SCARAB DEVELOPMENT

THE ENERGY-WATER NEXUS

ABSTRACT

The International Energy Agency (IEA) maintains that an energy revolution is necessary in order to counteract global warming and in order to reduce the world's present unsustainable dependence on fossil fuels. Furthermore, the IEA holds that co-generation must play a major part in this revolution.

Less than 35% of the total primary energy input in thermal power plants is converted into electricity. More than 60% of the primary energy is converted into heat in the process - and only ten percent of this heat is utilized beneficially.

This means that, in power production, more than half of all fuel is wasted. The energy lost globally in power generation represents a significant missed opportunity for savings both in energy cost and in CO2 emissions.

Electricity consumption constitutes 17% of total final energy consumption, while heat which is produced for direct consumption constitutes 47%. More than 75% of this heat is produced from fossil fuels. The potential benefits to be gained by replacing this heat with CHP, and also by the subse- quent re-use and polyuse are probably large and remain to be explored.
Heat can be used even more efficiently by incorporating water treatment.

1. THE INTERNATIONAL ENERGY AGENCY (IEA) PROPOSES TO INTENSIFY ITS FOCUS ON THE USE OF CO-GENERATION

In spite of major efforts, the pace of the ongoing introduction of renewable fuels is far too slow to counteract global warming and to reduce our current unsustainable dependence on fossil fuels.

"According to IEA, an energy revolution is needed to achieve a 50% reduction of global CO2 emissions relative to current levels by 2050 – a target that is deemed a condition for a long-term global rise in temperature of 3 degrees C maximum." (7)*

In Co-generation and Renewables, Solutions for a low-carbon energy future, 2011, IEA proposes an intensified focus on the use of co-generation. This would increase the efficiency of the use of both fossil fuels and of renewable fuels. Furthermore it could also speed up the introduction of renewable fuels.

The basic proposition is that "The carbon intensity of gas-fired plants can be greatly reduced if, besides the electricity from gas-fired plants, the resultant excess heat generated is also put to good use. For the same level of carbon emissions, more useful energy is generated ...assigning value to heat from power plants increases the overall ef- ficiency." (21)

Also - "...by combining electricity generation with heat generation, co-generation increases flexibility in the energy system... a surplus in one part of the system can be balanced by a deficit elsewhere." (25)

Even higher efficiency can be achieved by integrating low-temperature distillation systems into power and heat generation systems.

Co-location of power and water plants is already widely accepted as a means to increase efficiency through synergies. The integration of power and water plants in polygeneration will increase synergies and efficiencies even further.
As an additional efficiency benefit, low-temperature distillation will enable zero liquid discharge, i.e. the complete beneficial use of minerals and other potentially valuable components from salt water and from industrial waste water, i.e. the recovery of what are currently considered to be contaminants and pollution. Also, the complete recycling of industrial process water will become possible.

2. THE DOUBLE LOW-CARBON BENEFIT OF CO-GENERATION

"Several renewable primary energy sources gener- ate electricity via prior thermal generation. These techniques can, therefore, enjoy a double low-carbon benefit. First, the use of renewables bears obvious low-carbon credentials. Second, by operating in co-generation mode, these technologies enjoy the benefits of energy efficiency - another key low-carbon solution."(13)

Co-generation may also increase efficiency in cases where no fuel is used to generate the thermal energy - as in, for example, geothermal plants. "The hot water remaining from electricity generation - independent of the type of geothermal power plant - can be used in cascade methods for district heating and other direct heat use applications. In high temperature geothermal resources, heat may be regarded as a by-product of geothermal power production in terms of either waste heat released by the generating units or excess heat from the geothermal source. Power generation from lower temperature sources in binary plants usually strive for economic viability by seeking an additional revenue stream from the sale of heat." (15) Where there is a market for waste water purification, for desalination, for ordinary industrial process water or feed water for desalination or for ultra pure water, low-temperature distillation could thus improve the economic viability of a geothermal power plant.

3. CO-GENERATION IS A KEY TO A SUSTAINABLE FUTURE

According to IEA less than 35% of the total primary energy input used in thermal power plants, is converted into electricity which is delivered to customers. And more than 60% is converted into heat in the process. Most of this heat is wasted today. An earlier study made by Scarab based on information from IEA showed that only about ten percent of all available "waste" heat is used. This means more than half of all fuel is wasted! – "Space heating for the crows." – as the saying goes.

The commercial development of co-generation is therefore a vital key to the achievement of a sustainable future.

