

**Title:**

**Introducing a novel thermodynamic cycle  
(patent pending), for the economic power  
generation from recovered heat pumped  
from the huge global thermal energy  
storage reservoir called earth.**

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## The problem of economy for low temperature heat recovery.

Heat extraction from low temperature waste heat sources is not difficult, but it borders on the uneconomical due to the low heat to power conversion efficiency. Using the geothermal classification, heat sources  $>200^{\circ}\text{C}$  are regarded as high and conversion efficiency may reach  $> 25\%$ , while heat sources in the  $150^{\circ}\text{C} - 200^{\circ}\text{C}$  are classified as moderate and conversion efficiencies range  $20 - 25\%$ , while a heat source in the range  $100^{\circ}\text{C} - 150^{\circ}\text{C}$  is regarded as low and heat to power conversion efficiencies are only  $10 - 20\%$ . Heat sources below  $100^{\circ}\text{C}$  are regarded as uneconomical to convert to power due to the low heat-to-power conversion efficiency, and is used for non-electrical applications only. Conversion efficiency in general is limited by the second law of thermodynamics:

$$\eta = (\text{Qin} - \text{Qrej}) / \text{Qin} \quad = \text{Work} / \text{Qin}$$

where **Qin** = input heat, and **Qrej** = rejected heat (in rankine and organic rankine cycles, the latent heat of condensing the low pressure exhaust vapor back to liquid). With a conversion efficiency of only  $10\%$ , the latent heat in the exhaust represent  $90\%$  of the input heat, and therefore the condenser cooling need huge cooling towers which are very expensive and waste a lot of water (for wet cooling) that is made to evaporate for the cooling effect. Low conversion efficiencies also decrease the power density of the converting machine, also increasing the required specific capital investment.

Only the economy of scale may offset some of these low efficiency converters eg. the very large OTEC converters built in the sea which convert the heat in some  $20^{\circ}\text{C}$  surface water using cooling with cold ( $4^{\circ}\text{C}$ ) deep-flowing water streams with conversion to power efficiencies  $< 5\%$ . These installations are extremely large and capital extensive, as they are designed for the MW range to be economical, but not many exist around the globe, mainly due to the large capital investments required.

## The ideal "black box" cycle for heat recovery and power generation.

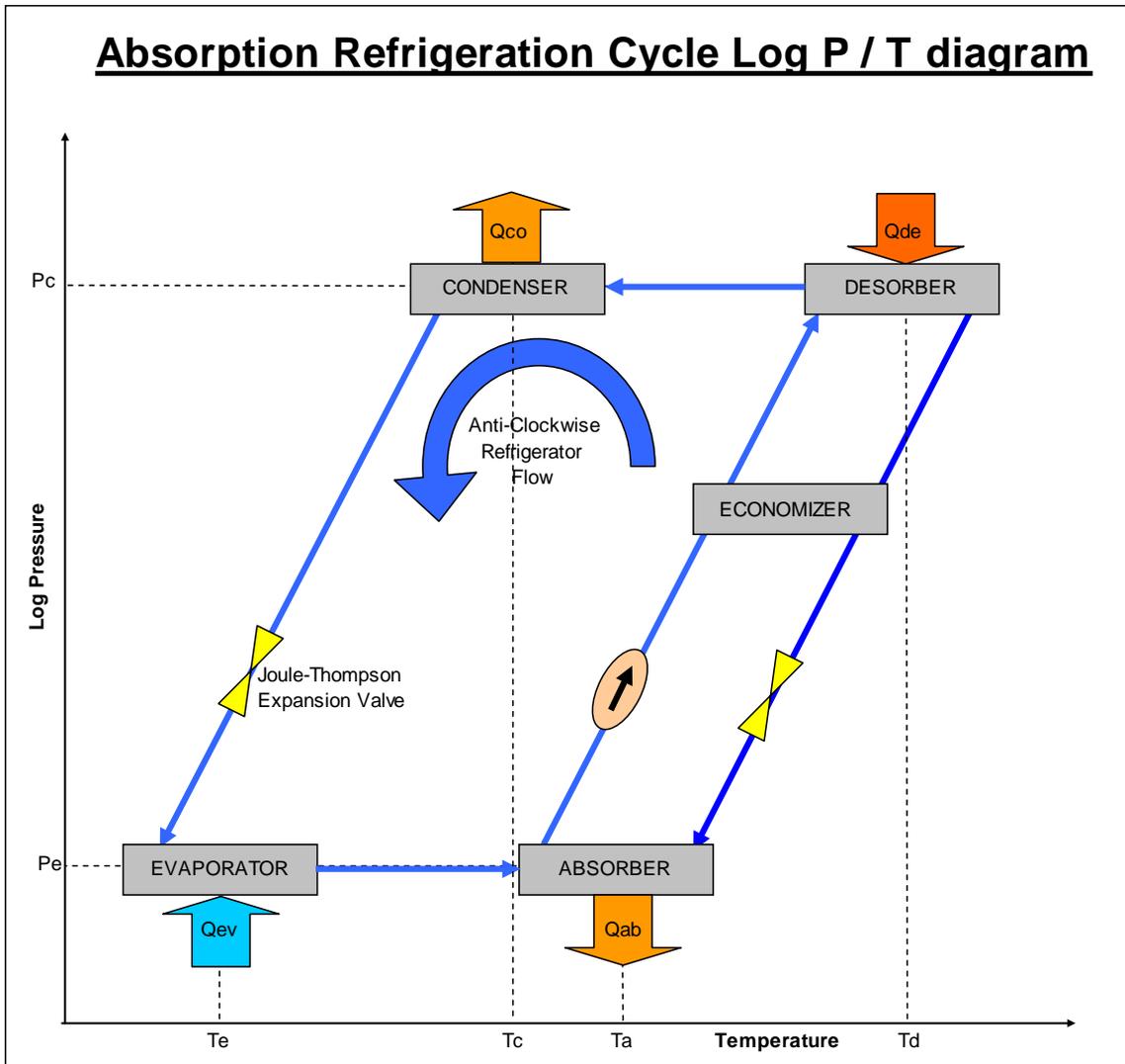
Should we tax our minds to defining what, in our wildest dreams, we would want a heat recovery power generation thermodynamic cycle to be we could list things like:

1. It should have a heat to power conversion efficiency sufficiently high to generate power economically even at very low heat source temperatures below  $100^{\circ}\text{C}$ .
2. It should ideally be able to extract heat in the range of  $10^{\circ}\text{C} - 20^{\circ}\text{C}$  (below ambient) so we can use it to extract power as well as deliver refrigeration from ambient water sources like ponds, dams, rivers, lakes and the sea.
3. Preferably have no requirement for cooling towers that waste water for evaporative cooling, as well as money due to the large structure costs.
4. Must be easily scalable from a few kW to several MW electrical power per unit.
5. No greenhouse emissions may be released into the environment to really produce "green power". All materials and organic media used in its construction and operation must be environmentally friendly.

6. Must have a small capital investment requirement in line with other, more conventional current state-of-the-art renewable power generation equipment.
7. The cycle must be made up of re-combining existing, proven equipment for quick deployment and not rely on novel technology requiring years of development.

A technology with all 7 characteristics as listed above would definitely be classified as a seriously disruptive technology and cause an energy revolution in the next few years.

**Figure 1**



## Heat extraction from the environment using intermediate temperature waste heat.

Looking at some heat recovery and conversion to power technologies, let us start with the ammonia-water absorption thermodynamic cycle used as a heat-driven refrigerator. The standard binary absorption refrigeration cycle as sketched in Figure 1 as a Logarithmic

Pressure vs. Temperature graph above is well known in refrigeration circles already since the fifties. In the graph of Figure 1, the absorber and evaporator is on the low pressure ( $P_e$ ) line, while the desorber and condenser is on the high pressure ( $P_c$ ) line. This binary cycle may be made up of ammonia in aqua mixtures (or other mixtures like LiBr-H<sub>2</sub>O for example). In the rest of this document we assume we talk about NH<sub>3</sub> - H<sub>2</sub>O mixtures only, to keep the explanation simple.

