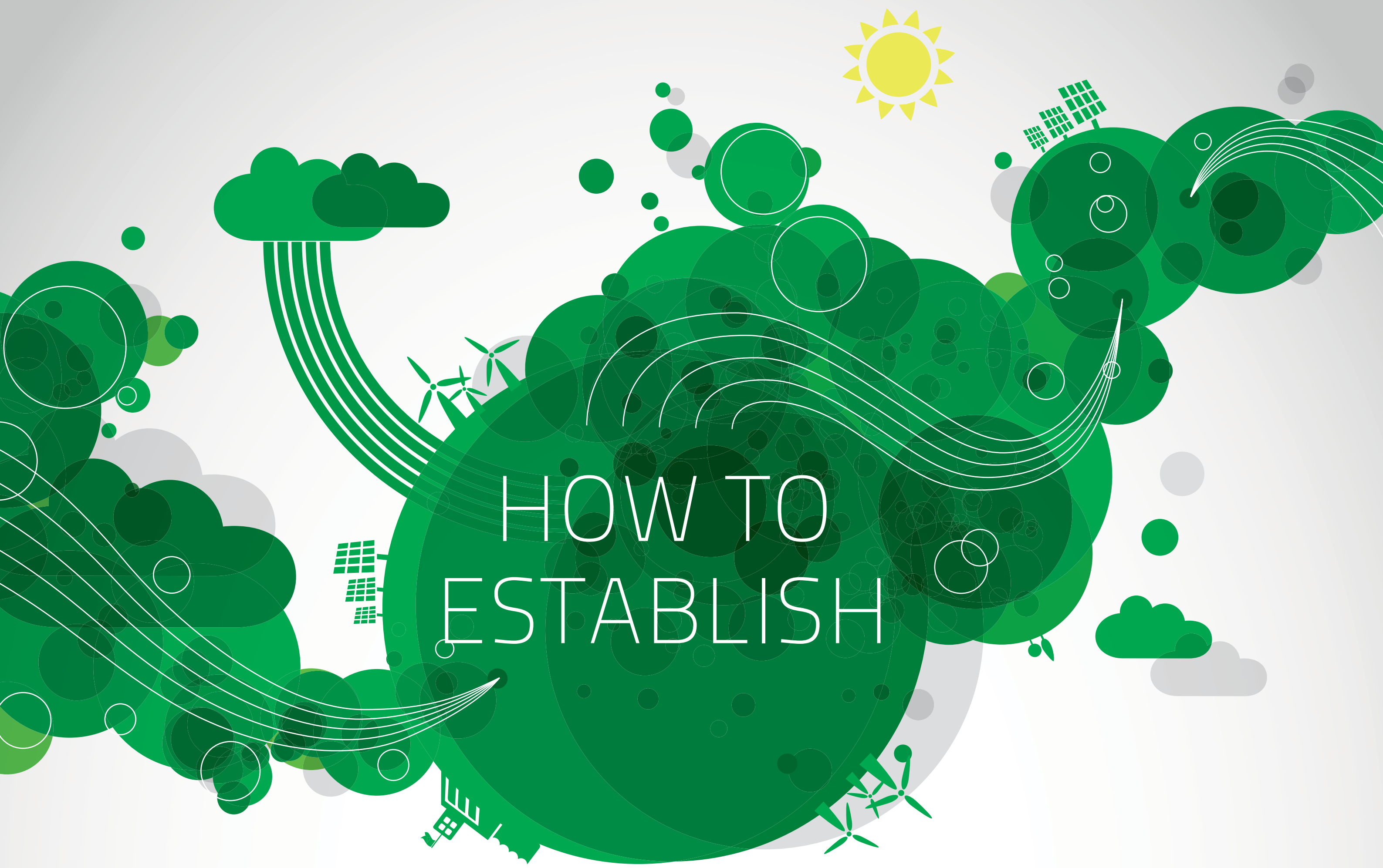

HOW TO ESTABLISH RENEWABLE ENERGY PROJECTS

PROCEDURES, SUPPLY CHAINS AND SYSTEM BOUNDARIES OF RENEWABLE ENERGY SOURCES

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South Baltic PROGRAMME

RES Chains

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About this Guidebook

Dear Readers,

The project "RES-Chains" has been successful in identifying sustainable renewable energy source chains (RES-Chains) to encourage sustainable development within the South Baltic Region in a cooperation of partners from Denmark, Sweden, Lithuania, Poland and Germany over the last 3 years. The focus of its work was on the renewable sources biomass, biogas, solar power, wind power and hydro power as the most relevant RES in the cooperation area – which is the reason why the guidebook focuses on these forms, too.

The document is intended to give a high level understanding of the most significant aspects to consider when selecting supply chain each of these types of RES.

Resulting from this work, the document on hand intends to give an introduction to how the solar power, hydropower, biomass, biogas and wind energy can be used and what supply chains gives high climate and environmental benefits from a lifecycle perspective.

To enable a target-oriented and specific approach it has been structures into five chapters, one per RES. Best practices for every RES illustrate how the implementation of such projects can work well and give you additional guidance with related planning.

We hope that this guidebook turns out to be helpful for your RES projects. The project partners remain available for questions and cooperation on the topic even after the official end of the project in 2013.

Lennart Tyrberg, Representative of the Lead Partner of "RES-Chains", Energikontor Sydost

Solar PV and Solar thermal

How to start the project – implementation steps

Choosing a location

The output from a PV installation depends on the following factors:

_ Natural conditions, i.e. the daily variation due to the rotation of the earth and the seasonal one plus solar radiation available at the site

_ Tilt and orientation
_ Shading and seasonal performance
_ Ambient temperature (PVs efficiency is lower in higher temperature surroundings)
_ Legal and organisational issues

The specifications below will give you a detailed understanding of the mentioned aspects and what has to be taken into consideration related to this.

Natural conditions

The amount of solar energy that can be used depends mostly on local factors such as solar irradiation, meteorological conditions, land availability and demands for energy services – boundary conditions that differ from country to country and from region to region. Solar panel companies can provide specifications and prices regarding solar panels efficiency, life span, panel size and cost and advise you regarding the potential efficiency of the planned project in consideration of the specific side factors.

Orientation and tilt

To receive the best annual energy output from solar panels, is important to locate them in correct direction and in correct position – tilt and orientation are the key factors here. In general, PV panels are mounted flat over the roof so that their tilt corresponds with those of the roof. However the optimal tilt angle if the solar modules is one equal to the latitude of the installations. As only few roofs are perfectly adapted to the solar requirements, the panels often have to be pitched to an angle less than the latitude.

To obtain the maximum amount of energy from the sun, solar modules shall be oriented geographically. The optimum orientation in Europe is true south. However, the modules can face some degrees west or east of true south without significant decrease of performance.

Solar PV arrays are made up of modules of about 1.5 m². It is enough for most available roof shapes to be accommodated. For example, a 3kWp system could comprise 15 panels taking up an area of 20 m² and will generate roughly 2,500 kWh per year.

Shading and temperature

Shading depends on the landform, surrounding buildings, chimneys, trees, TV aerials and vent pipes, and every other object which can cast a shadow on the solar panels. All the modules are connected, so any shading will affect the performance of the whole array. Minor shading can result in a major loss of energy. The installed system should not be shaded between 10am and 4pm. Early and late shading in a day are tolerated. In the Table below, typical over-shading factors are displayed.

Overshading	% sky blocked by obstacles	Overshading factor
Heavy	>80%	0.50
Significant	60% - 80%	0.65
Modest	20% - 60%	0.8
None or very little	<20%	1.0

Table: Over-shading factors

High temperature makes PV modules performance decrease (the drop in performance is more significant for crystalline silicon than amorphous silicon). It is necessary to consider this in design to allow air flowing over the backs of the modules to maintain high performance.

Energy can be produced even on cloudy days. Without direct sunlight it is possible to obtain as much as 30% of amount of energy from sunny day.

With all this, the seasonal spread of energy generation from PV has to be considered. Here, the general rule applies for Europe that everywhere the highest energy generation is during the summer months, and the lowest during the winter.

Environmental impact

A great resource is provided by sun for generating clean and sustainable energy. Use of solar systems release no CO_2, SO_2, or NO_2 gases, and do not contribute to global warming. Solar modules, over its estimated lifetime, will produce much more energy than it was used for their production.

The potential environmental impacts (land use, habitat loss, water use, or use of hazardous materials in manufacturing) mostly depend on the used technology and the scale of the system.

Big scale solar facilities, depending on their location, may contribute to land degradation and habitat loss. All depends on topography, technology, and intensity of the solar resource. However, land impact can be reduced by placing the system at lower-quality locations. Small scale solar arrays have a very small land use impact.

Water is not used when electricity is generated from solar PV, but in manufacturing processes some water is used to produce the components. In addition, module manufacturing process includes a number of hazardous materials, which are mostly used in cleaning and purifying process. These materials include , sulfuric acid, nitric acid, hydrochloric acid, hydrogen fluoride, 1,1,1-trichloroethane, and acetone.

Thin-film PV cells contain more toxic materials than traditional silicon photovoltaic cells, ex. gallium arsenide, copper-indium-gallium-diselenide, and cadmium-telluride. Manufacturers are strongly motivated to ensure that these rare and valuable materials are correctly recycled.

Global warming emissions are not produced during energy generation from solar systems, but in other stages of solar life-cycle, mainly in transportation, manufacturing, maintenance, installation, decommissioning, etc.

Legal aspects

PV and solar heating and cooling technologies face different legal barriers for big and small projects. Utility-scale projects face siting, permitting and financing challenges to develop land with favorable solar resources. No access to transmission can be the barrier for both, small and large systems with complex access laws, fees, permissions and related procedures being in the focus here.

Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009

The Directive for the Oromotion of Renewable Energies defines binding renewable energy targets by 2020 for every EU Member State, stronger provisions for the reduction and simplification of administrative barriers and access to the grid for renewable energy systems included.

The construction and installation

What type of solar system is the best one for your project? Option 1: PHOTOVOLTAIC (PV)

Photovoltaic systems convert sunlight directly into electricity that can be used to replace or supplement the electricity supplied by the utility grid. In this sector, small installations are in the majority*. This work with photovoltaic as a micro-source has number of advantages:

1. The energy is produced in high energy consumption time of a day (between 8:00 a.m. and 6 p.m.).
2. Photovoltaic Installation is very simple and does not require special tests or measurements.

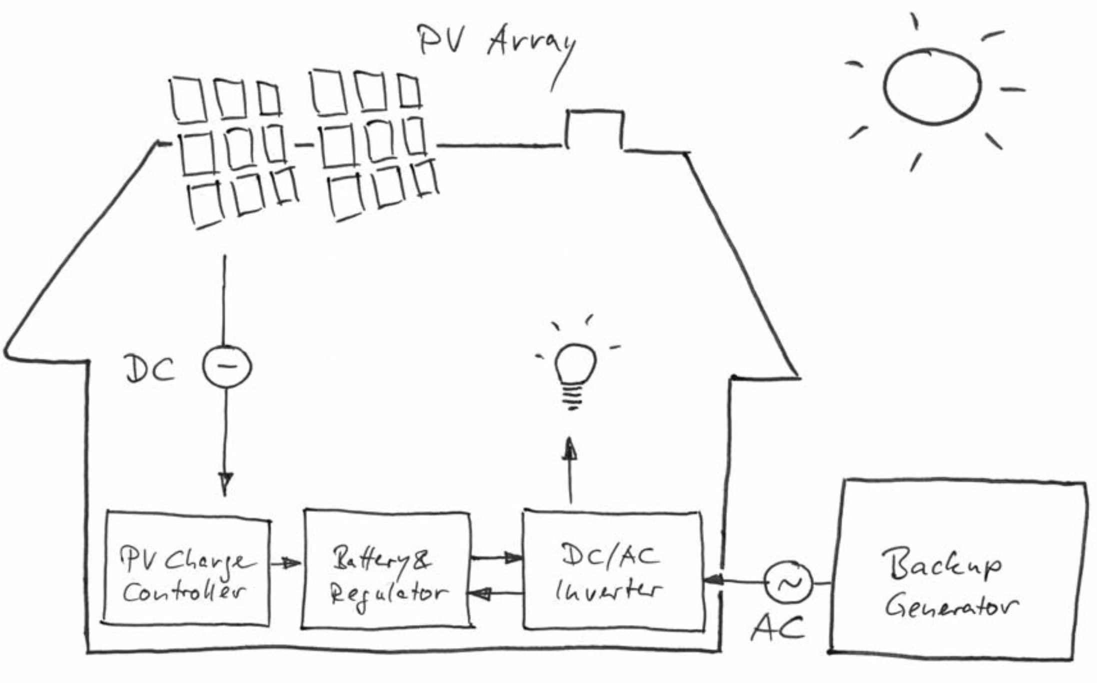
* In Germany 71% systems are micro-installations (installations with a capacity of 1-10 kWp on the roofs of residential buildings) and small installations (10-100 kWp on public buildings, farms and small commercial power plants).

3. From the users' point of view, PV is maintenance-free, does not contain moving parts, does not generate any smoke, odor, or sound.

4. The plant is located in the roof, which is normally an untapped space.

How does the system work?

_ PV panels transform the incoming solar radiation into electricity.
_ Batteries store excess energy.
_ PV Charge controllers control the charging current that goes into the batteries. It improves the charge of the batteries, increasing their lifespan.
_ DC/AC Inverter converts direct current (DC) to alternating current (AC).



Three basic types of Solar Panels

Monocrystalline solar panels (made with monocrystalline cells) are the most expensive panels, but more efficient (15 – 20%) than the newer and cheaper polycrystalline and thin-film PV panel technologies. Their purchase price depends on materials used to panel production, which is mainly based on very pure silicon and involves a complicated crystal growth process.

Polycrystalline or Multicrystalline solar panels (panels made with poly- or multi-crystalline cells) are slightly less expensive and a little less efficient than monocrystalline cells. The difference between monocrystalline and polycrystalline solar cells is that one is produced from a single crystal of silicon and the other is produced from a piece of silicon consisting of many crystals.

Here, it is important to stress that it is not only the type of solar panels will that decides upon the cost and performance of whole, but also a solar inverter, the installer's labour costs and the orientation of the house's roof and tilt angle of panels.

Amorphous solar panels are a thin layer of silicon deposited on a base material such as metal or glass. They are relatively cheap to produce and widely available. Still, their lower price goes along with lower energy efficiency here. This type of panels is mostly used for small devices, e.g. calculators or garden lamps. The tendency for a use in larger applications is increasing.

Option 2: SOLAR THERMAL SYSTEM

Solar energy systems can be passive or active. A passive solar heating design does not include any sort of mechanical heating device. The building features absorb heat and then release it to maintain the temperature within the home. Active solar energy systems use the same principles as passive systems except that they use a fluid to absorb the heat. Solar thermal collectors absorb irradiance from the sun and convert this into heat for hot water.

Solar water heating systems are the simple and widely used solar energy collection and utilization devices. They supply hot water for domestic use and are based on natural circulation (so called thermosyphon principle). Two types of water heating systems are available here: direct and indirect heating.

Direct Solar Water Heating – sun's heat is captured directly in collectors for the household's hot water supply. Collector pipes filled with water are linked to an insulated storage tank (often located inside the house). Water inside the pipes, heated by the sun, flows into the storage tank. Direct systems are more efficient that indirect ones, but they require more maintenance to keep the pipes clear of mineral deposits. Direct solar thermal systems also work best in warmer climates where the system is less prone to freezing.

Indirect Solar Water Heating – Indirect systems use fluid (such as freon, distilled water or propylene Glycol) with a low-freezing point to absorb radiant energy from the sun. After the fluid is heated in the collectors, it travels through a heat exchanger, where the heat it contains is transferred to the household water.

How does it work?

_ Cold water enters the system from mains supply
_ Solar Controller activates the pump if the collector is warm enough
_ The fluid circulates round the collector, and is heated by sun
_ This fluid then goes to a tank and heats up the water via a coil
_ If required a second coil brings up the water to the pre-set temperature via an existing boiler
_ At the end hot water goes through the taps.

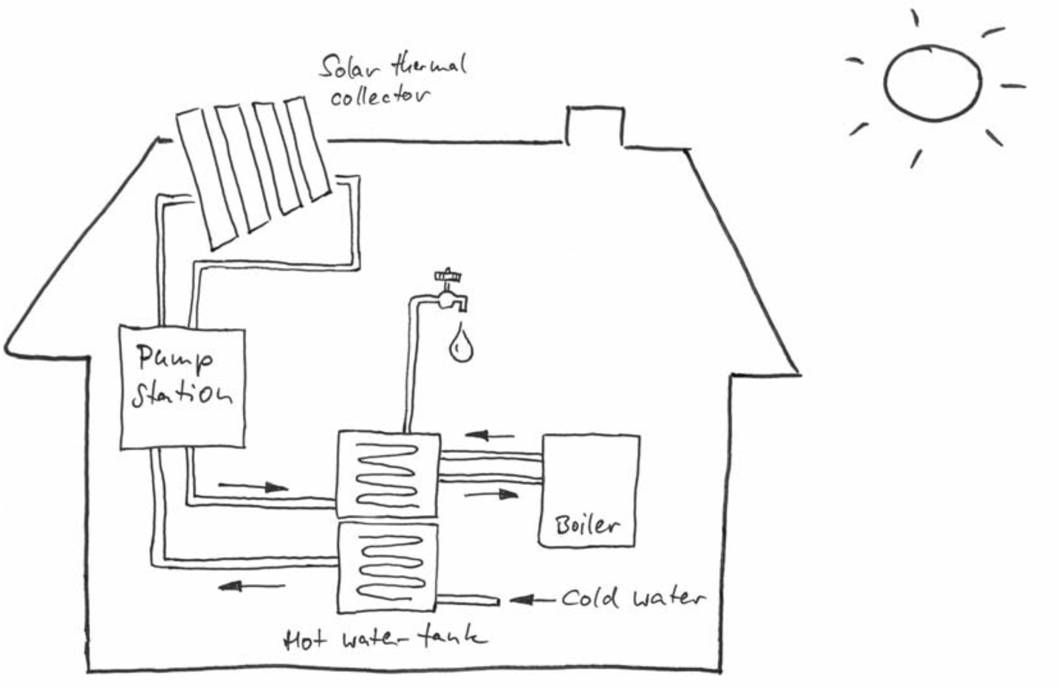


Figure: General schematics of active solar thermal system

Producers

It is not an easy task to choose the right PV cells producer. On the market there are many companies, offering different technologies with different configurations. To choose the right producer, it is important to follow the manufacturer's brand. Big producers, with proper facilities and infrastructure, are safer, regarding quality, but also regarding fulfillment of guarantee obligations.

Integrated producers (having silicon, wafers factories and producing the panels), are less dependent on market changes. Modules should have a certificate of quality, such as TUV, VDE, or appear on the List of Certified PV modules of Institute of Energy & Transport (IET) of the European Commission.

Warranties

There are several types of warranties that come with a system. These include product warranties which cover defects in manufacture; system warranties which cover proper operation of equipment for a specific time period (usually 5 or 10 years) and annual energy performance warranties covering the guaranteed output of the PV system.

System warranties	Power warranty (annual energy performance warranties)
Ensure that dealers or manufacturers will correct defects in materials and workmanship, loose modules, wire faults and other issues.	Ensure that solar panels will produce a certain level of minimum output over a certain number of years or the manufacturer will fix/replace the panels, or provide compensation to the homeowner.
Market standard is 10-years warranty	Market standard: 90% of the nominal power after 10 years, and 80% after 25%
Additional warranty terms to consider	
compensation for the power loss due to the badly running module	
reimbursement of the cost of replacing the defective module, replacement for the new, the financial compensation	
warranty calculated from the date of delivery to the customer, not from the production date	
Replacement of the module damaged in transportation (ex. delivery terms INCOTERM)	linear decrease in power warranty

Installation

Before choosing the panels and planning the whole system, it is important to think about three key pre-installation areas:

1. Planning permission: In most of cases it is not necessary to apply for planning permission, however there are limits and conditions (e.g. for houses in conservative area) which have to be taken under consideration before deciding to continue with solar installation. To be sure that the permission is not needed, it is recommended to contact local council's planning permission department.
2. Roof suitability: Solar installation shall be installed on the south facing roof. There should be approx. 10-20m² of free, not covered by any obstacles (such as chimney, trees, etc.), roof space.
3. Structural Considerations: Before purchasing the solar installation, it is important to make sure that the structure has sufficient load bearing capacity to support a system.

In preparation for the installation of photovoltaic panels, you need to consider many factors, the result of which will depend on the efficiency of the installation:

1. Location - latitude, which determines the angle of the sun,
2. Slope of the surface on which will be installed PV panels or solar heating collectors (roof pitch, bump, etc.),
3. Obstacles (such as: underground utilities, skylights and roof windows, roof systems, etc.) and shading the installation (trees, buildings, chimneys)
4. Technical design (such as technological routes, fire ways, fences, transformer stations, power lines, etc.)
5. Technological requirements (such as snow load, etc.)

First and most important aspect for the system installation is an avoidance of shading of the panels by other objects (or by other panels).

There are three main ways to install solar panels:

1. Roof installations – placed flat on the pitched roofs, they do not cause shading.
2. Roof installations installed on the support structure – used on flat roofs to form a right angle. It is very important to make a wind load calculation, because withstanding panels can be taken out by the wind.
3. Ground installations – installed on supporting structures, tilted at a correct angle to the sun. Between panels should be sufficient distance to avoid shading.

Off-grid or on-grid?

Apart from direct consumption by producer, solar photovoltaic energy can be fed onto the power grid under the feed in tariffs (FITs) set by the government for the amount that electricity suppliers pay for the electricity generated by solar panels. Feed-in tariffs are the most popular renewable energy policy mechanism.

Maintenance and Operation Phase

Apart from little maintenance, solar systems do not need a lot of attention.

Solar panels roof mounted are regularly cleaned by falling rain. There is no big need to wash them often. Solar panels ground mounted, or located near high trees, need more attention, and should be regularly brushed or pressure washed. Washing should be done while it is not too hot weather to avoid damages of the system. The whole system needs periodical inspections, e.g. on a sunny day in spring and autumn each.

Decommissioning

Solar installations should only be removed by qualified professionals who use appropriate access and safety equipment for work on roofs. Decommissioning should only take place when there is no solar irradiation. Alternatively solar panels/collectors can be covered for at least 5 hours to let them cool down.

Recycling of PV can be divided into three main components: metal, glass, and silicon wafers. Glass and metal are easier to recycle by using existing solutions. Undamaged silicon wafers can be used in production of new solar cells.

