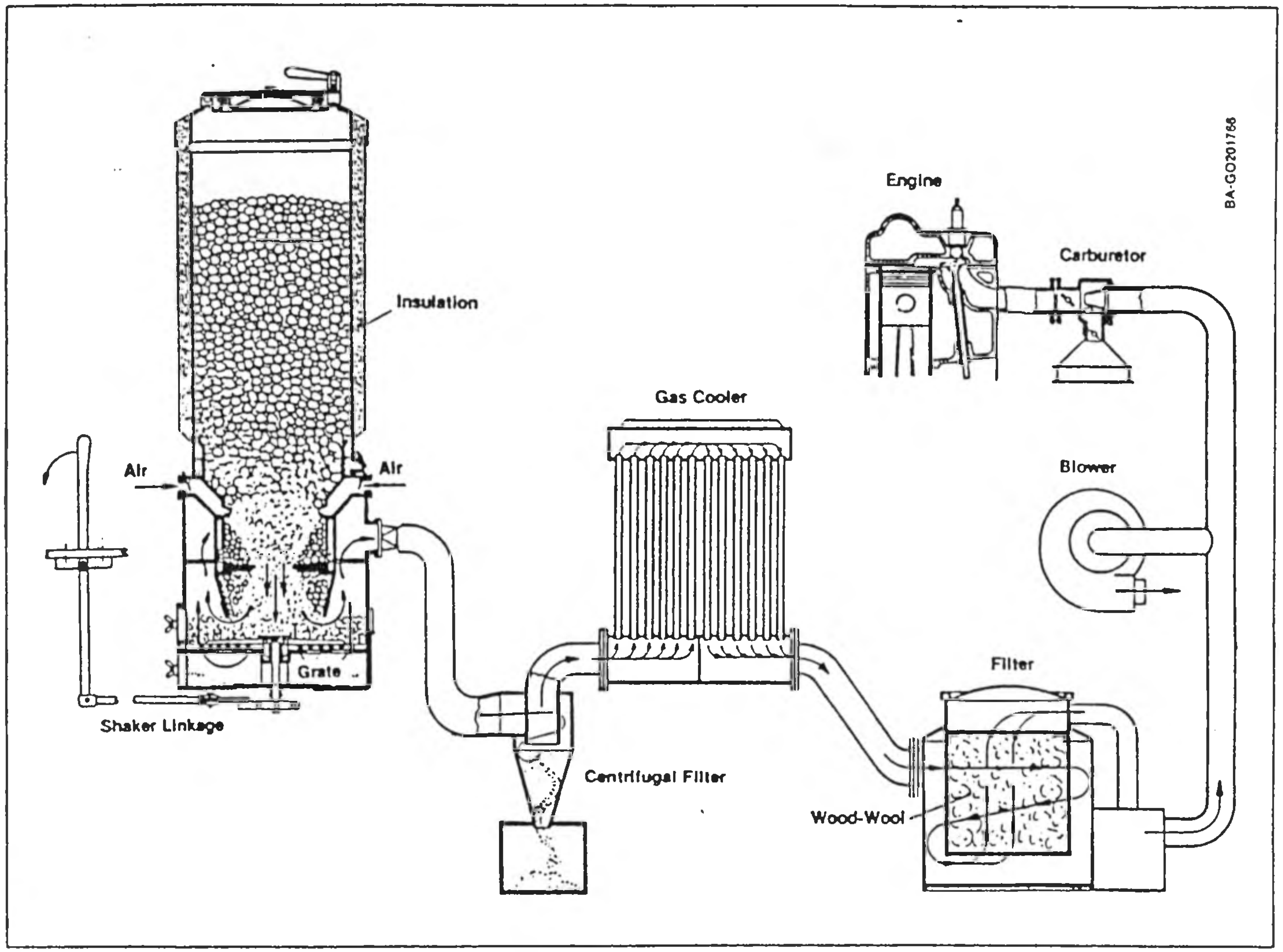
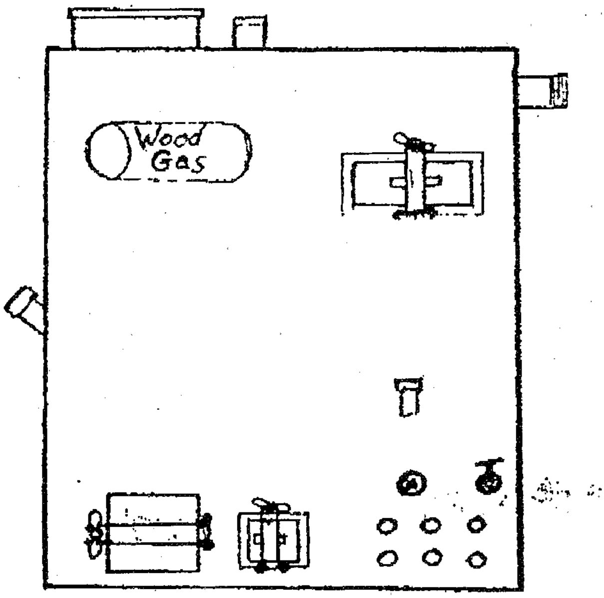
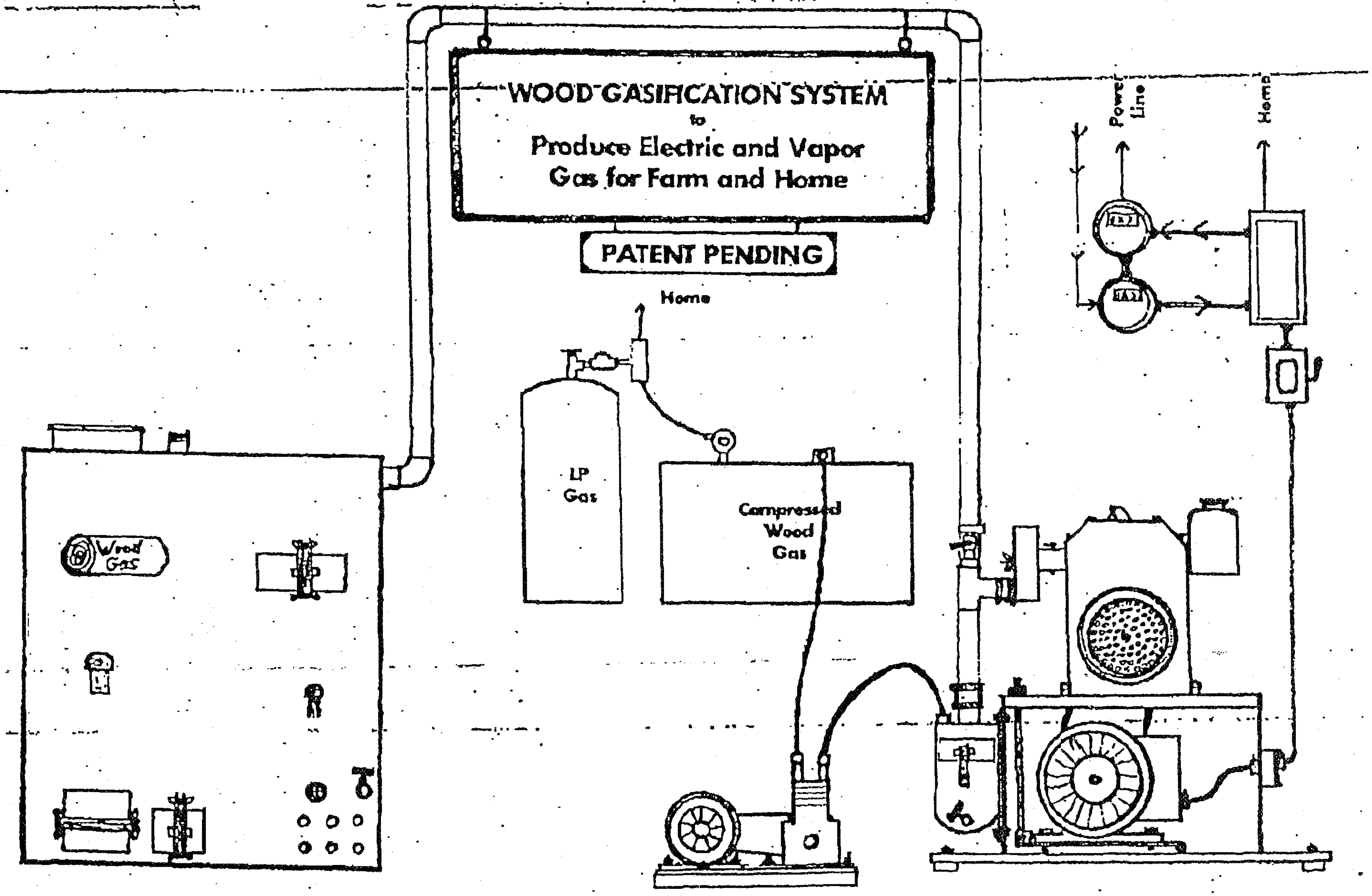


Fig. 8-3. Typical vehicle gasifier system showing cyclone and gas cooler (Source: Adapted from Skov 1974)

