MSc Program
Renewable Energy in Central and Eastern Europe

Industrial low temperature waste heat - considerations and approaches to a meaningful use, demonstrated in a case of closed-cycle aqua-culture

A Master's Thesis submitted for the degree of
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supervised by
Dr. Mario Ortner

Joachim Schreiber

9835180

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Affidavit

I, **Joachim Schreiber**, hereby declare

1. that I am the sole author of the present Master Thesis, "**Industrial low temperature waste heat – considerations and approaches to a meaningful use”** 90 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master Thesis as an examination paper in any form in Austria or abroad.

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Abstract

Raising energy efficiency by an order is crucial when it comes to even getting close to slowing down man-made climate change, let alone stopping it. At the same time heat-involving industrial processes are a pillar of modern society as is food production and both are not just supporting an ever-growing world population but are at the same time also expected to grow exponentially. This thesis will highlight possibilities to use low temperature waste heat and at the same time combine the efficiency-measure with a sustainable food-production-project that can be situated in the midst of its customers, instead of being in a far away rural area. Joining these two together as smoothly as possible, an overall increase of efficiency shall be demonstrated that does not sacrifice the need calculate economically in the long run. Carefully assessing the approach and planning the systems integration provides the basis for a showcase scenario: Saving energy from going to waste while simultaneously producing highly valuable fish-protein in an utmost sustainable way when it comes to energy-consumption, water-consumption, distance to the customer and of course an ecologically certified breeding-environment that does after all (also) put the well-being of the useful animal on top of the list. An all-rounder that will as well help directly to mitigate climate change and overfishing just like excessive transport-related emissions, the overwhelming trade balance deficit when it comes to fish-imports, and even create local jobs. Stopping greenhouse gas emissions in a paradigm of constant and exponential growth needs nothing less than solving problems "Seven at one blow".

For practical use, several calculations and assessments both of technical and economic nature are provided and backed up with real figures. As far as technological assumptions are concerned, the numbers may very well keep their value for a good amount of time, while the economic figures might on the other hand be out-of-date rather soon: Quickly changing subsidy regimes or market prices of both energy in its various forms and the produced fish as well as the feedstock, may vary strongly over time. To compensate for that, the emphasis is rather to put the technical options and the "bigger picture" under the assumption that in the long run prices for fossil energy carriers *and* food will rather climb along with the intense need to mitigate climate change.

Table of content

List of Tables

List of equations

List of figures

List of Abbreviations

AC	Air Conditioning
°C	Degree Celsius
CFC	Chlorofluorocarbon, halogenated hydrocarbons, etc…
CO2	Carbon Dioxide
CO	Carbon monoxide
COP	Coefficient Of Performance
EU	European Union
FLH	Full Load Hours
GHG	Green house gas
H^2	Hydrogen (binary molecular form)
HE	Heat Exchange(r)
HP	Heat pump
IRR	Internal Revenue Rate
LED(s)	Light Emitting Diod(s)
LNG/LPG	Liquefied Natural Gas/ Liquefied Petroleum Gas
LRMC	Long Range Marginal Cost
LTWH	Low temperature waste heat
O&M	Operation & Maintenance
ORC(s)	Organic Rankine Cycle(s)
R	Universal gas constant
SME	Short- & Medium Enterprise
R&D	Research & Development
ROI	Return Of Investment
rpm	Rounds per minute
t/a	(metric) tons per year
USP	Unique Selling Proposition
VIE	Vienna International Airport

1 Introduction

The task is ... not so much to see what no one has yet seen; but to think what nobody has yet thought, about that which everybody sees.

(Erwin Schrödinger, quoted in L. Bertalanffy, *Problems of Life*, 1952)

Energy efficiency-measures could at current consumption levels become one of the major contributors when it comes to climate change mitigation. The unprecedented crude oil prices of the years prior to the 2007-2009 financial crisis posed as strong incentive to search for all kinds of efficiency options. The current drop in energy prices may well cause some slowdown in these efforts but they will most likely become very important again if oil prices start skyrocketing once more. Since various attempts to increase efficiency *within* certain processes will sooner or later reach their economic or technological maximum, this thesis sets out to look "outside the box" for at least one idea on how to utilize Low Temperature Waste Heat that would either normally be discarded because of low temperature or the solutions one might usually think of first do not apply to this case for either economic or other reasons. Trying to lay as many upcoming or existing problems of society on the table as possible – be it energy consumption, climate change or providing nutrition for an ever-growing population – shall provide us with the possibility to seek (out)/after solutions, combining pieces of the puzzle that did at the first glimpse seemingly not have to do something with each other. The solutions we can create will turn out to be more integrated and thus solving more problems at once, the longer we look at the bigger picture. In nature, solving the issues at hand – be it photosynthesis, producing nutrients at the bottom of the food chain as well as branches supporting the leaves is not all to be solved in "one plant" – do we assume this in one power plant or factory? Nature integrates multiple layers of cycles such as ground life in humus to produce the basic chemical blocks, with which higher plants or organisms will need to do their task. In this bio-cascade, the waste of one becomes the basic material of the other. This master-thesis will thus attempt to show exactly such an occurrence in a modern day industrial- or entrepreneurial environment, combining two very different players which each other and highlight the multitude of possible approaches if efficiency is not raised *within* one firm but in *cooperation* with another – a maybe very unusual one. Regarding the example chosen for this thesis, closed cycle aquaculture for locally and sustainably produced fish seemed to be the most promising, since very low-grade waste-heat can be used to heat up the fish tanks, because fish can only tolerate moderate water temperatures due to the nature of dissolved oxygen to vanish from the water if it becomes too hot. On the other hand, fish-protein is a qualitatively high nutrient, usually produced under very questionable conditions (both uncertified aquacultures *and* overfished seas!) and additionally causing a negative trade balance in this sector plus a remarkable amount of transportation-related GHG-emissions.

1.1 Motivation

For that thesis I basically saw a couple of bigger issues that needed to be taken into consideration, in order not to develop just another technologically sound solution but also to make sure it would be a feasible one when it comes to reality check. Too many wonderfully sounding utopias have been created, being technologically 100% correct but feasible only in another world: One where either economics played a tertiary role, as long as the most "beautiful solution" could just be realized. Or, one where everybody lived in peace or could initially be reconciled, so a global grid of solar-hydrogen pipelines could end world energy scarcity and fresh water shortage at once and for all. However, in reality, technological possibilities have to step back behind economic objectives and those again behind political ones and so on, in many cases only leaving us with the lesser of two evils instead of a masterstroke. Thus, my intention was to find two very important areas – such as food production and energy efficiency - and couple them together in a way a biologist might want to call a "symbiosis". I also wanted to keep it very much on a local level that would easily work in a multitude of regions and countries, rather being repeatable than presenting an once-and-for-all-large-scale solution. I also have to admit that I am fond of searching for compatibility amongst things that already prove that they actually work. Climate change is an issue I personally think already got out of hand. For the sake of my own "spiritual health" I none the less constantly try to tell myself that life does not evolve linearly, but can take rather steep turns and come up with surprises someone may even be tempted to call "miracles". None the less, I also have to confess that I am not such a dreamer anymore, that I would actually give "Carbon Capture & Storage" or a "Starship Enterprise-style fusion reactor" a shot at *anything*.

I am convinced this technology will (just like operational fusion reactors, now promised to the public since 50 years) simply stay some technicians daydream, not even coming close to contributing to a solution that comes in time, when we already broke through the 400ppm CO_2 concentration-mark. We are like a boxer in the ring, being hit hard too many times already: Still too proud to stay down but facing immanent defeat and maybe even fatal injury, if we keep on doing what we are doing. We need practical solutions right now that really help making a difference. Not just a fig leaf for our consciousness.

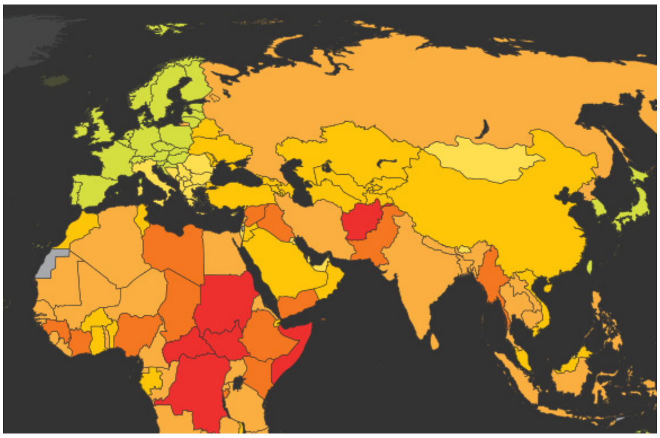
This thesis is an attempt to set out and see which "claims" are not so hard to dig but highly promising and which are now dug by so many because the ground is soft, though never yielding a real solution *or* properly addressing the magnitude of trouble we as a society are in, a species on a global scale. We have to face the facts as fast as we can and act rather yesterday than tomorrow. Waiting for some miracle-technology that will spare us all sacrifices of our brainless consumerism (that is nothing but a war against our own ecosystem), is foolish and maybe our biggest weakness. We cannot dig another well, while the house is already on fire.

We have to act now.

Thermodynamic processes and simple heat-involving processes widely used in all sorts of stationary and/or mobile applications – be it propulsion or production- are of relatively low efficiency and / or do need remarkable temperature gradients to function properly (eg. obtained in "cooling-towers" of various cooling-cycles, etc.). At the same time, climate change might be the biggest technology-related challenge to humankind after we managed not to nuke ourselves during the cold war. But in this last and fortunate case we only needed *not* to do something – simply *not* push "the button" that would have started worldwide annihilation. Whereas now, we are facing severe necessary changes that have to be *made* – fast, properly and with considerate conviction. Not just cutting total energy consumption when it comes to fossil fuels, but also in energy efficiency. If we really want to even get close to staying within a survivable 3°C increase of global average temperature, efficiency-measures will have to play a major role, given the fact that all our efforts will be conducted in an environment of growing world population and under an essentially undisputed doctrine of everlasting economic growth. Renewables will in many cases only contribute partially, simply because the sun does not always shine, nor does the wind blow permanently or trees grow fast enough. Wonderful but utopian fantasies of abundant solar hydrogen or limitless power-to-gas-supplies for Europe from North-African desert areas will in most cases not be able to come in time, as we are not just facing massive security-issues there, but also are not willing to afford –monetarily or ethically – to simply switch Europe's energy-dependence from one foreign power to an even more instable or hostile one. Let alone simply "occupy" the very countries for the sake of climate change mitigation and energy security! As beautiful as a scenario with abundant solar hydrogen from North African deserts and solar-desalinated seawater for all its deserts and scarcity-ridden populations would sound; having to defend these facilities against insurgencies or criminal groups such as ISIS, Al Qaida or other warlords that managed to get a hold on some weaponry during the civil wars of Egypt, Syria, Libya etc. would not just increase the need for severely equipped armed forces to protect the facilities but also lead to skyrocketing cost for the energy or water produced there – rendering all attempts of renewables to compete with cheap fossil fuels on grid-parity senseless: A sad reminder on how far the distance can sometimes be when it comes to comparing "economic potential" to "technical potential" or political feasibility.

This thesis will thus not only try to give an overview on energy-efficiency approaches but rather on a particularly tricky part of energy-efficiency: Waste-heat (WH) is generally considered less valuable then electric energy or fuels, because they still give the opportunity to be either used for heating, energy production or even for computing, whereas heat generally is mostly viewed as the (end-point) final point of all thermodynamic processes. WH, especially "low temperature WH" (LTWH) is mostly produced either in industrial zones and business-parks were no possible consumers are situated that would not also be producing their own, or the temperature and mass-flow (MF; volume*density per time) of one of the many coolants and media is simply too small to be sold or utilized for anything except giving purpose to a cooling-tower or condenser. Furthermore, raising the over-all efficiency of a steam-cycle or Organic Rankine Cycle in place – even just by a few percent – may in most cases already proof to be economically unreasonable.

Fig.1: Circled Europe - risk atlas[1]



In energy efficiency applications, usually all high-yield excess-heat-sources are tapped first for heat recuperation. A steam turbine producing electrical energy may be left by steam, several hundred degrees Celsius (°C) hot, a chemical plant might perform reactions to produce certain compounds that will produce excess heat of about 100-150 °C, all in a range of temperature that leaves a lot of opportunities if you want to think about a meaningful use like district heating (with long-range distribution piping and other costly but enabling investments). But other applications – in the vast majority of cases – will not provide us with such useful and abundant heat for further use. Imagine a well insulated refrigeration-facility's cooling-unit or the heat that is produced were gases (or mixtures) such as air are compressed. Here, the media are much "thinner" or less dense and the temperatures involved are much lower, thus narrowing down the scope of possibilities pretty much. The lower the temperatures get and the smaller the amount of bearing media, the more difficult it usually proofs to put this heat into meaningful use: Especially when it comes to economic evaluation which after all is the straightedge of all businesses and - amongst other considerations - that of the state.

1.2 Core objectives

Waste heat comes in abundance of different working media as well as in a vast number of possible industrial processes and is produced in almost any production process. This thesis

[1] http://maplecroft.com/media/v_maplecroft-20141224_154557/themes/img/gr/2014/atlas_landing_maps.jpg

will attempt to give a comprehensive overview on the most common definitions, processes, working-media and related energy-contents in comparison. That shall help to pinpoint available technology, temperature gradients and mass-flows in a sufficient way to accomplish certain tasks at hand. And vice versa help define a range of necessities having to be met on the search for a suitable supplier of WH for a predefined project of any sort.

This work will be the general base analysis for *all* kinds of possible LTWH-applications. None the less, sustainably breeding fish throughout the year by avoiding "winter idle" and keeping the artificial habitat at ideal-temperature 24-7, will be the main focus of choice: The more-than-quadruple-impact of a) utilizing LTWH for the sake of energy efficiency and reduction of GHG-emissions b) the sustainable production of locally bred fish thus c) avoiding transport costs as well as d) avoiding to contribute to already massively depleted fishing grounds due to overfishing and e) lowering the balance of trade deficit connected to fish-imports[2] seems to be the approach with the most promising leverage. Last but not least, fish poses as an ideal showcase because they generally do not tolerate high temperatures but rather lower ones because they are dependent on oxygen dissolved in water for breathing with their gills, which vanishes into its gaseous form if the aquifer is overheating. Indeed a meaningful utilization of LTWH could be demonstrated for an application that might turn out to be one major future technology to provide locally produced protein for an ever-growing demand whilst supporting cuts in GHG-emissions on all sides.

To ease project-evaluation on a quick glimpse and save lots of time for the technician, most commonly used working media and coolants will be catalogued and their specific heat-properties etc. used in a calculation-tool, that offers the ability to quickly determine certain process-properties (on a tablet for example) so reasonable assumptions can already be made in-situ – more or less instantly. Any technician wishing to assess the situation at hand and "translate" the WH-potential into another medium (temperature-mass-flow) can therefore narrow down the possibilities in a rather precise estimation. To show what good even LTWH could do in practical life, the fish breeding-example will also be viewed in the realistic light of subsidisation (EU, National + province), real government programs. Possible benefits of working together with an efficiency- or constructions/facility-

[2] Balance of trade deficit in 2012: ~330 Mio. Eur. (Mannen, 2013:719).

"contractor"[3] will be highlighted, in order to give companies that might not have the equity to implement such efficiency-measures themselves, a means of reducing their energy cost and consumption and thus GHG-emissions.

1.3 Citation of main literature

Most of the literature concerning thermodynamics derived from the technical universities library. Another very helpful source was the "google scholar"- search engine, especially on topics like "heat-pump" and other special terms. For latter, proper citation is no problem because Google-books are complete, provide all information on author, publishing year, cross-references to other relevant literature and they are much more up to date when it comes to cutting-edge technology than the university's library. Some information concerning subsidies, position papers by various ministries and other governmental bodies, like simple statistics also provided content used in some chapters of this thesis and are marked as such. Unfortunately not all of them could be obtained in English language because their content (especially Austrian fisheries and aqua culture in particular) simply are too specific in order to being translated. Here, the bigger picture can be obtained within the European-level position papers and program frameworks concerning the very issues. Some pieces of information – even though at some point possibly traceable through history down to a certain person or author- have not been marked as such or "cited" in a classical sense, because over a course of time they can now be regarded "common knowledge" amongst a reasonably informed readership. This does in particular -but not necessarily only- apply to the question whether or not climate change is still a scientific question or can already and within common knowledge be seen as a fact that does not require extraordinary scholarly debate, citation and highlighting.

1.4 Methods

Besides research within literature obtained at the Technical University's library, a wider variety of Internet sources have been used to create a bigger picture of the issues at hand. While some of the cited information could also be classified as "common knowledge" – at least amongst a more informed or interested public – the author did in most cases try to

[3] Cf. definition of OGUT (n.d.)

provide sources for either statistical information or state-of-the-art technical environments and their impact. The most important method still might be "inference & induction" in a logical context, as described in the above quote by Erwin Schrödinger, meaning that new knowledge or findings often emerge from a new perspective on reality rather than radical changes in reality itself, by new inventions for example. In simple words: We are now facing the same principle laws of physics as our ancestors in the Middle Ages. But on one hand we created a more complex world by using these laws to our purpose and thus created new problems that haven't been there until we started to interfere with this world. Others were constantly "imposed on us" by the daily struggle of life and just changed their "face" as we worked on solutions, as for example infectious diseases were replaced by antibiotics, that in turn were over-used, creating various resistances, and so forth. Some of these problems will only be solved if we allow ourselves to look at things in a new way. So one method I clearly want to mention in this context, is something one could call "use what you got": First of all, it is carried by respect for what others achieved before, on the other hand I clearly believe that we simply do not have the time to "reinvent the wheel", given the ticking clock regarding global warming, biodiversity decline or resource scarcity, worsening annually as the "earth overshoot-day[4]" is constantly homing in onto 1st of January. I think the approaches are so different, that one can easily speak of "different schools" already: Can we take the time to develop "Carbon Capture & Storage" for another 20 or "Fusion Reactors" for another 50 years at the risk of failing to deliver needed capacities? Creating very likely new problems as we are increasing complexity by means of new and even more far-reaching inventions?

Or are we rather facing an extreme situation that is calling for desperate measures like in the popular movie "Apollo 13"[5], were NASA-Scientists had an hourglass on the table, knowing that they had to come up with something within no time, only with the items and tools they knew were readily available? The author tends to lean to the latter, explaining lots of arguments and their origin within this paper. The method is clearly based upon the assumption that we *do already* have *everything* it takes to make things right. Except maybe for a global, clear and adequate understanding of the urgency & impact of man-made climate change and the devastation, caused by exponential growth.

[4] Global Footprint Network 2015, http://www.overshootday.org/
[5] http://www.imdb.com/title/tt0112384/

Since we are not just facing technical issues but also have to work against a clock, ignoring this time-component will equally mean failing the task. Without a second stab at it.
That – besides the wish to come up with very practical outcomes – is the reason for another set of sources used in this paper: Documents and technical descriptions obtained directly at the Munich International Fair for Wastewater Technology "IFAT 2014"[6], which partially will be included in the annex. This will despite all academic research, give the opportunity to place the given project right in the midst of reality.

2 Definitions

2.1 Waste heat (high-, medium- , low temperature)

In this chapter, basic definitions concerning the topic shall be presented and different angles of their deriving explained. Possible existing problems, which derive from the definitions, or the question why certain approaches are chosen due to certain tasks at hand shall be highlighted. Generally speaking, any excess heat that is not being put to further use is considered to be "waste"-heat. If heat is needed in a certain process or is simply produced unintentionally after production, or upon storage and shipping (like, for example, in air-compressors, gas liquefaction-facilities, bakeries, steel works), it is characterized as such, before someone finds a good use for it.

Some applications such as steam- or gas-cycles (single or binary, Rankine, Brayton, Stirling, Otto or Diesel, etc.) may even produce such WH intrinsically because they are naturally operating coolers and condensers between heat source and heat sink, use *real gases* instead of *ideal* ones, must be operated with certified technical gases instead of the perfect ones an engineer would love to chose because those would be either too toxic, inflammable, instable or expensive and so on. Other processes, like pushing of coke in steelworks simply cannot be done at lower temperatures because of the chemical processes that involve tremendous amounts of heat. Referring to WH within this thesis will only address the actual physical *heat content* of the medium and not fuel value of certain by-products like flue gas or coke oven gas (CO and H^2 mostly) that might even still not only

[6] IFAT (2014), http://www.nfm-ifat.de/2014/de/home.php

be very hot upon production themselves but also combustible on top of that[7]. These are rare occurrences and usually involve very high temperature processes and are thus at this point only mentioned for the sake of completeness. The same with radiation – a non-medium-bound heat source that is mostly used in solar concentrators and combined cycle plants: Either can the radiation of the sun be seen as primary power source and thus never as “waste”, or, regarding its utilisation, quickly gets transferred into a heat-transporting medium such as oil or water. Of course, thermo-electric elements -as they are used in space for example, where the high vacuum does not allow for any heat-transport outside a space-ship rather than radiation do exist, are again of too little significance in terms of proliferation to be mentioned any further.

The detailed definition and classification whether a given heat source is considered to be high-, medium-, or low-temperature, is varying from case to case and only agreed upon in broader terms. To make a clearer distinction in single cases, a heat source that might be classified as “high”-temperature in one case – say for example in a laundry-facility: Here, the wastewater may sometimes reach the sewer with 80°C whilst the exhaust vapour of the drier with its e.g. 50°C may be viewed as “medium”-temperature. However, in case of the evaluation of a steel plant, the 80°C – sewage water might not even be considered medium but low-temperature waste heat (in this very case), and so on. To gain conceptual clarity for this publication, the following ranges and definitions are assumed:

High temperature WH occurs for example in steel- or glassworks, were a lot of heat is needed to prepare components or melt the material, but actually has to be gone if the actual product is to be stored or shipped. Of course thermal waste treatment plants also generate a lot of heat, which (in the case of Vienna for example) is used both for electricity-generation and district heating. Here steam- or ORCs can be used to produce electricity in economic scale, utilizing the waste heat that might be left after steam-production (and is) usually used in the very plant itself for propulsion- (eg. hydraulic pumps) or cooling-issues.