4. FROM BASIC CO-GENERATION...

CHP – combined heat and power production - is a well-proven technology in, for instance, the generation of power and "district" heating for buildings and in the generation of power and heat/steam for industrial uses. In this case all fuel input could be utilized beneficially, except for the minor losses in heat ex- changers and piping. The overall (electricity and heat) conversion efficiency of a CHP system is between 80 and 90 percent. This technology is proven and profitable but has still not become very common due to institutional restraints and commercial myopia.

5. ...TO POLYGENERATION

To make co-generation economically attractive, several beneficial add-ons are presently being developed under the umbrella of Polygeneration. These are:
Low temperature electricity generation - for instance by running an ORC-engine (Organic Rankin Cycle) on the heat from a power plant an additional 10 percent of electricity can be produced from the same quantity of fuel. This technology is relatively unproven but it is entering the market at present and it will become a profitable investment once it has become sufficiently widely adopted to achieve economies of scale.

Absorption cooling - i.e. the use of heat for cooling - is a well-known technology which has been in commercial use for decades in small refrigerators. Now there also exist projects to develop larger systems.

The concept co-generation was coined when district heating was added to the generation of electricity. When cooling was added, the concept of tri-generation was coined. With the further addition of low-temperature electricity generation and low-temperature water purification/desalination, the concept of poly- generation was born.

The concept of polygeneration is still not well-known. The first European Conference on Polygeneration was held in 2007 and the second was held in 2011. The organizers were, among others, the German Deutsche Luft- und Raumfahrt (DLR) and the Spanish Plata- forma Solar de Almeria (PSA).

Scarab Development AB of Sweden has collaborated with the polygeneration team at the Royal Institute of Technology (KTH) in Stockholm since 2003 in order to integrate low-temperature powered water treatment into various polygeneration concepts. The technology which Scarab promotes for this purpose is Membrane Distillation (MD).