Model S-80 - S-120
Gasifier
for
Stationary Power Units



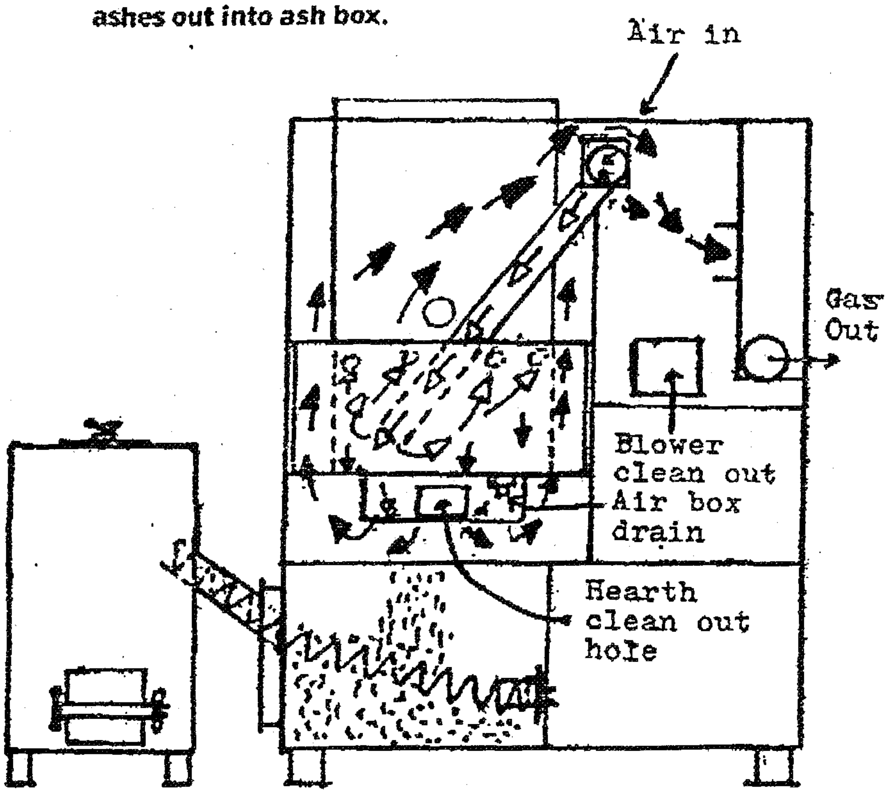
- These gasifiers are designed to run stationary power units and electric generators.
- Designed to run continuously. It does not have to be shut down to put in fuel.
- Designed to run with lid on or off and fed with auger.
- Designed to run on dry sawdust or any other fuel that will burn and has 25 percent or less moisture.
- Designed to run different size engine by changing restrictor ring, which takes approximately five minutes.
- Does not have any moving parts.
- Has only two parts that can wear out, and they can be changed in about ten minutes.
- All filters are washable and can be reused.
- Designed to run with very little maintenance.
- Designed to give many years of trouble-free service.


WOOD GASIFICATION SYSTEM
to
Produce Electric and Vapor
Gas for Farm and Home
PATENT PENDING
Home
Power Line
Home
LP Gas
Compressed Wood Gas
Wood Gas

HOW THE GASIFIER WORKS

Air is drawn in air intake, down to air box. The air circulates around air box and into air nozzles, burns from air nozzles down to restrictor and is now gas. Gas goes down through grate and up around fuel hopper and air intake. This cools gas and preheats air coming in. Gas goes into blower and from blower either into boiler or scrubber.

As gasifier is burning and producing gas, fuel feeds into hearth by gravity. With grate rotating and agitator rotating, this keeps fuel from bridging and keeps ash and clinkers worked down through grate. The ash scraper scrapes ashes down through hole in gasifier and drops into ash pit. The ash auger takes ashes out into ash box.



PRODUCTION OF GAS

The gas is derived by partial combustion of the fuel in gasifier. Because of limited acces to air the combustion of the fuel is not complete, but gasification of fuel material occurs without further combustion of the produced gas.

The air is supplied through air intake which preheats air to air nozzles. In front of these nozzles the combustion zone is established. The heat from this zone dries and turns fuel to charcoal. In the combustion zone a reaction is happening where carbon (C) is reacting with air and carbon dioxide (CO_2) to produce carbon monoxide (CO), and the remaining water is vaporized.

Under the combustion zone is the reduction zone or the restriction ring where small glowing chips are held. The passing gas is now reduced through contact with the glowing coals according to the following formula:

Carbon dioxide (CO_2) is reduced to carbon monoxide (CO). Water vapor (H_2O) is reduced to hydrogen (H_2).

The generated gas has the following approximate contents:

COMBUSTIBLE	VOLUME PERCENT
Carbon Monoxide (CO)	20-30
Hydrogen (H_2)	10-25
Methane (H_4)	0-4
NON-COMBUSTIBLE	
Carbon Dioxide (CO_2)	2-15
Nitrogen (N_2)	45-50

FUEL FOR SB* SERIES GASIFIER

These gasifiers are designed to use sawdust or a fine fuel no coarser than 3/8" feed pellets. Fuel has to be around 15% to 25% moisture and a low ash content. Material like paper or cardboard and agricultural bio-mass has to be run through hammermill, and then is too light and bulky to use straight, but will work good mixed with sawdust or small pellets or cubes.

Wood chips and cubes have to be mixed with sawdust. These gasifiers are open top design and if too coarse a fuel is used too much air is pulled through fuel and will not gasify. The fine fuel will create its own air seal.

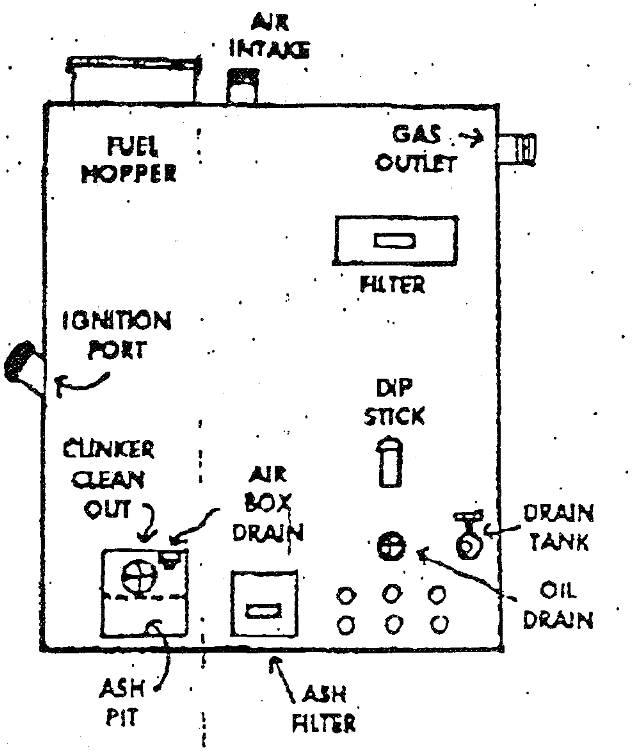
Fuel that has too much moisture will cool gasifier and not run hot enough to dislocate water and gas will be saturated with water and tar which can cause engine to miss and cause sticky valves; or if gas is used for heating, fuel in the gas line will build up with tar and soot.

Fuel that is too dry will produce too much heat and gas will not be as high in B.T.U.'s. It will not have as much hydrogen ($H2$) content with gas. If fuel is too dry, you can mix some high moisture fuel in with dry fuel.

APPROXIMATE VALUES OF DIFFERENT FUELS

FUELS	B.T.U. PER LB.	ASH CONTENT	RATING
Sawdust	5,500 to 7,000	[illegible]	Excellent
Sawdust Pellets	8,000 to 9,000	[illegible] to 1.0%	Excellent
Corn Cobs	8,000 to 8,900	1.5 to 4.0%	Excellent
Articoke Tops	9,000 to 11,000	0.1 to 1.5%	Excellent
*Rubber	16,000 to 17,000	0.5 to 1.5%	Excellent
Paper & Cardboard Pellets	8,500 to 9,500	1.0 to 4.5%	Good
Agricultural Bio-Mass Pellets	7,000 to 8,000	1.0 to 5.0%	Good
Peanut Hulls	7,500 to 8,500	1.5 to 4.0%	Good
Cocoanut Shells	8,000 to 9,500	0.8 to 1.5%	Good
Corn Stalks	7,800 to 9,500	6.0 to 7.0%	Poor
Wheat Straw	6,500 to 8,000	4.3 to 10.4%	Poor
Rice Hulls	5,700 to 7,200	15.0 to 23.0%	Not Suitable
Bituminous Coal	11,000 to 13,000	9.0 to 11.0%	Not Suitable
Anthracite Coal	12,500 to 14,500	6.0 to 8.0%	Not Suitable

*Has to be mixed with sawdust



S-80 will run engine from 10 to 30 h.p.
Two S-80s hooked together will run engine from 20 to 60 h.p. or up to 150 cu. in.

S-120 will run engine from 150 to 250 cu. in.
Two S-120s hooked together will run engine up to 500 cu. in.

Weight	S-80	150 lbs.			Fuel Capacity - 5 Gallons
Weight	S-120	200 lbs.			Fuel Capacity - 20 Gallons
Dimensions	S-80	26" Wide	36" High	12" Deep	
Dimensions	S-120	32" Wide	44" High	16" Deep	

For more Information call or write:

Manufacturer

Dealer

R & R Wood Products or
Route 3
California, Mo. 65018
(816) 458-6511

Pyrolysis oil as diesel fuel

by Stefan Gros, Laboratory Manager
Wartsila Diesel International Ltd, Diesel Technology

Abstract

Wood waste pyrolysis oil is an attractive fuel alternative for diesel engine operation. The main benefit is the sustainability of the fuel. No fossil reserves are consumed. The fact that wood waste pyrolysis oil does not contribute to CO_2 emissions is of utmost importance. This means that power plants utilizing pyrolysis oil do not cause additional global warming. Equally important is the reduced sulphur emissions that this fuel alternative implies. The sulphur content of pyrolysis oil is extremely low. The high water content and low heating value is also expected to result in very low NO_x emissions.

Utilization of wood waste pyrolysis oil in diesel engines, however, involves a lot of challenges and problems to be solved. The low heating value requires a new injection system with high capacity. The corrosive characteristics of the fluid also underline the need for new injection equipment materials. Wood waste pyrolysis oil contains solid particles which can clog filters and cause abrasive wear. Wood waste pyrolysis oil has proven to have extremely bad ignition properties.

The development of a reliable injection system which is able to cope with such a fuel involves a lot of optimization tests, redesigns and innovative solutions. Successful single-cylinder tests have already been performed and they have verified that diesel operation on wood pyrolysis oil is technically possible.

Introduction

The sustainability aspect in power generation concepts has received a lot of attention lately. This is a consequence of the growing energy demand, which is especially noticeable in the developing world. Equally important is the environmental impact of power generation. Wood pyroslysis oil (WPO) as a diesel fuel is a concept where a renewable fuel source is combined with low exhaust gas emission levels. Development work is presently at an early stage, but the concept has considerable potential, especially with the increased focus on CO_2 emissions.