Rich mixture (assume 40% NH<sub>3</sub> in aqua) is pumped from the low pressure (assume 3,57 Bar absolute) absorber via the economizer to the high pressure (10 Bar abs) desorber, where high temperature ( $T_d = 90^\circ\text{C}$ ) heat ( $Q_{de}$ ) boil off some nearly pure NH<sub>3</sub> vapor, which flow to the condenser on the same high pressure level ( $P_c = 10$  Bar abs), where it is condensed by removing or rejecting some heat ( $Q_{co}$ ) to cooling water at the intermediate temperature ( $T_c = 30^\circ\text{C}$ ). The remaining NH<sub>3</sub> in aqua in the desorber after boiling off the NH<sub>3</sub> vapor is a lean mixture (assume 35% NH<sub>3</sub> in aqua) flowing via the economizer back to the absorber at the lower intermediate temperature ( $T_a = 45^\circ\text{C}$ ). The pressure is dropped to the lower pressure ( $P_e$ ) by the restrictor valve in the lean liquid mixture line. The economizer is just a simple heat exchanger, cooling the returning lean mixture by heating the pumped, upwards flowing rich mixture. High pressure ( $P_c$ ) condensed liquid NH<sub>3</sub> from the condenser expand through the Joule-Thompson expansion valve isenthalpically to the cold ( $T_e = -2^\circ\text{C}$ ) evaporator on the low pressure ( $P_e$ ) line. Evaporating liquid NH<sub>3</sub> in the evaporator absorb heat ( $Q_{ev}$ ) as refrigeration from the environment as the temperature ( $T_e$ ) may be quite low (may be  $-2^\circ\text{C}$  if the pressure ( $P_e$ ) is 3,56 Bar absolute. The intermediate heat rejection temperatures ( $T_c$ ) and ( $T_a$ ) are normally kept in the  $30^\circ\text{C} - 50^\circ\text{C}$  region, to make sure cooling water slightly above ambient, at say  $25^\circ\text{C} - 35^\circ\text{C}$  can absorb the rejected heat from the cycle. The desorber high temperature ( $T_d$ ) is determined by available waste heat temp, and may be some  $70^\circ\text{C} - 90^\circ\text{C}$  or higher. If we assume the temperature ( $T_d$ ) to be  $90^\circ\text{C}$  the pressure ( $P_c$ ) would rise to about 10 Bar absolute, which is the 35% NH<sub>3</sub> in aqua mixture saturation pressure.

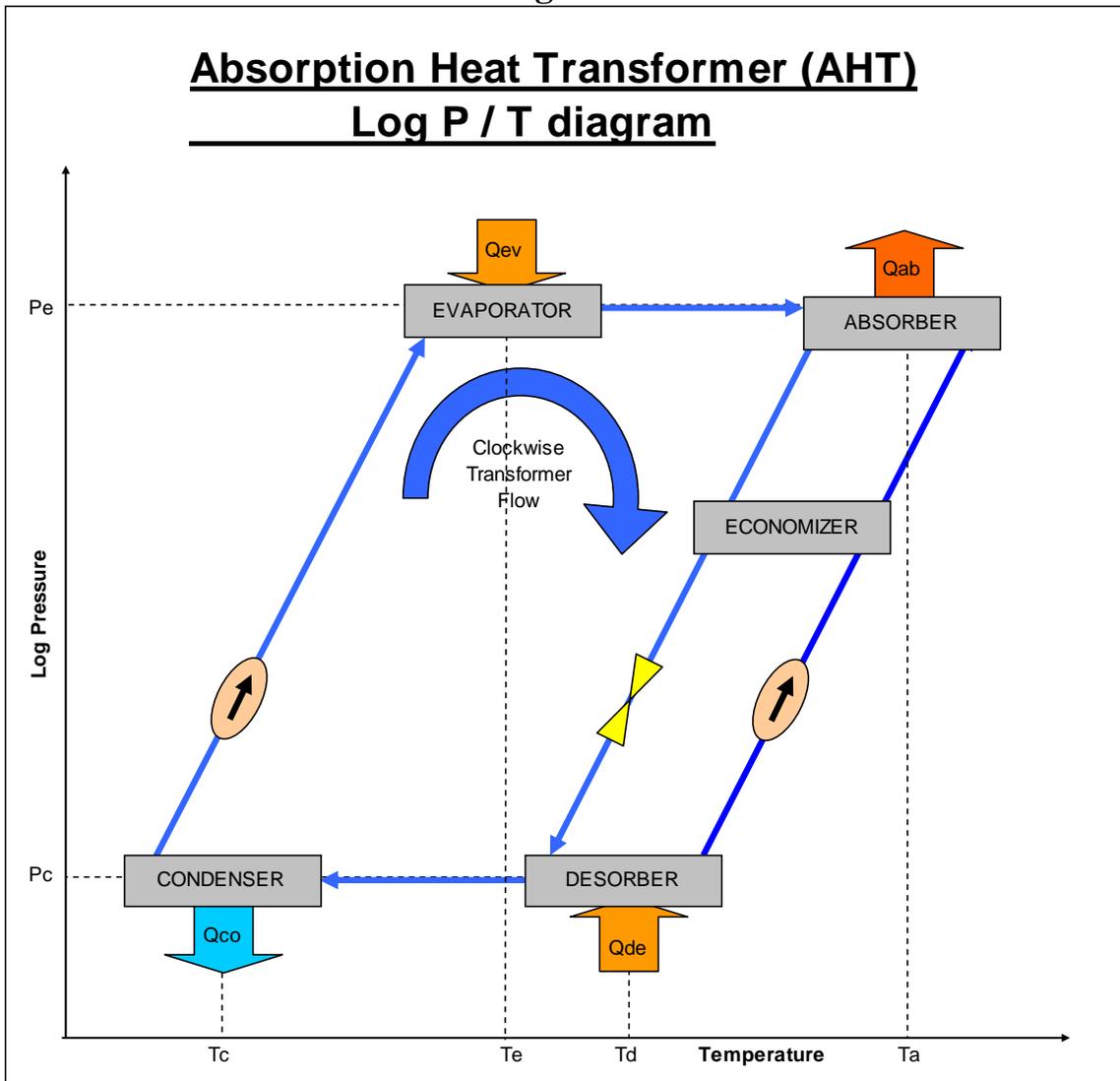
Although the heat ( $Q_{ev}$ ) extracted at  $-2^\circ\text{C}$  from the environment is used to vaporize the liquid NH<sub>3</sub> to vapor (also at  $-2^\circ\text{C}$ ) the absorber temperature is kept higher. The process of absorbing NH<sub>3</sub> into a sub cooled lean mixture of NH<sub>3</sub> in aqua is exothermic and the absorption heat would raise the temperature of the absorber if it is not cooled sufficiently, carrying away the rejected heat ( $Q_{ab}$ ). The sensible heat required to heat the cold vapor from  $-2^\circ\text{C}$  to the absorber temperature of  $45^\circ\text{C}$  amount to 266 kJ/kg, but the heat generated in the absorber by absorbing the heated vapor into the 40% NH<sub>3</sub> in aqua mixture calculate to 1398 kJ/kg. The sensible heat amount to only 19% of the absorption heat! Incidentally, if the pure NH<sub>3</sub> vapor was condensed at  $45^\circ\text{C}$  instead of absorbed, the heat generated would have been 1154 kJ/kg, which is 83% of the absorption heat. The heat of solution (HOS) is therefore  $1398 \text{ kJ/kg} - 1154 \text{ kJ/kg} = 244 \text{ kJ/kg}$  under these pressure, temperature and mixture concentration levels.

## **Pumping extracted waste heat to higher temperatures to gain conversion to power, cycle efficiencies.**

Perhaps a better example of how the heat of solution assist to create higher temperatures can be seen in the absorption heat transformer. A typical example is sketched as Log P vs. Temp graph in Figure 2 below.