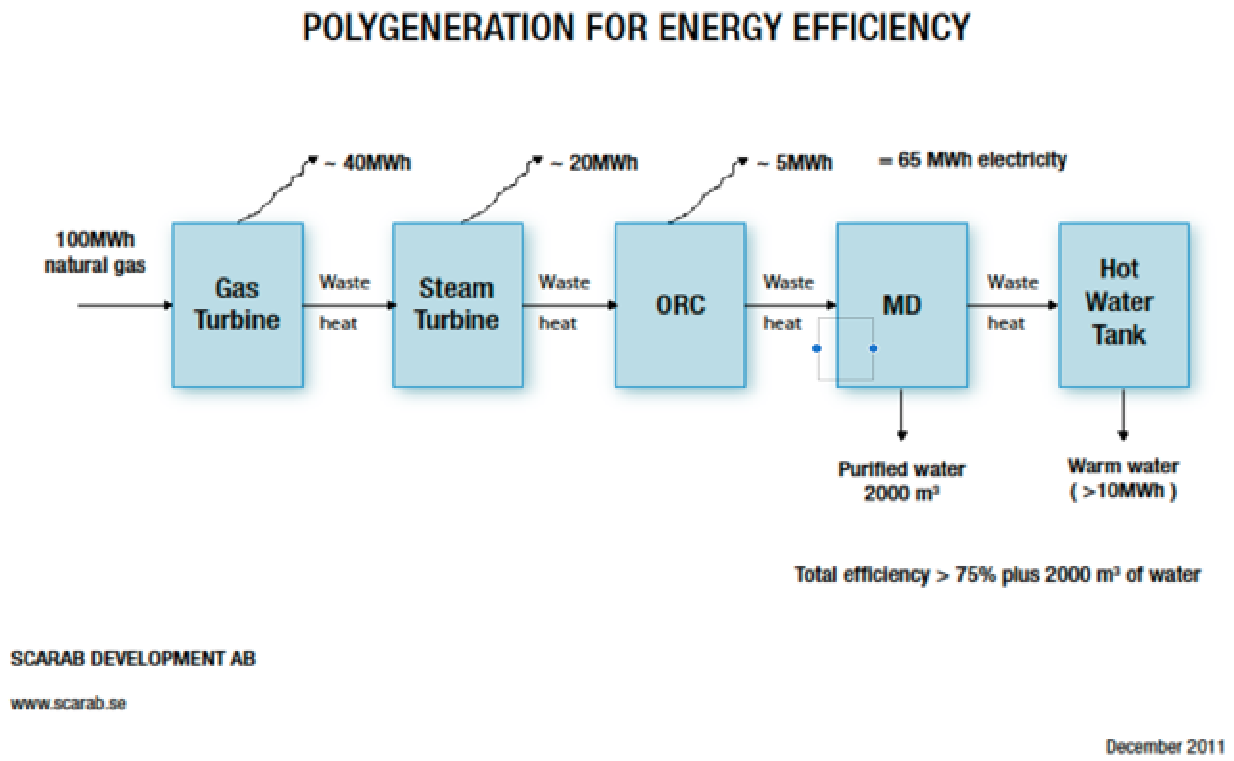

Figure 1: Polygeneration for energy efficiency

6. FROM SMART GRID TO SMART ENERGY

There is much to be gained by using electricity in smarter ways - for example in smart grid concepts. However, since electricity constitutes less than 20% of total global energy use, there is even more to be gained by broadening the concept to also include other energy uses and by folding these into the intelligent systems. If polygeneration as here depicted is included, we would extend the concept from the means by which electricity is produced and used to the total energy balance - in other words, from smart grid to smart energy. This would have a substantial impact on total fuel demand.

7. THE BENEFITS OF CO-GENERATION WILL BE AN INCREASE FROM 45 TO 90 PERCENT IN FUEL EFFICIENCY

"The average global efficiency of fossil-fuelled power generation has remained stagnant for decades at 35% to 37%. Technology already exists today to bring the generation fleet closer to 45% efficiency... Going significantly beyond 45%, for a large part, does not reflect a lack of incentive to research and develop new technologies to extract energy stored in fossil fuels in more efficient ways. It has more to do with the intrinsic, theoretical constraints on the conversion of heat into electricity." (6)

"Notwithstanding gains that could come from research efforts over time, power generation efficiency will plateau below the level of overall efficiency that the best co-generation plants can achieve. Co-generation allows 75% to 80% of fuel inputs, and up to 90% in the most efficient plants, to be converted to useful energy. The two-thirds of input energy lost globally in traditional power generation represent significant missed opportunities for savings on both energy cost and CO2 emissions."(6)

In the BLUE Map Scenario which is considered indis- pensable by the IEA to counteract global warming and our current unsustainable dependence on fossil fuels, co-generation plays a major part. "In the case of co-generation plants fuelled by renewable energy sources, the low carbon benefits are obvious since they derive from the renewable nature of the fuel. However, these also apply in the case of plants fuelled by other types of fuel. Co-generation is considered as one option that contributes substantially to energy efficiency... accounting for 58% of total contribution." (5)

Planning already now how to use this heat is essential because - "At the onset of the project, planning how the heat from power production will be used avoids the cost disincentive of future expensive retrofitting to convert a power-only generation plant into a co-generation plant." (15) The greatest disincentive in retrofitting is often the fact that the cost is very difficult to estimate at the outset, which means that even the minor cost of an initial feasibility study may be difficult to estimate and therefore also to justify.

8. STAND UP HEAT, AND BE COUNTED!

"So far, most attention has been focussed on renewa- ble energy for electricity. However, IEA analysis shows that the global share of heat in total final energy consumption in 2008 was much greater than that of transport, electricity and non-energy use." (8) For instance, while electricity consumption constituted 17% of total final energy consumption, heat constituted 47%.

Although methods of producing heat vary from location to location, very little is produced in a sustainable way. In Iceland the main part is produced by geothermal means while in Sweden a large part is derived from biomass. However, looking at the OECD as a whole, more than 75% of all heat is produced from fossil fuels, while, for instance, geothermal heat and solar heat together amount to a mere 0.6%.

Process heat in industry today seems to be seen mainly as a problem to be gotten rid of. Unfortunately - "... little data is available on industrial heat demand... Considering that heat represents such large shares of total final energy consumption (37% in OECD coun- tries and 47% globally), the value of this available heat is clearly underestimated. The need for low-carbon energy makes co-generation and renewables an obvious combination."(10)

9. MEMBRANE DISTILLATION AS A COMPONENT OF A LOW-CARBON ENERGY FUTURE

Co-generation and polygeneration opportunities are not always readily available. They must be developed. This problem has many aspects - first of all the planning of habitation and infrastructure, secondly regulatory changes and finally technological advances. The future use of MD will be influenced by all these aspects.

MD will be introduced as more attention is paid to:

1. total efficiency of power production (MD driven by the cooling cycle),
2. total efficiency in industrial energy use (MD driven by the process heat cycles) and
3. total efficiency in general of heat consumption (MD integrated in heat delivery systems)

It is worth pointing out that MD competes to a very minor degree with other efficiency enhancements because in the MD process, the heat is only used to move water molecules from an evaporation stage to a condensation stage with much the same efficiency as with heat exchangers.