Diesel power generation

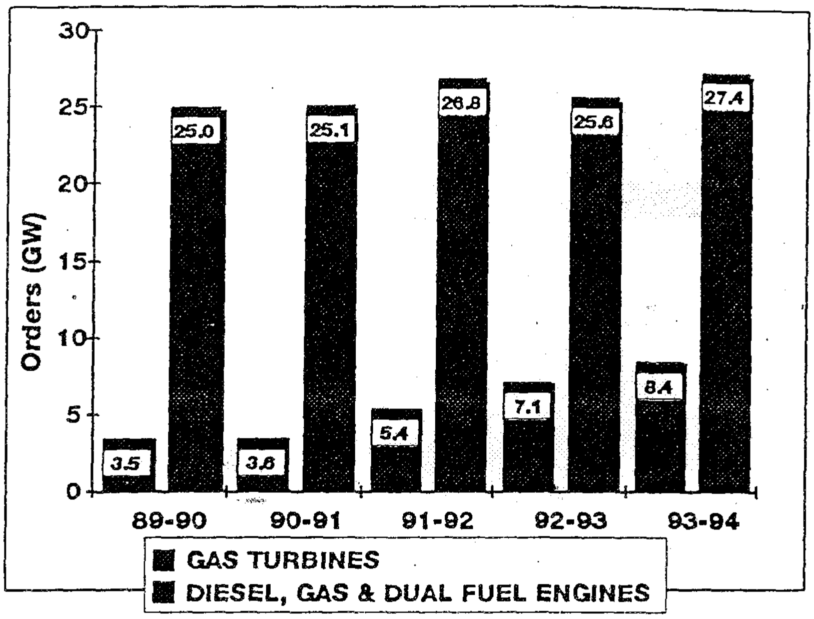


Fig. 1. Diesel engine and gas turbine orders.

One decade ago the diesel engine had a quite modest role in power generation. This has changed dramatically during the last five years as can be seen from the diesel engine and the gas turbine order statistics shown in Fig. 1. Gas turbine power plants had for many years dominated newbuilding in power generation. From being below 15% of annual gas turbine orders in 1990 the diesel engine concept had grown to more than 30% of turbine orders in 1994. This positive development has many reasons including:

- short delivery times; 12 months for 100 MW_{el}
- high electrical efficiency; ηel = 45%
- fuel versatility; HFO, GO, gas LPG, crude oil
- low emissions ;CO_2, CO HC, PM; NO_x and SO_x emissions are low with appropriate fuel choice or abatement technique

The short delivery time and the simple way the diesel power plant can be enlarged by gradual addition of engines has made the diesel concept very attractive in developing countries. The fuel versatility and the possibility to retrofit the power plant for natural gas utilization make the customer less sensitive to fluctuations in fuel prices.

Environmental considerations

The greenhouse effect caused by water, carbon dioxide and other gases is a condition of life on earth. A change in the balance towards more heat absorbance by the atmosphere may, however, have severe consequences such as:

- less areas suitable for agricultural activities
- higher sea level
- more tropical storms
- changes in groundwater reserve

A pyrolysis oil concept utilizing renewable resources will result in CO_2 emissions which are part of the global carbon cycle and thus cause no additional greenhouse effect, see Fig. 2.

SO_x emissions causing acidification is also completely avoided by the pyrolysis diesel concept because the fuel does not contain sulphur.

CO and hydrocarbon emissions from a diesel engine are traditionally at a very low level thanks to high temperatures and pressures resulting in a high degree of complete combustion. The extreme

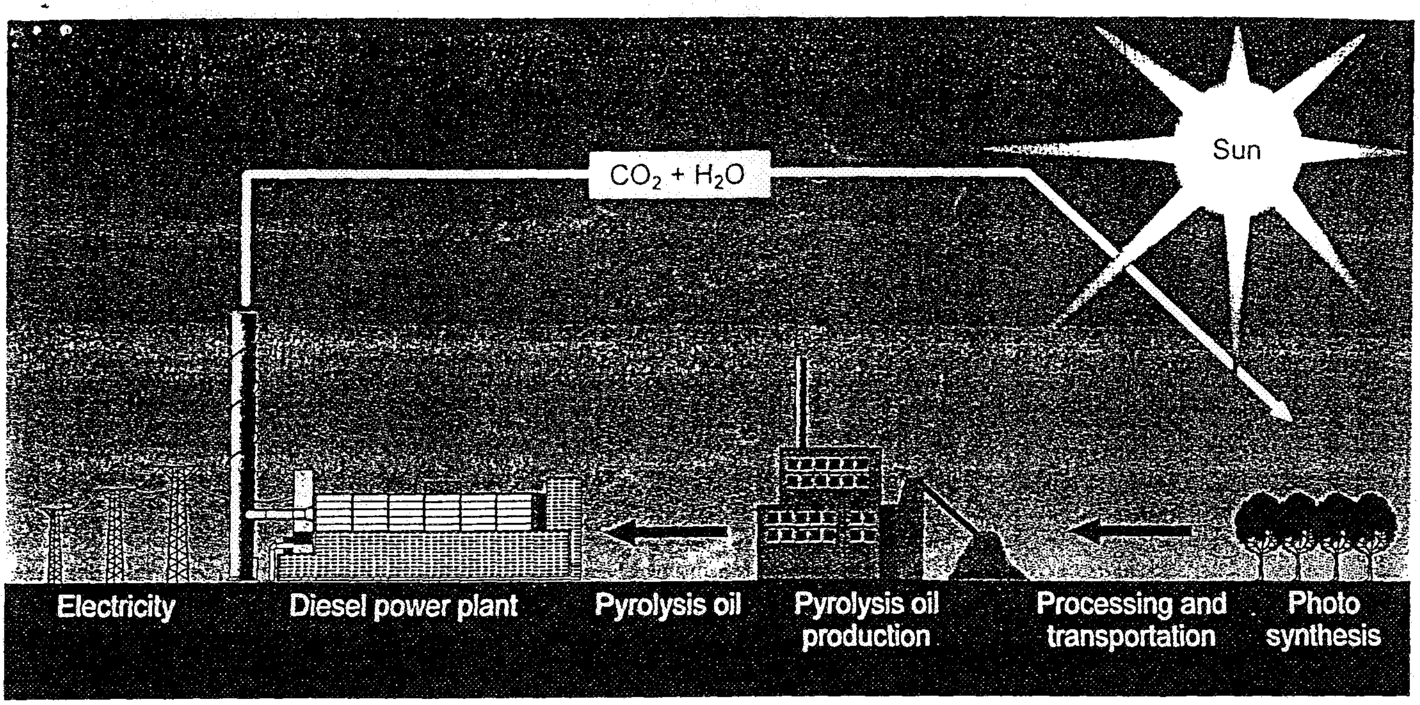


Fig. 2. Wood pyrolysis oil as fuel makes the CO$_2$ emissions part of the global carbon cycle.

properties of the wood pyrolysis oil may, however, lead to a different combustion pattern, which may increase these emissions. This is an aspect which must be carefully optimized.

NO$_x$ emissions contribute to acidification and are also involved in the ozone forming mechanism at ground level. If not controlled, the diesel engine emits fairly high concentrations of NO$_x$ as a consequence of high combustion temperatures and pressures. Efficient primary and secondary reduction techniques exist for NO$_x$ emissions. In this respect the pyrolysis oil has an advantage; the low heating value in combination with high water content will suppress the formation of hot combustion zones and thus suppress NO$_x$ formation.

Summary

The wood pyrolysis diesel concept has successfully been tested in a single-cylinder configuration in a Vasa 18V32 engine. The test clearly demonstrated the need for pilot injection. The fast burning rate of WPO was also recognised. The preliminary emission measurements also showed that the concept has an environmental-friendly profile.

LIQUID BIOFUEL PRODUCTION: COMMERCIAL ASPECTS

ROBERT G. GRAHAM
PRESIDENT & CEO
ENSYN TECHNOLOGIES INC.
GREELY (OTTAWA) ONT.

ABSTRACT

Ensyn Technologies Inc. has developed and commercialized a process to produce liquid fuel, for use as a fuel oil substitute in boilers, from wood residues and other biomass. The process, known as Rapid Thermal Processing (RTP^{TM}) is analogous to cracking in the petroleum industry where crude oil is refined to gasoline, other fuels and petrochemical products. In essence, RTP converts wood to "liquid wood" (and bark to liquid bark, bagasse to liquid bagasse, etc.) in very high yields which approach 75% of the mass of the wood entering the system. The liquid is pourable and pumpable at room temperature, burns cleanly and efficiently, and has between 55 and 65% of the heat value of fuel oil on a volume basis. Several RTP plants are in commercial operation (ie. with commercial contracts for feedstock and full production guarantees) and there are three commercial combustion systems/boilers using RTP liquid biofuel and ranging in capacity from 20 to 70 MBTU/h (6 to 20 MW). Commercial demonstrations for diesel and turbine engines fired by liquid biofuel are in progress in partnership with Wartsila Diesel (Finland) and Orenda (Hawker Siddeley Canada), respectively.

With the exception of certain European countries where renewable fuels are exempt from CO_2, sulphur and other fossil fuel taxes or where bioelectricity is given favourable rates, the liquid biofuel product is economical only where wood feedstock is viewed as a waste material. In general, purpose-grown, energy-farm type biomass is therefore not a viable feed material for commercial RTP projects. Where green wood wastes/residues are available at zero cost, the liquid biofuel requires a price of between 4 and 5 $/MBTU for a project to proceed.

