

TITLE: BIO-RENEWABLE THERMAL ENERGY HEATING AND COOLING SYSTEM AND METHOD

5 CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority under 35 U.S.C. § 119 of a provisional application Serial No. 60/804,148 filed June 6, 2006, which application is hereby incorporated by reference in its entirety.

10 BACKGROUND OF THE INVENTION

U.S. Patent 7,040,108 ('108) described a method of recovering thermal energy from various environments and utilizing it in a process or storing it for later use. The basic configuration in the '108 patent utilized a single evaporator and water cooled condenser with a compressor, expansion device, receiver, circulating pump and hot storage tank. This patent emphasized the heating capability of the refrigeration process and extended the use of refrigeration technology towards the maximum utilization of the refrigeration cycle for its heating affects within a given application. The refrigeration cycle was defined as a process involving a compressor, heat exchanger (condenser), expansion device, and evaporator. Thermal energy was to be collected in the evaporator from air or from liquids or slurries and was generally to be placed into a liquid stream or storage device where it could also be used to heat a space or process. The '108 system operated in a single mode, that is, reclamation.

SUMMARY OF THE INVENTION

25 The present invention extends the teaching of U.S. Patent 7,040,108 to include a formula or methodology for application of the refrigeration process to further enhance or optimize the utilization and control of refrigeration for the transformation of thermal energy available in one environment/media to another environment/media. This is not the simple transfer of thermal energy from location to location but the efficient transformation of thermal energy from one condition to one or more conditions desirable for a given application. This is accomplished through the balancing of the environmental variables with the properties of the refrigerant and the capabilities of the compressor.

For example, in a meat processing facility, chillers are used to maintain workplace temperatures that are suitable for safe processing of the meat and boilers are used to heat kill process water and wash water. The system of the present invention will provide the chilling while also providing a fixed temperature of liquid refrigerant to the expansion
5 device and generating heated water for the kill process and the wash down. The fixed liquid refrigerant temperature helps to optimize the performance of the compressor where most chiller condensers are currently exposed to the variability of the ambient air temperature which will cause compressor performance to vary off of the optimal condition.

The combination of compressor configuration, refrigerant, condenser configuration,
10 expansion device/configuration, and evaporator configuration are driven by the requirements of the application and the nature of the refrigerant selected. One goal of the system configuration is to achieve the most desirable balance of refrigerant and lubricant conditions at the compressor while optimally utilizing thermal energy sources and thermal energy sinks available in the application.

15 With this teaching and methodology the use of refrigeration for heating and cooling is extended to new horizons whereby with new refrigerants and refrigeration system configurations we will have capability to displace a significant portion of the world's combustion based furnace or boiler capacity, while providing refrigeration or cooling to the same application. This technology may also lead to the co-location of complimentary
20 energy-intensive applications to help reduce or eliminate dependence on external fuel sources.

One aspect of the present invention is the utilization of multiple evaporators and multiple condensers tied to a single compressor so as to increase the utilization of waste heat.

25 In another aspect of the present invention, refrigerant heat is split for multiple uses. For example, the heat can be used for generating water, liquid or steam that is hotter than the condensing temperature of the refrigerant. Producing steam represents use of the hot path to produce a phase change on the environment side of the refrigeration process.

In another aspect of the present invention, a circulating loop with a water tank,
30 pump and a condenser/heat exchanger provides control to the head pressure, so as to provide control and storage of higher temperature fluid, and to control the subcooling

temperature for the improvement of the evaporator heat collection capacity, and to uniquely improve compressor efficiency. While subcooling has been used in the prior art, such use is provided by robbing a portion of the system refrigerant to cool the remaining liquid refrigerant prior to introduction into the expansion device to help improve heat collection capacity in the evaporator. In comparison, the present invention uses water or a process stream to do this subcooling, rather than the refrigerant. This improves performance by collecting additional useful heat in the process stream through the subcooling of the refrigerant, as well as boosting the heat collection efficiency of the evaporator. A circulating loop provides the basis for control of subcooling conditions to maintain higher compressor efficiency.

Another aspect of the present invention relates to desuperheating, which is known in the prior art, but only for the purpose of extracting the heat available from the superheat in the high temperature refrigerant vapor to heat water, while the remainder of the heat is rejected. The present invention utilizes the full heat path towards heating a liquid prior to allowing rejection or switching to a heating application from a secondary priority, which is unique, and specifically not in conjunction with a circulating and storage loop used for process control. This invention utilizes the full heat path as a priority and utilizes the desuperheating segment to produce and/or store water or fluid at temperatures above the condensing temperature of the refrigerant before allowing rejection or lower priority use. Splitting the refrigerant hot side for various uses or controls significantly advances energy utilization beyond the prior art, which focused on rejection of the refrigeration heat.

A further aspect of the present invention is the splitting of the cold side of the refrigeration process, in conjunction with splitting of the hot side. Evaporators in series or in parallel provide certain challenges, such as control of pressure in the suction line when two parallel evaporators operate at different temperatures and pressures. Evaporators in series are a challenge to supply cooling at temperatures that are suitable for both environments, since the outlet temperature drives the control of the temperature of the refrigerant in all evaporators.

With the system of the present invention operating in the reclamation and cogeneration mode, a significant thermal emission reduction is provided, since the thermal energy that previously was going to be wasted is now recycled back into the bio-renewable

process. The formula that has been developed for controlling the environmental balance is premised upon the first and second laws of thermodynamics, so as to balance the energy of the system of the present invention from both the refrigerant and environmental perspectives, thereby achieving results and control of process beyond traditional refrigeration processes.

The system has the ability to heat potable water, cool interior space areas, use the hot water for heating interior space areas, recycle thermal energy by cooling one area while heating a second area, and save significant amounts of energy while completing these tasks.

A three-way reclaim valve is used to switch between the water-cooled condenser and the external condenser. This valve along with a check valve draws the refrigerant out of the external condenser and back into the system and keep the refrigerant from pooling in the external condenser. This allowed the system to provide heating, cooling and water heating.

The ability to control the condensing temperature at the temperature of the water tank via the circulation system is a unique characteristic. The use of water for control, while also using the heat for useful heating, is unique. The temperature of the water in the tank sets the head pressure of the compressor (i.e. corresponding to the condensing temperature of the refrigerant).

The limitation of the single condenser, is overcome with a system that used two condensers in series each with its own tank and circulating system. This allows the first condenser to absorb all of the energy it could before the second heat exchanger begins to absorb energy. As the first heat exchanger system reaches the maximum condensing temperature, the majority of the heat is being captured by the second heat exchanger. As the system continues to operate, the water in the first circulation loop becomes hotter than the condensing temperature and the refrigerant entering the second heat exchanger is now accepting some superheated vapor refrigerant. The temperature of the first loop is above the condensing temperature of the refrigerant. This allows the system to heat water to over 200F in a batch mode operation.

For continuous mode operation, cold water is introduced at the inlet of the circulating pump of the second circulating loop to allow the system to operate at a condensing temperature attributable to the mixture temperature of the hot water in the tank

and the cold water entering the system. This allows the system to operate at lower head pressures while generating higher temperatures. A reciprocating compressor operating on R22 can operate in continuous flow mode at temperatures as high as 130F without exceeding acceptable head pressures. This would be the result whether the system had one
5 or two condensers. Applicants call the phenomenon tempering.

The same flow strategy is also applied to the hot water entering the first circulating loop. If the hot water is introduced at the suction of the circulating pump, the first condenser sees a mixture temperature that is lower than the tank temperature. Thus the system can absorb more heat at a given condition in the first condenser due to the greater
10 temperature differential. The first circulating loop controls the head pressure of the compressor, thereby increasing compressor efficiency.

The system performs better when the first condenser circulating loop is at or below the maximum condensing temperature of the refrigerant in the system -- which for the given system was around 125F -- and the second circulating loop is still relatively cool.
15 The second loop is removing additional heat and sub-cooling the liquid refrigerant. The second circulating loop controls refrigerant subcooling, which also improves efficiency of the compressor.

Subcooling provides two benefits:

1. The system gains the heat of subcooling for useful heating of the water.
- 20 2. When the refrigerant is expanded in the TX valve there are fewer flash gas losses (i.e. there is more liquid refrigerant to boil in the mixture inside of the evaporator and the heat transfer into the evaporator can be increased).

A third circulating loop may be provided for controlling desuperheating.

Thus, a second use for the dual condenser mode operation is to provide subcooling
25 to increase the capacity of the system. It then follows that a third condenser can be used to provide both the ability to heat liquid to higher temperatures and subcool the refrigerant for the same system, yielding improved system performance.

Use of multiple evaporators and multiple condensers in parallel circuits to provide any combination of heating and/or cooling and the use of multiple condensers and
30 circulating loops in series within a circuit can be expanded for use of configurations in whatever capacity is needed. Any number of circuits can be applied or any number of

condensers or evaporators in series to not only satisfy the requirements of any application but to optimize the utilization of the refrigeration system and maximize the cost benefit of the system installation for a given application.

Thus, a formula has been developed which describes the nature of the system in
5 terms of both its physical and economic variables. Since a refrigeration system has never been applied in this manner, this formula is unique and describes the nature of the system for a wide variety of applications. The formula parameters allow the system to be evaluated as a viable alternative in the thermal energy infrastructure of the world.

The thermodynamic formula inputs bio energy in the form of ambient air and
10 recycled energy balanced on the capacity of the refrigerant and the compressor by first applying the energy into the application and rejecting the remaining energy in order to balance on the capacity of the refrigerant and compressor to all new levels.

As used in this application, "environmental thermal energy" is defined as thermal
15 energy that is available and exists naturally or has been released to an environment by an exothermic process.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic drawing of a basic prior art heating, cooling and hot water configuration according to the '108 patent.

20 Figure 2 is a schematic drawing of another embodiment of a prior art basic heating, cooling and hot water configuration according to the '108 patent.

Figure 3 is a schematic drawing of an embodiment of a basic heating, cooling and hot water configuration according to the present invention.

25 Figure 4 is a schematic view of an embodiment of the present invention showing heating, cooling and hot water utilizing multiple heat sinks.

Figures 5A and 5B are schematic drawings showing alternative embodiments of a heating, cooling and hot water system having a warm water heat sink according to the present invention.

30 Figure 6 is a schematic drawing of another embodiment of a heating, cooling and hot water system having thermal loops and thermal storage according to the present invention.

Figure 7 is a schematic drawing of yet another embodiment of a heating, cooling and hot water system with mixed superheat cogeneration and rejection according to the present invention.

Figure 8 is a schematic drawing of still another embodiment of a heating, cooling
5 and hot water system utilizing superheated liquid according to the present invention.

Figures 9 and 10 are schematic drawings of further embodiments of a heating, cooling and hot water system with subcooled liquid according to the present invention.

Figure 11 is a schematic drawing of another embodiment of a heating, cooling and
10 hot water system with superheated heated liquid and supercooling according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Formula for controlling environmental balance with the refrigeration cycle.

Applicants have developed a universal formula necessary for balancing the co-
15 generation of heat and cold within the refrigeration cycle with the constraints of two (or more) environments to be affected or controlled by the refrigeration process.

The variables must be balanced relative to the requirements of a given application of the system. The first consideration is the choice of a refrigerant that has physical properties that will allow evaporation and condensation at temperatures that meet the
20 demands of the application within the compression ratio and operating temperature limitations of available compressors and compressor oils. There are many materials and mixtures of materials having refrigerant characteristics. As a broader array of application conditions are considered, new refrigerants will be selected or created to harness the efficiencies of the refrigeration cycle. Once a suitable refrigerant is selected, the formula
25 can be applied along with the appropriate engineering principles to select or design the refrigeration system components that will properly balance the refrigeration cycle and withstand the rigors of the application.

