Worldwide Status of Closed Loop Ground Source 'Geothermal' Heat Pump Systems

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ABSTRACT. In recent years Closed Loop Ground Source Heat Pump Systems have developed into a viable technology with many thousands of new installations per year. This energy technology is variously described as renewable energy, geothermal energy, solar storage, and the rational use of energy. Perhaps fortuitously, these systems are commonly labelled 'geothermal systems'. For the label to remain, the geothermal industry will need to accommodate this rapidly evolving technology within its sphere of direct use applications and promote these systems on a worldwide basis. The current status of CLGSHP systems is described here together with the reasons for their rapidly increasing numbers. A brief summary of current worldwide CLGSHP activity is provided in an Appendix.

INTRODUCTION. At the 1990 gathering of the international geothermal community in Hawaii, the proceedings (GRC 1990) give no obvious evidence of Closed Loop Ground Source Heat Pump (CLGSHP) Systems. Further investigation reveals that mention is made of them by Lund et al (1990) in the update of direct use applications in the USA. The only technical paper on CLGSHP systems (Rybach et al, 1990) described the thermal operation of downhole heat exchangers (DHEs), a Swiss variant of closed loop systems.

In fact CLGSHP systems were quietly developing considerable momentum, especially in the USA, even in 1990 - largely ignored by the mainstream geothermal community. In the period since the Hawaii GRC conference, there has almost been an explosion of both growth and interest in these systems, primarily in the USA. To illustrate the current and potential impact of CLGSHP systems, the results of a limited survey carried out here can be summarised very simply. In 1994 there appear to be somewhere between 200,000 and 300,000 ground source heat pump systems installed in the USA (GRC 1994b). It is not clear that all of these are closed loop systems, but most of them are. Currently ≈40,000 are installed per annum. The rest of the world would appear to have ≈80,000 installed, with ≈50,000 of these in Sweden. The other countries with any significant activity are Canada, Austria and Switzerland. New installations in the 'rest of the world' (ie ex USA) appear to be between 5000 and 8000 per annum (see Appendix).

Taking the following (conservative) values:

Number of CLGSHP installations	=	330,000
Average installation thermal capacity	=	10kWt
CLGSHP 'Efficiency' (see SPF below)	=	3
Air source heat pump 'Efficiency' (SPF)	=	2.4

then the currently installed CLGSHP units are displacing 2.2GWe of generating capacity that would be required for the equivalent load delivered as resistance heating. Alternatively, if the CLGSHP systems are deemed to have replaced air source heat pumps this figure reduces to 275MWe. Note that the currently installed worldwide geothermal electricity generating capacity is ≈6GWe (Fridleifsson & Freeston 1994).

However, this picture will change dramatically over the next 5-6 years if recent announcements concerning CLGSHP activity in the USA prove to be attainable Following increasing interest by the US energy and environmental authorities (Pratsch 1990, GRC 1992), the latest US development has been the formation of the Geothermal Heat Pump Consortium (IGSHPA, 1994a) The objectives of this body are to increase the rate of installations from 40,000 to 400,000 units/ yr by the year 2000. This is a formidable challenge considering that the long established air-source heat pump market in the US is currently ≈800,000 to 1 million units/yr. Additional targets are to reduce greenhouse gas emissions by 1.5M metric tons/yr of carbon equivalent, save over $300x10^9$ MJ/yr, and create a sustainable market for geothermal heat pumps that is not dependent on utility rebates or government incentives.

Applying the same conservative parameters adopted above, and assuming zero additional growth in the rest of the world, CLGSHP systems will be displacing 8 to 9GWe of electricity that would be required for the equivalent electric resistance heating, or the extra 1.1GWe that would be required to drive air-sourced units. As a combination of resistance heating and air-sourced heat pumps will be replaced, these figures represenf upper and lower bounds. The Consortium is aiming to displace 3 to 5GWe in the USA alone.

While this proposed growth may seem ambitious, the US DOE has already announced (GRC 1994a) proposals to fund US$35 million of a US$100 million, six year effort to 'promote wider acceptance of ground source heat pumps'.

WHAT ARE CLGSHP SYSTEMS? The unwieldy acronym, CLGSHP, very specifically delineates these systems. They consist of a fluid carrying, sealed loop, buried in the ground, either vertically or horizontally, which is connected to a heat pump, located inside the target building. The heat pump is capable of providing space heating and/or space cooling and/or water heating.

Nowhere in CLGSHP does the word 'geothermal' appear. However, because of the use of the ground as the heat source (or sink), these systems are commonly described and marketed as 'Geothermal' heat pump systems. The reality is that CLGSHP systems are very good examples of an energy technology that transgresses the commonly accepted energy discipline boundaries. The heat source is provided through a varying mix of solar storage and geothermal heat flow. Generally speaking, shallow, horizontal systems are primarily solar storage systems, while the deeper vertical systems are driven primarily by geothermal heat flow (Eskilson 1987). To further complicate the issue, heat pumps are usually classified under 'rational use of energy' or energy conservation. To some extent this explains why a considerable body of literature and activity related to CLGSHP systems lies outside of the mainstream ,geothermal domain (eg IEA 1991, Caneta Research 1993). Being on the periphery of mainstream solar thermal. renewable, direct use geothermal, and generalised heat pump technology results in CLGSHP systems "falling between. several stools" and may be why very little attention is being paid to them by utilities and energy administrators outside of North America and Sweden.