INTRODUCTION

In its broadest sense, Rapid Thermal Processing (RTP™) covers the conversion of all types of carbonaceous materials to liquid fuels, high quality fuel gases, and chemicals. Commercial RTP™ activities (including the actual implementation in the market as well as the short-term R&D initiatives) are much narrower in scope, and are focussed on the production of high yields of light, non-tarry liquids (ie. "bio-crude") from wood residues and other biomass for fuel and chemical markets. Chemicals are of significant interest from an economical point of view since they typically have a higher value than fuel products. Liquid fuels are of interest for many reasons:

1. Liquid fuels do not have to be used immediately after production, such as is the case with hot combustion gases or combustible gases produced via gasification. This allows the decoupling of fuel production from the end-use (ie. the conversion of fuel to energy).
2. The higher energy density of liquid fuels vs. that of fuel gases and solid biomass results in a large reduction in the costs associated with storage and transportation.
3. The costs to retrofit an existing gas or oil fired combustion system are much lower than replacement with a solid fuel combustor.
4. In general, liquid fuel combustion is much more efficient, controllable, and cleaner than the combustion of solid fuels.
5. The production of liquid bio-crude permits the removal of ash from the biomass prior to combustion or other end-use applications.
6. Gas or liquid fuel-fired diesel or turbine engines cannot operate commercially on solid fuels.

Although wood represents the biomass which is of principal commercial interest (including a vast array of wood residues), bagasse, various straws, non-recyclable paper and other cellulosic materials are also of significant interest.

RTP™ is not an incineration process. In commercial applications, it is simply the liquification of biomass by the addition of heat at atmospheric pressure in the absence of air or oxygen. There is no direct combustion in the conversion unit. In effect, wood is converted to liquid wood, bagasse to liquid bagasse, straw to liquid straw, etc. The liquid is pourable and pumpable at room temperature, and has approximately the same heating value as the feedstock entering the conversion unit.

The typical liquid yield from a representative hardwood at 10-15% moisture content is about 73% by mass in industrial operations. In general, the yield increases slightly with an increase in feedstock cellulose composition and slightly decreases with an increase in feedstock lignin composition. However, the energy yield remains approximately constant since lignin-derived liquids have a higher energy content than cellulose-derived liquids. These liquids are produced as a single phase and are not to be confused (either in appearance or chemical behaviour), with the heavy tars produced via conventional pyrolysis or as a gasification by-product.

RTP™ was commercialized in 1989 after about 10 years of research, development and demonstration. Current product applications include boiler fuel and food chemicals (flavourings, natural colourings, etc.) It is important to note that the primary liquid product or "bio-crude" is essentially the same whether it is destined for the fuel or the food chemicals markets. However, if intended for fuel use, the downstream RTP™ equipment can be operated in a manner to reduce the moisture content, increase the heating value and decrease the char/ash content.

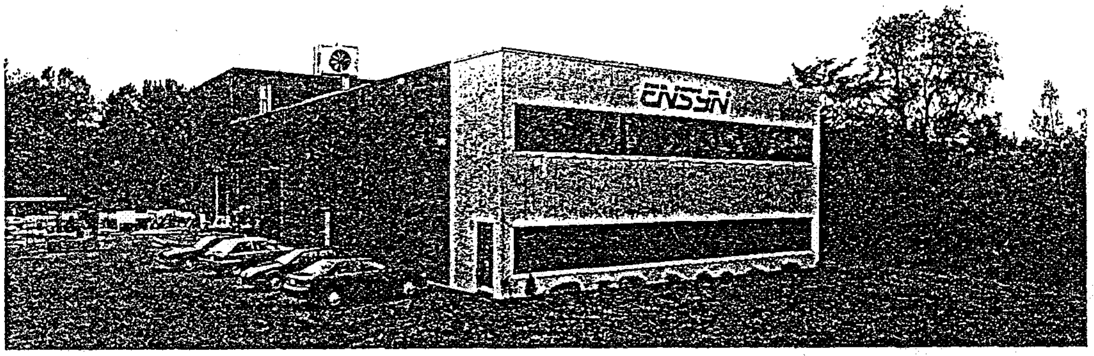
Other product applications which are expected to be realized over the short-term are "bio-diesel" fuel, "bio-turbine" fuel, wood preservatives, polymers/resins and activated carbon. These products are being developed both independently by Ensyn and in cooperation with strategic partners throughout Europe and North America.

RTP

THE IMPACT OF TECHNOLOGY

> "...we consider RTP technology as very promising... the most advanced and capable [method] of producing liquid fuel from biomass on a commercial basis."
>
> G. Grassi
> Directorate-General for Science, Research and Development
> Commission of European Communities
> [European Union]

> "ENSYN Technologies Inc. has become the world leader in fast thermal conversion of biomass."
>
> CANMET Annual Report
> Canada



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ENSYN
TECHNOLOGIES INC.

RESULT 180

CADDET
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IEA
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US 93.516/3A.H01

Cogeneration for
residential buildings

Oil-fired cogeneration system for residential use

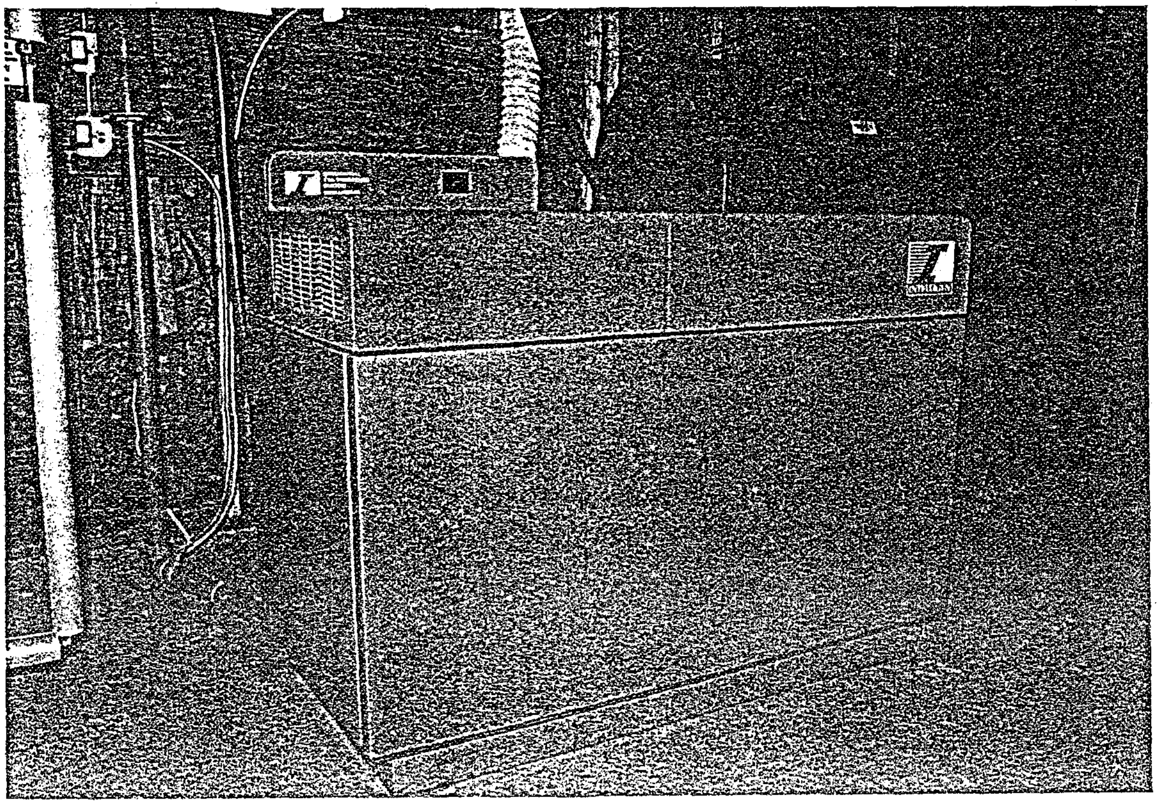
Summary

Intelligen Energy Systems, Inc., a three-year old entrepreneurial company, has developed an oil-fired residential cogeneration system. This unit, the Model Alpha-550, is intended to replace conventional heating systems in single-family homes, provide for the home's space heating and domestic hot water needs, and supply a substantial portion of their electric power requirements.

Brookhaven National Laboratory supported the manufacturer of the cogeneration unit by determining the energy efficiency of the unit. Their test results indicated significant energy efficiencies and potential energy savings which have been confirmed by field tests.

Highlights

- Efficiency rating of 93 %
- Over 13,000 kWh saved over 21 months



Aim of the Project

Intelligen's objective in developing the Alpha-550 was the design of a commercially-viable cogeneration system that provides both heat and electric power, with an increased energy efficiency, to a single-family dwelling. The product may be used as a replacement for existing heating systems as well as in the construction of new housing.

Intelligen enlisted the assistance of Brookhaven National Laboratory to conduct the evaluation of one of its field test units. Brookhaven researchers developed a direct thermal efficiency measurement technique to precisely determine the efficiency of the heating system based on enthalpy (heat) flow measurements into and out of the cogeneration unit.

Another field test unit was installed in an occupied house and operated for an extended period of time. Electrical energy usage was measured and compared with that for a baseline period.

The Principle

As shown in Figure 1 the Intelligen system consists of an engine, a generator, a heat exchanger, and electronic controls. Heat given off by the engine (both jacket and exhaust) is transferred to a hydronic distribution system, while heat from the generator is transferred to a warm-air stream.

The system is designed to supply hot water for hydronic baseboard heating systems and domestic hot water, 5 kW of electricity and a significant amount of warm air which can be used to heat the space where the unit is installed, or which can be ducted to other parts of the living space. Further it is designed to burn heating oil (No. 2), which is consumed in an 8.2 kW (11-hp), two-cylinder (1850 rpm) diesel engine. The engine powers a single-phase induction generator. The heat from the water-cooled engine is combined with the heat recovered from a tube-in-shell exhaust heat exchanger and is circulated to the hydronic baseboard zones located throughout the house, exactly as in a conventional hydronic boiler system.

The unit is controlled by a proprietary system based on a Motorola microprocessor chip with input from standard heating-system controls. The control system has an input/output port for connecting a service terminal for diagnostic tests.

The Intelligen system was designed with certain factors in mind, including:

- power output sufficient to completely offset the average residence's electrical consumption throughout the heating season;
- simple, annual maintenance requirements;
- quiet operation;
- durability;
- a proven long-term life expectancy;
- an elementary interconnection to the home's electric service.

