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VIRTUAL BALKAN POWER CENTRE FOR ADVANCE OF RENEWABLE ENERGY SOURCES IN WESTERN BALKANS

WORKSHOP 1.1: GUIDELINES FOR RENEWABLE ENERGY SOURCES TECHNOLOGIES

AGENDA

Bosnia and Herzegovina, Tuzla, University of Tuzla, Faculty of Electrical Engineering
10. March – 11. March, 2005

Thursday, 10th March

$8^{30} - 9^{00}$	**Welcome coffee – Registration**	
$9^{00} - 10^{00}$	**Welcome and Introduction of participants and guests**	**UNTZ**
$10^{00} – 10^{30}$	**Introduction of the Workshop**	**JR**
$10^{30} – 11^{00}$	**RES Potentials**	**DMSG**
$11^{00} - 11^{30}$	**Short Description of all Relevant RES**	**JR**
$11^{30} - 12^{00}$	**Wind Power**	**UNI-ZG**
$12^{00} - 12^{30}$	**Photovoltaic**	**UNIMB**
$12^{30} - 13^{00}$	**Biomass Fired ORC-Power Generation**	**TUS**
$13^{00} - 15^{30}$	**Official Lunch**	
$15^{30} - 16^{00}$	**Biomass Fired Stirling Engine Power Generation**	**JR**
$16^{00} - 16^{30}$	**Small Hydro Power**	**INTRADE, ETF**
$16^{30} - 17^{00}$	**Absorbtion refrigeration**	**JR**
	End of the first WS day	

Friday, 11th March

$09^{00} – 10^{00}$	**Geothermal**	**CRES**
$10^{00} - 10^{30}$	**Biogas Production&Power Generation with Otto Engine**	**JR**
$10^{30} - 11^{00}$	**Pelletizing of Woody Fuel for Room Heating for Small Automatic Boilers**	**ISTRABENZ**
$11^{00} - 11^{30}$	**Short Review of Biomass and Solar Driven Equipment**	**“People heating” Co.**
$11^{30} – 12^{30}$	**General Discussion**	
$12^{30} – 14^{00}$	**Lunch Break**	
$14^{00} – 15^{00}$	**Planning our future VBPC RES Project activities**	
15^{00}	**End of workshop**	

Sixt Framework Programme, Priority 6
Sustainable Development, Global Change and Ecosystems
Contract: INCO-CT-2004-509205

Participants

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6. Framework Programme, Priority: International Cooperation (INCO),
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**Virtual Balkan Power Centre for Advance of
Renewable Energy Sources in Western Balkans**

Balkan Power Center Report

Guidelines for Renewable Energy Sources Technologies

Workshop T.1.1, WP 1

**University of Tuzla, Faculty of Electrical Engineering, Tuzla,
Bosnia and Herzegovina, 10. – 11. March, 2005.**

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INDEX

SUMMARY

During the two days workshop “Guidelines of Renewable Energy Sources Technologies” which was held in Tuzla, Bosnia and Herzegovina, the participants have presented their contributions. The Workshop belongs to the project “Virtual Balkan Power Centre for Advance of Renewable Energy Sources in Western Balkans”, project acronym: VBPC-RES, Contract INCO-CT-2004-509205, under the Sixth Framework Programme, Priority 6, Sustainable Development, Global Change and Ecosystems. The Workshop No. 1.1 is a part of the Work Package 1 (WP1) of the VBPC-RES project.

From the technical point of view the contributions reflect the deep knowledge of the authors on the presented topics. The contributors presented many interesting details regarding design, operation conditions, technical details, selection of the suitable and the cost-effective equipment. The contributions were understandable and a benefit for the audience.

The organizing committee could welcome representatives of the state energy regulatory commission, Canton of Tuzla’s Ministry of Science and Ministry of Industry, Canton of Tuzla’s Ecology Agency, graduate and postgraduate students, interested entrepreneurs and the participants of the project. All of them have actively discussed the best solution regarding the RES technologies which can be successfully applied into isolated regions.

At the beginning of the workshop Prof. Halilčević, University of Tuzla, as the host and the organizer of this workshop (WS) greeted the participants. The introduction to the WS was made by Dr. Podesser from Joanneum Research, Institute of Energy Research, Graz, Austria. He underlined the main goals of the Work Package 1 with special emphasis on the Task 1.1. His presentation comprised a short review of our tasks, the way of our collaboration, best available conversion technologies and practical experience in RES implementation.

The program of the WS comprised 11 contributions from Project Partners. The main points of their contributions are presented below.

D. Popović, E. Boškov, DMSG, Novi Sad, Serbia and Montenegro: “Potentials of Renewable Energy”

The opening contribution presents the objectives and the strategy of implementation for each renewable energy source in Western Balkan countries (WBC) depend on its specific characteristics and the program of use. It was assumed that the WBC could have in common a significant increase in the share of renewable energy sources in the next decades, which will follow the general trend in EU countries.

The Renewable Energy Sources (RES) - technologies like bioenergy, geothermal heat, small-scale hydro power, low temperature solar heat, wind electricity, photovoltaic and thermal driven electricity production have the potential to provide energy services with zero or almost zero emissions of both air pollutants and greenhouse gases. The analysis of the renewable energy potentials requires detailed investigations on theoretical, physical, technological, environmental and economic aspects. Some of the leading RES with significant potential in WBC have been introduced from this perspective. The WBC analyzed in this study is: Bosnia and Herzegovina, Croatia, Macedonia and Serbia and Montenegro. The current status of total energy generated from RES and its forecasted increase, as well as the installed capacities is provided. National RES strategies will have to be harmonized with the EU strategy. Some of the priorities that can be realized in WB countries with short pay back period are revitalization of old/non-functional small hydro power plants, replacement of electricity and liquid fuel for heating, wind projects, utilization of available bio waste in industry and agricultural farms. Significant barriers which stand in the way of the accelerated development of renewable technologies can only be overcome by appropriate frameworks and R&D policies. As energy market is currently changing by the process of liberalization, the support mechanisms which are compatible with open market philosophy must be adopted.

M. Božičević, University of Zagreb, Croatia: "Wind Power"

In the contribution the wind power is analyzed as one of the possible solutions for energy supply in isolated regions of the WB countries. The major application of wind energy today is electricity production, with two major fields – isolated grid or central grid applications. Guidelines for design of a wind turbine, taking into account the wind speed properties of a given location are presented, as well as the aspects of turbine design. Factors influencing the amount and quality of electricity produced have been thoroughly discussed. Because wind speed fluctuates randomly, extensive guidelines for operation and control of a wind power plant are presented. Current trends of the design of wind turbines as well as their economic and environmental behavior are discussed.

A. Hanžič, University of Maribor, Slovenia: "Photovoltaic"

The photovoltaic (PV) technology is presented in this contribution. Due to a lack of electrical energy in the world, the countries need to ensure the appropriate production of electrical energy to achieve economical independence. Under the EU there are several programs to foster electrical energy from RES to satisfy the need for electrical energy as an alternative to conventional energy sources. Judging by a growing number of applications, the European market is very interested in solar energy, especially in PV products. At the same time, also the Western Balkan regions will be a very interesting future market for PV products.

The photovoltaic power systems have made a successful transition from small stand-alone sites to large grid-connected systems. The utility interconnection brings a new dimension in the renewable power economy by pooling the temporal excess or the shortfall in the renewable power with the connecting grid. This improves the overall economy and the load availability of the renewable plant; the two important factors of any power system. In the more distant future environmental concerns and the finite supply of fossil fuels make it certain that the sun, as the only inexhaustible energy source, will also be used for large scale power supplies. Just a fraction of the solar energy that falls upon the earth would cover our entire current energy demand. Thus, no restrictions are presented by the original energy supply. At the end, he stated that the investment in PV technology and production is excused as soon as we take a look of today and tomorrow PV market.

D. Popov, Technical University of Sofia, Bulgaria:
"Biomass-fired ORC-Power Generation"

The contribution introduced to the audience the basic principle of Organic Rankine Cycle (ORC)-power generation plants. Power plants based on ORC are very promising solution for biomass co-generation with nominal ratings between 450 and 1500 MW electric per unit. The ORC is a thermodynamic cycle that uses an organic working fluid (instead of steam) to generate electricity. Seven years after the commissioning of the first industrial installation of a biomass cogeneration plant based on an ORC turbo-generator and thermal oil boiler several reference plants are running successfully in Europe in continuous and unattended operation.

The biomass potential in West Balkan Counties is abundant but not quantified well yet. The contribution also presented a survey on the existing biomass potential for the countries in the region, notably Albania, Bosnia and Herzegovina, Croatia, FYRO Macedonia, Serbia and Montenegro. The application possibilities range from forestry, farming to wood processing. The biomass potential for ORC-power generation in West Balkan Countries is significant, but the overall political and economical conditions have to be done more favorable the construction of pilot and demonstration plants.