The basic formula can be written in a number of formats. For a refrigeration process using direct expansion in terms of the application environments and electricity use:

30 (1) Desired change in environmental conditions at location of evaporators – Evaporator side piping losses and heat gain + Electricity consumed – Compressor and motor

losses = Desired change in environmental conditions at location of condensers –
Condenser side piping and heat losses.

This relationship can also be represented in terms of the of the refrigeration cycle
itself. For example, equation 1 can be written as follows:

- 5 (2) Evaporator energy collected – Evaporator side piping losses and heat gain +
Compressor work = Condenser energy rejected – Condenser side piping and heat
losses.

These relationships share the following sub-relationships:

- 10 (3) Evaporation energy collected = Desired change in environmental conditions at
location of evaporators.
(4) Condensation energy rejected = Desired change in environmental conditions at
location of condensers.
(5) Compressor work = Electricity consumed – Compressor and motor losses.

15 The generic terms utilized in the foregoing equations will be derived in the terms of
the specific application or refrigeration cycle and will conform to the laws of the
conservation of mass and energy with consideration of the significant losses. These
equations are utilized to determine the practical scale and configuration of refrigeration
system that will maximize the utilization of both heating and cooling resources while the
refrigeration cycle is in operation and thus maximize the overall benefit of the installed
20 system.

The formulae provides the basis for designing the system to match the
environmental requirements with the refrigeration system requirements and optimize
operating efficiency for simultaneously utilizing both the heating and cooling sides of the
refrigeration cycle. In comparison, the goal of prior art systems was generally to maximize
25 performance while satisfying either the heating or the cooling side.

Classes of refrigeration application.

There are three classes of refrigeration application based on the utilization and
efficiency of the refrigeration process: Rejection, Reclamation, and Cogeneration.

A. Rejection

Historically, the majority of refrigeration applications fall into the rejection class. In rejection, one side of the refrigeration process is always wasted. For example, an air conditioner transports heat from inside of a building to the outdoors. The desired benefit is the cooling of the space, while the heat (including the electricity used to run the machine) is displaced or rejected to the environment. Similarly most refrigerators, chillers, and freezers will simply reject the heat they are collecting to the environment where the condenser is located without consideration of the utilization of the heat for any useful purpose. An air to air heat pump is similar in that it cools the space while rejecting heat in the summer, and heats the space while rejecting cold in the winter. Rejection refrigeration systems are the least efficient systems since they utilize energy to either heat or cool, but never both. Rejection systems have their place since they provide value to a process that pays for itself through product protection or production. In many applications however, rejection systems such as chillers and freezers exist along side of boilers or furnaces which provide space and process heating based on combustion. These applications are candidates for conversion to reclamation or cogeneration refrigeration.

B. Reclamation

With volatility in energy prices, and uncertainty regarding the balance between energy supply and energy demand, more and more refrigeration systems are utilizing some form of reclamation. In reclamation, some portion of the heating or cooling that may have historically been rejected is captured and reused for some useful purpose. Collecting heat from a waste stream of an application and using it to heat water, space, or some other process stream in the application is reclamation, as described in U.S. Patent No. 7,040,108. Collecting heat from the exhaust of an animal confinement to heat the confinement or collecting heat out of the waste water or drier vent exhaust of a laundry to heat wash water are specific examples. In reclamation, the refrigeration system is often designed or optimized for utilization of one side of the refrigeration cycle while the other side is utilized as much as possible, but not necessarily all of the time or to the fullest extent possible.

The time dependent nature of many processes and the change of seasons is accommodated by the present invention wherein the refrigeration process is designed with

additional flexibility to allow it to be utilized more efficiently and to a greater extent within a given application, including the need for multiple evaporators and multiple condensers to meet the priorities and time dependent requirements of the application. A reclamation application may include periods of operation where priorities require rejection and may at times operate in cogeneration mode (discussed below). For example, Applicants' system installed in a home will operate in cogeneration mode when heating potable water while providing comfort cooling. The same system will however switch to rejection mode when the potable water is heated to its limits and more comfort cooling is required. If in the same home application, the external evaporator is positioned so that it can take advantage of the drier exhaust and bathroom and oven exhaust fans then the system will operate in reclamation mode during the heating season or while heating water during the cooling season when there is no call for comfort cooling. Since the system is capable of operating in this variety of modes, it enjoys the potential of annual performance that exceeds that of many conventional refrigeration based heating or cooling systems. Several examples of reclamation configurations are described below with respect to the drawings. A unique characteristic of each of these systems is that when it operates in reclamation mode, it utilizes 100% of the heating side of the refrigeration cycle. Most reclamation systems only utilize a fraction of the heating capacity. A home heating and cooling system falls into the reclamation category since it may at times use rejection, reclamation or cogeneration, which is better than pure rejection but not as good as pure cogeneration.

Cogeneration

When both the cooling and the heating side of the refrigeration cycle are fully utilized within a process, the application is called cogeneration. As mentioned in the reclamation section above, an example of cogeneration is when a refrigeration system is used to provide comfort cooling while heating potable water. This effective utilization of the resource can be extended in a housing or hotel application if the same system can be used to heat a swimming pool and/or hot tub. However, due to daily and seasonal variability in outdoor atmospheric conditions, housing applications are rarely pure cogeneration applications. Pure cogeneration applications will mostly be found in agricultural, commercial and industrial applications where both cooling and heating are

used to produce a product. In an ethanol plant for example, heat rejected from the cooked mash on its way to fermentation or from the fermentation process itself may be collected and used to heat the cook water or to heat the condensate returns for the boiler. In the future, advances in refrigerants and refrigeration equipment may allow refrigeration systems to operate at temperatures that will allow refrigeration systems to displace the boiler. Power plants, bio-diesel plants, chemical and petroleum refineries, commercial laundry/dry cleaners and a host of other energy intensive process oriented industries provide opportunities for cogeneration with a refrigeration system.

The configurations shown in the drawings are examples of refrigeration systems where the formulae described above are used to maximize the reclamation and cogeneration opportunities in an application.

The goal is to maximize utilization of a balanced refrigeration cycle in a configuration that will minimize energy consumption and maximize efficiency and value to the application. The systems are able to utilize the optimal combination of rejection, reclamation, and cogeneration as driven by the requirements and limitations imposed by the application. The systems are capable of utilizing all three classes of operation within the same installation.

The bio-renewable reverse thermal energy nature of the system

Historically the refrigeration process has been thought of as a simple transferring of energy from one location to another at the expense of electricity to operate the compressor. The present invention endeavors not to simply transfer thermal energy, but through controls and system design, to transform thermal energy relative to its most desirable condition in a specific application given the constraints and capabilities of the refrigerant, compressor oil and the equipment. This is evident for example in the ethanol process described previously as an example of cogeneration. The fermentation process requires a fixed 95°F while the cooked mash is held at 180°F. Fermentation gives off heat as the bacteria metabolize sugar into alcohol. The mash is maintained (excess heat is collected) by the system and transformed into 130°F to 180°F water depending on the design of the refrigeration process.

The invention is capable of transforming electricity from any source into thermal “bio-energy” through reuse of thermal energy that would historically have been wasted to the environment and through reduction of toxic emissions associated with conventional combustion based heating systems. For example, in a conventional ethanol plant, the cook water is heated using a natural gas, coal, or biomass fired boiler. The excess heat in the cooked mash must be removed before it can be prepared for the fermentation process. This historically has involved use of heat exchangers to provide heating to other parts of the process but also requires additional cooling either from a chiller or cooling tower to finish the cooling process, since the mash must be colder than most other stages of the ethanol production process. This is also true for maintaining the fermentation process at 95°F. Thus a fuel is burned to heat a process stream and the heat is then rejected to the environment, or a biological process creates excess heat which is rejected to the environment. This mode of operation is prevalent in most industries today because historical energy prices and energy supplies have allowed it and until now there has not been an economical way to utilize the low grade “waste” heat. With Applicants' system however, the energy that would be wasted can be reclaimed to provide the desired cooling and heating affects simultaneously. Also, as technology and refrigerants advance, it will be possible to more precisely match the desired operating conditions on both sides of the refrigeration cycle.

The system displaces direct fired sources of heating and their associated emissions. Since the wasted energy and solid and gaseous emissions would have otherwise been emitted into the environment, the thermal energy reclaimed by the new, inventive system is bio-energy. A bio-energy system also exists when the energy that is reclaimed is derived from living organisms (such as in animal confinements, alcohol producing bacteria or incubating eggs). The system will inherently displace carbon dioxide (CO₂), carbon monoxide (CO), and nitrogen oxide (NO_x) emissions from all carbon based combustion processes and it will displace sulfur dioxide, mercury and ash emissions from oil, coal, solid waste or biomass combustion. Given the system displacement or reduction of CO₂, SO₂ and other emissions, it may be possible in the future to qualify projects for the production of emissions credits (currently SO₂, NO_x, Hg, and CO₂) which have a marketable value in the present U.S. cap and trade emissions reduction strategy. The

extent of the displacement of emissions and the ecological impact is measured relative to the renewable energy nature of the system within an application at a specific location.

The renewable nature of this bio-energy can be derived by comparing the efficiency of the system with the efficiency of thermal power plants that generate the electricity for the application site. Thermal plants include fossil fuel fired plants, nuclear plants, biomass fired plants, solar thermal plants and geothermal plants. All of these types of generation emit significant amounts of waste heat into the environment, and the combustion based systems produce large quantities of combustion products that contribute to air and water pollution. The efficiency of thermal generating plants is characterized by the heat rate which is defined as the Btu input of fuel (or thermal energy) per kWh of electricity output. The system operation in reclamation or rejection mode can similarly be characterized as the Btu of heat output per kWh of electricity input (the reverse thermal characteristic). If the system performance (Btu output/kWh input) is greater than the average heat rate (Btu input/kWh output) of the thermal electrical generating system, then the ratio of the two represents the renewable contribution of the system operation.

For example, if Applicants' system operates at 12,000 Btu heat output per kWh electricity input while the thermal generating system is producing electricity at 9,000 Btu/kWh, then the Applicants' system is contributing $(12,000/9,000 - 1) * 100 = 33\%$ renewable thermal energy (i.e. 1 unit of energy provides 1.33 units of energy for a desired purpose). The average local Btu/kWh heat rate of the generating system will vary as different generating units with different efficiencies are used to meet load. So the renewable energy contribution will vary over time as the heat rate of the generating system varies. However it can be seen that the system provides a new incentive to work towards driving the thermal generating system heat rate to lower values.