In addition, system control of the cogeneration unit is based on proprietary operating algorithms using a programmable microprocessor, including service diagnostics and multiple levels of safety

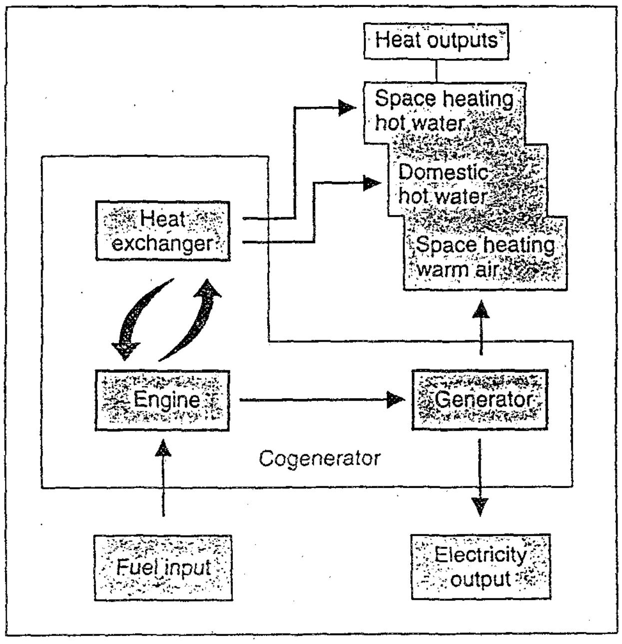


Figure 1: The cogeneration system showing energy flows.

built in to protect the unit and the residence in which it is installed. Existing/standard wall thermostats are used to control circulators and/or zone valves. Outside air is used to eliminate energy losses from induced infiltration.

Results from the laboratory testing revealed a 92.8 % efficiency rating - a new high-end reference mark for the efficiency range of oil-fired residential heating equipment. Approximately one-quarter of the output (4.8 kw) is in the form of high-quality electrical power, which displaces electricity generated by utilities.

The unit outputs approximately 11.4 kW for hydronic circulation during normal heating conditions. When the control system detects that the unit is approaching its capacity, this output is boosted up to 20.2 kW by electric water heating elements (which are directly powered by the cogeneration unit).

The Situation

Oil is used to heat more than twelve million homes in the United States. These residences consume approximately 586 TWh (10^{12}) of oil per year, more than USD 10,000 million worth. The vulnerability of the oil-heat consumer to fluctuations in oil prices and availability of oil, the lack of alternative energy sources, and the concern about acid rain has prompted the US Department of Energy to assist the private sector in developing a technology base from which advanced energy-efficient oil combustion systems can evolve. The evaluation of this residential cogeneration system is a component in this effort.

Period of operation	Energy consumption [kWh]	Average monthly consumption [kWh]
Feb 1990-Nov1991 (baseline)	14,237	678
Feb 1992-Nov 1993 (after installation of Alpha-550 unit)	942	45

Table 1: Energy consumption for a baseline period and with a cogeneration unit installed.

The Model Alpha-550 residential cogeneration system was developed by Intelligen Energy Systems, Inc. in 1991. Intelligen built ten field test units during 1992, one of which was loaned to Brookhaven National Laboratory for evaluation. The Brookhaven testing was performed between August and November of 1992. The remainder of the units were installed in a variety of residential and commercial sites for field testing.

The Massachusetts home in which the unit is installed has approximately 240 m^2 of heated living space plus an unheated basement and garage. The house was built in 1988 and is insulated according to the standard building practices of the time. The closest city with comparable degree-day data is Nashua, New Hampshire, which averages about 7,000 degree-days per year. The unit is intended to compete in the marketplace with more traditional heating systems which do not produce electricity.

Table 1 compares the kWh consumed by the residence during a baseline period to the usage with the cogeneration unit installed. Utility company data do not record the actual energy savings, but the comparison to a baseline period gives a reasonable approximation of the savings. The comparison reveals an average savings of 633 kWh per month. This saving is achieved by using only about 10 % more fuel which corresponds to an incremental 70 kWh of oil.

The Organisation

Intelligen Energy Systems, Inc. was founded in 1990 to develop, manufacture, and market residential cogeneration systems. Its corporate mission is to provide technologically advanced, efficient, environmentally sound small-scale electrical generation products and services to residences and small businesses.

Since 1976, the US Department of Energy's Office of Building Technologies, working through Brookhaven National Laboratory, has concentrated its efforts on upgrading the technology applied to residential and light commercial space-heating systems. Researchers at Brookhaven National Laboratory's Combustion Equipment Technology Laboratory, in cooperation with academic and private sector organisations, are developing and evaluating innovative systems and components. Over the past decade, researchers at Brookhaven have identified many energy saving space-heating retrofit options and technologies that are then introduced into the marketplace.

Economics

The cost of the unit is approximately USD 7,500 plus installation of USD 500-1,000.

A cost/benefit analysis based on an estimated price of USD 0.26 per litre (USD 1 per gallon) of fuel oil and USD 0.12 per kWh (typical rates for the northeastern portion of the United States where the field test units are installed) shows that during a typical hour of operation the Alpha-550 unit consumes USD 0.54 in fuel oil and produces USD 0.60 of electricity and USD 0.49 of heat. The energy saving of 633 kWh per month and the extra 70 kWh of oil used give a total energy saving of 563 kWh per month. This gives an annual saving of more than USD 800.

Evaluator

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* IEA: International Energy Agency
OECD: Organisation for Economic Co-operation and Development

IEA

The IEA was established in 1974 within the framework of the OECD to implement an International Energy Programme. A basic aim of the IEA is to foster co-operation among the 23 IEA Participating Countries to increase energy security through energy conservation, development of alternative energy sources, new energy technology, and research and development (R&D).

This is achieved, in part, through a programme of energy technology and R&D collaboration currently within the framework of 35 Implementing Agreements, containing a total of more than 60 separate collaboration projects.

The Scheme

CADDET functions as the IEA Centre for Analysis and Dissemination Demonstrated Energy Technologies for all IEA CADDET member countries.

This project can now be repeated in CADDET member countries. Parties interested in adopting this process can contact their National Team or CADDET.

Demonstrations are a vital link between R&D or pilot studies and the end-use market. Projects are published as a CADDET 'Demo' or 'Result' respectively, for on-going and finalised projects.

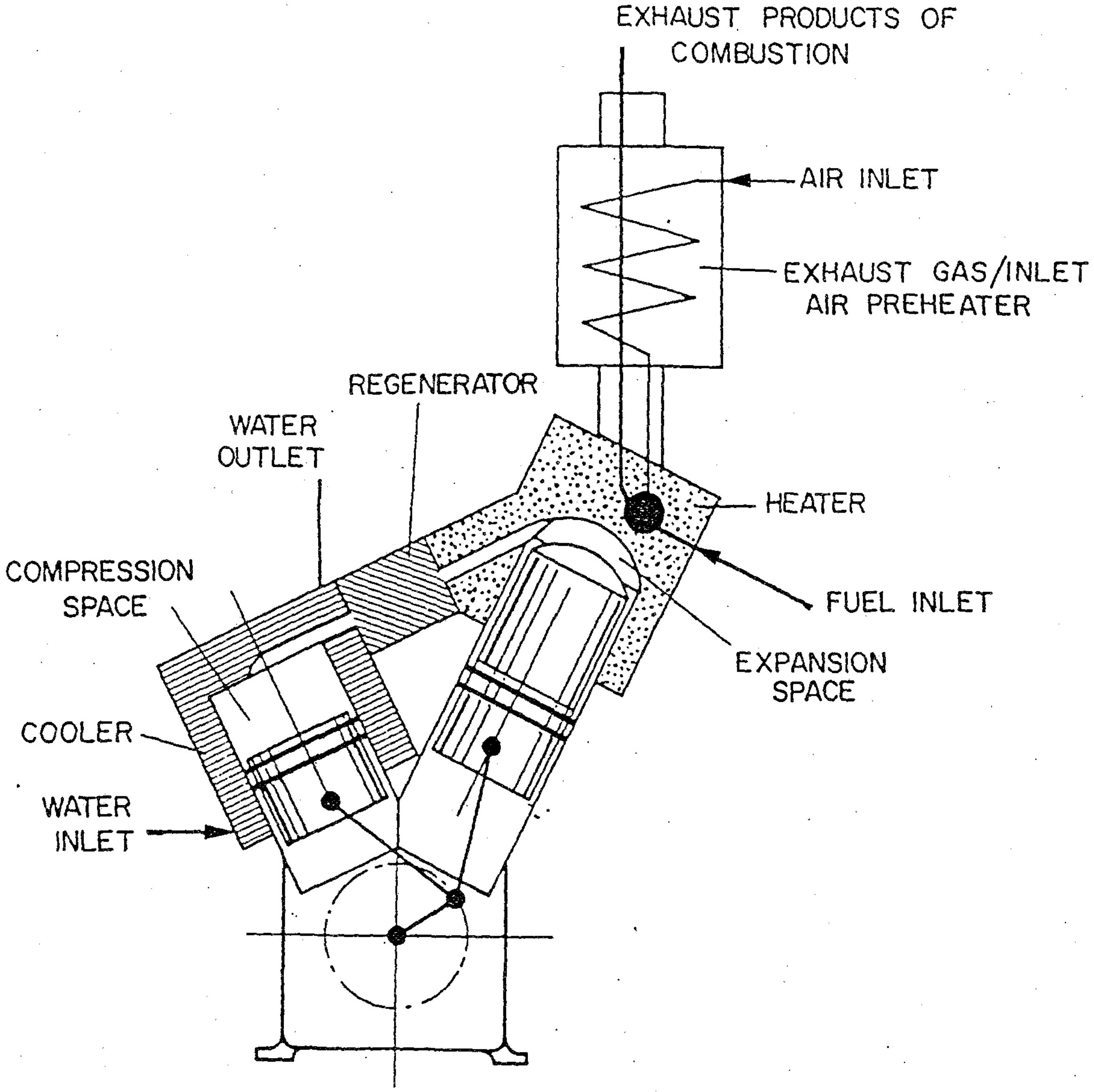

Fig. 1.8 Diagram of practical opposed-piston Stirling engine.