E. Podesser, Joanneum Research, Graz, Austria:
"Biomass Stirling Engine"

The contribution focused on power generation by means of the biomass fired Stirling engine. The biomass fired Stirling engines could be an excellent conversion process for power generation in isolated regions in the power range from some kW to about 100 kW, especially in rural areas of the WBC. Biomass must be prepared as wood chips or as log wood for burning in a biomass furnace. The hot flue gases of the biomass furnace in the temperature range of about 800 to 1000 °C are used directly without hot gas cleaning. The critical section of the plant is therefore the heat transfer from the hot flue gas to the heat exchanger of the engine. Meanwhile engine experts are able to design the hot heat exchanger in such a manner that fouling by the ash content of the flue gas could be avoided. But cleaning of the heat exchanger is necessary time by time. The Stirling engine itself can convert about 25 % of the transferred heat in shaft power. In applications at district heating plants about 9 % of the biomass fed is converted in electricity and the rest is sold as heat to the consumers. The share of the power of this conversion process could be increased up to 18 % of the burned biomass if the heat rejected is not needed for room heating purposes.

A. Ajanović, Intrade, Sarajevo, Bosnia and Herzegovina
N. Rajaković, University of Belgrade, Serbia:
"Small Hydro Power"

The experience in small hydro plants for generation of electricity is presented in this contribution. The authors introduce the hydropower as the leading renewable source for energy production. Energy production using hydropower can avoid emissions of CO_2 and greenhouse gasses into atmosphere is reduced, while a well-designed small power plant can be easily fit into local eco-systems.

To qualify as a small hydro power plant (SHPP), a typical installed capacity ranges from 3 to10 MW, depending on a country. SHPP transforms the potential energy of water via kinetic into electrical energy. The most important prerequisite which should be checked in order to make a techno-economical justified small hydro power plant must be done in the view of terrain valuation on the places of water intake structure, derivation canal and/or pipeline under pressure as well as powerhouse. In addition, determination of basic parameter of current like flow rate (discharge) and net head must be done. With the correct valuation of mentioned prerequisite it is possible to make an optimum choice of all necessary equipment. A well-designed SHPP has a pay back time between 5 to 10 years, depending on electricity price in the respective country.

E. Podesser, Joanneum Research, Graz, Austria: "Absorption Refrigeration"

Absorption refrigeration is the topic of this contribution. Heat production from RES in isolated regions of the WBC is much cheaper then the production of power. The consumption of electricity and power therefore should be avoided if alternative conversion processes, e.g., thermal driven cooling machines instead of electric driven vapor compression cooler can be used. Especially the absorption refrigeration technique can replace the conventional electric driven cooling for all applications. Absorption refrigeration can be used in the air conditioning sector at evaporation temperature of 5 °C, as cooling aggregates for food storages at –10 °C and in the section of deep freezing at –30 to –50 °C. RES heat production techniques are able to reduce water at that temperature level. About 60 % of the driving heat is transferred in the air conditioning sector in to coldness, 45 to 50 % in the food storage application and 30 to 35 % of the driving heat in the deep freezing sector.

The contribution presents some interesting ideas on component design have been realized already. A broad demonstration of small, heat driven absorption refrigeration machines, which are able to run with RES such as in air-conditioning plants, higher generator temperatures for brine cooling, or in the freezing sector from –20 to –40 °C. The investment costs for these demonstration plants have to be subsidized due to the environmental friendly refrigeration technology by using RES, like solar and biomass. An interesting example of a subsidized demonstration project in Austria, State Styria, is a solar/biomass heat driven ammonia/water cooling machine in a private winery.

R. Padinger, Joanneum Research, Graz, Austria: "Biogas Production"

The biogas production could be a simple and efficient technology for isolated regions with agricultural activities. The manures of cattle, hogs and other animals at a farm are collected automatically in the cowshed, mixed with straw, grass and water and are conveyed in a digester. At temperatures between 28 and 34 °C bacteria grow in the substrate and produce methane by a biochemical process. Besides of about 40 to 75 % methane, carbon dioxide is produced too. The ignition temperature of biogas is about 700 °C and the necessary concentration in air 6 to 12 %. The thermal value of biogas with a 60 vol.% methane is 21,6 MJ/m_N^3 . Biogas can be burned for power production in Otto engines. About 30 % of the thermal energy of the biogas is converted in power, 30 % is available as heat in the cooling water of the engine with temperatures of 70 to 90 °C, and about 30 % contains the hot combustion gas of the engine at about 400 °C. The hot cooling water of the engine could drive thermal driven air conditioning plants and the hot exhaust gas can operate all deep freezing absorption refrigeration applications. Regarding the environmental aspects of this technology it have to be said that methane has a Global Worming Potential which is 21 times higher than carbon dioxide. Therefore the plant must not have any leaks, where methane could be escape.

A. Urbančič, B. del Fabbro, Istrabenz Energetski Sistemi, Nova Gorica, Slovenia: “Pelletizing of Woody Fuel for Room Heating”

The experience on pelletizing of woody fuel for small automatic boilers is presented in the concluding contribution. Pellets are a current and efficient way to use wood in domestic heating. Upgraded fuel improves significantly cleanliness, availability and convenience for use of wood fuels. Wood pellets are produced from sawdust, shaving and chips. Generally, raw material is hard or soft wood, free of bark with ash content of 0,8 % or less. Fuel pretreatment and processing includes all the steps necessary to produce an upgraded fuel from a harvested biomass resource. Fuel characteristics: material of uniform size and structure, dense, large surface, and low water contents enables high efficiency of conversion process.

Pellets, used in special pellet boilers are characterized by high combustion efficiency, low air emissions, very low ash production and fully automatic fuel charging. In addition technical complexity and investment costs are reduced in comparison of woodchip boilers. The contribution briefly presents the physical and chemical characteristics of the fuel, existing standards in Europe and its production. Technical, economic and environmental characteristics of wood pellets domestic heating are described, too, as well as the important elements of its design and selection.

Conclusion

At the end of the workshop T1.1, the German company Lambda, which is introduced into AGR group, presented own experiences using methane from landfill sites and coal mines for electricity generation. They presented the stationary de-gasifying facilities for landfill sites with performance of 100 to 3.000 m^3/h and more. The latest technology guarantees for efficient and ecological treatment of the landfill gas – as large or small as necessary, as quiet as possible, according to local conditions. With existing facilities it is possible to develop 0,9 MW to 1,5 MW electric power, depending on the amount and the quality of landfill gas.

The workshop has been finished with a Consortium meeting, where the results of the workshop were discussed and future activities identified in details.

1 INTRODUCTION

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1.1 Introduction to the work package (WP) 1

The WP 1 of the project "Virtual Balkan Power Centre for Advance of Renewable Energy Sources in the West Balkans" (VBPC-RES) is generally dealing with available technologies of renewable energy. Out of the large variety of well known RES technologies are those selected which are especially suitable for isolated regions of the Western Balkan Countries (WBC).

Isolated regions in the WBC are remote regions like rural areas on the mainland and islands which are not connected to the grid. For those isolated regions economical considerations result that micro and small power stations are significantly cheaper than the construction of the grid connection by transmission lines or sea cables. The common practice in the past and also now is the building of fossil fuel powered engines/generator stations at the islands especially for the summer tourism and for the need of entrepreneurs or in the rural areas to provide the there living people and the small companies with power and light. Therefore in the frame work of VBPC-RES suitable renewable energy sources in isolated regions are identified and available conversion processes are selected. It is therefore the main task of the WP 1 to pick out the best of the proof RES-technologies for transfer and implementation in the isolated regions of the WBC.

The selection procedure of appropriate RES technologies for isolated regions is specially focused on decentralized electricity production. Special emphasis is put on high efficiencies of the conversion processes and on the environmentally friendly technique in comparison to fossil powered one. Due to the fact that the decentralized production of power and electricity by heat engines, photovoltaic plants or other technologies is significantly more expensive and technically demanding, it makes sense to avoid processes, like electric hot water preparation, electricity-driven vapour compression air conditioning and refrigeration for the food storage, and electricity-driven sea water desalination. Hot water preparation can be done much better by solar collectors, biomass combustion or the use of waste heat. Biogas produced in a biogas digester and fed by a micro distribution grid can be used, e.g., for cooking and other domestic chores. Necessary air conditioning and refrigeration could be managed by heat driven cooling processes, like lithium-bromide/water absorption machines or desiccant air conditioning systems in buildings. The well known water/ammonia absorption refrigeration technique can be implemented as well for the production of refrigeration for food storages and for the demand of cold in small companies as well as for air conditioning

The following topics are worked out in WP 1:

- Potentials of RES in isolated regions
- RES - conversion processes for isolated regions (Task 1.1 to Task 1.4)

- *Task 1.1: Guidelines of RES technologies*
- *Task 1.2: RES in isolated regions*. Technical definition of RES-plants.
- *Task 1.3: Operation and control in RES power systems.* Energy distribution, system operation and control in the local network.
- *Task 1.4: RES project implementation:* Technical and non technical aspects of implementation. Barriers and country specific items. Potentials for special implementations.