Heat transformers are used to raise temperature levels of large waste heat sources eg. a solar pond, to values more conducive to higher efficiencies of converting the heat to power.

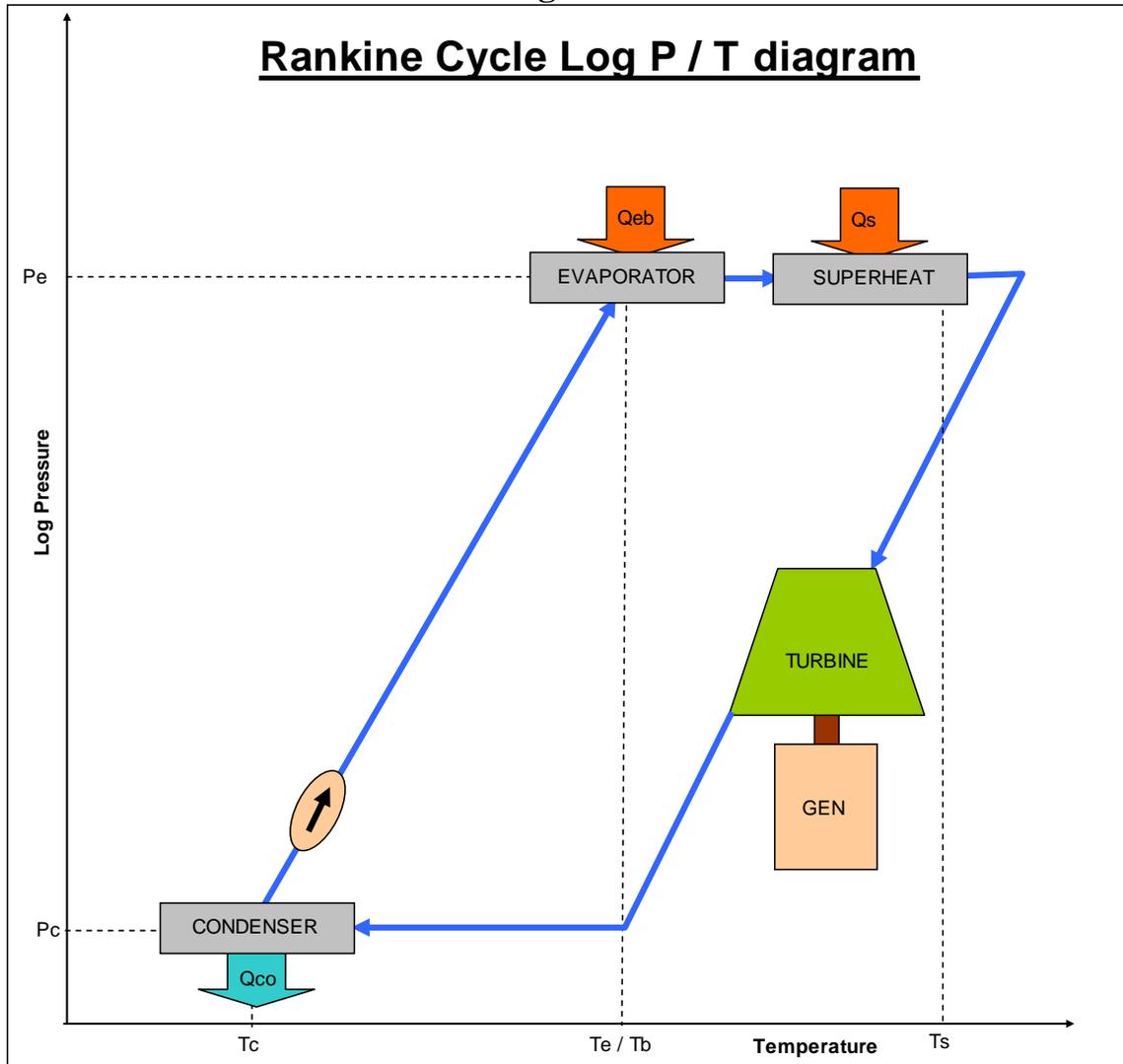
**Figure 2**



In a solar pond, heat is trapped by a salt gradient which reverse the temperature-density relationship. High temperature heavily salted water has a higher density than the less salty, lower temperature water solution that rise to the top of the solar pond. Heat at temperatures of 60 - 80°C generated by the solar radiation is accumulated in the bottom of the salt gradient pond. A heat transformer may be used to pump a large proportion (some 50%) of the heat at this temperature up to 120°C or more and this transformer technology has been matured over the past 20 years or so.

Looking at Figure 2, notice that the desorber and condenser is now at the low pressure level ( $P_c$ ), while the evaporator and absorber is now at the higher pressure ( $P_e$ ).

**Figure 3**

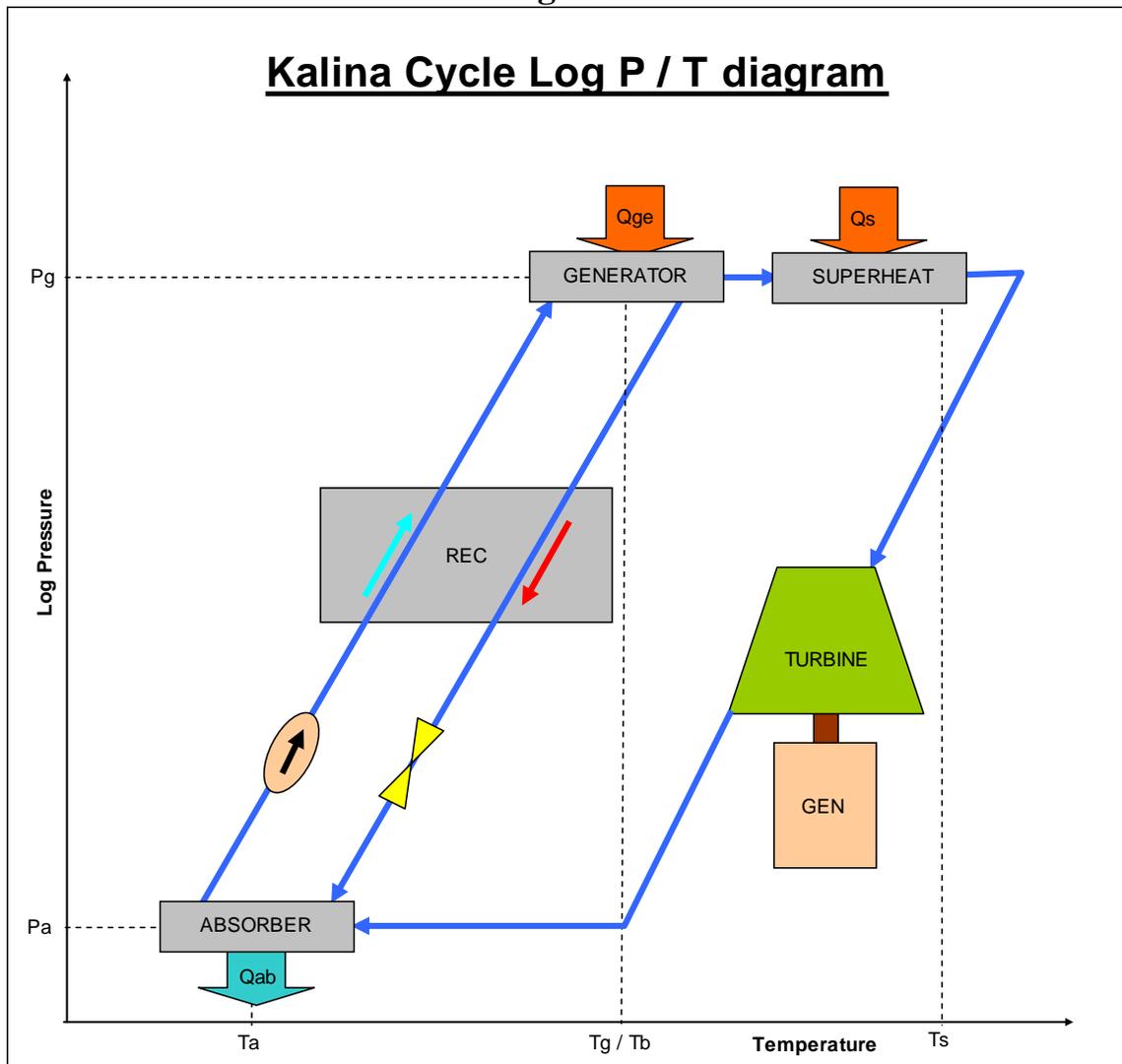


Although the liquid and vapor flows are now flowing clockwise, the operation is basically the absorption refrigeration cycle operated in reverse. Here we see high pressure vapor from the evaporator flow to the absorber and heat the absorber to higher temperature. In practice some 50% of the available heat at 60 - 80°C may become available at the higher absorber outlet temperature ( $T_a$ ) of 120°C or more, while a smaller amount of water is cooled to condenser temperature ( $T_c$ ).