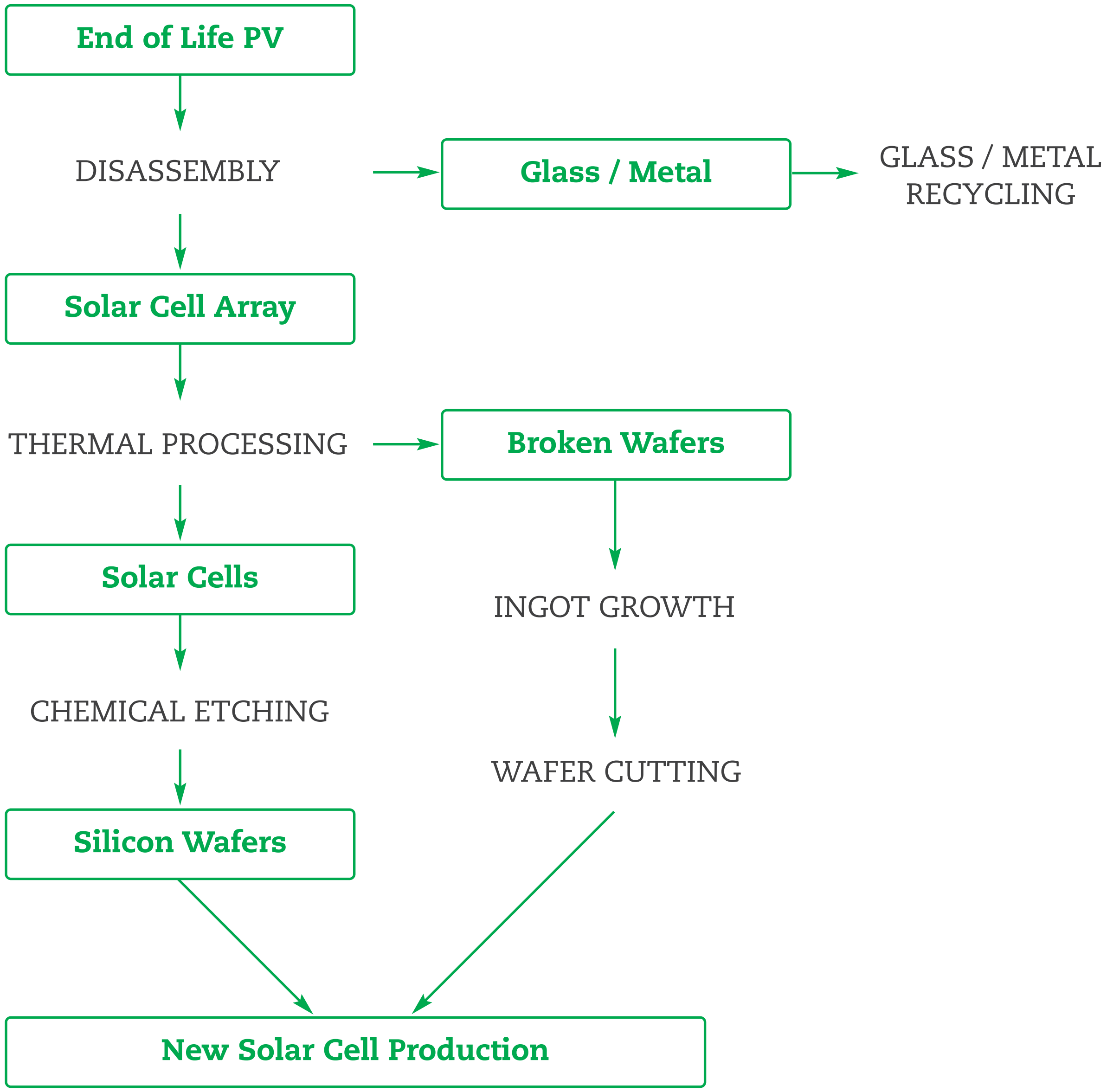


Figure: Overall PV Recycling Process

Windpower

Life-cycle challenges

Carbon footprint

The manufacturing of basic materials, their further processing and transportation, the installation, the operation and the disassembly of the turbines plus recycling of residues consume large amounts of energy. Instead, the energy source used for this current production is available free of costs and residues.

The proportion of the energy amounts used for all product related processes within the life cycle is referred to as energy payback (energy returned on energy invested, EroEI). A life-cycle assessment implemented by a manufacturer resulted into a predicted energy payback factor of 35 to 51 for a wind turbine type with 2.3 MW nominal capacity at an onshore site, depending on the quality of the different sites which are located in different distances from the coast.

The carbon footprint is a different way of looking at this, stating all carbon dioxide emissions produced during the product life cycle. The calculations are not standardized; the results may differ significantly depending on the system boundary extent.

Other greenhouse gases are included here, too, which is why the carbon footprint is expressed in grams of equivalent carbon dioxide per produced kilowatt hour ($gCO_2eq/kWhe$).

But the information on energy payback and carbon footprint of turbines may differ significantly also for other reasons. This is, on the one hand, related to the different turbine designs and total yields determined for the site, on the other hand related to the age of the turbines. The development efforts related to wind turbines have increased significantly since the 1990s which is reflected in higher yields and optimized designs.

The carbon footprint that can be achieved these days is indicated for onshore turbines as 8-30 gCO2eq/kWhe, for onshore turbines as 9-19 gCO2eq/kWhe.

A study issued in the UK assumes that ranges from 4-7 gCO2eq/kWhe for onshore turbines and from 3 to 5 gCO2eq/kWhe for offshore turbines can be achieved by 2030.

Impact on creatures and landscape

Depending on their site, wind turbines, as all other buildings, have impacts on their environment. They particularly act on the habitats of flying animals that are scared or hit by the rotating rotors. Turbines installed on sea effect on the marine ecosystems in addition. The future will show which changes are durable and what will be accepted after a certain acclimation period, the results have to be documented in related studies.

Only of temporary nature is the very dominant optical presence of wind turbines with their height of up to nearly 200 metres. In most cases, they are designed for a life-cycle of 20 years and will be removed after this period of time.

Typical process steps

A wind energy projects economic success depends directly from the selected installation site and from the wind conditions expected there. Other factors that have a major impact on the project's cost structure are the consistency of the ground and the environment of the turbine to be installed as well as the efforts that have to be taken to connect the turbine to the grid. Third factors are determined by construction law and nature and environmental protection laws.

Selecting a site

Natural Conditions

<u>Wind conditions</u>

Generally, it can be stated that optimum conditions for operating a wind turbine occur on the sea and in direct vicinity of coasts. The wind can build up over long distances here, undisturbed by land-scape formations, buildings and vegetation.

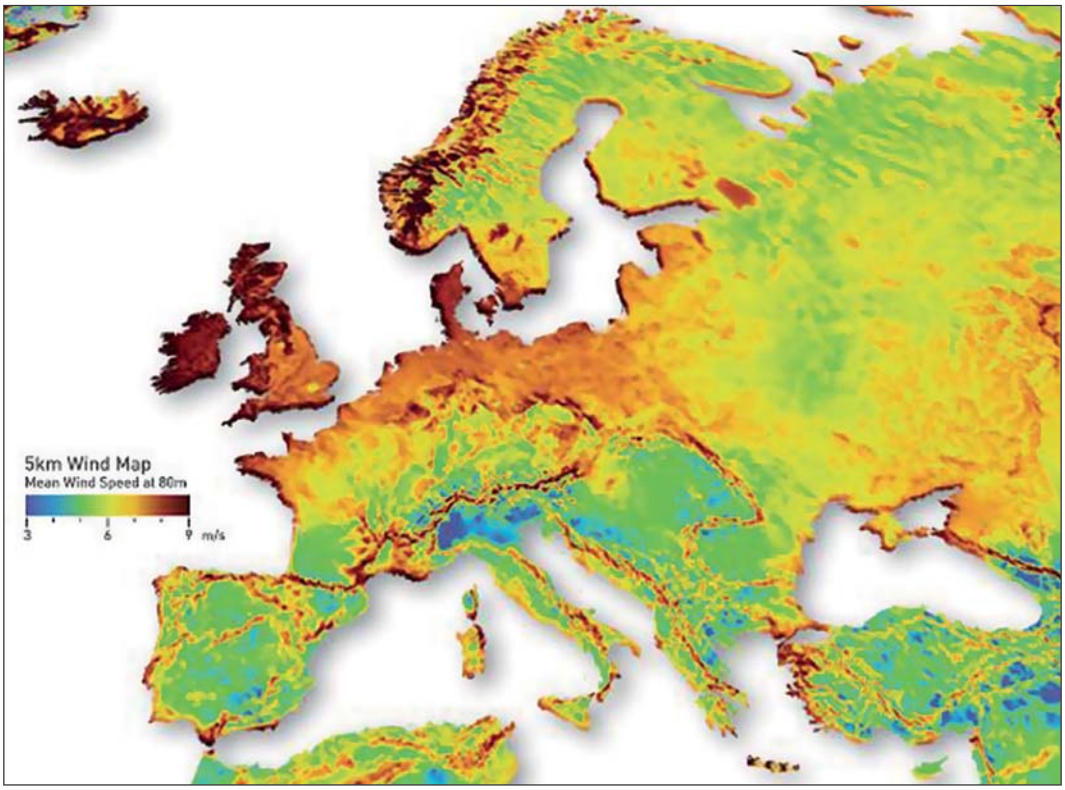


Figure: Average annual wind speed in 80 metres height, overland, bleed [Source: www.3TIER.com]

Onshore, there is a boundary layer influenced by the landscape which is, depending on the type of surrounding area, up to several 100 metres high.

These influences can be reduced via a higher hub height as the disturbing effect decreases with altitude in the lowest atmospheric layer. The degressive gain of wind speed can be roughly calculated with simple formulas. Thus, for instance, an increase of a hub height from 80 to 120 metres in a forested area can be calculated as wind speed increase for about 10%. If the energy content of the wind which depends on the third power of the wind speed is considered, the available energy increases for about 30%. If the surrounding area is even and without impacting elements, this influence is reduced. A yield increase of less than 10% only can be expected here.

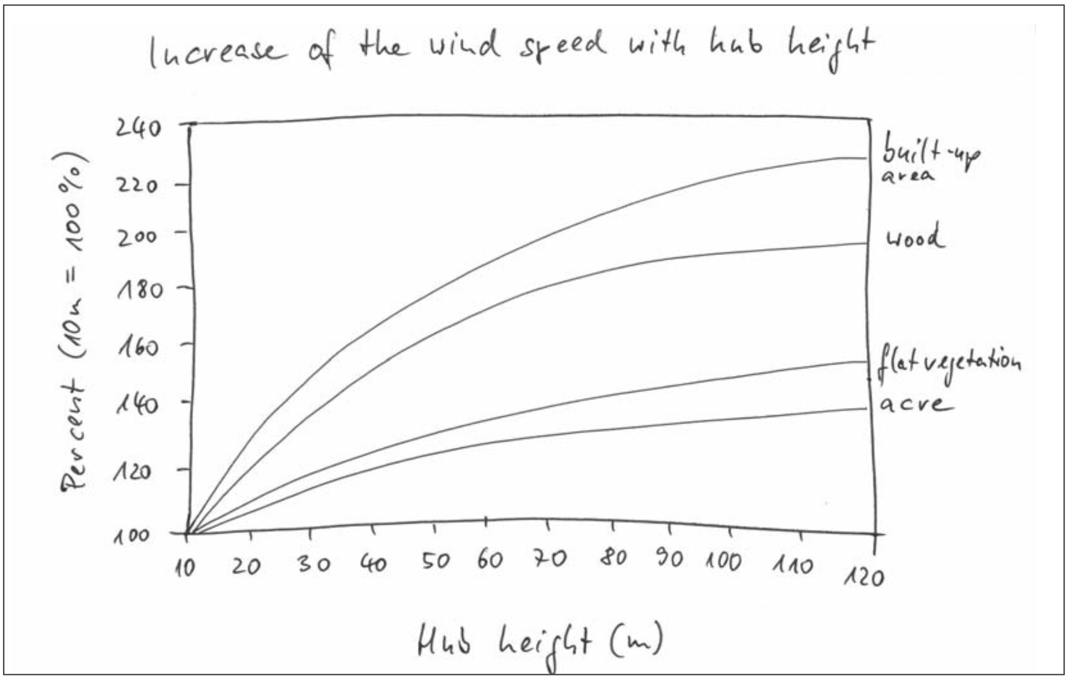


Figure: Effect of hub height and territory type on the wind speed

Wind maps are mostly created on the basis of data that apply for 10 m or 80 m heights. Consequently, they have to be converted to the needed hub height for yield calculations.

For estimating the yield, the share of the different wind intensities has to be connected to the wind turbine power curve. Again, a rough approximation in form of a mathematical model for estimating the distribution can be made based on the average wind speeds typical for the region.

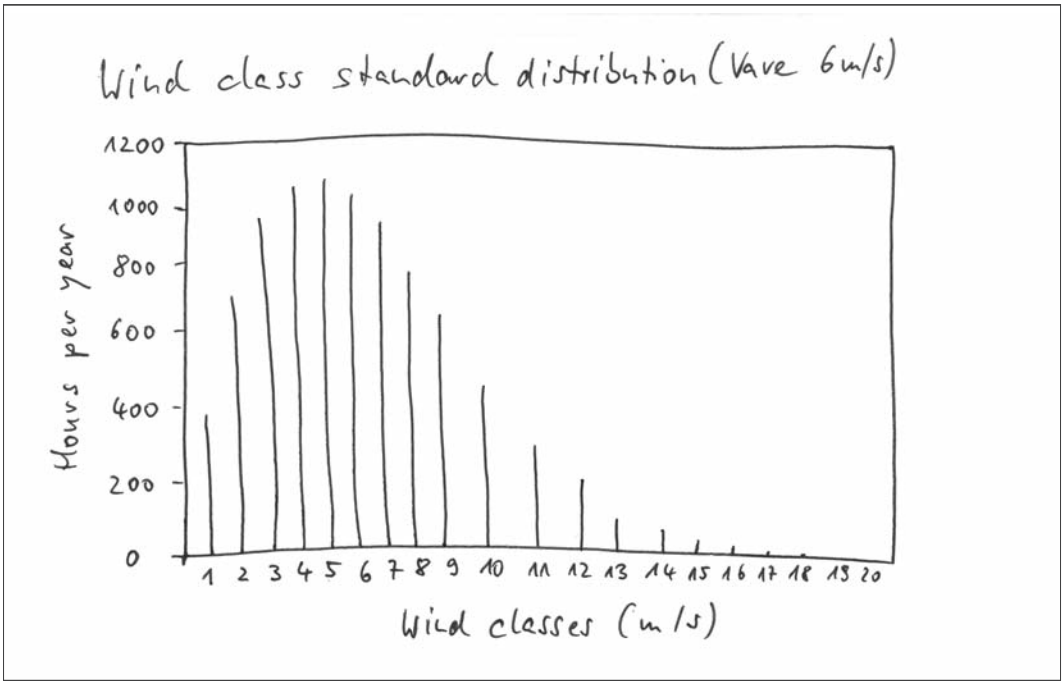


Figure: Principle distribution of wind classes according to Weibull, example for an average annual wind speed of 6m/s

The distribution of the occurring wind classes over the year is directed by the course of the seasons. Thus, stronger winds occur more often during autumn than during the summer months.

The local effects on the wind situation are also locally limited ones, as those of mountain-valley or sea-land winds that change significantly over the course of the day.

Some of the wind energy available at the site is not used for economic reasons. Most of the wind turbines regulate the production to nominal capacity at wind speeds between 10 and 12 m/s. This reduces the loads acting on the components, a compromise that reduces the turbine construction costs significantly. The yield losses from this are limited as the distribution displayed in figure 4 shows.

Ground and landscape

The efforts related to the tower foundation depend on the soil characteristics. Foundations built on rocks have other requirements than those for sites with soft soil, such as fens, where pile foundations are needed. A completely special field is offshore turbine foundations where not only foundation and tower have to be considered for the design layout, but also those parts of the building that are surrounded by water. The changing water levels, swell and ice situation create special requirements to design and turbine dynamics.

If a site is technically and economically suitable for wind turbine installation at all, depends on the accessibility of the construction site. Remote sites are often far away from heavy-load approved roads, the bridges of normal roads are often only designed for normal traffic.

Legal aspects and environmental impact

Legal restrictions

Large wind turbines have to be approved and designed in accordance with construction law. Framework conditions are, apart from the minimum construction requirements to the turbines, land-use plans, military and aviation requirements, nature protection and, of course, the protection of human beings. The environment should be impacted as little as possible by pollution, noise or visual stimuli.

Most regimentations result into minimum distances from certain objects and maximum heights or to requirements to turbine operation that can indeed influence each other. For instance, the operation of flight warning lights on wind turbines is obligatory near airports. And residents who are exposed to permanent light stimuli during the dark will experience this as reduction of their life quality which can result into a further relocation of suitable sites.

Grid operators might have the right to intervene in certain load situations. If good turbine utilization and low current consumption of current customers coincide, the operator of the wind turbine has to ensure that his/her own plant feeds less current into the grid which shall prevent grid overloads.

Impact on nature

The impact on a wind turbines natural environment can be generally structured into four stages: installation, operation, disassembly and the time after turbine disassembly.

Onshore turbine

Installation and disassembly are short but intensive stress periods particularly for animals, though limited to a manageable area. The period is comparatively short, lasting only a few weeks and can, as mixture of construction noise, bright illuminations at night and restless scenery, be considered as preliminary disturbance.

For animals that live on the ground, the production operation goes mainly along with sibilants and mechanical sounds caused by the turbine, which are partly conducted from the tower to the ground as structure-borne sound. Some birds and other flying animals are threatened by the rotor blades.

The remaining footprint of the construction site after turbine disassembly depends on the scope of disassembly works. Foundation elements that remain in the ground, compacted crane parking sites and construction roads have a direct impact on the surface vegetation and the habitat of animals living underground.

The blade tips of larger rotors move with speeds of nearly 250 kilometres per hour which means that a blade tip passes one single spot at the outer rotor diameter end every two seconds. Collisions may occur if animals have not become used to these special characteristics of wind turbines in advance.

Offshore- WEA

The common technology related to the installation of pile foundations in water is a ramming of the piles into the sea ground. As the water as incompressible medium carries the construction noises with high energy density over long distances nearly without losses, animals inside the catchment area can be disturbed and, in shorter distances, even harmed. Some projects tried to reduce the vibrations and, thus, the noise by installing curtains made of air bubbles in circles around the construction sites.

As for the onshore turbines, the marine environment is impacted by operation noises, too. Still, the vibrations conducted by the water in form of structure-borne sound can be recognized by animals more distinctly and, as described above, over larger distances. Investigations implemented on installed offshore wind farms show that marine habitats are significantly impacted by buildings and landfills under the water surface. Sustainable changes of the ecosystems, as, for instance, settlements of previously not occurring animals, may happen at these artificial reefs.

Disassembly works related to offshore turbines will not cause disturbances as significant as during the installation in the underwater world. Still, a complete removal of the buildings would cause problems for cohabitations established there before.

After the easily reachable components are removed the piles hidden in the sea ground and, if applicable, landfills remain there as residues.

Construction and installation

Types of wind turbines

Apart from many different technically implemented basic principles regarding drive principle and construction, the installation of systems with horizontal drive train axis has established itself for larger wind turbines. Within this group, the following versions are offered as series turbines.

Wind turbines with stall or pitch rotor blades.

Stall blades

The performance control at higher wind speeds is based on the deteriorating aerodynamic features of the rotor blades. These systems have a simple structure, the power curve decreases in the range above nominal wind speed and the components have to be designed for comparatively high loads.

Pitch blades

The blades can be pitched electrically or hydraulically via the longitudinal axis and, thus, will always reach the exactly intended aerodynamic propulsion. The installation is complex, the power curves are always at nominal capacity in the regulating range and the load acting on the entire building can be influenced by the control system.

Wind turbines with and without gearbox between rotor and generator.

<u>Drive train with gearbox</u>

The turbine rotor turns with 10 to 20 rotations per minute at larger wind turbines. To convert this slow rotation for the, with more than 1000 rotations per minute much faster running, generator, a gearbox is installed between. These turbines tend to have smaller and lighter nacelle, but comprise of more component groups that have to be maintained and that can fail.

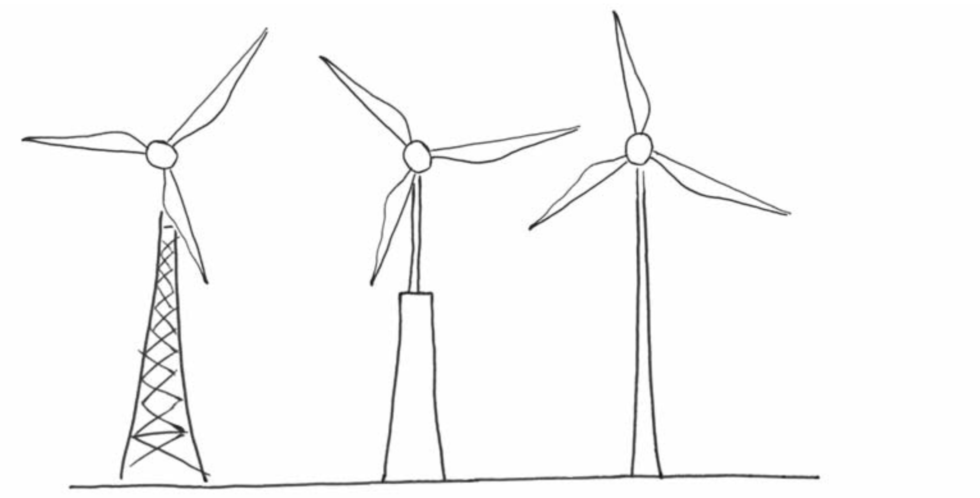
<u>Drive train without gearbox</u>

To achieve the same performance as a fast-running generator, a slowly rotating generator has to have a multiply larger diameter. Thus, the nacelles of these turbines are very heavy and voluminous but have a simply structure and less components that may cause turbine failures.

Tower structure

Another distinguishing mark of land-based turbines is the tower structure. The transportation of the conical steel towers becomes more and more difficult here so that casted concrete towers or mixed constructions become an alternative. In addition to other special versions, there is a lattice tower version. It is the lightest available and, thus, easily transportable construction but characterized by an extensive assembly and maintenance.

From a certain turbine size on, the tower basis must have a diameter of more than 4 meters for economic reasons.



As soon as large components of offshore turbines have reached the quay edge, no transportation restrictions due to unsuitable roads, bridges or passages exist anymore. They are loaded onto ships. Tower segments can even be towed through the water as floating tubes to the installation site by seagoing tugs.

Operating conditions

Sites near or on the sea require enormous corrosion protection efforts. In addition to the use of special protection layers on metal surfaces, the nacelles are partly encapsulated to keep the aggressive, humid and salty air away from the internal assembly.

Special technical solutions have to be found in some cases for turbines installed in the inland to keep dusts from industry, agriculture or even desert sand away from the sensitive components.

In other sites, there are special climate conditions such as extreme coldness in subpolar regions, high temperatures in tropical areas or even both extremes together over the course of the year in central-continental regions. Accordingly heavy precipitations have to be considered, too. Such conditions require an increased use of insulation material, heating systems and sealing systems or of largely dimensioned cooling systems when equipping the wind turbines.

Onshore / Offshore

The transportation devices and cranes needed for installing onshore wind turbines can usually be used even for other construction or industry projects. In addition, there are current grids that cover large areas onshore where the produced current can be fed in. The cable routes that have to be newly laid are of manageable length.

The cost share for onshore turbine installation and grid connection is of minor importance, even the installation of a single wind turbine can be economically reasonable.

For installing offshore turbines, special vessels for transport, pile driving and crane works are needed, which are very costly in construction and operation. The connection of an offshore wind farm to the onshore grid requires, depending on the distance of the site from the coast or from the next submarine cable, significant efforts for laying the connection cables. In addition, there are legal environmental protection requirements according to which flora and fauna at the sites as well as along the cable lines have to be investigated and evaluated prior to the project.

The cost share for installing offshore wind farms and connecting them to the grid is of high importance. Economically reasonable are mostly large projects with a lot of turbines the costs can be distributed to.