To demonstrate the impact of reducing the heat rate for thermal generating systems, for example, let's apply a 7000 Btu/kWh thermal generation heat rate. This is in the range of newer combined cycle natural gas fired power plants. The renewable energy contribution of Applicants' system becomes $(12000/7000 - 1) * 100 = 71.4\%$ (i.e. 1 Btu of energy provides 1.714 Btu of thermal energy). This implies that by shifting natural gas and propane use from direct combustion in residential, commercial, and industrial applications to use in combined cycle power generation systems while at the same time applying

Applicants' system technology, we can significantly reduce the amount of waste thermal energy and the amount of combustion products emitted into the environment. To further drive this point, assume for example that the renewable energy contribution formula that is an alternative to Applicants' system will operate at 100% efficiency (i.e. subtract 1.0 from the ratio). In reality, a direct combustion system would usually have a conversion efficiency in the range of 80% to 93% which means that an additional 7% to 20% of the heat energy that would have been used (and its associated emissions) would have been lost to the environment compared to use of the system. Another way to say this is that one Btu of natural gas or propane provide 0.8 to 0.93 Btu of useful heating. Therefore, for the sake of comparing alternatives, we subtract the efficiency of the direct combustion system from the efficiency of the Applicants' combination/combined cycle generating system to determine the renewable energy contribution adjusted for the competing alternative (i.e. if the alternative is a 93% efficient boiler the renewable contribution is $(12000/7000 - 0.93) * 100 = 78.4\%$. This implies that the system will produce 1.784 Btu of useful heating per Btu of useful heat that would have been provided by a 93% efficient direct fired boiler.

Applicants' system in a reclamation or cogeneration scenario will typically operate in the range of 11260 Btu/kWh to 13650 Btu/kWh, and new advances are expected to increase the upper limit. As the reverse heat rate increases, the overall bio-renewable impact of the system will increase proportionally. A system running at 13650 Btu/kWh running on electricity from a gas fired combined cycle that will displace a 93% efficient gas fired boiler will produce a renewable contribution of $(13650/7000 - 0.93) * 100 = 102\%$ (i.e. 2.02 Btu of useful heating will be generated from a Btu of gas fired in the combined cycle plant and amplified by the system relative to 0.93 Btu of useful heating if the same Btu was directly fired in the 93% efficient boiler).

Since not all electricity generation comes from thermal sources, some correction should be made for the affect of non-thermal electricity sources. Non-thermal renewable energy sources have little if any airborne or thermal emissions and include technologies like wind, wave, hydro and solar photo-voltaic power. The impact of non-thermal renewable generation on the Applicants' system renewable contribution will be proportional to the fraction of the total mix of generation produced from non-thermal sources. However, the contribution of the Applicants' reverse thermal process and system

relative to a non-thermal electricity source is better described based on the coefficient of performance (COP) or Btu of heat output per Btu of electricity used by the Applicants' system. The units operating in reclamation and cogeneration mode are generally capable of operating at a COP of 3.3 or greater. This level of COP is also possible in rejection mode, however the temperature of the heat source such as outdoor air on a very cold winter day during the heating season when the system is running in rejection mode can degrade the COP to levels as low as 1.0. For example, assume the system is operating in reclamation mode at a COP between 3.3 and 4.0. A COP of 3.3 corresponds to a reverse heat rate of 11262 Btu/kWh while a COP of 4.0 corresponds to a reverse heat rate of 13650 Btu/kWh (i.e. $11262/3413 = 3.3$ and $13652/3413 = 4.0$ where 3413 is the conversion constant between Btu and kWh (i.e. 1 kWh of electricity will provide 3413 Btu of thermal heating from a resistant electric heater). At a COP of 4.0, the unit in reclamation mode will be generating 4 Btu of thermal energy for a process for every 1 Btu of electricity consumed. Thus, Applicants' system multiplies the thermal capacity of electricity generated from non-thermal sources by a ratio equivalent to the COP.

The total renewable contribution of Applicants' system in a generation mix that includes non-thermal generation is represented in the following example. Take the 13562 Btu/kWh RASERS, the natural gas fired combined cycle power plant operating at 7000 Btu/kWh heat rate and a non-thermal renewable energy contribution of 10% competing with a 93% efficient direct fired boiler. The renewable energy contribution of our system then becomes $(13562/(0.9*7000 + 0.1*3413) - 0.93) * 100 = 112.56\%$. As the thermal generation heat rate is reduced and as the non-thermal contribution is increased this formula will be reduced to the COP of the system. The minimum possible heat rate of the thermal energy systems is 3413 Btu/kWh since that would mean that they were operating at a conversion efficiency of 100% (i.e. 1 kWh = 3413 Btu).

When Applicants' system operates in cogeneration mode, then the renewable contribution arguably becomes equal to the COP, since the cooling affect would have been required regardless of whether the thermal heating affect was utilized or not. In-other-words if you produce and use the energy for the cooling affect of the system, then the heating affect, if it is fully used, comes for free.

The above discussion demonstrates that the Applicants' system allows thermal energy based electricity generation systems to produce bio-renewable thermal energy when the conversion efficiency (heat rate) of the electricity generation system is combined with the conversion efficiency (reverse heat rate) of the Applicants' system. It was also shown
5 that the Applicants' system effectively multiplies the renewable contribution of non-thermal renewable electricity sources by the COP of the Applicants' system. Also, Applicants' system operated in cogeneration mode has a bio-renewable thermal energy contribution equal to the COP of the system.

The assumptions made regarding heat rates and efficiencies are within the range of
10 nominal performance for thermal systems in operation today. The renewable contribution may infer that the efficiency of the combined system exceeds 100%. However, Applicants' system does not create energy, but rather transforms thermal energy that would normally be wasted or exhausted into the environment into useful thermal energy. The refrigeration
15 cycle, through proper use and control of the phase change properties of a refrigerant, amplifies a small input of energy (electricity) into a larger quantity of thermal energy available for use in a variety of applications.

There will be additional ecological benefits of displacing direct fired thermal heating systems with the Applicants' system besides the reduction in the emission of thermal energy and products of combustion. One example is the reduction in use of
20 makeup water for boilers and cooling towers or evaporative coolers. Another is the reduction in use of scale and biological water treatment chemicals for the boiler and the cooling towers. In consideration of all these things, the environmental and economic footprint of fossil fuel utilization can be significantly reduced through implementation of the Applicants' system. As natural gas and propane used for direct thermal heating of
25 onsite industrial, commercial, agricultural, and residential applications is displaced with Applicants' system technology, more natural gas and propane will be available for cleaner, more efficient combined cycle gas fired electricity generation. Since Applicants' system technology generates bio-renewable thermal energy it may also be classified according to its bio-renewable nature to allow it to participate in the renewable energy incentives
30 programs and renewable energy credit markets with at least the following benefits:

- (1) capable of reducing the emissions of waste thermal energy and the products of combustion resulting from fuels used for thermal heating processes at a rate defined as the renewable energy contribution.

Renewable energy contribution is derived according to the following formula:

$$\text{Renewable Energy Contribution \%} = (\text{RTHR} / (\text{REFTH} * \text{THPHR} - \text{REFNTH} * 3413) - \text{CompEff}) * 100$$

Where:

RTHR = the reverse thermal heat rate of the system, Btu heat output / kWh electricity input

THPHR = the heat rate of thermal generating plants, Btu heat input / kWh electricity output

REFTH = Fraction of generation mix provided by thermal plants

REFNTH = Fraction of generation mix provided by non-thermal generation systems

3413 = conversion from Btu to kWh or the THPHR of a 100% efficient thermal generating plant

CompEff = conversion efficiency of the thermal energy system that the system competes with Btu heat output / Btu of fuel fired.

- (2) Thermal energy at efficiencies greater than 100% when the efficiencies of the system reclamation are considered in combination with the efficiency of thermal generating plants.

- (3) Capable of generating thermal energy at a maximum efficiency defined as the coefficient of performance of the system. This occurs when electricity is used that is derived from a non-thermal source, when the efficiency of a thermal generation source reaches 100% and when the system operates in cogeneration mode. The Coefficient of Performance is defined as the Btu of energy output divided by the Btu of electricity input.

- (4) Operating in cogeneration mode produces both heating and cooling at the cost of operating the cooling system plus the cost of operating any additional fans, pumps or controls required to manage the heating side of the process.

Three commercial applications of the system

There are a vast array of applications where the Applicants' system can be applied to take advantage of its bio-renewable characteristic and its flexibility to operate efficiently within the three classes of refrigeration application. From the perspective of commercialization, there are three broadly defined markets that will benefit from the system. A few specific market segments are identified for each (though the lists are not intended to be exhaustive).

a. Housing and commercial heating and cooling

- Single Family
- Multi-family
- Hospitality & Dormitory
- Offices
- Retail
- Warehouses/storage
- Non-process facilities (manufacturing, assembly, laboratories, etc.)
- Animal confinements
- Greenhouses and plant nurseries

b. Industrial heating and cooling

- Powder coating and baked on painting operations
- Food processing facilities (meat, dairy, baking, frozen foods, etc.)
- Foundries

c. Inline process

- Ethanol and biodiesel processes
- Power plants
- Applications with both boiler and chiller or cooling tower
- Various chemical, petroleum, drug, and agricultural byproduct refining processes
- Hatcheries/incubator climate control systems
- Hay, grain or product drying processes

The new and unique feature of the system technology in these markets is its flexibility to take advantage of reclamation and cogeneration opportunities in each application. Use of the Applicants' system in place of combustion based technologies has also been shown to provide residual benefits in specific applications. For example, humidity can be better controlled to help reduce potential for disease and pests or various process elements can be significantly reduced such as the use of fresh water for cooling an incubator. The system will also work in concert with other energy efficient solutions, renewable energy systems or energy storage systems to provide an additive or multiplicative affect. For example, a two pipe heating and cooling system in a hotel, hospital, or other commercial facility can be retrofit to include water source heat pumps in each unit and Applicants' system that will operate between the boiler and the chiller to significantly reduce the rejection mode operation of the chiller and the combustion of the boiler. The Applicants' system will use cogeneration to take excess heat in the loop and apply it to heating potable water or the swimming pool and hot tub. If the loop needs additional heat, the system will use reclamation to take waste heat from the continuous exhaust system, waste water or other heat sources in the facility to provide the needed heating. The Applicants' system possesses a unique market potential in a broad range of applications, some of which are described in the following sections.

Thus, Applicants' system provides flexibility to utilize rejection, reclamation and cogeneration in an optimal manner to maximize energy savings and emissions reductions for a wide array of applications. Claims for specific applications are listed at the end of this patent description. Applicants' system can provide residual benefits such as reduction in humidity or reduction in water usage in some applications that can be as valuable as the energy savings and emissions reduction benefits.

Specific applications and configurations that demonstrate the three classes of refrigeration application and the bio-renewable energy nature of the system
Multi-heat source / multi-heat sink configurations

To allow the Applicants' system to take advantage of reclamation and cogeneration opportunities it has been necessary to extend the definition of the system described in U.S. Patent 7,040,108 to allow utilization of one or more evaporators and one or more

condensers for a given refrigeration cycle. In the most basic configuration this allows the Applicants' system to provide space heating, comfort cooling and potable water heating in any facility. The configuration of the evaporators and condensers can be adjusted from application to application. Some applications may require only one evaporator and one
5 condenser. Some applications may require two or three evaporators and one or two condensers. The number and type of evaporators is determined by the availability and type of excess, waste or ambient heat resource and the demand for heating or cooling for the application. The number and type of condensers is determined by the number and type of required heating and cooling demands of the application. The number of evaporators and
10 condensers associated with a given unit is also driven by the economics of the installation and the timing of the available heat sources and the timing of the heating and cooling demands. When heat resources and heating and cooling demand do not occur simultaneously, it often becomes necessary to consider thermal storage as a method of retaining heat or cool for later utilization. In some instances the cooling demand
15 consistently exceeds the heating demand in which case storage capacity for heat can be reduced by utilizing a higher storage temperature. These concepts are developed in greater detail in the following descriptions relating to Figures 1 through 6.