Small Stirling Free-Piston Engines for Cogeneration

by

William Beale, Gong Chen

Sunpower, Inc.
Athens, Ohio

June, 1992

Introduction

In any situation where combustion is used for space heating or other purposes, there is a potential application for cogeneration machines which can recover some of the otherwise wasted available energy in the combustion process and convert it to electricity or mechanical power while at the same time providing heat to the process at lower temperature. The energy recovery potential from such cogeneration is very large. Approximately 20 percent of the energy consumed in the United States today is used for fossil-fuelled space heating, and of that amount about 20 percent is reasonably recoverable with the use of appropriate heat engines. This amounts to about 15 percent of the electricity requirement of the country (Reference 1).

The engines needed to approach this large available energy potential must have special characteristics which are not available on the market today. They must be efficient over a wide range of power output, have very low maintenance requirements and long life, and produce very little noise and pollution. Ideally, they must be adaptable to any fuel or heat source. And needless to say, they must be cost-beneficial.

A current Department of Energy-industry funded solar joint venture (Reference 2) is developing just such high reliability, low maintenance free-piston Stirling generators in the power range 5-25 kW. While they are specifically designed for solar power generation, these engines are also ideally suited for cogeneration. This paper describes such engines and their applications to cogeneration.

History of Free-Piston Stirling Engines

The free-piston Stirling engine with linear alternator has had a long development time, starting in the early 1960s (Reference 3), and continuing at an accelerating pace through many prototypes for many purposes to the present (Reference 4, 5). The machines now being developed for solar applications produce between 5-25 kW and must have the life, maintenance and efficiency required to be cost-effective in that demanding role. The free-piston concept was chosen because of its greater promise of fulfilling these requirements in comparison with kinematic Stirling, Rankine and gas turbine alternatives. The free-piston Stirling has been chosen by NASA for space power for the same reasons.

Description of Cogeneration System

Figure 1 shows the general layout of a typical free-piston system. It is comprised of a burner, a linear motion resonant engine with attached linear alternator, and a power and burner control system. The burner is fitted with a recuperator which recovers heat from the exhaust to heat incoming combustion air and/or deliver heat to some other function. The engine is a hermetically sealed linear motion machine with a displacer which moves gas between hot and cold heat exchangers, and a piston which expands the working gas in the hot space and compresses the gas when it is in the cold space in order to produce power to drive the alternator. The magnets of the alternator are directly attached to the piston and generate electric power as they move by the stationary wire windings surrounding the magnet ring. All moving parts have non-contact bearings and seals, so there is no intrinsic life-limiting or power degrading wear. The engine contains no oil or other material other than its helium working fluid. It can operate in any orientation.

Unlike kinematic Stirling machines which use either pressure variation or mechanism changes to effect power control, the free piston can respond rapidly and efficiently to load changes by way of variations of the relative motions between the piston and displacer. This power control feature, along with hermetic sealing and absence of oil and contact bearings entirely eliminates the problems of sealing, load response, contamination and durability which continue to vex linkage-driven Stirling machines.

Since the engine can attain high fractions (60-70 percent) of Carnot efficiency, it can be designed to operate efficiently at heater wall temperatures of 600-700 °C, much lower than, say, gas turbines, which must use exotic high temperature alloys to attain good efficiency. This means that relatively inexpensive alloys such as 300 series stainless steels can be adequate to give engine-alternator thermal efficiency in the high 30 percent range.

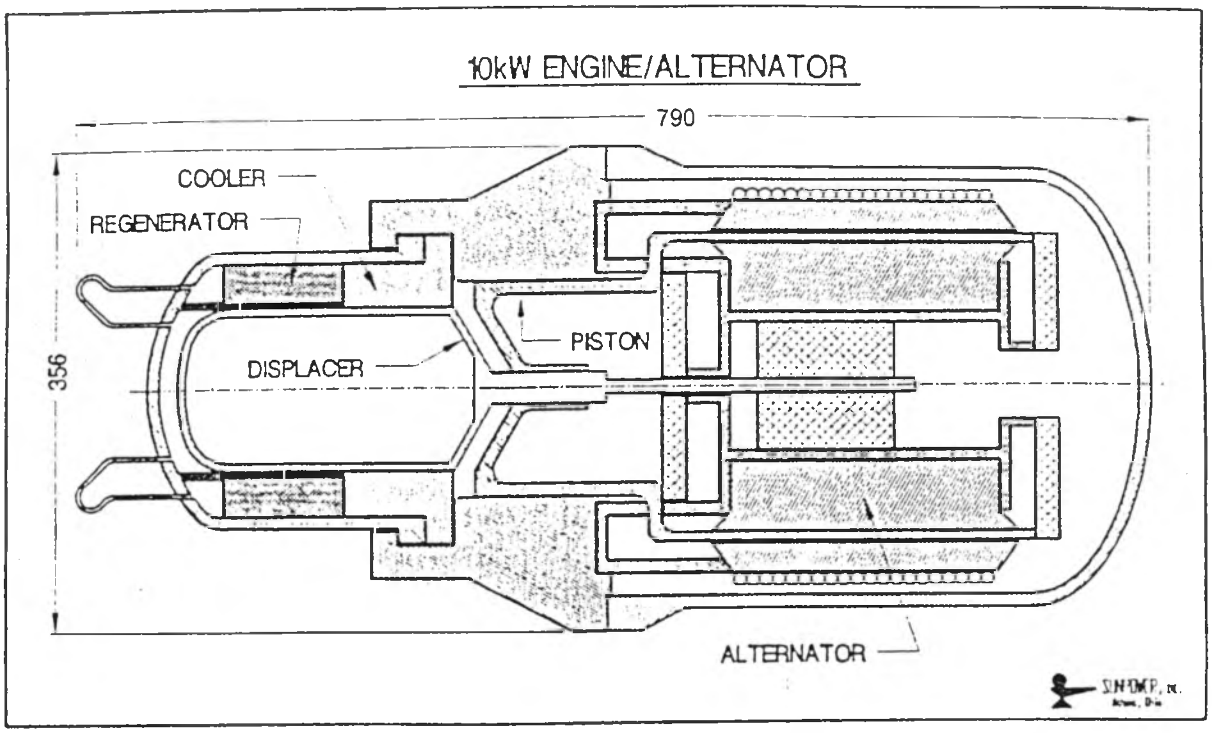

Figure 1: 10 kW Engine/Alternator

Figure 2 is a photograph of a prototype 7 kW solar electric generator engine in a test cell. This prototype has an unnecessarily heavy commercial pressure vessel since it was the cheapest and most readily available, but production 10 kW machines would be much less heavily made. In this photo, the insulated object to the right is an electrically heated sodium heat pipe simulating a solar absorber. Cogeneration units typically would substitute a natural gas-fired burner for this heat pipe.

Table 1 shows the dimensions of a 10 kW engine-alternator-burner-control as packaged for use as a cogenerator. It has much less external volume than the 7 kW prototype in Figure 2 and has approximately the same package volume as a diesel system of the same power.

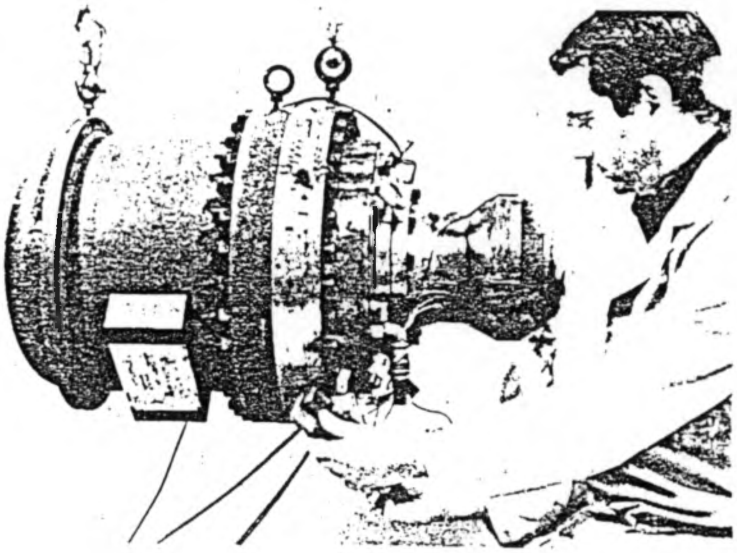

Figure 2: 7 kW Engine/Alternator Undergoing Final Tests in Sunpower Test Cell

Performance of Free-Piston Cogenerator

The performance comments made here are based on both experiments and computer simulations. The computer simulations are calibrated to match the results of the experimental data, and any extrapolations from that calibrated datum reflect performance and can be assumed to be reasonably representative of achievable performance of the extrapolated designs, which are geometrically similar and not greatly different in size from the experimental machine. For example, 7 kW engine operating data are used to calibrate the simulation code and predict the characteristics of the slightly larger 10 kW engine.

An important characteristic of the free-piston machine is its high efficiency over a wide range of delivered power. The system efficiency stays within 2 percentage points of the maximum over a power modulation from full power to 60 percent of full power. It is important to note that the efficiency is that for the engine-alternator only. Total system efficiency must include the burner efficiency, fraction of discharge heat used, and auxiliary power requirements, which are specific to each use.

Figure 3 shows a typical energy flow diagram of a Stirling free-piston cogenerator used in a situation demanding the maximum of electricity in relation to heat used for other purposes. From this and known energy costs, hardware costs and local alternative resource costs, economic payback times can be derived.