Maintenance and Operation Phase

The operation of wind turbines is fully automated. In addition, the machines are looked after by remote monitoring teams via internet or telephone connection. So it is only maintenance and repair works that require a work of human beings at and in the turbines.

In addition, there are service operations for removing smaller operational disruptions. The maximum maintenance wind speed has to be considered during these maintenance works which is the wind speed limit until which the turbine can be entered and works can be carried out there.

As a rule, maintenance works are implemented every 6 months.

The maintenance of offshore turbines is also very much influenced by the seasonal accessibility of the sites. The conditions on sea in autumn and winter are often that unfavourable that the parks cannot be accessed for several weeks. Turbine failures that occur during these times result into longer down-times and, thus, to accordingly reduced annual yields.

The maintenance works comprise, in addition to extensive checks of all turbine components, of oil exchanges at the drive system gearboxes or main gearbox, the re-lubrication of the bearings, the exchange of brake linings and coal brushes or the exchange of filter mats.

Apart from the wear parts, most plants are designed and approved for an operation period of 20 years. Larger components are only exchanged in case of failure.

Decommissioning

Calculating a wind energy project also includes the formation of reserves for turbine disassembly and for decommissioning of the construction site as specified in the building permission. These completion works are partly financed by selling the material to be scrapped which can have a considerable value. Getting materials from such sources is also referred to as Urban Mining.

After the life-cycle of the wind turbine has come to an end, the wind turbines are shut-down and disassembled by cranes step by

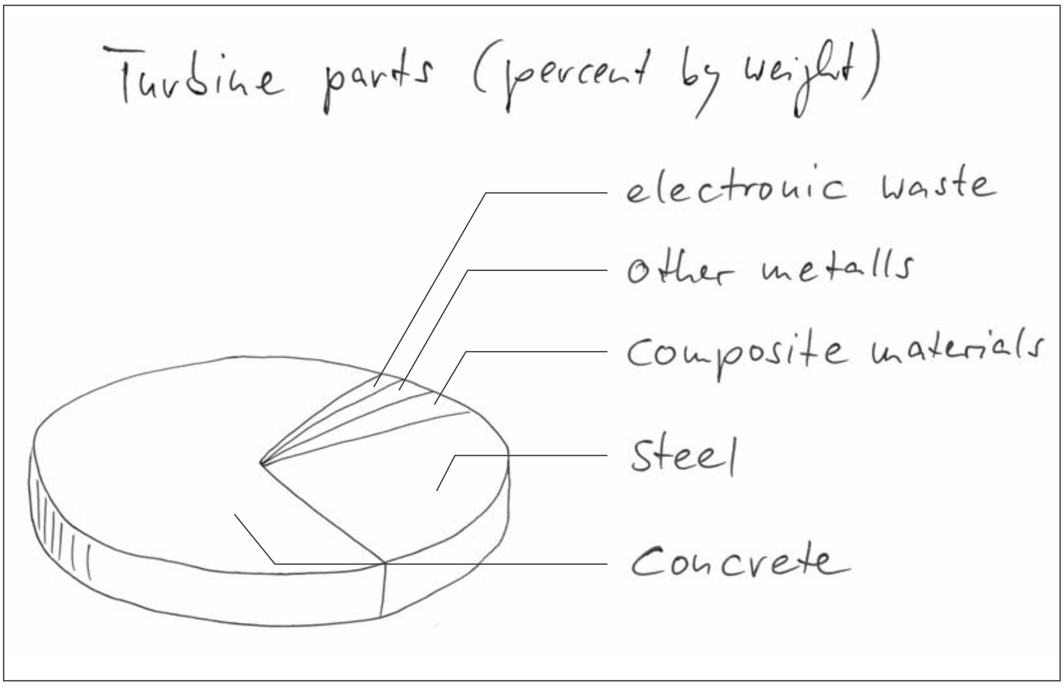


Figure: Mass percentages as rough estimation; different conditions may occur, depending on turbine type, hub height and tower type.

step. The disassembled component groups reach the ground nearly without destructions. Component groups that cannot be reused are dissected into smaller pieces for easier transportation. This applies mainly for conical steel tower, rotor blades and nacelle cover. If the foundation has to be recovered, it has to be put into pieces, too, and separated from the welded steel components.

Wind turbines consist of more than 90% concrete and steel which can be recycled with proven technologies. Steel components are completely reused as scrap, concrete is turned into gravel. Other metals, such as copper or aluminium, which occur – compared to the total amount – in small shares are treasured raw materials, too.

When disposing electronic waste, that contains poisonous substances, and consumables like oils and greases proven recycling structures can be used.

Only about 3% of the building are composite materials, which are mainly used for rotor blades and nacelle covers. Still, they are the largest problem for the operator when disposing the turbines these days. Here, for instance, extensive safety measures have to be taken when cutting fiber materials as the pulp that may occur during this process can be inhaled and cause long-term physical injuries of human beings or animals, similar to asbestos.

Components made of glass fibre or carbon fibre reinforced plastics are mostly temporarily stored these days due to a lack of applicable technologies. Final depositions on dumps are forbidden in some country because of the material composition. An application from the cement industry referred to under the keyword Geocycle offers a disposal perspective. The composite materials are first use as fuel for production. The silicon enriched ashes are added to the cement.

The thermal use of rotor blades and other components made of GFP has the still best application opportunities these days; the caloric value is half as high as those of hard coal. Still, melted glass tends to stick the components together in the combustion space during the glass fiber reinforced plastic burning.

A total rotor blade mount of 50,000 tons is expected for the year 2020 globally.

Foundations of offshore turbines are expected to remain in the sea bead after the end of the turbine life-cycle as long as they do not cause risks for shipping. As artificial reefs, some of them bring even positive aspects for marine habitats, increasing the variety of marine species.

Hydropower

Life-cycle challenges

Although hydroelectric power plants are widely accepted alternative to fossil-fuels based technologies, they can be also a source of greenhouse gases during the whole lifecycle. The construction of dam involves use of steel and concrete which, in turn, involves emission of carbon dioxide. During operation, there is a flooding of biomass, and during decommissioning there is an enhanced mineralization of carbon in sediments, which all has some carbon footprint. These processes are more described in details in further chapters, with focus made on measures that shall be taken to lessen them.

The exact emission depends on site-specific characteristics. However, current estimates suggest that life-cycle emissions can be over 0.5 pounds of carbon dioxide equivalent per kilowatt hours. In contrast, estimates of life-cycle global warming emissions for natural gas generated electricity are between 0.6 and 2 pounds of carbon dioxide equivalent per kilowatt-hour and estimates for coal-generated electricity are 1.4 and 3.6 pounds of carbon dioxide equivalent per kilowatt-hour.

Organic material enters the reservoir together with rain during spring and settles to the bottom. When summer comes, thermal stratification of the reservoir forms a surface layer of less dense, warm water where levels of dissolved oxygen are relatively high. The dissolved oxygen in the colder water on the bottom layer reacts with the organic sediments, what leads to its depletion. Hydro-turbine intakes typically withdraw water from this oxygen-depleted layer, which is a reason of low DO levels in the

> In many hydropower reservoirs, the problem of low dissolved oxygen (DO) levels occurs, which is potentially harmful to aquatic life.

water released from the turbine. Low dissolved oxygen levels are potentially harmful to aquatic life. In order to combat the problem, it is important to select the site which does not favor the loss of dissolved oxygen and to apply aeration technologies in turbine systems.

There are many dams and reservoirs around the world, where sedimentation has reached a stage where adequate power generation is no longer possible. Apart from problems with efficiency, projects with moderate to heavy amounts of organic sediments face problems with low dissolved oxygen in reservoir releases. Again, the best solution to manage the problem is firstly, a proper spatial planning of the facility and secondly, appliance of one adequate infrastructure, equipment or soil conservation measures.

Hydropower can have serious negative consequences on fishes.

Dams act as a barrier to migration of organisms, and they also affect water temperature and silt build-up in downstream river stretches. Turbines can also produce serious injuries to these organisms, and is a reason to fish kill. From that reason, fish species and their migration routes should be carefully investigated prior to the investment. The constructed facility should have a fishway or other infrastructure which allows undisturbed migration. These and other practices are described more widely in further chapters.

It should be noticed also, that not only fish species are affected. In flat basins large dams cause flooding of large tracts of land, destroying local animals and habitats.

Spatial planning: What to consider when choosing the location for a hydropower station?

First step of the spatial planning should be a preliminary site assessment to indicate whether a site is worth considering further. Second step is a feasibility study that uses accurate data and looks closely at costs. Tasks that should form components of a feasibility study are hydrological survey, system design, system costing and estimate of energy output and annual revenue. As far as the selection of the adequate site is considered, crucial aspects are its natural conditions and legal access limitations.

Natural conditions

Hydropower is extremely site dependent. First of all, a sufficient stream flow is required, and secondly, the topographic conditions of the site which allow for the gradual descent of the river giving sufficient head for power generation. When a site has been identified as topographically suitable for hydropower, next task is to investigate the availability of an adequate water supply. For a watercourse, where observations of discharge over a long period are not available, it involves work of hydrologists, the study of rainfall and stream flow, the measurement of drainage basins, catchment areas, evapotranspiration and surface geology. At this early stage of investment, it should not be forgotten to take into consideration measures to reduce further environmental problems, such as greenhouse gases emission, oxygen loss, sedimentation and impact on fishes.

Measures to reduce carbon footprint

Factors which determine the amount of greenhouse gases (GHG) released during anaerobic decay of flooded biomass, are, among others, amount of flooded vegetation cover, soil type, water depth, and climate. Life-cycle emissions from large-scale hydroelectric plants built in semi-arid regions are modest: approximately 0.06 pounds of CO2eq/kWhe, but in tropical areas or temperate peatlands these indicators are much higher. According to studies carried out by Bauer in Europe, these releases can vary considerably depending on the specific GHG releasing characteristics and are in the range between 0.35 g CO2eq/kWhe for reservoirs in the alpine region and on average 30g CO2eq/kWhe for reservoirs in Finland, although peat soils are believed to have higher GHG releases.

Measures to reduce oxygen loss

Most often, hydropower plants which experience problems with low dissolved oxygen are these with reservoir depth greater than 50 feet and a retention time greater than 10 days. Also other factors, such as terrain, size and type of watershed, seasonal temperature variations, intensity and frequency of rainfall and amount of inflow affect the DO levels in hydropower releases. In general, these include plants where watersheds yield moderate to heavy amounts of organic sediments and where, because of climate conditions, thermal stratification isolates bottom water from oxygen-rich surface water.

In the bottom layer, organisms and substances in the water and sediments consume and lower the dissolved oxygen.

Measures to reduce sedimentation

There are many dams and reservoirs around the world, where sedimentation has reached such a stage that adequate power generation is no longer possible. Apart from problems with efficiency, projects with moderate to heavy amounts of organic sediments face problems with low dissolved oxygen in reservoir releases. Again, the best solution to manage the problem is firstly, a proper spatial planning of the facility and secondly, appliance of one adequate infrastructure, equipment or soil conservation measures.

Measures to reduce impact on fishes

Each water body is characterized by different fish species of different migratory routes. When a site is selected, it is important to estimate fish biomass and biodiversity losses in numerous damming scenarios using an ecological model of fish migration.

Legal aspects and environmental impact

Hydropower project, like any other, can proceed only when one has the right to utilize all the land in question. It is also crucial to establish access routes for staff and necessary equipment. It should be remembered that water courses often form property boundaries, therefore the ownership of the banks and existing structures may be complex. Additionally, when hydropower plant is constructed on protected areas, it is necessary to consider if planned investment may have a significant impact on ecosystem of Nature 2000. This is also so called EU's eel directive, according to which all member countries have to take measures that allow 40% of adult eels to escape from inland waters to the sea, where they can spawn. One of the proposed actions is making it easier for fish to migrate through the rivers.

Construction and installation

What type of power plant?

There are several types of hydroelectric plants in use. The most typical are:

Impoundment/reservoir hydroelectric plant

This plant uses a dam to store river water in a reservoir. Released water feeds the turbine activating a generator to produce electricity. The water is released either to meet changing electricity demands or to maintain a constant reservoir level.

Pumped storage hydroelectric (PSH) plant

This is an impoundment plant with pumped storage feature. The system incorporates two reservoirs, lower and upper. During off-peak hours (e.g. at night) the electricity is relatively inexpensive so it is used to pump water from the lower to the upper basin. At a time when demand is high, this water is released to create power at higher price.

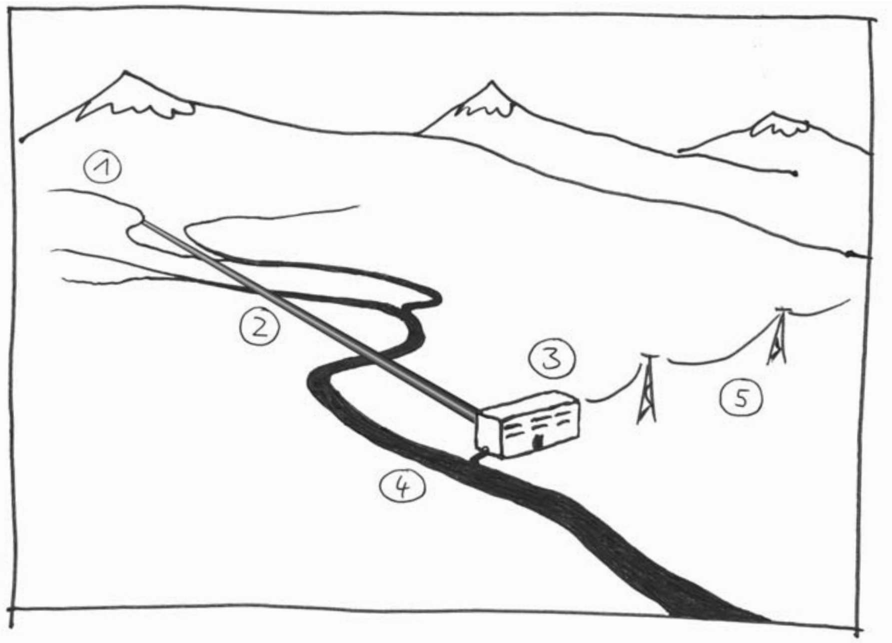
Run-of-river (ROR) hydroelectric plant,

which is also called diversion or streaming hydroelectric plant. It operates without dam or resevoir, hence provides no storage of water. In this system, some of the water of the stream is diverted upstream through a pipeline (penstock). It passes through a turbine to generate electricity and then reenters the original stream.

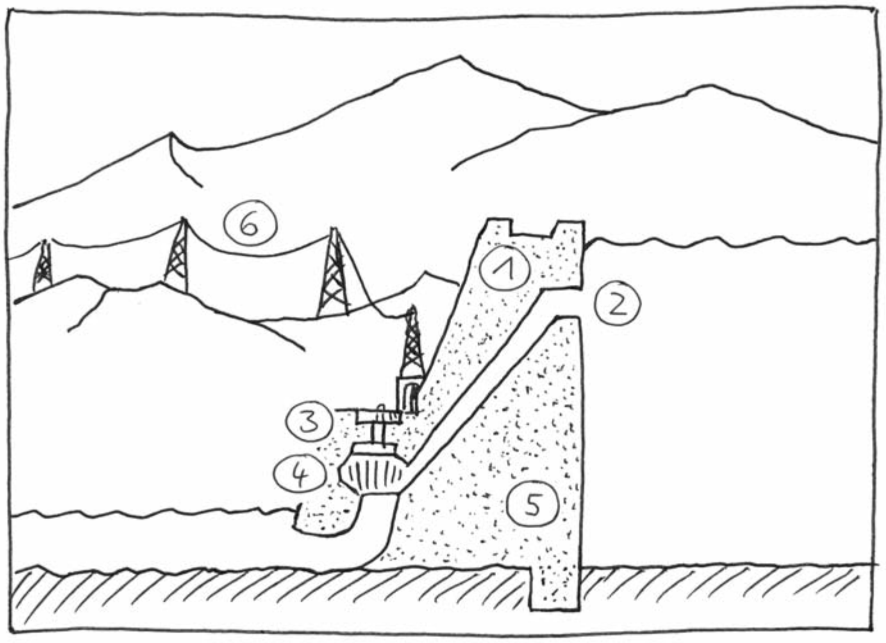
The PSH facility requires suitable terrains with significant head between the two reservoirs and significant amount of water resource. On the other hand, ROR plants must be built on a river with a consistent and steady flow.

Application of each type of power plant depends highly on natural conditions.

One important drawback of ROR hydroelectric power scheme, is that it is not adjusted to consumer demands. As these projects has little or no capacity for energy storage, much more power is generated e.g. during spring freshet than in drier summer



1 Weir: *small pond required to keep penstock*
2 Penstock: *steel pipe (usually bunded) drops water to the powerhouse*
3 Powerhouse: *house turbines and power generation unit*
4 Tailrace: *water returned to source*
5 Transmission lines



1 Dam: *stores water*
2 Penstock: *carries water to the turbines*
3 Generators: *rotated by the turbines to generate electricity*
4 Turbines: *turned by the force of the water on their blades*
5 Cross section *of conventional hydropower facility that uses an impoundment dam*
6 Transmission lines: *conduct electricity, ultimately to homes and business*

months. Impoundment, and especially pump-storage hydroelectricity, is very good for improving overall energy efficiency.

PSH, however, has a lot of other drawbacks from environmental perspective. Pumping may increase the water temperature, which implicates the oxygen loss, and stir up sediments at the bottom of the reservoirs which deteriorates water quality. Operations involved in energy production from PSH plant may also trap and kill fish. The less disruptive option to the natural state of a river and aquatic ecosystem is the ROR plant, because it does not change the natural course of the stream. Moreover, the important feature of ROR plant is lack of reservoir, which would impound and flood large tracts of land. In consequence, there is no need to reallocate people living at or near the river, the terrestrial wildlife habitats are not destroyed and the landscape is not significantly changed.

There are technologies to mitigate the ecological impact on fishes and other species and to compensate for the potential oxygen loss which will be discussed in further chapters. In some cases, the PHS system may stabilize water level and maintain water quality. The potential impacts are always site-specific.

It should be taken into consideration as well, that PSH plant relay on electricity. Thus, it cannot be considered a renewable energy. Moreover, storage schemes in general have a higher footprint, than run-of-river schemes as they require large amounts of raw materials, such as steel and concrete to construct the dam. Another contribution to greenhouse gases emission of hydropower plants that use reservoirs is related to flooding of biomass and soil. This is because the flooded biomass decays aerobically (producing carbon dioxide) and anaerobically (producing both, carbon dioxide and methane).

When the reservoir is dammed, water flow velocity decreases within it, which allows increased particle deposition. Accumulated sediments contain noticeable levels of carbon which may be released to the atmosphere during the decommissioning phase. Moreover, the turbidity of water decreases which implicates increased light penetration, contributing to the fixation of carbon dioxide.

Another carbon footprint of hydropower plants with reservoirs is related to sediment build-up.

In results, greenhouse gases emission resulting from pumped storage, run-of-river and reservoir varies significantly. Carbon footprints for run-of-river schemes are estimated as lower than 5gCO2 eq/kWh, whereas for storage schemes as for ~10-30gCO2eq/kWh. From the life-cycle assessment perspective, it is therefore crucial that emission factors and impact on hydrological regime are not ignored when considering construction and relicensing of hydroelectric dams.

What capacity should be installed?

The installed power is a function of the flow volume and the head of the power plant. Therefore, one of important classification of hydroelectric power plants is based on its sizes, and consequently on capacity installed.

Category of hydroelectric power plant	Capacity installed
Large	> 30 MW
Small	0.1 – 30 MW
Micro	< 0.1 MW

Table: Classification of hydroelectric power plants based on their sizes

The diagram below shows a plot of the 100 year sediment volume versus the installed power capacity of the analyzed reservoirs in United States. Sediment yield correlates with the size of the drainage basin. However the installed power of hydroelectric plants has a direct relationship with the amount of sediments trapped behind the dams.

As the accumulation of sediments in reservoirs depends on the installed capacity, one way to minimize greenhouse gases emission might be installation of a chain of smaller power plants on the same river instead of one larger hydroelectric plant. In addition, because small hydroelectric plants trap less sediment, it is easier to lessen sediments accumulation by flushing smaller sediment amounts downstream. Therefore, instead of becoming a carbon source, sediments return to the stream flow and reach the ocean, which constitutes the ultimate global carbon sink.

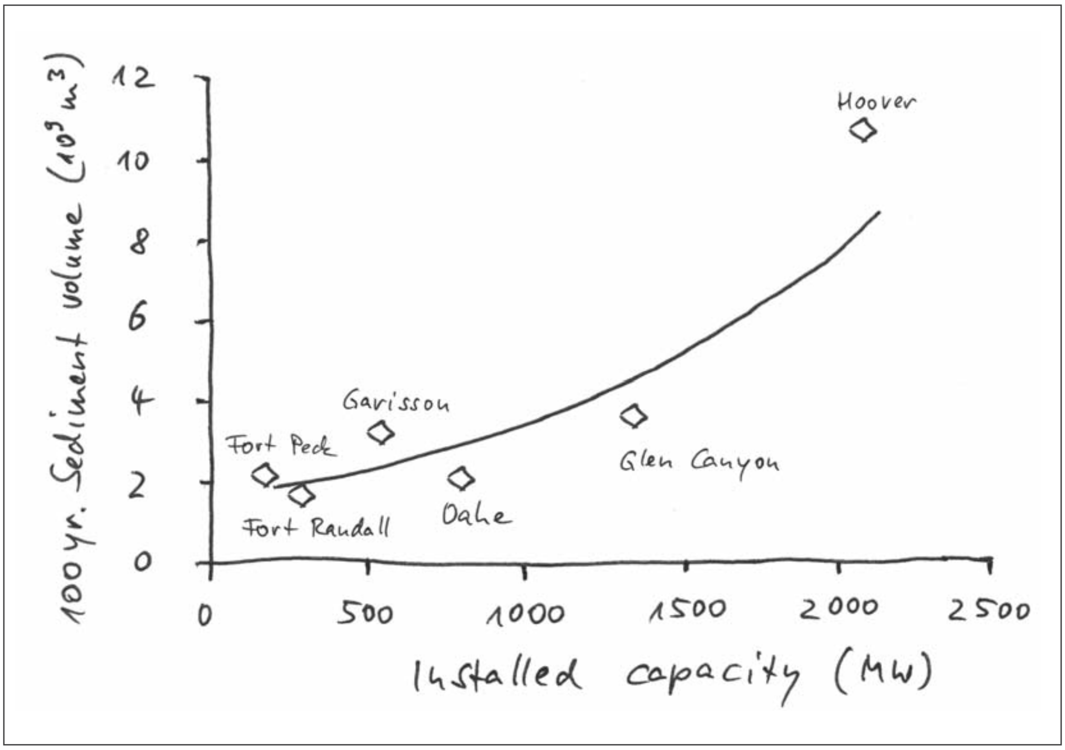


Figure: Sediment volume in six of the ten largest United States hydroelectric power plants after 100 years versus installed capacity

It should be remembered also that one of the feature that correlates with high oxygen losses in a river body, apart from climate condition, depth of the reservoir and the retention time, is power capacity. Hydroelectric plants likely to experience these problems include those with power capacity greater than 10 MW.

What type of turbine shall be installed?

The selection of the turbine depends upon the site characteristics, principally the head and flow available, plus the desired running speed of the generator and whether the turbine will be expected to operate in reduced flow conditions. However, hydroelectric schemes can be divided into three basic categories, based on head applied, which correspond with use of specific type of turbine.