Important items, like energy storage, system operation and control techniques, techno-economic analysis and environmental impact are integrated in the tasks of WP1.

The task work is done by the participating contractors as the experts on RES technologies and the results are tabled as written contributions. These contributions are presented at the task workshops which are also open for interested experts, students and entrepreneurs of SME in RES.

1.2 Introduction to the Task T 1.1

The Task 1.1 of the WP1 is focused on RES-technologies. Guidelines of RES technologies are worked out by the participating contractors to explain understandable the RES conversion in power and cooling. The well known RES conversion techniques, like hot water preparation by solar collectors or biomass combustion are not directly explained in detail. The main work was concentrated upon conversion technologies using the RES wind, solar, biomass, hydro energy with the output of power or cooling.

An important part of the Task 1.1 is the assessment of the “RES-Potentials” of the WBC. The “Guidelines for RES-technologies” are divided with respect to the audience in three main parts: (1) General, (2) Guidelines for planners, installers and students, (3) Guidelines for politicians and decision makers with a special emphasis on the state of the art, economics and environmental aspects. The technology guidelines are therefore written in such a manner that the mentioned group can understand the explanations easily.

The following arrangement of the guidelines shows the technologies selected and a short description of the content.

Wind power:

Basics on design, power curve of typical turbine, turbine technology, power control, general explanation of the electrical part, state of the art, development need and references.

Photovoltaic

Understandable theoretical introduction, power inverter, protection facilities, state of the art, development trends, environmental impact, system costs and future developments.

Biomass fired ORC-power generation

Existing examples for the technology, thermodynamic background, plant lay out, energy balance, control of the ORC unit, market available ORC-units, specific electricity generation costs, environmental impact, potentials in WBC and references.

Biomass fired Stirling engine power generation

History of Stirling technique, explanation of the Stirling principle, types of engines, state of the art, demonstration plants, development need, environmental data, economical calculation results and references.

Small hydro power

Cost efficiency, global characteristics, utilisation of small reservoirs, perspectives of further constructions, water resources, terrain valuation methodology, hydraulic structures, turbines and generators and references.

Absorption refrigeration

History of RES cooling, sorption refrigeration systems, design tools, principle of the single stage, continuously working cycle, process design results, operation and control, Investment and operation costs, environmental aspects (ozone depletion, global warming, Total Equivalent Warming Impact-TEWI, comparison with vapour compression technique), potentials and references.

Geothermal energy

Generation, kind of usage, temperature levels, electricity generation, non-electric usage, sea water desalination, geothermal greenhouses, room heating and cooling, economical calculations of the geothermal electricity production.

Biogas production

Principle of aerobic fermentation, decomposition, composition of biogas, physical property of biogas, fermentable material, biogas technology in developed countries, biotechnological parameters, technical parameters, process control parameters, design of biogas plants, demonstration of technology, green house gas balance and references.

Pelettizing of woody fuel

Rough woody material features, wood pellet quality standards, pellets production, pellets characteristics, transport of pellets, heating systems, design guidelines of heating systems, environmental issues.

The technologies selected cover an interesting field of applications in the isolated areas of the WB countries, e.g. islands of the Adriatic Sea or villages in rural areas on the mainland.

2 POTENTIALS OF RENEWABLE ENERGY

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2.1 General

The objectives and the strategy of implementation for each renewable energy source in Western Balkan countries depend on its specific characteristics and the program of utilization. However, they all have in common a significant increase in the share of renewable energy sources in the next decades, which is in accordance with the general trend in EU countries. Renewable energy has an important role to play in reducing carbon dioxide (CO_2) emissions. It also helps to improve the security of energy supply by reducing the community's growing dependence on imported energy sources. Renewable energy sources are expected to be economically competitive with conventional energy sources in the medium to long term.

Natural flows of renewable resources are immense in comparison with global energy use. This holds both from a theoretical and technical perspective; however the level of their future use will primarily depend on the economic performance of technologies utilizing these flows.

In a broad sense renewable energy sources refer to hydropower, biomass energy, solar energy, wind energy, geothermal energy, and ocean energy. The term ’new’ renewals suggests a greater focus on modern and sustainable forms of renewable energy, in particular: modern biomass energy, geothermal heat and electricity, small-scale hydropower, low-temperature solar heat, wind electricity, solar photovoltaic and thermal electricity, and marine energy. However, ‘new’ renewals contribute only 2 percent of the world’s primary energy use. Such renewable energy sources that use indigenous resources have the potential to provide energy services with zero or almost zero emissions of both air pollutants and greenhouse gases.

The analysis of renewable energy potentials performs detailed investigations in theoretical, physical, technological, environmental and economic aspects. Some of the leading renewable sources with significant potential in WB have been introduced from this perspective. WB countries analyzed in this study are: Croatia, Serbia and Montenegro, Bosnia and Herzegovina and Macedonia, with provided status of total energy generated from renewable sources and their forecasted increase, as well as installed capacities.

Furthermore, a rapid expansion of energy systems based on renewable energy sources will require actions to stimulate the market in this direction. This expansion can be achieved by finding ways to drive down the relative cost of new renewals in their early stages of development and commercialization, while still taking advantage of the economic efficiencies of the marketplace. In any case, significant barriers stand in the way of the accelerated development of renewable technologies, which can only be overcome by appropriate frameworks and policies. As energy market is currently undergoing the process of liberalization, support mechanisms that are compatible with open market philosophy must be adopted.

2.2 Renewable Sources Potential

A large number of studies have estimated the future potential of renewable energy technologies, both in terms of the technically feasible energy output that could be secured from each technology type, and the economic potential, taking into consideration cost and other limiting factors. The analysis of potentials leads to the following detailed investigations.

- Theoretical potential: It covers the whole energy content, which can be delivered by an energy conversion technology in the WBC. For several technologies (essentially solar, wind, wave and biomass) this potential is large indeed.
- Physical potential: It covers that part of the whole energy content, which is limited by the today known physical properties of a process, amount of energy that might be extracted from the available resource using known technologies (future technology judgments are required, such as conversion efficiencies – will they improve and how much).
- Production-engineering potential: It covers that part of the whole energy content, which is not limited by the production capacity in the WBC
- Ecological-topographical potential: It covers that part of the whole energy content, which is not limited by environmental factors, like pollution of air, water, soil, as well as noise and unfavorable optical changes of the environment.
- Economic potential: It covers that part of the theoretical potential, which can be compared in view of costs with the conventional technique. The application of conversion processes, based on fossil fuels, release pollutant substances, like SO2, NOx, CO, CO2, CxHy and dust, which causes damages on human and environment.
- Politico-economical costs, the so-called external costs, arise and have to be considered.

2.2.1 Hydropower

Hydroelectricity is obtained by mechanical conversion of the potential energy of water in high elevations. An assessment of its energy potential requires detailed information on the local and geographical factors of runoff water (available head, flow volume per unit of time, and so on). Hydropower (large and small) contributes 17 % to production of electrical energy in Europe, ranging from 99 % in Norway, 76 % in Switzerland, 65 % in Austria, 51 % in Sweden, down to 23 % in France, 12 % Czech Republic, 6 % Poland, 4 % Germany, 3 % and less in the UK and some other countries. The estimated hydropower potential and exploitation in Europe is presented below:

Countries	**Economical Feasible Potential (GWh/a)**	**Production from Hydro Plants (GWh/a)**	**Exploitation Ratio (%)**
Selected 15 EU Countries of which	390.000	320.000	82
Austria	50.000	38.000	76
France	72.000	70.000	97
Germany	25.000	25.000	100
Italy	55.000	52.000	95
Spain	40.000	35.000	88
Sweden	85.000	68.000	80
Selected non-EU countries of which	480.000	250.000	52
Romania	30.000	16.000	53
Switzerland	36.000	34.000	94
Turkey	120.000	40.000	33

Source: IEA, Eurostat, Hydropower & Dams and own interpolation/computations

Because rainfall varies by region and country, hydro energy is not evenly accessible. Rainfall may also vary in time, resulting in variable annual power output.

