Decentralised Energy Self-Sufficient Supply and Disposal Systems

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1 Summary

Sources of fossil energy and water are increasingly diminishing. Particularly on islands there is a partial or complete lack of these resources. For that reason concepts with the goal of replacing fossil energy using and absolute minimum of water must be developed.

Sources of fossil energy can only be replaced with techniques that make use of solar energy such as photovoltaic, wind, implementing water for energy such as hydroelectric dams and through production of energy in processes such as anaerobic fermentation (the use of methane gas that is formed in fermentation, for instance in a co-generated power-station (coupling of power and heat) for the production of heat and energy.) Small villages, rural settlements, hotels and chalets are often located outside of the bounds of the conventional energy supply and disposal systems that communities and public offer. Because this locations are often situated in very ecologically sensitive areas, it is particularly necessary to make very rational use of water and energy there.

The current concepts for the supply of electricity to island and island systems are mostly based on the use of solar cells with battery storage and a diesel power unit to bridge the peak loads and periods of bad weather. Including water and waste disposal in these systems, demands a new ecological-oriented, wholistic perspective without which the energy needed for waste disposal can double the energy consumption for the entire island systems.

Here new and comprehensive concepts for supply and waste disposal are called for which can provide a reliable and self-sufficient operation. In this paper, the separate components of energy and water supply as well as sewage purification and treatment of organic waste for a self-sufficient supply and waste disposal system for island and island systems will be presented.

2 Introduction

In order to decrease global warming and the resulting negative effects on our climate, it is necessary to radically reduce the emission levels of CO_2 caused by our use of energy. Beyond that, it is a matter of principle to conserve the limited resources and to reduce the levels of pollution caused by the use of energy. The reliable supply of energy which can fulfil both economic and ecological demands, is an essential foundation for the economic and ecological development of modern industrial society, where international competition is strong. Research and development focussing on the rational use of energy and renewable energy sources make considerable contributions to the spread of a scientific and technical foundation for the economic system and thereby to securing quality of life.

A large range of procedures using renewable energy sources already exists, for instance wind and solar energy, hydro- and geothermal power and the use of biomass. Technologies for the energetic use of biomass have already reached a high technological level. Included are the already widely used thermal conversion and the production of biogas using typical basic substratum and relatively simple installations (for instance in agriculture).

The energetic use of biomass not only allows the reduction of $C0_2$ and conservation of resources, but also has the advantage of generating employment in various regions, giving added income to farmers as well as providing products and opening up markets for middleclass enterprises.

There is also a future market, particularly for the producing nations, to export these technical installations.

European Dimensions

In its white book, "Energy for the Future: Renewable Sources of Energy," the European Commission has set an ambitious goal for the future use of renewable energy. By the year 2010, 12% of the gross use of federal energy in the European Union should be provided by renewable energy sources. In order to attain this goal, the use of biomass and other technologies must be tripled. Concretely this means that a considerable increase in production of heat and fuel and an increase of 10 fold in the production of electricity will be covered by use of biomass. Of the 120 million additional tons RöE, renewable energy such as biomass should make a sizable contribution to the gross federal consumption of the European Union, namely approximately 90 million tons RöE, this being 75 % of the entire sources of energy.

The resulting investment sum for the European sector by the year 2010 in bioenergy is 400 billion DM.

Because of these estimates, the energetic use of biomass has considerable short and middle term market potential. The mentioned 90 million t RöE (which corresponds to a biomass equivalent of 340 million t of wood, approximately) must be planted, harvested or gathered, prepared and transported. This will lead to a considerable increase in employment in the area of biomass production and suppliers, for instance from agriculture and forestry.

3 Supply and Disposal Concepts

With appropriate choice for dimensions, various supply and disposal components can be designed to a self-sufficient system for installations on islands. Management systems (for instance in reference to energy) which take the technical procedural necessities as well as cost aspects into account are especially important for an operation which is both suitable for the situation and economically viable.

The goal of developing supply and disposal concepts should be to replace the fossil energy sources using the absolute minimum of water.

The supply and disposal concepts should be appropriate for the various different conditions of locality, for instance isolated hotels, farms, chalets etc. For example the co-generated power-station (coupling of electricity and heat) is only available on the market with the size of approx. 5 $kW_{electric}$. In order to assure that this is employed economically, adequate fuel must be available.

The following is a discussion of individual components for energy and water supply as well as sewage purification and organic waste treatment.

3.1 Energy Supply

Where no central energy supply is available, diesel power units are often used. But because of its detrimental effect on the environment, a diesel power unit is not a good alternative. Using renewable energy sources is advisable because of the solutions they offer.

With respect to the geographical and topographical location of settlements, villages or isolated hotels and chalet, the following self-sufficient systems can be implemented and when necessary, they can be linked together as hybrid systems:

- Photovoltaik systems
- Wind power systems
- Water turbines
- Solar collector panels
- Co-generated Power-Stations (fuelled with biogas or plant oil) and
- Oil, natural or Propane gas storage as a security measure

(see figure 1)