According to the literature, most of the hydropower plants experiencing problems with low dissolved oxygen have Francis turbines. It is believed that the most cost-effective solution to increase the downstream DO level is to use some form of Francis turbine aeration.

Category of hydroelectric scheme	Head used in the scheme [m]	Types of turbine usually associated with the scheme
low head	5 – 25	Kaplan
medium head	25 – 50	Francis or Crossflow
high head	50 – 150	Francis
high head	>100 ?	Pelton

Types of turbine usually associated with specific head schemes

Turbine operation creates a potential hazard to fish species. Once a fish enters a turbine system it is subjected to changes in physical geometry and flow characteristics that, in certain zones along the path, can be injurious. The overview below schematically shows the damaging zones within a turbine system.

Potential causes of stress and injury to fish are, in general, mechanical (strike, abrasion, and grinding) and related to flow characteristics (pressure fluctuations, shear stress, turbulence and cavitation). It is,

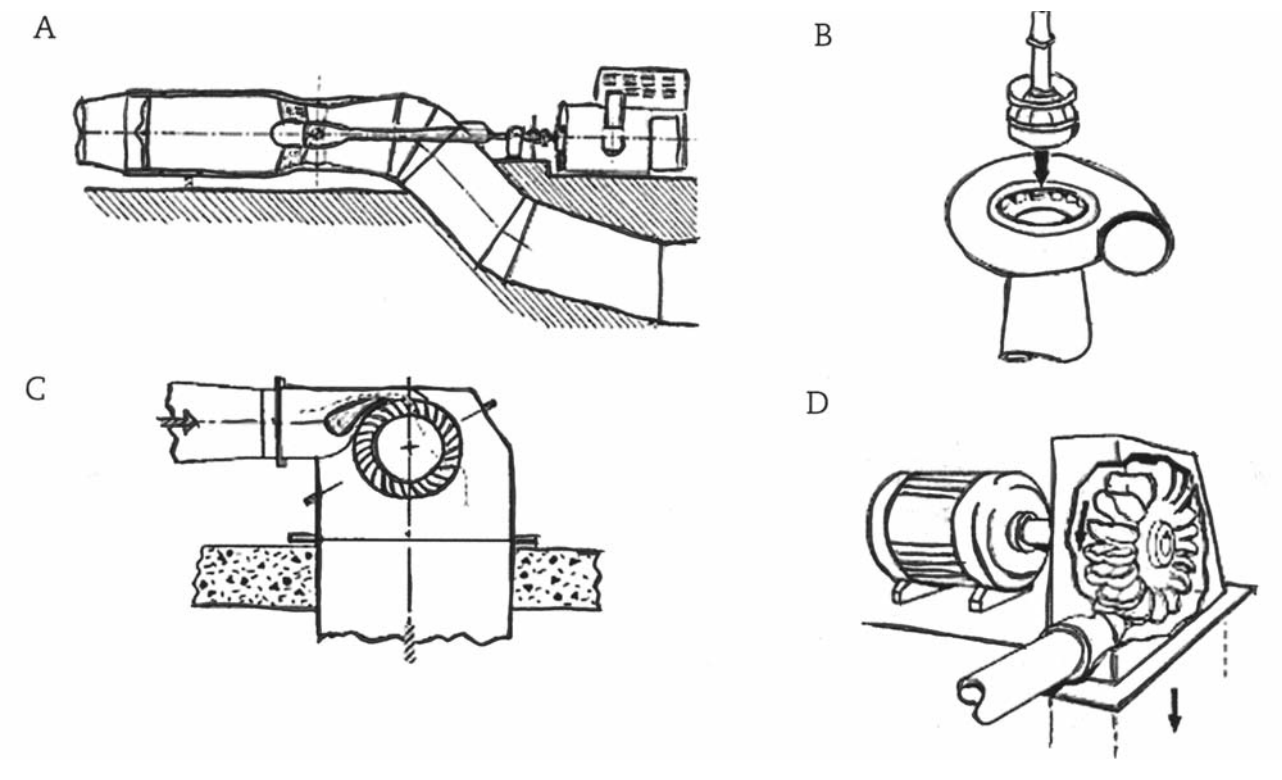


Figure: Typical water turbines: A) Kaplan, B) Francis (spiral-case), C) Crossflow, D) Pelton therefore, understandable that the survival of the fish passing through a turbine is not only dependent on the environmental setting of the facility and fish species, but also on the type and size of the turbine, and its mode of operation.

Highly important features of turbine for the fish survival are gap sizes, runner blade angles, wicket gate openings and overhang, and water passageway flow patterns. The reason of high fish mortality may be the basic design of some small, Pelton-type turbines operating in high-head installations. The water is directed onto clamshell buckets mounted on the periphery of the impeller wheel in order to impart a torque on the impeller. High rotating speeds and tight voids are not conducive to fish survival. On the other hand, the survival of

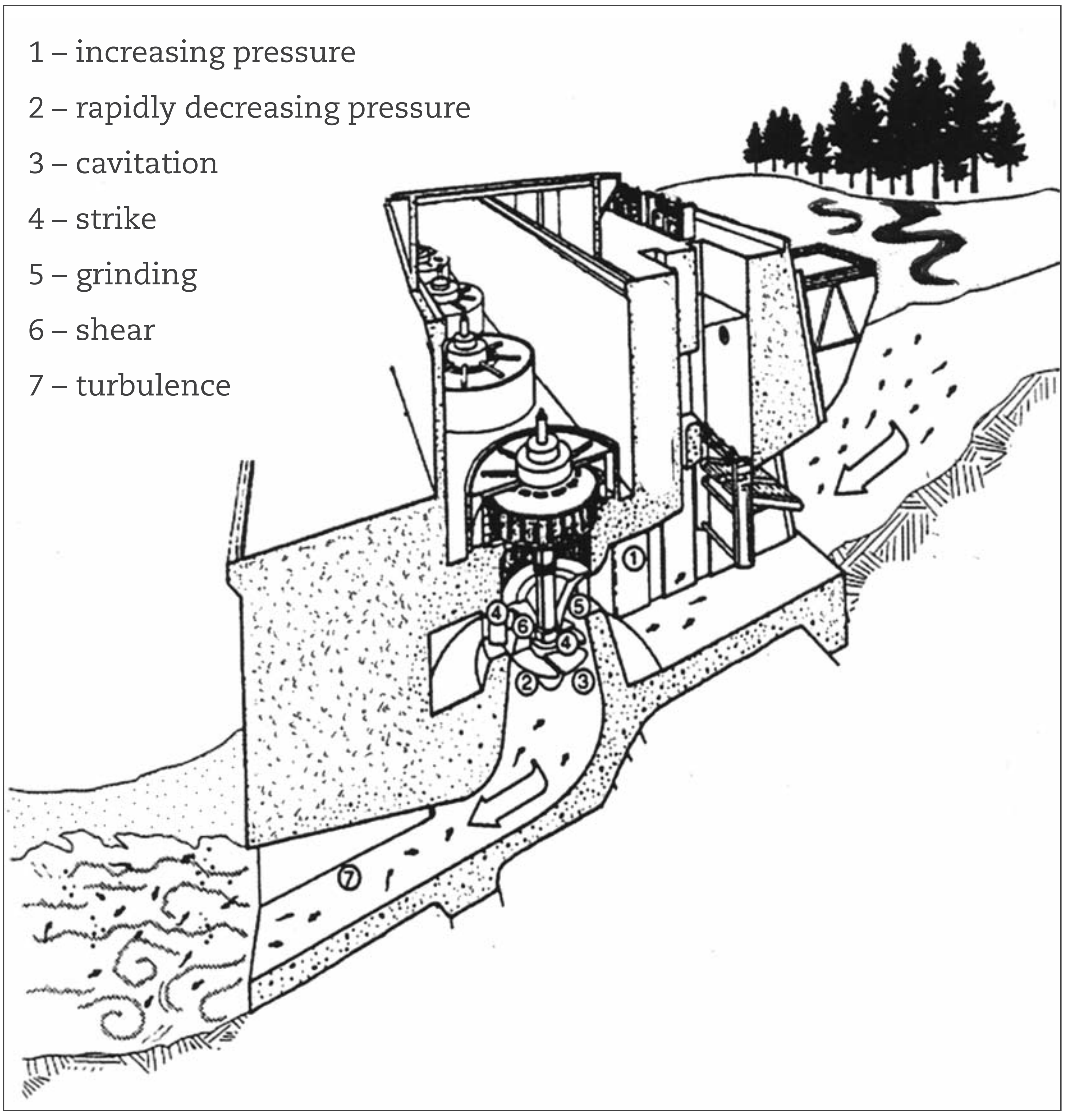


Figure: Schematic diagram showing locations within a turbine system where fish injury mechanisms are believed to occur.

small fish encountering turbine types with larges clearances, such as Kaplan or Francis, is also low.

Considering that rate of change of pressure is harmful for some fish species, it should be highlighted that high head turbines are, most often, smaller units and have a high rate of pressure change per unit time, whereas low head turbines are typically large units and are characterized by a lower rate of pressure change per unit time. As far as the turbulent shear stress is concerned, some Kaplan turbines have gaps near wicket gates and runner blades, and leakages from these as well as non-optimal turbine operation implicate production of vortices with high shear stress zones. Vortices in the draft tube may also cause shear stress damage to fish in Francis turbines. Continuously, there are investigations carried out in order to design a more "fish-friendly" turbine.

How to facilitate fish migration?

There are several measures to lessen the negative impact of hydropower installations on fishes. Fishways (water passages) are built as a by-pass of the hydro-plant so that fish can migrate up or downstream. To allow fish to pass upstream so-called 'fish ladders' are constructed. These are series of pools one above the other, so that fish can jump up from one to another.

One way of excluding fishes from intakes is screening mesh fine enough so that small fishes are not ingested into the turbine.

These screens have to guide fish towards a water passage, which is often placed diagonally to the flow, with the bypass in the downstream part of the screen. Uniform velocities and optimal currents upstream of screens must be provided to effectively guide fish towards the fishway.

In order to avoid fish impingement, sufficient screen area must be provided to create low flow velocities. Physical screens can be made of various materials: perforated plates, metal bars, wedgewire, plastic or metal mesh. A fine-meshed screen will accumulate large volumes of debris, therefore an automatic cleaner becomes essential to keep the turbine running. Physical screens cause obstruction of the flow, therefore there are other methods of deterring fishes called "behavioral barriers", such as electrical fields, bubble curtains and sound waves.

Figure: Fishway in Grzybowski Mlyn (Poland)

How to mitigate sedimentation?

Type of solution to over-sedimentation will depend on the individual project characteristics and the potential environmental impacts the remedial measures might cause to the river downstream. For these purpose, one may use equipment such as: drag line, dredging and hydro-suction. Other methods - soil conservation, bypass of incoming sediment and sediment diverting and sediment trapping, are described below.

Soil conservation

This is the strategy applied in the upstream watershed of a reservoir. It focuses on reducing sediment inflow to dam reservoir. Three basic patterns are:

<u>Structural measures:</u>

_ terraced farmlands,
_ flood interception and diversion works,
_ gully head protection works,

_ bank protection works,
_ check dams,
_ silt trapping dams;

Vegetative measures:

_ growing soil and water conservation forests,
_ closing off hillsides,
_ reforestation;

Tillage practice:

_ contour farming,
_ ridge and furrow farming,
_ pit planting,
_ rotation cropping of grain and grass,
_ deep ploughing,
_ intercropping and interplanting,
_ no-tillage farming.

For a large watershed with poor natural conditions, this strategy can hardly be effective in the short term.

Bypass of incoming sediment and sediment diverting

Reduction of sediment by constructing flood bypass tunnels going around a reservoir is a common practice. Where possible, the bypassed flows may be used for warping. Sediment diverting can also be used downstream from dams when hyperconcentrated flow is flushed out of reservoirs.

Sediment traps

In order to prevent the entrance of suspended sediment transport, special traps are constructed downstream of an intake. Their role is to diminish the flow velocities and turbulence. In result, a decantation of suspended sediments occurs in the trap. This diminishing is obtained by an enlargement of the canal, controlled by a downstream weir.

Core process

How to maintain good quality of water?

Major measures taken to improve water quality in reservoirs and downstream areas are:

_ Temperature control considering the growth of fish by installation of selective water intake facilities;
_ Reduction of abnormal odour or taste of the water in reservoirs by installation of full thickness aeration and circulation facilities;
_ Reduction of outbreak of red tide in reservoirs by development of fresh water red tide treatment vessels;
_ Treatment of heavy metals discharged from copper mines located upstream of dam.

How to mitigate oxygen loss?

Improved hydraulic design of a turbine allows for providing air into the turbine as a way of increasing the downstream dissolved oxygen (DO) level. For turbines with aeration systems it is crucial to monitor trends for air flows under similar operating conditions to detect aeration system problems.

Decommissioning

Dams are not eternal structures and various problems may arise that result in a decision of removing the hydroelectric plant. The reasons of decommissioning are typically:

_ aging of dam structure and reservoir sedimentation,
_ safety (breaching, drowning, liability),
_ economics (loss of original purpose or economic value, high costs of maintenance),
_ excessively high environmental impact.

Decommissioning includes activities such as: breaking up of concrete pads, foundations, intake and tailrace structures, and dams as well as removal of access roads that are not maintained for other uses; re-contouring the land surface; and re-vegetation .

Measures to mitigate carbon footprint and other emissions

After dam demolishment, the options are to allow sediments to travel downstream, to dredge or otherwise control sediments, or to leave sediments in place. When reservoirs are drained, the amount of solar radiation transferred and absorbed increases as a result of the shallower water table. In consequence the substrate temperature also increases and more mineralization of soil organic carbon (SOC) occurs.

That means increased rate of carbon release from sediments in the form of carbon dioxide and methane (greenhouse gases).

It should be taken into consideration that there are numerous emissions from decommissioning activities that should be reduced as much as possible. They include:

_ Vehicle tailpipe emissions, diesel emissions from large equipment and generators ,
_ Fugitive dust from many sources such as land clearing, structure removal, backfilling, dumping, restoration of disturbed areas (e.g. grading, seeding, planting), truck and equipment traffic.

Measures to mitigate impact on water quality

Decommissioning involves activities that cause soil erosion and weathering of newly exposed soils. These results in leaching and oxidation that could release chemicals into the water, discharges of waste or sanitary water, presence of dissolved salts from untreated groundwater used to control fugitive dust, and pesticide applications. In order to minimize the potential for soil erosion, disturbed areas ought to be contoured and re-vegetated.

Measures to mitigate impact of hazardous materials and waste

The removal of the facility will certainly involve large amounts of waste produced. It should be remembered, however, that e.g., concrete and masonry, steel, power cable, and pipelines could be recycled and sold as scrap or used in road building or bank re-stabilization projects. Industrial wastes, such as lubricating oils, hydraulic fluids, heat transfer fluids, dielectric fluids, coolants, solvents, and cleaning agents should be properly handled and not released to the environment.

Measures to mitigate impact on ecological resources

After removal of an impoundment, land should be reclaimed. Grasses and forbs may initially be more plentiful than existed after the project development. This could increase forage for some wildlife species. Reclamation of forest or sagebrush habitats could take decades or longer and requires significant effort.

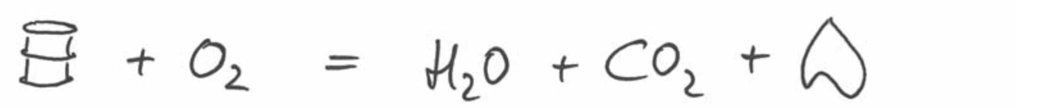
Biomass

Supply chain aspects for Biomass

The energy contained in a biofuel was originally stored by photosynthesis and is latent in the form of energy-rich chemical compounds.

Viewing the photosynthesis qualitatively as:

one may regard the re-extraction of the bound energy as a reverse photosynthesis:



This is indeed the over-all process but to run this process in an efficient way so as to economize with the natural resources and not produce too much emission on the way, some more things have to be considered.

The first thing is that the heat energy released from the combustion process is, in itself and in most cases, not desired. The aim with the energy extraction process is usually not limited only to produce hot flue gases but to produce either an energy carrier such as electricity, district heating or maybe a fuel aimed for transportation or to actually deliver an energy service of some kind. Sometimes, these demands require that the biomass is transformed from its original state and turned into a fuel that is better suited for the final process demands than the original biomass.

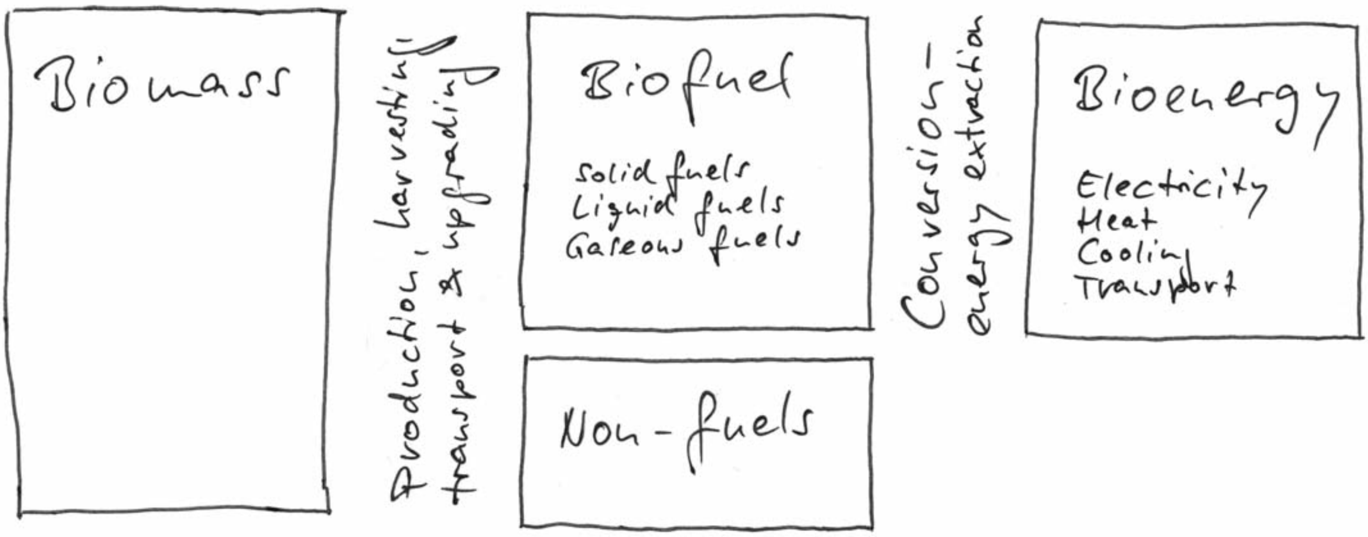


Figure: Terminology according to EN 14588

Biomass can be of different origins

Biofuel can be solid, liquid or gaseous and is simply a fuel produced directly or indirectly from biomass

Bioenergy is energy from biomass. Hence, an energy carrier such as electricity produced in a power plant firing bio-methanol may, but is usually not, be called bio-electricity.

Energy carriers are commercial products such as biofuel, electricity, steam, district-heating water or alike used to transport energy from a producer to an end-user.

Energy services are what the customer, the end-user, ultimately wants. Energy services can be of many different kinds such as mechanical work (i.e. a moving car or to run an air compressor), thermal energy (i.e. heat for cooking, for climate control or for high temperature processes such as glass melting), light (for illumination or for laser-cutting) etc. The energy service desired puts demands on the energy carrier which puts demand on the energy conversion from the fuel to the energy carrier and may, ultimately, put demands on the fuel as such.

The process best suited in a local or regional context will be completely determined by the state of the biomass available and by the energy service ultimately required. There are a huge number of different process options to provide biofuel of different qualities but to summarize, the following table may suffice.

Biomass	Fuel		Examples of processes involved
Solid	Solid	Energy	Drying/Comminution/Compaction/Torrefaction …
Solid	Liquid	Energy	Liquefaction/Gasification + chemical synthesis
Solid	Gaseous	Energy	Thermal gasification + gas upgrading/Landfill gas
Liquid	Liquid	Energy	Esterification (FAME, diesel substitute)
Sludge	Liquid	Energy	Fermentation (alcohol/ethanol, gasoline substitute)
Sludge	Gaseous	Energy	Anaerobic digestion (biogas, biomethane)

Table: Summary of available process chains for biomass-to-energy

As seen from the summary table, regardless of the actual state of the biomass, the biofuel can be gaseous, liquid or solid, thereby being more or less suitable for a number of different processes. Again – with no ambition to present a full list – one may summarize the suitability of different fuels for different final uses:

Fuel	Well aimed for
Solid, low heating value, high ash content	District heating (DH)/Steam cycle electricity (SSE)
Solid, low heating value, low ash content	DH/SSE
Solid, high heating value, high ash content	DH/SSE/Cement kilns
Solid, high heating value, low ash content	Individual house heating (pellets)
Liquid, low heating value (dilute alcohol etc)	Additional or stand-alone fuel in DH/SSE
Liquid, high heating value, clean	Transportation (FAME/Ethanol)/Industry
Gaseous, low heating value	Additional or stand-alone in DH/SSE/Industry
Gaseous, high heating value	Transportation/Industry/Combined-cycle

Table: Summary of available process chains for biomass-to-energy

The processes listed below are by no means complete. Just some examples:

_ FAME (fatty acid methyl esters) may be used to replace diesel oil in car engines but may just as well replace the use of light fuel oil in most any industrial process, such as glass production, but also in combined-cycle electricity production. Ethanol can be used in the same way, and so can purified bio-methane.
_ A solid biofuel with sufficiently high heating value – provided it is suitable for milling – can be used for co-firing with pulverized coal in most any coal-fired power plant.
_ Low heating value and contaminated gas, such as landfill gas, can be used in a stationary internal combustion engine – provided the engine is modified to suit the gas quality – for local combined heat-and-power production. The same thing applies to non-upgraded biogas from an anaerobic digester.

Hence the table is only to introduce the variety in uses and to illustrate that biofuel can be used in any scales from individual house heating to large scale industrial high-temperature applications.

From the above, it becomes natural to separate the supply chain into two parts: Biomass supply and Fuel preparation.

Biomass supply compared to fossil fuel supply

One of the main differences between biomass and fossil materials is the simple fact that biomass remains a biologically living matter and it is also chemically active throughout the supply chain, while fossil fuels may be considered biologically inert. This will affect the risks during handling and storing and becomes manifest in the facts that biomass will deteriorate during storage because of biological activity while – at the same time – allergenic spores may accumulate in the fuel.

The biological activity will alter the composition of the material and will also have an influence on the moisture distribution in the piles of material. If stored in closed compartments the biological activity may deplete the air of oxygen causing an acute risk for suffocation in cases where the compartment is entered. Product gases from the deterioration may also be poisonous like carbon monoxide or hydrogen sulphide or explosive, like methane. The temperature rise caused by the biological activity may also, ultimately, trigger self-ignition.

The self-ignition process in biomass piles is not understood in detail but generally speaking it is believed that the initial phases are due to biological activity followed and partially acting in parallel with chemical, heat-releasing reactions.

With fossil fuels, there is also a risk for auto-ignition, especially in the case of coal storage, but in these cases the main cause is rather because of chemical reactions than of biological activity. Similarly, the emanation of hazardous gases from storage of fossil fuels is believed to be the result primarily of chemical reactions rather than of biological activity.