Medium temperature WH could, for example, come out of a chemical plant, in which processes are running at considerable lower temperatures than in a blast furnace, but still at a couple of hundred degrees like galvanization, special surface-coating etc. Medium-

[7] Ussar, 1980:37.

temperature-WH would also be found in certain processes in oil refineries and – as in the case of the refinery in Schwechat, Austria, possibly be used in district heating and cooling. Here, since the early 80ies, the nearby Airport (VIE) is connected with an approximately 3-km-long piping system, conveying enough heat from the refinery for the whole airport's buildings, both heating and cooling-demand[8].

Low temperature WH which is seen in most of the cases (because most of our everyday processes do not involve very high temperatures), comes in an even broader abundance of possible sources. A bakery, a dry-cleaning-shop, stove enamelling or baking-finishing shops, server-farms as well as simple heating systems, AC-systems, and sewage-water are just a representative fraction of the vast abundance of LTWH-sources that surround us in everyday life. Stating this, it is clear, that on one hand the amount of energy wasted under these circumstances is probably the highest. On the other hand it might also be the most complicated-to-solve heat sink when it comes to efficiency measures, since concentration, distribution, and economic value or scaling make it much more convenient to first get hold of high- and medium temperature sources. None the less, the sheer necessity of increasing worldwide energy efficiency will make it paramount to take care of this "ugly duckling" of engineering and – given the enormous potential – stop thinking even a single new project without also taking cheap and abundant LTWH-sources into account at any assessed plant location. In probably a desirable future in which lots of renewable solar, wind and hydro-electricity is in the grids, heat pumps for all sorts of purposes – but especially for concentration and storage – may be as abundantly distributed just like today's refrigerators are already.

2.2 Usual Challenges for using LTWH (technical economical, logistical)

Heat content or "internal energy" is another very important dimension in this respect, which is necessary if we are to understand and evaluate a heat source at hand, and its viability to a certain purpose or to start an assessment in finding possible uses. The higher a material's "specific heat"-value is, the more energy is contained within a given amount

[8] Schwarz, JAHR 1979: p.149

or unit at a certain temperature (Fig.3). The better its thermal conductivity is, the quicker this heat can be gotten into or out of the very medium: If one sits in a 100°C hot sauna, for example, one can easily bare this heat because air does not conduct heat very well, nor is the heat content per volume very high, whereas sitting in water of the same temperature or having steam condensing on one's skin would instantly cause serious burns. Volcanic lava can – even after decades – still contain enough heat to enflame a wooden stick. On the other hand, a small pool of very hot waste water may in total contain *less* energy than the whole arctic sea. But still – the *energy density* of the smaller pool of hot water will make it easier for a technician to make use of this energy because it will take less *power* (input of work over time) to concentrate the WH or to recuperate it to such a point that it can be put to use again: Getting enough energy out of the arctic sea for a full, hot bathtub, will take the same heat pump much longer than it will take to make us a hot bath with the couple of thousand litres of hot or warm waste water from the "small pool" in the quoted example. So the most relevant questions will always remain: How much volume * density (pool) or per time (=mass-flow/ well) can be obtained, at which temperature and specific heat, and at which efficiency can the contained heat be transferred into another desired medium. Here specific heat[9] plays an important role again.

Q …heat added

c...specific heat

m...mass

ΔT...change in temperature

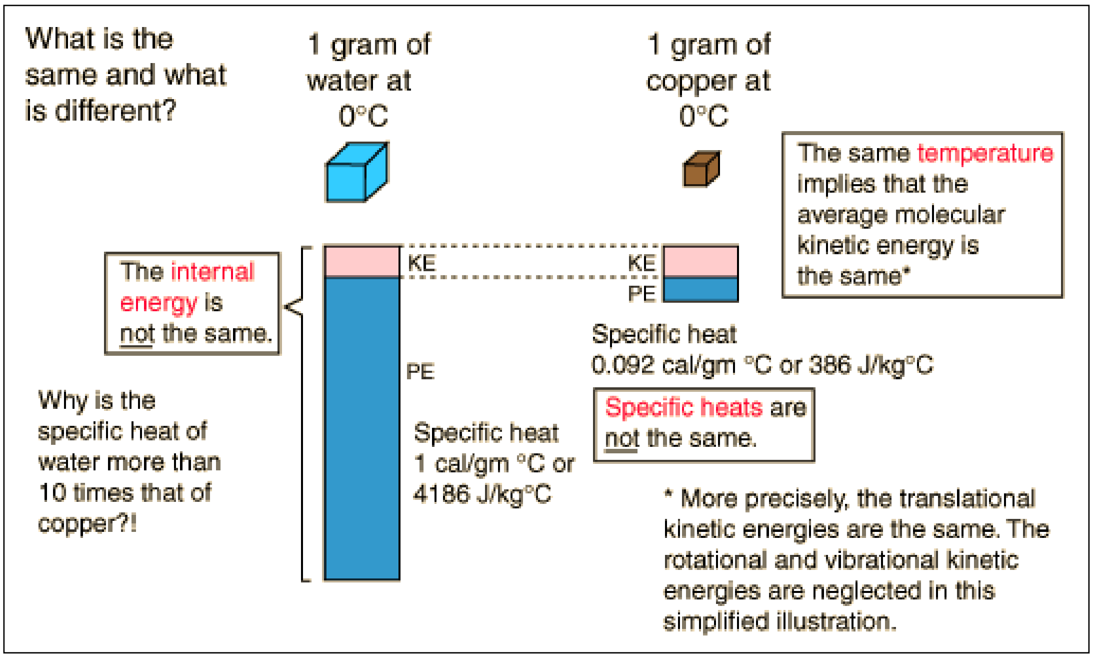
$$Q = cm\Delta T$$

Equ. 1: Specific heat formula

If the temperature of a substance is increased, it's kinetic energy is. But the total heat-content[10] (=internal energy) is the dimension that comes with the specific heat.

[9] http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/spht.html
[10] http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/inteng.html#c4

Fig.3: Relation of heat content versus temperature[11]



Gradient is another term in use for energy conversion models. It defines the difference between the source and the "target-pool" or the "sink" how it is sometimes called. Like in the arctic-sea-example mentioned before, total energy content is not necessarily of concern, but the gradient that has to be overcome or can be utilized. A heat pump (HP) can for example work much more effective or at higher COP, if the gradients that have to be bridged are rather small. Of course modern air-heat pumps can function in winter conditions of down to -20°C and below. But performance would be far better, if warmer air could be used to heat up water or feed into the heating cycle of a home.

The gradient is mathematically described as a vector. In practical engineering, this is not just of importance when it comes to energy-conversion (K/m), especially in recuperation but also in practical planning and choice of construction material. Pressure- or temperature-gradients may be important considering stress on major components, and define or narrow down the technical scope or area of use: Machinery, constantly used at more or less room temperature for example has to withstand far lower stress on material than the inside of an oven of any sort, that is repeatedly heated up to a couple of hundred

[11] https://www.physicsforums.com/proxy.php?image=http%3A%2F%2Fhyperphysics.phy-astr.gsu.edu%2Fhbase%2Fthermo%2Fimgheat%2Fintex.gif&hash=33ebcc45f538d74852b3f035019203d6

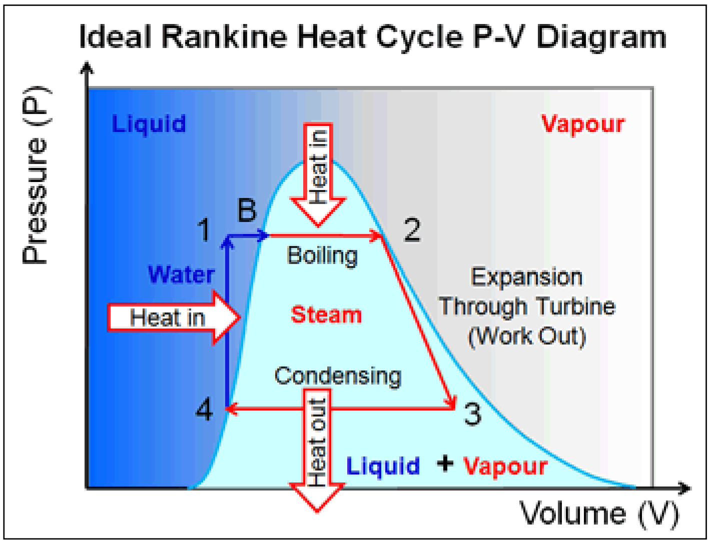
degrees and then cooled down again afterwards. Submerged drill-equipment (e.g. deep-sea-drilling or geothermal explorations) at 3000m depth (head, water) has not only to withstand ~301 atmospheres of pressure-head (~300 kg/cm² or 3000 metric tons per m²) against each part of it. To archive enough gradient in hydraulic pressure in working fluids at the bottom of the sea, these 301bar must be added on top of each bar, engineers need down there, in order to move drills, open or close valves, etc. That of course puts lots of strain on materials, which usually equals high or even astronomic costs. Very exotic applications like the heat exchangers in thermoelectric elements on satellites may not only have to withstand high vacuum, but may additionally be facing not only huge temperature gradients (for example from +80°C from a nuclear decay-battery to the dark side of the satellite at -150°C), but also cosmic radiation and bombardment with micro-meteorites and so on (see Fig. 5: Corrosion examples).

A lack of demand in a certain spot, compared with **low energy prices** or **high investment cost for a distribution system** will in many cases be obstacles too, when it comes to using LTWH. First, in an industrial area, everybody else may very well be producing their own LTWH and no private households with according demand may be situated alongside. Building a piping system to reach these households may as well prove unfeasible due to transmission losses, cost of piping and so on. A heat source that can be completely lucrative if it is situated in the neighbourhood may very well be completely worthless if the demand is one kilometre away and piping would have to be dug into the ground or just constructed on the surface. Sometimes the sewer system may come in handy, because it can in some cases be regarded as an existing “distribution system” that is rather constantly tempered over the year and can transport water of various temperatures. Though, that is mostly downhill: Flowing along the incline, in the direction towards the treatment plant.

3 Industrial processes relevant for LTWH

In this chapter, the vast abundance of processes involving certain amounts of heat or waste heat is characterized by means of definitions that can be used more or less to describe the broadest variety of them. Also the differences between reversible and irreversible losses will be explained, since not always simply inventing something new can raise the efficiency. Sometimes excess heat is a "necessary evil" when it comes to steam turbines or other applications in which steam- or in technical terms Rankine- or Organic-Rankine-cycles are used. Processes are almost never isentropic because real gases do not behave ideally and real machines produce internal losses, are subjected to friction etc. Most commonly, gases or vapours are involved in processes closely connected with waste heat:

Fig. 4: Ideal Rankine Cycle[12]



As shown in figure 4, work is only extracted between point 2 and 3, as the high-pressure steam is allowed to expand in the turbine into low-pressure-steam. As the condensing between 3 and 4 has to be accomplished, all (the) heat that is left to keep the water in gaseous form has to be removed. That is usually done in a condenser which in case of a power-plant has to be cooled by means of a cooling tower or the flow of a river. All heat

[12] Graph taken from: The Electropaedia, see http://www.mpoweruk.com/images/rankine_pv.gif

that is vented off or "dumped" in the river is "waste"-heat. In a gas liquefaction plant essentially the same thing happens in the opposite direction, creating the excess heat: Effort in the form of *work* e.g. by a piston has to be put into the gas in order to compress it, which heats it up simultaneously. At the smallest possible scale, every scuba diver might have witnessed this effect when filling the air tank as well as its instant cooling, when it is being emptied rapidly. Gas liquefaction in plants producing LNG/LPG or technical gases (liquid air etc.) also produce such excess heat on a large scale even tough for both cases, meaningful use for the waste heat can be thought of. These corresponding effects between temperature, pressure and volume are described by

- Boyle's Law, stating that pressure (P) and volume (V) are indirectly proportionate or that increasing volume at constant temperature leads to decreased pressure in a gas.

Equ. 2: Boyles law

$P \sim \frac{1}{V}$ or described as a product: $P_1 V_1 = P_2 V_2$

- Gay-Lussac's Law, stating that pressure (P) and temperature (T) are directly proportional or that increasing temperature at constant volume leads to increase of pressure (P) in a gas.
-

Equ. 3: Gay-Lussac's law

$P \sim \frac{1}{T}$ or described as a product: $P_1 T_2 = P_2 T_1$

All other industrial processes not concerning gases (or liquid phases of them in steam cycles etc.) but liquids such as waste water do not make such models necessary, since liquids are basically incompressible and thus not subjected to these laws. Also solids, even though in some cases compressible to a certain extent, practically are neither. The waste heat contained in liquids and solids such as sewage water, rectification-products upon storage or solids after baking, casting, forging, coating will end alike, though have to be transported into a heat-bearing medium commonly used to collect it, concentrate it, store it or transport it. In a few cases, the solid is directly used as storage, for example in concrete core wall activation (= Betonkern-Aktivierung) in buildings, using the large and inert concrete core to cool the building in summer or save heating costs in winter. But also then, the means of transporting the heat is again managed by another medium such as water. So let's take a closer look at these!

3.1 Heat-bearing media

Depending on application and specific need, a wide variety of heat-bearing media is commonly used. In primary or secondary processes they can range from liquid metals, molten salts, water and liquids such as oils or ammonia (NH_3), pure or in mixtures. Additionally used are substances that would be gaseous at room temperature and atmospheric pressure: Hydrocarbons or halogenated hydrocarbons (CFCs, chlorofluorocarbons which are nowadays mostly banned due to their ability to destroy the planet's ozone layer and contribute to climate change), helium, CO_2 and various mixed technical gases, contrary to common air as a naturally occurring mixture of gases.

After comparing volume, pressure and temperature it will be easier to understand the differences in **internal energy** (or heat content), as a function of **specific heat** as well as **mass** and **density** when "Avogadro's Law" and the "Law of Dulong and Petit" are introduced.

- Avogadro's Law, stating that volume (V) and amount (n; 1 mole = 6,022 x10^{23} atoms or molecules; mol) of an *ideal gas* are directly proportional if temperature and pressure is constant (k).

$$V \sim n \qquad \text{or in other form:} \qquad \frac{V}{n} = k$$

- The law of Dulong and Petit, correlating (the) internal energy (J/g K) per *amount* (mol), contrary to *volume* or *mass* (g) shows that the big differences in "specific heat" or internal energy per **unit mass** almost vanish, if atomic weights (g/mole) are taken into consideration:

Copper 0,386J/g K x 63,6 g/mole = 24,6 J/mol K

Lead 0,128 J/g K x207 g/mole = 26,5 J/mol K[13]

Equ. 5: Law of Dulong & Petit

$$C_s . M = C_{v.m} \approx 25 \, (J.K^{-1}.mol^{-1})$$

Whereupon C stands for "*the heat needed to raise the temperature of 1g of a substance by 1 degree Kelvin (K)*", M for the *mass* and "*Cv,m*" for the constant volume molar heat capacity of a 1-dimensional *harmonic oscillator* (see Fig. 9).

The given formula will in this case only be valid for *solids* and with the restriction that it will not be valid in very extreme – be it high or low – temperatures: Not for gases or liquids and especially not for liquids with a certain content of solid freight and so on.

For an engineer, who has to plan a facility around various technical necessities mostly using standardized parts, the concept of specific heat per volume or unit mass is more practical than the concept of amount: Delivery rates of pumps for example are usually compared in volume per time or head pressure. In many cases, many other physical properties of a coolant or heat-bearing medium have to be taken into account additionally: In some cases water might have a favourable specific heat, but cannot be used for example due to its neutron-moderating properties (cf. Table 1.: Liquid metal cooling in fast breeding reactors) or the boiling point that would make it necessary to operate a certain cycle at tremendous pressures in order to keep the volumes under control and thus water from turning into steam or superheated steam from forming droplets (dry steam). Tackling such high pressures naturally makes thicker vessels, piping and boilers necessary, as well as special turbines with highly temperature- or corrosion-resistant rotor blades: In some of the turbine stages, rotor tips reach supersonic angular velocity (at a couple of 1000 rpm), and must not touch a single droplet of water within the "dry steam" in order not to be severely damaged or even destroyed by pitting or cavitational corrosion.

[13] http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/dulong.html#c1

Fig. 5: Corrosion examples (photos compiled by the author)

On the other hand, not too many different materials can be used all through the cycle or installation at hand: As shown in figure 5, the combination of 2 or more different metals can cause pitting or electrical corrosion as well because – due to the formation of an electromotive chain – the most non-precious metal is "corroded away". This may in turn contribute to "freight" and total solvate-content etc.

So these effects must not be treated lightly, since they can and will contribute to each other: An impeller blade corroded by cavitation for example will loose its balance, causing vibrations and thus embrittlement in screws, foundations and so on, possibly causing total failure or even complete destruction of the plant. In very exotic applications (as the mentioned liquid metal cooling-cycles), amalgamation – the dissolution of one metal in mercury/liquid sodium – may also be a serious issue and has a strong impact on the choice of heat-bearing medium and combined piping-material or safety issues: Burning oils or sodium can for example never be extinguished with water or may in the case of leakage into secondary cooling-water result in clogging or even spontaneous combustion or gas-explosion.

A very careful planning has to weigh the "pros & cons" of each available medium, depending on possible exposure to radiation, pressure-volume-curves at desired or unavoidable temperatures, available heat sink(s) for the condensers (if necessary), and of course supply-, cost-, safety- and regulatory issues.

Table 1: Common heat bearing media (own table)

Medium	Process	Temperature- & pressure- range
Liquid metal (sodium, mercury)	Primary cooling-cycle in some types of nuclear reactors (submarines, fast breeders[14],...) or mercury-steam-turbines	~390 – 450°C ~10 bar (= atmospheres), 700-900°C[15] respectively;
Molten salts[16]	Cooling cycle in some nuclear reactors (e.g. thorium[17]-cycle[18]) & concentrated solar[19] power plants	Up to 1000°C atmospheric pressure (~1 bar)
Oils	Concentrated solar power-plants, cars, ships, planes, solar cooling[20],...	Above 100 to ~450°C atmospheric pressure up to ~30 bar
Water	All thermal power-plants, all types of vehicles, heating systems, heat pumps...	Above 0°C to several hundred °C atmospheric pressure up to several hundred atmospheres
Gases (pure)	all cooling devices, ACs, refrigerating facilities, compressors, liquefaction units	Various
Mixed gases (individually & artificially manufactured)	all cooling devices, ACs, refrigerating facilities, exhausts, compressors, liquefaction units, heat pumps, household refrigerators,...closed gas cycles of special-purpose generation-facilities (e.g. NASA)	Various
Air (contrary to "technical gases" though "mixture")	Coolers, condensers, cooling-towers, vehicles, compressors, liquefaction units, ACs, heat pumps, fans...	Various

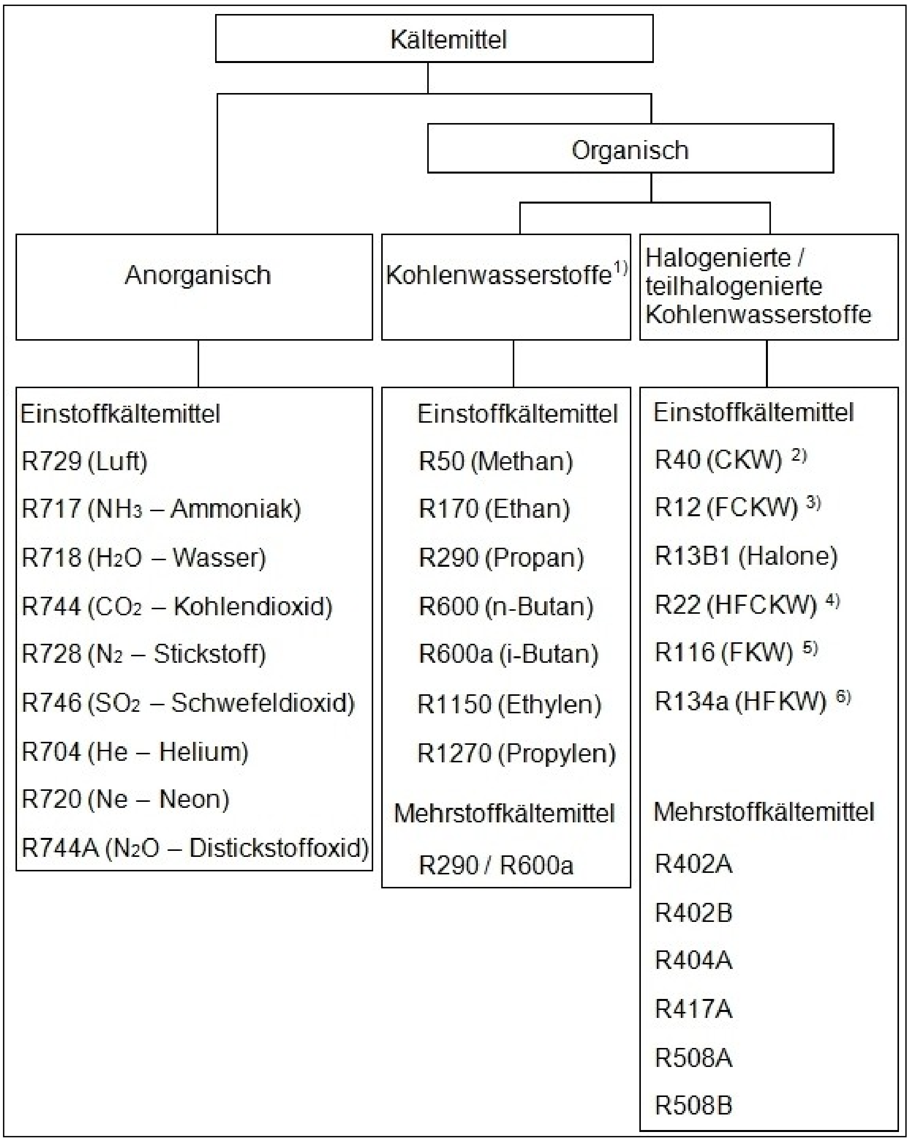
[14] Cf: Lexikon Energiewelten: Brutreaktor, HEA 2015
[15] Invernizzi, 2013: p. 206
[16] Cf: Lexikon Energiewelten:Brutreaktor, HEA 2015
[17] The Weinberg Foundation, 2013
[18] World Nuclear Association, 2015
[19] Pacheco et al. 2001
[20] PSA, Plataforma Solar de Almería, n.d.