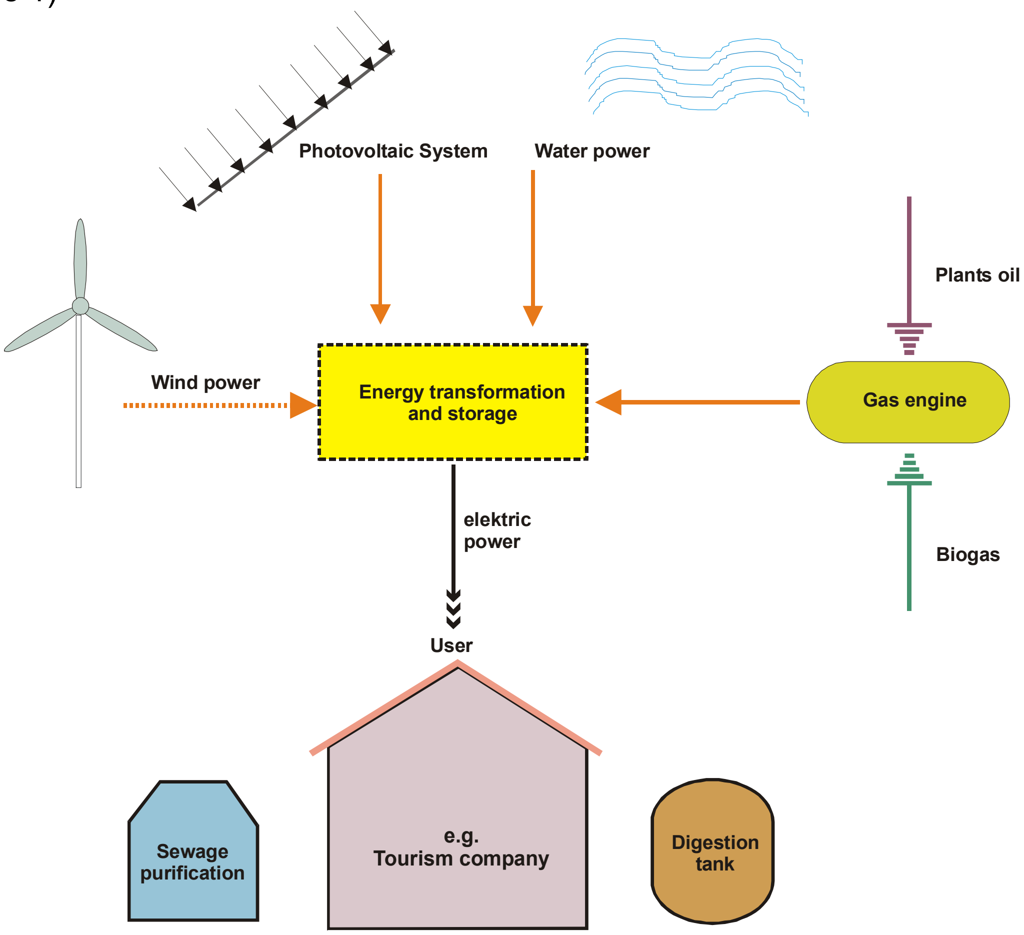

Figure 1: Renewable Energy Supply

In this paper the coupling of power and heat in co-generated power-stations should be explained as an particularly efficient system.

3.2 Water Supply

The supply of water for drinking and other uses is made available for decentralised consumers by pipes for drinking water from public water suppliers, wells or springs, rain or surface water.

There is much potential to save or to avoid using water: For instance, drinking water quality should not be used for cleaning and watering.

In the following, only the decentralised water supply will be discussed, this being a difficult problem to solve for isolated structures.

3.2.1 Water Transport

If wells are used to supply drinking water, then the water available must be hauled up with pumps. Because running these pumps only requires a steady flow of low-energy, renewable energy sources can be used here.

The dimension and size of the pumps is dependent on the height and amount of the water to be hauled up; the energy supply can thus be suited to individual needs.

Wind and/or solar energy can be used as the energy source for pumping systems in wells. Figure 3 is a schematic plan of two pumping systems for wells using this application.

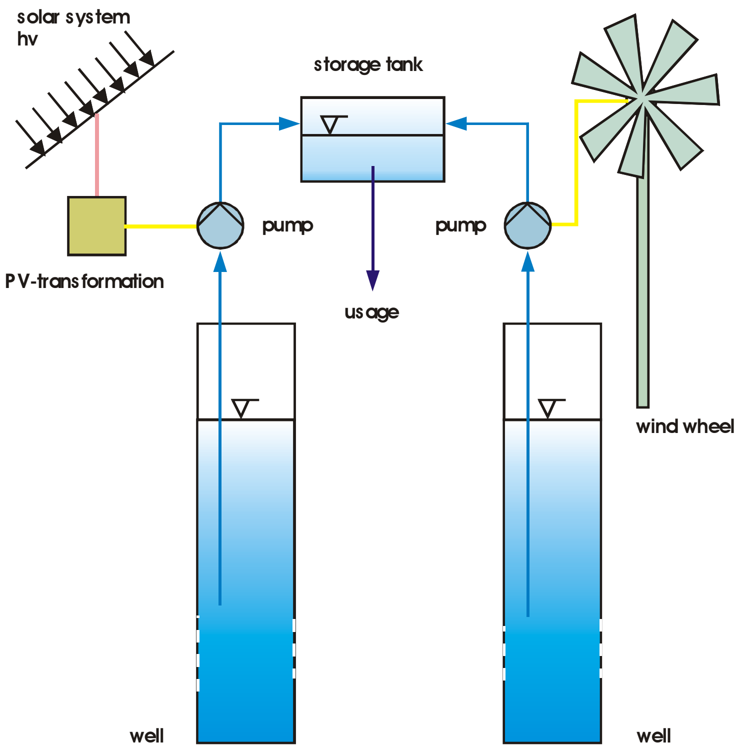

Figure 2: Pumping systems for wells with energy supplied by windmills and photovoltaic cells

3.2.2 Use of Rain Water

By using rain water, the use of water can be economised, valuable water resources can be conserved and less cost is involved to produce and transport drinking water.

Even though Europe belongs to a region of the earth with the most abundant supply of water, there are big regional differences in availability of water. There are areas where water is lacking as well as areas in which the water level is falling due to the high degree of surface sealing.

For that reason, using drinking water sparingly and making use of rain water are effective strategies for water conservation.

By using rain water to flush toilets, sprinkle the lawn and to wash clothes, ca. 33 % of the daily use of water can be saved; using it for drinking water after it has been purified will bring 100 % conservation.

From an ecological point of view it is sensible to store and use rain water close to where it fell and allow it to seep into the ground (see Figure 4), instead of letting it run out as quickly as possible directly or indirectly into surface water reservoirs.

Hereby there is not only a reduction of the water pollution load, but also increased evaporation and ground water levels, contributing to improvements in the regional hydrological balance.

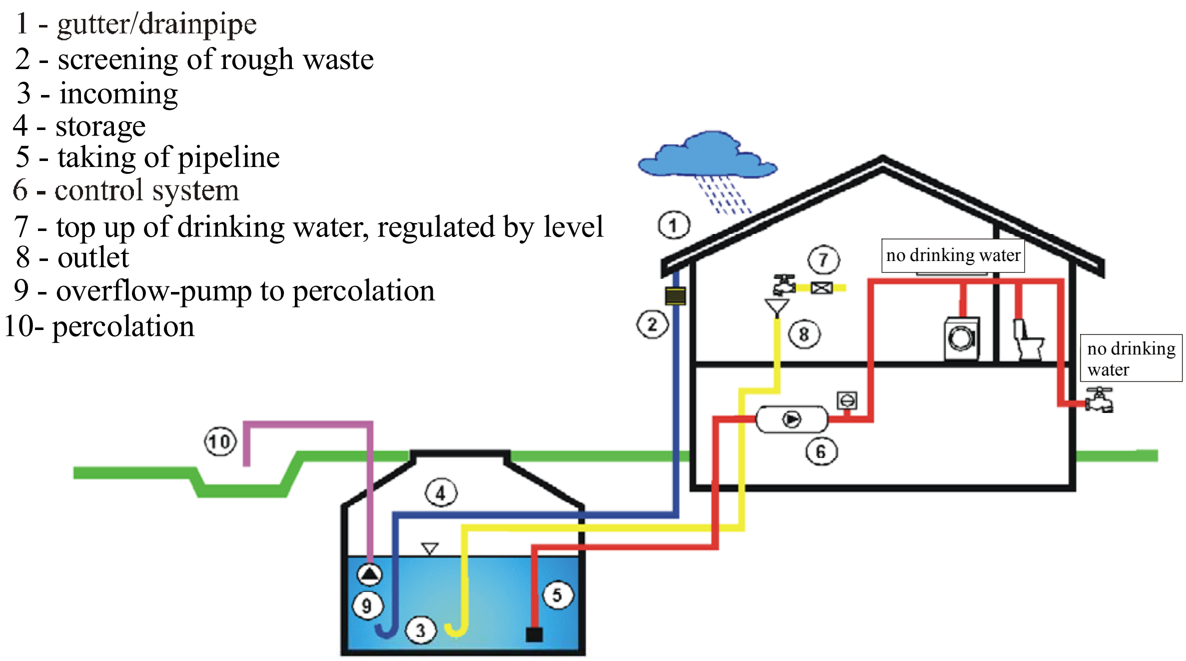

Figure 3: Use of rain water in combination with over-flow pipe in an example of a single family home

3.2.3 Water treatment

If the water, taken for drinking, comes from wells, springs, surface and rain water, it can carry along various contents from its origin. For that reason the water must be purified and degerminated.