The second major difference between fossil fuels and biomass aimed for energy is the concentration at the point of origin, the location where it is exploited. For fossil fuels, the point of extraction is solely determined by the concentration and by the simple fact that the concentration is high enough to make production economically feasible. Hence, fossil fuels are, per definition, produced only at such locale where they are concentrated, be that at sea, in a desert or wherever.

The production of biomass for energy purposes is more complex since it may be – and today often is – part of a local or regional policy. So the production of biomass for energy may be part of a social policy to abate unemployment in a rural area, it may be part of a system to solve a major waste handling problem in an urban area, it may provide an extra income for a forest owner or it may be subsidized to stimulate a transformation of local or regional agriculture from one type of production into another.

Summary

Currently, resulting from the first decades of the 2000's, when there was a rapid expansion of biomass use for energy purposes in countries and areas where the large-scale bioenergy production and use has no tradition, there are many examples worldwide when biomass aimed for energy production is produced in ways that are not economical in the long run.

Still, there are also examples where the urge for profitable biofuel production have led to the establishment of monocultures of crops for energy production which may well put the biological diversity at risk and may hence not be ecologically sustainable. And there are even examples when cultivation of energy crops has replaced cultivation of food and/or fibre crops.

Consequently, it is not necessarily so that the production of biomass for energy purposes is done under thorough consideration of its built-in limitations, but in some cases it may even be set in direct violation to the natural conditions and in these cases, usually at a significant cost.

Biomass supply – unit operations

Harvesting

Splitting the biomass into four major groups, forest and felling residues, residues from agriculture or aquaculture, residues from industrial processes and societal waste streams, one readily realizes that the former two fractions have many properties in common and so do the latter two.

For the first two groups, the solid biomass/fuel is a side-product to a utility that was already produced before, and the "harvesting" in such cases is a question of collecting something that was (in the case of straw, for example) or was not (in the case if thin branches at a felling site, for example) previously collected. From a logistic point of view this may then involve an additional operation on-site and it may even involve additional machinery.

In case of a combined harvester collecting and baling the straw simultaneous to threshing, the selling of the straw to an energy plant causes no extra cost as compared to any other use of it. There may be a hidden cost, though, because the farmer may have to replace the straw with some other, commercial, product for internal use at the farm. In this case, the additional logistics are fundamentally nil

– while there still is an external cost that needs be considered since the side product originally had another use and the use for fuel is competing.

In aquaculture – as well as for some agricultural side-products – the competitive use may be one of great significance, like the use of algae or of press-cakes for fodder. This is mentioned only to make it clear that to understand the real cost for the harvested material, one has to understand and appreciate the different alternative uses.

In some cases may the collection of industrial residues for energy be highly automatized, like using pneumatic transport from the individual dust-bins below the cyclones at a joinery to get all the sawdust into one place. In other cases – such as the collection of putrescible fish rinsing from a food processing industry – the collection process may have to involve a change of the production logistics themselves.

The collection of clean societal and household waste fractions poses specific problems. For household waste, the quality, i.e. the cleanness, of the fuel fraction is completely determined by the separation obtained.

A good separation can be obtained in two ways: Either, responsibility is put onto the households to perform the separation or a designated sorting facility is established.

Transport

The transport of biomass is typically limited by the *energy* (bulk) *density*.

The lower the energy density, the less becomes the total amount of biomass energy that can be loaded on board a carrier (a railway car, a truck, a boat…) with a limited loading capacity as expressed in volume. And: The less the carrier capacity, the higher the transport cost.

> Energy density is energy content per volume, not to be confused by the heating value which is the energy content per weight.

However, transport of biomass is not only a question of cost but may also have a significant influence on the quality. Transport on dry dirt roads, and this is often the case as harvesting of agricultural products as well as of forest residues often occurs in dry weather and in rural areas, may significantly increase the ash content of the fuel because of road dust settling on the fuel. The problem is easily eliminated by covering the fuel by a tarpaulin during transport.

Drying

The heating value of biomass is determined by three factors independently,

_ The composition of the dry, ash-free substance and the its heating value $q_{NET,DAF}$
_ The ash content, weight fraction f_{ASH}, dry basis
_ The moisture (water) content, weight fraction f_W, wet basis

For most biomasses, the dry ash-free substance consist of cellulose ($q_{NET,DAF}$ = 16 MJ/kg), hemicellulose ($q_{NET,DAF}$ = 16 MJ/kg), lignin ($q_{NET,DAF}$ = 26 MJ/kg), extractives ($q_{NET,DAF}$ = 30-35 MJ/kg) and fatty acids ($q_{NET,DAF}$ = 30-35 MJ/kg) in variable proportions depending on the type of biomass. It is important to realize that the heating value of the dry ash-free substance cannot be accurately calculated by simply adding these values using the weight fractions as weighing factors but that such a simple addition will only give a rough estimate.

The table below – compiled from a number of sources – gives an indication of the expected heating values for a few different assortments of biomass.

Expanding the expression for the net (the lower) heating value of any biofuel with ash content f_{ASH} and moisture content f_W yields

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$$q_{NET} = q_{NET,DAF} \cdot (1 - f_{ASH} - f_W - f_W \cdot f_{ASH}) - 2.443 \cdot f_W \ \ MJ/kg$$

This equation reveals that the most important factor for the heating value is the moisture content.

The moisture content in biomass is of two different kinds. A fraction of the water is bound to the cell walls by hydrogen bonds while the water content exceeding this amount is present as free water contained in the cell cavities.

Agro-by-products	Woody biomass	Agro-industrial	Agrobiomass
Rape seed refuse	Bark	Extracted presscakes	Canary grass (*phalaris*)
27.5 – 28	19 – 21.5	20.5 – 21.5	18.5 – 19.5
Fruit kernels	Stem wood (*conifers*)	Press cakes (*olive*)	Straw
17.5 – 23	19 – 20	17.5 – 19	17.5 – 19.5
Corn refuse	Stem wood (*deciduous*)	Press cakes (*grape*)	Hay/*miscanthus*
17 – 18	18.5 – 19.5	16.5 – 17.5	18 – 19
Nutshells/rice husk	Poplar/*salix* (SRC[1])	Cotton spills	Cotton stalks
14.5 – 19	18.5 – 19	16.5 – 17.5	15.5 – 18

Table: Approximate values of $q_{NET,DAF}$, MJ/kg, for a few biomasses

Drying can be accomplished mainly in three different ways:

_ **Open-air drying** is the cheapest and simplest method. The biomass needs to be exposed to sun and air while, at the same time, it is protected from rain and from wet soil. Hence, the biomass must be piled in porous piles, oriented to be exposed to wind and sun but covered to be rain protected. This can be applied for such biomass fractions that lend themselves to build porous piles, such as tree branches or treetops, i.e. felling and forestry residues. For straw and some other types of agricultural side-products such as stalks, tops and haulm, the most common is to leave the material evenly distributed in the field for a few days. In favourable conditions and provided sufficient time, open-air drying may bring the biomass down to equilibrium with the surrounding atmosphere.

_ **Mechanical de-watering** can basically be accomplished either by centrifuging, a common method with sludge, or by mechanical pressing, often applied with wet bark and/or with some agricultural residues. What can be achieved via mechanical de-watering is typically limited by the mechanical energy input but for practical applications moisture contents after de-watering are usually still higher than 50%.

[1] *SRC – Short Rotation Coppice – is the term used when utility plants like wheat are replaced on agricultural land by fast-growing trees for energy purposes.*

_ **Forced drying** is the most expensive method requiring a forced draft of air to be supplied through the material. The material must be permeable to the air stream to avoid too high requirements of pressure with the fan and the air supplied can be at ambient temperature or at an elevated temperature. By forced drying, the final moisture content can be pre-determined and the drying process can be controlled.

If possible, and depending on the type of biomass, the supply chain should be planned to include open-air drying.

Comminution

Almost regardless of the process – be it combustion, gasification, digestion, fermentation or any other process – the solid biomass will need to be fragmented to enhance process performance. Fragmentation – for example of tree branches – will also radically increase the bulk density when the material is loaded on to a carrier and will hence improve transport economy as outlined above.

Different types of materials, as well as different demands on the final particle size, will require different types of equipment but without going into too much detail one may distinguish four major types of machinery commonly used.

_ **Chippers.** There are several different types of chippers but common to them is that they typically use sharp tools, “knives”, to cut the material into smaller pieces. The output from chippers is typically in the size range 5 – 50 mm. With some designs, the material is even coarser and the chippers producing such coarse fractions, chunks of material, are sometimes referred to as chunkers. Chippers are commonly used with relatively hard and coarse materials such as woody biomass. A well-designed chipping process may produce particles that are about equilateral so that the ratio between the tallest and the shortest measure of length, width and height is less than about 5. Equilateral particles will improve the performance with subsequent feeding of the particles into any type of reactors. The energy requirement for chipping is to a great extent depending on the shear strength of the material chipped.
_ **Shredders.** While the fragmentation principle of a chipper is usu-

ally that of cutting the principle of a shredder is rather to tear the material into longer or shorter strands or strips. Since the principle of a shredder is hence completely different from that of a chipper it is clear that the shredder will usually produce a material where the length of the particles is commonly much greater than any of the two cross-sectional measures. So particles will become needle-like. The energy requirement for shredding is strongly depending on the tensile strength of the material.

_ **Mills.** The most common type of mill in these applications is the hammer mill. In the hammer mill, fragmentation is obtained by rapid impact on the particles and the specific energy requirement will be strongly depending on the hardness of the material. The size of the product is determined by a sieve at the mill output and can be anything in the size range from 0.01 – 5 mm.

_ **Crushers.** Crushing is an operation in which particles are fragmented through a relatively slow compression process unlike the rapid impact occurring in hammer mills. Fragile and brittle materials, such as coal or coke, are commonly milled in ball mills or rod mills. In these types of mills the actual process is crushing. For some assortments of biomass where solid mineral contaminants may be present, demolition wood, stumps, formwork timber, crushing between blunt tools such as in a jaw breaker may be the best alternative. In case of co-firing biomass with coal and if the biofuel is delivered as pellets or briquettes the biomass may be milled together with coal in ball- or rod mills. The prerequisite for crushing to work is that the material is brittle.

It is obvious that the total energy requirement for comminution is not only depending on the material but also on the size reduction and on the construction.

Storage

Storing is an unavoidable step in any solid biomass supply chain.

The problems associated with storing do mainly come back to the fundamental fact that biomass is degradable. Degradation processes start the very moment the biomass is harvested and cannot – in general terms – be avoided. However, there are some factors that are advantageous to degradation and such factors should, as far as possible, be eliminated or at least avoided. Generally speaking one may distinguish two main routes for biodegradation:

_ **Aerobic degradation.** Aerobic degradation occurs when the biomass is readily accessible for molecular oxygen, i.e. air, and ultimately results in the biomass being completely converted to carbon dioxide and water vapour. In popular terms this process may also be called composting.
_ **Anaerobic degradation.** Anaerobic degradation may occur if the biomass store is depleted from oxygen because it is so compact as to prevent ventilation or if it is stored in a closed compartment.

For both processes to start, it is necessary that the simplest sugar compounds in the cell liquid are readily accessible for micro-organisms. This occurs once wet biomass is fragmented and hence it is true to say that the first condition to favour biodegradation during storage is to store fragmented and wet biomass.

Typically, both processes will start by mould fungi establishing in the material. Mould is tolerant to wide limits of humidity and oxygen and since mould spores are omnipresent, this establishment will occur within days after the biomass pile has been built. The types of mould may be different depending on the material stored and on the climatic zone, but they will be there.

To minimize degradation during storage it is important that the material is stored in such a form that promotes ventilation and minimizes the temperature increase inside the pile. For some types of biomass, such as tree branches, this is easy to accomplish simply by storing the material in its original form. For other types of biomass – such as maize leaves – a porous pile cannot be established unless some type of scaffolding is erected.

Some types of biomass, such as household waste, are best stored in air-tight plastic bags resembling those used for silage.

This reduces the possibility for aerobic degradation and also minimizes the risks for malodour spreading and also keeps rodents under control.

In case high porosity cannot be obtained, the piles will instead have to be low enough that natural draught can be established through them. For agricultural residues this height is only a few meters, 1-

3 m at the most, and the storage will require a large land area. For wet wood chips, mixed fractions including bark, may the height be up to 6-7 m while for pure stem-wood chips the height may be up to 15 m. Shredded wet bark, which will form compact piles, may only be stacked up to about 3-4 m, just like most agro-residues.

While a proper storage may exhibit losses of combustible material – i.e. of the total energy content – less than 1% per month an improper storage may lead to total losses in the order of magnitude 10% per month or even more.

Homogenization

Regardless of how well the supply chain may be designed there will always be a need of short-time storage near to the energy plant. As pointed out in the previous text section, this short-time storage should best be designed so as to keep different assortments separate. But the process – be it combustion, gasification, biochemical conversion or whatever – is generally speaking best operated on a reasonably constant feedstock quality. Hence, the material needs be homogenized prior to feeding.

Homogenization may aim at two major aspects:

_ Homogeneity with respect to particle size and shape
_ Homogeneity with respect to average composition, including moisture content

The former is best achieved by mixing the raw materials just prior to fragmentation and, if the demands on homogeneity are extremely high, by a subsequent compaction into pellets, see the next text section.

For the latter it must be remembered that as soon as biomass is left by itself, the biological deterioration commences and that this deterioration will lead to an internal re-distribution of moisture in the pile and to a non-homogenous material. Hence, mixing must be postponed as long as possible and should preferably be done by the front-loader driver just prior to feeding the material to the day-hopper and not earlier. For the stability of the subsequent process, it is therefore essential that the driver of the front-loader is properly instructed. He or she will have a very important role to play as it comes to the stability and to the performance of the combustion/gasification/… process.

Compaction

As mentioned, the bulk density is one determining factor for the energy density and for transport economy. The bulk density is determined by two factors, namely the material density itself and the degree of packing obtained when the material is loaded.

In some applications, when the hauling distance is long, pelletizing or briquetting may be worthwhile prior to transport. For example the bulk densities of stubbles or cutter shavings are typically less than 100 kg/m^3. If the material is pelletized, the bulk density is increased to about 6-800 kg/m^3. With briquettes the corresponding values are about 3-500 kg/m^3.

In pelletizing, the material must first be milled to a suitable particle size – different depending on the material – and then isostacially compressed to form durable particles of a uniform shape. To make pellets, the isostatic pressure must be high enough to completely break the cell structure, for lingo-cellulosic biomass typically about 700 bar. For briquettes, the demands on mechanical durability are lower and the necessary pressure is only about 150-200 bar.

Another technique is baling. Baling is typically applied in close connection with the harvesting/collection process and does not involve milling.

Conveying

A stable feed is essential for any process, be it combustion, gasification, biochemical treatment or anything else.

The typical process layout with a biomass energy system will be that there is an intermediate outdoor store on-site, that the material is mixed and fed to a final fragmenter, conveyed to a day hopper and from that is finally fed to the process. So the process chain will contain three different conveying steps:

_ Conveying the un-fragmented material
_ Conveying fragmented material

_ Emptying the hopper

Depending on the biomass may the un-fragmented material be more or less non-uniform in shape and size. Characteristic of biomass is that it is fibrous and that that it has a low density. The fibrous or ropy structure will often result in a tenacious material with knots and in some cases, like in the presence of bark strands may the material be sticky enough to twist around the feeding screws and actually stop the feeding completely. Similarly may an ever so well controlled collection of a clean household waste fraction contain kitchen pans or pantyhose to stop the feeders. With biomass originally collected from the ground – residues from felling sites, agricultural residues etc. – will stones be present more or less frequently. With demolition wood one will have to expect chunks of concrete, nails, screw, hinges and things like that.

In case screws are used and to guarantee a smooth operation of the primary feed it is therefore essential first that the drive motor for the screws is dimensioned with sufficient power and second that the diameter and the pitch of the primary screws are large enough to handle anything that may be present in the fuel.

During fragmentation, the size range of the material is narrowed as compared to the raw material. With the low density of biomass this means that the particles are lighter and with the fibrous structure it also means that the particles will often have a ragged surface. These things combine to make friction between the particles a dominating property causing comminuted, raw biomass to have very steep repose angles, in some cases even negative. This, in turn, means that mass flow control of the material becomes very difficult since for example a conveyor belt will not be filled to the same level all the time nor will the volume transported through a screw be constant.

Also will the lightness of the material set a limit to the inclination angle for flat conveyor belts at about 30–40° to horizontal. With centreless screws the inclination may be steeper, about 60° to horizontal, except for pellets where again the limit is about 30–40°.

The design of biomass hoppers must take the repose angles into due account. The low density of the individual particle in combination with the ragged surface makes raw biomass have a high tendency for bridging. To avoid this, hoppers should be designed to expand downwards, so they should be designed with a negative slope of the walls. For pellet hoppers exceeding about 1 m in cross section, this is not necessary but the hopper may be designed “the normal way” as long as the bottom angle is steeper than 45° to horizontal.

Quality control

On arrival at the receiving plant, the biomass must undergo quality control. The quality control aims to determining the total delivered amount of biomass, the energy content of the biomass delivered and, perhaps, the ash content and/or –properties.

In many cases the final transport to the energy plant will be road transport by truck and the solid material will be present in containers. There are then two different ways to determine the total amount delivered namely volume measurement or weight measurement.

The method for volume measurement is basically to estimate the degree of fullness in the containers and to use the known container volume in combination with this factor to determine the volume delivered. Since the bulk density cannot be accurately determined, this method will involve two uncertainties, namely the uncertainty in volume and the uncertainty in bulk density and the total amount received will then suffer from a total uncertainty equal to the sum of these two. Experience values from Swedish plants reveal that the total uncertainty with this method is in the order of magnitude + 10% or even more.

The applicable European federal standard is EN 15103.

Weight measurement, weighing the loaded truck on arrival and the empty truck when leaving, provided of course that the scale is properly calibrated, reduces the total uncertainty to less than + 1%.

For moisture content as well as for ash properties the degree of uncertainty in the final value all comes back to the sampling. Picking only few samples from the top of the container is not enough to guarantee that the total sample is representative for the load. Again, there are European standards available: EN 14778, 14779 and 14780.

Biomass: Biofuel

Supply chain aspects for biofuel

Though the final aim is always to release all the chemically bound energy in the fuel, and though this ultimately occurs through a combustion reaction, it may sometimes be desirable to separate the energy release into separate steps. In such cases, the biomass or the solid biofuel is chemically converted into a new fuel such as a liquid or a gas prior to the final combustion.

Conversion processes may be thermochemical, low-temperature chemical or they may be biochemical.

Fuel conversion shall be used only in such cases when the efficiency gain in the final combustion process is big enough to "pay" for the energy lost in the conversion

or

In case the original, solid material cannot be used for the specific process so that the conversion is necessary because of demands by the final process

or

In case the conversion process adds environmental benefits, such as a possibility to clean the feedstock from extrinsic or intrinsic impurities and thus produce a clean fuel

It is important to remember that biomass fuels were used to produce everything – steel, glass, cement, brick – up until the early 1800's.

Hence, fuel conversion is only scarcely necessary from a strict thermodynamic stand.

Processes

The shortest possible process chain is that in which solid biomass is turned into a solid biofuel and the fuel is combusted.

Option 1: Combustion

The ultimate process to release 100% of the energy in any fuel is always combustion.

Combustion is – per definition – a complete oxidation of the fuel content of carbon and hydrogen into carbon dioxide (CO_2) and water vapour ($H_2O(g)$). During the combustion process, many of the fuel impurities will also oxidise to a higher or lesser extent, some of them, like nitrogen and sulphur, producing harmful emissions (NO_x and SO_x).

For practical purposes a wet solid fuel consists of two major components, namely:

_ Water
_ Dry substance

As made clear previously, the water content is one major factor determining the fuel quality in terms of the energy content.

From a simplified combustion point of view, the dry substance may be regarded as composed from three different substances:

_ **Ash.** This is the residue obtained after complete combustion.
_ **Char.** This is the carbonaceous residue after pyrolysis.
_ **Volatiles.** This is the weight fraction of the dry substance lost during pyrolysis.

The *amount* of ash in a fuel is normally presented as weight-% on a dry basis and should be determined according to the method devised in EN 14775.

The *volatiles content* is commonly specified as weight-% on a dry basis and should be determined according to EN 15148.

The standards referred above are those valid for pure solid biofuels – for recovered fuels please refer to EN 15403 and EN 15402 instead. For recovered fuel fractions is may also be of interest to determine the total content of biomass in the material, EN 15440.

As wet, solid fuel enters a hot combustion environment where sufficient amounts of oxygen are present, the process commences through the following steps – schematically:

1. **Drying.** This is the release of the fuel moisture in the form of vapour and is an endothermal or heat consuming process.
2. **Pyrolysis.** This is the release of the volatile, partly combustible, matter and is again an endothermal process.
3. **Gas combustion.** This is the combustion of those components in the volatiles that are combustible. This process is exothermal, i.e. heat is released.
4. **Char combustion.** This is the final burn-out of the solid residue and is again an exothermal process.

These four steps – often occurring partly or completely in parallel – constitute the complete combustion of the fuel.

Option 2: Low-temperature chemical conversion

Low-temperature chemical conversion is mainly used to produce diesel substitutes (bio-diesel) from fatty acids. The raw material can be excess vegetable oil from agricultural production, rapeseed oil, soybean oil and alike but also residual cooking oils from – for example – restaurants or from food processing. Basically, the process is to add OH-groups from an alcohol to the molecules. The process thus involves simple bulk chemicals like ethanol or methanol, it runs at low temperatures and the total conversion may be almost 100% so losses as such are small.

The total energy balance is strongly depending on the addition of alcohol and typically the total energy provided from the alcohol amounts to about 10 – 20% of the energy contained in the final product.

The only process introduced here is the general production of fame.

Fatty acid methyl esters are mainly used as diesel substitutes (biodiesel) from fatty acids. The raw material can be excess vegetable oil from agricultural production, rapeseed oil, soybean oil and alike but also residual vegetable oils from – for example – restaurants or from food processing. The feedstock needs to be filtered and free from solid impurities and water prior to the process, so the collection and handling needs be such as to provide a reasonably clean feed. Basically, the process is to add OH-groups to the fatty acid and thus transform it into an ester. This is achieved by the addition of an alcohol, typically ethanol or methanol in the presence of a catalyst, typically at low process temperatures. As compared to the raw vegetable oils, esters have favourable properties with respect to storage (they are more stable). The resulting fuel quality, as measured by the cetane number, is strongly depending on the combination of feedstock and alcohol but some combinations – like coconut oil and ethanol – will typically yield cetane numbers > 70. Such quality fuel, provided it is not contaminated, can serve as a diesel substitute without any need for modifications of the engine while other fuels, such as RME produced from rapeseed oil and methanol (cetane number > 50) may call for engine modifications. It is also important to remember that the final product must be purified so as to be free from residual fatty acids and from water since they are very corrosive. The process involves common bulk chemicals like ethanol or methanol, it runs at low temperatures and the total conversion may be almost 100%.

The total energy balance is strongly depending on the addition of alcohol and typically the total energy provided from the alcohol amounts to about 10 – 20% of the energy contained in the final product.

FAME – fatty acid methyl esters – as is the common acronym for this group of fuels, can be used as diesel substitutes as well as diesel additives or can be used to replace light fuel oil in any process.