## **Converting heat to power using the rankine cycle and variants thereof.**

For easy comparison, the heat to power conversion cycle we call the rankine cycle have also been plotted on the Log P vs. Temp graph as Figure 3 above. Condensate is pumped from the low pressure ( $P_c$ ) condenser at temperature ( $T_c$ ) to the evaporator at high pressure ( $P_e$ ) and evaporation take place at temp ( $T_e/T_b$ ) due to heat input ( $Q_{eb}$ ), supplemented by some superheat energy ( $Q_s$ ) at temperature ( $T_s$ ). The superheated vapor is then expanded isentropically delivering power in the turbine and the low pressure ( $P_c$ ) exhaust vapor is then condensed by rejecting the heat of condensation ( $Q_{co}$ ) to colder cooling water circulated through the condenser. Superheat is used to avoid the damaging liquid droplets condensing out of the vapor stream while it expand isentropically. If an expander more liquid tolerant than a turbine, (like a liquid piston-, screw- or two-phase expander or even a flooded scroll expander etc.) is used to produce power, superheat is not required.

**Figure 4**



The rankine cycle is not a binary cycle, but use only one medium in various phases (water / steam). Should an organic refrigerant be used it is called an organic rankine cycle

(ORC). This is done specifically when working with very low temperatures where steam density and pressure is too low to be practical.

## Converting low temperature heat to power using the Kalina cycle.

Mixtures of ammonia and water may be used to form the Kalina cycle with certain advantages. This cycle Log P vs. Temp graph is plotted in Figure 4 above, and the similarity with the rankine cycle is clearly visible.

Comparing the basic Kalina cycle of Figure 4 with the absorption refrigeration of Figure 1 it is obvious the rich mixture of NH<sub>3</sub> in aqua is pumped in both cases through the economizer (recovery exchanger) to the desorber (generator) at high pressure and temperature so the input heat can boil off some nearly pure NH<sub>3</sub> vapor for use. In the Kalina cycle this vapor is heated further and then expanded in a power turbine before being absorbed again at low pressure and temperature. In the refrigeration unit the generated vapor is condensed and then expanded via the Joule-Thompson valve to the evaporator, where it extract refrigeration cold from the environment at low temperature before being absorbed again in the absorber at low pressure.

The main advantage of using the Kalina cycle instead of the rankine / ORC is that the rankine / ORC cycles have a boiler / evaporator operating at constant temperature on fixed pressure called a temperature "pinch point", while the boiler / evaporator of the Kalina cycle vary the boiling temperature according to NH<sub>3</sub> concentration, even on fixed pressure. For example if heat should be recovered from a hot liquid at say 200°C, the rankine / ORC cycle operating on fixed pressure would be able to extract heat from the liquid, as long as the temperature is above the pinch temperature, which may be 100°C for example. Below the pinch temperature (of 100°C in this example) the remaining heat in the source liquid would go to waste, as it cannot be recovered. In the Kalina cycle however, there is no pinch temperature, meaning heat will be extracted at fixed pressure from 200°C down to the practical limit, say 40°C, and therefore in heat recovery applications the Kalina cycle is able to extract a lot more energy from the waste heat source, and therefore deliver much more power.

In both these cycles, however, the second law of thermodynamics dictate that the conversion efficiency  $\eta = (Q_{input} - Q_{reject}) / Q_{input} = \text{Work done} / Q_{input}$  which can in most cases be re-written in temperature terms:

$$\eta_{ideal} = \eta_{carnot} = (T_{high} - T_{low}) / T_{high} \quad \text{with temps in Kelvin (K).}$$

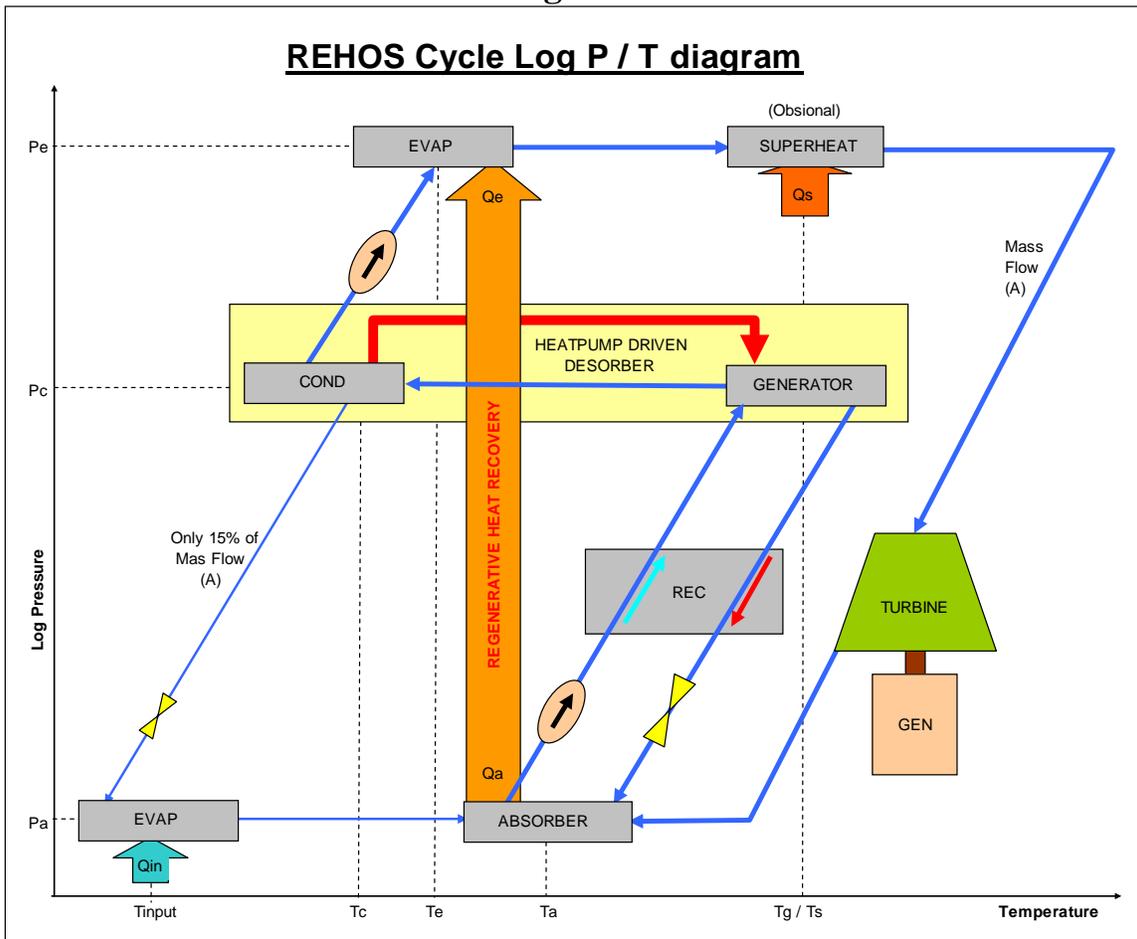
Using high temperature of 100°C and low temperature (due to availability if cooling water at 30°C from a cooling tower) of 40°C limit the maximum ideal efficiency ( $\eta_{carnot}$ ) = 16%. Real practical efficiencies normally would approach 80% of the ideal, calculating to 12,9% efficiency for this example. This low efficiency is a result of the large amount of heat rejection  $Q_{reject}$ , being the latent heat of getting the low

temperature, low pressure turbine exhaust vapor condensed, (or absorbed) back into liquid form, which is a lot less energy intensive to pump to higher pressures.