From the various technologies for purification of water, only the use of filters as a particularly simple process requiring only low specific energy and membranes as a particulary efficient and diverse method will be dealt with.

Water purification of water using Filters

Slow and fast reacting filters are used for this process, whereby the slow reacting filter (5-20 cm/h) have a physical, chemical and biological effect. The effective portion of the filter is situated mostly in its top layer which can be peeled off when the filter is used up (increased resistance of the filter). Usually sand is used as filter material.

Fast reacting filters (4 - 7 m/h for open, 10 - 20 m/h for closed filters) can be backwashed and act as space filters. Depending on the various purposes for filtration, different materials are used, for instance quartz, sand, anthracite and activated carbon. For special tasks, filter materials are used which react specifically to the contents in the water.

These methods of filtration require only minimal specific energy. Other than having a pump, slow reacting filters need energy only for peeling off the top of the filter layer (if it is automatic) and fast reacting filters need energy only for the backwashing. These can be supplied through renewable energy sources.

Water Purification using Membranes

Using membranes, various different contents can be filtered out of the water such as bacteria, dyes, calcium, salt etc. The disadvantage of the procedure is the relative high use of energy, which however can be provided by renewable energy sources. Figure 4 shows the schematic plan of an simple installation using membranes and renewable energy sources.

Depending on which measure of water purification and the size of the particles that need to be removed, different procedures will be applied:

- micro-, ultra- or nanofiltering,
- electrodialysis and
- reverse osmosis.

In very warm climate zones condensation is made use of to obtain fresh water.

<u>Desalination</u>

A special field of the water treatment is the desalination of sea water.

Actually the methods for desalination of seawater are thermodynamic ones or based on reverse osmosis. All of them are working on a very high energy level.

Therefore labscale experiments were used to develop another desalination-technology focusing on a lower energy consumption. One of the possibilities to be used for drinking water extraction is the membrane distillation.

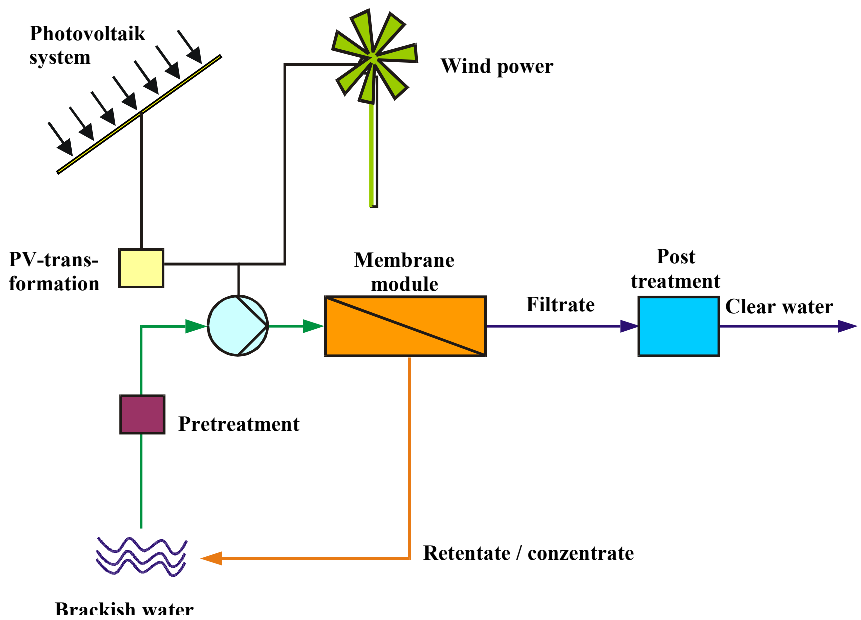

Figure 4: Water Purification Installation

At the moment engineers of ISET are working with this technology for finding out the special conditions of a perfect operation.

For liquid-solids separation a porous membrane bordered to two liquids with different temperatures is used (see figure 5).

The difference of partial steam pressure results from temperature difference.

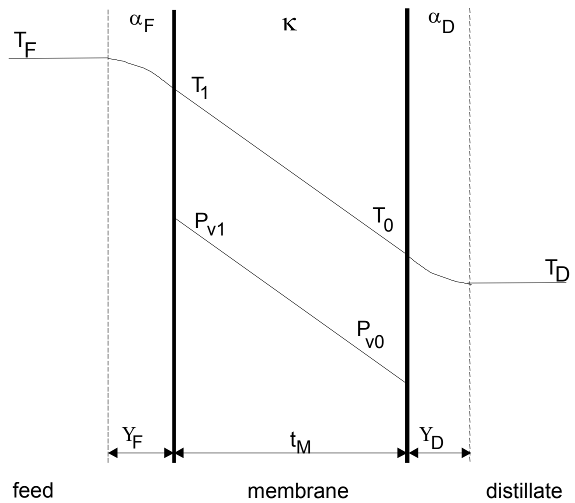

Figure 5: Profile of the temperature and the steam pressure at the membrane considering the temperature polarisation

T_F (T_D): temperature of the feed (distillate)

T_1 (T_0): temperature on the feed side (distillate side) at the membrane

P_{v1} (P_{v0}): steam pressure on the feed side (distillate side) at the membrane

α_F (α_D): heat transmission coefficient of the boundary film between feed flow (distillation flow) and the membrane

κ: caloric conductibility of the membrane

Y_F (Y_D): thickness of the boundary film between feed flow (distillate flow) and the membrane

t_M: thickness of the membrane

On the input side (feed side) it is the warm aqueous solution, e.g. sea water, on the effluent side (distillate site) it is the condensed steam diffused through the membrane. The temperature difference between the two liquids causes a steam pressure difference.

This steam pressure difference is the driving force for the transportation of steam molecules through the pores of the membrane.

Performance influencing factors are the membrane composition and differences in steam pressure level. In general increasing feed temperature (operation running at 60 - 80°C) and temperature difference (2 - 10°C) cause a higher mass transport through the membrane.

This process acts at a comparably low energy level, allowing renewable energy sources to be used.