3.2 List of most common coolants, compressed media and used aggregate states

Coolants or refrigerants are most widely used in all sorts of cooling devices, ACs, refrigerating-units from SME-cooling-chambers to large-scale refrigerating facilities of medical, pharmaceutical or food industry or in temperature-regulated cargo vessels such as ships, planes or trucks. They are commonly classified by their chemical properties as depicted in Fig.6. Even though most of them are gaseous at room temperature and atmospheric pressure, in technical descriptions mostly unit mass (g, kg) are used to describe refrigerant-content or refilling-procedures.

Units of volume would be misleading, because of the changing aggregate states during the processes at hand – thus leaving an uncertainty, even though internal energy could be described more evenly by means of energy-per amount (J/mol K) and an ideal gas would always come with a volume of 22,4 litres per mole (at room temperature or 25°C). But naturally this is only an approximation for calculations. Specific coolants are varying from that and mixtures in particular, especially if for example different substances are mixed that do *not* form an *azeotrope* but will separate into their different aggregate states and concentrations during the very processes, as for example in absorption-coolers using water-ammonia-mixtures.

Fig.6: Types of cooling agents[21] (incomplete list)



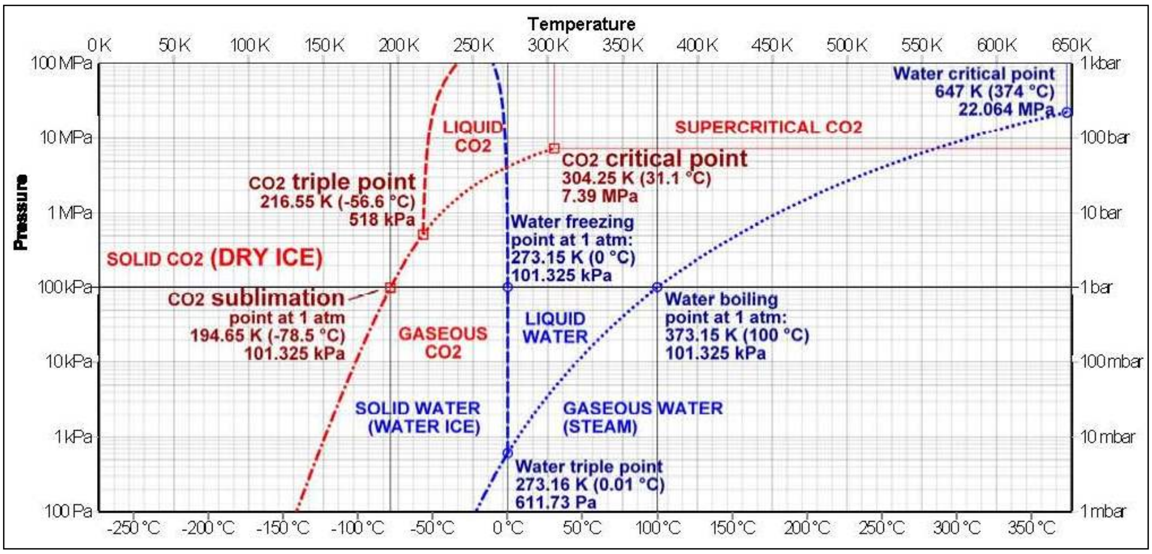
Additionally, it remains a basic fact that also refill-procedures are much simpler if *weight-units* are used for the measurements of coolant content and transport: The weight of a refrigerant in the system always stays the same – no matter what aggregate state, volumes or pressures are found. Thus complicated calculations, starting with the temperature and pressure of the delivered refill can be ruled out completely, simplifying maintenance-efforts and planning in practical engineering. Of course it is in the nature of all coolants, that they *can* but not necessarily *have to* come in different aggregate states as they are employed in the very case. In a car for example, we want to avoid the cooling-water to boil and become steam, because this would mean the breakdown of the car. Neither do we want different media to *mix* again in this example – as the excess engine-heat is transported

[21] Rienhardt (2013): Nomenklatur der Kältemittel,

through the oil and the motor frame into the cooling-water and from there into the surrounding air at the grille-face-panel of the car. In this case, different cooling-cycles are used.

In a common household fridge for example, this is different. As depicted in figure 4, a cycloid change of aggregate state and p/v-ratio is employed to deliver the desired task: Cooled, pressurized and liquid refrigerant is injected into the fridge's walls via the vaporizer, surrounding the goods we wish to keep fresh. Allowing it to expand into gas as pressure is dropping in the injector, volumes are increasing while simultaneously energy is taken into the gas, thus withdrawing heat from the inside of the fridge. The coolant is therefore getting warmer (increasing its internal energy to be precise), as it passes the (thus cooled) cargo and then being pumped back into the compressor in its gaseous form: There, volume is reduced, pressure is increased and thus the temperature is rising. Now it is forced through the heat exchanger known as the black grille at the back of the fridge, releasing the excess heat into our room, basically heating it up almost unnoticeably. Pressure stays constant in this case as well as volume, but temperature is dropping by means of this heat exchange with the surrounding air, thus causing the coolant to condensate back into liquid form, starting the cycle again. The so witnessed changes of aggregate-states are called "phase transitions" (or "sublimation" if the state changes directly from solid to gaseous). The change in internal energy is not linear in the case of a phase-transition as depicted in figure 6 and 7.

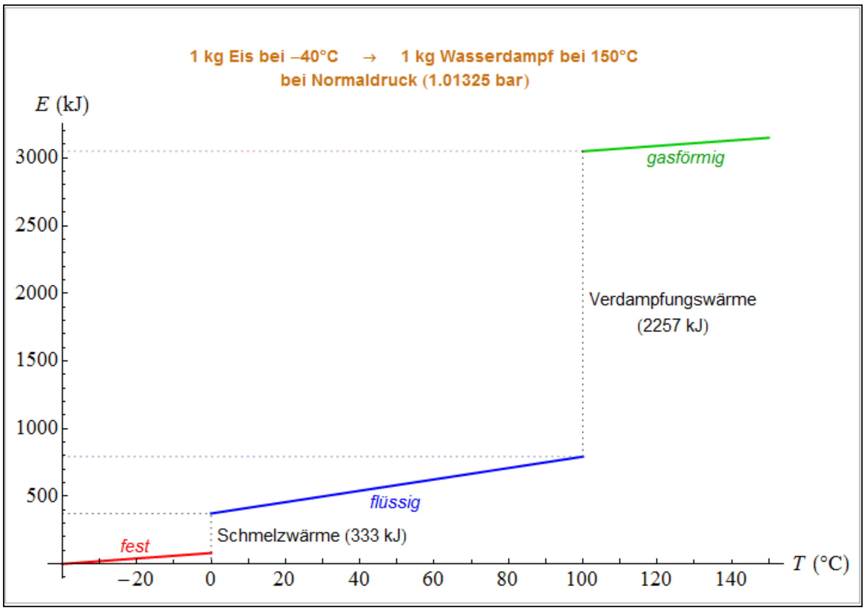
Fig.:7 Sublimation and phase-transition[22]



[22] Graph taken from Wikipedia, Sublimation (phase transition), see: fromhttp://en.wikipedia.org/wiki/Sublimation_(phase_transition)#mediaviewer/File:Comparison_carbon_dioxide_water_phase_diagrams.svg

The following figure shows the amounts of energy needed to melt a 1kg-block of ice at minus 40°C and atmospheric pressure into liquid water and then bring it into the gaseous state of steam at 150°C. It can be seen clearly, that the actual phase transitions are forming "steps" within the very dualistic diagram. Whereas the whole diagram shows exponential behaviour in energy content, the single steps between the transitions are happening in a linear fashion. It is important to understand that the *exponential* component of this correlation is based on the fact, that temperature can be described as "kinetic energy within the material" of a substance – be it a solid body, a liquid or a gas. The average velocity (as in $E=mv^2/2$) would in this case equal the thermal movements of the very particles in the substance.

Fig. 8: Energy involved in phase transitions[23]

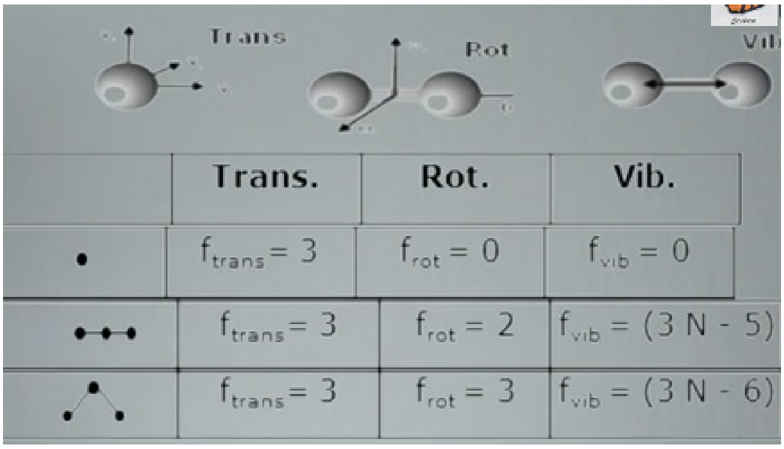


Other possible aggregate states like "Bose-Einstein Condensate" at the "cool end" of the chart or plasma at the hot end of it are just mentioned for reasons of completeness but not further commented due to their lack of relevance in the given context: Either if it comes to proliferation in daily life or relevance for low-temperature applications and thus LTWH. The description of molar-heat capacity by physical-chemistry using the concept of "degree of freedom" can explain how the different gases come to have so different specific heat: Noble gases (single atom) can move in all three directions in space (x, y, z) thus they are

[23] Embacher (n.d.): Auf dem Weg vom Eis zum Wasserdampf

said to have 3 degrees of freedom, also called translation. Atoms in diatomic gases like Oxygen and others (O_2, Cl_2, N_2...) additionally can oscillate towards each other *within* the molecule, adding 2 more degrees of freedom of this *vibration* PLUS another 2 for *rotation* along its longitudinal- & transversal axis. Obviously in a tri-atomic gas or let alone a mixture of different gases, the number of degrees of freedom increases additionally, following the rules depicted in figure 8. Thus it is shown how water even though less dense than the earlier compared metals for example – does have such an enormous specific heat: The number of degrees of freedom are many PLUS it has a dipole, creating additional forces between the molecules, preventing them from parting or in other words – turning into steam.

Fig.9: Molar heat content: Degrees of freedom in gases[24]



	Trans.	Rot.	Vib.
•	$f_{trans} = 3$	$f_{rot} = 0$	$f_{vib} = 0$
•–•–•	$f_{trans} = 3$	$f_{rot} = 2$	$f_{vib} = (3N - 5)$
•/\•	$f_{trans} = 3$	$f_{rot} = 3$	$f_{vib} = (3N - 6)$

In *solid bodies like salts* (crystals) or metals as mentioned in Table 1, according to the

- **Rule of Neumann & Kopp**, the molar heat capacity derives from the sum of the molar heat capacities of the elements and their ratio contained in it, following the

- **Rule of Dulong-Petit**, stating that the specific heat capacity of solids is defined as 3R/mol whereas "R" being the universal gas-constant.

Equ. 6: Rule of Neumann & Kopp

$$R = 8{,}314462175 \, \frac{J}{mol.K}$$

[24] http://www.ipf.uni-stuttgart.de/lehre/online-skript/waerme/freiheitsgrade.gif

So for one mole of the (solid) salt lithium-fluoride (LiF) that would mean: 1 * Li + 1 * F = 1 * LiF, because 1 mole of lithium and one mole of fluoride combines to one mole of LiF, equaling 1 * 3 * R= ~25 J K^{-1} mol^{-1}

This is particularly important when the physics behind the practical engineering has to be understood, because R directly correlates work in gases to amount and temperature:

Equ. 7: Work-temperature-relation

$$R = \frac{work}{amount\ x\ temperature} \qquad \textbf{or as well} \qquad = \frac{PV}{nT}$$

Because pressure (P) equals force per area:

$$R = \frac{\frac{force}{area}\ x\ volume}{amount\ x\ temperature} \qquad \text{which equals}$$

$$= \frac{\frac{force}{(length)^2}\ x\ (length)^3}{amount\ x\ temperature}$$

And work is defined as force x length.

So these rather complex physical relations and not yet mentioned quantum-effects at lower temperatures are another reason why not temperature or molar heat capacity are used in practical engineering but *specific* heat.

3.3 Heat exchange - technical approaches from "fly-by" to Heat-Pump, overview

It has to be mentioned, that not only the heat-content and mass-flow is vital to satisfy economic or technical needs in a WH-recovery project but also the following issues[25] might enable or limit WH recovery:

Continuity – Many processes like cutting off blast furnaces or pushing coke in steel-works (high temperature) release vast amounts of energy but not in a continuous flow but rather

[25] Halada, 1981: p.14

"surge like". Also many other processes that involve discontinuous release of heat like periodic re-filling of a smoke-house in meat processing (medium temperature) and porcelain-calcination involve such discontinuity. But it may also occur in medium- or LTWH-applications and cases such as peaks in sewage-water temperature and volume due to daily routines or limited capacity of laundry-machines[26] (low temperature). This may for example cause the necessity for large storage-facilities in order to capture the heat upon occurrence and utilize it continuously in a downstream process.

Freight – Especially flue- or exhaust gases with promising internal energy may in many cases come with an abundance of toxins or simply dust that will very quickly cause dramatic efficiency-losses due to jamming of heat-exchangers (dust) or corrosion if for example phosphoric- hydrochloric- acid (e.g.biomass-furnace) or sulphuric acid (e.g. coal-incineration) is formed in the cooled exhaust-stream if incineration-products start to form bonds with water-vapour- initially present *separately* in the hot gas. If a heat pump or heat exchanger is cooling the flue-gas, condensation-temperature might in some cases be reached thus leading to "acid rain" within the machinery. Of course this can be tackled by engineering with the means of using high-quality alloys such as Hastelloy® and other highly stable stainless steels. But these alloys are in many cases extremely expensive and might therefore render heat-extraction senseless from an economic viewpoint none the less. Where environmental specifications and laws make dust-catchers, fat-separators, skimming-tanks or flue-gas-scrubbers necessary anyway, one might find an option downstream that doesn't involve such high investments into anti-corrosion and dust-removal but it may come at the price of lesser quality in accessible heat. Of course also liquid heat bearing media can contain freight of many sorts: From dissolved salts or metal ions to a variety of nutrients or detergents like in sewage water. The given heat-source will have to be inspected thoroughly in order to choose the right materials, coatings, treatments or maybe a so-called *sacrificial anode* that will dissolve or corrode instead of the piping and machinery.

Regulatory issues - In some cases, regulations and specifications requested by law or for example the insurance may cause difficulties in heat-recuperation efforts and may even render them unsuitable: If for example (already very efficient) condensing-boilers

[26] See Fig.25 in: Brunk et al. 2013: p. 36

("Brennwertgeräte") are used, exhaust-gases come at a very low temperature of around +/- 60°C already, which is very little compared to other thermal engines. But still, this temperature could be used in certain applications – even to produce electricity if needed and economically reasonable. But the residual temperature on EXIT after WH recuperation might drop so far, that only in winter, a necessary "chimney-effect" can be guaranteed to get rid of the combustion products. In summer, additional ventilation (usually accomplished with electric ventilators) might be needed in order to expel the gases into the surrounding air where they can not pose a safety risk. The electricity needed by the fan, imposed by the regulatory authorities for safety-reasons, can in such a case render the whole project economically unfeasible despite heat-source and proper application for it.

Technical risk – Inherent technical risks of several sort and its avoidance can also cause additional cost whereas the ideal solution by means of the engineering possibilities might have come much cheaper: If for example a medium size or big refrigeration-facility's waste heat was to be used to avoid winter- and autumn idle in fish-aquaculture, as in the core-example of this thesis. A counter-current flow heat-exchanger used to heat the fish-tank's water within the fly-back containing the refrigerant of the cooling-facility, would ideally need no additional electrically powered pump, could reduce pump-load in the absorption-cooler of the supplier, heat-supply would be guaranteed throughout the year but the refrigerant was to be ammonia within the absorption-cooler: In this case an intermediary heat-pump or additional transfer-cycle with an additional safety-"layer", separating the toxic ammonia from the freshwater might still be necessary to avoid total dead-loss of the fish-production in case of ammonia leakage. Here, additional investment-cost may have to be taken, but can in certain cases pay back quickly, if the reduction of risk or in permanently running insurance-cost is taken into consideration or negotiated properly.

As an upside to this, the heat-pump can be used as a backup if the cooling-facility is out of operation due to failure, refill or inspection: Modern heat-pumps can work with satisfying Coefficient Of Performance (COP) even in winter conditions *and* can in reverse-mode even protect the aquaculture from over-heating in summer. Many models can be operated in switching-mode even between different media, switching the heat-source from whatever primary medium to for example the surrounding air and so on, if needed.

Environmental conditions – Climate and weather conditions and thus heat-demand and other related parameters might vary strongly over the course of a year. It may be easy to find a commercial customer for some excess heat in wintertime but eventually one may have to find additional use for excess heat in summer, in order to be operational within a reasonable amount of full load hours (FLH). In other cases, for example the river intended to take on the cooling as the heat sink in a certain process has to be assessed thoroughly, because regulatory maxima of alteration – especially increase in temperature – of the aquifer must not be exceeded for the sake of marine life as well as the proper functioning of the technical installations. In case of water-scarcity, additional dry-cooling-towers can increase the investment-cost as well as O&M-cost or conflict with neighbouring parties due to noise-pollution dramatically: "*Since the quantity of heat that needs to be released into the environment may be greatly superior to the useful work produced, (...) the quantity of water necessary for the condensation may be remarkable (e.g. 60 times the flow of steam to the condenser)(...) in evaporative cooling-towers (...) in most parts naturally draught cooling towers (...) water consumption is (...) around 2kg per electrical kWh (...)*" (Invernizzi, 2013: 34) produced. Dry air cooling – due to the only modest heat-bearing capabilities of air – may make massive surfaces and vast volumes necessary to cool the condensate. This cannot only lead to noise-pollution from the electrical fans producing the air-flow necessary, but can also increase condensate-temperature and thus (especially in summer) can limit discharge-pressure of the turbine at hand (=limitation of electrical output = income). Such environmental effects may be to one's advantage or disadvantage, depending on regulations and public participation, heat-source, alternative options for the use of the WH and alike.

Specific problems – Depending on the used medium bearing the waste-heat, some very specific problems can occur if the LTWH is to be utilized. Wastewater from industrial sites, various enterprises or facilities such as hospitals and dormitories[27] for example do provide very valuable amounts of WH *throughout the year*. This heat can either be recuperated by means of heat-exchangers or heat pumps in the sewer itself or a storage-tank built for that purpose initially or in retrofitting. Here, a discharge-temperature of below 10°C should be avoided in order not to disturb proper functioning of the downstream waste treatment plants (properly functioning bio-degradation of nutrients by

[27] Brunk et al., 2013: p.52

micro-organisms). Additionally, one has to deal with the forming of a bio-film on all (heat-exchanging) surfaces, causing the so-called "fouling-effect". This gradually increasing coating of all surfaces with micro-organisms such as algae and bacteria of various sorts can and will cause a severe drop in heat-exchanger-efficiency and or even cause corrosion to an extent were economic heat-recovery is rendered impossible[28]. With the rise in importance of waste-water-heat-recovery, several solutions be it mechanical (e.g. scraper) or physical ("Lotus-effect" nano-coating or "anti-fouling-paint") have been introduced to the market by various firms, competing for feasible, reliable and cheap solutions for industrial or private use. Which solution is to be preferred and suitable can strongly vary from case to case, given the temperatures at hand, oxygen-saturation, pH or nutrient-fright, just to name a few. In some cases sewage-water may again come in high volume and temperature but direct counter-flow heat-exchangers or *sewage water* in *general* may not be suitable for reasons of *policy or marketing* rather than *technical risk*: In case of a fish-farm, one might not even get close to the point where the produced fish is viewed as qualitatively inferior due to the mentioning of chemical-plant- or hospital-sewage-water in the same sentence with the fish, intended for human consumption and high-quality certification.

3.4 Market-Analysis of state-of-the art heat exchangers and recuperating technology

Heat exchangers come in a wide variety and abundance of system types and combinable working media. Most large-scale industrial heat exchangers are custom made individual productions fitted for the very purpose at hand. So naturally, even though one may research a good overview[29] of manufacturers, it is not just unlikely but impossible to find all models on the market. But that is not much of a problem, since within the last decade or so the wheel hasn't been newly invented. What really is important though, is the leap forward in performance that was possible. Large scale heat pumps nowadays cannot just use all sorts of heat-sources but also can achieve high feed line temperatures, like for example at Drammen[30] in southern Norway, were seawater at 8°C in average is used to power the

[28] Brunk et al., 2013: p. 5
[29] See: IFAT Munich (2014) www.messe-muenchen.de/de/messen_und_events/eventkalender_contentmaster_20032.php
[30] See: Drammen Heat Pump, http://en.wikipedia.org/wiki/Drammen_Heat_Pump

town's district heating network at 90°C feed, covering 85% of the total heat demand this way. This 14 MW unit runs at an average COP of 3.0, powered by Norway's cheaply produced hydro power electricity at almost zero emissions.

Many manufacturers do not just build custom units but are offering easy-to-install heat exchange-units that can also be coupled with heat pumps to increase heat levels. Some can easily be set into the wastewater-drain to recover heat, some can even be added in a modular way to make the maximum use of excess heat in sewage water if need be. The types of heat-recovery-technologies range from "passive" ones like counter-flow heat exchangers that virtually function without any moving parts to highly sophisticated devices like heat-pumps that involve compressors, working media, electrical- or gas-turbines, valves, sensors and so on.

Depending on the given circumstances, a simple counter-flow-setup may be desirable because it performs its task without additional energy uptake/consumption. In other cases – especially if high gradients have to be overcome and heat can not just be exchanged but has to be "concentrated" in an "up-hill"-fashion (from cold to warm), a heat-pump is vital because passive exchange only works in the natural direction of dissipating energy: from high to low potential.

Figure 10 shows a highly efficient design in which the counter-flow is directed over very big surfaces to accomplish as much transfer as possible in as little volume needed. Of course it is needless to say, that such filigrane designs are much more sensitive to freight and clogging than shell-and-tube designs. Especially in very big applications and industrial scales, the cheaper and far easier-to-maintain tubular designs are seen more frequently. Still, also plate-designs are available in industrial size (Fig.11).