## Combining regenerative heat recovery with heat pump concepts to form the novel REHOS (Regenerative Heat of Solution) thermodynamic power cycle.

Looking at the Log P vs. Temp graph of the REHOS cycle sketched in Figure 5, it is immediately clear that we added another pressure level, ( $P_e$ ) above the generator / condenser pressure ( $P_c$ ). This allow us to use an evaporator with nearly pure NH<sub>3</sub> at a temperature ( $T_e$ ) lower than the original absorber temperature ( $T_a$ ), similar to the absorption heat transformer (AHT), so we can **regeneratively use the wasted heat of absorption in the absorber to heat the evaporator** at the elevated pressure ( $P_e$ )! This have a result of not having any heat rejection from the absorber, as all the latent heat is then regeneratively re-used as indicated by the orange arrow in Figure 5 below!

Figure 5



Another major innovation comes with the use of a **heat pump to extract the latent heat of condensation from the condenser at the low temperature ( $T_c$ ) and add it to the generator for boiling off some nearly pure NH<sub>3</sub>**. Keep in mind that the evaporation process of boiling off some NH<sub>3</sub> happen at a pressure ( $P_c$ ) corresponding to the same

pressure of condensing the same mass of NH<sub>3</sub> in the condenser. With such a small differential pressure the heat pump use very little energy to move the heat back from the condenser to the generator. More on the heat pump is discussed later.

The REHOS cycle sketched in Figure 5 actually consist of **2 cycles combined, namely** a standard absorption refrigeration cycle for extracting heat at low temperature from the environment (anti-clockwise flow of a small mass (only 15% of the power mass flow (A) in the left bottom corner), **combined with** a special regenerative heat recovery power generator (clock-wise flow of a large mass flow (A) on the right). Energy balance around the cycle dictate that the combination of refrigeration heat input (Q<sub>in</sub>) together with any required superheat (Q<sub>s</sub>) (if sourced from outside the cycle) at least equal the turbine power output, with the heat pump compressor as parasitic wasted energy. Not having any heat rejection therefore give a much more favorable cycle efficiency calculation:

**Cycle efficiency  $\eta = (\text{Power} - \text{Compressor} - \text{Pumps} - \text{Radiation Loss}) / (\text{Heat\_input})$**

Keeping in mind that **Heat\_input = Q<sub>in</sub> + Q<sub>s</sub> = Power =>  $\eta = 85\% - 95\%$**

Due to the low compression ratio required from the heat pump as well as the high density vapor at the elevated pressure (P<sub>c</sub>) being around 5 or 6 Bar absolute, the function may easily be fulfilled using a (subsonic) injector type compressor, routing the injector drive vapor from the high pressure (P<sub>e</sub>) vapor directly after the evaporator on the 3rd pressure level. This pressure may be some 14 Bar absolute (or higher) in practice. Heat and mass balance calculations show the mass injector drive vapor to be only 6,2% of the power mass flow (A) and the injector entrainment ratio would be around 16,2 : 1. This was calculated assuming vapor jet expansion of 75% isentropic, and the entrained vapor compressed at 75% isentropic.

## **Comparing conventional vapor compression (VC) heat pumping with the bubble heated HOS heat pump.**

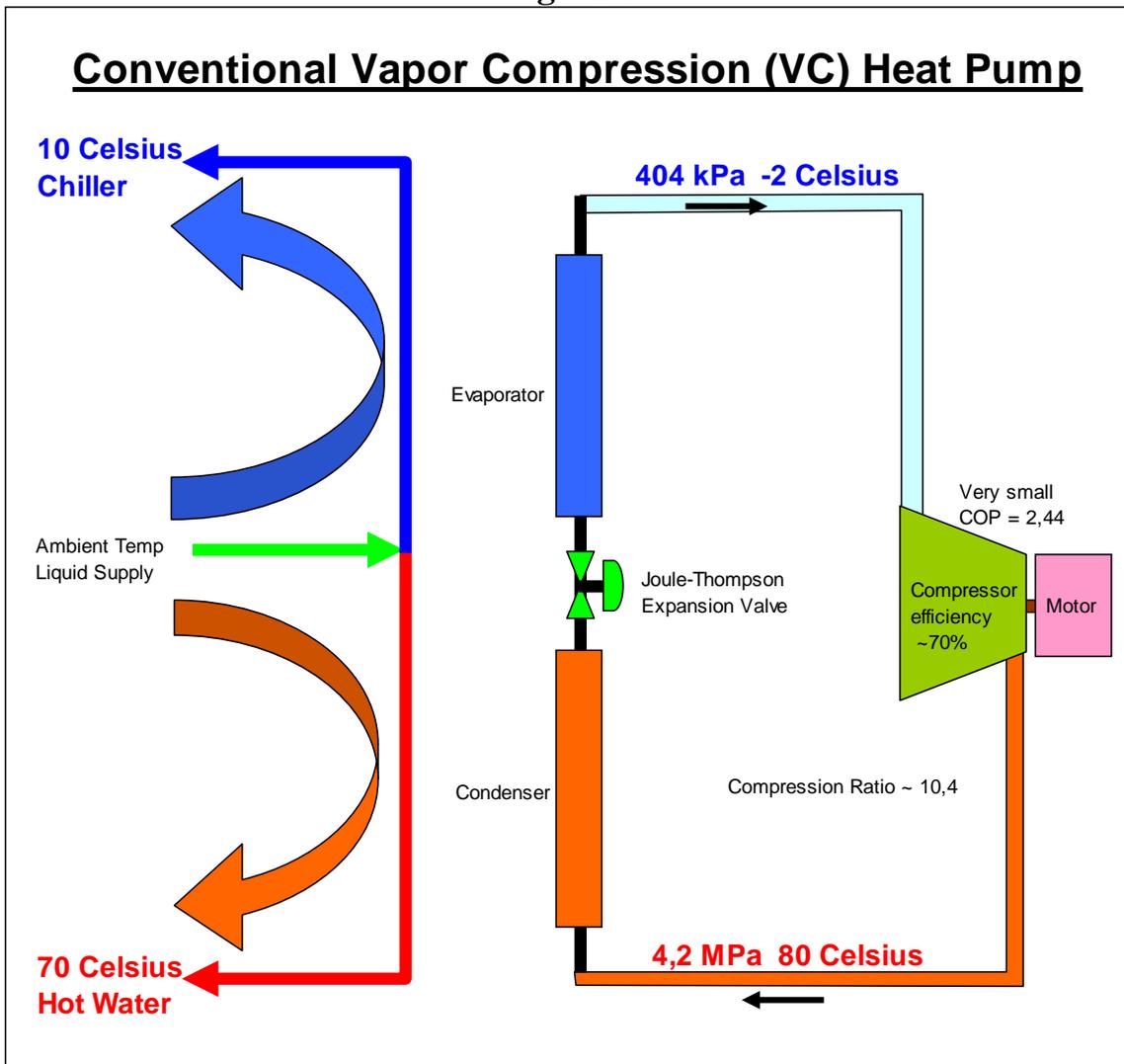
Figure 6 represent a conventional vapor compression (VC) example heat pump operating with pure ammonia (NH<sub>3</sub>) as medium. On the compressor inlet side the liquid NH<sub>3</sub> in the evaporator is flashed to vapor at 404 kPa abs to drop the temperature to -2°C. The isentropic compressor (working at an estimated 70% isentropic efficiency) compress the vapor to 4,2 MPa abs, representing a condensing temperature of 80°C. The compression ratio being about 10,4 the compressor motor need to work fairly hard to condense the compressed vapor at 4,2 MPa abs in the condenser. The overall **heat pump COP (Coefficient of Performance) calculate to 2,44** meaning that the heat pumped would be 2,44 times the electrical energy used by the compressor motor.