Figure 6 shows the schematic plan of an installation using membrane distillation and renewable energy sources. Figure 7 shows the experimental plant at ISETe.V., Hanau.

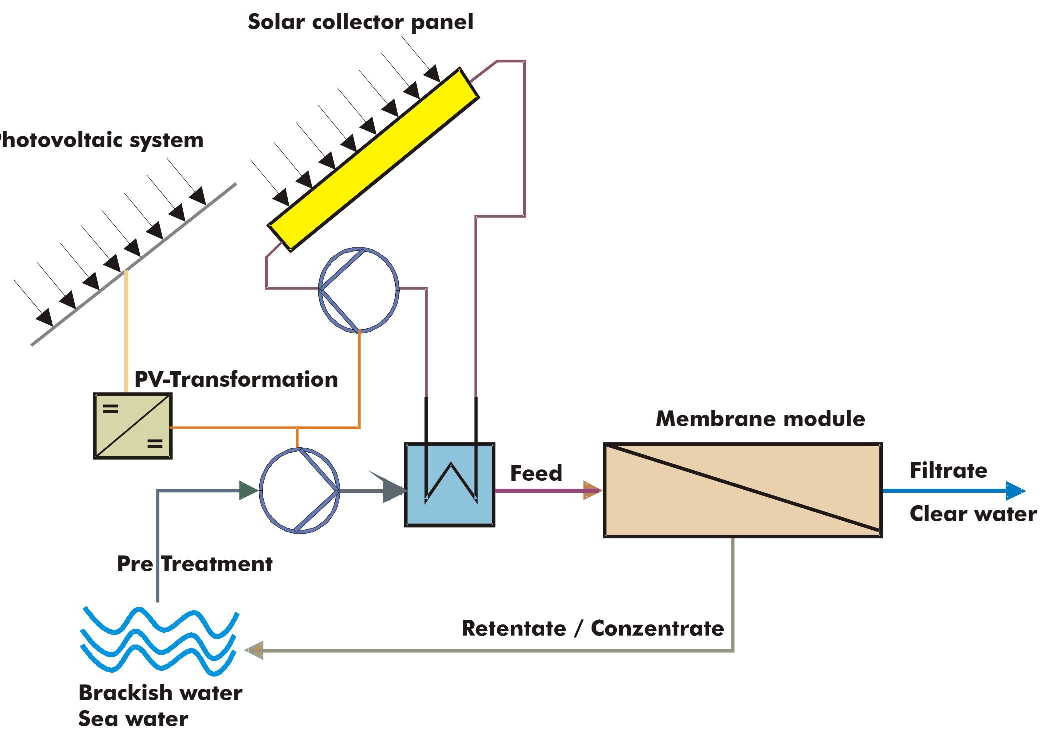

Figure 6: Desalination by using membrane distillation and renewable energy sources.

Figure 7:	Experimental plant of membrane destillation

Water Degermination

In order to destroy possible bacteria, drinking water must be degerminated.

Degermination through UV and the combination of UV-H_20_2 can be recommended here. The use of UV lights for degerminating drinking water has long been practiced successfully.

The advantage of this procedure is that no chemical substances are introduced and no chemical reactions are initiated while destroying the bacteria.

The disadvantage is that degermination effects are short-lived; after 24 hours the water can begin to germinate again.

A relatively low energy d degermination process using UV can be easily implemented, combining photovoltaic installations as the energy supplier. If, in addition to UV radiation, H_2O_2 is used, many organic contents in the water can be eliminated.

Figure 8 shows a water degermination system through UV designed by the Company VitaTec UV-Systeme GmbH, Freigericht/Germany in co-operation with ISET e.V. Kassel/Germany).

Figure 8: Water degermination system (Ca. VitaTec in co-operation with ISET e.V.)

3.3 Sewage Purification

Taking the surrounding population and the location into account, small and decentralised sewage treatment plants can be constructed for isolated hotels, farms, small settlements, chalets etc.

In the case of a permanent decentralised sewage disposal, the purified water should be dumped into an appropriate receiving body of water, or after thorough inspection in individual cases, it can be allowed to seep into the ground. Only sewage (not rain water) should be allowed to be dumped into small and decentralised sewage treatment plants. Only installations that can deal with the demands to minimise the noxious substances should be implemented (in Germany this is in correspondence to §7a WHG), i.e the small and decentralised sewage treatment plant must fit the requirements for biological treatment.

The following can be applied for the biological level:

- Procedure with technical sewage aeration: activated sludge plants or fixed bed, trickling filter and rotating disc filter installations (DIN 4261, Part 2),
- Natural procedures: sewage treatment systems using plants, ditches with two-layers of sand, sand filter pits and soil filter
- Procedure with anaerobic digestion

The choice of which method will be used is dependent on the specific topographical, geographical and climatic conditions and from the kind of sewage that is to be purified.

The following components of sewage purification should in any case be applied:

- Separation of coarse matter
- Equalising or regulation tank
- Biological purification – aerobic and anaerobic (for methods with technical aeration, in including separation and return of sludge)

The purified sewage can then be re-used for sprinkling and irrigation and/or cleaning purposes.

3.3.1 Examples

Technical Sewage Aeration - Rotating Disc Filter

This technique which uses only little specific energy, is inexpensive, space saving, easy to control and can be used in extreme localities. As energy source photovoltaic cells or wind wheels can be used.

Below the process using rotating disc filters is depicted (figure 9,10 and 11).

With a rotating disc filter installation, PE or PP disks are secured on a shaft which is run by a motor and about 1/3 of it is submerged in the sewage to be purified. Through the turning motion, the micro-organisms that are on the disks are provided with nutrients during the time of their submersion, and with oxygen during the rest of the time.

At the end of the shaft the sewage is clarified in the sludge separator. The sewage that has been purified in this way should be re-used for watering and irrigation. If this is not possible, it be dumped out or allowed to seep into the ground.

With suitable construction, the rotating disc filter guarantees to a large degree the elimination of nutrients through the decomposition of carbon, nitrifying and denitrifying.