Table 1: Characteristics of 10 kW Cogeneration System

Power — 10 kW maximum
Output — 120 VAC, 60 Hz
Engine /Alternator
    Efficiency — 35 % (electric power out/thermal energy to engine)
    Dimensions — length 80 cm; diameter (maximum) 40 cm
    Weight (including burner) — ~200 kg
Control Type — microprocessor control maintaining heater head temperature and output voltage, response time 3-6 cycles (60 Hz)
Design Life — >40,000 hrs (target 100,000 hrs
Bearings and Seals — non-contact throughout
Pressure Vessel — welded shut
Working Fluid — helium at 4 MPa
Heater Head Temperature — 670 °C
Heat Rejection Temperature — 60 °C
Auxiliary Power Requirement — <1 kW

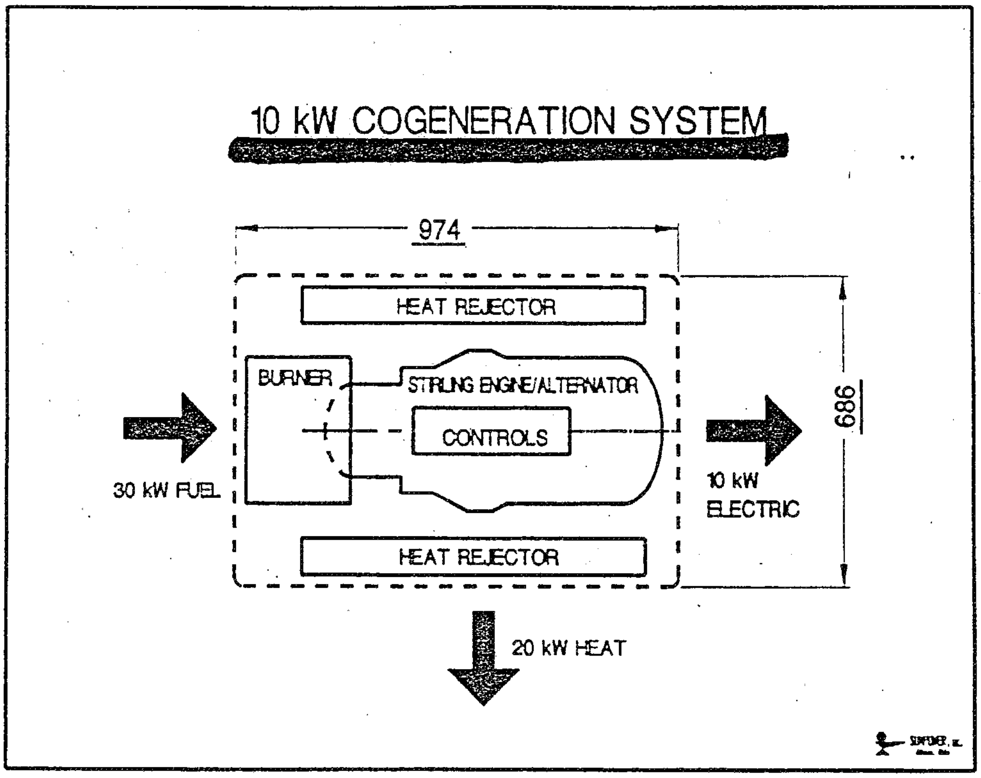

Figure 3: Diagram Showing System Energy Flow

A very important characteristic of the free-piston Stirling generator is its scalability. Its achievable efficiency does not change appreciably over a range of design power from several hundred watts to 25 kW.

Another advantageous characteristic of this machine is its ability to retain high fractions of Carnot efficiency (the theoretical limit for any heat engine) at quite low temperatures. For example, a small engine optimized to 300 W of electric power at 500 °C heater temperature can be reoptimized to retain 60 percent of Carnot efficiency at a heater temperature of 300 °C. One reason for this is that the heat exchanger walls of low temperature machines can make use of very high conduc-

Table 2: Some Applications of Free-Piston Cogenerators
With Temperatures and Heat Source

Application	Temperature	Heat Source
high concentration solar	670 °C	concentrated sunlight
diffuse solar	300 °C	non-imaging concentrator
home congeneration system	500-720 °C	natural gas, biomass
farm cogeneration	500-700 °C	biomass
industrial cogeneration	300-700 °C	natural gas, biomass, waste heat
supermarket refrigeration	700 °C	natural gas

tivity material such as pure copper, since wall stresses can be designed to be low enough for this relatively weak material. Again it should be noted that this fraction of Carnot refers to the engine-alternator only. Auxiliary power requirements and burner characteristics must be factored in to obtain system efficiency.

The linear alternator is a well-understood machine, and can be designed with great confidence to perform as required. Alternator efficiency is a known function of component mass and cost. More than 90 percent linear alternator efficiency is routinely measured in solar system tests.

Manufacturer costs analysed for the solar joint venture program are currently estimated to be $650/kW for the engine-alternator in production rates of 100,000/yr. The rest-of-system costs, for the burner, controls, heat exchangers and auxiliaries must also be added to get system costs. These are conventional components similar to those already mass-produced.

Uses Of Free-Piston Cogenerators

Long life, high efficiency, low maintenance and controllability from a distance (dispachability) add to make this cogenerator exceptionally attractive both to individual users and to grid operators. Independent users can expect to have reliable systems, especially if they include multiple engines, battery packs and inverters, and grid operators can expect to have the advantage of controllable micro-power plants at strategic points along the grid, for example, at end of line where voltage drop can be a problem. This would give their customers constant voltage, use of otherwise wasted heat, and highest reliability.

Another advantage is fuel flexibility. Since the engine is able to receive heat from any source, the burner can be made to operate on non-fossil fuels, including minimally prepared solids such as agriculture waste products—grain husks, straw—as well as prepared biomass such as wood pellets. A particularly attractive potential is in waste heat recovery from industrial process streams.

Another attractive heat source is diffuse sunlight. If sunlight is partially diffuse, as is typical for eastern United States in the summer, it is not attractive for high temperature solar engines which require direct radiation and high concentration, but it would be sufficient for non-imaging concentrators operating free-piston machines at temperatures in the 200-300 °C range. Such low temperature thermal machines may be a strong competition to photocells in cost-effective solar energy conversion.

Table 2 gives a partial list of potential applications, temperatures and heat sources.

Conclusions

Hermetically sealed free-piston Stirling engines are at present under rapid development in a government-industry solar power joint venture. The solar program targets of life, maintainability, efficiency, noise, power flexibility and cost are also ideal for domestic and commercial cogeneration applications using natural gas, low temperature solar, or rough biomass heat sources. The success of the solar joint venture will open possibilities in energy conservation from heat sources now not using their available energy, especially domestic space heating systems.

References

1) *Scientific American* Special Issue: Energy for Planet Earth; Vol. 263, No. 3.; New York, NY; September, 1990.
2) *Sandia Technology Bulletin:* Energy and Environment, Sandia National Laboratories for U.S. Department of Energy, Albuquerque, NM, January 1992.
3) Free-Piston Stirling Engines—Some Model Tests and Simulations; Beale, W.T.; Society of Automotive Engineers; Detroit, MI; 1969.
4) 3 kW Stirling Powered Generator Set; Berchowitz, D.M., Richter, M., Shade, D.; 22nd Intersociety Energy Conversion Engineering Conference (IECEC); Philadelphia, PA; 1987.
5) NASA overview of free-piston Stirling technology for space power application; Slaby, J.; 24th Intersociety Energy Conversion Engineering Conference (IECEC); Washington, D.C.; 1989.

TESE001 STIRLING ENGINE

TESE001: Tamin Enterprises Stirling Engine Number 1

Basic Description

TESE001 is a single cylinder, air charged, pressurized engine which will produce 1 kW of power at 1200 rpm with low vibration. Design life is 5000 hours. This engine is a rhombic drive engine with concentric, finned heater and cooler and a stainless steel foil regenerator. The rhombic drive component dimensions (crank radius, connecting rod length, and eccentricity) are similar to the General Motors GPU-3 engine.

- ☐ Overall Size: TBD
- ☐ Mass: TBD
- ☐ Working Gas: Air, pressurized
- ☐ Fuel: TBD
- ☐ Cylinder Bore: 12.7 cm (5.00 in)
- ☐ Hot Cylinder Stroke: 3.15 cm (1.24 in)
- ☐ Hot Cylinder Swept Volume: 399 cc (24.3 cu in)
- ☐ Cold Cylinder Stroke: 3.15 cm (1.24 in)
- ☐ Cold Cylinder Swept Volume: 380 cc (23.2 cu in)
- ☐ Power Output: Design 1 kW at 1200 rpm

Major Components

- ☐ Heater: finned, stainless steel or Inconel
- ☐ Burner: TBD
- ☐ Regenerator: Concentric, stainless steel foil
- ☐ Heater Head/Cooler Thermal Isolator: titanium
- ☐ Cooler: Finned, concentric aluminum waterjacket
- ☐ Displacer: hollow titanium weldment
- ☐ Piston: aluminum
- ☐ Piston Rings: Bal-Seal molded lip seal
- ☐ Timing Gears: 1 bronze, 1 steel, helical with 10.16 cm (4.000 in) Pitch Dia

Brief History

Design began in March 1993. TESE001 was originally intended to be part of a co-generation system to supply electricity and hot water to an energy efficient house. The fuel was to be wood pellets. Tamin Enterprises was to design and build the complete system including pellet burner, water heater, generator, and Stirling engine. Work on the complete system terminated when funding was not granted to the customer. Design is approximately 70% complete and some engine parts such as seals and timing gears are in stock.

TESE002, a smaller atmospheric engine, was constructed to aid in the design to TESE001.

SOUTHEASTERN
REGIONAL
BIOMASS ENERGY
PROGRAM

SERBEP Update

JANUARY 1996

A Publication for the General Biomass Community

The Southeastern Regional Biomass Energy Program is one of five regional biomass energy programs. It is administered for the U.S. Department of Energy Office of National Programs by the Tennessee Valley Authority's Environmental Research Center in Muscle Shoals, Alabama. The 13-state region includes Florida, Kentucky, Mississippi, Georgia, North Carolina, South Carolina, Virginia, West Virginia Missouri, Tennessee, Louisiana, Arkansas, and Alabama.

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BIOSTIRLING^{TM} PROGRESS

Stirling Thermal Motors (STM), Inc., Ann Arbor, Michigan, has recently received a DOE contract to demonstrate the feasibility of linking a Stirling engine to a biomass-fueled, two-stage combustor (gasifier). Stirling engines are external combustion engines (see October 1993 *SERBEP Update*); their major advantage is their ability to use virtually any type of fuel.