Basic heating, cooling and hot water configurations

20 Figures 1 and 2 demonstrate basic configurations of the '108 patent. Figure 2 is similar to Figure 1, and adds the concept of using a heat exchanger and circulating pump to remove heat from the storage tank for a purpose such as heating a space or heating a second stream. Figures 1 and 2 are practical configurations for applications where there is a need for heating based on heat collected from a single ambient source or stream. These
25 configurations were however inadequate to provide year-round heating and cooling for a home, for example, since the heat source changes from inside of the home during the comfort cooling season to the outside for the heating season. In addition, the cooling load in a comfort cooling application often exceeds the potable water heating requirements so a method of rejecting the extra heat generated by the comfort cooling process is needed.

30 Figure 3 demonstrates the use of the three-way reclaim valve and the reclaim check valve to switch between the water cooled condenser and the air cooled condenser. Also

illustrated is the addition of 2 two-way solenoid valves used to supply liquid refrigerant to two evaporators labeled "A-Coil Evaporator" and "Evaporator". Multiple two-way valves or three-way valves may be used interchangeably for switching between multiple condenser paths or switching between multiple evaporator paths as the application requires. Care must be taken to provide a means to reclaim the refrigerant in a given path that is not in use, if that path could hold enough volume of liquid refrigerant to starve the unit while using other paths. This is particularly an issue for condenser paths. Without this control, when the ambient temperature around the condenser drops, the refrigerant will tend to migrate to the condenser (condense inside of the condenser) and starve the unit of refrigerant. Reclaim is not as important for the evaporator paths since all evaporators are tied directly to the suction of the compressor. The three-way reclaim valve provides a convenient method of reclaiming refrigerant to the suction of the compressor from the reclaim port on the valve. The use of normally open 2-way solenoid valves (if used) is also important to avoid having the valves fail closed and causing a deadhead situation for the compressor. The use of the 3-way valve is again superior since it will always have one port open and will fail open to only one port.

This configuration provides the basic components necessary to provide heating and comfort cooling to any facility (home, office, warehouse, factory, etc.) while also heating the potable water. The ability to cogenerate by heating potable water while providing comfort cooling provides a significant advantage. If the outdoor evaporator can be located where it can use reclamation from heated streams leaving the facility, then the overall performance of the system can be further improved during the heating season, and while heating water when there is no cooling demand.

There are also many applications beyond simple space conditioning and potable water heating where the second condenser (or third or fourth, etc) and the two evaporators (or third or fourth, etc.) can be placed in locations to take advantage of specific heat sources and provide useful heating to spaces or processes. Applying multiple evaporators and multiple condensers in this way allows the system to be configured to take maximum advantage of reclamation and cogeneration opportunities in any application. The drive to maximize performance must be tempered relative to the economic and residual cost/benefit of the specific configuration in the specific application.

Heating, cooling and hot water with multiple heat sinks

In some instances, an application presents an opportunity to provide useful heating of multiple locations or processes such as the heating of a space and the heating of a large heat sink such as a swimming pool or a process stream. U.S. Patent 7,040,108 disclosed the use of one loop for the heating of a space but did not disclose the multi-circuit possibility. Figure 4 demonstrates the use of more than one heating circuit tied to the hot water tank to allow the system to provide heating to multiple demands at or below the controlled temperature of the hot water tank. The desired temperature of the heat sink must be at or below the operating temperature of the Applicants' system while operating on a given refrigerant to allow heat transfer into the heat sink. In a housing or hospitality application, where there are swimming pools, this configuration allows the system to reduce, if not eliminate, rejection mode operation and maximize cogeneration during comfort cooling operation or a continuous process cooling operation. A second heating circuit is used instead of a second water cooled condenser when the heat demand is at a temperature significantly below the typical refrigerant condensing temperature (hot tank setpoint) of the system. This will allow the Applicants' system to control refrigeration system operation and in some instances avoid excessive frost formation on the evaporator(s) and suction piping. Each heating loop will have a solenoid valve to control flow of water through the loop based on application demand and priority. A flow control valve may also be placed in each loop to allow the heat transfer out of the tank to be limited to the heat entering the tank from the water cooled condenser. Each loop may have its own circulating pump as shown in Figure 4 or a single pump may be used to supply circulation for all loops.

Heating, cooling and hot water with warm water heat sink

A slight variation of the multiple heat sink concept advanced in Figure 4 is demonstrated in Figure 5. In this configuration, warm water is supplied to the cold supply of plumbing fixtures throughout a facility except possibly for water used for drinking, ice making and food preparation purposes. The intent is to provide additional heating load during the cooling season to help avoid the need for rejection mode operation as with an air cooled condenser. The system would not be used during the heating season unless it

provides value to some process within an application. The fact that the cold water supply is heated will reduce the demand on the hot water since the mixing at the point of use will be biased more towards the cold than usual to arrive at the same level of comfort for the user. There are also commercial applications such as laundry operations, dairy cow drinking water supply and humidification systems for incubators where 70°F to 90°F water is preferred to typical ground water temperatures. Using 70°F to 80°F water in the toilets and cold water piping to limit condensation and sweating can help reduce mold formation in walls and ceilings and reduce liability for people slipping on wet floors in public restrooms. Restaurants may be able to utilize the warm water supply to avoid rejection mode operation of an air cooled condenser during the comfort cooling season.

There are two configurations presented in Figure 5, cool water supply with mixing valve and cool water supply with independent tank. Both options reduce energy consumption by reducing the need for rejection mode operation during a cooling process and can be used in specific applications where warm water is desirable. The Hot Control valve is opened and Cool Control valve is closed only when the hot water tank is satisfied and the system is calling for cooling. As soon as the hot tank calls for heating, the valves will return to their de-energized positions (the Hot Control valve will close and the Cool Control valve will open).

The mixing valve configuration allows warm water to be generated on demand helping to reduce concerns about bacterial growth in warm water storage tanks. This approach is best used when there is a continuous demand for cool water since there must be a demand for cold water to provide continued support of the comfort cooling demand. The independent tank option allows a larger supply of heated water to be stored and available for use and it allows the comfort cooling to be extended for a longer period of time after water usage or during periods of time when there is no cold water demand. An additional benefit of the tank relative to the mixing valve is that the water supply temperature to the user will not suddenly switch from cold to cool or from cool to cold when the hot and cool control valves actuate. If the temperature of the cool water tank reaches its set point, the system will either shut off the cooling process or switch to a heat rejection mode if it is available until water is used allowing the system to continue to generate hot or cool water.

If a mixing valve were added to the tank configuration the tank could be heated to a higher temperature while controlling cool water temperature at the faucet.

The cold water bypass valves in the independent tank option are used to allow the cool water tank to be used to store hot water during the heating season. Bypass valve 1 is closed and bypass valve 2 open when the system is calling for cooling. Bypass valve 1 is open and bypass valve 2 is closed when the system is calling for heating. These valves may be manually operated valves or automated to respond to the system thermostat. During the heating season, if the bypass valves are properly set for bypass mode, the thermostat on the cool tank may be set to allow it to reach hot water temperatures. During the comfort cooling season the thermostat on the cool tank may be set to hold the temperature to the warmest acceptable temperature for cool water supply.

Heating, cooling and hot water with thermal loops and thermal storage

The Applicants' system with its flexible configuration provides a unique capability to support heating and cooling operations that involve thermal fluid loops and thermal energy storage. The thermal loop or storage system may operate to provide either cooling or heating on demand. Figure 6 depicts a basic thermal system with both fluid loop and thermal storage. The fluid and storage media may be water, a mixture of glycol and water or one of any number of thermal fluids available on the market. The storage system may also utilize phase change or phase change materials to boost the energy density on the storage device.

The Applicants' system refrigeration cycle configuration is the same as any of the multi-heat source / multi-heat sink configurations illustrated in Figures 4 and 5 except this configuration explicitly utilizes a chiller as one of its evaporators. There is only one condenser shown however a specific application may call for additional condensers. For example, a second condenser may be used to reject heat to a cooling tower or air cooled condenser when a facility's heating demands are satisfied and there is still need for comfort cooling. If the system is used only for cooling, the Heating Heat Exchanger, associated piping and the Fluid Control valves may be omitted from the configuration. If the system is used only for heating, it will take the configuration of the system depicted in Figure 4,

except that now the hot water tank might involve a phase change mechanism to increase the storage capacity of the system.

The circulation loop between the water cooled condenser and the hot water tank adds a heat exchanger in the loop rather than utilizing a separate circulating loop. This offers the advantages of providing the highest temperature for the heat exchange with the thermal loop/storage system and it avoids the operation of an additional pump. It does imply however, that the circulating pump must be wired to operate whenever there is a call for heat from either the thermal system or the water storage tank. It also forces the configuration of the thermal system loop to have the Chiller Fluid Control and Heating Fluid Control valves to avoid heating the loop during cooling operations when the system is in operation. The alternative would be to provide an independent heat circulating loop between the hot water tank and the thermal system loop as illustrated in Figure 4. This eliminates the need for the Chiller Fluid Control and Heating Fluid Control valves and places the chillers and heating heat exchangers on the same loop, however it adds the cost of operating an additional pump. Both approaches will work and will be selected primarily on the basis of cost versus the effect on system energy efficiency. The number of pumps and the configuration of the thermal loop system will vary from application to application. The thermal system loop may or may not include a thermal storage device (Heat/cool Fluid Tank) depending on the requirements of the application. This implies that in some instances the tank and one of the pumps in the thermal system will not exist. Backup heating and cooling may come from any economically viable source tied into the thermal loop. In most thermal loop systems like this today, the backup heating and cooling would be provided by a boiler and chiller or cooling tower.

This Applicants' system configuration provides a unique opportunity to utilize reclamation and/or cogeneration to significantly improve the efficiency of existing thermal loop systems in many facilities and it offers opportunity for a number of new applications where thermal energy (heat or cool) can be efficiently stored for later use. Consider, for example, the two pipe heating and cooling system example discussed above regarding the commercial application of the Applicants' system in a hotel. The two pipe system is represented by the thermal loop system either with or without the tank. The tank will often be used in this application since it provides a dampening affect to the loop to help reduce

the variability in loop temperature. The chiller is used in cogeneration mode operation to provide cooling to the thermal loop system while it heats the potable water for showers and laundry or it heats a swimming pool. The Evaporator (one or more of them), operated in reclamation mode to provide heating to the thermal loop system, can be located in various exhaust streams such as the continuous makeup air system exhaust, restaurant kitchen exhaust, laundry drier exhaust, or the wastewater from the showers and laundry. The Applicants' system is sized to match the typical base load heating and cooling for the facility within the constraints of the available heat sources and heat sinks. The backup heating and cooling systems may then be sized to makeup the difference between extreme operating conditions and the typical operating conditions. Another sizing approach would be to size the system to satisfy the demands usually experienced during the spring and fall and size the boiler and chiller for the remainder of the winter and summer extremes. The loop may be operated either in hot and cold mode to provide heating and cooling via a simple fan coil in each hotel room or the loop may be operated at a given temperature such as 55F to provide heating and cooling via water source heat pumps in each hotel room or temperature controlled space serviced by the loop. It would be possible to also provide backup heating and cooling from a ground connected heat pump system as opposed to a boiler and chiller if sufficient ground connection capacity can be economically obtained in an environmentally acceptable manner at the application site. With the Applicants' system, the scale of the ground connected system can be reduced to help hold down overall implementation cost.