WHY CLGSHP SYSTEMS? This question needs to be split - why heat pumps, followed by why ground source heat pumps? The first is only dealt with very briefly here.

William Thompson (later Lord Kelvin) is attributed with the earliest mention of a 'heat multiplier' in 1852. This machine would 'permit a room to be heated to a higher temperature than the ambient temperature, by using less fuel in the machine than if such fuel was burned directly in a furnace' (Sumner 1976a). It was a sign of the times that the only interest shown by an energy rich Britain was in the possible cooling of public buildings and British residencies in India.

A very significant proportion of high grade primary fuel is currently 'burnt' at high flame temperatures (order 1000's°C) to either directly provide space heating (order 10's°C) or to generate electricity which is subsequently degraded back to low level space heating temperatures. In contrast, heat pumps make use of the fact that the world sits in a vast bath of low grade heat at temperatures between -20°C to +30°C. Using some primary 'input' energy, heat pumps are capable of upgrading this low grade heat at ambient temperature to useful space heating temperatures. In 'reversed' mode the units can provide cooling by extracting heat from a room, upgrading it, and rejecting it to the external environment. The ratio of the primary energy used, to the heat energy delivered in this process, is a measure of the efficiency of the machine, usually referred to as the Coefficient of Performance (COP).

Current worldwide interest in all forms of heat pump application is reflected in publications from the International Energy Agency's

(IEA) heat pump centre at Novem in the Netherlands. The member countries are Austria, Canada, Italy, Japan, The Netherlands, Noway, Sweden, Switzerland, and the USA. By the time of the 1995 World Geothermal Congress the centre will have published a ma'or three volume review of worldwide heat pump activity. As well as covering the member countries, reports on heat pump activity in Australia, Belgium, China, Denmark, France, Germany, Greece, Korea, New Zealand, Poland, Spain and the UK will be provided (IEA 1994a). CLGSHP systems are a sub-set of the overall heat pump market, and it is likely that all of the countries listed here that are not already major players, could potentially have interests in ground loop systems.

By far the largest number of heat pumps currently manufactured are air-sourced heat pumps. These either absorb or reject heat to the ambient air depending on whether they are in heating or cooling mode. The majority of heat pumps are electrically driven, but oil/diesel or gas fired primary movers are also used to drive the compressors.

The significant point about air-sourced heat pumps that are used for space heating or cooling is that for much of the time these engines are not able to operate at their design point, and hence at their optimal efficiency. This is because the source air temperature oscillates both daily and seasonally - while the required delivery temperature is fixed. In addition at times of peak demand for heating, the ambient temperature is at its lowest value, and conversely so for cooling. Under both of these conditions the COP of the heat pump declines significantly from its optimal design point value.

Due to its much larger thermal inertia the ground is able to provide a far more stable sourcelsink temperature than ambient air. Thus an appropriately designed ground source heat pump system is inherently capable of running for more of the heatinglcooling season at a source/sink temperature that is close to its optimal design point. This is the fundamental advantage of ground source heat pump systems. In any space heatinglcooling application where an air-sourced heat pump is considered to be viable, a ground source heat pump is capable of operating with a higher overall efficiency.

The considerations for installing a ground source heat pump therefore reduce to:

i) Does the added initial cost/complexity of providing the ground source outweigh the potentially lower running costs of such a system to the extent that it is deemed 'uneconomic' versus an alternative system?

ii) Is it physically possible to install a ground source system - ie is there adequate ground volume available?

COPs and SPFs: Some of the bad press associated with heat pumps generally is that their 'energy multiplication' ability or COP has not lived up to expectations. Car manufacturers' claims of high fuel efficiencies at 'a steady 56 mph' are rarely sustained in practical driving situations. A similar issue arises for heat pumps in that COPs are often quoted for ideal operating conditions. In order to provide a measure of their average efficiency over an entire heating or cooling season, the Seasonal Performance Factor (SPF) is used. CLGSHP systems, which are at a relatively early stage in their technological development, are already capable of delivering SPFs of over 4.

Total fuel efficiency: The importance of these new, high SPFs, together with recent improvements in the efficiency of bulk electrical generation in terms of the total amount of primary fuel needed to provide space heating andlor cooling should not be overlooked. For many years it has been commonly accepted that electricity can only be supplied to the end user with an overall efficiency of $\approx$33%. In an era where heat pumps were able to deliver SPFs of 3 or less, electrically driven heat pumps could only approach an overall efficiency in delivering heat of <100% (ie 0.33xSPF).

However, new oil or gas fired combined cycle andlor co-generation plant can achieve electrical generation efficiencies approaching 50% or more. With SPFs of 4 to 4.4 for CLGSHP units, total efficiencies of 220% (4.4x50%) are possible - ie a net energy 'gain' of 120% over the original thermal content of the primary fuel. (The extra energy being 'reclaimed' from the bath of low grade heat available from the ground).