Option 3: Thermochemical conversion

Thermochemical conversion makes use of elevated temperature, and in some cases elevated pressure, to convert the solid. For most processes, the heat needed to arrive at the process temperature is generated through a partial combustion of the feedstock. Depending on the actual temperature and on the process layout, more specifically: the heat recovery system, this partial oxidation will introduce energy losses from the feedstock to the product. Also, the temperature of the product fuel will be that of the process. Unless this sensible heat is recovered and used in the process it will represent another loss.

Thermochemical processes introduced here are low-temperature pyrolysis, high-temperature pyrolysis, thermal liquefaction and thermal gasification.

Low-temperature pyrolysis or torrefaction

While a complete pyrolysis requires temperatures in the range of 700 – 900°C, the process starts already at significantly lower temperatures, about 100°C. When biomass is heated up – in absence of oxygen – to temperatures about 300°C, a partial pyrolysis will occur and the material be dried. A pyrolysis at such low temperatures will not fully evaporate the heavier hydrocarbons produced but they will be retained in the dry residue rendering the product some hygroscopic properties. At the same time, the product becomes brittle, its heating value is increased and the density decreases. The main part of the ash will be retained in the solid product and hence the ash content will increase. Some fuel impurities, such as part of the sulphur and chlorine contents, will be released with the pyrolysis gas while others will retain in the solid product.

The heat required for the process represents a loss but can be supplied by combustion of the gaseous and liquid pyrolysis products and may be kept well below 10% of the total energy contained in the original fuel depending on the moisture content of the feedstock.

The solid fuel thus produced can be used in a variety of processes.

High-temperature pyrolysis or charring

The higher the pyrolysis temperature becomes, the larger the fraction of the volatile components that are released during the process and the smaller the fraction of residual solid. Ultimately, about 70-80% of the dry substance may be released as pyrolysis products and only about 20-30% of the dry weight be retained as solid charcoal, so the density decrease is significant. Since practically all hydrocarbons are given off during this process, the product will not have any hygroscopic properties. The high process temperature will release the main part of volatile impurities such as sulphur and chlorine, which will then be present as hydrogen sulphide and hydrochloric acid in the pyrolysis gas.

The heating value of the charcoal, in this case almost pure carbon but with the main part of the mineral ash components still present may be as high as about 30-35 MJ/kg but the total energy used for the pyrolysis process will represent about 10-20% of the total energy contained in the feedstock – again depending on the original moisture content. The solid charcoal produced can be used in a variety of processes.

The pyrolysis can also be steered towards a liquid product by setting the temperature to about 500°C and shortening the residence time. To heat up the feedstock within the short residence time required for maximum output of pyrolysis oil (about 1 second) the process needs a preceding milling of the material. The total energy balance, including pyrolysis oil and solid residue, is in the same order of magnitude as for high-temperature pyrolysis, i.e. about 80-90% of the feed energy is retained in the products.

The pyrolysis oil produced will consist of a mixture of hydrocarbons and organic acids, water, volatile fuel impurities and other compounds and will need purification and further upgrading unless it is immediately burned.

Thermal liquefaction

In case biomass is heated to intermediate temperatures – about 400°C at pressures around 10 bar – in the presence of steam and carbon monoxide, the formation of a liquid product is maximised. The liquid product quality may – to some extent – be controlled by the use of catalysts. Since the span of molecular weights in the liquid product can thus be limited, the product will generally have a significantly higher quality than pyrolysis oil while it will still contain a significant amount of volatile impurities.

The requirement for a pressurized process will limit the total efficiency to about 80-90%, in spite of the relatively low process temperature. The product can be further refined into a high quality fuel.

Thermal gasification

In thermal gasification, the aim of the process is to convert the solid fuel completely into a combustible gas mixture. To obtain this, high process temperatures (in the range 700 – 1100°C) are required and a significant fraction of the feedstock energy will be found as sensible heat in the product gas. In the simplest processes (air-blown), the major energy containing components in the product gas will be carbon monoxide, hydrogen and methane and the gas will be heavily diluted by nitrogen. The gas may also be heavily contaminated by heavy hydrocarbons depending on the process layout, co-current, counter current or well mixed. Counter-current processes will yield the lowest tar content in the product gas. Changing medium from air to oxygen or to a combination of oxygen and steam gives the opportunity to significantly change the proportions of the combustible gas components. The high process temperature and the aim to transform 100% of the solid to gas will also render the main part of the fuel impurities to ultimately enter the gas phase.

Regardless of the gasifier medium remains the fact that a significant amount of the feedstock energy will be present in the form of sensible energy. Thus the total efficiency obtained in thermal gasification is strongly dependent on the system design and on the recovery and use of sensible heat from the product gas.

The choice of gasifier medium and technology are crucial for the usefulness of the product gas – direct combustion or subsequent chemical synthesis to refined products.

Option 4: Biochemical conversion

Biochemical conversion makes use of micro-organisms to convert the solid material.

Micro-organisms thrive at different temperatures, cryophilic (-15 to 15°C), mesophilic (5 to 50°C) and thermophilic (50 to 100°C). The main processes used occur at mesophilic temperatures about 30 to 45°C and the loss of energy in sensible heat is limited. However, the reason that the micro-organisms are active is that they gain energy from the process, and that energy is taken from the feedstock. So, again, the conversion process introduces an energy loss. Biochemical processes introduced here are fermentation and anaerobic digestion.

Fermentation

Fermentation of biomass to alcohol by common yeast is limited by the fact that yeast fungi basically can ferment only such sugars with 6 carbon atoms in them (hexose's) while many of the sugars present in biomass are pentose's, i.e. they contain 5 carbon atoms. With natural yeast the fermentation is actually limited only to glucose but starch as well as some other types of sugar can be enzymatically transformed into glucose and hence qualify as fermentable. Thus, only some materials, those where fermentable sugars are readily available for the enzymes and the yeast, are naturally suitable for alcohol fermentation while most are not. However, two of the main constituents in plant cell walls – cellulose and hemicellulose – are both basically built up by fermentable sugars. The problem is that they are partly crystalline and are embedded in lignin, so that the sugars are not accessible. Different pre-treatments including dilute acids, hot water or ammonia make it possible to break this structure, de-crystalize the cellulose and make the sugars in cellulose and hemicellulose accessible for subsequent fermentation. These processes are still under development and so far they suffer from high costs as well as of some of the by-products being inhibitors to the fermentation process. There is also research on-going to genetically modify micro-organisms so as to render pre-treatment unnecessary.

The product from fermentation is a dilute alcohol that needs be concentrated through distillation to attain fuel quality.

Anaerobic digestion

This is a completely different process from fermentation and one that can work with a wider span of substrates. The main advantage is that this process can make use of feedstock in the form of slurries or sludge such as sewage sludge or industrial fibre sludge, wet manure, waste food and alike, feeds that cannot be used for energy production in any other way. While yeast fungi are the main actors in fermentation digestion takes place through a complex and sequential interaction of – mainly – bacteria. Simplified, the anaerobic digestion starts with the substrate being hydrolysed to soluble organic compounds like fatty acids, sugars and amino groups. These compounds are then further degraded into alcohols and acetic acid, the acetic acid finally being broken down into carbon dioxide and methane. In parallel with the formation of acetic acid there is also a direct formation of hydrogen and carbon dioxide, both of which are partly combined to methane. Since there are thus a large number of intermediate products formed during digestion and since the microorganisms are very sensitive to their living environment, a thorough process control is needed to avoid accumulation of process inhibitors. Temperature, pH-value, hydrogen content etcetera must all be kept under surveillance to make the process run smooth. The process is also very sensitive to changes in feedstock quality.

The product from anaerobic digestion is a mixture of gases, mainly methane about 50 to 70%, carbon dioxide some 30 to 45% plus hydrogen sulphide, ammonia, hydrogen chloride and other impurities. The gas can be burnt in boilers or in IC-engines without upgrading but most common is an upgrading via pressure-swing adsorption or pressurized scrubbing to methane contents exceeding 95%.

Emission and efficiency aspects

Modern, automatic, straw-fired boilers aimed for the intermediate scale 5-20 MWth will exhibit total combustion efficiencies well exceeding 90% while small-scale firing using manual feed one bale at a time will still be inferior with total efficiencies in the range 80-90% in the worst cases. The CO-emission levels from small scale (single farm scale) boilers may be in the range of 500 – 1000 ppm, which may indicate also high emission levels of unburned hydrocarbons.

In the large scale (50 MWth and up), where pulverized fuel firing and/or co-firing with coal in circulating fluidized beds or using pulverized fuel are the most common technologies, emission levels are as low as with any other fuel except, of course, that the high chlorine content may prove problematic.

With pure straw firing in CHP applications, the high alkali-chlorine levels may call for a lowering of the steam overheating temperature (as compared to coal firing) to protect the superheaters and hence prolong the life of the plant and reduce maintenance cost, but Danish experience seems to indicate that this needs not be the case if co-firing is used. A common proportion is to add about 10-120% of the thermal load by straw, the remainder being coal, and as a general experience there seems be no adverse effects to superheater life from this. This general experience is also supported by the experiments and experiences from co-firing conducted and reported by the IEA.

Biomass: Waste

Supply chain for combustible waste fraction

The problems associated with waste do to a great extent boil down to quality aspects and to the undefined content of contaminants. Hence, a number of standards are in place to control the use of waste and to guarantee that the treatment of waste for energy purposes is done in a proper way with respect to the environment. Some of the current standards are

"Waste", from households, from industrial processes, from societal activities, from agriculture and other sources, is a huge resource – often neglected.

General aspects:	EN 15357	Terminology, definitions and descriptions
	EN 15358	Quality management systems
Sampling:	EN 15442	Methods for sampling
	EN 15443	Preparation of laboratory samples
Analysis:	EN15400	Determining the calorific value
	EN 15402	Determining the volatile content
	EN 15403	Determining ash content
	EN 15407	Determining the content of C, H and N
	EN 15408	Determining S, Cl, F and Br
	EN 15414	Determining moisture content (3 separate standards)
	EN 15440	Determining content of biomass

Considering that all these standards have been updated or issued during 2010 and/or 2011 it is clear that "recovered solid fuels", as is the proper name of combustible waste fractions fulfilling the quality standards, is something considered a relatively new phenomenon.

The over-all scope and system perspective is this (adapted from EN 15357):

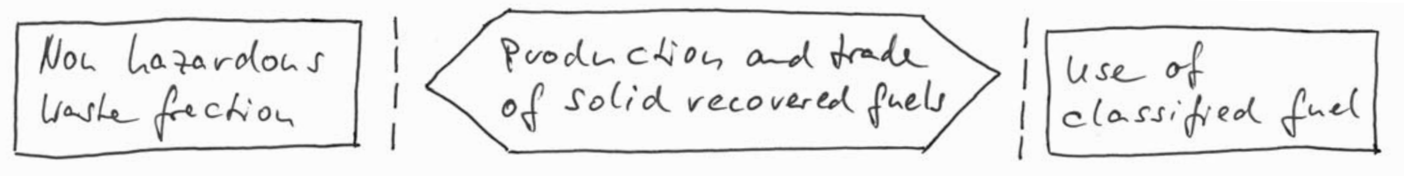


Figure: System limits for solid recovered fuels

Beside the above standards, relevant legal information concerning recovered solid fuel fractions can be found in several federal directives and the reader is referred to http://europa.eu/legislation_summaries/environment/waste_management/index_en.htm .

The implications of the schematic in figure 12 are:

- The raw material for SRF can be any non-hazardous waste fraction fulfilling the quality criteria set up by a producer/trader.
- The producer/trader upgrades the waste fraction in one or more respects so that it fulfils the quality requirements of a fuel user – an energy plant, for example.
- Then this producer or trader actually handles – per definition – a "solid recovered fuel".

Key words in the schematic are the fact that the raw material must be non-hazardous.

With respect to what is considered hazardous waste, the federal law has generally adopted the definition of the Basel Convention, the full text to be found on the net. However, there are also some further specifications in the federal "List of Wastes" that need to be considered before a waste resource can be used for energy purposes. In connection with the LoW, one must also consider the special directives valid for waste handling.

The most important parts of the convention text are the annexes where Annex III contains an extensive list of properties, each of which qualifies to render a substance hazardous while Annex I is an extensive list of industrial or societal origins or product classes, each of which renders the waste hazardous. Thus, the Basel convention defines the left-hand side box in figure 01-04 1, namely the raw materials that may be used but it must also be recognized that the individual state may impose their own restrictions following article 3 in the convention.

Though the Basel convention is focused on trans-boundary movement of hazardous waste, the annexes in combination with state law will provide the first legal basis to determine what may be used for raw material in the individual state.

Following the above, it becomes clear that the use of recovered fuel is subject to strict constraints and that any fuel production process must be carefully planned. A number of good examples can be found at http://ec.europa.eu/environment/waste/studies/.

Hence, the key factors for waste utilisation will generally consist of the following three steps:

1. Decide that the waste stream is non-hazardous as defined in the Basel convention
2. Determine the actual content of biomass according to EN 15440
3. Decide whether a separation of the biomass is economically and environmentally feasible

In case the outcome from the third step is that the process is feasible, the next stage consists mainly of a choice between three options:

1. Use the separated and clean fraction to produce an upgraded fuel (RDF, refuse-derived fuel or SRF, solid recovered fuel, quality demands for certification being very high) suitable for stand-alone combustion. This option will require a very thorough quality control throughout the fuel production process.
2. Use the separated fraction as a co-combustion fuel, for example, in cement production kilns or any other industrial processes apt to it. In this case, the demands put on the fuel will be depending

on the general demands put on the fuels for the industrial sector in question. In co-combustion applications, the main concern will be the corrosive properties of the fuel fraction, mainly characterized by its content of chlorine and sulphur. Depending on the base fuel composition and the environmental demands set to the plant, also heavy metals may be a major concern.

3. Use the fuel in waste incineration plants designed and aimed for mass burning of municipal solid (household) waste. In this case, the directive on electricity produced from renewable fuels (2001/77/EC) and the waste incineration directive (2000/76/EC) as well as state legislation will apply.

Household waste is, in the Basel convention, in a special category, namely "requiring special consideration". The meaning of this is that household waste may, in some cases, classify as hazardous – sometimes not. The major demarcation line between hazardous and non-hazardous fractions is set by the chlorine content and on the content of heavy metals.

Thus, the separation of the waste into well-defined categories is absolutely crucial.

Characteristics and amounts of wastes

The total amount of waste generated in the European federation exceeds 2 billion tonnes (2,620 million tonnes in 2008) whereof approximately 35% is non-mineral (data from Eurostat).

Out of this, more than 200 million tonnes (7.7%) was household waste, more than 100 million tonnes (4.4%) was animal and vegetal, 70 million tonnes (2.6%) was woody waste and almost 60 million tonnes was paper and cardboard waste.

There is still a significant amount of the waste going to landfills while the total amounts incinerated have not increased substantially since the last 15 years. On this point, current federal statistics are ambiguous since there is really no clear distinction between incineration aimed for energy production ("incineration with heat recovery") and incineration aiming only to reduce the volume prior to landfill. However, waste combustion in 2009 supplied approximately 30 TWh of electricity and 55 TWh of heat, approximately 50% of which was classified as renewable.

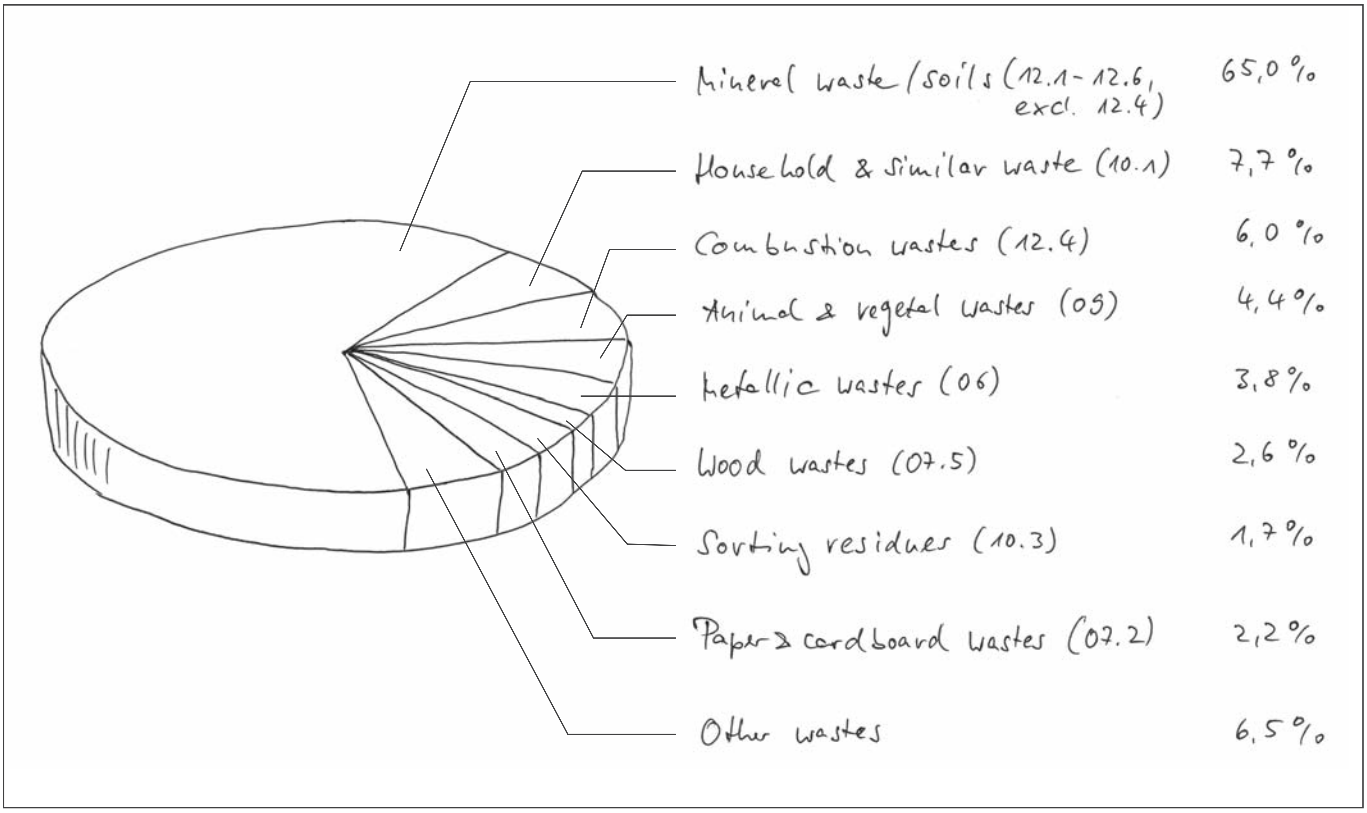


Figure: Distribution of total waste (2008) into categories

A rough estimate based on 70% thermal efficiency in the plants used and a heating value about 12 MJ/kg would then yield that the total amount used "with heat recovery" would amount to about 30-35 million tonnes or about half the total amount incinerated. This is only just the roughest estimate but it serves to indicate the order of magnitude for the remaining resource: approximately 80-90 TWh on an annual basis. Hence it is well worthwhile to consider waste fractions as a part of a future, sustainable and renewable energy supply system.

The households are responsible for 60-90% of the total municipal waste generated while the remainder can be attributed to the commercial- and service sectors. With proper information to the households, to commercial enterprises and to the actors in the service sector, all the municipal waste may well fall within the non-hazardous category as defined in the Basel convention. In 2008, the total amount of municipal waste was 254 million tonnes corresponding to 506 kg per year and person and this is a fairly stable amount.

The amounts of construction and demolition wastes are strongly depending on the over-all activity in the building sector and that is again strongly depending on general economic activity. Hence, this is not a stable source for fuel, a source that can be relied upon as a base fuel. However, the amounts may be significant. A survey performed by AvfallSverige in 2009 revealed that during 2004, about 200,000 tonnes of wood-waste was produced by the Swedish building sector. By 2006, the corresponding amount was only about 2 000 tonnes. The types of material available from the building sector are for example formwork timber – basically stem-wood contaminated by chunks of concrete – as well as interior/exterior woodwork and timber from building frameworks. Parts of this will have been impregnated with anti-rot agents, parts of it will have been painted, but parts will be clean and will serve well as a clean fuel.

Other industrial sectors – primary producers like agriculture, forestry, food processing and building sectors excluded – producing solid, combustible waste fractions to any extent worth mentioning, are first and foremost the service sector, producing paper-waste, and manufacturing industry in general, producing waste in the form of used and broken wood packaging and pallets.

Waste handling – specific unit operations

Planning for an increased use of waste fractions for energy purposes is double-edged: On the one hand, the total amount of waste from society and from households tends to go hand-in-hand with economic development, but on the other hand a sustainable long-term development must be based on a material management more efficient than the present.

The “waste hierarchy” illustrates in five simple steps what must always be the basis for waste management:

1. The highest priority is to take measures to reduce the total amounts of waste generated in households, in industry and in the public sector.
2. Second priority is to take active measures to re-use the products, for their original purpose or for new purposes.

3. The third step – in case none of the first two is applicable – is to recover the material by sorting, by composting or by digestion.
4. Only if none of the above is feasible does energy recovery by incineration in CHP-plants become a main alternative.
5. If none of the above is applicable, one will finally have to dispose of the material in a landfill.

The consequence of the waste hierarchy is thus that the local planning must be based on an active strive to minimize the total amounts of waste for incineration. At the same time, the fraction finally incinerated shall be as clean as possible. This requires an active participation from the households, and the garbage collection system must be developed to aid the households to actively separate fractions so as to fit the waste hierarchy.

Collection systems and fractioning – household waste

Obviously, the system to collect household waste must be depending on the nature of the households.

Apartment houses – full service

In apartment houses, city centres as well as densely populated residential areas, the full service system should be preferred. With a full service system, a common waste collection bag or container is made available to the tenants on the ground floor. The deposit of waste into the central container may be by a refuse chute or that the individual waste bag must be brought down and manually be put into the container.

The fundamental idea with the full service collection is that the individual tenant shall not have to leave the building but can get rid of all their refuse at one place inside the house, regardless of the subsequent process.

The waste containers are emptied on a regular basis and a simple visual control that fractions are duly separated can be done in the individual building. Hence, infor-

The waste collection room should also be equipped with small containers for paper, glass, metal and/or other fractions.

mation feedback to the tenants can easily be organized within this system and the separation efficiency can be maintained at a high level. The company/organization responsible for collection and transport will finally have the full responsibility to keep the different fractions separated for further transport.

Free-standing houses – kerbside service

With single-family free-standing houses, terrace houses or semidetached houses, the situation becomes different and individual waste bins to be placed by the roadside on collection day become the most attractive alternative. In this case different waste bins may be dedicated to different fractions, often separated by a colour code, but the driver of the collection vehicle will not be able to see what is actually in the bin and the separation actually obtained is often inferior to what can be achieved by a full service system.

For a system like this to work properly, it is crucial that household confidence is high and it simply may not happen that a bin of a certain colour is ever seen to be collected in the wrong vehicle.

Bring system

With a bring system, the households are required to bring the waste to collection stations and to put the separate waste fractions each into its own container. Since this requires that the households not only separate the fractions at home but also pack them so as to make the transport to the collection station comfortable, it tends to give as a result that any waste fraction that might be wet or cause bad smell indoors is wrapped in plastic bags and that a plastic fraction is hence present in all the different waste fractions.

In apartment houses – where space for storing the household waste for a period of time may be an issue – this type of systems tend to counteract waste fractioning. A common reaction by the tenant is to strive for a minimization of the amount of waste stored in the apartment and to carry only one bag at a time to the collection station. Hence the garbage bag is filled to the rim and the priority to minimize carrying tends to take over the priority to keep fractions separate.