A good example of a system where this configuration is used for heat storage is in a green house. The greenhouse is subject to significant solar gain on clear days even when the outdoor temperatures are cold. This affords the opportunity to collect the excess heat during the day and utilize it to heat the space during the night. Ideally, a phase change material will be used in the storage tank to increase the energy density of the storage tank and the phase change material will be selected to allow storage at the normal condensing temperature (hot water tank set point) of the Applicants' system. An advantage of removing the excess heat from the greenhouse (beyond the obvious benefits to the plants) is that the total amount of heat that might be collected will increase, since the cooler temperature in the facility will reduce losses to the outdoors and more solar energy will be

captured in a cooled space than in a heated space. This will be true of any solar thermal collection system when it is coupled with Applicants' system. When the collector is cooled, it will collect more heat. The collected heat may be used directly by circulating the heated stored fluid and if the storage system temperature falls below a useful heating temperature, the system can be used to extract additional heat from the storage tank until it reaches a temperature that will prohibit reasonably efficient operation.

Heating, Cooling, and Hot Water with Parallel Units

In some applications more than one energy reclamation unit with its various components is required to satisfy the heating and/or cooling requirement. In these applications, particularly in commercial and industrial settings, it can be more economical to utilize one circulation pump and/or a common hot water tank for more than one unit. The more easily controlled multi-unit configuration on the water circulation side is a parallel configuration so that each unit will experience the same operating conditions or water temperatures in the water cooled condenser. Using a series configuration will cause downstream units to experience higher temperatures in the water cooled condenser and as a result higher compressor head pressure and refrigerant temperature. While this temperature differential could be used as a means of turning units on and off, it can be difficult to synchronize the controls with the hot tank thermostat. Each unit will have its own heat sources and will be controlled independently relative to those sources. Care should be taken to try to group units with reasonably similar heat sources to allow the units to operate at relatively similar operating conditions on the refrigerant side. For example, one unit may be servicing a chilled water loop at 40°F while the other unit is reclaiming heat from a wastewater tank at 125°F. The compression ratio of the two compressors could be significantly different relative to the condensing temperature which is controlled by the temperature of the hot water tank. The unit operating on the colder environment may reach a compression ratio condition that exceeds the recommendation for the compressor before the hot water tank thermostat is satisfied, putting that unit in danger of failure or reduced operating life.

A disadvantage of using common circulating pumps and common tanks for a group of units operating in parallel is that all of the units will be out of operation if the pump, the

tank or a common header experience a failure. The redundancy of using a circulating pump for each unit or supplying a spare pump in parallel may be required in some applications to minimize risk or costs associated with an outage.

5 Summary of benefits for Multi-heat source / multi-heat sink configurations

- (1) The Applicants' system can utilize one or more evaporators or one or more condensers independently to optimize utilization of available heat sources and heat demands according to the timing of events within a given application process. This extends the use of one evaporator and one condenser as disclosed in U.S. Patent
10 7,040,108.
- (2) The Applicants' system can be used to provide heating, cooling, and heated water for any application.
- (3) The Applicants' system will utilize 1 or more 3-way or 2 or more 2-way valves and controls to switch between evaporators and between condensers according to the
15 priorities of the application that are defined in the control system.
- (4) The system can provide hydronic heat to one or more heat sinks via a hydronic heating loop.
- (5) The system can provide both chilled water and heated water for a hydronic heating and cooling system.
- 20 (6) The system can provide tempered water in place of cold water as a way to avoid use of an air cooled condenser during comfort cooling season. This reduces energy consumption by avoiding fan operation, increases heat storage capacity, and reduces sweating from pipes and fixture.
- (7) Units can be installed in parallel to utilize common circulating pumps and storage
25 tanks for increasing capacity while reducing installation cost.
- (8) The system can be used with phase change materials to efficiently store heat or cold for later use in a process or facility.
- (9) The Applicants' system can be used with solar thermal heat collection systems or
30 greenhouses to maximize the thermal energy capture because the collector is continuously cooled which reduces losses to the surroundings and increases the amount of thermal energy that can be collected.

Multi-stage heat dissipation configurations

The condensing path or heat dissipation side of the refrigerant cycle, can be split into useful subcomponents for the purpose of transforming environments or process streams from one state to a desired state. For example, it is possible to utilize one portion of the heat dissipation path of the refrigeration cycle to heat a process stream while another part of the dissipation path is producing steam. The refrigerant passes through three physical phases (vapor, vapor/liquid mixture, and liquid) during heat dissipation. The refrigeration processes associated with each phase are desuperheating (vapor), condensing (vapor/liquid mix) and subcooling (liquid). Desuperheating and subcooling occur over a range of temperatures while condensing occurs at a single temperature or over a small range of temperatures if the refrigerant is a mixture of refrigerants. Each process occurs at approximately the same pressure, except as affected by pressure losses in the piping and system components. In general, each segment of the heat dissipation path may be used to accomplish specific tasks and each segment may be further split to satisfy application requirements. Because the refrigerant is going through a phase change and experiencing significant variation in density, it will be desirable to select heat exchangers that best accommodate the specific phase of refrigerant being processed. For example a heat exchanger and associated piping that handles superheated vapor will be sized and designed differently than a heat exchanger and piping that will process subcooled liquid and both of these may be different than a heat exchanger and piping that processes a vapor/liquid mixture. The physical state of the application space or process streams may also pass through or be in various phases such as if water were heated to produce steam which will further impact equipment and process design.

In the prior art, the water cooled condenser or external condenser of the system was assumed to accept or reject all of the energy associated with desuperheating and condensing. With multiple water cooled condensers, two or more heated conditions can be controlled at a desired temperature. Little attention has been given in the prior art to the energy of subcooling, although subcooling is a critical factor in claims related to frost formation on evaporators and will be an important consideration for process efficiency for some refrigerants. When subcooling is applied, a second or third water cooled condenser (technically called a subcooler) will be required, as described in the following sections.

When the universal formulae and the principles of the classes of refrigeration are applied to an application, the best arrangement and split of the heat dissipation path will be determined so that the refrigeration process and the application requirements will be balanced.

5 The following sections, along with Figures 7 through 11, describe a few of the basic configurations and applications where the heat dissipation path of the refrigerant can be split to satisfy the requirements of an application. As with any embodiment of Applicants' system, the multi-stage heating configuration may be designed for a continuous heating process, batch heating, or both, depending on the application requirements. The
10 configurations described below extend the multi-heat source / multi-heat sink approach disclosed above to include multiple heat exchangers in a given heat dissipation path and the ability to control operation to heat process liquids to higher temperatures.

Heating, cooling, and hot water with mixed superheat cogeneration and rejection

15 A special refrigeration configuration has been developed for applications where the cooling demand exceeds the heating demand but the application will benefit from stored thermal energy at a temperature higher than the normal condensing temperature (hot water tank set point temperature). The configuration is illustrated in Figure 7. The configuration on the refrigeration side is like other multi-heat source / multi-heat sink configurations
20 except that there are two 3-way valves on the condenser side of the compressor and those valves are configured and controlled in a special way. The 3-way valve C3V1 supplies compressed refrigerant to the water cooled condenser or to the external condenser. Valve C3V1 as shown, is not a 3-way reclaim valve however it can be, since check valve 1 is required. Valve C3V1 allows the system to operate in normal water heating mode or heat
25 rejection mode (if the second condenser is not used for some specific heating application). The second 3-way valve C3V2 is positioned down stream of the water cooled condenser and discharges either to the receiver or to the external condenser. Valve C3V2 must be a 3-way reclaim valve since it will be used to draw refrigerant out of the external condenser when the water cooled condenser is being used to heat the hot water tank to temperatures
30 below hot water tank set point (i.e. the refrigerant will be condensing in the water cooled condenser). When both valves are energized the system will continue to heat the hot water

tank above the normal hot water set point (normal refrigerant condensing temperature) when there is a call for additional cooling. The water cooled condenser will operate in desuperheat mode (i.e. the refrigerant remains a vapor in the water cooled condenser and is passed to the external condenser to complete condensation). Thus the system provides a mixed cogeneration and rejection mode operation when used for comfort cooling and water heating. The refrigerant leaving the water cooled condenser at temperatures above the condensing temperature is still a vapor and will then travel to the external condenser to be condensed. It is important that the hot refrigerant lines between the water cooled condenser and the external condenser are insulated to help keep the refrigerant from condensing in the lines before it arrives at the condenser. Preferably, the external condenser is physically located below the water cooled condenser so that any refrigerant that condenses to a liquid prior to the external condenser will be carried by gravity to the external condenser. As with any refrigerant cycle the receiver should be positioned below all condensers to allow the refrigerant to flow by gravity from the condensers to the receiver.

As the temperature in the hot water tank increases, the temperature of the refrigerant vapor traveling to the external condenser will increase. As these temperatures increase, the amount of energy captured in the water will decrease. For many refrigerants the amount of heat captured in the water will range from 10% to 20% of the amount that would be captured while operating the hot water tank at or below the refrigerant condensing temperature (i.e. 10% to 20% of normal cogeneration capacity and 80% to 90% rejection). However, the amount of thermal energy stored in the hot water tank will be greater than it could have been if the system were simply switched to rejection mode when the hot water tank reached its normal set point or the maximum condensing temperature of the refrigerant. Because the tank temperature is higher than the condensing temperature of the refrigerant, the system cannot revert to simple water heating mode until the temperature in the tank is reduced to the condensing temperature of the refrigerant.

This configuration is ideal for any facility with a high cooling load that can use a limited amount of higher temperature water. One example is a carwash that is co-located with a restaurant. The cooling demand in a restaurant (particularly from the kitchen) will coincide with meal times, while the heating demand for the car wash will coincide with the

car wash cycle which will usually be greatest after work hours on weekdays and all day on weekends. The heat rejected from the kitchen will be stored in the hot tank at the highest temperature permissible for the installed equipment and the water going to the car wash from the hot tank will be tempered down to acceptable conditions for use in the carwash by use of a mixing valve. At the point where the car wash demand reduces the hot tank temperature to the normal set point temperature, the system will revert to normal water heating mode to eliminate the rejection mode operation of the external condenser and maximize heat capture into the water.

The above examples assume that the external condenser operates to reject heat. It is not necessary that this condenser be used solely for rejection. For example, a combination dry cleaner / laundry with a small laundry load could use this configuration to provide comfort cooling for the dry cleaning process while generating water at 80°F, 125°F, and 180°F. The 125°F water would be generated using only the water cooled condenser while the 80°F and 180°F water would be generated using both the water cooled condenser and the external condenser, which in this case would be another water cooled condenser. Thus the external condenser would be used to heat incoming cold water to 80°F, which is a luxury that adds value to the laundry process but is usually not affordable when heating water with a fuel. The heat rejection goes to a useful heating process that is optional.

Use of this configuration must be weighed against use of larger storage at normal condensing temperature and the improved efficiency afforded through reduced rejection mode operation given the larger storage capacity. One of the following configurations may also provide a more effective solution for some applications.

Heating, cooling, and hot water with superheated liquid

In some applications it is of value to incorporate two or more water or liquid cooled condensers in series to achieve one or more objectives as was identified in the dry cleaner/laundry example described in the previous section. These condensers may provide desuperheating, condensing or subcooling to the refrigerant while heating the liquid to desired conditions or providing stable, efficient refrigeration system operation.