In a few countries with integrated energy planning it is being recognised that, for example, it makes more energy sense to burn gas in high efficiency combined cycle generation plant, distribute the electricity over existing grids, and deliver heat via heat pumps, than to build highly expensive gas distribution networks, simply to burn gas in 80%-90% efficient gas condensing boilers (Steadman and Bouma 1994).

APPLICATIONS OF CLGSHP SYSTEMS. From the description provided so far it could be assumed that CLGSHP systems are only suitable for the average North American domestic house. While this is by far the largest application to date, these systems have been successfully installed in a wide range of space heatinglcooling situations.

The water sourced heat pump units are capable of transferring heat to or from either an internal air or water circuit. In the USA many domestic properties already have in-situ air ducting which allows CLGSHP units to be retrofitted to provide air heating andlor cooling. In addition, de-superheater units on the heat pumps provide some or all of the domestic hot water. For larger commercial buildings the heatingland or cooling can either be provided through air ducting, or by a warm water circuit connected to fan units distributed throughout the building. Typically these distributed units are automatically reversible, allowing different parts of the building to be heated or cooled as the internal building load varies throughout the day and season. The ground loop then only has to absorb or reject the net heat load.

The CLGSHP systems installed in Europe predominantly supply underfloor water heating circuits - commonly referred to as hydronic heating, or radiant floor systems. These are common in Scandinavian houses, and are now becoming a preferred method of heating in some new American and European houses. Architects are showing a strong preference for them because of the perceived comfort level, and the absence of inconveniently located radiators or air duct outlets.

In parts of the world a large potential market could lie in retrofitting central wet radiator systems It is commonly held that heat pumps are not capable of delivering adequate heat transfer rates frcm the radiators to the air Sumner (1976b) discussed this many years ago for the UK situation pointing out that heat pumps could supply adequate heat for most if not all of the heating season Supplementary resistance heaters, as offered on many CLGS heat pumps can supply a boost if required It appears that retrofits for wet systems are being successfully used in Sweden today (Micklesson 1994) A convincing demonstration that these systems can deliver acceptable and responsive comfort levels would extend the potential European market considerably

The low delivery temperatures from single stage heat pumps could be overcome by using two stage heat pumps. Although they would be more expensive, they are more efficient than single stage units because each stage works with a lower temperature drop. Even with single stage heat pumps, most manufacturers offer supplementary resistance heating modules that provide top-up heating in extreme weather conditions. This facility is used by designers to size the ground loops for the mean lowest outside temperatures, using the additional resistance heating for exceptionally cold weather only.

Ground sourced heat pumps are capable of delivering space heating and cooling in a variety of ways. For individual descriptions of the wide range of applications that CLGSHP systems have been used in, the reader is referred to the IGSHPA newsletter, The Source (IGSHPA 1988-1994). All sizes of housing, from low cost units to luxury homes, apartment blocks, petrol (gas) stations, supermarkets and shops, churches, educational institutions, restaurants, telephone exchanges, state buildings, and sports centres have all been successfully fitted with these systems. Very high levels of customer satisfaction are reported in surveys conducted by the utilities involved (eg IGSHPA 1993).

A recently announced (IEA 1994b) large scale installation will suffice to demonstrate the confidence that is being placed in these systems to deliver both technically and financially (albeit in the American situation). 4000 domestic units are being installed, at a rate of 20-25 units per day, on a single Air Force base in Louisiana. The heat pump manufacturer is claiming SPFs of 4.5. Financial savings are expected to exceed US$100 million over 20 years, with substantial reductions in energy consumption and hence pollutants compared to the existing units. The finance package for this project results in the installer standing to gain 78% of the financial savings made through the reduction in energy and maintenance costs.

WHY ARE CLGSHP SYSTEMS BEING INSTALLED? With the dominant activity taking place in North America, the primary reason for the current interest in CLGSHP technology there is driven by the electric utilities. Many of the smaller utilities that are collectively known as the Rural Electric Cooperatives, together with utility giants like Tennessee Valley authority in the USA, and Ontario Hydro in Canada - have all provided promotions and incentives for the installation of these systems.

As there has been to date no external source of funding, it can be inferred that these utilities have strong internal commercial reasons for why they wish to induce customers to convert to these systems. Elements of the legal and commercial frameworks that these utilities currently operate under that influence these policies are:

Demand side management (DSM): This currently fashionable phrase refers to the analysis by power providers of how to manage their customers' power demands such that the utility optimises the utilisation of generation and distribution facilities, CLGSHP systems offer the utilities two very important features in this respect. Compared to electric resistance heating, and air sourced heat pumps, CLGSHP systems offer a significant reduction in peak power demand. Thus if CLGSHP systems can be substituted for resistance heaters and air source heat pumps, more consumers can be supplied with existing equipment, and/or the requirement for new generation capacity can be avoided. This improvement to the utility can often be non-linear in nature because as power demand increases utilities have to switch in progressively less profitable power supplies.