Fig. 10: Plate Heat-Exchanger[31]

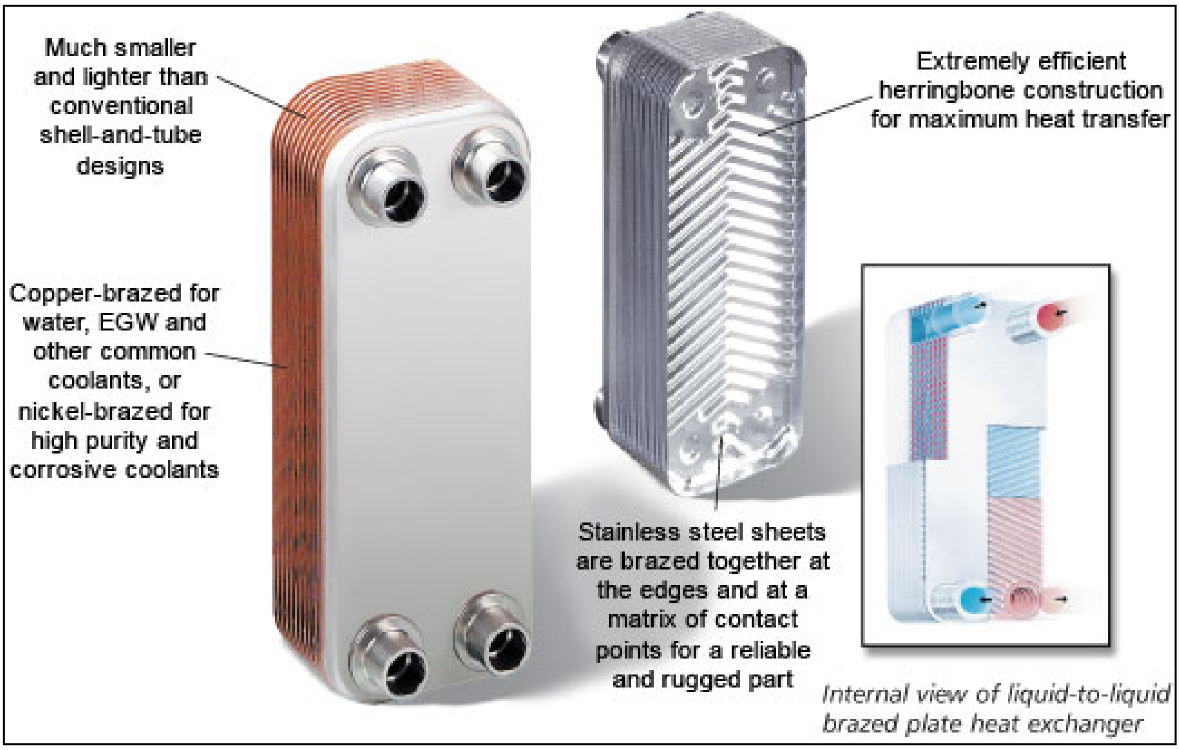


Fig.11: Plate design HE, industrial size[32]

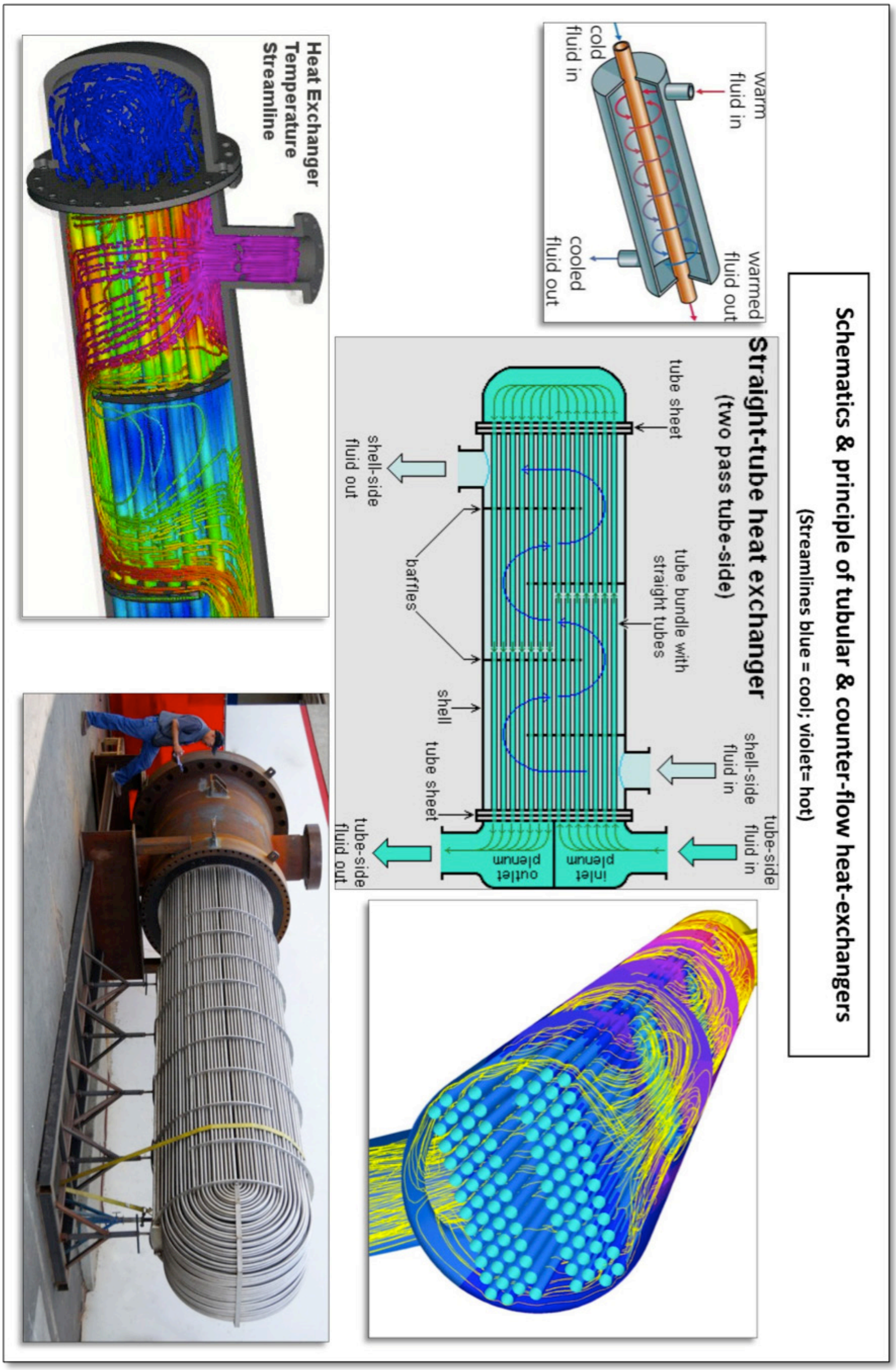
Plate designs may come at a very high efficiency, but they are rather expensive and provide rather small volume-flows. Tubular design on the contrary was used already in stem-engine-boilers. If the end-caps are unscrewed, the long tubes can be drilled-out in case of clogging, fowling or boiler-scale.

Active heat-exchanging-units, such as heat pumps for example, are not only using the normal or process-inherent flow of the medium. They can use various heat-sources – be it liquid or gaseous –

[31] http://www.solartubs.com/images/heat-exchanger/brazed-plate-heat-exchanger.jpg
[32] http://www.fahrer.ch/typo3/typo3temp/pics/4e854c8145.jpg

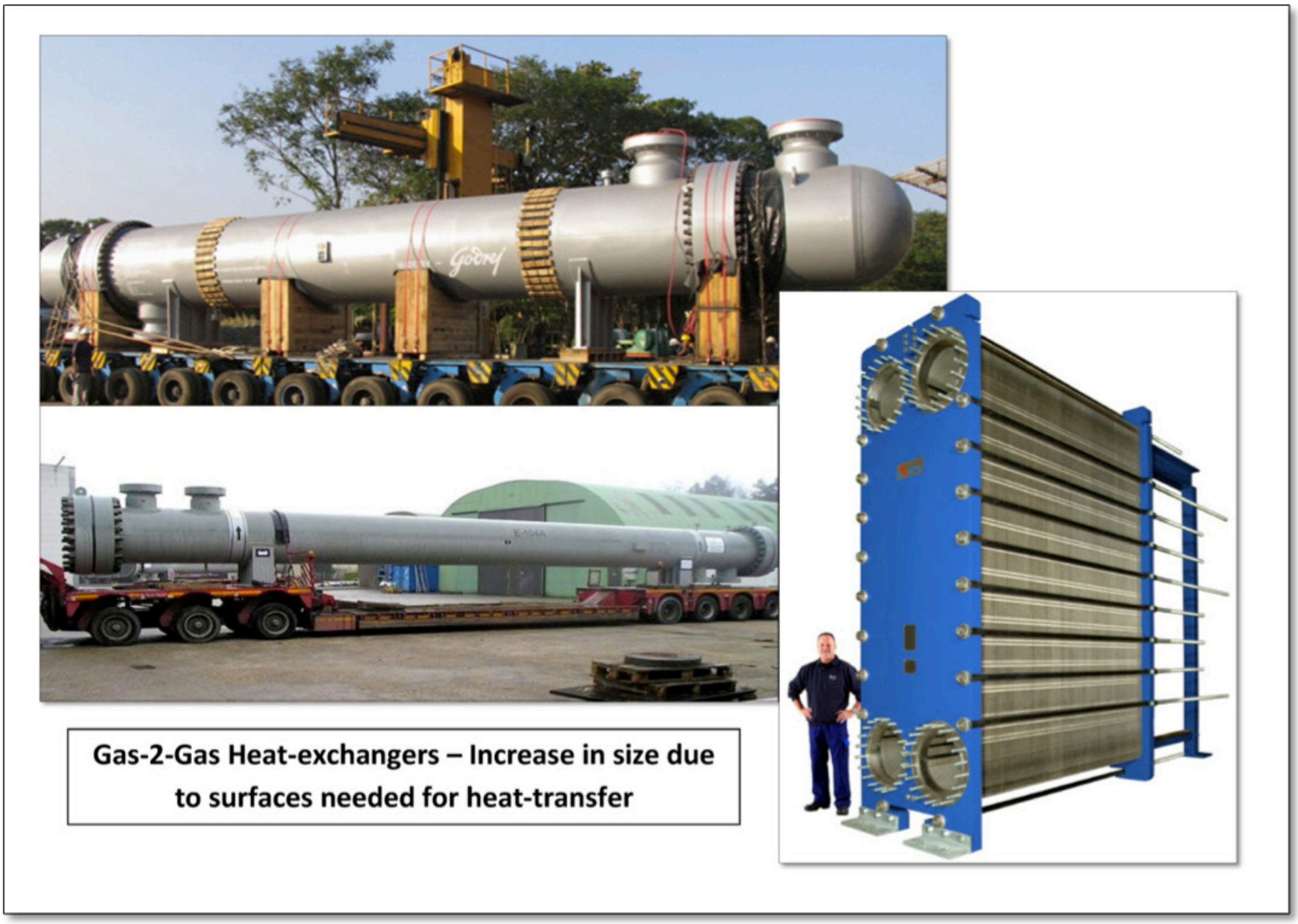
by means of the cooling agent or working medium within their compressing-cycle. This working medium does not only help to take heat out of stationary heat sinks such as pools, silos, lakes and ground-water, air or in case of geothermal heat-collection even solids such as concrete (concrete core wall activation) or soil (geothermal deep-well, or near-surface-collectors).

Fig.12: Basic tubular design HE; counter-flow; temperature-streamlines (photos compiled by the author)



Even though tubular + plate heat exchangers do exist for gas-to-gas heat exchange, they usually only are used in high-temperature applications due to the poor heat-bearing capablities of gases and the fact, that no heat-exchange beyond the thermal equilibrium of product (hot) and coolant (cold) can be obtained and the surfaces have to be enormous in order to exchange the heat (Fig.13; gas-2-gas HE). This in turn leads to high cost or in some cases poor volume-flows, which especially in passive-houses can cause bad air quality.

Fig.13; Gas-2-Gas Heat-Exchangers (photos compiled by the author)[33]



Heat pumps on the other hand, will also be able to not only concentrate heat by means of work, up to levels far above source-temperature. The rankine-cycle described in Fig. 4 will in such a case basically be reversed. In reverse-mode they can also be used to discard heat and –for example in the hot season – be used for cooling as they are used for heating or

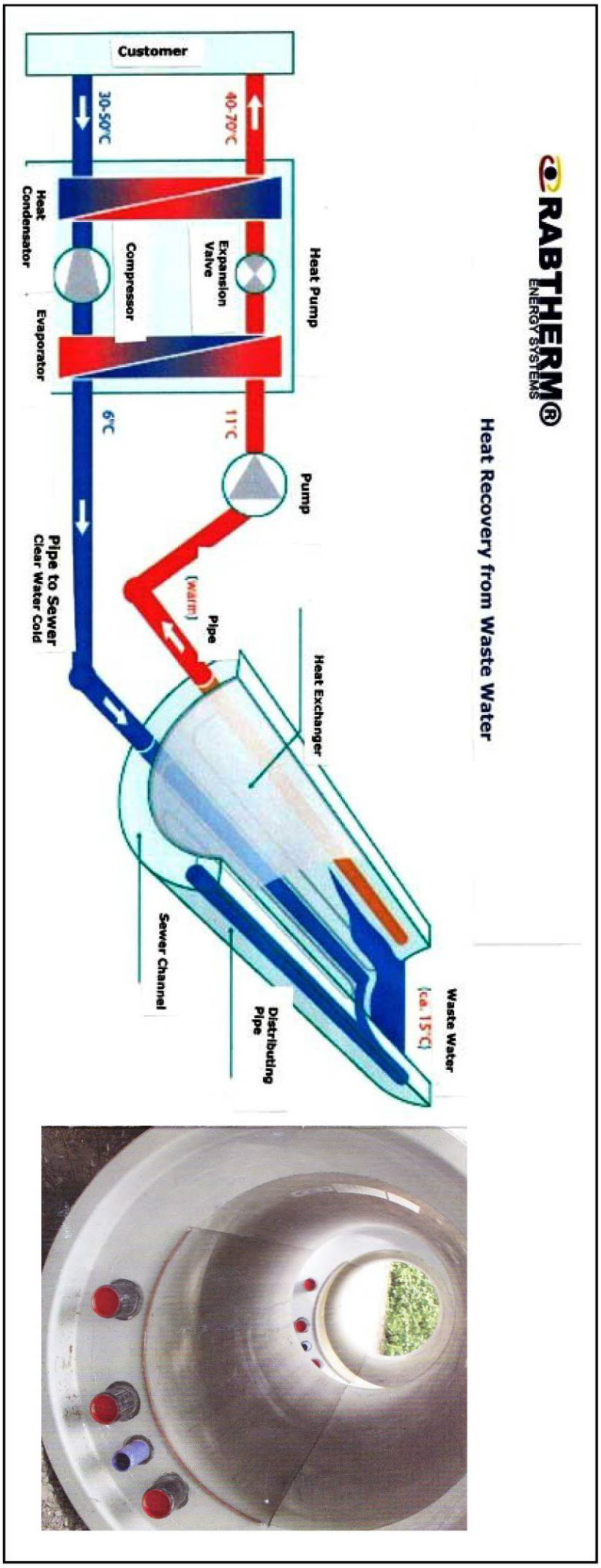
33 http://www.godrejped.com/godrej/processequipment/ProductImages/Largeimages/Gas&Gas-Heat-Exchanger.jpg

hot-water-production in other situations. Clearly, in any case the performed heat-transfer will be work-intensive, as long as the heat is transferred against the temperature gradient. The efficiency at which primary energy is used in order to accomplish this, is specified as the COP – the "Coefficient Of Performance". It simply weighs the amount of heat concentrated against the work (electricity, gas) needed for it. In an easy example, in which a kWh of gas may cost 3 Euro-cents and a kWh electricity 4 Euro-cents, a heat pump with a COP of 3.0 will deliver 3 kWh worth of heat at an input of 1 kWh of electricity at a cost of 4 Euro-cents. The equal amount of heat produced by a gas-boiler would thus have cost 9 Euro-cents, saving 5 Euro-cents in the process, summing up to almost 56% in cost-reduction. Even without knowing the detailed decutible cost per year of any given project: This proportion makes it very likely that any reasonable investment will pay back rather soon. If the electricity was poduced in a sustainable and renewable way, the reduction in GHG-emissions may even be close to 100%. However, all of the mentioned systems can of course be combined, in order to transfer as much heat as possible in the desired direction by means of passive heat-exchange and then only use work for the energy that has to be transfered "uphill" – against the temperature gradient.

3.5 Technological overview of heat-exchangers in regard to combinable working media

Since some possible media have already be described, the focus will now be on some that are very promising but not yet very commonly used or distributed. Given the abundance of heat and the already existing distribution-network (= sewer-system!), this can only be accredited to the lack of political will, thus to poor building-standards and construction-requirements for developers. Figure 13 shows a heat recovery-system that can be used in any sewer – newly constructed or refurbished or as a modular replacement for a given stretch.

Fig.14; Heat-Pump Solution for sewage-water waste heat utilization



Of course not only the sewage itself can be used as a heat source – the air within the sewer also provides a very useful source of excess heat, which can even be seen on cold days: The warm and moist air keeps a constant temperature throughout the year and will also provide perfect conditions for an air-2-air-heatpump during the cold season, when the surrounding air-temperature may sometimes fall well below zero. Here again, especially industrial sewage will provide a constant supply during the day, while private households usually contribute in the morning and evening hours. Over-boarding freightage with corrosive or otherwise destructive compounds does – at least if compliance with legal standards can be assumed – not have to be feared within an average European city-sewer.

4 Overview on a variety of possible applications

Even after focusing solely on LTWH, the abundance of possible applications is still vast. Especially if one does not only take into account the classical models such as district heating, household-hot-water-generation and so on. “Out of the box” of these classical approaches one quickly finds a variety of possibilities were LTWH can either contribute to a mix of energy-carriers used to complete a task at hand, or deliver a service, as well as accomplish it by itself without the necessity of adopting additional heat-sources or energy-carriers except maybe for the electricity used in the heat pump. Four such cases are described in *“Dezentrale Wärmerückgewinnung aus häuslichem Abwasser*“ (Brunk et al., 2013)*,* focusing on sewage water from a hospital, two student’s dormitories and a business-hotel. By means of a storage-tank and a heat pump, the produced waste water, that comes at slightly above room temperature throughout the year, is cooled down to around 10°C in order to not disturb biological water-treatment downstream. These 3 very similar examples are merely a glimpse of the possibilities there are. Given the fact, that these examples are lead as businesses but do not directly count as “industry”, the production and thus amount of useful wastewater could even be bigger on an industrial scale. The sewage system in this case, could be regarded as an existing distribution-network, delivering the waste-heat to neighboring homes without additional need for costly groundwork and piping. If a low-energy building or zero-energy-facility is planned from scratch, one could even plan the sewage-connections in such a way, that especially warm wastewater from either (industrial) washing-machines and baths (e.g. surface-treatment) is collected separately in order to make use of a lower gradient (higher source temperature) for the HP to reach a higher COP if the freshwater has to be heated to 60°C in the storage tank for example. Of course also central heating can be either accomplished or supported by such means – both in private or business environment, depending on the supply with warm waste water, heat-demand of the target object and of course its thermal characteristics like, tightness of windows, thermal conductivity of walls and quality of insulation etc. Hot water for human consumption and sanitary use, has to be heated to around 60°C in order to avoid Legionella-bacteria to live and grow, because it can cause a deadly form of pneumonia. In this case the hot sewage-fraction is more ideally to be used, when it comes to gradient and

COP. For bringing air in offices or family homes up to comfortable 21-22°C, the lower tempered sewage is sufficient and can in the hot season also pose as a heat sink in order to AC the rooms by warming up the sewer. Reverse-mode operation of the HP, as in heating up the heat-exchanger in touch with the sewage water can under certain conditions be used to kill-off and help remove the bio-film that is causing the fouling-effect or delay its repeated formation.

Besides such very common approaches in housing and facility management, another less widely used approach would be to heat up greenhouses for either producing food or flowers in the agro-industry. The intensity of sunlight to guarantee the formation of biomass throughout the year by means of photosynthesis might (especially in Europe and similar climate zones) be sufficient and is more and more commonly supported by low-consumption daylight-LEDs. Temperatures in the cold period of the year on the other hand usually drop to levels were plant growth cannot be sustained at an economic – or any – level without additional heating. Especially in the production of biomass, an enclosed compost-facility dealing with leftovers, excess biomass and off-cuts, naturally produces very much heat through the activity of the microorganisms, breaking down the long-chained and complex molecules (mostly) into humic-acids, CO_2 and inorganic matter. In some unfortunate cases, heat is accumulating to such an extent that even self ignition of such sites has been reported and must constantly be avoided. Of course, the temperature-limits needed to sustain microbial activity must be guaranteed, but through the utilization of excess heat, the whole composting-process can even be accelerated:
Piled-up and moist biomass quickly starts to disintegrate by the work of fungi like yeasts and other microorganisms. These piles, having a high volume compared to their surface, can in many cases not radiate or cool-off (by evaporation) the produced heat, thus accumulating it within, sometimes reaching temperatures close to pasteurization-point or above, killing off a big number of these micro-organisms. In nature itself, this seldom occurs because layers of highly bio-active debris and biomass usually cover only the thin top-layer of the ground and can therefore never overheat this much. Even though the "feedback-loop" of rising temperature and microbial activity versus microbial death due to overheating in manmade compost-piles is regulating itself, it is none the less slowing down the digestive processes. By using the really remarkable amounts of heat produced by these processes, well below the "deadly temperature" but staying within the optimal temperature-range of the microbes, one cannot just tap into a free source of heat but also

induce massively enhanced microbial activity, unhampered by regular or constant overheating. The dual advantage of such an approach will thus not only be the reduction of costly fuel-consumption, but also an increase in humus-output that can directly benefit the gardening and fertilization operations. The cycle closes with a final adaptation: The compost-temperature is allowed to rise sharply just once at the end of the digestion-process to sanitize the humus. This will ensure the heat-induced reduction of microbes and germs or plant-diseases possibly harmful to the own cultures before the compost is brought out as fertilizer once again to help building up higher plant biomass. A cycle not quiet unsimilar to the thermodynamic cycles in combustion engines, replacing instantaneous combustion with a sort of "slow-motion enzymatic combustion" producing useful heat, CO^2 and water vapor almost free of charge, at temperatures almost too high to be accounted as "Low Temperature WH".