2.2.1.1 Technology options and status

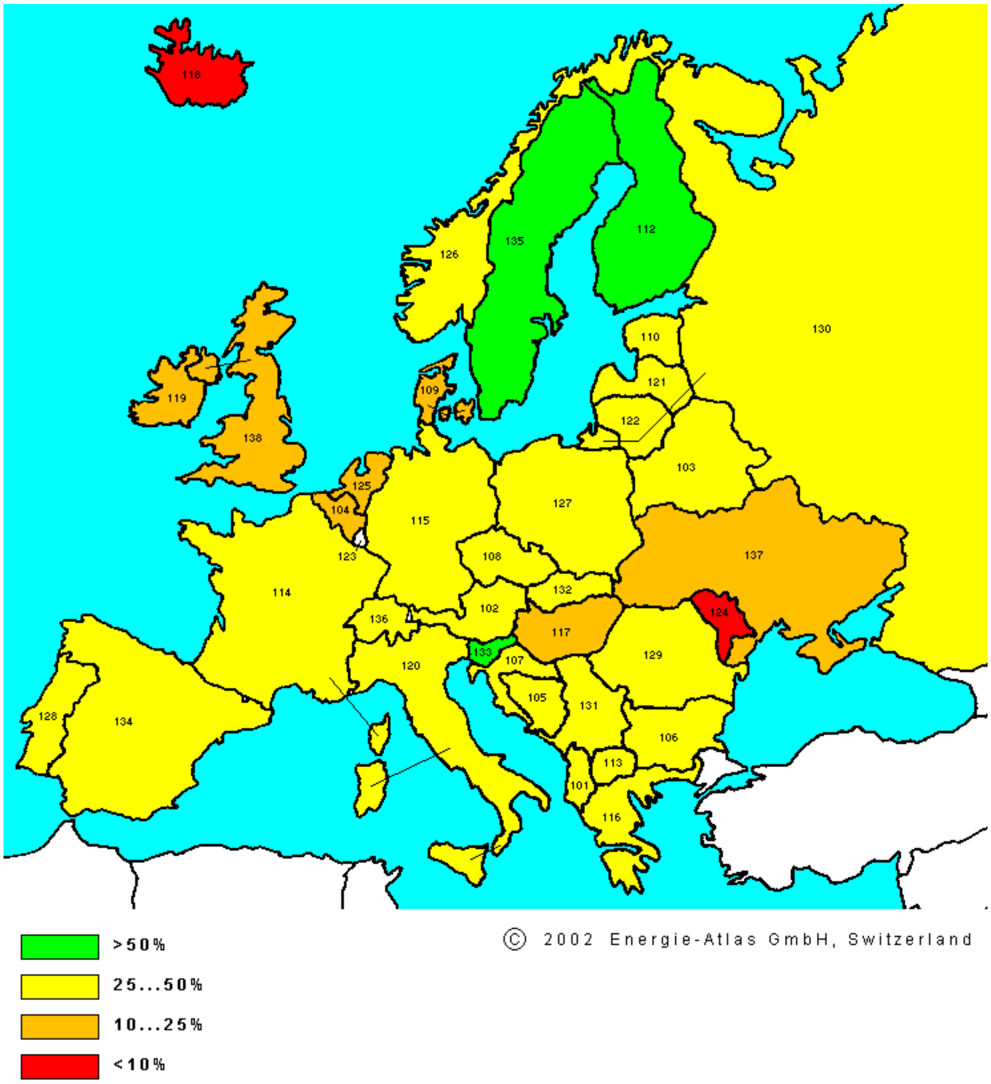
Hydroelectricity generation is regarded as a mature technology, unlikely to advance further. However small-scale hydropower can expect further technical development. These hydropower plants fit into the environment and cause fewer hazardous environmental impacts. With the choice of very favorable sites, the use of existing administration and existing civil works for flood-control purposes, the costs of small-scale projects could come down substantially. The major element of cost-efficient small-scale hydropower plant construction is the short construction period (as the prices of construction materials, manpower and equipment constantly change).

2.2.1.2 Environmental and social issues

Modern construction tries to include in the system design several technologies that minimize the social and ecological impacts. Some of the most important impacts are the displacement of local communities, changes in fish amount and fish biodiversity, sedimentation, biodiversity perturbation, water quality standards, human health deterioration, and downstream impacts. However, it is important to note that hydropower projects (not including the construction phase) produce almost no greenhouse gas emissions or air pollutants.

2.2.2 Biomass

Biomass can be classified as plant, animal manure or municipal solid waste. Forest plantations, natural forests, woodlands and forest waste provide most woody biomass, while most non-woody biomass and processed waste come from agricultural residues and agro-industrial activities. Biomass resources are abundant in most parts of the world. The present biomass contribution to the total world energy needs approaches 14 % (50 EJ/a on a total contribution of 406 EJ/a) and is essentially based on agro-forestry residues and natural forest. However, the biomass challenge is not so much an issue of availability but sustainable management, conversion, and delivery to the market in the form of modern and affordable energy services. Combustion of biomass to produce electricity is applied commercially in many regions. The globally installed capacity to produce electricity from biomass is estimated at 40 GW(e). Large percentage of territory in WB countries is covered in forests, which means that potentials for biomass use are significant.



Europe: Productive forest area in relation to the total area of the country

2.2.2.1 Technology options and status

The use of biomass is a complex system with large variety of raw materials and treatment procedures that offer a lot of options. Biomass energy conversion technologies can produce heat, electricity and fuels (solid, liquid and gas). Most biomass is used in traditional ways (as fuel for households and small industries) and not necessarily in a sustainable manner.

The big advantage that biomass offers over other renewable energy sources such as wind and solar is that it can be stored and used when needed. Hence it can provide a constant, non-fluctuating supply of electricity. The key technical challenges to be overcome in order for bio based industrial products to be cost-competitive are finding new technology and reducing the cost of technology for converting biomass into desired bio based industrial products;

2.2.2.2 Environmental and social issues

Bioenergy systems have nowhere near the global warming impacts of fossil-fuel plants. They can be referred to as carbon dioxide neutral, given that the plant material absorbs as much carbon dioxide during its life as released when burned to produce electricity. The main concern with regard to emissions from biomass power production is the release of unburned particles that contribute to human health concerns. Pollution control technologies are available for removing these particulates from the smokestack.

The production of energy crops can also be a cause for concern. If these crops are grown in the same unsustainable manner as most food crops are today, biomass does not offer a sustainable alternative to current fossil-fuel-fired power production. However, if energy crops are produced with minimal use of chemicals, they could potentially advance agricultural lands and improve wildlife habitat. Many of the crops that are being considered for energy production could be grown in a sustainable, low-impact manner.

2.2.3 Solar energy

Solar energy has very high theoretical potential. The amount of solar radiation intercepted by the Earth is much higher than annual global energy use. Large-scale accessibility of solar energy depends on a region’s geographic position, typical weather conditions, and land availability. The proportion of the sun’s rays that reaches the earth’s surface is enough to provide for global energy consumption 10,000 times over. On average, each square meter of land is exposed to enough sunlight to produce 1,700 kWh of power every year.

2.2.3.1 Technology options and status

The amount of final energy will depend on the efficiency of the conversion device used (such as the photovoltaic cell applied). On average, each square meter of land is exposed to enough sunlight to produce 1,700 kWh of power every year.

Solar energy in the stricter sense can be used in three ways:

- Solar thermal collectors use the solar radiation falling on them to heat tap water (and, to a lesser extent, to heat water for space heating).
- Photovoltaic modules convert solar radiation directly into electricity.
- Solar thermal power plants use solar heat by concentrating solar radiation (for instance using mirrors focused upon a "solar power tower", or by means of parabolic troughs) and then conveying the energy of the medium thus heated to a turbine or to a Stirling engine.

Annual Solar Energy Potential

Region	Minimum Exajoules	Maximum Exajoules
North America	181	7,410
Latin America and Caribbean	112	3,385
Western Europe	25	914
Central and Eastern Europe	4	154
Former Soviet Union	199	8,655
Middle East and North Africa	412	11,060
Sub-Saharan Africa	371	9,528
Pacific Asia	41	994
South Asia	38	1,339
Centrally planned Asia	115	4,135
Pacific OECD	72	2,263
TOTAL	**1,575**	**49,837**

Note: The minimum and maximum reflect different assumptions on annual clear sky irradiance, annual average sky clearance, and available land area.

2.2.3.1.1 Solar heat

The potential of solar heat is also huge. In the 15 "old" European Union member states alone (prior to enlargement in 2004), the solar thermal industry anticipates a potential totaling one billion square meters.

Barcelona, the capital city of Catalonia, has shown how this potential can be tapped. In 2000 the city adopted a regulation prescribing the installation of solar thermal systems when new buildings are constructed. As a result, the overall installed area of solar collectors has grown about tenfold, from 1,650 to 15,677 square meters. Israel has one of the strongest efforts that are being made to harness solar energy for water heating, with installed collector area of 67 square meters per 1000 inhabitants in 1999. This is due to the construction laws in force: Since as long ago as 1980, installation of a solar thermal system is mandatory for all newly constructed residential buildings, hotels and public facilities.