Concomitant with CLGSHP systems requiring less primary electricity to deliver equivalent levels of heating or cooling, the utilities' overall load factors can also be considerably improved if these systems make substantial inroads - resulting in overall improved utilisation of installed equipment. Further discussions of the important role that heat pumps generally, and therefore CLGSHP systems in particular, can play in DSM, have recently been reviewed by the IEA (IEA 1994c)

Total cost analysis for replacement power: When applying to build new generation/distribution facilities many North American utilities are now required to provide detailed cost analyses of their proposals together with the alternatives of providing conservation and or rational use measure - so called 'lowest total cost' analyses. In many situations the provision of CLGSHPs can be demonstrated to be a lower cost option for providing 'new' megawatts of electricity compared to constructing new generation, transmission or distribution plant. Pratsch (1994) suggests that with an installation rebate of 250$ per 3.3kWt, each saved kWeh of capacity costs the utility 1.2 US cents vs 3 to 6 cents/kWeh for a gas fired power plant costing $800/kWe installed.

Market penetration: In markets where electricity is trying to compete with other heating fuels, such as, oil, gas or wood, electric resistance heating is often not sufficiently competitive to gain new market share for the electric utility. With CLGSHP systems capable of providing space heating and/or cooling andlor hot water, with a significant reduction in electricity consumption, this technology is allowing utilities to penetrate and retain markets that had been falling to competing fuel sources.

The 'driving forces' behind CLGSHP systems described above have nearly all arisen in an aggressively market driven economy which has, however, advanced considerably beyond the concept of 'more kWs sold equates to more profit made'. The benefits of DSM, 'least total cost analysis', and increased market penetration, however, have not taken great hold outside of North America yet.

The relatively small number of non-North American countries that have any CLGSHP activity have in some cases specialised, local reasons for advocating it. Sweden subsidised CLGSHP systems in the early 1980s because of its growing difficulty in providing any additional, environmentally acceptable generating capacity, given the moratorium on nuclear, and opposition to further hydropower development. Noway, which until recently had very low cost hydropower available, has realised that rising power demand will not match installed capacity, and is now promoting an interest in heat pumps. Holland has a strong commitment to CO_2 reduction and is advocating a large scale heat pump programme which may translate to an interest in CLGSHP units.

Pollution **reduction/energy** conservation: In those areas where electric utilities are under increasing pressure to take action to reduce overall pollution levels per kWt delivered, CLGSHP systems offer very significant advantages. Compared to resistance heating, CLGSHP units can deliver the same space heating for one third of the total kWe. Compared to existing air-sourced heat pumps they offer a 25% reduction in electricity consumption. These reductions translate to directly proportional reductions in the pollution production per kWe being produced by the particular generation mix operated by the utility. Because of the reduction in peak power requirement, there can also be a beneficial non-linear reduction in pollution, because older, more polluting generation equipment may not have to be brought on line.

For utilities that are under pressure to adopt energy conservation measures, CLGSHP systems deserve consideration. Recent analysis in the UK has shown that the potential capital cost per unit of electricity saved can be comparable with other popular forms of energy conservation. This is because, despite a high capital cost, the lifetime of these systems combined with the large energy reductions compared to electric resistance heating and air sourced cooling, result in cost effective energy conservation.

CLGSHP SYSTEMS AND COMPONENTS. Other sources of relatively constant source/sink temperature for heat pumps exist - eg rivers, lakes, ponds, together with water wells and geothermal aquifers. All of these sources however, are geographically limited. CLGSHP systems, by contrast, can be usefully installed in most geographic and geological settings in most climatic conditions. In using sealed loops there is minimal likelihood of any subsurface environmental interference. There are no issues of abstraction or reinjection of fluids, and no long term interference with water tables or aquifers

Although on a world scale CLGSHP technology is relatively unknown, there is now overwhelming evidence that these systems are technically proven. They can be routinely delivered for systems ranging in size from single family low-cost housing (a few kWt) through to large commercial/institutional building complexes with space heatinglcooling loads of order MWt.

One of the reasons for the rapid expansion in CLGSHP systems is that while the concept has been known about, and experimented with for many years (eg Sumner 1976b), it is only within the last decade that technologically compatible components have become widely available at the right price to allow reliable, energy efficient, easily reproducible, and economic 'systems' to be built and sold.

CLGSHP systems currently being installed fall into two categories - those in which the ground loop circulates water (or water/antifreeze mixture), and those in which the refrigerant is directly circulated through a ground loop (so called 'DX' systems).

a) Water loop systems:

The main components of water loop systems are the ground loop(s), ground loop circulating pump(s), a suitable circulating fluid and a water sourced heat pump.

Ground loops - The successful operation of the ground loops has required attention to the following:

- The areal/volumetric/geometric distribution of sufficient length of ground loop that is able to sustain acceptable ground source temperatures for the heat pump.
- The development of grout and grouting techniques for pipe in vertical boreholes, and backfill methods for horizontal trenches, that ensures good long term thermal contact while preventing ground water movement.
- The availability of pipe and pipe jointing methods that can provide reliable, leak resistant loops that can be installed without requiring any attention for long periods (several decades).