Logistic aspects on waste

Depending on the number of fractions to be collected there are a great number of different vehicles available for the collection, two of which are the most common in cities.

For **full-service systems** the rear-loading and compressing truck is the most common. One main advantage by the rear-loading truck is that it works also in narrow inner-city areas and that the operational space required is limited. Another advantage is that the most common rear-loaders can handle also loose material. Rear-loaders with two parallel compartments are available, but most common are the ones with only one compartment. Thus, logistics may have to be organized so that several trucks are in operation, each handling only one or two fractions.

A major drawback with full-service systems is that the transport from the waste collection room to the truck typically requires manual transport and hence the truck must carry a workforce of, typically, 2-3 workers. Assuming one driver and two assistant workers, two buildings may be served at the same time while – in case of a heavy container or bag – both workers may in some cases be needed simultaneously. The manual hauling from collection room to truck is not only labour intensive but also time consuming.

Therefore, full-service systems tend to be expensive but at the same time they may provide a good fractioning.

With **kerbside systems**, side-loading trucks are dominant competing with rear-loading. With standardized household waste bins, the emptying into the side loader can be automatized so that the whole operation can be performed only with one driver in the truck. However, cheap as it is, the side-loading truck is unsuitable for narrow streets or city centres. Another problem with automatized side-loaders is that loose material cannot be handled.

With colour-coded bins or bags, or with separate collection days for different fractions, a high degree of fractioning can also be achieved.

Colour-coded bags can be collected in one operation and then be automatically separated at the plant using robots. Such systems are already in place and tend to work well though recent studies seem to indicate that transparent bags with coloured polka-dots on them tend to improve the precision of the separation as compared to non-transparent bags with a solid colour. The results are only preliminary but it is believed that the citizens become more precise in their sorting efforts if the garbage is visible inside the tied-up bag than if it is hidden inside a non-transparent bag. Colour coding can just as well be combined with full-service systems provided the bags are robust enough to survive the chute.

To maintain the participation of the citizens, the colour-coded bags must either be delivered to the door in connection with the collection or they must be easily and freely available close to the living areas.

With **bring systems** for collection, the most common is to use either container-carrying trucks or open trucks to which the collection containers are emptied. In the latter case, it is obvious that paper, plastic and other lightweight material well suited for compaction to economize transport cannot be handled while heavier fractions and materials that shall not be compacted such as glass or metal for recycling are often handled this way. However, the system as such allows certain flexibility depending on the containers and the number of fractions can easily be extended, provided space is available.

Depending on the maintenance of the containers and the trucks, the container handling may cause technical problems. Thus, this type of systems require a thorough planning and also tend to require a higher maintenance cost than the other ones – though the handling is potentially very smooth and efficient if only the equipment is well maintained.

However: Bring systems are not well suited for organic waste and – as pointed out above – tend to "produce" less well-defined fractions than the other systems. For storage-insensitive fractions, though, like glass, paper and metal, they work well and are widespread.

The above text and the systems outlined all serve one and only one purpose, namely to produce the cleanest possible fuel fraction at the lowest possible cost. However, since no guarantees can ever be provided, the composition of the fraction finally delivered will always be variable. Therefore, and to be able to recover the energy from the variable fuel quality at an environmentally acceptable level, the so-called "waste incineration directive" (2000/76/EC) and a number of other federal laws are in effect in this area. Some of the most prominent laws (all accessible online at http://www.eur-lex.europa.eu) are the waste framework directive 75/442/EEC from 1975, the hazardous waste directive 91/689/EEC and the waste shipment directive (EEC) 259/93, all with their later additions and amendments.

Article 10 in the waste incineration directive specifies in some detail not only the measurements to be performed at plants using waste fraction as a fuel but there are also certain design requirements with respect to the gas residence time and the combustion temperature. Altogether, these requirements make waste-fired energy plants expensive not only to build but also to operate and it is sometimes advantageous to co-ordinate the waste handling systems for a region or a number of municipalities rather than to build incineration plants in every community. In such cases, waste may be hauled long distances between regions, between states or even internationally. However – though the waste itself may be treated elsewhere – the ultimate responsibility for the treatment still remains with the company, organization or authority that originally collected it. It will be up to the authority originally holding the waste fraction to set up and negotiate the contracts for the final handling and it will also be up to the original authority to follow up these contracts.

Storage and sanitary aspects

Hence, for comfort reasons, the individual would want to dump this waste either in the chute (full service) or in an outdoor waste bin (kerbside collection) as soon as possible. These are also the preferred and most common systems to collect mixed household refuse and wet organic materials. Several different questionnaires tend to show the same tendency, namely that these are the methods preferred by the households.

The individual household does not want to keep wet residual waste indoors for any prolonged period of time.

However, the attitude towards dry waste fractions that are insensitive to storage is quite different. Such waste fractions – glass, paper, metals and plastics – may well be accepted to be stored in the individual households for a period of time and then brought to collection stations, provided space is available in the house or apartment. For paper waste – which is a large fraction of total household waste and hence may become a nuisance to carry to a collection station – full service and kerbside are both common systems in parallel to bring systems. Glass, metals and plastics, though, are most commonly collected using containers to which the material must be brought by the individual citizen (bring systems).

There is a successively increasing awareness among individuals and households that waste recycling and re-use is of crucial importance to the sustainability of modern society and in most western and European countries, the households are willing to take part of this responsibility.

There is also a trade-off and the households may accept the responsibility and extra work associated with waste fractioning only if they are convinced that the municipality and the subsequent handling and treatment actually takes full advantage of the separation done. Hence feedback to the citizens is crucial and it is essential that the infrastructure and the logistics work properly so that no mistakes occur.

Given this, the most common system solutions are either full-service or kerbside collection of combustible residual as well as organic waste fractions and bring systems for paper, plastic, metal and glass fractions. In case a full-service system is established, paper and plastic fractions are often incorporated in this while glass and metal fractions are most often handled by a bring system.

Comminution and homogenization

With waste fraction, un-defined as they are, comminution using any kind of sharp tools should be avoided and shredding is the most common for household waste.

For construction and demolition wood that may contain chunks of concrete as well as nails and other pieces of metal, crushers are the most common.

Quality control

Looking now specifically at the two main fractions that may be "produced" through a proper infrastructure they are:

_ A clean, reasonably dry, biomass-rich combustible fraction suitable for use in CHP plants, for co-combustion in coal-fired plants or in industrial processes.
_ A clean organic fraction suitable for composting, for anaerobic digestion or for fermentation, usually in combination with other substrates.

Fuel fractions originating from waste may sometimes have unacceptably high contents of chlorine, other halogens, sulphur and heavy metals. Of special importance in the case of combustion in CHP-applications or any other processes involving electricity production are the corrosive compounds formed from chlorine and sulphur. Other important compounds in the flue gases from combustion include molten and corrosive ashes.

The sensitive parts in the plant are, primarily, the steam superheater surfaces, exposed as they are to high internal steam pressures, to high temperatures and, on the outside, to corrosive flue gas components. The corrosive properties of the gas will thus set an upper limit to the steam temperature and –pressure attainable and with waste derived fuels this limit may sometimes be as low as 400 °C and about 80 bar, comparable with the data in nuclear power plants and far below those attained in any modern coal- or biomass-fired plants, not to mention those achieved in gas-firing.

The steam pressure and the steam temperature prior to the turbine are the two parameters of highest importance with respect to the total electricity efficiency.

As can be understood from the previous paragraphs, the quality control with respect to fuel fraction analysis is of utmost important in case of waste streams for energy.

Typically, the combustible fraction is composed by nine major components, here characterized by their ultimate analysis with respect to carbon (C), hydrogen (H), oxygen (O), nitrogen (N) and sulphur (S), together with ash. The analysis is given in % by weight on a dry basis and the (very approximate) reference heating value (dry, ash-free basis) in MJ/kg:

	C	H	O	N	S	Ash	$q_{NET,DAF}$
1: Plastics	60	7.2	22.8			10	25.9
2: Rubber	78	10		2		10	37.2
3: Leather	60	8	11.6	10	0.4	10	27.9
4: Textiles	55	6.6	31.2	4.6	0.15	2.5	21.1
5: Wood waste	49.5	6	42.7	0.2	0.1	1.5	17.4
6: Paper	43.5	6	44	0.3	0.2	6	16
7: Cardboard	44	5.9	44.6	0.3	0.2	5	15.9
8: Food waste	48	6.4	37.6	2.6	0.4	5	18.4
9: Garden waste	47.8	6	38	3.4	0.3	4.5	17.9

Table: Typical ultimate analysis for combustible fractions in MSW

The plastic fraction is certainly combustible but is not biomass. Typically, the plastic fraction present in household waste is some 5-15% and mainly consists of food packaging and plastic bags.

The two below the dotted line – food waste and garden waste – should both, preferably, be separated into the general waste fraction treated by anaerobic digestion rather than being present in the combustible fraction.

Federal European statistics on waste are not yet fully co-ordinated but compiling data from a number of different investigations one can see that the over-all composition between states tend to vary significantly with paper and cardboard about 20 + 10% and plastics 10 + 5% making up about one third of the total. Glass, ceramics and metal, together with other inert fractions like renovation waste and alike is typically about the same amount, one third, with biodegradables making up for the rest. However, as pointed out, the composition is highly variable and depending on local/regional conditions.

Using 16 MJ/kg for the paper fraction (20% by weight), 26 MJ/kg for plastics (10%) and 18 MJ/kg for biodegradables (33%), the remaining 37% non-combustible this yields 11-12 MJ/kg dry material.

The moisture content in the fuel fraction depends strongly on the fractions present but is also affected by the way the collection is organized but may generally be assumed at about 20%, finally yielding a typical heating value for the wet waste about 8-10 MJ/kg. This is a typical value and may well be used for dimensioning purposes though it must be remembered that the collection logistics will have a strong influence and may contribute to a higher value.

As mentioned previously, the content of chlorine in MSW may sometimes be high, almost up to 1% by weight (dry basis). The chlorine sources are mainly two, namely plastics (i.e. PVC) and common salt as remains in food residues. In combustion, chlorine may contribute to the formation of chlorinated hydrocarbons, such as dioxin. Since any detailed description of the combustion chemistry would go far beyond the scope of this report, this will not be treated further. One major role of the "waste incineration directive", 2000/76/EC, is to suppress the formation of such compounds. Hence, any waste combustion equipment aimed for waste fuels must be thoroughly dimensioned to fulfil the demands set in this directive.

With waste, the ash content is usually high, only scarcely below 15% by weight, and the ash starts melting already at low temperatures, sometimes as low as 700°C. Typically, the waste will be shredded prior to feeding into the boiler and magnetic materials will be separated, but there will still be significant amounts of ashes and the melting temperature will not be affected by the separation of magnetic materials.

Hence, boilers for direct combustion will have to be designed to cope with large amounts of molten ash in the fireplace. Such dedicated boiler designs are available on the market since long and show a very high availability and reliability.

The gases from waste combustion will contain several corrosive components in relatively (as compared to clean biofuels) high concentrations. In CHP-applications, this will limit the steam superheating temperature, usually to about 350-420°C, and hence the total electricity efficiency that can be obtained from waste combustion.

Direct combustion for heat production or, if the low electricity efficiency can be accepted, CHP is the major alternative for the combustible waste fraction.

Biomass: Biogas

Typical supply chains for Biogas

Substrate supply

The production of biogas, the anaerobe degradation of organic material, is one option of energy production from biomass. A big variety of biodegradable substrates is suitable for the production of biogas. To these belong liquid and solid manure, energy crops, agricultural by- and waste products and organic waste. Especially because of the competitive situation between food production and energy production the use of by- and waste products (agricultural, industrial and societal) has to be assessed in a positive way.

The main substrate suppliers for the biogas process are agriculture, public waste disposal system and food (processing) industry. In the agricultural sector a distinction between cultivated biomass (energy crops) on the one hand and by- or waste product on the other hand should be done. Energy crops are cultivated solely for the production of energy.

The cultivation of energy crops claims the same resources like the cultivation of food crops and so exists a competitive situation. Hence a further expansion of areas for energy crops should only be carried having regard to food safety and ecological aspects.

To reduce and avoid the competitive situation between food and energy production, also crop residues and other agricultural “waste” products, e.g. crop residues and manure, should be used in biogas plants as well. In normal course of operation manure is collected and stored for fertilization and now has to be conveyed to the biogas plant. Crop residues mostly are left in-situ for humus reproduction. Residues have to be collected separately.

Manure is an excellent biogas substrate that stabilizes the process of digestion. It also implies a high GHG mitigation potential. But also here ecological aspects are to be respected in order to counteract soil degradation and water pollution.

Organic waste products, e.g. organic wastes from household and business or catering wastes are suitable for the biogas production as well. The collection, separated or not, is carried out via the regular waste collection. In case of a separated organic waste collection the pre-treatment is substantially reduced to a non-separated collection. The digestion covers the required treatment of these wastes and energy production at the same time.

Transport

In agricultural biogas plants the transport does not play a leading role. The transport distances mostly span few kilometers. In industrial, waste processing and plants that are reliant on additional purchase of substrate the transport distance is crucial for profitability. With increasing costs for fuel the situation can change rapidly. If external substrates are used as well as receiving control should be carried out (see figure below). This control contains at least the exact amount, impurity inspection and substrate characteristics like dry matter content.

Figure: Substrate transportation and receiving control (Photo: University of Rostock)

Storage

The function of a substrate storage space is to provide substrate capacities for several hours or even days for the plant operation. During storage losses of gas-building potential and different types of emissions are possible. Methods have to be established or storage has to be organized in a way, that aerobe degradation and emissions, e.g. NH_3 or CH_4, are minimized. Soil and groundwater contamination are to be prevented as well. To these methods belong siloing (conservation) of biomass, an adequate compacting and a sealing and covering of the biomass.

Figure: Storage space (silo) for energy crops and manure storage (covered) (Photo: Kaiser Baustoffwerke, Sammer Werksvertretung)

Especially the storage of organic wastes should be realized as an enclosed building to minimize emissions (odour, noise, gas, liquids etc.). Hereby a way exhaust gas can be treated specifically.

Figure: Delivery hall organic waste (Photo: Jennifer Grünes)

Treatment, Preparation

The scale and character of pre-treatment depends on the kind of substrate that is intended to be used. It can affect the transportability and processability as well as the degradability.

1. Sorting and impurity separation

According to the origin of the substrate the separation of impurities can be necessary for continuous workings plants in order to protect conveying facilities and prevent sedimentation inside the fermenter. Especially organic wastes and agricultural by-products can contain impurities, e.g. stones. Often the separation takes place in the preliminary tank, but also separators directly in front of the conveying facility are common. In addition manual separations are still state of the art.

2. Comminution

The comminution of solid or fibrous substrates on the one hand extends the surface area. This area then is available for the biological degradation, what leads to faster degradation. On the other hand it ensures the operability of the conveying facilities. Therefore conveying and comminution facilities often are combined or even integrated, e.g. conveyor screws with cutter trimming and perforated disc macerator. Also external comminution facilities like shredders or mills are set up.

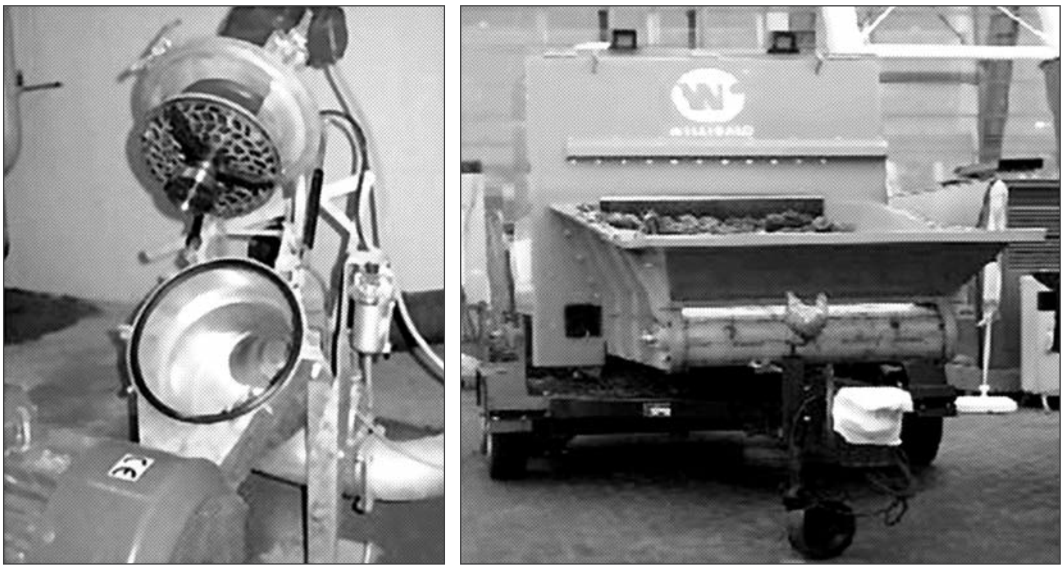


Figure: Perforated disc macerator and external shredder (Photo: Hugo Vogelsang Maschinenbau GmbH, KWS)

3. Homogenization and mashing

To realize the pumpability and to inoculate the substrate liquids are added to the substrate. For this purpose mainly liquid manure, percolation water, separated liquid digestate and very rarely fresh water are used. Especially after hygienization the inoculation is necessary to ensure a continuous and stable degradation. Changing substrate compositions constitute a challenge for the microorganisms inside the fermenter. Reduced gas yield or even a breakdown may result. A homogenization, which means mixing different types of substrates, hence is relevant. The mixing can take place in the preliminary tank or directly inside the fermenter.

4. Hygienization

Hygienization of biogas substrates is defined as heating the biomass up to 70°C with a residence time of one hour. This method is used for hygienically critical material, such as slaughterhouse waste, catering wastes etc. The hygienization takes place prior to fermentation.

Digestion

The process of anaerobic digestion can be distinguished by four typical parameters:

1. Dry matter (dm) content

The dry matter content affects the consistency/viscosity of the contents of the fermenter as well as the capability of the substrate mixture to be pumped. The "wet fermentation" is defined as the digestion of pumpable input with a maximum dm content of 15%. This type of digestion can mainly be found in farm-based/ farm-sized plants working with manure.

The so-called "dry fermentation" or "solid-state fermentation" uses substrates with a dm content starting at 30%, where the transport capability can be called stapable. This type of digestion applies to the use of renewable raw materials/ cultivated biomass.

2. Type of Loading

Depending on the feeding system of the fermenter the biogas plant can be defined as a continuous or a discontinuous plant. The discontinuous operation mode, also known as batch operation, is mainly utilized for dry fermentation, where several containers are alternately fed. As a result a constant gas production and quality can be ensured. The batch operation plays a role in laboratory-scale plants for fermentation tests as well.

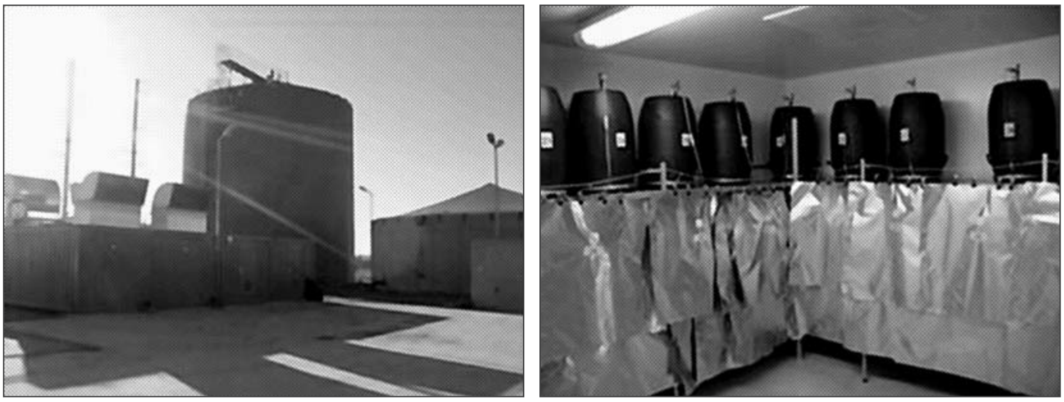


Figure: Batch fermentation (container-scale and laboratory-scale) (Photo: Fachverband Biogas e.V., University of Rostock)

The prevailed operation is the continuous operation mode. The fermenter is fed regularly several times a day. After the start phase, in which the plant is start up a constant gas building is ensured.

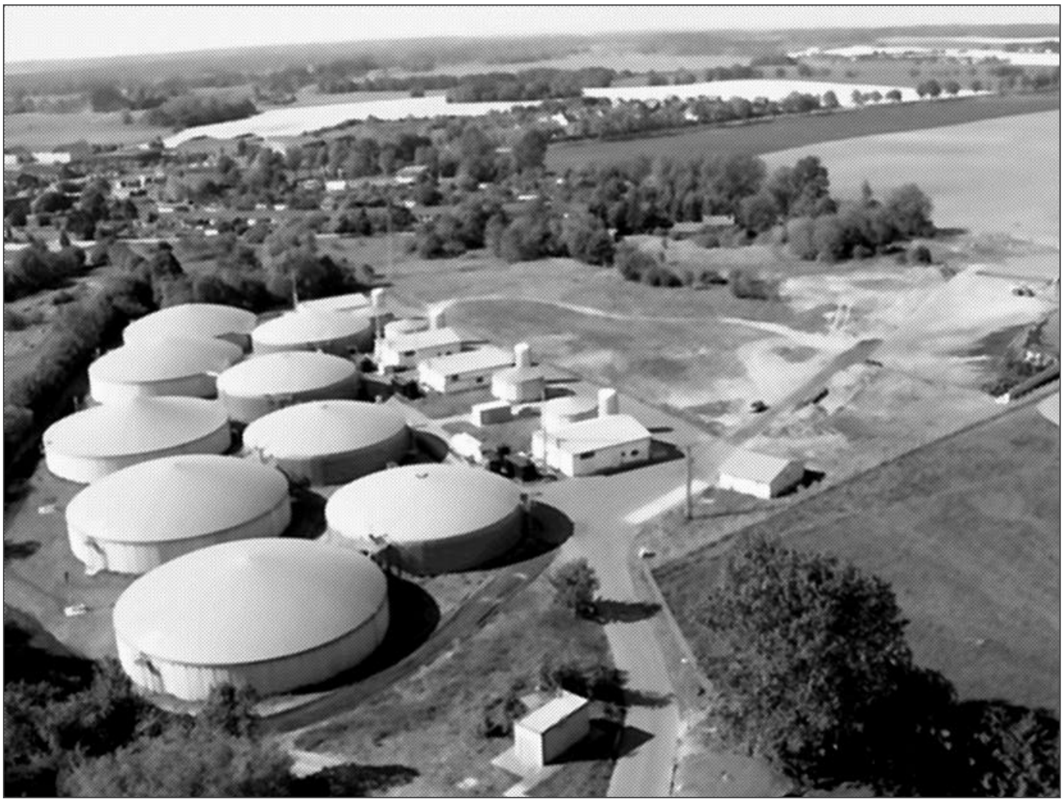


Figure: Continuous working biogas plant (Photo: Bützower Wärme GmbH)

3. Number of process phases

If the biological steps of hydrolysis (and acidogenesis) and methanation, with the specific demands on environmental conditions, e.g. pH-value, are separated, that means the decomposition of macromolecules is located upstream from methanation, the process consists of two phases. If all phases of biological degradation take place in one container, the process is called one phase.