2.2.3.1.2 Photovoltaic

Economic aspects are the main obstacles to tapping this potential. However, in sparsely populated off-grid areas photovoltaic supply is often more cost-effective than a connection to the power grid. Consequently, photovoltaic can contribute considerably to improving quality of life and promoting sustainable development, particularly in rural areas of developing countries.

2.2.3.1.3 Solar thermal power plants

Power generation in solar thermal power plants requires high levels of direct solar radiation, as only this can be concentrated optically. This requires a high number of sunshine hours as well as solar irradiance that is only rarely reduced by clouds or haze. Such conditions prevail in warmer climate zones. Consequently areas such as the southern Mediterranean region are particularly suited to this technology. The annual solar power output of such plants amounts to about 200-300 GWh/km² land area. Theoretically, a covered area of about 45 km x 45 km (corresponding to 0.03 % of the suitable areas in North Africa) could meet the entire electricity requirement of Germany. WB countries are among the highest in Europe with annual solar irradiation.

2.2.3.1.4 Solar buildings

The application of passive solar principles in building designs contributes to the reduction of (active) energy demands for heating, cooling, lighting and ventilation. Recent developments of building technology together with advanced, well calculated system technology reduce the demand for heat energy by a factor 10 to 15 in comparison with houses built some 30 to 40 years ago.

2.2.3.2 Environmental and social issues

Solar technologies do not cause emissions during operation, but they do cause emissions during manufacturing and possibly on decommissioning (unless produced entirely by ‘solar breeders’). One of the most controversial issues for PV was whether the amount of energy required to manufacture a complete system is smaller or larger than the energy produced over its lifetime. Nowadays the energy payback time of grid-connected PV systems is 3 to 9 years, and is expected to decrease to 1 to 2 years in the longer term.

2.2.4 Wind energy

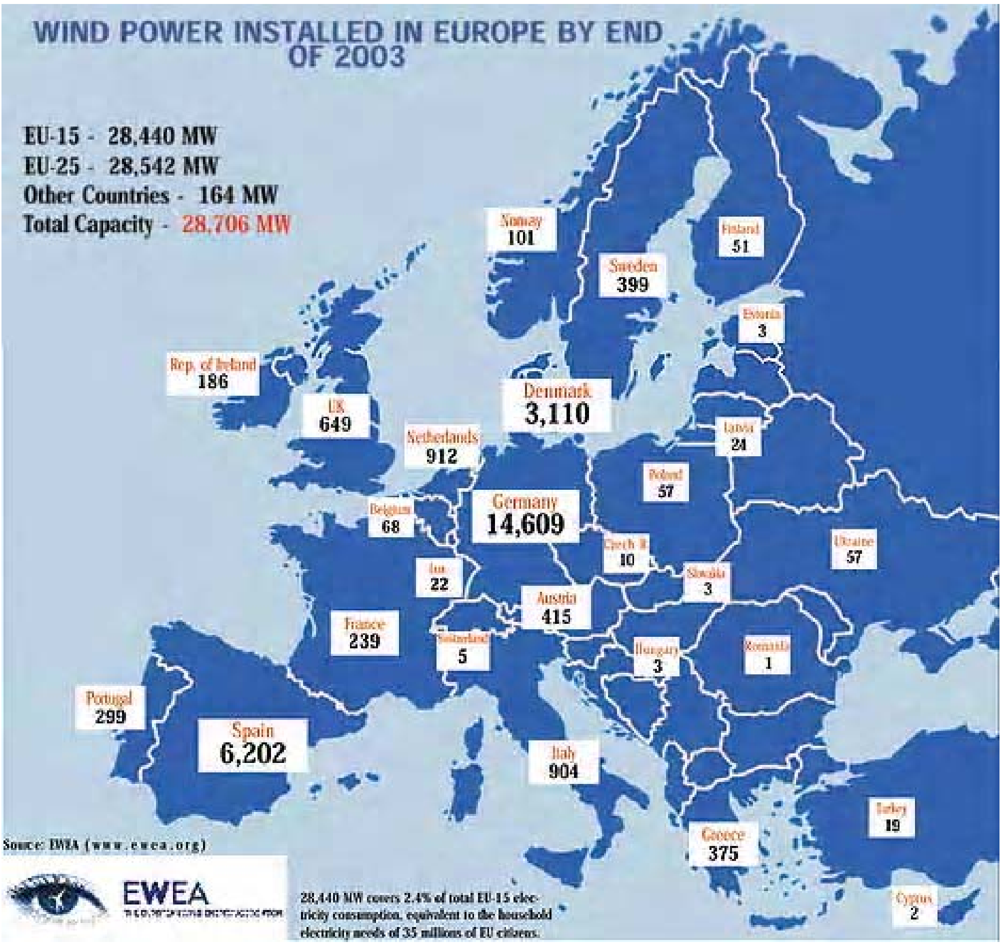
Several factors determine the amount of land area suitable for wind energy development within a particular grid cell in a region of high wind energy potential. The important factors include the percentage of land exposed to the wind resource and land-use and environmental restrictions. The land area exposed to the wind for each grid cell can be estimated based on a landform classification and ranged from 90 % for relatively flat terrain down to 5 % for mountainous terrain. Environmental exclusion areas (including parks, monuments, wilderness areas, wildlife refuges, and other protected areas) are areas where wind energy development would be prohibited or severely restricted. The wind electric potential per grid cell is calculated from the available windy land area and the wind power classification assigned to each cell. The amount of potential electricity that can be generated is dependent on several factors, including the spacing between wind turbines, the assumed efficiency of the machines, the turbine hub height, and the estimated energy losses (caused by wind turbine wakes, blade soiling, etc.).

2.2.4.1 Technology options and status

Modern electronic components have enabled designers to control output and produce excellent power quality. These developments make wind turbines more suitable for integration with electricity infrastructure and ultimately for higher penetration. There has been gradual growth in the unit size of commercial machines, from 30 kilowatts of generating capacity in the 1970s (rotor diameter 10 meters) to 5 megawatts (110 to 120 meters diameter) and more at present.

By the end of 2002, worldwide installed capacity had topped to around 30,000 MW, with 22,000 MW in Europe, mainly Germany, Spain and Denmark. In fact, electricity production from grid-connected wind turbines has been growing at an impressive rate of about 30 percent per year.

This is a map produced by the European Wind Energy Association (EWEA) of wind energy in Europe in 2003.


WIND POWER INSTALLED IN EUROPE BY END OF 2003

Source: EWEA (www.ewea.org)

28,440 MW covers 2.4% of total EU-15 electricity consumption, equivalent to the household electricity needs of 35 millions of EU citizens.

2.2.4.2 Environmental and social issues

Negative environmental aspects connected to the use of wind turbines are discussed as acoustic noise emission, visual impact on the landscape, impact on bird behavior, moving shadows caused by the rotor, and electromagnetic interference with radio, television, and radar signals. In practice the noise and visual impact cause the most problems for development of wind farms.

Wind can diversify agriculture-based economies, create local jobs, keep energy consumption local, broaden the tax base, and provide new business and investment opportunities for farmers. For people who need to bring power lines into their property an independent system could have a lower cost. For an independent, off-grid, power system the efficiency of lights and appliances is extremely important.

2.3 Western Balkans Countries

2.3.1 Croatia

In the year 2000, total primary energy consumed was about 360 PJ, out of which 75 PJ was produced from renewals. The expected consumption of energy produced from renewals in 2030 differs for the three scenarios and equals 100 PJ in S1, 130 PJ in S2 and 160 PJ in S3.

The Croatian government has in 1997 started five national energy programs dealing with renewable energy sources: BIOEN (biomass and waste), SUNEN (solar energy), ENWIND (wind energy), MAHE (small hydro) and GEOEN (geothermal energy).

Goals and strategy of each of the national energy programs differs according to national potentials of each energy source and its peculiar characteristics. However, a common goal of the five programs is an increase in renewable energy use.

Solar energy is expected to contribute mainly in thermal energy production; primarily in low temperature appliances and the passive solar architecture will reduce the need for thermal energy in buildings. The photovoltaic panels are now being used for electricity production in special cases. According to the national energy program SUNEN at this price level their wider deployment is not expected before 2010.

Forests cover more than 40 % of Croatian territory, which means that potentials for **biomass** use are significant. Within the national energy program BIOEN it has been demonstrated that by 2030 at least 15 % of the total energy consumed could be obtained from biomass. It will be used for production of thermal energy and electricity.

The use of ***geothermal*** energy for medical purposes has a long tradition in Croatia. The potential of already discovered geothermal fields is 839 MW of thermal energy and 47,9 MW of electric energy. The projections for geothermal energy use in the year 2030 range from 400 TJ/a in scenario S1 to 720 TJ/a in scenario S3. The use of geothermal energy is analyzed and supported through the GEOEN national energy program.