Such decomposition-energy can be found in many biological or chemical processes and is not necessarily reduced to solid biomass like dung or cut-offs. Different fermentations or even exothermal chemical reactions rooted in solvation-energy (diluting acids or certain salts, etc.) and alike could be the source of LTWH even though this is not very common.

A very integrative case of course is that of a closed cycle aquaculture for the production of locally produced fish. Since fish is one of the fastest-growing markets when it comes to protein supply for human consumption, it is needless to say, that it is as well one of the most problematic ones in terms of production-circumstances or transport-related GHG emissions. Overfishing, decline in biodiversity (in case of Asian mangroves where most shrimp and Tilapia are produced) or health issues for locals and overseas consumers alike (pathogens, antibiotics, excrements…)

4.1 Efficiency effects & subsidies: Example Closed Cycle Fish-Aqua-Culture

For this thesis, a very specific approach to use LTWH was mentioned and will in this chapter be described closely: Closed Cycle Aqua Culture for fish-farming. The given example poses as an ideal showcase of how deep integration of certain processes can actually be accomplished and to which extent efficiency can be archived.

Several angles have to and will be taken into account to evaluate the over-all quality of the project at hand:

- Increase of technical efficiency (amount of LTWH recuperated
  + GHG-emissions avoided)
- Savings in O&M-cost due to utilization of LTWH vs. common energy carriers
- Regime of subsidies (EU, national and county-level)
- Combinable subsidies from different areas of focus (energy, nutrition, R&D...)
- Market /-development & achievable added value and thus
- Approximate ROI/ desired IRR

Besides the increase of efficiency that is desirable if it comes to climate change mitigation, one always has to keep economical feasibility in focus. This on the other hand will be dramatically easier to archive, if the regime of subsidization does not only support the efficiency-measure or technology itself but also provides an environment that allows staying economically sound over a given period of time. Here the author explicitly reminds of the mass-foreclosures[34] of Austrian biogas-plants: After their period of feed-in-tariff-subsidisation, many of them had to close because neither had their LRMC reached grid-parity nor have they been planned to use biogenic waste-materials but rather fodder-corn that was massively subjected to world-market price volatility, again following high oil-and gas prices (fertilizer, pesticides) or a sharp increase in demand for high quality fodder (worldwide increase in meat & dairy-product consumption).

Of course nobody can look into the future, but as far as one may dare the attempt, farming locally and sustainably produced fish seems to be a promising undertaking, given the current market situation in Austria, the EU, importing-countries and the Federal Ministry's official planning papers:

About 7-8 kg/per capita fish annually are consumed in Austria at the moment. Over 90% of this demand is currently satisfied by imports, which led the ministry of agriculture and fisheries to set the self-sustenance-goal with sweet-water fish officially to grow from

[34] Strobl (2012)

currently ~34 % to a desired 60 % in 2020 (equaling a total increase from 2.400 tons to 5.500 tons per year).
Closed cycle aquaculture currently contributes only at a minimal share of below 150 t/year and is set to rise to 500 t/year, according to the ministerial paper "Aquakultur 2020[35]".
Special emphasis on piloting closed cycle farms with accompanying scientific measures (like the one at hand) are mentioned *explicitly*. Currently the only competition arises from outdoor-aquaculture which today mostly focuses on carps (natural ponds) and trout (percolation farms), fingerling, Zander and various catfish. For several reasons, this competition is currently fighting uphill, due to reduced output and increased cost: Since sustainability-certifications of various sorts are more and more becoming an USP, many fish-farms switched to organic production. This led to reduced outputs because of rigorous feed- & fodder-regulations as well as regulatory controls. Therefore the so produced fish moved into the (very) high-price market-segment and thus further away of being a regular source of healthy protein for the vast majority of people and public institutions such as hospitals, schools, prisons or retirement-homes.

Parallel to that, health- and lifestyle-consciousness led to a significant increase in fish consumption, whereas this rise in demand mostly was met by imports (~95%, including seafood). Those imports consequently also rose by 100% in the last decade, leaving domestic production with its ~3.100 t/year versus 61.254 tons of imports per year far behind. The ~200 Mio. Euro trade balance deficit consequently arising in 2007 – that will very likely have doubled by now – is a clear explanation for the ministry's eagerness to take serious action.

These measures amount not only to subsidies but also to enabling help in regulatory issues such as quickly released granting-notices and unusual support in stakeholder research. The monetary support mostly consists of:

- Good subsidies for efficiency measures in companies→ waste-heat recovery, and /or reduction in pump load (=electricity consumption) via flyback-flyback-uplink etc…

[35] Blaas (2012)

- From 2015 – 2022 huge subsidies-program in the frame of EFF (European. Fisheries-Fund) explicitly targeting over-fishing through the support of aquaculture

A further positive price development due to the EU-commission's resolution[36] to turn to sustainable fishing[37] from 2015 onwards[38] in order to save what is left of the heavily depleted[39] European fishing grounds and rapidly growing demand for fish worldwide can undoubtedly be foreseen. It is furthermore very helpful that any LTWH can technically be used to heat the fish-tanks, be it from CHP, refrigeration units, cement plants, process heat from air compression and so on. This does not only arise from the fact that unlike for domestic hot-water preparation, the water for the fish does NOT have to be pre-heated to 60°C in order to avoid the growth of "Legionella sp.". The fish-farm does operate either an ozone or UV-light sterilization-unit, which ideally renders all pathogens inert. That in turn allows the HP not only to easily operate at desirable COP, even if the heat source is itself close to the operating-temperature of the fish-farm at ~26°C, but makes further heat-concentration unnecessary.

Except for the initial filling of the tanks, the fish-production functions at only 5-10% freshwater/day compared to the total installed volume. This technology does thus not only offer high resource- & cost efficiency but is also exemplary when it comes to saving water. Of course, the discarded water can itself be subjected to heat-recuperation in a counter-current heat exchanger as it leaves the plant, further reducing the need for heating the fresh water with the LTWH or electrical pumps. Fortunately there are turn-key-plants[40] on the market that can be equipped with various types of heat-sources and can be used with a wide spectrum of species. Of course different species will demand different temperatures, oxygen saturation, technologies (sweet-/ saltwater) and thus higher or lower investment cost.

Risks -The initially high investment for a 200t/ year output of African catfish-farm sums up to ~1,5 Mio.€ „turn-key" from scratch[41]. The a little more complex technology may

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[36] European Commission (2015a)
[37] European Commission (2015b)
[38] European Commission (2015c)
[39] Cf. WWF Census of marine Life; http://wwf.panda.org/about_our_earth/blue_planet/news/census_of_marine_life/
[40] See for example "Pal Anlagenbau": http://pal-anlagenbau.de/aquakultur/philosophie-fischproduktion/
[41] Telephone interview with a Contractor who wished to stay anonymous due to marketing reasons

come with a considerable need for precise planning needs, that should involve the desired „Aquaculture Stewardship Council[42]"-certification framework from the very beginning. Plant-handling initially may come with a significant demand in well trained personnel, because some fish specimen don`t tolerate much erratic fluctuation in parameters such as oxygen-saturation, ammonium-content, germs, temperature etc.

Advantages - Very high yield in fish can be gained due to constant and ideally warm temperatures, ruling out „winter-idling", which is usually so typical for European and all comparable climate regions. This means that the merchandise „portion-fish" can be obtained after only a ~150 day period instead after 2 years (factor 4,87) in a normal European outdoor environment.

The necessary heating cost due to use of LTWH is remarkably reduced if not almost negligible, the electricity needed to circulate the water and run the HP may remain the bigger issue in this context. The chosen species of *African catfish*[43] on the other hand is very sturdy.

Fig. 15:African Catfish; Caught & caught walking (Photos compiled by the author)[43]

That finds its expression in highest tolerances for erratic change in parameters due to the naturally occurring habitat conditions in African aquifers, especially during the dry season: African catfish can breathe atmospheric air for up to 2 days whilst "walking" on land to search for another pond or food. It also survives various salt concentrations due to its evolutionary adaptation to the extreme conditions of its original habitat, were due to drought and high temperatures, oxygen-levels, mineral-content and number of specimen per unit volume water can and do reach very harsh limits and fluctuate strongly over the

[42] Cf. ASC, Aqua Stewardship Council, http://www.asc-aqua.org/index.cfm?act=tekst.item&iid=61&lng=1
[43] Clarias gariepinus, see: FAO, Fisheries and Aquaculture Department (n.d.)

course of a year. For example: Our common trout (Salmo trutter) will not tolerate water-temperatures above 12°C and associated (low) oxygen saturation and it will die from stress in populations of more than approximately 140kg fish per m³ of water. The African catfish on the contrary, has to be kept at a minimum of 200kg/m³ and tolerates up to a maximum of 450kg/m³. That resembles an astonishing ratio of almost 50:50 of fish and water (!) in original African conditions in aquifers of the dry season, were these predatory fish suddenly turn into non-territorial "friendly" and calm beings, refraining from eating each other, due to a very special and evolutionary unique natural behavioral pattern. In the harsh African droughts, this mechanism of course is an important evolutionary mechanism that is vital to the survival of this species in these almost unbelievable conditions and densities.

Unaffected by environmental conditions like floods, predators, bio-invaders, upstream-water-quality, insecticides, climate conditions and such influences, the risk of total dead-failure reduces massively if hygiene is held up high. The need for expensive emergency-oxygen fumigation-units can in the case of catfish be avoided completely because of the naturally high tolerances of the African catfish. Due to the compact construction and low area-consumption, this technology is also compatible with urban areas. That contributes to the over-all efficiency again when it comes to climate-friendly transportation: The direct situation in the proximity of an area of high demand equals low transportation and thus cooling-cost, -time and thus GHG-emissions. These additional effects are possibly again subject to subsidies. On top of that and to possibly further reduce the O&M-cost as well as the "footprint", the combination with organic waste-water-treatment can lower costs further. A corresponding area of organic plant wastewater-treatment of at least a good fraction of the daily produced nutrient-rich waste-water can very well be integrated into the architecture of the facility, while posing as another area that can be subject to subsidization. Common reed-cane – bio-treatment-plants have already been standardized (ÖNORM[44], DIN, ISO[45]; EN[46]) and green facades or roofs will themselves under certain conditions not only be subsidized but contribute to insulation against both heat-loss and overheating. The so treated waste-water can either be re-used or at least be subtracted from the amount of sewage for which the municipality will claim treatment-fees.

[44] http://www.aee.at/aee/index.php?option=com_content&view=article&id=479&Itemid=113
[45] http://www.ots.at/presseaussendung/OTS_20060209_OTS0162/biologische-kleinklaeranlage-ohne-strom-lt-europanorm-en-12566-3-typengeprueft-bild
[46] http://www.constantflow.at/bemessung-nach-oenorm

4.1.1 Economic aspects of a 200 ton/year fish plant example

In order to calculate an exemplary project, the assumption of a completely fresh start will be made: The greenfield-strategy, organized around a general contractor[47] to avoid supply-problems and execution-chaos by means of a turn-key facility with clear and strict time-frames and according penalty rules to avoid idling & delay.

Table. 2; List of items for NPV-calculation (own table)

Item required	Type of cost & amount	Specifications
Plot of land + concrete foundation, including basic grid connections	Investment (long term)	close to the heat-source; inside a business-park or under a highway-flyover in the middle of town
Simple multi-purpose hall, steel-frame; corrugated steel frame wall, insulation;	Investment (long term)	Simple, galvanized against high moisture environment, no electromotive series, no summer overheating
Fish-tanks, total volume reflecting 200t/year output + PP-piping; disinfection & cleaning gear	Investment (long term)	According to ASC certification necessities, e.g. square tanks
Valves, shutters, filters, circulating- & backup-pump, lighting + electrical works	Investment (long term)	No electromotive series, same metal throughout the water cycle (e.g. stainless steel)
UV-germ unit, biological water treatment unit, drum-filter, automatic feeders, Automated analysis equipment & data loggers, internet-uplink for remote control & emergency alarm	Investment (medium term)	Expensive real-time-analysis-unit centrally accessible for ALL fish-tanks via regularly rinsed small pipe-grid, instead of expensive redundancies PER TANK
Heat exchange units: 1) LTWH-supply + 2) pre-sewer wastewater-heat-recuperation, 3) backup+ overheating-mitigation (summer) : heat-pump	Investment (medium term)	Multi medium & reverse mode option heat-pump for sewage water, air + primary medium mode
Optional: Rooftop PV-for own consumption	Investment, leasing, contracting, or rent-out of roof to 3rd party	For example www.dachgold.at

[47] See for example "Aquatech": http://www.aquaculture-com.net

Processing units (Stunning, scaling, gutting, filleting, smoking, packing); ice-machine, refrigeration,...	Investment (medium term)	200.000 kg/year (365-15 days)~570kg capacity/day
Optional: Botanic-wastewater-treatment-unit (part of architecture) I) reed: horizontal, surge II) facade greening, vertical, continuous	Investment (long term)	Close cooperation with authorities to ensure ROI by means of lower canal dues& sewage fees
Fingerlings/ hatchlings, feed & fodder, water, electricity	O&M-cost	According to ASC certification + feed-norms; probably using local meet-residues as allowed since 2014
Skilled personnel for water & fish management, fish-processing, packing....	O&M-cost	
Certification cost: International Food Standards, ASC, AMA,...	O&M-cost	Consumer trust, big retailers & public procurement + higher price segment
Analysis-chemicals, veterinarian supplies + pathology-detection kits,...	O&M-cost	According to regulations
Facility management, inspection, repairs, insurances, security & safety training & equipment	O&M-cost	To minimize insurance cost – close definition of needs to lower insurance rate
Local area: farm-gate-sales & cooperation ("Biokistl", food-coops, school-restaurants, direct sales)	O&M-cost Marketing/ Community Building	Highest monetary reward in direct or local sales without retailer margins
Catchment area: institutional customers (municipalities, retirement homes, KAV, retailers...)	O&M-cost Marketing	Necessary to move enough product + diversify sales environment
Waste treatment & disposal	O&M cost – vs additional inccome	Reduction as far as possible; alternative appropriation e.g. as dog-food or fertilizer
Total Investment costs	1,5 million Euro	Figure acquired in numerous off-record telephone-interviews
Total O&M costs	10% of investment/year not including personnel cost: 150.000Eur	Crude estimation

Even though the initial investment costs have been verified in numerous telephone interviews with turnkey-providers, they all refused to being cited because of a) concurrence & Know-How issues and b) lack of pinpoint or accurate figures or planning:

A closer look into precise figures would only be possible if details could be discussed, such as construction-site exploration, concrete & foundation-works and so forth. Some suppliers refused to name any figures outright, in order not to be wrongly put into the "expensive corner" without having had the option of laying down all their knowledge, possibilities, advantages, also concerning specialist personnel recruitment, "friendly" insurances, support in marketing and supply-chain management, hatchling-nursing, pathogen prevention and emergency service response time. Some for example could guarantee the plant facilitation at 5% freshwater – regarding the over-all tank volume; Others would only guarantee 5-10% which could – given the sewage-fees and freshwater cost – pose a big difference in the total-cost-of-ownership (TCO) analysis. Given the desired plant output of 200.000 kg per year, a total breading time of ~150 days and a capacity of 570kg as times 350 days and the certifiable density of 350kg fish/m³ water these differences matter indeed: 570kg per day were as 350kg/m³ density equals 1,629m³ daily needed for full capacity;
To supply these amounts over 350 days/ year this will equal 570,15m³ of total volume installed, close to 600m³ so to say. Preferably in 10 tanks of 60m³ each, to allow for continuous production of differently mature fish and a possible containment of pathogen occurrence. Just to give an impression on how much that is: 60m³ is roughly the volume of a standard tanker as shown in the following picture:

Fig. 16, 60m³ standard tanker[48]

5% of that equals 30.000 litres of daily freshwater intake whereupon 60.000 litres of freshwater intake in the 10% example are making a huge difference and not just by means of water cost. If 30.000 liters per day are needed and a constant flow of freshwater over

[48] Source: http://www.bock-silosysteme.eu/bilder_allg/tanktc30.JPG

20h (not 24h, for "conservative estimation") is taken into account, a *minimum* hourly delivery rate of 1,5m^3 is required. With standard piping diameters (clear diameter) that will leave us with a 20mm diameter pipe (DN/ID) and an hourly capacity of 2,3m^3 at 2 m/second flow rate according to (*Sammelzuleitungen, Steigleitungen, Stockwerksleitungen)* ÖNORM EN 806-3. A small & standard "Q3"-type watermeter with a permanent troughput capacity of 4m^3/h would be able to deliver the required 30m^3 in a normal working-day of 7,5h. Internal friction and pressure-loss especially between the DN20 (3/4") to DN25 (5/4") pipe-to-meter-coupling is intentionally neglected in this case due to lack of practical relevance: The plant can practically be filled with fresh-water day & night which will not only improve wastwater-heat-recovery (no surges!). Also the watertreatment described in figure 17 can handle small amounts in a continuum much better than large surges. Table 3 shows, that larger diameters are not even necessary if 5% can not be met or a 24h continuous discharge should be impossible for whatever reasons.

Table. 3: Pipe clear-diameter & water throughput per hour[49] (own table)

Throughput in m^3/h in Municipal Waterpipes at general requirement v=2m/s	
Sammelzuleitungen, Steigleitungen, Stockwerksleitungen gemäß ÖNORM EN 806-3	
Norm Inside-Diameter (DN/ID) in mm	**Discharge Flow m^3/h**
6	0,2
10	0,56
13	0,96
15	1,3
20	2,3
25	3,6
32	6
40	9
50	14
65	24
80	36
100	56
125	90
150	130
175	174
200	230

When it comes to wastewater-fees, one has to say that municipal (MA31[50]) wastwater-duties are calculated[51] by the exact volume one is drawing from the municipal supply system[52] plus what comes from (a) well(s) if such an option is used. Exemptions ("unter

[49] Source: http://www.duerholdt.de/?id=232 (own graph)
[50] https://www.wien.gv.at/advuew/internet/AdvPrSrv.asp?Layout=stelle&Type=K&stellecd=1999072815584780
[51] https://www.wien.gv.at/recht/landesrecht-wien/rechtsvorschriften/html/f8600000.htm
[52] https://www.wien.gv.at/amtshelfer/bauen-wohnen/wasserwerk/wasseranschluss/abwassergebuehrherabsetzung.html

Nachweiserbringung") are possible if water is used for irrigation, is sold-off with products, evaporated for cooling or alike. Second, the municipal fees on water-connections variate heavily from standardized small diameters to "over-sized" diameters: Not only installation costs but also the "connection fee[53]"have to be payed, which will be set according to the diameter[54]. Wereas DN25 and DN40 both come at 1000,58€ "Anschlussabgabe", DN50 already comes at 2429,98€ - 240% of the DN40. Also the annual "base fee" will change from a minimum of 24,15€ up to a maximum of ~290€/ year. One cubic meter of fresh-water costs 1,8€, so water consumption is a big issue here: 30m³ per day will cost 1620€ per month or about 20.000€/ year. The important difference between 5% or 10% freshwater becomes ultimatley visible. The whole importance becomes even more obvious, if sewer- or wastewater fees are also taken into account: Since every cubic meter drawn from the city grid (or even drawn from a well) is directly assumed sewage. Thus, the municipality charges 1,97 Euro for every cubic meter in 2015[55], adding with another ~21300€ but only in the 5%-freshwater example. Further more, Vienna passed a law in 2013, introducing an inflation escalator clause.

The introduction of an organic wastewater-treatment facility that is well integrated in the architecture of the fishfarm (green roof, facade greening,...) could substantially cut the cost here PLUS act as an eye-catcher: 21.300 Euro/ year at an inflation of 1,5% will grow to more than 24.700€ within 10 years. So an investment into such an upgrade may very well pay off in very short time, due to the savings possible and the low implementation- or prime-cost.

A project[56] by the German branch of the world-renowned agricultural machinery-brand "John Deere" in Mannheim, Germany, has shown that up to 10m³[57] per day of grey water can be treated on a 150m² roof, without putting so much load and strain on the structure, that it would have had to be supported or adapted. The water thereafter reached a quality that by means of strict German (and thus EU-) standards was safe to perculate into the ground.

[53] https://www.wien.gv.at/recht/landesrecht-wien/rechtsvorschriften/pdf/abl/abl2013047.pdf
[54] https://www.wien.gv.at/amtshelfer/bauen-wohnen/wasserwerk/wasseranschluss/herstellung-anschlussleitung.html
[55] https://www.wien.gv.at/amtshelfer/bauen-wohnen/wasserwerk/wasseranschluss/abwassergebuehr.html
[56] See: http://www.spiegel.de/wirtschaft/unternehmen/dachklaeranlage-oeko-tueftler-will-abwasserentsorgung-revolutionieren-a-647620.html
[57] Simantke (2010)

Unfortunately it has not yet been possible to verify the prime cost, but what can be seen on varios depictions[58] and the patent file, "low budget" is about the definition of the whole unit (see fig.17 on the following page). The plants seem to have a life-expectancy of up to 25 years, are free-floating with their roots in the plastic sumps and are well within the flat-roof load-bearing range (snow etc.) because no substrate or soil is needed. The construction mostly consists of pond-liner, PVC piping and a couple of fittings. Cooling load in summmer is reduced as well as heating demand in winter, the regenerated water is used for flushing toilets.