A two water cooled condenser configuration shown in Figure 8 is similar to Figure 7 except it includes the second water cooled condenser WCC2 and its own circulating loop

and storage tank in addition to the external condenser EC. This system is capable of producing two temperatures of water or liquid, mixed cogeneration/rejection mode operation as described in the previous section and rejection of heat via the external condenser. The first water cooled condenser WCC1 is used for generating water or liquid at temperatures greater than the normal condensing temperature of the refrigerant. It will operate in condensing mode until the temperature of the water in its circulating loop exceeds the condensing temperature of the refrigerant. At that point WCC1 will handle superheated refrigerant vapor and is capable of heating the water in its circulating loop and storage tank to a temperature that approaches the temperature of the superheated vapor entering WCC1. Tanks, pumps, valves, piping, insulation, etc. associated with this loop must all be selected to withstand the temperatures that are desired or possible with superheat operation. Testing with R22 in a 5-ton reciprocating compressor has yielded water temperatures in the neighborhood of 200° F in batch mode operation. The refrigerant vapor entering WCC1 can be in the range of 220°F to 260°F. This implies that it would be possible to generate steam at atmospheric and low pressure conditions using R22. This was verified in testing, as a few times the system vapor-locked due to steam formation in WCC1. A different heat exchanger and piping arrangement would have been needed to separate the steam and water for a steam production process.

WCC2 is used to heat water or liquid in its circulation loop up to the maximum condensing temperature of the refrigerant as controlled by the thermostat in WCC2's hot water tank. This water can be supplied either to WCC1's circulation loop or to a hot water supply system for the application. When using a system like this it is good to have a use for a hot liquid at the condensing temperature provided by WCC2 and at a higher temperature provided by WCC1. When WCC1 is in desuperheating mode on an R22 system, 80% to 90% of the available heat will come out through WCC2 while 10% to 20% will come out through WCC1. These percentages will vary with the refrigerant used in the system.

Cold water is introduced into the WCC2 loop on the suction side of the circulating pump to take advantage of tempering. If the system is controlled to produce a continuous flow at a specific temperature, the cold water will mix with the heated water entering WCC2. This can allow the tank in the WCC2 loop to operate at 5°F to 8°F higher than the

normally acceptable condensing temperature of the refrigerant, since the compressor will see a head pressure corresponding with the mixed water temperature rather than the temperature of the water in the tank. The flow in WCC2's circulating loop is controlled using the Hot Circ Flow Control valve and the tempering water flow rate can be controlled by the Tempering Flow Control valve. These flow rates can be adjusted to obtain the desired level of temperature control. This tempering affect is of course only available if there is a continuous flow of water through the system. Similarly, hot water leaving the WCC2 tank is routed to the suction side of WCC1's circulating pump. This allows the desuperheating process to see a lower temperature at the water side inlet to WCC1, which increases the amount of heat transfer that can be obtained for a given temperature in WCC1's tank. The HT Supply Flow Control valve is used to control the flow of water to allow the system to maintain a set point temperature leaving the tank. If there was no Hot Supply line (i.e. the system heats water on a once through basis) then the HT Supply Flow Control valve could also provide the same affect as the Tempering Flow Control valve for WCC2's circulation loop. The number, style and location of flow control valves will vary with the requirements or opportunities of an application. For example, if the Hot Supply and HT Supply are exposed to atmospheric pressure, then the flow control valves will be best located in the Hot Supply and HT Supply lines. Another example is where a 3-way proportional control valve can be located in the circulation line between the tank and the tempering supply. The 3-way valve would discharge water at a rate sufficient to allow the temperature in the tank to be held relatively constant. The priority in any combination of flow control valves will be to ensure that the compressor head pressure is controlled to within acceptable limits while meeting the temperature requirements of the application. There is no need to limit the circulation flow rate in WCC1's circulation loop although it could help to impose a temperature differential across the water side of WCC1 to promote better heat transfer.

Theoretical analysis shows that given the right evaporator conditions and proper equipment selection while using existing refrigerants, the refrigerant condensing temperature (WCC2) can be maintained as high as 150°F. The greatest limitation on the use of this configuration is the temperature of the superheated refrigerant vapor, or more importantly, the temperature of the oil in the superheated vapor entering WCC1. This

temperature must remain below the point where the oil begins to break down and lose its lubricating capability. The choice of refrigerant and the efficiency of the compressor can have a significant impact on this temperature. With proper equipment selection the configuration can be used to produce saturated steam at low pressures. An additional heat exchanger of appropriate design would be needed to generate superheated steam.

Hydronic heating loops can be applied to either tank. The return from a hydronic loop originating in the WCC1 tank may return either to the same tank or to the WCC2 tank. The primary factor in determining which tank it will return to is the temperature of the return relative to the temperature of the tanks. If the return is hotter than the temperature in the WCC2 tank it must be returned to the WCC1 tank, the return from a hydronic heating loop originating from the WCC2 loop must return to the WCC2 tank.

The utilization of this configuration, to produce a liquid or vapor at a temperature higher than the nominal refrigerant condensing temperature, will be useful in any application where there is a need for cleaning or sterilization of clothing, and equipment such as in laundry, agricultural, food processing, and medical sectors. For example, a hatchery has a significant cooling load to keep the eggs from over heating. The hatchery also needs to sterilize the equipment used to hold the eggs and the chicks several times a week. This configuration can be used to generate and store high temperature water for use in the wash while maintaining the cooling for the eggs.

Heating, cooling, and hot water with subcooled liquid

Figure 9 is the same as Figure 8 except it utilizes the configuration very differently. The objective of this utilization is to provide heated liquid at the condensing temperature in WCC1 and warmed water from subcooling in WCC2. The circulating loop for WCC2 is used to maintain an average temperature in the tank for subcooling. This is useful if the water usage through the system is intermittent or the temperature of water returned from hydronic heating loops is variable. The tank helps to keep the refrigeration system operation more stable. If the conditions of the cool liquid entering WCC2 will be consistent such as might be the case with a once through heating system, the circulating loop and tank may not be necessary as depicted in Figure 10. In this case, the warmed

water is introduced directly into the suction side of the WCC1 circulating loop pump. There may be applications where warmed water or liquid can be useful.

This configuration will be important for use of refrigerants such as R410A and R422B. The added subcooling is important for obtaining the maximum efficiency out of the refrigeration cycle. When the refrigerant is expanded through the TX valve, a certain fraction of the refrigerant is converted to a vapor and the rest remains a liquid. The expansion process is considered to be isenthalpic or it occurs at a constant enthalpy. Enthalpy is the measure of the energy content of the refrigerant in Btu/lb. The enthalpy of the liquid refrigerant leaving condenser WCC2 will be greater than the enthalpy of the liquid leaving WCC2, since some energy will have been imparted to the water or liquid. This subcooling will allow the fraction of vapor in the mixture to be lower and the fraction of liquid in the mix to be higher after the TX valve. Since the refrigeration effect is produced by the boiling of the remaining liquid fraction of the liquid/vapor mixture in the evaporator, the mixture generated from the subcooled refrigerant will be able to capture more heat in the evaporator. When the evaporator captures more heat, the refrigeration effect is increased and the COP of the system is enhanced. The maximum refrigeration effect occurs when the liquid refrigerant is subcooled to the temperature which corresponds to saturated liquid at the suction pressure or pressure at the inlet of the evaporator. For some refrigerants such as R410a and R422B the system can lose in the neighborhood of 40% to 50% of the refrigeration effect during expansion in the TX valve. By using subcooling, the refrigeration effect and system efficiency will be significantly increased.

This utilization of this configuration can be applied anywhere that the system can be used with consideration of the issues related to using once through subcooling as in Figure 10 or using a tank and circulating loop as depicted in Figure 9. To take advantage of the subcooling, the system is best applied in situations where there will be a consistent flow of water or liquid to be heated or in the case of a hydronic heating system to be reheated.

Heating, cooling, and hot water with superheated liquid and subcooling

Figure 11 illustrates a system configured to provide subcooling via WCC3, condensing via WCC2 and superheating via WCC1. The configuration basically combines

the concepts of the previous 2 sections to arrive at a way of generating higher liquid temperatures while maintaining higher efficiency through use of subcooling. The same concepts of superheat and subcooling apply except they are combined into the same system. A fourth heat exchanger would be needed prior to WCC1 in the refrigeration path if the system were to be used to generate superheated steam.

When multiple heat exchangers are connected in series, the designer must be careful to size the equipment to control the pressure drop on both sides of the heat exchangers or water cooled condensers. The pressure drop on the refrigerant side should be held to a minimum to help limit compressor power requirements and maximize capacity. The pressures and pressure drops on the water or liquid side should be controlled to avoid creating low pressure points where heated liquid may become prone to boiling where it isn't desirable. If boiling occurs, the system will be subject to vapor locks and cavitation in water pumps.

Summary of Multi-Stage Heat Dissipation Benefits:

- (1) The ability to use two heat exchangers (referred to as a water cooled condensers WCC1 and WCC2) in series in the refrigerant path to provide heating of water or a liquid to temperatures higher than the normal maximum condensing temperature of the refrigerant at the head pressure of the system. WCC1 desuperheats the refrigerant while WCC2 condenses the refrigerant.
- (2) The ability to use two heat exchangers in series in the refrigerant heat dissipation path to provide subcooling of the refrigerant to improve system refrigeration and heating effect, overall system capacity and coefficient of performance. WCC1 desuperheats and condenses the refrigerant and WCC2 subcools the refrigerant.
- (3) The ability to use three heat exchangers in series in the refrigerant heat dissipation path to provide both subcooling of the refrigerant and heating of water or a liquid to temperatures greater than the normal maximum condensing temperature of the refrigerant. This provides improved performance as well as improved system flexibility and increased application opportunities. WCC1 desuperheats the refrigerant, WCC2 condenses the refrigerant, WCC3 subcools the refrigerant.

- 5 (4) The ability to apply any refrigerant to the claims of this section with allowance for equipment needed to accommodate specific properties of the refrigeration that may not have been specifically identified in this description. For example, the equipment used to refrigerant R410A must be capable of handling the higher pressures required for operation using R410A.
- (5) The ability to use any reasonable number of heat exchangers in series in the refrigerant heat dissipation path to achieve a goal of heating one or more liquids to desired conditions.
- 10 (6) The ability to use any reasonable number of the appropriate heat exchangers in series in the refrigerant heat dissipation path to boil water or other liquid being heated.
- (7) The ability to use a thermostatically controlled tank and circulation pump with each heat exchanger in series to provide heated liquid storage and consistent or controlled process temperatures.
- 15 (8) The ability to generate heated water in batch or on a continuous basis. For continuous flow the ability to apply any variety of water flow control regimes to provide compressor head pressure control or subcooling control while obtaining the desired quantities of water heated at the desired temperature. Flow controls may include but will not be limited to manually operated valves or any of a variety of
- 20 automated valves operated to vary the flow so as to maintain the desired temperature of a given circulating loop and storage system.
- (9) The ability to control the temperature of liquid refrigerant leaving the last heat exchanger in the refrigerant heat dissipation path through use of the thermostatically controlled tank and circulating pump at a temperature which
- 25 improves the refrigeration system performance by helping to control ice on the evaporator and allowing the compressor to operate at a more efficient operating point.
- (10) The ability to apply multiple sets or circuits of series heat exchangers in parallel from the same compressor using 3-way or 2-way valves to take advantage of
- 30 different operational opportunities in an application.