Energy is supplied to MD at a certain temperature. The same energy, with a slight loss, is released from the MD at a predetermined lower temperature. There is a loss in exergy, which can however be regulated as desired. In many systems this loss is inconsequential, in some it may even constitute a benefit (i.e. in cooling) and in some it will constitute a cost. These aspects will determine the economical feasibility of MD.

To put it simply, the heat energy recovered from the condensation side of MD can often be re-used (again) for other uses – e.g. for heating or for hot water – or as feed for power or heat production.

10. PROCESS INTENSIFICATION

Modern processes are more vulnerable to fluctuations in electricity supply. An increased need for reliability is leading more industries to install dedicated power plants. In some cases this is necessary for the reason that the power supply is unreliable - as in a textile mill in a growth economy. Where the power supply is more reliable the reason may be that the continuous supply of electricity is very critical for the process economy, as in a semiconductor manufacturing plant. In these cases a combined heat and power plant is the obvious choice.

Even when the CHP is installed for reasons of reli- ability, this will of course improve the fuel economy of the plant and thereby also the plant's long-term profitability.

In such a plant, after the heat which is generated has served as process heat, its return temperature to the power unit is higher than optimal. The instalment of one MD step on the water's return to the power unit would therefore bring about improved process efficiency.

When there is no need for process heat, enough heat for the MD will normally be provided by means of cooling the power unit. If one wants to generate a larger volume of pure water, cooling from ovens, pumps, fans, conveyers and other equipment can also be used. In fact, all electricity ever consumed ultimately winds up as heat. Some of this heat could be used, while some could not.

Even when there is no need for cooling, the instal- lation of an MD unit would be profitable. When incorporated into any heat flow, MD would produce pure water at a very low cost. The losses in the heat exchangers would be less than 10 kWh (heat) per ton and pumping costs would typically be 0.5 kWh (electricity) per ton.

In general, MD can be incorporated into most industrial processes and there are numerous uses for MD which can contribute to a low carbon energy future.

11. CSP AND MD

Areas which are especially propitious for large scale solar generation often also suffer from water scarcity. Yet they are not always uninhabited deserts. "... regions such as Middle East and North Africa (MENA), South-western United States and the Mediterranean, which have the best potential for solar CSP, are relatively close to inhabited and/or industrial areas. Some large metropolitan areas in divers parts of the world including Athens, Cairo, Houston, Istanbul, Jaipur, Johannesburg, Lima, Riyadh and Sydney are likely to benefit from CSP by 2010 (IEA). With proper planning, heat derived from CSP can be used gainfully to dramatically increase overall efficiency of a CSP system." (17)

"One application in which heat from CSP plants could be used is desalination, especially at a time when many regions that are suitable for CSP, due their large levels of solar irradiation, face severe fresh water deficits."(17)

"Using the heat may have the added benefit of reduc- ing the cooling water requirements of a CSP system. By finding a use for excess heat from CSP plants, co-generation can lower the amount of water required to cool the system. This can make the CSP plant project more viable. Any plant that relies on heat generation to produce steam and generate power must also have a means to remove excess heat from the system once the steam has left the turbine...CSP systems, which are likely to be sited in water-deprived regions, may face an additional hurdle if not enough water is available to cool the system." (19)

An additional systems benefit is that the purified or desalinated water produced is easier to store over the day and seasonally than either heat or electricity. "Desalinated water is even easier to store than heat and excess desalinated water produced during the night can be stored to meet daytime needs." (25)

MD has been developed especially for low-temperature desalination and will therefore have a lower capital cost than any other potential competitor that may be run at low temperature - essentially Multi-Stage Flash (MSF), Multi-Effect Distillation (MED) or Vapour Compression (VC). The running cost will be similar or lower.

In the long term, solar energy will probably turn out to be the most important sustainable energy resource. The most promising technologies right now are thermal solar energy and photovoltaic solar energy. Thousands of companies are developing new photovoltaic methods. Hundreds more are develop- ing thermal. Scarab is developing an innovative proprietary technology for solar thermal co-generation of electricity and water by means of utilizing the cooling water from CSP or CPV in an MD process.

12. BIOMASS AND MD

The "boiler/steam turbine technology currently employed in most biomass-fuelled projects, produces much more steam than electricity. This supports the use of co-generation to increase the overall energy efficiency of such projects. However, in most regions, the demand for electricity is growing faster than the demand for heat." (14) Additional uses for this heat, such as water purification and desalination with MD, would therefore increase the feasibility of biomass power projects.