On the left side of the sketch of Figure 6 the heat exchanger coils are represented by the blue and red arrows, showing the blue heat pump cold side delivering chilled water at 10°C pumped from the ambient, while the red side delivering heated water at 70°C is shown at the left bottom.

Should we now build a heat pump working on the heat of solution (HOS) principles like an absorber in an absorption refrigeration system, we would have the novel bubble heated (HOS) heat pump sketched in Figure 7.

The left side of this sketch showing the heat exchanger coils is kept identical to the conventional VC heat pump, but the condenser and evaporator is replaced with a 3 meter high vertical tube filled with a mixture of NH<sub>3</sub> in aqua and kept at a constant pressure of 357 kPa abs. Due to the liquid column gravity pressure, the column bottom should be about 379 kPa abs, as the average density of 760 kg/m<sup>3</sup> with a 3m height would generate a 22,4 kPa differential pressure.

**Figure 6**



Noting that saturated mixtures of NH<sub>3</sub> in water at a constant vapor pressure of 368 kPa absolute (centre of the 3m vertical pipe) have the following characteristics:

**Table 1**

@ 368 kPa	65% NH <sub>3</sub>	12°C	$\rho = 723 \text{ kg/m}^3$
@ 368 kPa	60% NH <sub>3</sub>	17°C	$\rho = 733 \text{ kg/m}^3$

@ 368 kPa	55% NH3	23°C	$\rho = 743 \text{ kg/m}^3$
@ 368 kPa	50% NH3	30°C	$\rho = 753 \text{ kg/m}^3$
@ 368 kPa	45% NH3	37°C	$\rho = 763 \text{ kg/m}^3$
@ 368 kPa	40% NH3	46°C	$\rho = 773 \text{ kg/m}^3$
@ 368 kPa	35% NH3	55°C	$\rho = 784 \text{ kg/m}^3$

At the constant pressure noted in Table 1 above, the NH3 concentration has an inverted proportional relation to both the mixture density and its saturation temperature. This has the consequence that if you apply heat to the centre of the tube, some vapor is boiled off immediately, rising upwards as bubbles, while the heated, now leaner remaining mixture have a greater density and higher temperature, and would therefore migrate downwards, displacing liquid with lower density. This has the effect that heat added anywhere along the length of vertical column, would gradually establish both a temperature gradient with the highest temperature at the bottom of the column, as well as a NH3 concentration gradient with the highest concentration at the top of the column. These gradients are indicated on the sketch of Figure 7 as a red arrow pointing downwards in the direction of increasing temperature for the temperature gradient and a blue arrow for the concentration gradient pointing upwards in the direction of increasing NH3 concentration. These gradients would be maintained with the complete column saturated at all levels by the heat addition, but heat leakage (conductance only, as there is no convection) from the bottom to the top and NH3 concentration dispersion resulting from natural diffusion from the top to the bottom would soon break up the gradients if no heat is added to the column.

From the knowledge gained utilizing absorption refrigeration technology, we know that NH3 vapor would be very strongly absorbed in mixtures of NH3 in aqua, **as long as the mixture is sub cooled.** With the mixture saturated, no vapor from a bubble would diffuse into the surrounding liquid mixture and therefore no heat would be generated as no absorption is taking place. Should a NH3 vapor bubble come in contact with a sub cooled section of liquid mixture, the quick absorption of the vapor into the liquid, collapsing the bubble to generate heat, as already discussed when we described the absorber operation as part of the proven absorption refrigeration cycle above. Note that we have already proven that the sensible heat of heating cold vapor have a less than 20% influence compared to heat generated by absorption. The actual temperature of the vapor in the bubble is therefore of lower importance, as the large direct contact heat transfer is driven by absorption of vapor into the liquid mixture.

With the compressor running, saturated NH3 vapor is extracted from the top of the column, causing cooling by flashing NH3 from the 90% NH3 in aqua mixture (with heat of vaporization = 1179 kJ/kg) at -2°C. To compress this vapor with the compression ratio of 1,112 using a 70% efficient isentropic compressor require about 19,2 kJ/kg, making the heat pump performance (COP = Coefficient of Performance):

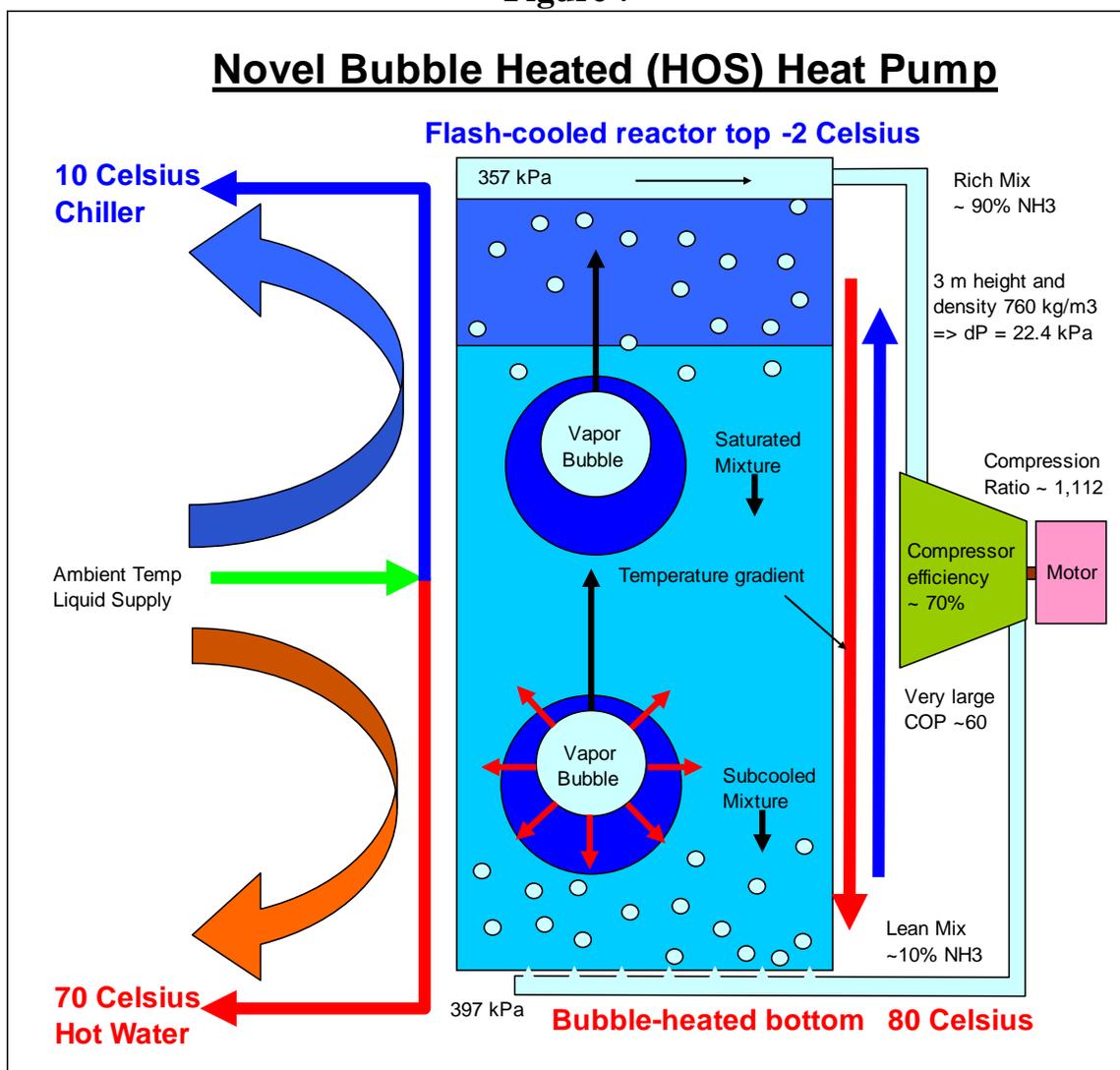
$$\text{COP} = \text{Heat Pumped} / \text{Power used}$$

$$\text{COP} = 1179 / 19,2 = 61,4$$

The compression process use so little energy that the compressed vapor temperature hardly change, at the most 1°C, so vapor is produced at -1°C with enthalpy 1198 kJ/kg. If we assume the bottom of the column is sub cooled (the requirement for heat to be transferred by absorption) to 80°C from the saturation temperature of 110°C at the stated pressure of 379 kPa.