- (11) The ability to apply a condenser for use in rejecting heat in parallel to a series of heat exchangers in the refrigerant heat dissipation path.
- (12) The ability to heat a liquid to temperatures higher than the normal refrigerant condensing temperature using a fraction of the available heat while rejecting the rest of the heat or using it in an optional heating process.
- (13) The ability to define a refrigeration system that uses two or more 3-way or 2-way powered valves to control the refrigeration process according to thermostats associated with various states or operating modes of an application. For example, the 7 controllable components of the system illustrated in Figure 8 are tabulated with the 6 operating modes of the system in the green table on the exhibit drawing. Operating modes include use of two different evaporators to collect heat to heat either the hot tank (WCC2) or the high temperature tank (WCC1). Also included is a mode for mixed cogeneration to the high temperature tank and rejection via the external condenser EC and a mode for pure heat rejection operation using the external condenser EC.
- (14) The ability to apply multiple compressors each with multiple heat exchangers in series in the refrigerant heat dissipation path in a parallel configuration with the circulation and tank system. In-other-words the circulation pump, tank and associated hydronic heating systems may be shared across multiple RASERS units each with their own evaporators and heat sources.
- (15) The ability to conduct refrigerant subcooling via a direct water (liquid) source or returns from a hydronic heating system where the mixture of water (liquid) entering the subcooler will be relatively consistent in volume and temperature, (Figure 10).
- (16) The ability to conduct refrigerant subcooling via a circulating system with a tank to help stabilize the operation of the refrigeration system when the supply and return water are variable (Figure).
- (17) The ability to heat water, glycol, oils, ethanol, or any liquid in the liquid cooled heat exchangers provided the heat exchangers are selected with respect to the properties of the liquid.
- (18) The ability to heat air or any gas or vapor in the heat exchangers provided the heat exchangers are selected with respect to the properties of the gas or vapor.

Multi-stage heat collection configurations

The Applicants' system may utilize any evaporator or evaporator configuration that satisfies the requirements of the refrigeration cycle while serving the demands of the application.

This patent previously described the use of more than one evaporator circuit to allow

5 thermal energy to be collected from different locations where only one evaporator circuit was used at a time. In this section we expand the definition of a circuit to include use of one or more evaporators in a circuit at the same time as dictated by the requirements or opportunities of the application. Some applications may require multiple evaporators in series and some may require multiple evaporators in parallel for a given mode of operation.

10 In general, the evaporator circuit may be split into more than one evaporator when the application provides multiple heat sources that are smaller than the nominal capacity of the Applicants' system selected to satisfy the thermal energy demands of the application.

The basic parallel configuration includes the use of an expansion configuration at each evaporator. The high pressure liquid refrigerant leaving the receiver may pass through
15 a set of valves (2-way or 3-way) to select the desired evaporator circuit based on environmental variables. After the valves, the refrigerant is split through use of tees or a distribution device to supply each parallel evaporator path in the circuit. It is important that the splitting process be designed so as to avoid expansion of the refrigerant until it reaches the expansion configuration. After the split the liquid refrigerant will pass through
20 the expansion configuration (TX valve, orifice, distributor, etc.) on its way to the evaporators. After the evaporators the superheated refrigerant will be recombined into the suction line feeding the compressor using tees or other means to collect multiple refrigerant streams into one. With parallel evaporators it may be necessary to utilize a pressure control device between the evaporators and the compressor to ensure that the pressure leaving the
25 evaporators is the same. An example where parallel evaporators can be used is in a hog barn. Two or more evaporators may be placed in front of separate exhaust fans to allow thermal energy capture sufficient to allow the unit to operate at nominal capacity.

The basic series configuration uses only one expansion configuration but splits the evaporator into two or more parts to provide the cooling effect to two or more

30 environments while satisfying the superheating requirements of the refrigeration cycle.

The multiple evaporators will usually be reasonably close to each other and the pipe

connecting the evaporators will usually be well insulated to avoid losing the refrigeration effect between the evaporators. The refrigerant may pass between the evaporators through a single pipe or it may pass through multiple pipes or a multi-port mixing device. An example where a series configuration is useful is where an environment may require a small or controlled amount of cooling relative to the total cooling capacity. The evaporators will be sized to support the controlled cooling activity and may be made from any material as dictated by the environment served by the evaporator.

The temperature of the refrigerant during evaporation (a liquid/vapor mixture) will be constant or for a refrigerant mixture, will vary by a small amount while the refrigerant is boiling within the evaporator (i.e. just like water boils at 212°F at standard atmospheric pressure). After all of the refrigerant is boiled, its temperature will begin to rise as more thermal energy is applied to the evaporator (this is called superheat). The temperature rise (degrees of superheat) is limited to only the amount necessary to avoid introducing liquid refrigerant into the compressor. It is also beneficial to limit the amount of superheat because the capacity of the compressor decreases as the amount of superheat increases due to the reduction in density of the superheated vapor as its temperature increases. The thermal expansion (TX) valve usually provides a means to adjust the degrees of superheat. The expansion and evaporator configuration must be selected to provide the best possible system capacity while satisfying the cooling demands of the environments served.

The evaporators must be selected to account for differences in the environmental conditions. For example if two evaporators operating in series experience different environmental temperatures then the evaporators may or may not be the same size depending on how much of the evaporation process each evaporator is intended to handle. In contrast two evaporators operating in parallel will likely be sized differently if they are exposed to different temperature environments to help match the temperature and pressure of the refrigerant leaving each evaporator. Parallel and series evaporator configurations are most easily applied to multiple similar environments. Series evaporator configurations can be more easily applied to multiple environments with different operating conditions or multiple environments with similar operating conditions.

Summary of Multi-Stage Heat Collection Claims

1. Ability to use one or more evaporators in an evaporator circuit.
2. Ability to connect multiple evaporators in series or in parallel on a single circuit.
3. Ability to use one or more evaporators to provide multiple controlled cooling
5 activities for air, water, glycol mixtures, oils, ethanol or any liquid, vapor, or gas to be cooled.
4. Ability to use multiple elements in the expansion configuration such as the TX valve, orifice, and distributor.
5. Ability to use evaporators manufactured from any material (copper, stainless steel,
10 aluminum, etc.) as dictated by the environment served by the evaporator to protect the evaporator from failure due to corrosion, erosion, thermal fatigue, or other phenomenon.
6. Ability to size evaporators to match different environmental conditions while obtaining desired refrigeration system operation.

Summary of Exemplary Uses of the System

Laundromat – In a laundromat, the system heats fresh water for a wash cycle while providing comfort cooling for the workers/customers, by collecting waste heat from the drier exhaust vents, or collecting waste heat from the waste water.

20 **Dry cleaner/Laundromat combination** – The system heats fresh water or tempered water from dry cleaner cooling system while providing comfort cooling for workers/customers, collecting waste heat from the drier exhausts, or collecting waste heat from the waste water.

25 **District heating** – The system utilizes the excess thermal energy from a laundromat, dry cleaner, or other energy intensive business located in a commercial or residential area to heat water that can be piped and metered to neighboring businesses or residents for direct use as heated water and for use in space or process heating.

30 **Meat Processing (kill and products)** – The meat processing process generally requires a significant amount of heated water for washing and sterilization. The system has the ability to heat water from several sources: waste heat from the singe process, excess ambient heat from the sterilization or cooking processes (comfort cooling), waste heat from

the carcass wash and facility cleanup wastewater, and heat expelled from the refrigeration processes required to chill the carcass prior to cutting or after processing. The ability to provide comfort cooling through use of a forced draft air handler with a-coil provided the environment does not present a high fouling potential. Finless evaporators may be used to recover waste heat from singe and waste water to minimize fouling and allow ease of cleanup. There is also the ability to collect heat expelled by the refrigeration process using an evaporator at the exhaust of the condenser. The system has the ability to directly provide refrigeration and water heating simultaneously. This is the most economical heat recovery mode since both activities are performed using the same kW of power that was going to be used for refrigeration regardless of how the water was heated.

Car Wash – The system heats wash water for a car wash and in floor heated water loops used for office heating and eliminates ice formation at the approaches to the wash bays. The heat derives from several heat sources: wastewater, excess heat in the office or mechanical room, excess heat from an adjoining convenience store or restaurant, warm humid air exhausted from the wash bays or the outdoor ambient air.

Restaurant – A restaurant benefits from both heating and cooling affects of the system. The kitchen is cooled year-round while water is heated for dish washing and for use in heating the restaurant. The restaurant can be cooled during high occupancy and during the cooling season while heating water for dish washing. Since the cooling load usually exceeds the water heating demand an air cooled condenser, warm water supply, or district water heating system will be needed during the summer.

Swimming pool – The system can heat swimming pool water using heat from the ambient air or from excess heat in the offices, shower house or mechanical room (comfort cooling).

Campground shower house – Shower house water can be heated with the system using heat from the ambient air or from excess heat and humidity in the shower house or mechanical room (comfort cooling). Comfort cooling in the shower house may help to extend the life of equipment and parts that are subject to the high humidity usually found within the shower house.

Animal Confinement – (Animals and foul including but not limited to: hogs, dairy cattle, beef cattle, chickens, turkeys, etc.) The system has the ability to heat the living space using the waste heat that is exhausted via the ventilation system or from comfort cooling in

critical areas such as the breeding room or boar stud area. Heating may be in the form of heating the air in the room or localized heating as for baby pigs in a farrowing crate or small animals for the first few days or weeks after they are weaned or hatched. Some animals may also benefit from the ability to heat drinking water using waste heat from an exhaust or heat captured from comfort cooling processes. Some stages of animal husbandry will benefit extensively (weight gain, survival, conception rates, reduced stress/susceptibility to disease...) by providing comfort cooling during hot humid summer days. Excess heat from comfort cooling is generally used for heating wash water or drinking water or is expelled in an air cooled condenser. If animal confinements can be properly co-located, the system has the ability to use excess heat generated by larger animals to heat spaces for smaller animals. Heating spaces using Applicant's hydronic heating system has the ability to reduce humidity and toxic gas loadings in the space when compared against direct fired propane or gas heaters. The system has the ability to use excess heat from animal confinements (heat and humidity generated by the animals) to heat anaerobic digesters year-round. The system can also provide the ability to transform the waste thermal energy to heat the residence, shop/office or to provide some heat input for low temperature grain drying either in the bin or in a drying process via an appropriate district heating system. In some specialized animal research facilities, the system has the ability to heat water for the sterilization processes using waste heat from ventilation exhaust, waste heat in the wastewater, and excess heat in the rooms where the sterilization equipment resides (comfort cooling for the workers).

Dairy – The dairy farm provides a unique opportunity. The system provides cooling for the milk and can be used to cool the offices, and milking parlor. A cooled parlor may contribute to comfort for the cows and increase milk volume. The captured heat can be used to heat Clean In Place (CIP) water and the drinking water. Warm drinking water may also help increase the amount of water the cows drink which can contribute to increased milk production. Since dairy manure is well suited for digesters, the excess heat from the various value added cooling activities can also be used to support an onsite digester.

In-Line Processes (General) – The in-line process involves the integration of the system into a process to utilize the simultaneous cooling and heating affects. Most in-line processes will use cogeneration on a continuous basis when the process is operating. The

introduction of the system will displace a portion if not the entire use of separate heat sources and cooling sources. Any manufacturing process that needs both heating and cooling presents an opportunity to apply the system.

Hatchery – The system also has the ability to collect heat from cooling water used to cool the incubators and from ventilation exhaust. The reclaimed heat can be used for space heating and to heat wash water and humidification spray water. The ability to recycle the cooling water will provide significant savings in water and wastewater disposal costs. The ability to integrate the system into the incubators will provide both heating and cooling inside the box through finned hydronic systems.

Anaerobic Digesters – Anaerobic digesters require close monitoring of temperature to ensure bacterial activity. The manure must be heated as it enters the digester and the temperature must be maintained throughout the anaerobic conversion process. Our system provides the ability to collect heat from the manure leaving the digester and use it to preheat the manure entering the digester. In addition the gas treatment systems and energy conversion systems often associated with digesters produce excess heat which can be captured and used to preheat manure and maintain the temperature of the manure in the digester. Waste heat from nearby animal confinements can also be captured and used as well as heat from the ambient air.