All of these issues have been successfully addressed and ground loops are now routinely installed in shallow trenches (1-2m deep) and/or uncased boreholes ($\approx$50-100m deep, $\approx$100-150mm dia). The loops are generally made of polybutylene or polyethylene pipe ($\approx$20-30mm dia) which is thermally 'welded' on site. Some ground loop installers are sufficiently confident to provide 50 year warranties for these loops.

The circulating pumps are enerally off the shelf, long life units similar to those develope! for the domestic central heating market. The circulating fluid is either water or a water/antifreeze mixture. Considerable work has been done on identifying suitable antifreeze additives that maintain good heat transfer properties while offering low viscosities and are environmentally acceptable. Glycol additives are common, but a more recent offering is a potassium acetate based additive, originally developed for airport runway de-icing.

b) Refrigerant loop systems

In these systems the plastic pipe is replaced by a copper ground loop which circulates the pressurised refrigerant directly to and from the compressor via a throttle valve. The combination of the copper to ensure excellent thermal contact with the ground together with the elimination of the water/refrigerant heat exchanger ensures that these systems have high SPFs. Because of the high ground to coil heat transfer rate, the copper ground loops can be smaller than water loops, saving on trenching or drilling costs. While they only constitute a small fraction of the systems installed in North America, they are, for example, the main CLGSHP system now installed in Austria. The difference is explained by equipment availability. differing regulatory views regarding the possible loss of refrigerant from the ground loop and lack of awareness of the technology.

NEW AND FUTURE DEVELOPMENTS OF CLGSHP. Although CLGSHP systems are now a fully established, non-experimental technology, there are a number of possible enhancements.

Ground loops: While fully acceptable horizontal and vertical ground configurations exist, it would appear that improvements are possible. Both the Slinky and 'spiral geometries, developed over the last 5 years increase the in-ground pipe density for horizontal systems, while reducing costly trenching requirements. Alternative geometric layouts of horizontal systems are being developed to reduce pipe and trench length requirements. In Sweden it has been demonstrated that optimal performance for the Scandinavian climate is obtained with horizontal systems only I m deep. This maximises the solar recharge for systems, which almost exclusively provide heating only. Further optimisations of horizontal ground loop geometry may be possible for differing combinations of geographical location and heat loading.

A very recent development is the GeoBag (IGSHPA 1994b), literally a sealed plastic bag of water placed in the ground horizontally or vertically, connected by a plastic pipe at each end to the water sourced heat pump. The geometry ensures enhanced surface area contact with the ground, provides a thermal buffer, and reduces circulating pump requirements.

Another development is the Standing Column Well (Sullivan 1994, Orio 1994). This is referred to as a semi-open loop system in which water circulating in a well is used as the ground heat exchanger. The heat pump is connected to the top and bottom of the well, with the intervening water column transferring heat to or from the ground as required. Due to the improved heat transfer efficiency compared to the completely closed loop systems, total bore lengths can be reduced.

The largest cost component in the ground loop installation is the trenching or drilling element. Cost reductions in drilling, by developing custom built single purpose, fixed diameter, limited depth, highly portable rigs could have significant effects on total installation costs. Vertical holes for CLGS loops ideally need to be drilled using seismic shot hole economics, rather than water well drilling economics. Sanner & Knoblich (in IEA 1991) provide a review of conventional and novel methods for installing vertical ground loops. High utilisation rates for the drilling or trenching equipment and associated labour force is an important element in minimising costs.

Heat pumps: Currently the market for water source heat pumps is a raction of the air-source heat pump market. As a result water source units have not benefitted fully from the economies of scale established for air-source units. In addition, water source units are yet to benefit from some of the technological improvements that have already been made to air-sourced units. The majority of installed CLGSHP systems are single speed units, Dual speed compressor units are now routinely installed, but fully variable speed units have yet to be announced. Both of these developments will improve the already high efficiencies of the ground coupled water sourced units.

A number of generic developments in heat pump technology which are currently being driven by the much larger refrigeration and air-sourced air-conditioning market will also benefit water source units if they are implemented. For example, new mixed refrigerant and Stirling cycle developments and the application of screw expander technology in the larger units promise considerable improvements ($\approx$30%) in overall thermodynamic efficiencies. There may be a temporary interruption in COP improvements while alternative refrigerants are developed. The Japanese have demonstrated an air-sourced heat pump with an SPF of 5.5 which they expect to introduce to the market (Steadman & Bouma 1994).

The increasing availability of gas driven heat pumps may result in the water source variants being available which will widen the potential client base for CLGSHP systems and bring the gas utilities into the arena. New air sourced gas fired units are achieving efficiencies of 130%, absorption units of 160%.

The development of ground source direct expansion (DX) heat pump systems also continues, and as environmentally acceptable refrigerants become available more countries may accept these compact, highly efficient systems as the optimal CLGSHP systems.

Systems engineering *of* CLGSHP systems: As with all engineered systems there are compromises to be made and optimal solutions sought. Complete CLGSHP systems require tradeoffs in capital costs versus running costs, minimisation of pumping costs vs ground loop lengths and pipe diameters and attention to a variety of other sizing issues. Optimisation of fully integrated systems will bring further price/performance benefits from these installations.