Introducing the vapor to the bottom of the column into the 10% NH3 in aqua mixture will firstly, heat the vapor from -1°C to the liquid temperature of 80°C, using 72 kJ/kg, after which the vapor bubble is absorbed releasing 1004 kJ/kg of heat to the bottom of the column, trying to raise the temperature, similar to the absorption heat transformer we described before. In this case the sensible heat (72 kJ/kg) required is only 7,2% of the absorption heat produced.

**Figure 7**



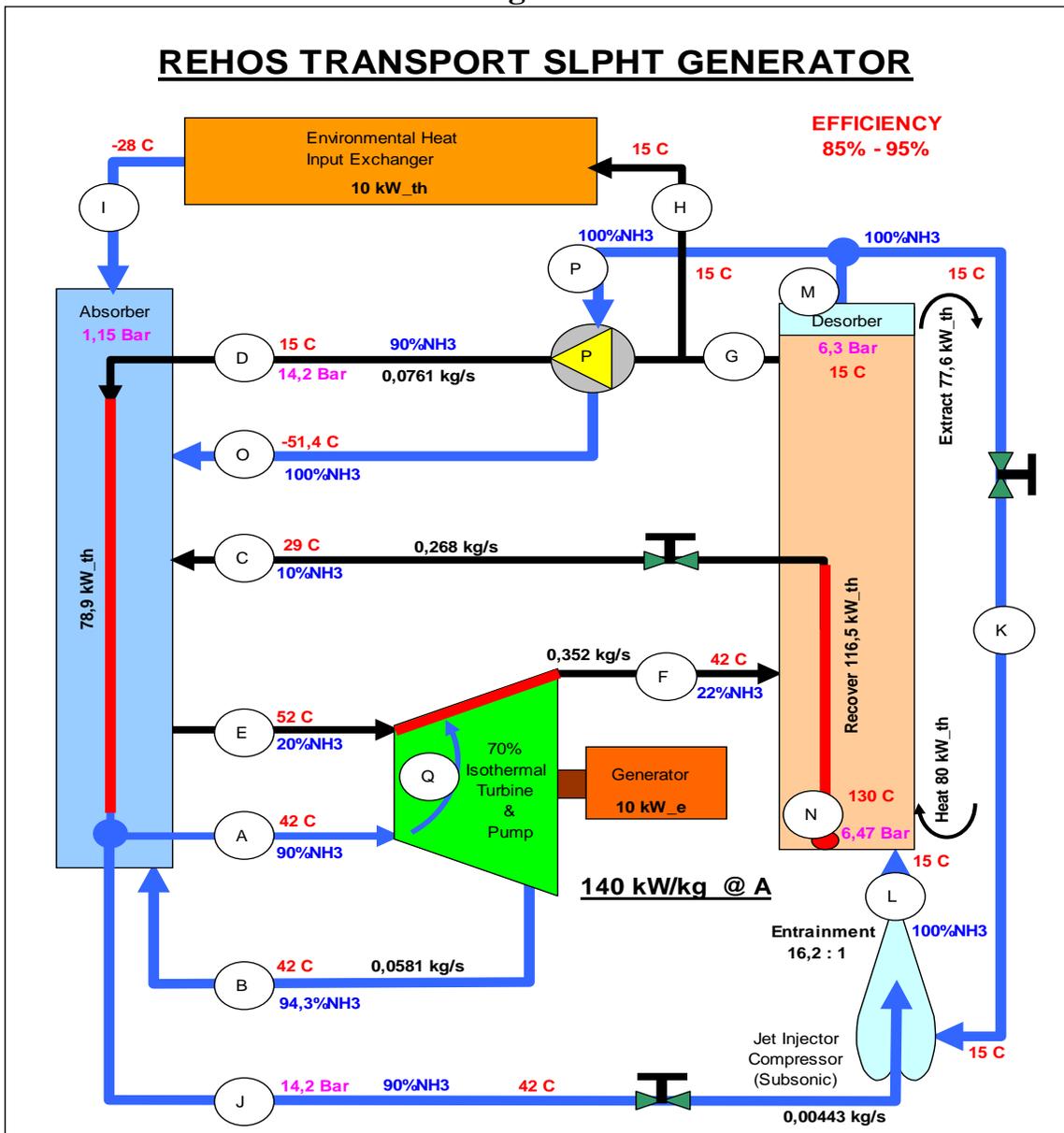
This continuous bubble heating of the bottom of the column quickly establish and maintain both the temperature and concentration gradient, but if heat is not extracted by the submersed heat exchanger coils (on the left of the sketch Figure 7) the column bottom

temperature would raise to the saturation level of 110°C with continued bubble absorption. At this temperature the column would be totally in saturation, so the vapor bubbles would pass through the column without any absorption.

Comparing the COP values of this novel bubble heated HOS heat pump with the COP of 61,4 with the conventional VC heat pump with COP value of 2,44 it is clear that the HOS heat pump will have an electric energy consumption of 25 times less than the conventional for delivering the same heat load, which is also the reason for using the superior HOS heat pump in the REHOS thermodynamic cycle of Figure 5.

The REHOS cycle sketched in Figure 8 below is my preferred layout of practical power plants, clearly showing the components it consist of.

**Figure 8**



The real values calculated from heat-, mass- and NH3 concentration balance are displayed in the diagram.

We also take note that the REHOS Thermodynamic Cycle can extract heat from as low as -28°C, as shown at reference point (I) in Figure 8, although the extracted heat is added to the thermodynamic cycle at the absorber outlet temperature, in the example of Figure 8 shown as 52°C, evaporating the 90% NH3 mixture at temp 42°C at point (A), and also, no heat is rejected out of the cycle, meaning that no cooling tower would be required!

## Costing aspects of the typical REHOS cycles.

All costing values were adjusted to 2017 US dollar using the US inflation adjuster found on the internet at [www.usinflationcalculator.com](http://www.usinflationcalculator.com).

From info published by the two references [11] and [12], cost information was gathered for the three heat exchangers, absorber, desorber and environmental heat input heat exchanger, pump and electrical generator and the cost of a typical ORC Expander was doubled to account for the custom-made Rotating Casing liquid piston turbine we call the SLPHT (Simple Liquid Piston Hydraulic Turbine).

Heat and mass balance on the layout as per Figure 8 has proven the absorber sizing to be about 8 kW<sub>th</sub> / kWe, the desorber some 12 kW<sub>th</sub> / kWe and the environmental heat exchanger 1 kW<sub>th</sub> / kWe.

Using the info as spelt out above, we calculated the Purchased Equipment Cost (PEC) for a 10 kWe REHOS Power Generator as listed in Table 2.