Bio-diesel Production – Bio-diesel production requires that the raw oil be heated and that the various process streams be heated and cooled at various points along the way. Most processes use a boiler to heat the oil and a cooling tower to help cool the process stream. Many processes also use a chiller at some point in the process. The chiller can be replaced with Applicants' stem to provide both chilling and process heating. In addition, the heat remaining in the bio-diesel after conversion may be extracted for process use. Heat in the cooling water going to the cooling tower can also be used to heat makeup or condensate water for the boiler or for heating a process stream. Excess heat in the boiler/mechanical room (includes waste heat generated by compressors) and waste heat from the boiler exhaust can also be captured and introduced into the process. Before the bio-diesel process, the oil is usually generated in an extrusion process. Extrusion generates a good deal of heat which might also be captured and reintroduced into the process at an appropriate location.

Ethanol Production – Ethanol production has some similarities to bio-diesel processing. The process involves a boiler and a cooling tower and may involve a chiller. The process streams are heated and cooled for the various stages of the process. Some ethanol processes utilize a great deal of fresh water to wet and cook the mash and makeup water for boiler. All of this water must be heated. The present invention can heat the water used for the cook process and preheat the condensate and makeup water for the boiler. Heat may be collected from the cooling water lines either before or after the cooling processes. In a retrofit application, the system can help to compensate for an undersized cooling tower. Excess heat from the boiler/mechanical room and boiler exhaust are also available for heating. It may also be possible to design a condensing system to cool the exhaust from the distiller's grain driers. In addition to recycling the heat, the condensed water can also be treated and reused in the process. Seasonal applications such as space heating or comfort cooling may also be incorporated into the plant however the payback on a season application is longer than the payback from supporting the process.

Canned or frozen vegetable or prepared food processing – The canned food process usually requires cooking and elevated temperatures to vacuum seal containers. The excess and waste heat from the process can be recycled into heated process and wash water using the system. The frozen food process usually requires chilling and may involve cooking or blanching. The excess or waste heat from these processes can be used to heat process or wash water. With our system the chilling process can perform both chilling and water heating. Excess heat can also be used to heat other parts of the facility or for a district heating system.

Painting processes – Powder coat and baked paint processes utilize ovens to cure the paint and produce a great deal of excess and waste heat. The system can utilize this excess thermal energy to heat wash water, heat other parts of the manufacturing facility or heat water for a district heating system.

Extrusion and molding processes – Extrusion processes generate a great deal of excess heat which can be utilized to heat other parts of the facility or to heat process and wash water. Some molding processes such as foam pallet forming utilize a great deal of heated water/steam and generate a large sensible and latent heat load in the facility. This system

can cool the facility and the cooling water while generating preheated water going into the boiler.

Boilers and Mechanical Rooms – Boiler and mechanical rooms provide opportunity to collect excess or waste heat and heat water. Air and refrigeration compressors generate appreciable amounts of heat and boilers have ambient radiation and convection losses as well as exhaust. Other types of equipment also generate heat. Our system will benefit compressors by cooling the air and the environment around the compressor. Cooler air will increase the density of the air and improve the capacity of the compressor and cooler operating conditions will reduce wear on the equipment and lubricating oils resulting from excessive heat. For boilers, the excess or waste heat can be reclaimed by the system to preheat makeup or condensate return water or to preheat combustion air. The scale of such systems can range from a few thousand Btu/hr to large utility scale power plants. Extracting heat from a boiler exhaust will require special evaporator configurations and use of materials such as stainless steel that will be suitable for the potentially corrosive boiler exhaust.

Greenhouse – A greenhouse provides a significant source of heat during the day. Even on sunny cold winter days the temperature in the greenhouse can climb and produce warmer temperatures than desired. During summer months the temperatures in a greenhouse become oppressive. This heat source can be utilized in a number of settings. In an actual functional greenhouse the excess heat generated during the day can be captured by the system and stored in heated water and then distributed into the facility at night. During the summer when excess heat prohibits plant culture the excess heat might be used to heat water for nearby processes. The greenhouse can also be used in commercial office buildings, apartments, hotels, concrete plants, hospitals or any building requiring heat that doesn't have a waste heat source. The greenhouse can be used to collect ventilation exhaust and solar heat gain (not necessarily used for growing plants). The heat captured from the greenhouse by the system can be used to heat water for showers, laundry, swimming pools, concrete mix on cold days, etc. By cooling the space the amount of thermal energy that can be captured will increase. The moisture in a building exhaust that is captured in the greenhouse can be collected and reused for non-potable uses or treated for potable use.

High Rise Buildings, Apartments and Hotels – The system can tie into large heating cooling and water heating systems for large high rise buildings. Using a hydronic loop and localized water heat pump/fan units heating and cooling can be accomplished in different parts of the building simultaneously by collecting excess solar gain from the sunny side of the building and transferring it to the shaded side of the building. Our system is used to chill the loop during the summer and the excess heat is used to heat potable water for showers/baths, laundry, swimming pools, etc., and can also be used to recoup heat from continuous ventilation exhaust and wastewater to makeup heat into the hydronic heating loop and to heat other spaces such as the parking garage, makeup air, etc. during the heating season.

Grain and Hay Drying – Heat from warm moist air exhausted from the drying process can be reclaimed by the system to preheat incoming dry air and improve the drying process efficiency.

Hydrocarbon to oil systems – Recently a number of systems are being developed for converting wet hydrocarbon materials to crude oil through a process involving high pressure and temperature (hydrothermal depolymerization). The system can be integrated into the process to preheat the hydrocarbon-water slurry based on heat collected from the discharged oil and heat losses from the process.

What is claimed is:

1. A bio-renewable thermal energy system comprising: a refrigeration system having a first evaporator, a compressor, and a first condenser which are operable in rejection, reclamation and cogeneration modes.
- 5 2. The thermal energy system of claim 1 further comprising a second evaporator operated independently of the first evaporator.
3. The thermal energy system of claim 2 further comprising a second condenser
10 operated independently of the first condenser.
4. The thermal energy system of claim 1 wherein the refrigeration system is operable for both heating and cooling.
- 15 5. The thermal energy system of claim 1 further comprising a hydronic heating loop.
6. The thermal energy system of claim 1 wherein the refrigeration system can provide both heated and chilled liquid or gas.
- 20 7. The thermal energy system of claim 1 wherein the refrigeration system utilizes environmental thermal energy from one source to heat another body of fluid or air.
8. The thermal energy system of claim 7 wherein the one source is a meat processing plant.
- 25 9. The thermal energy system of claim 7 wherein the one source is a car wash.
10. The thermal energy system of claim 7 wherein the one source is a restaurant.
- 30 11. The thermal energy system of claim 7 wherein the one source is an ethanol plant.

12. A thermal energy system of claim 7 wherein the one source is a laundromat.
13. A thermal energy system of claim 7 wherein the one source is a dry cleaner.
- 5 14. A thermal energy system of claim 7 wherein the one source is a swimming pool.
15. A thermal energy system of claim 7 wherein the one source is a shower house.
- 10 16. A thermal energy system of claim 7 wherein the one source is an animal
confinement building.
17. A thermal energy system of claim 7 wherein the one source is a dairy.
18. A thermal energy system of claim 7 wherein the one source is an in-line process.
- 15 19. A thermal energy system of claim 7 wherein the one source is a hatchery.
20. A thermal energy system of claim 7 wherein the one source is an anaerobic digester.
- 20 21. A thermal energy system of claim 7 wherein the one source is a bio-diesel
production facility.
22. A thermal energy system of claim 7 wherein the one source is a food processing
facility.
- 25 23. A thermal energy system of claim 7 wherein the one source is a paint coating
facility.
24. A thermal energy system of claim 7 wherein the one source is an extrusion
30 processing facility.

25. A thermal energy system of claim 7 wherein the one source is a molding process.
26. A thermal energy system of claim 7 wherein the one source is a boiler.
- 5 27. A thermal energy system of claim 7 wherein the one source is a greenhouse.
28. A thermal energy system of claim 7 wherein the one source is a human living facility.
- 10 29. A thermal energy system of claim 7 wherein the one source is a grain drying facility.
30. A thermal energy system of claim 7 wherein the one source is a hydrocarbon to oil processor.
- 15 31. An improved thermal energy utilization process having a refrigeration system with a hot side and a cold side, the improvement comprising: splitting heat from the hot side for use in multiple heating applications.
- 20 32. The improved process of claim 31 further comprising splitting the cold side for use in multiple cooling applications.
33. The improved process of claim 31 wherein the process utilizes a refrigerant having a condensing temperature, and wherein one of the heating applications is heating
25 liquid to a temperature greater than the condensing temperature of the refrigerant.
34. The improved process of claim 31 wherein one of the heating applications is the boiling of a liquid.
- 30 35. The improved process of claim 31 wherein the split heat is directed through multiple heat exchangers.

36. The improved process of claim 31 further comprising utilizing environmental thermal energy from one source to heat another body of fluid or air.
37. The improved process of claim 36 wherein the one source is selected from a group consisting of a meat processing plant, a car wash, a restaurant, an ethanol plant, a laundromat, a dry cleaner, a swimming pool, a shower house, an animal confinement building, a dairy, an in-line process, a hatchery, an anaerobic digester, a bio-diesel production facility, a food processing facility, a paint coating facility, an extrusion processing facility, a molding process, a boiler, a greenhouse, a human living facility, a grain drying facility and a hydrocarbon to oil processor.
38. An improved thermal energy utilization process using a refrigeration system having a water tank, a pump, a heat exchanger, and a compressor, the process comprising: controlling head pressure of the compressor using fluid in a first circulating loop so as to protect the compressor and maintain acceptable compressor efficiency.
39. The improved process of claim 38 further comprising controlling refrigerant subcooling using fluid in a second circulating loop so as to increase compressor efficiency and increase cooling and heating capacity.
40. The improved process of claim 38 further comprising a heat path which is utilized to heat a liquid before any heat is rejected from the process.
41. The improved process of claim 38 wherein the process includes a desuperheating segment which is used to heat a fluid to a temperature above the condensing temperature of the refrigerant.
42. The improved process of claim 41 further comprising using a third circulating loop to control desuperheating.

43. An improved thermal energy utilization process using a refrigeration system having a water tank, a pump, a heat exchanger, and a compressor, the process comprising: controlling refrigerant subcooling using fluid in a first circulating loop so as to increase compressor efficiency and increase cooling and heating capacity.

44. The improved process of claim 43 further comprising controlling head pressure of the compressor using fluid in a second circulating loop so as to protect the compressor and maintain acceptable compressor efficiency.

45. The improved process of claim 43 further comprising a heat path which is utilized to heat a liquid before any heat is rejected from the process.

46. The improved process of claim 43 wherein the process includes a desuperheating segment which is used to heat a fluid to a temperature above the condensing temperature of the refrigerant.

47. The improved process of claim 46 further comprising using a third circulating loop to control desuperheating.

48. A method of balancing a thermal energy recovery system, comprising: determining a desired level of thermal energy change at a specific location; choosing a refrigerant to use in a refrigeration system; determining how many evaporators to use in the system; determining how many condensers to use in the system; selecting a compressor for the refrigeration system; calculating energy losses from the evaporators, condensers and compressor; and maximizing the utilization of both heating and cooling resources during operation of the refrigeration system.