[58] For example Sadrzadeh (2011)

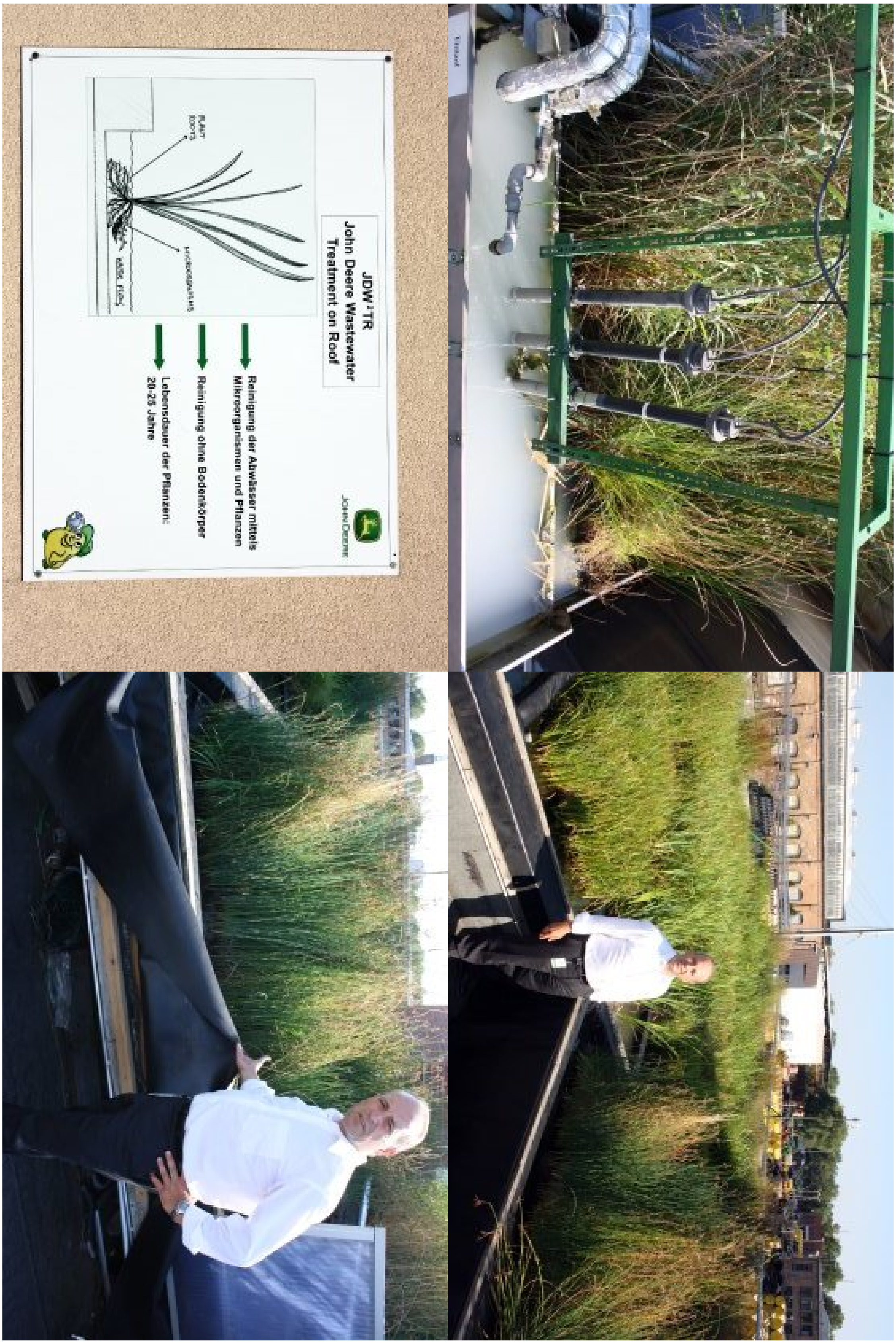


Fig. 17: John Deere factory rooftop water treatment unit in Mannheim; Germany[59]

[59] http://www.google.com/patents/US7718062

4.2 Discussion/calculation of 3 exemplary pump-loads and possible savings due to flyback-flyback-coupling

If we neglect the initial heating of the 600m³ total tank-volume and only concentrate on the daily replacement- discharge of 30m³ freshwater, we can narrow down the following key figures, given the fact that Viennese water never comes at more than 10°C. For planning one might just keep in mind that due to the further distance, tabwater will be 2°C warmer in Floridsdorf or Donaustadt than it is in Liesing or Favoriten[60]: 2°C difference in 10.950m³ annual waterconsumption will mean a lot of difference:

Equ.8: Estimated water & related energy demand

$$\frac{30m^3}{day} \; x \; 365 \; days = 10.950m^3 \; (p.a., 5\% \; threshold)$$

Specific heat of water...............4,18 J/gK	Energy to warm 1 L (kg) of water 1° = 1,16111 Wh
1Joul equals 1 Watt-second..............Ws	1m³ = 1 ton of water 1° = 1,16111 kWh
Fish-tank nominal temperature.......26°C	1°C x Δ16° x 1,16111 = 18,57776 kWh
Initial water temperature.................10°C	30m³ x Δt 16° = 557,3328 kWh / day
Δt..16°C	Total energy demand per year 203426,472 kWh

Or in a more appropriate term: 203,43 MWh/ year

In the quick overview losses are not yet assumed. Possible "Cooling-demand" in summer is also not yet subtracted. But given the fact that heat can be recuperated from the discharged wastewater of course within a counter-flow heat-exchanger[61]:

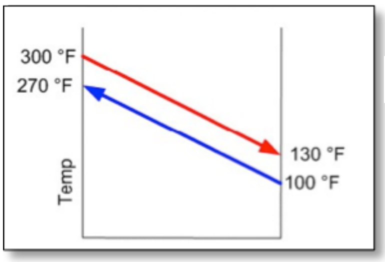
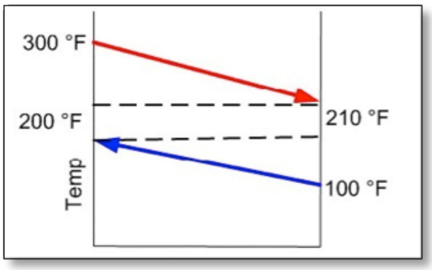


Fig. 18: Direct- vs counter-flow

←Counter-flow (high yield)

Direct-flow (low yield) →

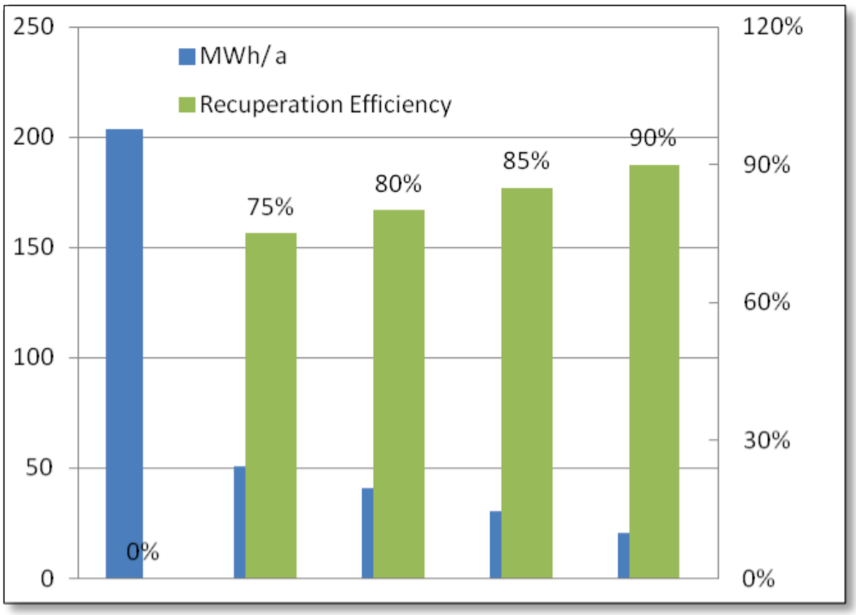


At such efficiencies, still beeing possible without the electricity-intensive use of a heat-pump, the amount initially calculated becomes a lot smaller.

60 http://wiev1.orf.at/stories/207113
61 http://www.laundry-sustainability.eu/de/Microsoft_PowerPoint_-_Modul_5_-_4_Warmetauscher_191107.PDF

Herefor really good online[62] calculators[63] do exist and in an not even very well adjusted cases, 75% recovery-rate can be accomplished. That would leave us with only 25% of the initially assumed energy demand and thus with 50.856,618 kWh annually. But it is safe to assume, that recuperation-efficiencies of more than 75% are truely possible. On the other hand, even with very good insulation, one might lose water and thus heat due to condensation in a considerable amount: to allow gas-exchange (CO_2/ O_2) on the water-surfaces for the sake of the fish, no permanent seal or "lid" can be established to protect the water-surface against evaporation.

Fig. 19 respectively Tab. 5: Recuperation-efficiency vs. energy demand (own table+ graph)



kWh/ year		Efficiency
203.426,472		0%
50.856,618		75%
40.685,2944		80%
30.513,9708		85%
20.342,6472		90%

~51.000kWh worth of natural gas would currently sum up to ~1300€ in annual utility bills which is really not absurdly much: Given a current gas-price of 2,5 cent/kWh (excl. VAT). Whilest the wastewater-fees are on the first glimpse causing much more cost than the potential energy demand, one now could effectively reduce the pumpload of a neighbouring unit by consuming their flyback-temperature and asking them for half the

[62] http://www.schweizer-fn.de/berechnung/waerme/wt/wt_start.php
[63] http://www.schweizer-fn.de/waerme/waermetauscher/waermetauscher.php

revenue. By using a counter-flow plate-HE, the following thermal transmission coefficients ("Wärmedurchgangskoeffizient"; k-Wert, TTC) can be obtained:

Table. 6: Plate-HE & thermal transmission coefficients[64] (own table)

Plate heat exchangers in different combination of fluids and working conditions and resulting thermal tramsmission coefficient ranges		
Plate –HE general	smooth channels, gas -2 water	20...60 W/(m²·K)
	smooth channels, liquid -2 water	350...1200 W/(m²·K)
	contour-plates; liquid 2-liquid	1000...4000 W/(m²·K)
Manufacturer's data	water -2- gas (1 atm)	10...50 W/(m²·K)
	water -2- gas (20 atm)	40...150 W/(m²·K)
	water -2-water	1000...8000 W/(m²·K)
	water -2- oil	200...400 W/(m²·K)
	oil-2-oil	80...120 W/(m²·K)
	steam – 2 - water	600...4000 W/(m²·K)
	steam- 2- gas	10...60 W/(m²·K)
	gas (1 atm) 2 gas (1 atm)	4...12 W/(m²·K)

This table can of course only touch the vast possibilities of combinations, pressures and HE-types. The figures for the TTCs are rule-of-thumb-estimations as can be seen in their spread of bandwidth. As mentioned before, engineering quality, fouling-effect or fluid-speed have a large impact on these and make every case a unique situation.

So the TTC contains 2 different informations: the ingenuity of the HE-engineer and the plant-operators ability to find ideal parameters like velocity, pressure and so on.

Possible revenue for the owner of a flyback heat-source comes to the power of 3 of the pumpload compared to the mass-flow: 2 of these 3 dimension come with the kinetic energy of the massflow: Twitce the speed contains 4 times the dynamic energy, while internal

[64] Source: Excerpt from http://www.schweizer-fn.de/waerme/waermetauscher/waermetauscher.php

friction also increases in a non-linear fashion hence it does not *add* up to the total dynamics but *multiplies* as the 3rd dimension: the rule of thumb is therefore that in a unit with high internal friction (lots of curvature, thin cailares or diameters in general, long distances,and so forth) the total potential for savings is exponentially higher (Fig. 20; Andreas Withs et al; Vatenfall, 2008).

Fig. 20: Grid pump performance[65]

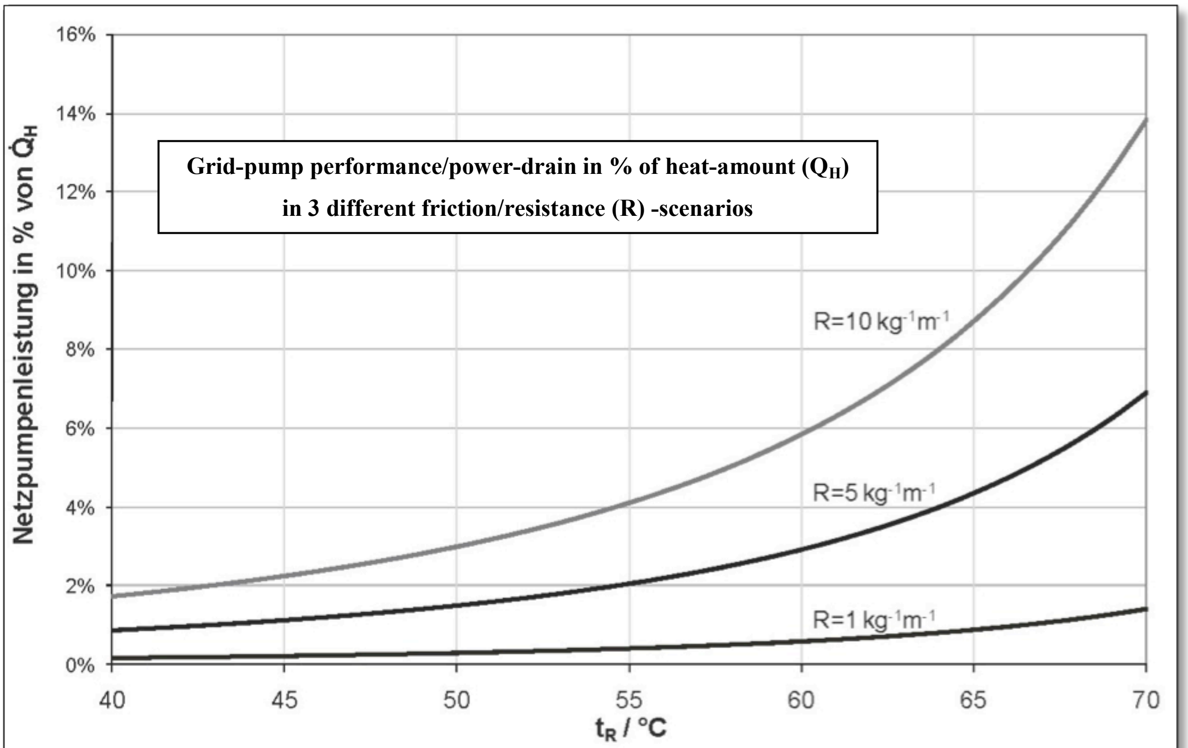


Bild 3-2 Leistung der Netzpumpen in Abhängigkeit der Rücklauftemperatur (t_V=const., $\dot{Q}$=const.)

The bigger the friction-factor of the grid or unit, the higher the pump-load necessary for circulation and therefore the potential for savings due to reduced fly-back-temperature[66]. It is safe to assume, that other important factors or scenarios will in the case of the project at hand, not have any influence:

In district heating-systems, one would also have to note the reduction in heat-losses in the piping-system due to reduced (fly-back-)temperature. If the district-heating (like in

[65] https://tu-dresden.de/die_tu_dresden/fakultaeten/fakultaet_maschinenwesen/iet/ew/forschung_und_projekte/mldh/vortraege/wirths_ruecklauftemperatur_13_dresdner_fernwaermekolloquium.pdf

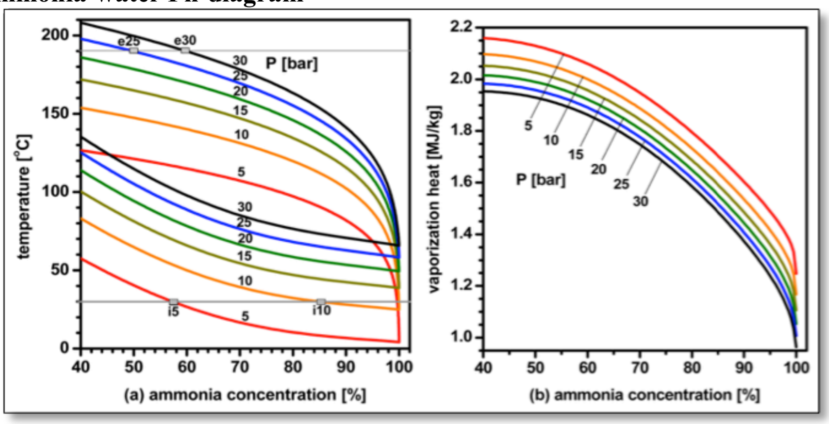
[66] Wirths, 2008: pp. 13-14.

Vienna) is used in conjunction with CHP-production from thermal waste-treatment and electricity-co-generation, reduced mass-flow or reduction in fuel-(=waste)-consumption may not make sense. In different (fixed or variable) mass-flow-scenarios, the reduction in fly-back-temperature can even cause a drop in electricity generation or an increase of fuel-consumption: If fly back temperature is lower, the steam generator/burner will take more fuel to re-heat it and produce the same amount of steam. If the mass-flow is reduced, and the same amount of fuel used, less steam is produced which will either reduce discharge-pressure in the steam-turbine. Over-all one has to admit, that thermodynamic assumptions have to be backed with thorough calculations and the assistance of simulation programs because of their sheer complexity. Depending on the very design of a unit, the possible shift in parameters and cause-and-effect-cascades are vast.

In LTWH-recovery, the approach is quiet easier: No power-generation or fuel-consumption has to be taken into account in the fly-back of the following 3 fictional but realistic LTWH-recovery examples. Again, practically usefull assumptions shall be made, looking at the topic from different angles in each example.

1) **Vienna Refrigeration-unit**[67]; "WKF GmbH", coolant: ammonia-H_2O-mixture[68]; base-load (insulation-issues) + peak load (charging with cargo)
2) **Hypothetical Server-farm**[69]; coolant: water[70]; cooling-load from idle- to peak processing; feedline 55°C; flyback ≤
3) **Vienna district heating** system fly-back: Water with anti-fouling-agent;

Fig. 21: Ammonia-water Ph-diagram[71]



[67] http://www.pes-austria.at/referenzen/kuehlhaeuser/
[68] http://www.academicjournals.org/journal/JMER/article-full-text-pdf/4BEAE984948
[69] http://www.welt.de/dieweltbewegen/sonderveroeffentlichungen/article116995623/Wie-mit-Wasser-die-Daten-kalt-gehalten-werden.html
[70] http://www.welt.de/aktuell/article108346294/Europas-schnellster-Rechner-wird-mit-warmem-Wasser-gekuehlt.html
[71] http://www.mdpi.com/entropy/entropy-16-02056/article_deploy/html/images/entropy-16-02056f3-1024.png

Ad1) The Refrigeration Unit

According to a contractors website, the actually existing "WKF GmbH" refrigeration-plant comes with the following features: 150.000m² frozen cargo storage for up to 40.000 pallets; 40t respecitvely 80t/day intake capacity for temperatures of down to minus 30°C, 400kW nominal power (NP) of which 300kW are recuperated for hotwater-production (40/65°C; 11m³ buffer-tank) and heating. A COP is not specified but characteristic would be anything from 3 to 8 kWh/m²/year – In big facillities like this one it could be safe to assume a more efficient (lower) figure, than in a 40.000m²- or smaller facility. Amongst other features it is generally using the following installations:

→ 10 air coolers type "Alpha Laval Airmax[72]" (400V; 8-160 kW NP) max. 30 bar OP, condensation at +30°C[73],
→ 4 pumps for NH3 Type "Hermetic[74] CAM" up to 22kW NP each

According to the manufacturer's manual, the condenser-fans come at nominal power of 8 to 160kW. In a 150.000m²-refrigeration-unit it is safe to assume, that the condensers will rather be situated on the higher end of this spectrum, as well as the 4 NH3-pumps will most likely rather have 20kW than one. Seemingly 300kW are already beeing recuperated, which leaves only 100kW as losses & LTWH. If two thirds of that is lost due to door-opening & closing-procedures or building-insulation-issues, the remaining 33kW will still provide the LTWH to not only cover the permanent freshwater-intake. They will most likely also pay for the additional installations on/before the condenser with the reduced utility-bills due to electricity saved: Calculating the power needed for the 1500 liters of hourly water-demand (see Tab.5/ Fig.19; 5%-scenario) of 30m³ per day at a water temperature of 10°C or a Δt of 16K respectively will allow a closer assessment. Because of the need for redundancyin the refrigeration unit, only half the named equipment will be assumed in full-load at any given time: 2 pumps and 5 condensers. The following equation will bring the core-example of this thesis – the aquaculture- into perspective concerning seize comparison.

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[72]http://local.alfalaval.com/de-de/produkte-loesungen/waermeuebertragung/luftwaermeuebertrager/luftgekuehlte-verfluessiger-gaskuhler/Documents/6.60%20%20%20%20Luft%20Luftk%C3%BChler%20einseitig%20ausblasend%20AirMax%20II%20Ammoniak%20PCT00049DE%202006-09.pdf
[73] http://www.peacesoftware.de/einigewerte/nh3.html
[74] http://www.hermetic-pumpen.com/system/assets/493/Refrigeration_E_01_2012.pdf

Equ. 9: Capacity needed for heating water in the aqua-culture

$$\frac{intake\ (liters/h)\ x\ specific\ heat\ c\ \left(\frac{kJ}{kg}.K\right)\ x\ gradient\ \Delta t\ (K)}{3412\ (conversion\ factor)} = kW$$

$$\frac{1500\ x\ {\sim}4\ x\ 16}{3412} = 28{,}13599062$$

So it will take capacity of roughly 28,14 kW to heat the 1500 liters of freshwater to the required 26°C coming in every hour. That said, we have to remember that this will be necessary INITIALLY to heat the tanks: In constant operation-mode, wastewater-heat-recovery will in case of a 75%-efficiency reduce the power needed down to only 7,03 kW. That is optimal, given the fact that sometimes some winter-days in Austria can get close to the minus 30° refigerator-cargo temperature: Scarcely but non the less. This really seems to be well within the range of the assumed 33kW that may be currently unused. On the other hand it leaves us with sufficient buffer, in case a total tank-refill has to be accomplished after e.g. pathogen-caused reset or technical problems that move the fresh-water-demand from the intended 5% per day towards the 10% mark. No matter which HE-technology will exactly be applicable (plate-HE with secundary counter-flow HE to double-safely-separate the fish from the toxic ammonia, etc.): If the elektricity-consumption of the 2x 20kW pumps and the 5 x 100kW Alpha-laval-condensers can be even reduced by only 10%, the following savings - assuming reasonable FLHs[75] can be realized:

$$\frac{(Power\ 1 + Power\ 2,\ (kW))x\ FLH\ \ (h)\ x\,rate\ (\frac{0{,}01\ €}{kWh})}{1-(savings-coefficint,\%)\ x100} = \frac{savings\ (€)}{year}$$

$$\frac{(40+500)\ x\ 6000\ \mathrm{x}\ 4{,}0}{900} = 14.400{,}00\ €$$

At least on paper, the energy-cost for the fish-tank-heating is reduced to zero, while the electricity-bill of the energy-supplier at hand can additionally be reduced by about 14.400€/year.