**Table 2**

SLPHT	10800 \$	53%
Absorber	2259 \$	11%
Desorber	3125 \$	15%
Environmental Heat Exch	428 \$	2%
Pump	130 \$	0,6%
Electrical Generator	3650 \$	18,4%
<b>Total PEC</b>	<b>20392 \$</b>	<b>2039 \$ / kWe</b>

Other elements of the Fixed Capital Investment (FCI) is listed in Table 3:

**Table 3**

Installation	20% of PEC	4078 \$
Piping	30% of PEC	6118 \$
Control & Instrumentation	20% of PEC	4078 \$
Electrical	10% of PEC	2039 \$
<b>Total FCI</b>	<b>36705 \$</b>	<b>3671 \$ / kWe</b>

Should we add Engineering & Supervision of 30% of PEC, being 6118 \$, as well as total Legal Cost of 2% of FCI, calculating to 734 \$, we come to a grant total overnight cost (Total Capital Investment Cost -excluding finance cost) of:

**Total Capital Investment = 43557 \$ for 10 kWe                    => 4356 \$ / kWe**

Although this calculated cost estimate is fairly high, it is for a very small unit of 10 kWe, and it is the first estimate for a pilot plant. Larger units and mass production aspects would easily drop the cost to 50% of this estimated prototype to beat the cost of even utility scale PV plants at about 2000 \$ / kWe. Also keeping in mind that power is extracted from ambient temperature water sources to drive the REHOS cycle power generator, delivering power at a capacity factor of 80 - 90%, so the capital investment cost should actually be compared to other base load power generators, like Advanced Nuclear at 5945 \$ / kWe, and not the current low capacity factor of 20% - 30% of Solar PV or Wind power without Energy Storage.

**We therefore have a revolution in the making, as the REHOS Cycle fulfill all 7 of the criteria we defined in the ideal, game-changing Black Box Cycle for heat recovery and the Generation of Power!**

## **Some typical application consequences using REHOS technology.**

**Electric Utilities -Enhanced cooling water heat recovery.** About 95% of existing power generation systems, coal, oil & gas fired, nuclear, solar thermal etc all have a rankine power block, cooled by water circulating through a cooling tower. This cooling water carry away the > 50% waste heat rejected from the power cycles. The circulated cooling water often leave the condenser at around 35°C - 45°C and is cooled in the cooling tower to 28°C - 32°C either direct by evaporation (wet cooling) or indirect (dry cooling). Cooling water temperatures for dry cooling in general are some 10°C warmer than evaporative (wet) cooling.

Using a REHOS Power Cycle to recover the heat in the cooling water, the total power delivered by the combination could double the original rankine power block power, without any increase in combustion fuel. Removing heat from the cooling system also have the positive effects of increasing vacuum in the condensers, increasing the original power block output power, as well as reducing the station's evaporation water use! Gradual addition of modular REHOS cycle turbines also create the ideal solution to gradually downgrade very old coal-fired power stations without decreasing station power produced and revenue earned, to work on reduced pressures to preserve their life, as well as create a gradual, economic path for utilities to migrate to future, more economic solar thermal and geothermal generation with 80 - 90% conversion efficiency generators operating on the REHOS Cycle. This gradual addition program would at the same time also gradually reduce the fossil fired power stations carbon footprint and CO2 release.

**Water Utilities -Enhanced water pumping recovering heat from pumped water.** As we know, dry climates across the globe, and drought conditions brought about by global warming effects, are very expensive to counter. Pumping water from available large water sources, like lakes and large rivers to drought-stricken area's are normally not an option, as the pumping becomes prohibitively expensive over large distances. This can change, however, by installing REHOS Cycle water pumps, set up to extract the required pumping energy from the (ambient) heat in the very water that is pumped! That puts a different perspective on water pumping altogether....

Also, the largest cost related to the desalination of sea water is actually the pumping cost, which could fall away to a very large extend by using REHOS Cycle water pumps..

**Mining Sector -Combined underground chilling and power generation.** Knowing that power for air circulation and lighting in underground mining operations, together with chiller services to get rid of the excess heat account for up to 30% of mining expenses, the REHOS Cycle, with its ability to provide both refrigeration and power simultaneously would revolutionize the mining industry.

**Agriculture -Free water pumping & refrigeration for fresh produce storage.** Pumps powering themselves from the water it is pumping, would really set the farmers free. No more electrical cables, switchgear and electricity costs for irrigation! A once-off capital investment is all that is required to serve all water pumping applications, free of any further charges. Small modular REHOS cycle power plants would also make the agricultural sector totally electricity-wise independent from local utilities, turning continents like Africa totally into the bread-baskets of the world, by empowering millions of people barely surviving currently to be successful farmers and food producers.

**Marine propulsion -Propulsion power by extracting heat from ambient sea-water.** REHOS Cycle power plants on ships extracting the propulsion power from the sea would definitely revolutionize the transport and freight sectors, not to mention the decreasing of their carbon footprint and CO2 emissions combusting fossil fuels like bunker oil or diesel to turn global warming around!

**Buildings & Hospitals / Schools / Residential clusters -Power and Air Conditioning from Geothermal heat extraction or nearby water sources like dams / rivers etc.** It would appear that the only limit to the use of these REHOS Cycle power generators would be our own limited imagination, but spreading this concept across the globe would drastically multiply the diversity of use for this revolutionary cycles as modular power packs.....**Finally we have a vehicle in the power-hungry global population to help the very same people to reverse global warming...**

## **Notes on safety and environmental issues using ammonia.**

Ammonia is a naturally occurring substance, that is also fabricated by man on a very large scale. Even so, only 3% of ammonia found on earth is man-made, as it is one of the most abundant naturally occurring substances.

NH<sub>3</sub> is fabricated in most countries across the globe, but only in the USA alone some 15 - 20 million tonnes of NH<sub>3</sub> and NH<sub>3</sub>-based fertilizers are produced, transported and used annually. Even so, NH<sub>3</sub> has an excellent, decades-long safety record being used as fertilizer and refrigerant.

Note that ammonia has no Ozone Depletion Potential (ODP) = Zero and also the Global Warming Potential (GWP) = Zero, making it a very useful non-greenhouse gas for use in refrigeration systems, fertilizer production and media to use in the novel REHOS thermodynamic power cycle.

NH<sub>3</sub> is easy to produce, using water (hydrogen, liberated by electrolysis), nitrogen, extracted from the air, as well as electricity that could well be any renewable power source. The water requirement of about 1 liter per liter NH<sub>3</sub> produced, is only 1/3 of the water requirement of producing ethanol, as well as very much lower than the water requirement for producing gasoline. There is therefore also a strong drive to produce NH<sub>3</sub> as "Green" replacement for gasoline and diesel fuels. The cost of NH<sub>3</sub> has already been established as stable at around the same for the energy of combustion content than that for diesel fuel. On a per liter basis the cost is about double that of diesel, making it one of the cheapest refrigerants available today.

It is, however, especially when mixed with water, highly corrosive and will dissolve metals like copper and brass and alloys containing copper, as well as aluminum and its alloys. Flammability is also low with a flash point of 651°C and NH<sub>3</sub> is difficult to ignite in open air, so danger of explosion is low compared to most other fuels.

Although ammonia is regarded as poisonous in high concentrations, NH<sub>3</sub> safety is a truly engineering issue. Leakages are also self-alarming, as most mammals can smell it dispersed in air at as low as 5 ppm. At 25 - 50 ppm it will drive most mammals out of the area, and is also by law the maximum permissible exposure for humans. Even at 500 ppm, it is unbearably irritating, but generally no long-term effects have been recorded for short exposure. On contact all you need to do is decrease the concentration by rinsing with a lot of water....Ammonia vapor density is much lower than air, so any leakage quickly rise and disperse naturally in the atmosphere.

The inventor of the Haber Process for the manufacture of NH<sub>3</sub>, Fritz Haber, was awarded a Nobel prize for developing this technology in the previous century that has provided fertilizer to help feed the world.

## **The next steps in the energy revolution initialized today....**

To make sure your company have a head start in servicing the huge global demand for power and water, it is advisable to **make contact with my company, with the view of becoming a licensee** for the provision or facilitation of the introduction of REHOS Technology to the global community. We could start by building a small pilot plant of 10 - 100 kWe for a chosen client together in Joint Venture, or maybe you are more interested in a few kW water pump pilot that power itself from the pumped water?

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