STM has been working for several years to develop a Stirling engine for automotive applications. The company also supplies an identical Stirling engine for the Dish/Stirling System in DOE's Utility Scale Thermal Power program, now entering its second year.

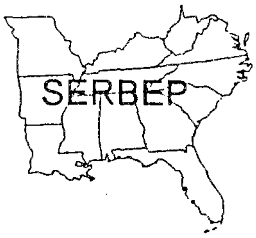
For the BioStirling^{TM} project, STM is working with Chiptec of South Burlington, Vermont, to develop a close-coupled gasifier/Stirling engine system. Chiptec has successfully employed several of its gasification units in schools and other facilities in the New England area. The Chiptec systems are automated and typically use wood chips for fuel.

Initially STM will employ its STM4-120 BioStirling^{TM} Power Conversion System to produce electricity in the 20 kW_e range. Power systems with up to 60 kW_e are planned. When commercialized, STM envisions wide use of the BioStirling^{TM} system for small-scale power generation for remote or rural applications in both domestic and overseas markets.

The STM4-120 produces 25 kW_e at 1800 rpm and 50 kW_e at 3600 rpm. The engine has 4 cylinders and uses either helium or hydrogen as the working fluid. Weight of the engine and generator is approximately 1,600 pounds.

For the proof-of-concept test of the STM4-120 system, a 500,000 Btu/hr Chiptec gasifier will be used. Gas from the gasifier will be used to fire a special burner mounted on the head of the Stirling engine. Waste heat from the burner will be used to preheat combustion air and boost overall efficiency. Approximately 1.7 kW of thermal energy will be produced for every 1 kW of electricity produced. Testing is anticipated to be completed in approximately six months.

For more information contact Lennart Johansson or Benjamin Ziph, Stirling Thermal Motors, 275 Metty Drive, Ann Arbor, Michigan 48103, phone (313) 995-1755, fax (313) 995-0610.



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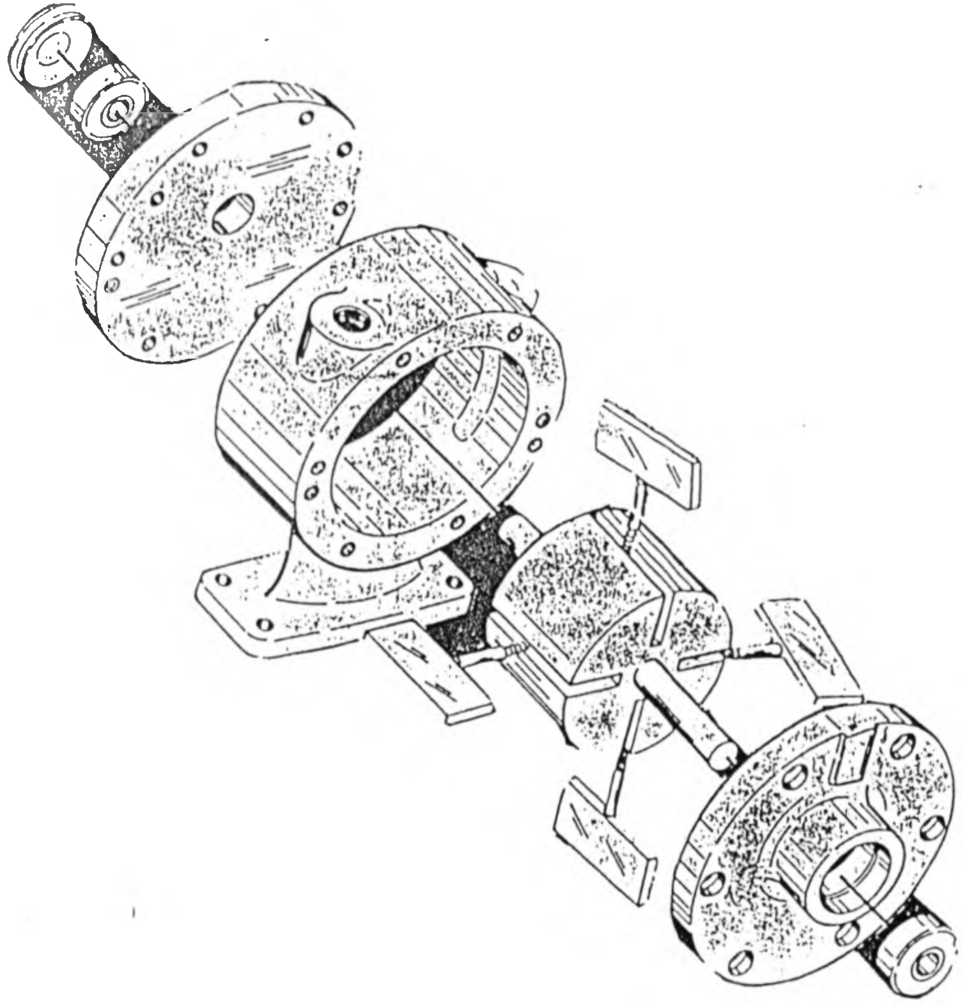


TURBINE EXPLODED VIEW

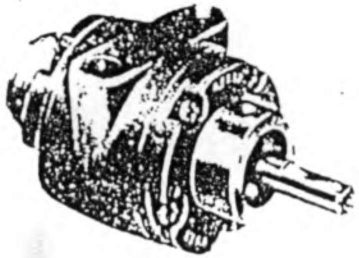
As you can see from the exploded view, Turbines are very simple machines when compared to piston engines. The vanes are self sealing and self adjusting for wear without any complex machanism. The bearings are sealed and are easily and inexpensively replaceable. A turbine should give you 10 to 12 thousand hours of service between bearing changes. Steam at 100 PSI is "damp" enough to provide almost instant evaporation at shutdown. Reason enough for the 100 PSI design.

Each turbine comes with a full year warranty.

TURBINES (General Information)

Traditional steam engines of the last century were large bore, slow turning, low pressure machines. Turbines were thought to be practical only in very large sizes. With the advent of modern materials for vanes, sealed bearings, and superior small casting techniques, the turbine has become very practical for small power applications. The turbine in small sizes now rivals the piston engine in steam efficiency and far exceeds it in reliability, maintainence, and certainly in price. For this reason we do not handle small piston engines. We offer plans for converting small gasoline engines to steam for those who still want a small piston engine.

Turbines are self starting from any position and may be completely stalled under load without damage. Both speed and power of the turbines may be varied over the entire operating range for maximum steam conservation. These Turbines may operate at much higher RPM than traditional piston engines making them much more practical for the generation of electricity without expensive and power robbing step-up



E-3 TURBINE ½ HP at 3000 RPM
80 PSI STEAM

FEATURES

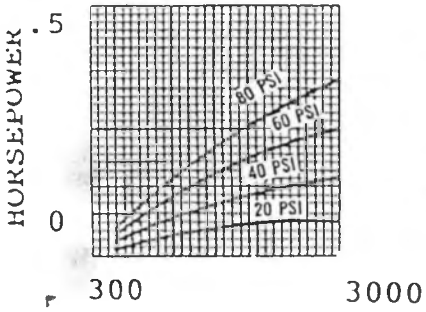
- CAST CONSTRUCTION
- SEALED REPLACEABLE BEARINGS
- VARIABLE SPEED 300 TO 3000 RPM
- VARIABLE POWER TO A FULL 1/2 HP

DIMENSIONS

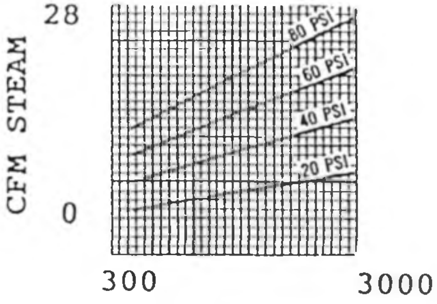
- 2.22" HIGH X 2.44" WIDE X 4.66" DEEP
- 3/8" OUTPUT SHAFT
- 1/8" STANDARD PIPE THREAD PORTS
- SHIPPING 3 POUNDS

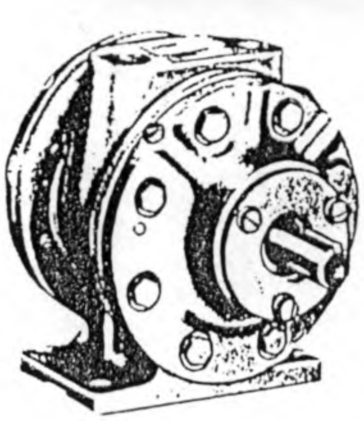
PERFORMANCE

HORSEPOWER VS RPM



STEAM CONSUMPTION VS RPM





(This is our most popular Turbine. Variable power 1/2 HP to full 5 HP.)

E-6 TURBINE 5 HP at 3000 R
100 PSI STEAM

FEATURES

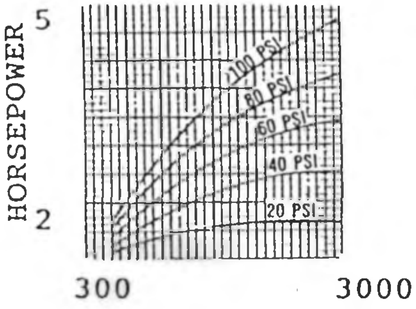
- CAST IRON CONSTRUCTION
- SEALED REPLACEABLE BEARINGS
- REVERSIBLE
- VARIABLE SPEED 300 TO 3000 RPM
- VARIABLE POWER 1/2 TO FULL 5 HP

DIMENSIONS

- 6" HIGH X 5" WIDE X 7-1/2" DEEP
- 5/8" OUTPUT SHAFT WITH 3/16" KEYWAY
- 1/2" STANDARD PIPE THREAD PORTS
- SHIPPING WEIGHT 21 LBS.

PERFORMANCE

HORSEPOWER VS RPM



STEAM CONSUMPTION VS RI