75 Nicoulin et al. (n.d.)

Compared to a case in which the fishtanks would have to be heated with natural gas at 2,5 Euro-cents/kWh, the total savings could sum up a little higher:

Equ. 10: Total savings estimation

$$(savings\ energybill\ freshwater) + (electricity - savings\ pumpload) =$$

$$= 28{,}14\ kWh\ x \frac{20h}{day}\ x\ 365\ days\ (\triangleq 7280\ FLH)\ x\ 2{,}5 \frac{cent}{100} + 14.400 =$$

$$= 5135{,}55 + 14.400 = 19.535{,}55\ \text{€/year}$$

The 20 hours per day - to be reminded- is the time that the 1,5m³ of water per hour take to accumulate to the needed 30m³ per day in the 5%-freshwater-scenario. Of course, raising gas-prices, increased freshwater-uptake or changing electricity-prices can influence this scenario on various ends in *a linear fashion (directly proportional)*. But the calculation shows a case in which 100% of the freshwater has to be heated from 10 to 26°C at a Δt of 16K, relying on condenser-waste-heat influencing the overall pumpload. Depending on whether the heat-recuperation with the aid of the counterflow HE before discharge into the sewer in the wastewater-cycle of the fish-plant is done or not, the savings on the pump-load might change dramatically on the side of the heat-supplier: The less heat is drawn from the fly-back and the more is recuperated from the waste-water, the smaller the savings in power needed for the cooling-system will be possible: As described in figure 20, this relation is *not linear*: Due to friction/resistance and mass-flow-inertia, this interrelation can even be of the 3rd order. Even though the uncertainties remain large, the overall picture indicates that looking into the details may proof worthy, especially since the calculation has been based upon the currently extremely low energy-prices. Depending on the insulation, the refrigeration-unit will provide base-load throughout the year and coresponding to delivery-frequency, commissioning or cargo-heat-content also certain peak-loads, that can be used to mutual advantage if a minimum of coordination is possible or exercised.

Ad 2) The water-cooled server farm

Serverfarms[76] or mainframe supercomputers 30-50% of their energy intake for cooling the CPUs instead of computing. To tackle this situation, modern supercomputers are often water-cooled for several reasons: Water has a better heat-bearing capacity than air, smaller volumes than with aircooling have to be moved, causing not just a decrease in energy-cost but also unbearable nois-pollution due to hundreds or even thousands of blowers[77]. Water also has the advantage of being completely nontoxic, which is very important in a closed room were employees would ultimately be endangered if NH_3 or CO_2 were to leak. The risk of short-circuiting the servers with water is negligible because negative pressure aswell as detilled water (de-ionized water) is be used. Besides the primary savings, the LTWH can ideally be used to heat buildings or "hot tabs[78]" – like the fishtanks.
According to the *green-IT* online-portal www.green500.org , 7 GigaFLOPS per Watt[79] is about the cutting edge benchmark of green-IT standards in 2015, rating the 3 PETA-FLOPS of Germany's mainframe *superMUC* from 2012, at least at

Equ. 11: IT waste-heat

$$\frac{3\ x\ 10^{15}\ (PetaFLOPS)}{7\ x\ 10^{9}\ (GigaFLOPS)} = \ 428.571{,}43\ Watts = \sim 430\ kW$$

If not more, because this greenIT-ranking is based on CPU benchmarks alone. RAM, and various other units may be less effective. So it does not wonder at all, that the company equipping *superMUC* is offering water-based data-center solutions from 40 to 250kW cooling-capacity[80].

Unlike in an engine, were a load is lifted or mass accellerated, (energy only "translated" into potential or kinetic energy) a computer performs a logical operation measured in Hetz or FLOPS. That will lead to the assumption, that almost 100% of the power used to power the calculations, will simultanously also be transfered into heat since the information produced does not have any comparable "energetic value". One could try to calculate the "heat content of informaion" out of quantum-mechanical spin, as the energy-value of an angular momentum of an almost mass-less electron ($9{,}1x10^{-34}$kg). But this intellectual

[76] http://www.welt.de/dieweltbewegen/sonderveroeffentlichungen/article116995623/Wie-mit-Wasser-die-Daten-kalt-gehalten-werden.html
[77] http://www.welt.de/aktuell/article108346294/Europas-schnellster-Rechner-wird-mit-warmem-Wasser-gekuehlt.html
[7878] https://www.youtube.com/watch?v=EgFs0sBY87k
[79] http://www.green500.org/news/green500-list-june-2015
[80] https://datacenter.eco.de/wp-content/blogs.dir/13/files/140306_3_stulz.pdf , p. 12 CyberAir III

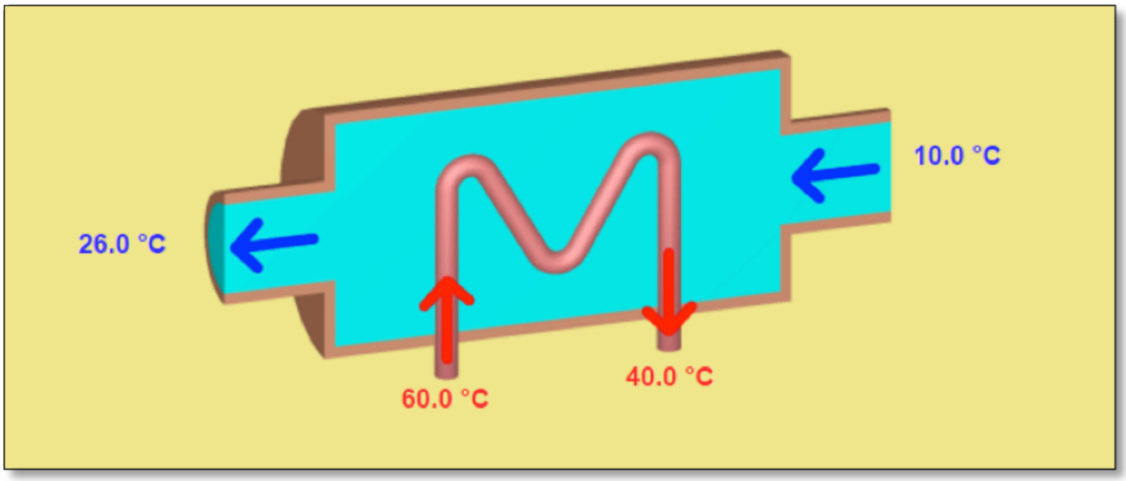
approach becomes obviously senseless in the given context – not only if a truely mass-less photon and its "angular momentum" in an optial fiber or the co-instantanous information-transfer in *Einstein's "spooky action at a distance*" is concerned. A truely phascinating aspect of LTWH though!

Anyway - 430 kW is again a far bigger amount than the aquaculture might need – even in case of no heat-recovery from the 5% sewage per day. The not even 30kW (28,14) could already be extracted from a telecommunications-facility or server-farm 1/10th of the seize of this supercomputer near Munich. Similar to the COP in a cooling-unit, datacenters & mainframes are measured in PUE or "Power Usage Effectiveness". It is – as described above- the factor of total facility power per IT-equipment power. The ideal PUE is thus 1.0, given that the IT-equipment does not need any additional cooling etc...which would only theoretically be possible in a supraconductive and closed system. Water-cooling in this case may directly enable a counter-flow plate-HE (water-2water), to heat the fishtanks. In case of 30kW necessary capacity for the 1,5m³/hour the following can be calculated[81]:

→ Cold side: Freshwater for aquaculture, 10°C feedwater, 26°C habitate temperature; freshwater 1,5m³/hour minimum;

→ Warm side: Sever-cooling water, 40°C feedwater, fly-back from CPUs: ~ 60°C

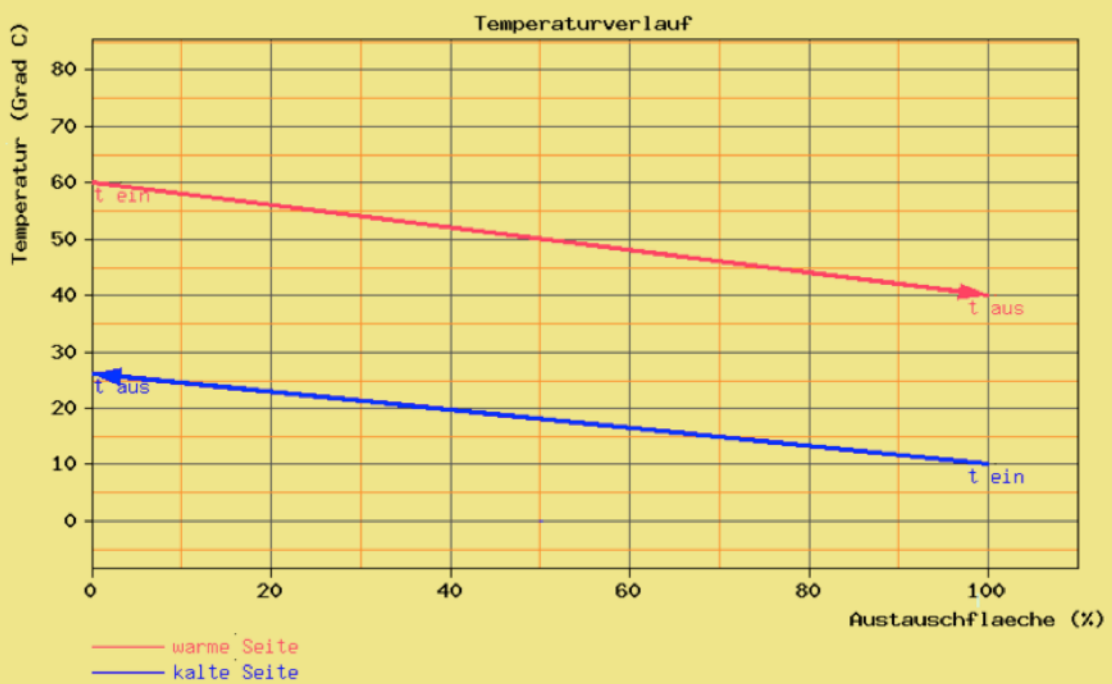
Fig.21: Heat-transfer server-farm or mainframe[81]



[81] http://www.schweizer-fn.de/berechnung/waerme/wt/wt_start.php

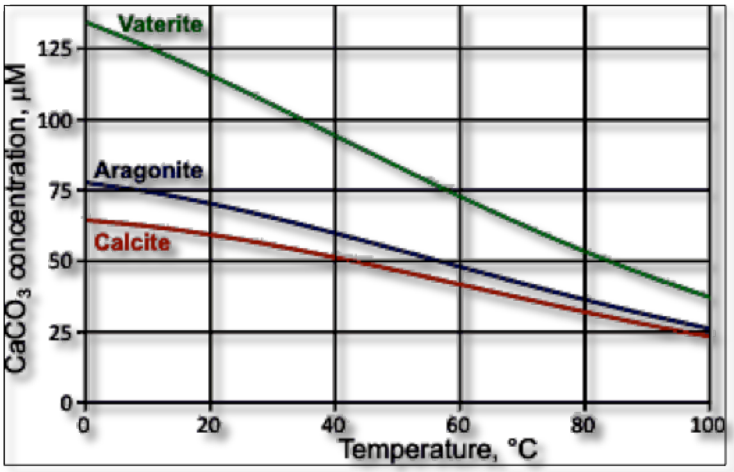
Table. 7: Heat-transfer server-farm or mainframe[81]

Wärmetauscherausführung	Gegenstrom	
Wärmestrom - Q - (kW)	27.8	
	kalte Seite	**warme Seite**
Volumenstrom - V - (m³/h)	1.50	1.21
Temperatur Eintritt - te - (°C)	10.0	60.0
Temperatur Austritt - ta - (°C)	26.0	40.0
Temperatur Differenz - Δt - (°C)	16.0	20.0
Logarith. Temperatur Differenz - Δt log - (°C)	32.0	
Medium	Wasser	Wasser
Medium Bezugstemperatur - tm - (°C)	18.0	50.0
Dichte - ρ - (kg/m³)	998.2	988.2
spez. Wärmekapazität - cp - (J/(kg*K))	4183.0	4181.0



Of course no COP of a plate-HE can be given like that, because not only does it work "passively" and without an additional pump (maybe causing some resistance in the hydraulic system that is of any relevance), but also can it have different active surfaces. The used media (in this case both times water) are also of significance like is the (maybe asynchronous) fluid velocity and so on. On the heat-source side, fouling will not be of any concern (unlike in a sewer or chemical plant maybe), while on the habitate-side in the fishtank, this issue will always play a vital role. One good reason to keep the HE-battery downstream and close to the UV- or ozone –disinfection-unit to have the advantage of low germination index. The good news on the other hand is, that the water does not have to be heated to 65°C for legionella sp. .mitigation. This will keep the plate-heat-exchanger mostly free from boiler-sclae due to over-heating and correlated loss of solubility of involved minerals. (pH assumed at 7,5/ neutral; concentration given in micro-mol per litre)

Fig. 22: Solubility of boiler-scale forming minerals[82]



A server-farm or supercomputer will most likely provide usefull heat throughout the year and in sufficient quantity: Supercomputers my produce more of it and specially in full turbo-mode, whilst servers most likely will usually have a base-capacity even in idle-mode and produce additioinal heat for example during working hours or special events like download-surges due to a new tv-series going online. The big temperature-stretching of 60 to 26° respectively 40 to 10° makes also small volumes of very small server-technology mass-flows a viable source of energy compared to the possibly 50-150m³ of NH_3 in the refrigeration-example.

[82] http://www1.lsbu.ac.uk/water/water_descaling.html

Ad 3) Vienna district heating system flyback

According to official sources[83], the 10 most powerful capacities in Vienna together sum up to 2613 MW, representing only 75,89% of total installed capacity. The total installed grid-length trippled in the 90ies to rach more than 1200km in 2014[84].

Table. 8: Largest Vienna-district-heating capacities[85] (own table)

Plant name, ranked by capacity	Capacity (MW)
1. Kraftwerk Simmering Wärmeauskopplung (630 MW)	630
2. Fernheizwerk Spittelau (400 MW)	400
3. Fernheizwerk Süd (358 MW)	358
4. Fernheizwerk Arsenal (325 MW)	325
5. Kraftwerk Donaustadt Wärmeauskopplung (250 MW)	250
6. Fernheizwerk Kagran (175 MW)	175
7. Kraftwerk Leopoldau Wärmeauskopplung (170 MW)	170
8. Fernheizwerk Leopoldau (170 MW	170
9. Sondermüllverbrennungsanlage Simmeringer Haide (75 MW)	75
10. Müllverbrennungsanlage Spittelau (60 MW)	60
Total:	**2613**

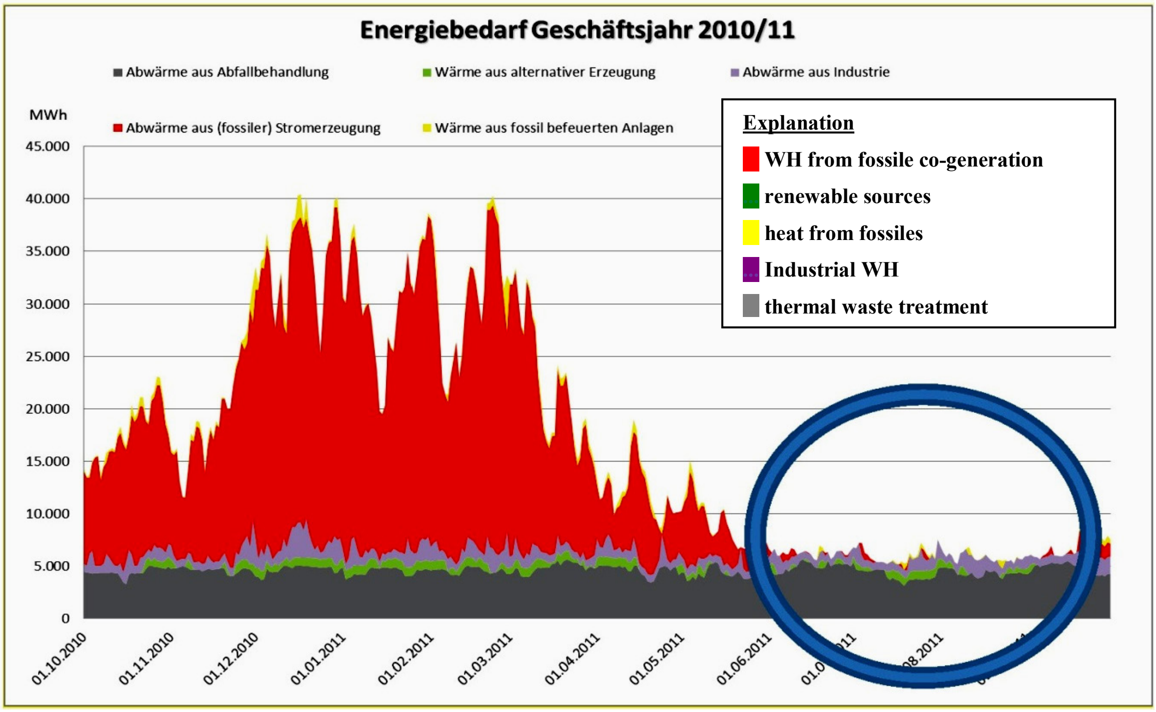
The enormous amounts of heat can only be transfered within the primary network at a maximal feed-temperature of 160°C (on very cold winter days) and pressures of 23-30 atmospheres to keep the water from boiling. Whilst in the summer, far more heat is produced than can be sold (even for cooling purposes), peak demand in winter is so high, that additional heat has to be produced by means of natural gas – far more than the thermal waste-treatment units and the biomass-pant can provide in total. That of course puts the demand for the aqua-culture in an unpleasant perspective if the load-profile is considered:

Not only, is heat-recuperation from waste-water possible to such an extent that only comparably tiny 30kW of additional capacity may be needed to keep the fish-tanks at the desired temperature. Even if considerable backup for extremely cold days, a drop in feedwater temperature to only 7°C for example, heating-demand for the building of the unit itself, a momentary lack of LTWH or other scenarios are taken into account and

[83] Stadt Wien, Energieplanung (Magistratsabteilung 20) (n.d.)
[84] http://www.nachhaltigkeit.wienerstadtwerke.at/oekologie/energieerzeugung-bereitstellung/fernwaerme.html
[85] Stadt Wien (n.d.) Energieplanung (Magistratsabteilung 20) (n.d.)

capacity is raised to 60kW peak that really changes nothing in the bigger picture. Especially in winter, were it is crucial to keep the fish well above 15°C in order for them not to stop growing completely, the heat-demand in the local population and businesses connected to the district-heating-grid is so high, that lowering the flyback-temperature of the grid is something nobody will want: Since far more capacity has to be delivered than would actually be needed for electrical –co-generation or waste-treatment, reducing the flyback will actually directly result in an increased natural-gas-demand if mass-flow is constant and feed-temprature and vleocity have to stay constantly high aswell to meet winter-demand. For the district-heating company it would indeed be counter-productive to allow such an attempt – let allone the really not very competitive pricerange of Vienna district heating rates. Now however the prices may change in the nearer future afther the "fracking boom": It would be out of the question to mainly use district heating in exactly a time of the year where it is mostly produced by means of natural gas and thus condoning GHG emissions. Even though the figures are a little outdated (2011) figure 23 shows pretty well what is happening in the winter months. It is most likely safe to assume, that with increased electricity production from renewables since 2010, the additionally needed heat for the district grid is produced under very unfavourable circumstances, given the european market situation for gas-fired powerplants and their LRMC.

Fig. 23: Energy demand 2010/ 11[86]



[86] Wallisch (n.d.): p. 6

4.3 Impact on GHG-emissions

There are different methodologies on how to estimate or calculate GHG emissions. Of course it is pretty simple to calculate reduced emission if a certain plant-configuration with certain features is refurbished to employ new and more efficient ones. It is however less easy to make the same for a newly planned project. From a marketing point of view of course it is advantageous to compare oneself to the worst possible concurrence on the market – or, simply hit the bottom of it: Zero carbon related emissions at all. From the engineering point of view, ther is mainly two big capacities that would possibly produce GHG-emissions: The heating system of the fish-tanks as well as the electricity-generation for the circulation-pump an maybe lighting & controls (which most likely are negligible if LED lights are used). Cooling-load may be neglected at all in summer, because this prolem can easyly be tackled by dissconnecting the WH-recuperation from the sewage-water discharge-unit and refill the tanks with unheated tap-water at 7-10°C. In addition to that, the organic roof- wastewater-treatment-facility with lots of evaporating green plants will naturally shield from to much heat input.

On the whole supply-chain of non-engineering issues on the other hand thre is a wide variety of options to look into the matter. Using LTWH may be a start and increase the suppliers and on's own efficiency. But how was the LTWH generated in the first place? Hydo power? A diesel engine? If for example the cooling-facilita of the 1st example runs at a COP of 3,5; less of the recuperated waste-heat will be probleatic – no matter what electricity was used to power the refrigeration unit. In the server-farm on the other hand, the same amount of waste-heat does come exclusively from the electricity used in the computing operations: If it is from hydro-power, then the "gray energy" of our fish produced will not add to the GHG-balance. If on the other hand the cheapest available electricity-mix is used due to financial reasons, then the detailed energy-mix has to be taken into consideration.