Studies of Croatian **hydro potentials** for small hydroelectric power plants show the technical potential of 177 MW. A part of this potential will not be commercially viable, and another part will be eliminated due to environmental constrains. Therefore it is projected that the total installed capacity in small hydro facilities will not exceed 100 MW. The national energy program MAHE is the main driving force for further deployment of small hydroelectric plants.

The **wind energy** potential in Croatia is currently unused. Among highest measured wind speeds are 7.3 m/s at 25 m above ground. There is only one wind farm (7 windmills) in island Pag, operational since February 2005, with P = 5.950 kW.

Nevertheless, the interest in wind energy utilization is significant and there are several ongoing projects. Within the national energy program ENWIND 29 locations have been analyzed and their potentials have been estimated at 400 MW installed capacity and about 800 GWh yearly production. Of course, the number of potential locations as well as the corresponding production is much larger.

Potentials of renewable energy sources for electricity generation still must be carefully analyzed. The estimated potentials vary between 3500 GWh in a moderate projection to 6000 GWh per year in the most optimistic perspective.

The international obligations regarding future shares of RES-e are result of political negotiations, and depend on current share of RES-e in a country, their unused potentials and GDP. The share of renewals in electricity production in Croatia is already very high, and depending on hydrological characteristics makes 40-60 % of total electricity consumption. However, this does not mean that no further increase of RES-e will take place in Croatia, because even the countries with already high share of RES in electricity production are committed to rising that share.

A very important topic, which needs to be given special attention, is that renewable facilities are very capital intensive and for that reason the price of electricity produced is in most cases still higher than the price of kWh from conventional facilities. Therefore support mechanisms for renewable electricity are needed, that are in line with the liberalized electricity market. The draft of the “Rules on Use of Renewable Energy Resources” stipulates a fixed premium for electricity from renewals to be paid above the weighted electricity market price. The Government will soon consider this.

The new Croatian legislative framework for the power sector is favorable towards renewable energy sources. It is expected that in the near future a target of 4,5 % of renewals in electricity consumed will be set for Croatia.

2.3.2 Serbia and Montenegro

Solar Energy - As in the case of other countries in the area, solar irradiation levels in Serbia and Montenegro are amongst the highest in Europe. The most favorable areas record a large number of hours, the yearly ratio of actual irradiation to the total possible irradiation reaching approximately 50 %. In the majority of the localities/areas the duration of sunshine ranges from about 2.000-2.500 hours per year. Of course, the monthly distribution is particularly important in determining utilization for heating; and whether back-up systems will be needed during periods of extended cloudiness. In 1998, annual sales of solar flat plate collectors were around 250,000 m2. Some 28,000 solar thermal units were in operation, replacing the equivalent of 0.14 TWh of fossil fuel derived energy being used mainly for water and space heating in the domestic and tourist sectors. The total potential for solar active technologies has been estimated to be approximately 50-60 % of heating demand in the cloudier central regions.

As in other uses, photovoltaic conversion of solar energy is at a much earlier stage in comparison to solar thermal technology. The first production capability for PV cells was established in 1989, and the pre-crisis potential was put at only 0,5 of total energy consumption by the Year 2000.

Geothermal Energy – Total geothermal potential is estimated at 185 000 toe. According to Serbian Efficiency Agency, geothermal energy of water wells exists only in some spas and agricultural companies. There are more than 100 registered geothermal wells of hot water, with temperature usually between 30 to 80 °C, and maximum of 110 °C.

Biomass – Estimated potential of biomass in Serbia is 2.58 million toe, where1.6 million toe are agricultural wastes and approximately 1 million toe wood biomass. 55 % of its territory is arable land, while 25 % are forests (1 toe = 11,64 MWh)

In Vojvodina, the region of Serbia, its economy is based on agricultural industry, and provides 8-12 millions of tons of biomass per year. Energy potential of biomass is concentrated in waste from forest and wood processing production (98 % from agriculture, 1.5 % from forest production and 0.5 % waste from wood production).

Hydro-electric Energy - In Serbia and Montenegro, small scale hydropower plants are used for power production, municipal supply with potable and industrial water, or irrigation. The total hydropower potential of SMN is estimated as 35.000 GWh/a. Out of this, 27.000 GWh/a is technically and economically useful, according to the present energy circumstances in the country and the latest technical achievements and economic criteria. From small scale hydropower plants with installed capacity less than 10 MW, averagely 2.131 GWh/a could be generated, and their total installed discharge would be approximately 650 MW. In the electric power generation system of SMN, with total installed capacities of hydropower plants being 3.507 MW, with average annual output of approximately 12.466 GWh, total of 57 MW is installed in the small scale. Nowadays, in Serbia and Montenegro, there are 39 small scale hydropower plants operating in Serbia and 7 in Montenegro.

Wind - Following inter alias the areas of Serbia and Montenegro where wind velocity exceeded 6-beau fort and the number of days this was the case. The locations with the highest velocities in 1999 and 2000 were the following:

Crni Vrh: 256–223 days
Ban. Karlovac: 128-155 days
Vranje: 133-156 days
Kopaonik: 134-144 days
Nis: 81-105 days
Beograd (Belgrade): 130-114 days

According to the investigations made by experts from Agricultural Faculty and Faculty of electronics from city of Beograd in 2003, potentials to produce electricity from wind in Serbia and Montenegro are as follows:

Average speed of wind: 4 – 6 m/s,
Potential (onshore) wind capacity: 11 000 MW,
Potential (onshore + offshore) wind capacity: 15 000 MW,
Electricity produced from (onshore + offshore) wind: 26,3 TWh/a

2.3.3 Bosnia and Herzegovina

IIn Bosnia and Herzegovina there are two major renewable energy sources: hydropower for electricity production and biomass for heat production. Hydropower means huge hydropower plants owned by Bosnian power utility companies, while biomass means use of wood as a fire fuel in the traditional form with no margins and prospects for efficiency utilization.

Wind Energy - in a preliminary study carried out on behalf of the GTZ (Deutsche Gesselschaft für Technische Zusammenarbeit) it was established that there is an economic potential of approximately 600 MW that could be developed by 2010, on the assumption that an appropriate incentive system to build wind power installations is set up. There are promising wind values shown by measurements taken before the war for the region of Trebinje through Mostar to Bugojno, and more up-to-date measurements in Kupresu and Podvelezje, with average speed of 10 m/s.

Biomass - There is considerable potential for the use of biomass for energy generation in the forestry sector (roughly 50 % of the land area of Bosnia and Herzegovina is wooded) and in agriculture. According to a study conducted by Innotech HT GmbH, Berlin, in 2003 on behalf of the GTZ, there is an unexploited potential of approx. 1 million m³/a of residual wood, wood waste etc. which could be used to provide heat to 130,000 residences or 300,000 inhabitants. One field where wood is already used in Bosnia and Herzegovina is where wood waste is converted into electrical energy in steam power plants, such as in the state-owned Krivaja factory in Zavidovici, manufacturing furniture and timber houses. With a maximum thermal output of 15 MW, peak electricity outputs of 4.5 MW are generated for the factory’s on-site power needs. There are also plans with the local authority for a group heating scheme in locality, but because of a lack of funding it has so far not been possible to put these into practice.

Solar Energy - With regard to solar irradiation, Bosnia and Herzegovina can be counted among the more favorable locations in Europe with solar irradiation figures of 1 240 kWh/m².a in the north of the country and up to 1 600 kWh/m².a in the south. The thermal exploitation of solar energy with flat-plate collectors is also practiced to only a limited extent. One of the first photovoltaic installations has been fitted on the roof of an orphanage in Trebinje. In view of the relatively high cost involved, the introduction of photovoltaic on the market beyond very small-scale consumers far from the utility grid is dependent on promotion programs and international projects.

Geothermal Energy - Bosnia and Herzegovina has a geothermal potential of 33 MWth. It must be said, though, that the temperature at three known locations in Bosanski Samac (85 ºC), Kakanj (54ºC), and Sarajevo (58ºC) is too low for electricity generation, which is why the reserves are currently only under consideration for thermal exploitation. Current activities relating to geothermal energy continue to be limited to exploitation for thermal use.

Hydro energy - the theoretical potential of hydropower in Bosnia and Herzegovina is stated as being 8000 MW, the technical potential 6800 MW and the economic potential 5600 MW. With an installed capacity of 2052 MW (53 % of electricity generation), hydropower is highly significant in Bosnia and Herzegovina, although its potential is far from being fully exploited yet (37 % of economic potential). The majority of the installations are more than 30 yrs old. Five existing hydro plants (total 1060 MW) are part of multi-purpose developments. There are 13 hydro plants with a capacity greater than 10 MW. Bosnia and Herzegovina has a small hydro power potential of 2500 GWh/a. Proposed plans include the installation of ten small hydro plants every year, with an average capacity of 1.5 MW each. In addition, a study by the Federation of Bosnia and Herzegovina lists a further 42 locations for small-scale hydropower plants with a total capacity of 51 MW which could be built on existing weirs.