The heat pump manufacturers are already producing units that offer features such as dual fuel sourcing, ie ground source water plus oil fired, ground sourced plus air sourced, and separate water heating only heat pump circuits. These features allow for minimisation of ground loop sizes to reduce initial costs and increased flexibility of operation.

Costs: Discussion of costs related to direct use geothermal applications, in common with any discussions of energy costs on a worldwide scale is notoriously difficult. Typically the running costs of any electrically driven CLGSHP systems are $-$60% less in heating mode compared to electric resistance heating, and $\approx$25% less than for an electrically driven air-source heat pump. In cooling mode the systems typically cost 20-25% less to run than air sourced heat pumps. In the USA, capital costs for domestic CLGSHP systems can be 50% to 100% more expensive than equivalent capacity air sourced heat pump installations and considerably more expensive than electric resistance installations. The objective is usually to achieve anywhere from $\approx$4 to $\approx$8 year pay-backs for the home owner. Consideration has to be given as to whether the CLGSHP unit is replacing just an air-source unit, or an air-conditioner and a furnace. For large commercial installations that provide heating and cooling, it is claimed that CLGSHP systems can have similar initial costs to air sourced installations This arises because there is no requirement for large external fan units or any associated building superstructure In addition savings can be made through the reduced plant room sizes required for CLGS units A detailed cost analysis for several regions of the USA which compared various alternatives for space conditioning systems has reported very favourably on CLGSHP systems (L'Ecuyer et al 1993)

A further complication with any analysis of the costs or savings associated with these systems arises from the internal benefits they bring to the generation and/or distribution utilities. From the evidence of North America the utilities in those countries are obviously prepared to make the systems sufficiently attractive to consumers in order to reduce overall operating costs to the utility. Not surprisingly this information is not generally available in the public domain.

Environmental issues: The main environmental benefit of CLGSHP systems lies in their ability to reduce the primary energy consumption required for space heatinglcooling and water heating. Heat pumps with fossil fuelled prime movers (ie gas or oil fired compressors), and gas absorption heat pumps with SPFs greater than unity are inherently capable of delivering more space heating than can be produced by direct combustion of these fuels. Electrically driven heat pumps, combined with modern fossil fired power stations can also achieve overall efficiencies greater than unity. Both types of heat pumps can therefore reduce the quantities of CO_2 and other pollutants produced in the combustion of fossil fuels. Electrically driven heat pumps, supplied with renewable, nuclear or geothermally generated electricity are able to provide space heatinglcooling and hot water with minimal, or zero levels of CO_2 production, and with far less energy consumption than is required by similarly sourced electric resistance units. For all of these cases CLGSHP units are more efficient than air-sourced heat pumps. In a summary on the impact of heat pumps on global warming and ozone depletion Laue (1994) reports that electric heat pumps with an SPF of between 2.5 and 4 will reduce CO_2 emissions compared to oil fired systems, and because of the various generation mixes will reduce CO_2 emissions in 10 out of 12 EEC member states when replacing gas fired boilers. Higher reductions of CO_2 could of course be achieved with gas or oil fired compression and absorption heat pumps. Laue also points out that electric heat pumps ,offer reductions in SO_2, NOx, CO, CxHy and dust pollutants mainly due to the centralised removal of these atmospheric pollutants at power station compared to the decentralised emissions from millions of individual heating systems.

The main environmental disadvantage of heat pumps is their use of refrigerants. According to Laue (1994) the majority of heat pumps currently use CFC-12, H-CFC-22 and R-502. Practically all new CLGSHPs use H-CFCs or even propane (in Austria). Unlike refrigerators though, heat pumps used for heating or cooling make a net reduction in emissions of greenhouse gases. This is because their overall effect on global warming is dominated by their reduction in CO_2 emissions (an indirect effect) compared to the direct effect of working fluid losses. Using the TEWI (Total Equivalent Warming Impact) indicator Laue (1994) shows that refrigerant losses from electric air sourced heat pumps vary between 0 and 12% of the total CO_2 equivalent emissions from oil fired boilers. Because of their increased SPFs, CLGSHP systems need less refrigerant than air sourced systems and show further reductions in TEWI factors.

Other environmental attractions of CLGSHP systems are;

i) unlike air-sourced units there is no requirement for an external fan unit, and hence there is no associated visual or noise intrusion. There are none of the public health issues associated with large air cooled units, and

ii) there is no interference with sub-surface water supplies and none of the water abstraction or reinjection issues associated with open loop systems.

Infrastructure: In common with other conservation and rational use measures that are installed at the end user location, an infrastructure for CLGSHP systems has to be established to support the wide geographical distribution of customers. This is recognised in North America and an impressive array of supporting measures have been established. In particular the International Ground Source Heat Pump Association (IGSHPA) at Oklahoma State University has made major contributions to this activity. Training courses are run both for individual installers and for new trainers. A comprehensive set of educational and promotional material, practical manuals and design software relating to CLGSHP systems has been assembled. An impressive effort has also gone into establishing a set of national design and installation, standards (albeit for the USA). The association currently lists over 800 members. Almost uniquely amongst energy technologies, the centre has also used nationwide teleconferencing via satellite television and phone-in services to promote CLGSHP technology to a series of different target groups, eg domestic users, architect/engineers, schools, and defence establishments.