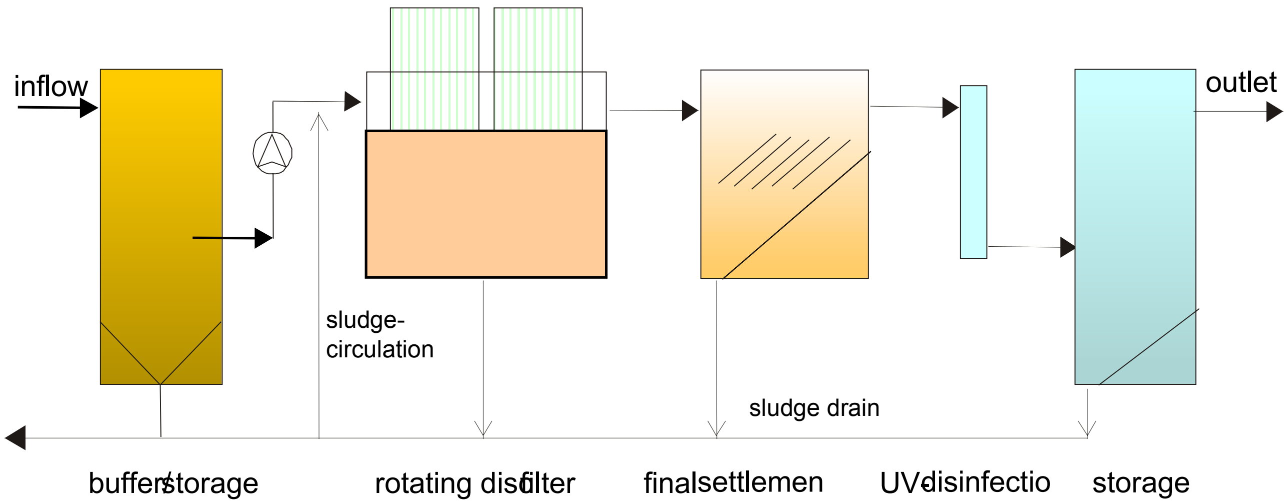

Figure 9: Sketch of a rotating disc filter system

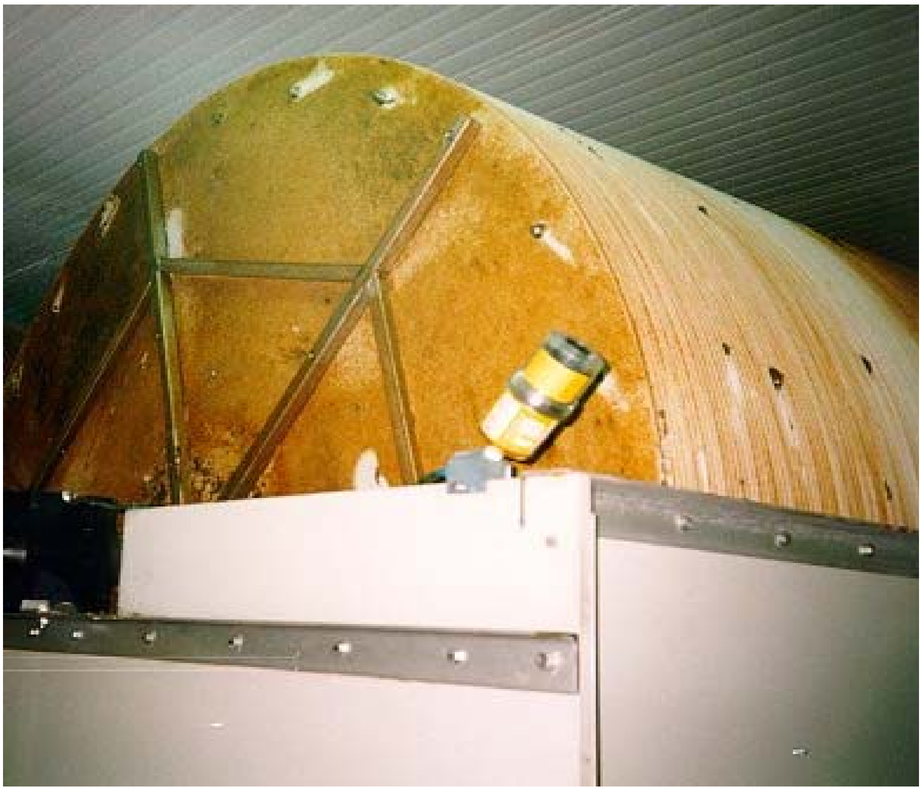

Figure 10: Rotating discs (Company: System S&P, Kirchberg/Germany)

Figure 11: Rotating disc filters (Company: System S&P, Kirchberg/Germany)

Anaerobic sewage purification e.g. by UASB-reactors

(UASB – Upflow Anaerobic Sludge

By using a USAB-reactor the carbon in the sewage will be converted to biogas with ~ 65 % methane. Carbon is minimised by anaerobic treatment. Ammonia and Phosphorus are still available e.g. for fertilisation. After disinfection the purified sewage can be re-used e.g. for irrigation. As energy source photovoltaic panels or wind wheels can be used. Figure 12 shows a sketch of an UASB-Reactor

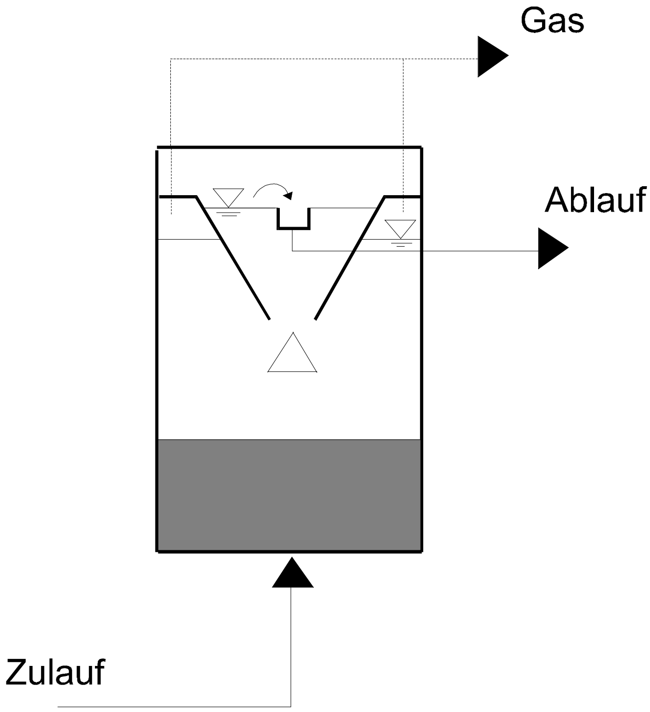

Figure 12: Sketch of an UASB-Reaktor

The technique of the UASB-reactors is distinguished by

- ✓ low specific energy consumption,
- ✓ space saving,
- ✓ easy control and maintenance

Figure 13 shows the UASB experimental plant at ISET e.V., Hanau/Germany

Figure 13: UASB-reactors at ISET e.V., Hanau/Germany

3.4 Treatment of Organic Waste

In this paper, only the treatment of organic waste is dealt with because it can be used for the supply of energy and heat. Organic waste includes biological waste and human excrement.

Until now biological waste has only been composted in the best of cases, and then used to fertilise other plants. The surplus sludge from the sewage treatment is usually simultaneously stabilised at the small sewage treatment plants and used for agricultural purposes. With this method, carbon is converted but no profit is made out of it.

In order to make use of the carbon in organic waste, the biological waste and the excess sludge from sewage treatment is allowed to anaerobically ferment which means shutting off its contact to the air. In order to make economic use of the fermentation, further organic substances such as faeces, urine, sewage from the kitchen including fat and screenings from sewage treatment (only organic matter) are fermented together.