13. HYBRID PANELS AND MD

Hybrid panels are a combination of solar cells and solar panels. These panels use the energy that the cell cannot extract from the sunlight and at the same time increases the efficiency of the cell by means of cooling it. This produces two benefits - a higher output of electricity and an additional output of heat. Since the demand for electricity normally is greater than the demand for heat, the option of using some of the heat for purification/desalination with MD would in- crease the commercial attractiveness of this emerging technology.

14. GENERAL COMPETITIVENESS OF MD

Even though MD has been specifically developed for the use of low temperature heat and has different specific advantages in that respect, MD must, just as all technologies, be competitive, and it must also have specific commercial advantages over competing alter- native types of water treatment / desalination.

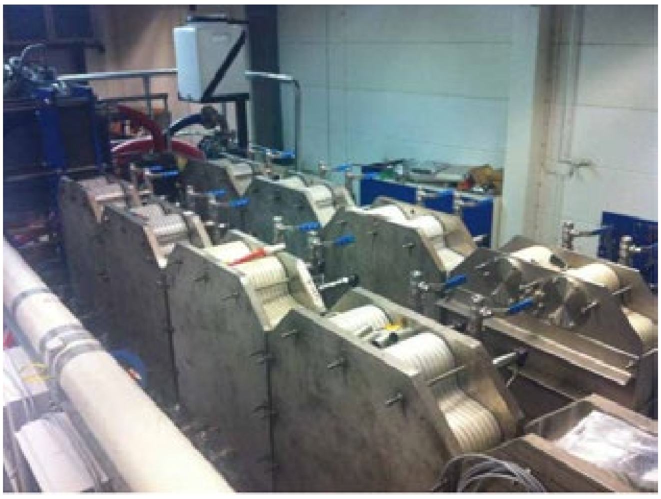

Figure 2: 10 000 litres per day MD demo in Stockholm

For the types of simple treatments which are used in large municipal water plants, sedimentation, flocculation, sand filters, MD is not competitive at the present time. For new smaller municipal plants which integrate co-generation with renewable fuels, MD will however be competitive if there are difficult contaminants to be removed or if superior water quality is sought.

For industrial process water, industrial waste water and for desalination, the two main competitors are Reverse Osmosis (RO) and Multi Effect Distillation (MED). Compared to both of these, the capital cost of commercial MD will be lower. MD separation does not depend on high pressures, high temperatures or vacuum. Therefore less expensive materials can be used in the manufacture of MD plants.

The cost for the personnel at an MD plant would be similar, if not lower, and the cost for chemicals would definitely be lower since the pre-treatment of feed water is not as demanding.

Regarding water quality, MD is superior to both RO and MED. Moreover it also operates at a higher concentration factor. MD removes all types of substances in water to a high degree and it can continue to concentrate the impurities until they have reached a higher degree of concentration. This makes recovery of the contents of the concentrate more profitable.

15. A COMPARISON OF ENERGY USE

MD uses 0.5-1 kWh of electricity per m^3 produced.

In utilizing cooling water from power production or industry, the heat energy used by MD is zero.

If integrated in a combined heat and power (CHP) process, the heat energy use is approximately 10 kWh/m^3.

15.1 REVERSE OSMOSIS (RO)

RO uses no heat energy and moderate amounts of electricity. The power consumption for RO - in desalination plant is approximately 3 kWh/m3. Sweet and brackish water processes use as little as 1 kWh/m^3.

15.2 MULTI EFFECT DISTILLATION (MED)

In a once through process without integration, all evaporative (distillation) processes would use roughly 700 kWh of heat in order to produce one M3. MED systems have been developed which reuse the heat energy and these may reach a GOR of 6 - 12, which means that they will use approximately 50 - 100 kWh of heat per m^3.

16. POTENTIAL COMPETITIVENESS

MD may compete with RO in all situations where it can make use of waste heat or be integrated in heat systems.

MD is competitive with both RO and MED in contexts where there is a need for low-maintenance, robust equipment.

MD is competitive with both RO and MED in the treatment of difficult to treat effluents in industries.

MD is competitive with both RO and MED in high con- centrations applications.

MD is competitive with both RO and MED in contexts where exceptionally pure permeates is required.

17. REPRESENTATIVE TEST RESULTS FOR SCARAB MD

Sample results in September 2014

Tap water spiked with NaCl	µS/cm	µS/cm at 44°C
	feed	permeate
Test 1	7980	0,7
Test 2	7980	0,65
Test 3	7980	0,6
Test 4	7980	0,6

Arsenic	Concentration µg/L	
	feed	permeate
Test A	9.08 ± 0.10	< 0.05
Test B	300	< 0.03

Ag nano particles	Concentration µg/L	
	feed	permeate
Test 1	3100	<2
Test 2	3100	<2
Test 3	3100	<2

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