The electric utilities have been the other main source of infrastructural support in the USA and Canada. Typically they provide marketing and promotional support. In some cases they also provide the high capital cost installation equipment, ie drilling rigs or trenching equipment which individual heat pump installers can call on. This ensures maximum utilisation of the equipment throughout a utility's distribution region and helps to reduce the unit installation cost.

CLGSHP SYSTEMS IN DEVELOPING AND NON-GEOTHERMAL COUNTRIES. This review indicates that CLGSHP systems are currently only being installed in countries with high GNP/head and high comfort levels. This does not have to be the case, the elements of the technology are all easily 'transferable'. In many developing countries significant fractions of newly installed generating capacity are often consumed by air-conditioning plant in commercial centres, hotels, government offices and the like. CLGSHP technology is if anything less complex than the air-conditioning technology, already being installed. Lower labour costs could yield lower loop installation costs than in highly developed countries, and the relative cost of providing the additional 'ground source' kilowatts may be considerably lower than providing the additional generating capacity. As a proportion of the ground loop costs would arise in local currency, the combined effect could be to conserve foreign currency while still providing the same air-conditioning capacity and/or releasing generation capacity for non-space cooling use. There are a number of mid-continental countries on all five continents with climates that swing between hot summers and cold winters. They are ideally suited to CLGSHP proliferation that could beneficially replace current combinations of inefficient oil furnaces and air conditioning units.

Of interest to the traditional geothermal community is that these systems do not require the availability of the generally accepted geothermal resource, ie accessible hot fluids at depth. Thus the ranks of the geothermal community may expand to accommodate countries that have no conventional geothermal resources, but who may develop indigenous CLGSHP activity.

CONCLUSION. CLGSHP systems are an established technology in the alternative energy market. They can provide steady and reliable heating and or cooling kilowatts at a lower cost than providing new generating capacity. In general they are considerably more energy efficient in overall terms than electric resistance heating, air sourced heat pumps for heating and/or cooling and are on a par with, or better than, fossil fuelled heating systems. In common with most renewable energy, rational use, and energy conservation schemes, they have a higher capital cost than the systems they displace, while often offering equal or reduced lifetime costs.

It is believed that the following factors will drive the proliferation of CLGSHP. to varying degrees, in differing markets:

- Internal financial benefits accruing to electricity utilities, by inducing existing or new customers to switch to these systems These will arise from increased generation/ distribution efficiency, reductions in peak load capacity, improved load factors, and increased market penetration against fossil fuel heating

- Legislative and taxation measures progressively introduced by governments to improve energy efficiency, increase energy conservation, and reduce CO_2 and other fossil fuel derived pollutants.

- Imaginative financing arrangements that will reduce the capital cost barrier to potential customers, while allowing them to benefit from the reduced total life cycle cost of a CLGSHP system (Geyer 1994).

- Increased awareness (or even some awareness!) at all levels of the nature, availability, reliability, and repeatability of CLGSHP systems.

Mainly by accident rather than design these systems have been (sometimes imprecisely) labelled as Geothermal systems. With or without the geothermal community they are likely to continue to be installed in increasing numbers. As they have no geographical limitation, the international geothermal community should consider how it can assist in the development and proliferation of these 'earth based' direct use applications. Current practitioners and advocates of geothermal direct use systems are ideally placed to promote and develop this technology in their own countries. The geothermal industry is fully capable of providing the elements of geology, drilling, and thermal design needed to deliver these systems in appropriate local contexts. It has even been suggested that because CLGSHP systems promote load levelling, they will lead to increased demand for base load generation, for which conventional geothermal power generation is ideally suited.

These systems will help to publicise the largely unsung benefits of geothermal energy as a reliable, predictable, and weather independent energy source. Will the title of a recent paper (Pratsch 1994) be realised - Geothermal : A Household Word? It will be interesting to peruse the proceedings of the World Geothermal Congress in 2000 for reference to CLGSHP systems.

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APPENDIX - Country summaries

This brief review of worldwide CLGSHP activity has been compiled from a mixture of published material and personal communications. In some cases the distinction between open and closed loop systems has been difficult to distinguish, and the numbers presented may be erroneous as a result. Readers are asked to notify the author of any omissions or corrections to enable future reviews to better reflect true worldwide CLGSHP activity.

USA - A discussion of the status of CLGSHP systems in the USA could easily provide a stand-alone paper in its own right. Current estimates of CLGS systems in place (GRC 1994b) are 300,000 units. It is estimated that between 25,000 and 40,000 CLGSHP units are being installed annually with a 25% annual growth in this figure. With annual sales of approximately 1 million air sourced heat pump units, a target of 400,000 GLGSHP systems installed per annum in the year 2000 has recently been proposed.