But the supply-chain also extends to the feed- & fodder of which most likely vast amounts will be used during a breeding-cycle: for each 1,5 kilograms of fish, the individuals will

have consumed 1,3 kg of feed&fodder which is astonishingly even below 1 (0,87): In case of aquaculture thuna, the coefficient is 1:25kg[87] - almost 29 times worse.
Given the 200.000 kg of fish that shall be produced annually, we will under ideal conditions therefore see a throughput of 174 tons of fodder-pellets. Now this is almost exactly the capacity of ten 16-tonners, if delivery by rtuck is necessary: So by just looking at the fodder, 2 possible sources of high amounts of GHG-emissions have popped up:
If the fodder is not certified organic, it will most likely contain corn or soybean wich has ben fertilized on the field using usual amounts of artificial mineral fertilizer: That will contribute hugely to GHG emissions! But unfortunately for the calulatory approach, the "tree of options" sprouts another branch her: Not only is fertilizer made out of natural gas, it will in case of nitrogen-ferilizer (ammonium nitrate or others) decompose into laughing-gas (N_2O) that comes with a GH-impact of 310 times (!!) that of carbon dioxide[88]. If the soybean is from south america, it wil not only very likely be GM-soy but also planted on former areas on wich highly climate-necessary primary rain-forest has stood, before it was burned down and turned into a field. That will not only have set free CO^2 on a grand scale but also deplete the humus-layer in which even more CO^2 has been bound.

So it is easy to see, that if GHG-emissions are to be taken seriously, supply-chain management is absolutely key. If the fodder is then delivered by truck or by train, can in such a scenario quickly become a background problem if the fish is produced right at the demand: In the midle of a city. At the earlyer mentioned trade-balance-deficit of ~95% imports, much of the fish either comes from horriply depleted fishing-grounds or from mostly un-certified Asian (tilapia + pangasius) or Norwegian (salmon) aqua-culture that do not only commit the most outrageous business-practices and environmental violations but also produce a product that is shipped aroudn half the world to land on our plates even though it should rather be treated as hazardous waste. Here again, depending on the method of transport – whether ship or plane is used- the GHG-emissions will get on top of the outrageous destruction of marine life, mangroves or the excessive use of antibiotics on the fish that would otherwise die instantly under the given conditions. Last but not least, one might also want to take a look at the distribution of the finished product – be it live fish, filets or leftovers for the dogfood-industry. Here also –from processing, cooling to delivery and storage one may want to work together.

[87] Cf: Asendorpf (2014)
[88] Cf: KlimAktiv Lexikon: CO2-Äquivalente, http://www.klimaktiv.de/lexikon-43.html

4.4 Exemplary List of subsidies

Subsidies in Austria are characterized by a couple of qualities – some good and some bad. On one hand, there is the upside of their sheer multitude, making it very probable for a project developer to finally find one or even more that actually fit. On the other hand, the long discussed "one-stop-shop"-principle, a basic reformation of the whole system to the effect of granting a better overview and fewer bureaucratic hurdles by bundling the issue in the hand of a single public entity has not yet been implemented – and given the political reality- will not be facing its implementation in the nearer future. So while one can easily find a couple of public corporations presenting subsidies, the necessary "back & forth negotiation" is often so demoralizing, that in some cases it might even be more cost-efficient to leave them be all along. A whole industry of advisors and consultants offering nothing but help and know-how in this "jungle of subsidies" has arisen due to the complexity of the matter. Not only does one have to primarily *find* the subsidies that seemingly fit the project. One of course also has to closely keep record of the given deadlines and call-criteria, for some may have to be applied *before* the actual project-start, some *during* and some can even be obtained *thereafter*. In many cases, the EU-policy enforces "de minimis"-rules which mean that over a certain percentage or total sum, an individual permission for subsidisation has to be obtained from the European Commission. Except for projects of national or transnational interest this is fairly unlikely or may even be subject to lawsuits by the concurrence on the grounds of discrimination and market distortion. Due to the multiplicity of public bodies engaged in subsidisation, the formal commitment by one of the bodies concerning a subsidy can in some cases mean the loss of another which one unfortunately could find out rather late: Since the public companies are all only giving advice on their very singular situation, the application for all other subsidies has to be mentioned at *each of the bodies* as early as possible in order to avoid some criterions of exclusion to pop up at the most unexpected moment and maybe after business-plans have been made. If one forgets to mention even the slightest detail concerning other subsidies or their amount, the fault lies solely with the applicant since one public entity is not responsible for the counsel given by another. The worst case would of course be the reclamation of already granted funds or suddenly appearing big holes in one's financial planning shortly before actual planned implementation. From personal experience I can only say, that in some cases it might as well be less demoralizing or work to simply let go of some subsidies that would be theoretically possible. The reasons for that include a) either the combination with other subsidies is (close to) impossible due to de-minimis-rules so one should pick “the bigger fish”, b) the amount of money granted in comparison to the demanded application-complexity, accounting & reporting modes and inflexibility of bureaucrats concerning natural changes in projects is highly undesirable c) the additional know-how that has to be bought-in is to expensive compared to the actual probability of winning an open call or d) creating complex company-structures (e.g. splitting the project into subsidiaries with co-dependent exclusive contracting) to ship around de-minimis-rules is either to complex, illegal or both. Of course, some calls are only open for tenders during such a small period of time, that a small or inexperienced project-team will lose one option because preparing the application for another or endless meetings with public bodies that have no connection to or idea about each other’s policies takes too much time. But even big teams and real professionals may stand no chance in situations as for example in the case of the national PV-subsidy-program of 2012, were the budget for the call (and thus the call) was finished after legendary 40 seconds[89](!). So it is natural to say, that subsidies can help in realizing a project, but one always has to bear in mind, that time is of the essence. One election later, the budget for a certain program can be cut so drastically, that it becomes close to financially suicidal, to risk hundreds of expensive man-hours to apply for a call that grants only 20% financing of “recoverable cost” at a probability of only 30% or less to actually win the call. But none the less: The variety of possibilities is very diverse and spans from direct payments in % of recoverable cost, (sometimes with a cap of total sums, e.g. 300.000 Euro per project, in some cases with an additional cap concerning a certain time-span etc)...to services like consulting and counselling by various experts for free or drastically reduced rates, abdication of company-founding-fees etc...As well as governmental guarantees for loans and mortgages in order to reduce risk and thus interest rates or increase a project’s credit ranking. Some programs are just open to certain groups like for example agricultural or farming entities, small and medium enterprises, as others may specially address e.g. gender-issues by especially or additionally awarding financial support to female-lead projects exclusively and so on.

[89] http://diepresse.com/home/wirtschaft/economist/752802/Solarforderung-schon-nach-40-Sekunden-vergeben

4.5 County/state, federal subsidies, European level programs

Besides the discussed subsidies that can be obtained for energy- or resource efficiency-measures and GHG-reducing measures, there are a couple of other subsidies that can be applied for. They in this very case reach from programs that support the settlement of businesses in a certain area (local level and EU-level), keeping elderly people in a state of employment or schooling-subsidies for people who have been unemployed or unable to find work for a longer period, in order to give them a means of income whilst taking the load off the social system (federal level). If a certain project is for any reason aligned with local policies, one might even be able to attract special support for the project, sometimes monetary, sometimes regulatory as in terms of shorter waiting-periods within the bureaucracy by means of prioritisation. Within the European level, there are the so called "Framework programs" (FP7 currently) as well as special programs concerning sustainability, resources or agriculture/ fisheries that may be combined within the project. In some cases again for example due to "de minims"-rule, only by using external R&D-partners for flanking research, impact assessment, product & innovation development, etc...One can clearly say that it is very much up to the applicant and the delivered creativity, to finally make the race for a certain subsidy or related program: One and the same intention or content, formulated in another way or highlighting other angles of the outcome may very well please the jury of the very institution, presiding over the funds, while the completely same thing presented in another way -focusing on other parts of the same research- may just be rejected. In some cases even researching the jury-member's professional background may very well help to "hit the spot" but under the line it is also about being lucky: Since authorities and subsidising entities do not necessarily grant the opportunity to retouch the application(s) and also only in rare cases deliver a deep explanation of a rejection or a failed tender, the applicant sometimes may feel a little bit like in one of Professor Watzlawik's "non-contingent reward experiments": Even if nothing is changed, made better or different – it just works sometimes and sometimes it doesn't.

4.6 Overview on differences: grants, loans, single payments, de-minimis etc.

There is a wide variety of possibilities to sort subsidies. First by level of the allocating authority down from EU-level, national bodies or even county or city-level, or by types of supported issues or area of emphasis like energy efficiency and climate-change-mitigation, sustainable development, nano-technology, research and innovation, market-introduction and so forth, as well as by sector or target group: Agriculture, service-sector or communal bodies. Any of these categories could also be sorted by their type, be it grants and loans, consulting-services, non-repayable allowances for investments, governmental guarantees on risk and ranking, feed-in tariffs or even governmental support by programs like the "Exportinitiative Umwelttechnologie[90]" (= "Export-Initiative Environmental Technologies").

Table. 4: Grants, loans, subsidies – levels & support (own table)

Granting Org.	Area of subsidy	Specific Name	Perk	Url (www)
Kommunalkredit Public Consulting (KPC)	Energy Efficiency	Abwärmeauskopplung	Money	LINK
Umweltberatung	Environment	n.a.	Service	LINK
Wiener Stadtgärten MA42		Green Roof	Money	LINK
FFG	Energy Efficiency	E-Mission	Money	LINK
KPC	Energy + NAWARO	Energetische Nutzung biogener Reststoffe	Money	LINK
bmvit	hausderzukunft	Smart Cities	Money	LINK
Wiener Stadtgärten MA42		Fassadenbegrünung	Money	LINK
KPC	Wasserwirtschaft	Forschung Wasserwirtschaft	Money	LINK
FFG	Forschungs-förderung	Horizon 2020	Money	LINK

[90] http://www.bmlfuw.gv.at/greentec/green-jobs/exportinitiative/exportinitiative-umwelttechnologien.html

FFG	Research Cooperation	Innovationsschek PLUS & KMU-Programm	Money	LINK and LINK 2
FFG	Market Introduction	Marktstart	Money	LINK
Ökobusinessplan	Environmental Improvement	Ökoprofit	Service	LINK
Ökobusinessplan	Environmental Improvement	Ökobonus	Service	LINK
Ökobusinessplan	Environmental Improvement; reporting & management	Nachhaltige Entwicklung	Service	LINK
Ökobusinessplan	Energy Efficiency	Energieeffizienz	Service	LINK
AWS – ERP-Program	Agricultural Efficiency, Innovation,...	Landwirtschaftsprogramm	Money	LINK
AWS	Big innovative demo-projects	NER300	Money	LINK
Ökobusinessplan	Consulting SMEs in financial matters & subsidies	Förderwegweiser	Service	LINK
AWS	Licensing, demo-projects, internationalization	Hausderzukunft - Tec4market	Money	LINK
bmvit	Production of the future	Produktion der Zukunft 2015	Money	LINK
FFG	SME R&D	Projekt.Start	Money	LINK

4.7 Impact on cost-effectiveness considering “Contracting”

Performance and energy contracting is not a completely new approach after all, but still somewhat new and not were widespread in Europe. It is mainly a service, providing the customer with an option that usually would not be in reach of satisfaction for example due to financial reasons or complexity. It is none the less maybe as revolutionary as the idea of “insurance”, were an incalculable risk (= magnitude x probability) is reduced to running cost of operation by means of a service-provider.

Performance and energy-contracting does something quiet related. If a business-owner can't afford necessary investments into the energy- and efficiency structure of his or her business, nor has the in-depth knowledge of state-of-the art technology, subsidies, suppliers and engineering, the contractor will step in: The contractor, possibly a facility-management and plant manufacturing-expert can be asked to assess the situation at hand and devise a technical and financial concept helping to improve the over-all performance and O&M-cost-situation. Of course, nothing is for free, but if the client shows enough financial stability in order to start such an endeavour, the contractor will be able to provide a couple of advantages compared to internal project execution.

Since the speciality of the hired firm shall be energy and efficiency, the provided service will in many cases be qualitatively beyond anything even skilled internal personnel could come up with. Not just technologically, also financially and in terms of internal handling-cost. The specialized area of service may not just provide the hired contractor with special purchase prices due to pooling effects. Due to the very nature of the service, the client is only confronted with a *single contractor* and not – like in case of an internal project deployment – with a manifold of electricians, plumbers, ventilation engineers, construction companies, authorities, financial institutions and so forth... this will not only save nerves but also provide the client with a single party to address in case of change of plan, warranty or misconduct. This cannot be under-estimated, since lawsuits in case of constructional defect or malpractice and so forth, will otherwise most likely end up in long-lasting battles between all contributing firms, mutual blaming and endless pleadings of authorized experts in front of court. Last but not least, the financial aspects are severe ones as well: The contractor does not only pre-finance all investments but also shall take care of all applications to authorities be it subsidies or plant-operation permits etc. The risk of losing a vital link of the project-chain to bankruptcy in the middle of deployment is also reduced to the point, where only the financial stability of *the very contractor* has to be checked with the bank, thus reducing the necessity of research, insurance and redundancies in order to avoid supply-difficulties etc...

In turn, the client will buy an *energy service from the contractor* over a course of time.
This can stretch from hot water and heating to pressurized air, electricity or process-heat of various kinds and levels. The contractor himself will make his margin via the cheap cost of purchase for the technical installations, the high degree of efficiency reached by means of

his know-how, cheaper loans due to his reputation, broad knowledge over subsidies that can be applied for and in this regard ideal dimensioning of all components. Of course, not 100% of the savings due to the instated efficiency-measures have to be handed over to the client at once but can also contribute to the margin, allowing both parties to capitalize on the project right from the start. If for example wood or biomass cut-offs are used for the new heating system, revenue cannot just emanate from savings in e.g. city-gas and increased over-all efficiency but also from avoiding waste-disposal-fees since the cut-offs can replace gas as the main energy carrier and don't have to be disposed-off anymore in a costly way. Intelligent and thus tricky, integrated solutions may essentially very well become possible due to such an approach.
One of the major clues is though, that after an agreed period of time, the whole unit or facility that provided the service is *handed over* to the original plant owner who called in the contractor. After the service-period with clearly defined FLH, service-intervals and maintenance-duties by the contractor, the whole investment is handed into the ownership of the service-customer at the appropriate book value. Even though the duties of the contractor usually end here, it is very common to uphold a maintenance-contract with the contractor due to obvious reasons such as familiarity with the installations and cost-effectiveness.

This concept can of course be deployed in various situations were a firm can be found that is either capable or willing to take on the project-specific issues at hand. Of course economy of scale plays a vital role in this as does the financial credibility of the soon-to-be service-customer, along with provided subsidies, current market-prices of primary energy carriers and over-all efficiency potentials and alike. So were ever there is LTWH and an idea of how to use it in an overall efficiency concept, it might be interesting to also evaluate this option.

5 Conclusions

It was the initial task to highlight industrial LTWH in case of a closed cycle aquaculture from all the angles examined in the course – be it management, efficiency, innovation, engineering or project development-issues like subsidies and legal backgrounds. After all it was demonstrated, that the varieties of waste heat that surround us are very abundant: Even only with regard to those cases falling under the "Austrian steamboiler law" (=Dampfkesselgesetz[91]) which regulates not only all boilers that contain or produce water hotter than 110°C but also all other applications and pressure-vessels that may contain gases of more than atmospheric pressure – including steam of course.

Enough waste heat for the given fish farm may in most cases not be coming from seemingly "obvious" sources like the local district heating system. During the analysis it showed, that due to all options of waste-water-heat-recuperation, even very small heat sources can be utilized for a $600m^3$-project producing fish at a rather high habitat temperature. So for the actual project planning it was demonstrated, that useful heat could most likely be coming from a very small source, one that might not even have been recognized (as such) on the first glimpse. On one side, this will increase the options on the search for a plant site or a strategic partner. On the other side, it was surprising to see how much energy is obviously wasted: The analyzed examples – except the district heating system – turned out to be almost 17 times respectively 3 times a too powerful heat source for the $600m^3$ total or $30m^3$ daily freshwater, needed for the fish-plant (Figure 24).
This fact and the demonstrated abundance of sources, technology and thus combinable working media makes such an aquaculture feasible almost anywhere.

[91] https://www.ris.bka.gv.at/Dokumente/BgblPdf/1992_211_0/1992_211_0.pdf

Fig.: 24 : Comparison of installed capacity/ WH potential vs. available waste-heat in winter (own graph according to given examples chapter 4.2)

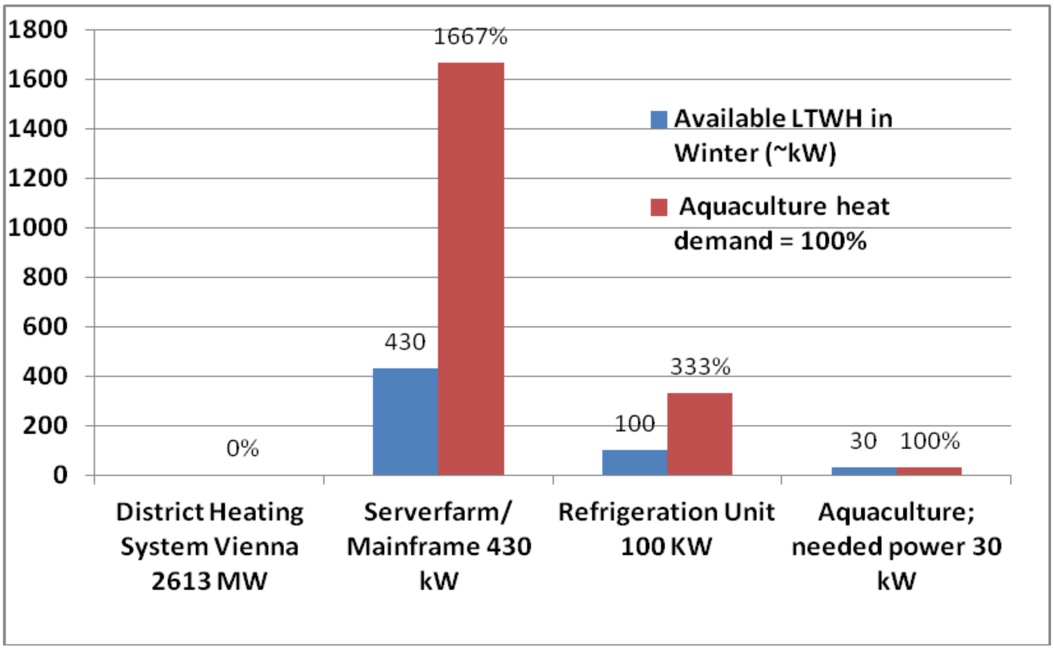


Figure 24 surprisingly shows, that even a supplier of heat with its 2,6 GW installed capacity may fall short as a source of waste heat in winter – the time when the fish will profit the most from a warm habitat. That was also the reason, why the district heating system was only evaluated under narrow presumptions – knowing that the circulation speed, feed temperature and thus system pressure will not only vary over the course of a year, but also between primary stations and secondary handover-stations. None the less and without any difference: The calculations showed, that in winter it would be counter-productive to use fly-back heat from the district heating system. It would make a discussion obsolete if that shall concern *primary* fly-back or the fly-back of secondary handover-stations.

It would very well be possible to reach other conclusions, if for example the customer-side of a district-heating or -cooling-system was to be evaluated instead of the thermodynamic and power-plant/co-generation-aspects in the Vienna example. Especially in "district-cooling" ("Nah-kälte"), in which absorption-cooling is employed to AC (office-) buildings, the outcome may very well be similar to the findings concerning the refrigeration unit. Unfortunately, the possible different plant-types, employed cycles and system-specifications like turbines and according pressures and so on, are so manifold that this work could merely scratch the surface of possibilities and cannot even closely claim to be a full spectrum analysis. To make the search for LTWH or waste heat in project-development more easy in general, the author recommends the upgrading of public data with a "Waste Heat Cadastre[92][93]": In housing, the amounts of sewage water can easily be interpolated by the number of residents or housing units, whilst in industry and business, the relevant information – in conjunction with the energy performance certificate ("Energieausweis")- could easily and *mandatorily* be collected as a *part of the plant operating permit*. It would thus for any project developer or resident be momentarily possible to access this data, like it is now done with the land register ("Grundbuch") or Geographical Information System(s).

How many new heating systems might be unnecessary if this vital planning-information was easily accessible and part of mandatory legislation to make use of heat pumps or wastewater-heat exchangers? It might turn out to be as vital for the over-all efficiency strategy as the "wind atlas" was for the triumph of wind energy, given the role heating plays in the total energy consumption of our society. Developing a compulsory registration of waste heat in order to provide data the public needs is absolutely overdue: Even though technology is well developed and easily available, due to the lack of public knowledge or data-accessibility, heat-recuperation mostly stays an option for company-internal project developers or very engaged frontrunners that go through all sorts of efforts in order to develop a reasonable showcase. Of course, this lack of data on the waste-heat potentials "around the corner" is – in the author's opinion – nothing less than a grave negligence; just as if putting number-plates on cars was a matter of voluntary courtesy. A clear sign on how little is really done against climate change from the legislative side, failing to provide the public with the means to participate in an effort to make a difference in the years we have left to do so. This is especially unfortunate, because obtaining the data during the plant-permission process would be possible at almost zero effort, apart from the development of applicable standards upfront.

Given the forecast concerning renewable energy prices and those of eco-electricity in particular, using heat pumps on warm air, exhaust gases or (waste-) water, like in the

[92] http://www.waermeatlas.at/
[93] https://www.energieatlas.bayern.de/thema_abwaerme.html

presented case of *Drammen*[94] in Norway with its abundant and cheap hydropower is key to a sustainable energy scenario. But only if the public knows, were to tap into this abundant heat source that surrounds us all year long.

Concerning current energy prices, the crucial factor for an aquaculture-fish farm will thus be the amount of freshwater uptake per day, since the researched sewer-fees showed much more impact on the overall running and operational cost: Almost 5 times as much energy as in the analysed scenario. But as a matter of fact, these outcomes demonstrate some other very interesting facts: In water-intensive applications, green roof water treatment cannot just decrease running cost *substantially* but should have much more significance in all O&M-considerations: It was also possible to show, that a wide variety of subsidies may be applicable both for energy related project-parts and innovative approaches like green roofs. In some cases one may even find a contractor that will help to finance the vital parts necessary for heat-exchange and efficiency measures in form of the "contracting model".

Last but not least, this thesis may even be the foundation to making further assumptions concerning technologically more complicated fish farms like those using salt water and so forth. This may also apply to the search for more exotic heat-sources, and basically it may indeed be an interesting approach to help meeting maybe *the* direst challenges of this century or be an inspiration for doing so: Climate change, resource depletion, population growth, overfishing and loss of biodiversity. If we *do not* lack something in this equation, it is waste heat, technology and opportunity.

[94] https://en.wikipedia.org/wiki/Drammen_Heat_Pump

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