2.3.4 Macedonia, FYRO

Macedonia has promising indigenous resources of renewable energy. These include hydropower, geothermal energy, biomass energy, and in the longer-term wind energy. Even a though a pipeline of financially viable renewable energy projects has been identified by different project developers, these are not being implemented because of financial and institutional constraints.

Wind Energy Resource Potential - although less windy than many northern European countries, wind energy appears to be a viable renewable energy technology in Macedonia. Being characterized by high mountains (some of the highest in Europe), it is reported that there are locations, which have annual average wind speeds exceeding 7 m/s.

Judging by the Greek wind energy sites, the study by Black&Veatch estimates that Lake Doiran, South east of the country would probably be the best, followed by the area along the Greek border, in the south of the country.

Solar Energy - solar irradiation in Macedonia is amongst the highest in Europe. The most favorable areas record a large number of sunshine hours, the yearly ratio of actual irradiation to the total possible irradiation, reaching approximately 50 % for former Yugoslavia as a whole, or 45 % for the mountainous central regions, particularly in Macedonia, due to the prevailing weather pattern. The primary form of solar energy and technology used are flat plate collectors for heating houses and some commercial and public premises. But their contribution to the total energy consumption is less than 1 %. Electricity production from solar photovoltaic sources will be restricted to research or remote locations, primarily for telecommunications. PV solar energy is still 300-500 % more expensive than alternative fossil fuel derived sources.

Macedonia derives useful energy in the form of heat from its **geothermal wells**. At present its geothermal water is used for heating greenhouses, residential houses, some commercial buildings, swimming pools and in balneology. No electricity is produced from geothermal energy in the country. The main hydrothermal systems are located in the East and North East of the country in the crystalline rocks of Macedonian-Serbian massive and are characterized by low TDS (total dissolved solids) and low corrosion activity. A number of geothermal areas composed by separate fields were discovered as a result of investigations from more than 50 prospecting and operating wells with a depth from 40 to 2100 m.

The total discharge of wells from the exploited fields in Macedonia constitutes 1000 l/s, the existing thermal capacity is 74.5 MWt. The proven thermal potential constitutes 220 MWt.

Biomass - in the period 1999-2001, the production of wood fuel and charcoal amounted to 787,000 m3, that of wood residues 3,638 m3.

In Kavadarci, centre for the wine production in Macedonia, there is interest in projects to prepare fuel briquettes from vineyard waste. The project sponsors have calculated that at current energy prices such a project would have a payback time of five to six years. Several other options for biomass use exist.

Hydropower - production of electricity from hydropower has fluctuated widely during 1980-2000: from about 1850 GWh (159 ktoe) in 1980 to848 in 1992 and 1389 in 1999, 626 and 757 in 2001 and 2002. In 2003, electricity generation from Hydropower was 1483 GWh (approx. 4 % of primary total energy production). Macedonia is divided into 3 separate drainage units/areas, which are identified by their major, rivers:

a.The Vardar River water basin/drainage area of 20.535 km2

b.The Crni Drim River drainage area of 3.350 km2; and

c.The Strumica River drainage area of 1.535 km2

According to a Master Plan prepared as long ago as 1976 and other studies made at a subsequent time, “the technically usable” hydropower potential of the rives in the country are about 5.483 GWh.

2.4 Conclusion

National RES strategy will have to be harmonized with the EU strategy regarding renewals. Some of the priorities that can be realized in WB countries with short pay back period are:

- revitalization of old/non-functional small hydro power plants
- automation of small scale hydropower plants already in operation
- replacement of electricity and liquid fuel boilers by biomass firing boilers
- utilization of available biomass wastes in industry and agricultural farms for heating
- assessment of wind and energy potential at most interesting locations and feasibility study

A very important topic that needs to be given special attention is that renewable facilities are very capital intensive and for that reason the price of electricity produced is in most cases still higher than the price of kWh from conventional facilities. Therefore support mechanisms for renewable electricity are needed, that are in line with the liberalized electricity market.

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3 WIND POWER

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3.1 General

Winds are the motion of air about the earth caused by its rotation and by the uneven heating of the planet's surface by the sun. During the day time, the air over the earth's crust acts partly as an absorber and partly as a reflector. Over the lakes and oceans, a great deal of this energy is absorbed by water or is involved in evaporation; hence, this air remains relatively cool. The warmed air over the land expands, becomes lighter and rises, causing the heavier, cooler air over the bodies of water to move in and replace it. At night the breezes are reversed, since water cools at a slower rate than land. Similar breezes are generated in valleys and on mountains as warmer air rises along the heated slopes. At night, the cooler, heavier air descends into the valleys. On a broader scale, large circulating streams of air are generated by the more intense heating of the earth's surface near the equator than at the poles. The hot air from the tropical regions rises and moves in the upper atmosphere toward the poles while cool surface winds from the poles replace the warmer tropical air.

The winds are also affected by the earth's rotation about its own axis and the sun. The moving colder air from the poles tends to twist toward the west because of its own inertia. The warm air from the equator tends to shift toward the east because of its inertia. The result is large counterclockwise circulation of air streams about low-pressure regions in the northern hemisphere and clockwise circulation in the southern hemisphere. The seasonal changes in strength and direction of these winds result from the inclination of the earth's axis of rotation at an angle of 23.5° to the axis of rotation about the sun, causing variations of heat radiating to different areas of the planet. /1/

Historically, wind energy was most competitive in remote sites, far from the electric grid and requiring relatively small amounts of power, typically less than 10 kW. In these off-grid applications, wind energy is typically used in the charging of batteries that store the energy captured by the wind turbines and provides the user with electrical energy on demand. Water pumping, where water, rather than energy, can be stored for future use, is also a key historical application of wind energy. The key competitive area for wind energy in remote off-grid power applications is against electric grid extension, primary (disposable) batteries, diesel, gas and thermoelectric generators. Wind energy is also competitive in water pumping applications.

In on-grid applications the wind energy system feeds electrical energy directly into the electric utility grid. Two on-grid application types can be distinguished.

1. Isolated-grid electricity generation, with wind turbine generation capacity typically ranging from approximately 10 kW to 200 kW. Isolated-grids are common in remote areas. Electricity generation is often relatively expensive due to the high cost of transporting diesel fuel to these isolated sites. However, if the site has good local winds, a small wind energy project could be

installed to help supply a portion of the electricity requirements. These wind energy projects are normally referred to as wind-diesel hybrid systems. The wind energy system’s primary role is to help reduce the amount of diesel fuel consumption.

2. Central-grid electricity generation, with wind turbine generation capacity typically ranging from approximately 200 kW to 2 MW.Central-grid applications for wind energy projects are becoming more common. In relatively windy areas, larger scale wind turbines are clustered together to create a wind farm with capacities in the multi-megawatt range. The land within the wind farm is usually used for other purposes, such as agriculture or forestry.

3.2 Guidelines for planners, installers and students

3.2.1 Guidelines for design

Long-term distribution of observed wind speeds conforms well to the so-called Weibull probability density function. The Weibull probability density function expresses the probability p(x) to have a wind speed x during the year, as follows [2]:

$$p(x)=\frac{k}{c}\left(\frac{x}{c}\right)^{k-1} e^{-\left(\frac{x}{c}\right)^{k}} .$$

This expression is valid for k >1, x ≥ 0, and C > 0. k is the shape factor, and it typically ranges from 1 to 3. For a given average wind speed, a lower shape factor indicates a relatively wide distribution of wind speeds around the average, while a higher shape factor indicates a relatively narrow distribution of wind speeds around the average. A lower shape factor will normally lead to a higher energy production for a given average wind speed. If a shape factor equals 2, the special case of Weibull distribution is called the Rayleigh distribution.

C is the scale factor, which is calculated from the following equation /2/

$$C=\frac{\bar{x}}{\Gamma\left(1+\frac{1}{k}\right)} ,$$

Where x is the average wind speed value and Γ is the gamma function.

A wind turbine turns the kinetic energy of the wind into mechanical energy which is used to turn the rotor and is finally converted into electrical energy. The amount of electricity delivered to the grid is dependant on the Weibull parameters and the power curve. The power curve of a wind turbine is a graph that indicates how large the electrical power output will be for the turbine at different wind speeds. An example of a power curve is shown in Figure 1.1.