4. Temperature range

<u>Psychrophilic (< 25°C):</u>

The psychrophilic temperature range does not lead to a high degradation and gas building capacity of the process. It is therefore not suitable for a business orientated plant.

<u>Mesophilic (37°C to 42°C):</u>

Most biogas plants operate in a mesophilic temperature range. It is the optimum temperature for a stable methane bacteria growth and hence for gas building as well.

<u>Thermophilic (50°C to 60°C):</u>

The thermophilic degradation shows fast degradation rates compared to mesophilic temperature range but also has the tendency for higher instability. A transition from mesophilic to thermophilic operation is possible through self-heating of the process.

Biogas treatment and conversion pathways

With regard to the composition of the contents of the biogas produced during digestion, named CH_4, CO_2, H_2S, water vapour and other, a treatment of the gas is necessary to allow a subsequent use. The various utilization paths require different types of treatment and upgrading. The biogas feed-in requires every single cleaning and upgrading steps and a final adjustment to natural gas quality. The cleaning and upgrading steps will be summarized in the following sections.

Gas cleaning and Upgrading (Bio-methane)

1. Drying

The subsequent cleaning facilities need a relatively dry gas, what makes a drying of the water saturated raw biogas inevitable. For this purpose three different types of drying are qualified. Through cooling the raw biogas under dew point, condensation of water vapour and other water soluble compounds can be managed. The principle of condensation drying is suitable for a subsequent CHP use of the biogas.

The absorption drying applies to bio-methane upgrading. In this procedure water vapour and hydrocarbons are separated by leading the biogas in a countercurrent process through glycol – the so-called glycol washer. This method is suitable mainly for high volume flow rates. For small and middle volume flow rates the adsorption drying is possible. This method provides a high drying performance by adsorbing water vapour on silica gel, zeolite or aluminium oxide.

2. Desulfurization

Hydrogen sulfide is a toxic gas that forms sulfuric acid when water vapor is present. On the one hand this acid causes corrosion on components of the plant, especially gas pipes and engines and on the other hand the efficiency of the downstream cleaning stages, e.g. carbon separation, are affected in a negative way.

The process of desulfurization can either be carried out biologically or chemically. The subsequent use and hence the level of cleaning determines the applied method. During the process of biological desulfurization, which is often carried out inside the fermenter, air is injected by a compressor and sulfur oxidizing bacteria convert hydrogen sulfide (H_2S) into sulfur (S). The bacteria populations are not able to react on fluctuating gas and H_2S amounts, so that the level of desulfurization can fluctuate as well. A cleaning capacity of 50 – 2.000 ppm is possible, whereby the cleaned biogas is suitable for combustion in CHP plants.

The external biological desulfurization can perform higher cleaning levels. The trickling filtration facilities contains of bacteria carrier material and a bacteria solution. The raw biogas is led through the carrier and the solution by what the H_2S-adsorption and oxidation is carried out. This method can eliminate up to 99% of the H_2S. The maximum cleaning level is 50-100 ppm. Due to high oxygen addition this method is not suitable for bio-methane upgrading. The biological air washers base on a counter-current principle. The raw biogas flows through an alkaline washing water, where H_2S is absorbed. The sulfur oxidation in the washing water is realized in the second process step. A purification capacity of 50 to 100 ppm is accessible even high loads. The biological air washer is suitable for bio-methane upgrading.

The sulphide precipitation is a chemical method of desulfurization inside the fermenter. Iron compounds are added to fix the sulphur to the digestate. A purification capacity of 50 to 500 ppm is possible for plants with low H_2S contaminations. The highest purification level can be realized with activated carbon adsorption. Purification capacities of < 5 ppm can be realized, what qualifies the method for bio-methane upgrading.

3. Carbon dioxide separation

The main components of biogas are methane and carbon dioxide. The carbon dioxide separation is a main part of methane enrichment, which is necessary for the biogas to be fed into the natural gas grid. Several methods are implemented for this application and are summarized in the following table:

Method	Description
Pressure Swing Adsorption (PSA)	Zeolites, activated carbon or other carbon molecular sieves are used as an adsorbent that permeates CO_2 under pressure. The desorption is realized by reducing the pressure. CH_4-contents of > 97% are possible.
Pressure Water Scrubbing	In countercurrent process the compressed raw biogas is led through a absorber column, where CO_2, H_2S and NH_3 is absorbed in water, which is sprayed from the top. The desorption is realized by reducing the pressure. CH_4-contents of > 98%.
Amine Wash (chemical wash)	In the amine wash process biogas is led through a washing media, where the components to be separated are absorpted. For the CO_2 separation Monoethanolamin is used as a washing media. Methyldiethanolamin and Triethanolamin are suitable for CO_2 and H_2S separation. The desorption is realized with water vapour. CH_4-contents of > 99%.

Method	Description
Selexol/Genosorb Scrubbing (physical wash)	The compressed biogas is put into contact with a washing solution (genosorb) that is able to absorb water vapour, CO_2, H2S. The desorption is realized by reducing the pressure, heating and rinsing. CH_4-content > 96%.
Membrane Separation	Separation of the gas components at the membrane basing on their different diffusion rates. CH_4-content > 96%.
Cryogenic Process	The cryogenic separation consists of two process steps. First the pre-treated biogas is liquefied (rectification) and in the second step the separation takes place at a low-temperature level by freezing carbon dioxide. CH_4-content > 99%.

Table Reference: FNR (2010)

4. Oxygen separation

The feed-in of biogas into the natural gas grid requires the compliance of national and international regulations. This also includes the maximum oxygen content of the bio-methane. Hence the separation of oxygen is mandatory. For this purpose the catalytic oxygen separation at palladium-platinum catalysts, where hydrogen reacts with oxygen to form water and the chemisorptions at copper-contacts are qualified.

Final adjustments

For the biogas upgrading to bio-methane, which fulfils the requirements for natural gas, final adjustment have to be carried out. Odorization of the inodorous bio-methane with sulphur-containing organic compounds and lately sulphur-free odorant is to ensure the perceptibility of the gas at leaks.

Furthermore a combustion characteristics adjustment has to be carried out to adapt bio-methane to the applied natural gas, which is characterized by the heat value, the relative density and the Wobbe-Index. The addition of air decreases and the addition of propane-butane-mixture increases the heat value. Under certain circumstances, depending on the grid to feed-in, an adjustment of the bio-methane pressure can be necessary.

Utilization of biogas

Use by Combined Heat and Power (CHP)

The use of biogas for a combined heat and power production is the most implemented conversion path in Europe. Mainly CHP plants with combustion engines coupled with a generator are used. To ensure the interoperability between the generated electricity and the public electricity grid, the engines operate with a constant revolution per minute (rpm). To drive the generator different types of engines are suitable for this purpose – different types of pilot injection and gas-Otto-engines (spark-injected), micro gas turbine or fuel cells.

The efficiency of the whole plant also depends on heat using concept for the exhaust heat. Depending on the location of the plant different concepts are conceivable. An important utilization path of the exhaust heat is the maintenance of the process temperature. It is used to heat up the substrate and the fermenter and keep the process stable.

Further heat use on the farm site consists in heating farm buildings (green houses, stables, aquaculture plants etc.) and residential buildings. In addition the supply of surrounding businesses and industries with heat and process steam is possible as well, depending on the demand and possible supply. As heating the farm building and the surrounding infrastructure is one possible heat use, also cooling this infrastructure is possible by converting heat into cold through sorption methods (Combined Heat Power Cold).

The heat supply of surrounding villages in a local heat grid is a more and more popular utilization path. Hereby advantages are offered for both partners. On the one hand the biogas plant owners can regularly and predictable sell a defined amount of heat, contribute to the local added value and increase the acceptance of their plants. On the other hand the consumers can reduce their energy costs, have a high supply security and are independent from energy-imports and the big players in the system.

A further possibility to use the exhaust heat is to produce additional electrical power by the principle of Organic Rankine Cycle (ORC). By evaporating a working fluid, which has a low boiling point, the ORC-turbine and the coupled generator are driven in order to produce additional electrical power. Furthermore many other heat using concepts already are or are to be developed in the next years, as an increasing efficiency of the plants is necessary to keep them profitable and requirements on sustainability gain importance.

Feed-in into natural gas grid

The feed-in of bio-methane into the natural gas grid represents an increasingly important utilization path of biogas. The grid provides storage capacities for renewable energies, which are urgently needed for further developments in this sector. There are several possibilities of distinction for the natural gas grid. It can be distinguished by the transported gas quality (high caloric and low caloric), by pressure levels (low, medium and high pressure grids or by supply level (transmission grid, supra-regional transportation grid, regional transportation grid and regional distribution grid).

The feed-in is subject to several national and international regulations, that characterize the quality requirements, the access to the grid etc. In Germany the DVGW (German Association for Gas- and Water-Compartment) regulates the quality requirements. To comply with the requirements the biogas has to pass the cleaning and upgrading steps mentioned above.

Figure: Symbol of bio-methane use for vehicles (Photo: Corntec GmbH)

Use as fuel for vehicles

Currently there is a variety of gas-powered vehicles available. Shall the biogas be used as fuel for these vehicles, it has to be adjusted to the required quality. On this account hydrogen sulphide, carbon dioxide and water vapour have to be separated and, as most of the cars are natural gas vehicles, it has to be upgraded to natural gas quality. For the application in the car the gas is compressed up to 200 bar and stored in a pressure tank.

Use for thermal energy production

Another, very simple, utilization path is the combustion of cleaned biogas for heat supply. Therefore burners are applied that are capable to combust different types of fuels. For biogas that is not upgraded to natural gas quality, the burners have to be adapted to the operation with biogas as corrosion is very likely.

Annex: Best Practices

KARPALUND- BIOGAS PLANT

KRISTIANSTAD MUNICIPALITY, SWEDEN
YEARLY GAS PRODUCTION: 41,000 MWH/ YEAR
START OF OPERATION: 2006

At the biogas facility in Karpalund, sorted household waste, by-products from the food industry and liquid manure is fermented in two anaerobic digesters with the volume of 6,000 m³ and 4,000 m³ where the substrates turns into biogas and certified bio fertilizer.

The produced biogas is transported through pipelines to upgrading facilities, where carbon dioxide and other unwanted content in the biogas is removed to increase the energy content in the biogas making it suitable to be used as fuel for vehicle. One of the upgrading facilities is located at Kristianstad's wastewater treatment plant that also produces biogas from sewage sludge.

The other upgrading plant is situated next to the bus depot in Kristianstad where the local bus fleet (city buses and intercity buses) are being filled up with locally produced biogas. There are also two filling stations available for personal cars and light duty vehicles in the city of Kristianstad. The residual products from the anaerobic digester are certified as biofertilizer and spread on nearby fields. The plant has a capacity to treat up to 150,000 tons of raw material per year.

The facility in Karpalund produces 41 GWh of biogas every year, corresponding to about 4, 4 million litres of gasoline. During the year 2012 approximately 39,000 MWh of biogas was sold as vehicle fuel, equivalent to over 4.2 million litres of petrol. The rest of the not upgraded biogas is used for production of heat at the at the district heating plant Allöverket.

More information:

www.kristianstad.se

WOODCHIP-FIRED HEATING PLANT IN JEZIERZYCE

JEZIERZYCE, POMERANIAN VOIVODESHIP/POLAND
OWNED BY: COMMUNAL PLANT IN JEZIERZYCE
MORE: WWW.ZGKJEZIERZYCE.PL
INSTALLED POWER (THERMAL): 1.30 MW
IN OPERATION SINCE: 2009

Woodchip-fired heating plant in Regional Biomass Centre (RBC) in Jezierzyce supplies housing complex and public utility buildings with heat. Used as biomass here are willow chips as well as coniferous and deciduous trees chips. However, in RBC there is not only a heating plant, but also the exhibition centre of renewable energy sources. The latter consists of a small wind power plant, a solar installation, one willow wood chips cutter and one conference-training hall. The photovoltaic cell and wind turbine are producing electrical energy. It makes the RBC a unique example that produces green energy from different sources – not only biomass, but solar and wind installations too.

Data sources:

1. Communal Plant in Jezierzyce
2. http://www.dobrepraktyki.pl/index.php?p1=4&p2=17&art=240&s=2
3. http://www.gp24.pl/apps/pbcs.dll/article?AID=/20090722/POWIATSLUPSKI/695879863



ALLÖVERKET – COMBINED HEAT AND POWER PLANT

KRISTIANSTAD MUNICIPALITY, SWEDEN
YEARLY ELECTRICITY PRODUCTION: 70 000 MWH
YEARLY HEAT PRODUCTION: 330 000 MWH
IN OPERATION SINCE: 1995

Allöverket is a bio-fuel-powered combined heating and power plant, established in 1995. It is estimated to have reduced emissions of carbon dioxide in the municipality of Kristianstad with more than 120,000 ton. The bio-fuel is waste from forestry such as forest residues, stem wood, residues from sawmill and a small amount of bark, sawdust and clean wood waste. It is collected from within a radius of 80 km. The most used fuel type for transportation is biogas and secondly diesel. There were two boilers which are fired with biofuels on Allöverket year 2010. The capacity of the thermal boilers is 75 MW (50MWth + 25 MWel), and the power of the generator is 15 MW. A second generator is to be installed 2013 with a capacity of 7 MW. The heat production was around 330,000 MWh and electricity production was 70,000 MWh in 2010. The boiler's heat production efficiency amounts to around 93% and is about 35% for electricity production.

More information:

www.kristianstad.se / Lennart Erfors, Kristianstad Municipality

HYDROPOWER PLANT IN KOTOWO

ŁYNA RIVER, KOTOWO, WARMIAN-MAZURIAN VOIVODESHIP, POLAND
OWNED BY: ENERGA HYDRO SP. Z O.O
MORE: WWW.ENERGA-HYDRO.PL
INSTALLED POWER: 1.00 MW
IN OPERATION SINCE: 2010

The hydropower plant in Kotowo is located in 125+750 km of Łyna river and is the second object of a planned cascade. It plays an important role in the ecosystem of the river. Waste material flowing down the river is extracted from the inflow screens and forwarded to utilization. Water flowing through the turbines gets aerated. Barrage is provided by a fish ladder equipped with resting chambers of different size with and a bottom lined with stones of different grain size, forming friendly spaces for resting fishes. Thanks to its length (134 m) and additional static channels filled by boulders, it looks like natural stream. As it surrounds the area of the plant, it seems to be a medieval moat around a castle.

Data sources:

1. Energa Hydro Sp. z o.o.
2. www.energa-hydro.pl/1,439,Historia-i-opis-.html
3. www.bartoszyce.wm.pl/33213-0,Elektrownia-Wodna-w-Kotowie,809852.html?



LILLGRUND – OFFSHORE WIND POWER

MALMÖ MUNICIPALITY, SWEDEN
OWNER: VATTENFALL VINDKRAFT AB
YEARLY ELECTRICITY PRODUCTION: 330,000 MWH
IN OPERATION SINCE: 2007

Lillgrund was built as a pilot project for off-shore wind power in Sweden. Therefore, there is extensive knowledge within the construction of the site, from financial to environmental aspects. The environmental impacts of the wind power plants have been thoroughly investigated and the process of finding public acceptance for the plant is well documented.

Lillgrund is an off-shore wind power park consisting of 48 turbines, hub heights of 68.5 m and rotor diameters of 93 m. The total installed power is 110 MW (48 á 2.3 MW).

More information:

http://powerplants.vattenfall.com/node/400

MCT BRATTBERG AB – HYDROPOWER

LYCKEÅBORG, KARLSKRONA MUNICIPALITY, SWEDEN
INSTALLED POWER: 80 KW (MAXIMUM 110 KW)
YEARLY ELECTRICITY PRODUCTION: 400 MWH
IN OPERATION SINCE: 2011

The hydropower plant at the company MCT Brattberg is located by the river Lyckebyån. It is a good example of how a small head (3 m) and a small water flow (in average 2.9 m^3/s) can be used for electricity production without any adverse environmental effects. Different businesses have used the river as a power source since 1760 and onwards. The current state of the hydropower plant was put into operation 1958 and was totally renovated 2011. The renovation included change of all electrical installations and computerized control systems as well as renovation of turbines and runner blades. The plant is connected to the internal electricity grid of the company as well as the external grid, where the surplus is sold using certificates (e.g. nights and weekends). Before the renovation the plant was only connected to a heater for tap water and heating of the buildings of MCT Brattberg. The plant now runs an air/water heat pump, and the oil consumption has decreased by more than 40%.

BIOGAS POWER PLANT IN NACŁAW

NACŁAW VILLAGE, WEST POMERANIAN VOIVODESHIP, POLAND
OWNED BY: POLDANOR S.A.
MORE: WWW.POLDANOR.COM.PL
INSTALLED POWER (ELECTRICAL / THERMAL): 625 KW / 680 KW
IN OPERATION SINCE: JUNE 2010

The Biogas Power Plant in Nacław consists of a field for components with a system of solid substrates supply (moving floor system), reservoirs (for liquid components, preliminary reservoir (1,000m^3), fermentation reservoir (1,500m^3) and post-fermentation reservoir (2,000m^3)), a technical building and a dual chamber reservoir for fermented liquid manure (20,000m^3). Liquid manure and corn silage play the dominant role as substrates for biogas production.

The biogas plant in Nacław is arranged in a way that allows keeping much of the sustainable development in the whole supply chain. In transport organization, rapid and low emission approaches are used: the landfill substrates are located near the bioreactors, so there is no need to transport them over long distances. Energy and heat are produced in cogeneration, which enables more effective use of substrates. Fermented slurry is used as a fertilizer in agricultural fields, and is applied to the soil by special bands just above the ground, so there is no loss of nitrogen.

Data sources:

1. POLDANOR S.A.
2. www.poldanor.com.pl
3. www.pois.gov.pl/Wiadomosci/Documents/8_Poldanor.pdf

SÖDERÅSEN BIOGAS PLANT

LOCATION: NEAR BJUV IN SKÅNE
AMOUNT OF GAS-FEED IN: 25 GWH PER YEAR
IN OPERATION SINCE: 2006

The biogas plant is dimensioned to treat approximately 65,000 tons of substrates of different nature. A large portion of the substrate at the facility today consists of sludge from a food company's internal treatment plant and is pumped to the biogas plant. Additionally, slaughterhouse waste, pig manure etc. are transported to the biogas plant by truck.

The biogas produced at the plant is upgraded and injected to the natural gas grid to be sold as vehicle fuel. In 2007-2008, the plant digested more than 50,000 tons of substrate and injected 2,500,000m³ gas/year = 25 GWh per year. The bio fertilizer produced at Söderåsen biogas plant leaves the facility in several ways. More than 25% or about 14,000 tons of the bio fertilizer are spread via pumping tubes in order to reduce the number of trucks to transport the manure. About 2,000 tons are taken by tractor to be spread on farmland a few kilometers away from the biogas plant. The remaining approximately 70% are stored and used depending on when one is allowed to spread the fertilizer.

Summary:

_ The methane leakage with upgrading in this plant is low.
_ The leakage of the CH_4 with production of biogas is low
_ To avoid releasing methane at potential problem in upgrading plant, biogas plant is equipped with a torch that will burn the excess gas.
_ Using a spreader tube system, this pumps the bio-fertilizer in the tubes to spread it in the fields, in order to reduce the number of trucks to transport the manure.

More information: www.bmz.se/dokument/biogas.html
Kjell Christensson, Skåne Energy Agency

KUNGSMADSKOLAN – PHOTOVOLTAIC PANELS

VÄXJÖ MUNICIPALITY, SWEDEN
INSTALLED POWER: 0.13 MW
YEARLY ELECTRICITY PRODUCTION: 110 MWH
IN OPERATION SINCE: 2008

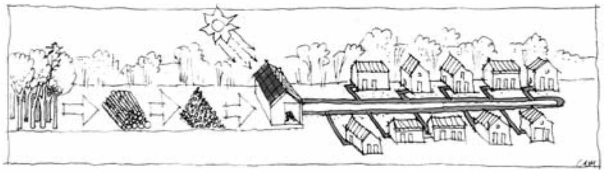
Kungsmadskolan in Växjö, a school with 1000 high school students built in 1962, is an example of photovoltaic installation on a school building. On an existing saw-toothed roof with optimal orientation, southward in 30° angle, 1,021 m² of solar cells were installed and connected to the local electricity grid. The yearly electricity production is 110 MWh. The electricity production is shown on two displays, one outside and one inside the school. Since a reinforcement of the roof to carry the weight of the installation was necessary, the roof was improved with 100 mm extra insulation. Also the old windows on the north side of the saw-teeth were replaced, and the total need of heat energy was reduced.

More information:

www.swedishcleantech.se/en/find_cleantech/Plantscontainer/Kungsmadskolans-solar-cells-in-Vaxjo/

BIOMASS AND SOLAR HEATING SYSTEM STELLSHAGEN

VILLAGE STELLSHAGEN, ADMINISTRATIVE DISTRICT NORTH WEST MECKLENBURG
OWNED BY: HWS HOLZWÄRME STELLSHAGEN E.G.*
INSTALLED POWER (THERMAL) WOOD CHIPS: 190 KW
INSTALLED POWER (THERMAL) SOLAR THERMAL: 67 KW
IN OPERATION SINCE: NOVEMBER 2010



In 2010, inhabitants and interested landlords built a central heating station to supply their village with heat and warm water. This heat production on the basis of regional wood chips was supported by a thermal solar system and distributed via their own local 1,089 m heating net. The connected residents have been supplied centrally with heat since November 2010. In the 1st stage of development, 14 customers were supplied, with approx. 2,000 m² apartments and business premises in total. Despite of the high investments in the beginning, the long term calculation is profitable, shown by the reached parameters of power and the economically figures so far.

The inhabitants of Stellshagen are the first in the region who are able to supply themselves with central heat made of regional wood chips owned by them. They have demonstrated that it is possible to build and operate a sustainable local heating system in a rural area. Thus, the project "HWS Holzwärme Stellshagen eG" is the first best practice for the initiative "(Bio)Energy Villages MV", while not coached by the initiative, but developed by the inhabitants itself.

**cooperative society that comprises of 10 inhabitants of Stellshagen*

SÖDRA LJUNGA NEARBY HEATING PLANT

SÖDRA LJUNGA, LJUNGBY MUNICIPALITY, SWEDEN
YEARLY HEAT PRODUCTION: 500 MWH
IN OPERATION SINCE: DECEMBER 2008

The heating network consists of a school, a church, four houses and six apartments. Before the implementation of the nearby district heating facility, these facilities consumed approx. 60,000 liters of oil per year which gave rise to around 160,000 kg CO_2 / year.

During the planning of Ljunga Nearby Heating plant the farmers had the support of the municipality. The municipality actively supported the installation of a renewable energy system in this village. The yearly heat production of this plant is about 500 MWh which results from burning 1,000 m^3 chips. The fuel used here is wood chip with wood pellet as a reserve. The wood chips for the plant come from surrounding forests. The owners are currently supplying all the wood chips. The chips are transported two times a year by trucks to the plant from a 5-10 km distance.

The bottom ash from burning of the chip is rich in nutrients and mixed with manure and then spread on the fields. The total estimated efficiency of the boiler in this plant is near 66%.

More information:

www.bioenarea.eu/practices/sodra-ljunga-nearby-heating/

Some photo impressions ...















More impressions?

Please, visit the website of the school contest "Renewable energies" implemented in our project.

www.res-photography.eu