The biogas or digester gas that is produced in this fermentation process is made up of 60 to 70 % of methane gas and can be used in a co-generated power-station to produce electricity and heat. Some portion of the resulting heat is needed, however to maintain the fermentation process. The rotted sludge can then be composted and used as fertiliser.

In figure 14, the process of anaerobic fermentation of the different substances is depicted.

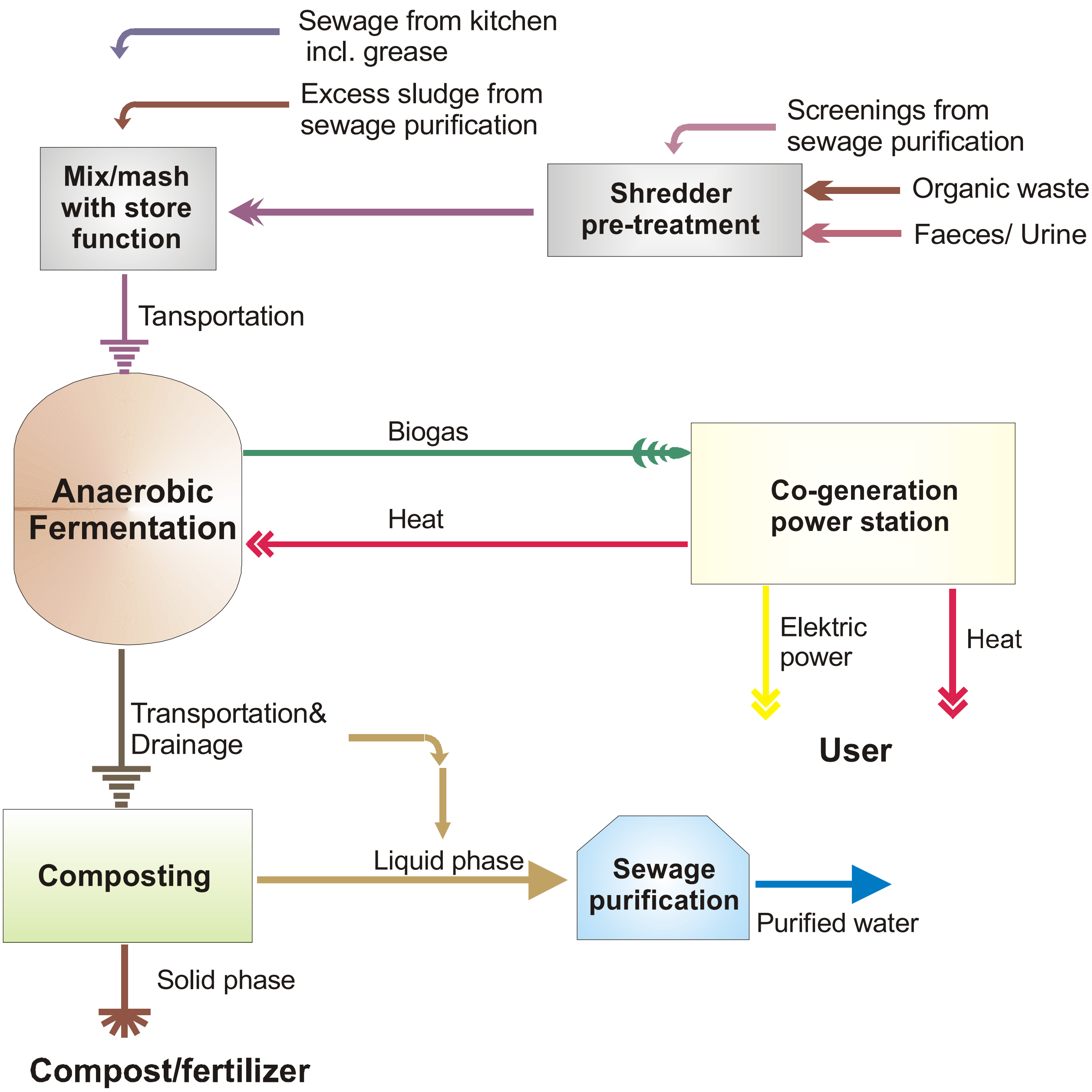

Figure 14: Anaerobic fermentation

4 Examples

4.1 Example of waterrecycling with anaerobic sewage treatment

Water is a resource running shorter.Consequently, the reuse of sewage e.g. for irrigation of surroundings, agriculture etc. has to be included even more in existing and planned sewage concepts.

Depending on its origin, the sewage contains several ingredients which can be used for irrigation as fertilisers in part.

An example for an reuse concept provides the anaerobic sewage purification by UASB-reactors and conclusive degemination.

To operate these plants autonomously the demand for energy will be complemented with regenerative sources of energy e.g. by photovoltaics and/or wind power.

The supply of freshwater for irrigation and toilet flushing systems can be reduced by ~ 50 % if the modified anaerobic sewage purification is applied. Also such a concept requires a minimum of energy.