Development of CLGSHP technology and application in the USA currently exceeds any activity going on elsewhere. The bulk of the systems installed are water to air units, because of the predominance of air-ducted heating/cooling facilities in existing houses. However, underfloor hydronic systems are now becoming popular. In the new-build market, of the 1 million single-family units built in 1993, a quarter had heat pumps installed. Many of these could potentially be CLGSHP units.

Canada - In recent years CLGSHP systems have been promoted and subsidised by Ontario Hydro, with the result that between 7000 and 8000 domestic units were installed. The subsidy has now been removed, although it is believed that Ontario Hydro are reviewing the situation. In addition there are between 30 and 50 non-domestic installations using CLGSHPs. With a large air-sourced heat pump base, Canada has a number of heat pump manufacturers who are able to supply water sourced units.

Sweden - In the period 1975-1985, with subsidies available for heat pump installation, Sweden was the most active country worldwide in GLGSHP systems. As well as developing the heat pumps, Sweden played a significant role in theoretical analysis of the thermal behaviour of ground loop systems (see eg Eskilson 1987). With the removal of the subsidy the market for these systems almost collapsed. However, it is now reported that, even without subsidies the market has grown to ≈1000/yr. With its small population, however, this makes Sweden as active as the US on a per head basis. Approximately 50,000 CLGSHP systems are believed to be in place to date out of a total of ≈230,000 installed heat pump based space heating systems (Granryd 1994, Mogensen 1994, Miklesson 1994, IEA 1993).

Switzerland - In the last 10 years Switzerland has been involved in the development of vertical borehole CLGSHP systems. Many of these are co-axial systems, in boreholes ≈100-130m deep. With regional and canton based incentives to install these systems, particularly as replacements for oil fired furnaces and un-bunded oil tanks the number of systems has risen to ≈6000 units. The majority of the systems provide hydronic underfloor space heating. Not to be outdone by Sweden or the USA, the Swiss lay claim to the highest 'areal density of CLGSHP systems in the world'! (Rybach and Gorhan 1995) .

Austria - Austria has long had an active space heating market for heat pumps. In the early 1980s about 10% of these systems were CLGSHP units, and this has now grown to ≈66% of new heat pump systems. The early systems had water circulating ground loops, but the majority of the ≈700 unit/yr sold today are direct expansion systems using R22 refrigerant. The heat pump units and direct expansion ground loops are completely factory assembled and are delivered to site as fully operational systems. Because of concerns with HCFG-22, propane is now being used as a refrigerant. However, because of its flammability the heat pumps are situated outside. The SPFs of the new units being delivered is in the range 4 to 4.4. Both horizontal and vertical ground loop configurations are used in Austria, with the majority of systems providing space heating. Strict licensing controls covering both heat extraction and environmental issues are in place (Ritter 1994, Halozan 1994).

Denmark - Literature describing a water to water CLGSHP unit suggests that Denmark has its own manufacturing capability for these systems. No information has been uncovered on the number of units installed or the current market size in Denmark.

Germany - There is growing interest in ground loop systems in Germany, with a national conference to be held at Giessen in October 1994. Sanner estimates that there may be a 'few' thousand ground loop systems, with several hundred of them being vertical (Sanner 1994).

Japan - Despite its extensive geothermal direct use activity and an annual market of 4 million residential air source heat pumps, Japan currently exhibits very little CLGSHP activity. Eleven coaxial vertical units based on Swiss designs are currently operating - 10 are domestic units and the other is used for a health centre. It is anticipated that an early application of these systems will be for road de-icing rather than for space heating/cooling (Morita 1994).

France - Little information has been found on the limited activity that is believed to be underway in France. Indigenous heat pump manufacturers provide suitable water source heat pumps, and all activity is currently in the residential market (Jaudin 1994).

UK - The earliest evidence of CLGSHP systems in England is provided by Sumner (1976a). In 1948 he was commissioned by the philanthropist Lord Nuffield to install prototype 3kWe heat pump units sourced with ground source coils in 12 domestic houses. Even in those days an SPF of 3 was reported. Sumner (1976b) later installed a unit in his own, house, and there is some evidence of possibly up to a dozen horizontal loop systems using Swedish water source heat pumps having been installed in the 1960s or 1970's in southern England. Current UK interest in these systems is minimal, with one installation recently completed, and a few more being designed.

Eastern Europe - Several of these countries have had a long history of geothermal direct use activity, with geothermal district heating systems, glasshouse heating, and many geothermal spas in operation. It is now reported that several of them are showing interest in CLGSHP systems. An installer is operational in Poland, and other countries are sending staff for training to American CLGSHP suppliers.

Norway - Until recently there was very little interest in these systems, primarily due to the low cost of Norwegian hydroelectricity and widely available indigenous oil. However, electrical demand is now closing rising faster than supply and the Norwegians,, active members of the IEA Heat pump, centre are now beginning to install these systems, primarily in domestic underfloor heating applications.

Russia - No quantitative information has been obtained for CLGSHP activity in Russia. However, (IEA 1993) a 10.3 kWt reversible domestic ground source heat pump unit is being manufactured that also incorporates a refrigerator. The unit is targeted at rural communities.

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