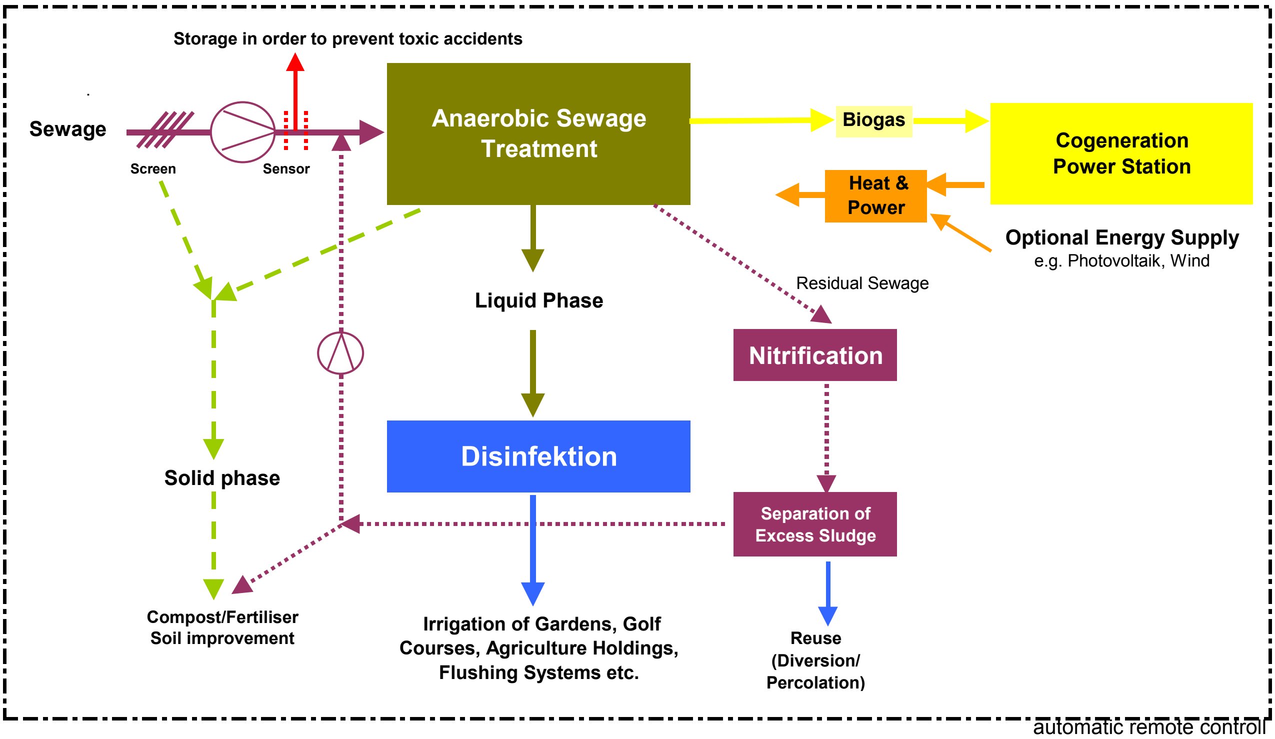

Figure 15: Sketch of an anaerobic sewage purification

Figure 16 and figure 17 show some data of the experimental plant at ISET e.V. Hanau/Germany.

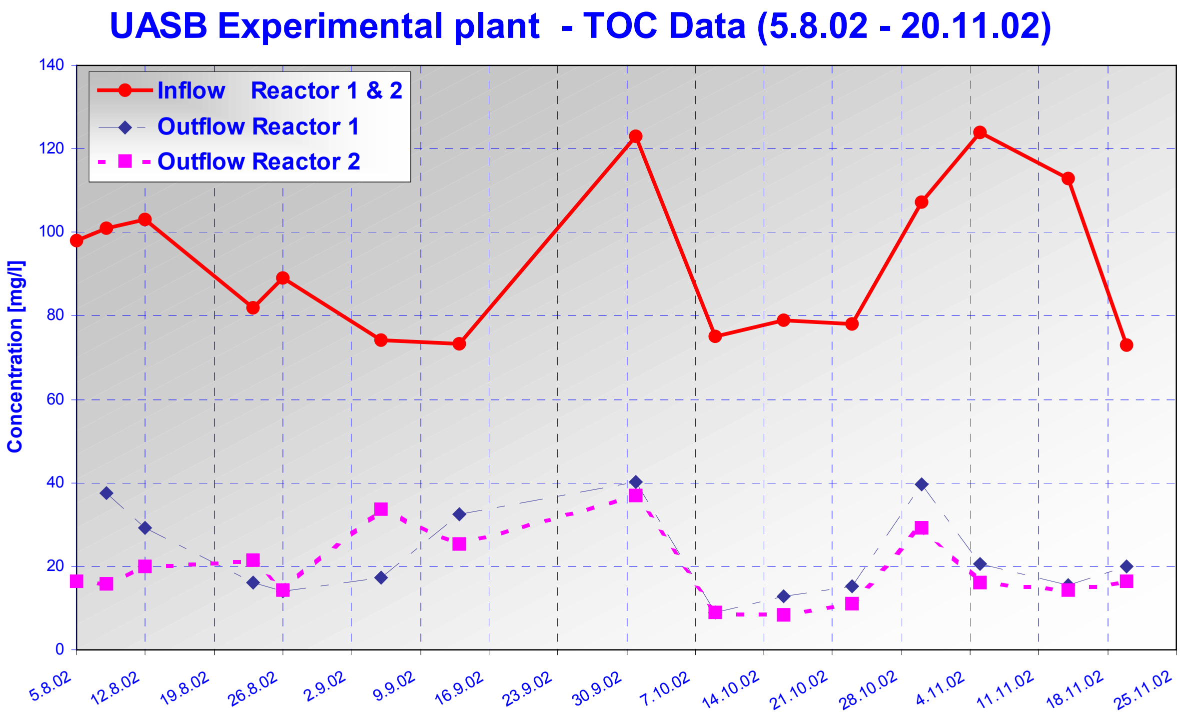

Figure 16: TOC data - Experimental plant at ISET e.V. Hanau/Germany

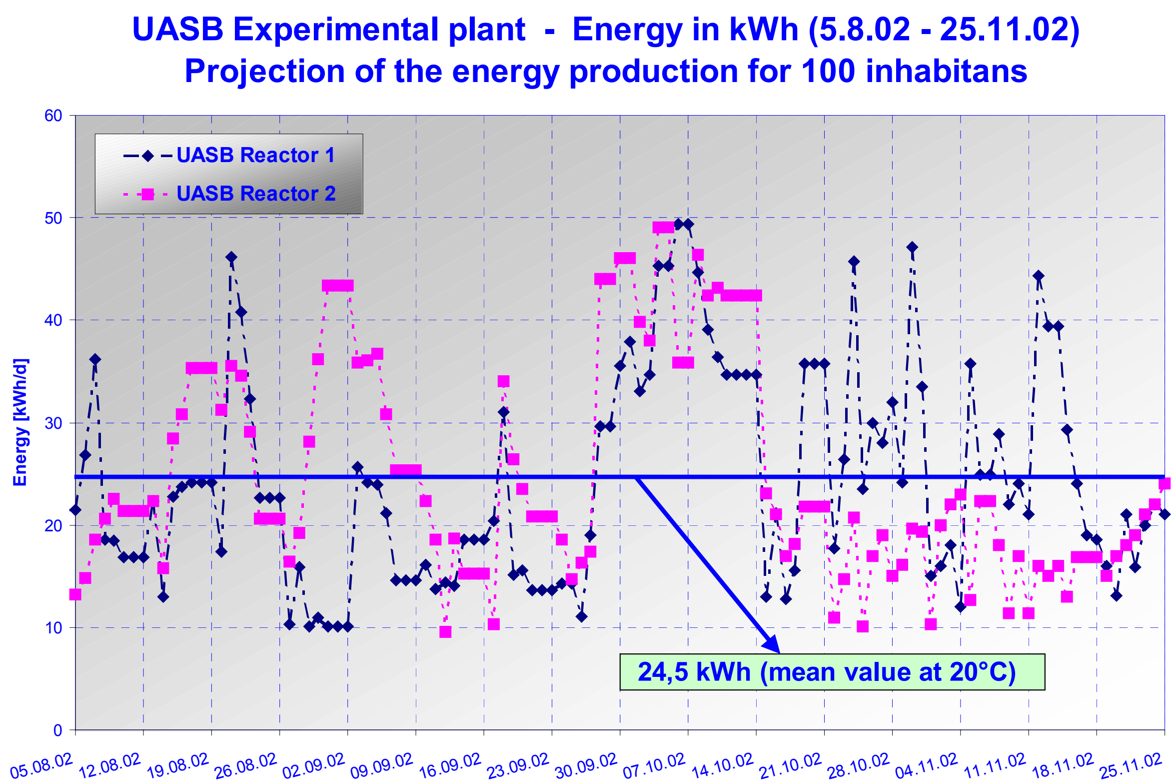

Figure 17: Energy in kWh - Experimental plant at ISET e.V. Hanau/Germany
Projection of the energy production for 100 inhabitans.

The energy production can be used to operate the inflow pump

4.2 Example of an Energy Self-Sufficient Supply and Disposal Concept

A possible comprehensive concept which conserves water and produces energy is the anaerobic fermentation of faeces, urine, biological waste, sewage water from the kitchen and excess sludge from sewage purification. In combination with a treatment of residual sewage from bath basins, showers, bath tubs and washing machines and the liquid phase of the anaerobic fermentation. This can be added into doses from a buffer container.

The purified sewage can then be re-used for sprinkling and irrigation and/or cleaning purposes.

The heat and energy from the biogas which is produced in the co-generated power-station can be used for the operation of fermentation and purification of the sewage water. The surplus can be channeled to the consumer (households, chalets, etc.).

The remaining need for heating can be generated with solar energy. The solar system can also be used to secure the supply of energy to purify and degerminate spring or rain for drinking and other uses.

Such a concept has the following advantages:

- emission free production of electricity through photovoltaic, wind and/or hydro-power
- emission free generation of heat through solar cells (water- or air collectors)
- acquiring digester biogas (fuel)
- thorough use of fuel through co-generated power-stations (coupling of electricity/heat)
- conservation of water by using the dry latrine
- only the purification of residual sewage, making for very clean sewage
- reduction of waste by using fermentation of the biological portion
- saving of diesel oil
- no soot- and smell-emissions
- an installation which is very simple and easy to operate

Taking a hotel as an special example

Using this concept with anaerobic fermentation and purification of residual sewage in a small hotel which operates all year with 20.000 overnight guests, with an energy requirement of approx. 190.000 kWh/year,
the following components are necessary:

- photovoltaic generator with approx. 100 m^2
- solar collector panel with approx. 65 m^2
- digestion container with approx. 8 m^2
- gas storage
- co-generated power station
- purification of residual sewage water
- if necessary storage for propane, natural gas or oil to be used as a reserve source

This example is a very special example, the concept depends extremely to the various different conditions of locality.

In table 1, the individual components for the provision of energy with the application of energy, the energy offered and the total energy consumption is depicted.

Table 1: Total energy of a small, special hotel with a self-sufficient supply of energy.

Energy Supply	Energy Use	Total Energy
Biogas Solar collector panel	Hot water/heating Hot water	63.000 kWh
Biogas Photovoltaic system	Electricity Electricity (lightning, kitchen appliance, pumps, degermination etc.)	39.200 kWh
Wood	Heating house/kitchen	72.000 kWh
Natural gas or oil	Cooking, lightning	12.800 kWh
	Total Amount	**187.000 kWh**

Result: With the use of biogas and solar cells and collector panels up to 9.000 litre of heating oil can be conserved.

Figure 18 illustrates the total supply and disposal concept for the hotel which operates all year around.

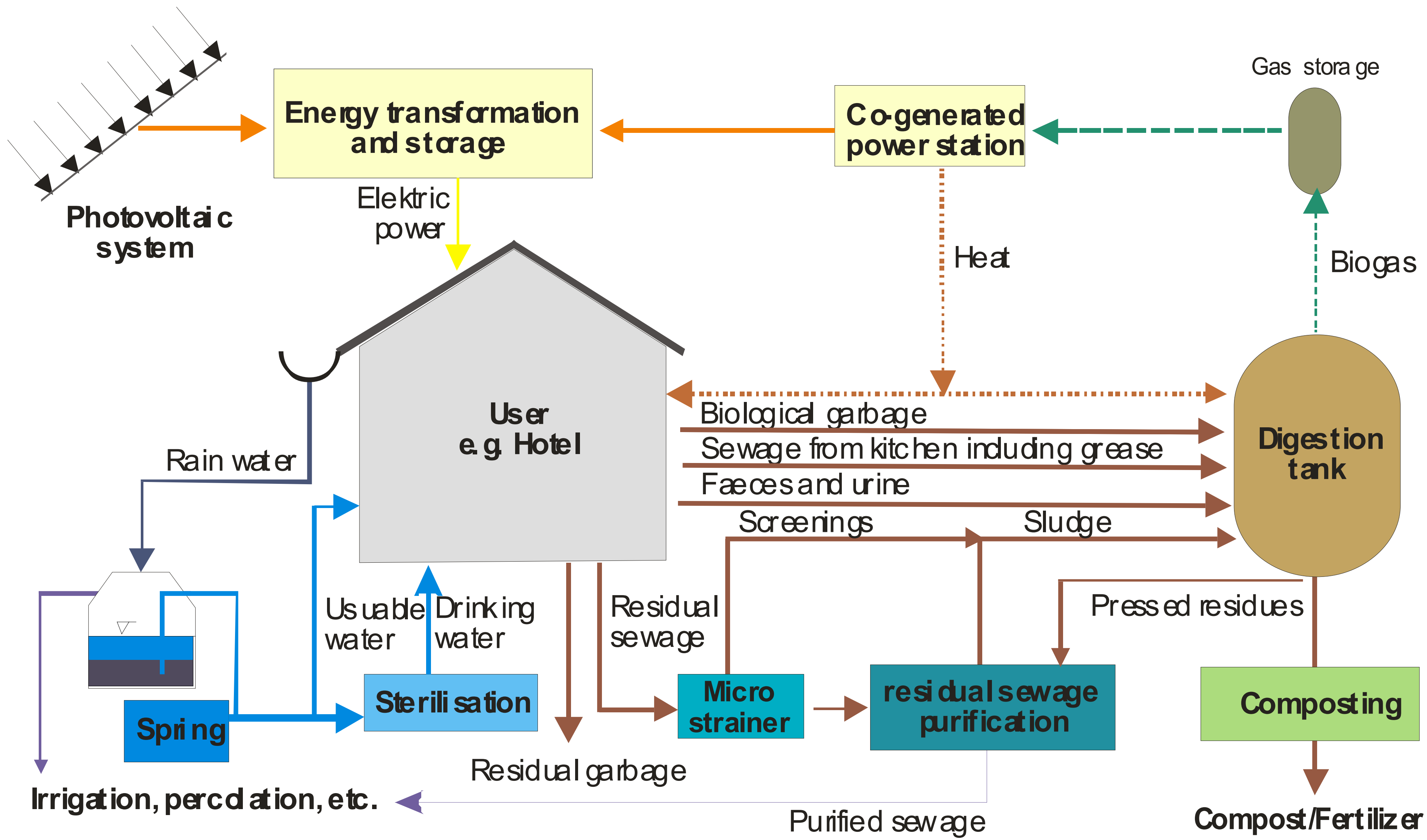

Figure 18: Concept for an energy self-sufficient supply and disposal-system for a hotel

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