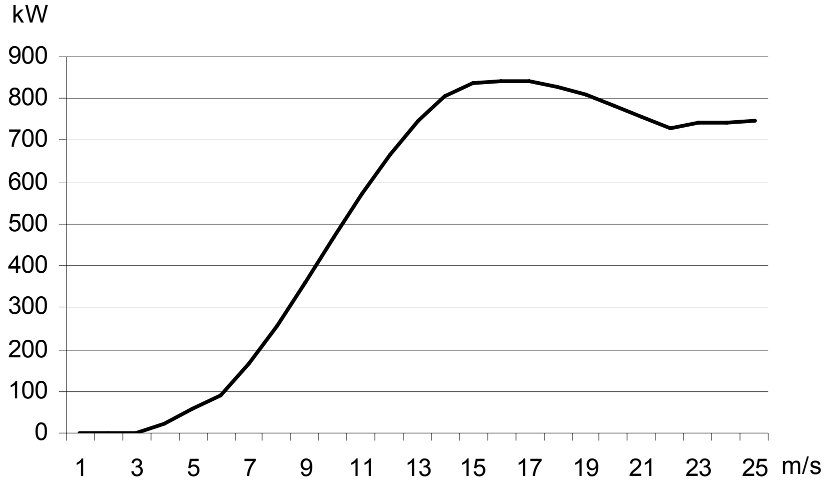

Figure 1.1 Power curve of a typical wind turbine

3.2.1.1 Turbine design

There are several aspects considered at turbine design /3/.

Vertical or horizontal axes

All modern wind turbines have horizontal axes. The only vertical axis turbine which has ever been manufactured commercially at any volume is the Darrieus machine, named after the French engineer Georges Darrieus who patented the design in 1931. The Darrieus machine is characterized by its C-shaped rotor blades. The basic theoretical advantages of a vertical axis machine are that generator and gearbox are placed on the ground and that no yaw mechanism is needed to turn the rotor against the wind. However, its main disadvantages are low wind speeds close to ground level, low efficiency of the machine and the fact that the machine is not self-starting. Further, replacing the main bearing for the rotor necessitates removing the rotor on both a horizontal and a vertical axis machine. In the case of the latter, it means tearing the whole machine down.

Upwind or downwind machines

Upwind machines have the rotor facing the wind. The basic advantage of upwind designs is that one avoids the wind shade behind the tower. By far the vast majority of wind turbines have this design. On the other hand, there is also some wind shade in front of the tower, i.e. the wind starts bending away from the tower before it reaches the tower itself, even if the tower is round and smooth. Therefore, each time the rotor passes the tower, the power from the wind turbine drops slightly.

The basic drawback of upwind designs is that the rotor needs to be made rather inflexible, and placed at some distance from the tower. In addition an upwind machine needs a yaw mechanism to keep the rotor facing the wind.

Downwind machines have the rotor placed on the lee side of the tower. Their main advantage is that the rotor may be made more flexible. This is an advantage both in regard to weight, and the structural dynamics of the machine, i.e. the blades will bend at high wind speeds, thus taking part of the load off the tower. The basic advantage of the downwind machine is thus, that it may be built somewhat lighter than an upwind machine.

The basic drawback is the fluctuation in the wind power due to the rotor passing through the wind shade of the tower. This may give more fatigue loads on the turbine than with an upwind design.

Number of Blades

Most modern wind turbines are three-bladed designs with the rotor position maintained upwind. Two-bladed wind turbine designs have the advantage of saving the cost of one rotor blade and its weight. However, they require higher rotational speed to yield the same energy output. This is a disadvantage both in regard to noise and visual intrusion.

Two- and one-bladed machines require a more complex design with a hinged (teetering hub) rotor, i.e. the rotor has to be able to tilt in order to avoid too heavy shocks to the turbine when a rotor blades passes the tower. The rotor is therefore fitted onto a shaft which is perpendicular to the main shaft, and which rotates along with the main shaft. This arrangement may require additional shock absorbers to prevent the rotor blade from hitting the tower.

Despite saving the cost of another rotor blade, one-bladed wind turbines are not very widespread commercially because the same problems that are mentioned under the two-bladed design apply to an even larger extent to one-bladed machines.

In addition to higher rotational speed, and the noise and visual intrusion problems, they require a counterweight to be placed on the other side of the hub from the rotor blade in order to balance the rotor. This obviously negates the savings on weight compared to a two-bladed design.

Pitch Versus Stall

The two principal means of limiting rotor power in high operational wind speeds - stall regulation and pitch regulation - are now discussed. Stall regulated machines require speed regulation. As wind speed increases, providing the rotor speed is held constant, flow angles over the blade sections steepen. The blades become increasingly stalled and this limits power to acceptable levels without any additional active control.

For this to work, the speed of the rotor must be held essentially constant and this is achieved through the connection of the electric generator to the grid. Briefly, a stall regulated WT will run at approximately constant speed in high wind, not producing excessive power and yet achieving this without any change to rotor geometry.

The main alternative to stall regulated operation is pitch regulation. This involves turning the blades about their long axis (pitching the blades) to regulate the power extracted by the rotor. In contrast to stall regulation, pitch regulation requires changes to rotor geometry. This involves an active control system to sense blade position, measure output power and instruct appropriate changes of blade pitch.

The objective of pitch regulation is similar to stall regulation, namely to regulate output power in high operational wind speeds.

For pitch and stall, costs are quite similar for each design type, but pitch regulation offers potentially better output power quality (this has been perhaps the most significant factor in the German market), and pitch regulation with independent operation of each pitch actuator allows the rotor to be regarded as two independent braking systems for certification purposes.

3.2.1.2 Wind power in electricity production

A schematic view of a wind turbine is shown in 1.2.

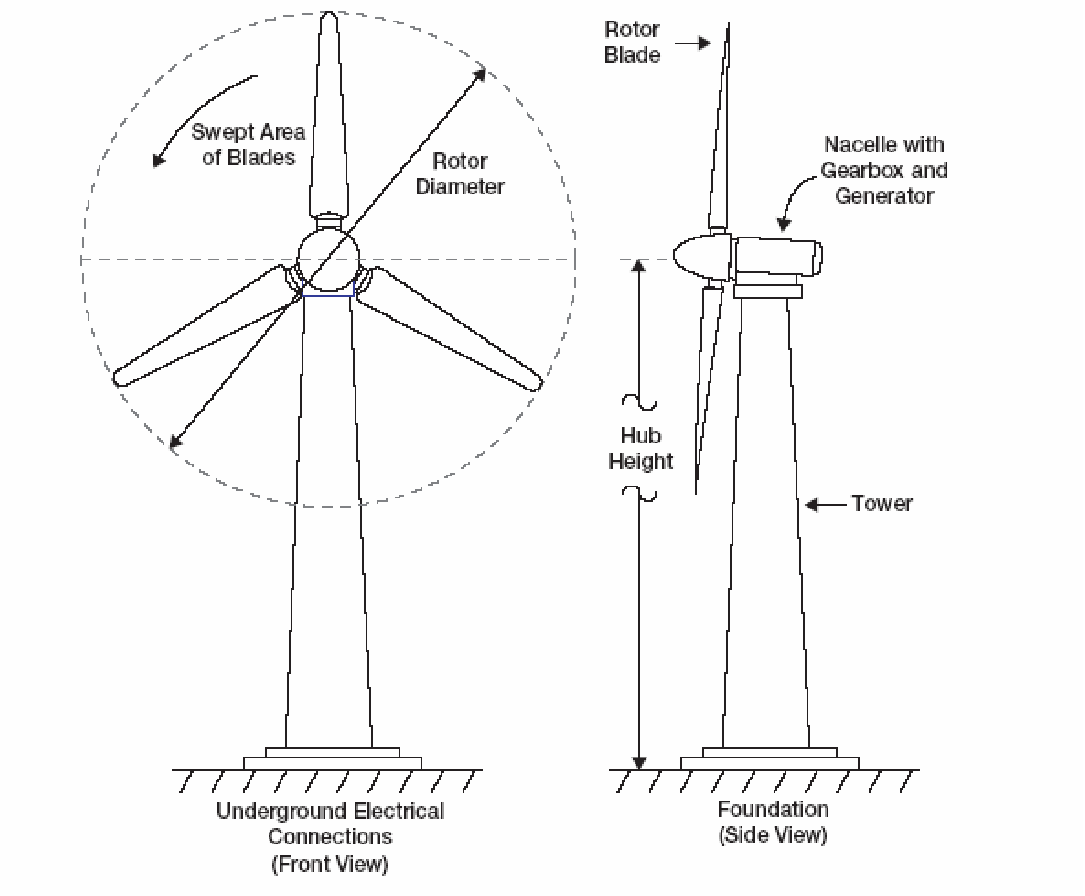

Figure 1.2 A schematic view of a modern wind turbine

Wind passes over the blades exerting a turning force. The rotating blades turn a shaft inside the nacelle, which goes into a gearbox. The gearbox increases the rotation speed for the generator, which uses magnetic fields to convert the rotational energy into electrical energy. The power output goes to a transformer where the voltage level is adjusted.

The amount of electricity produced from a wind turbine depends on three factors:

1. Windiness of the site

The power available from the wind is a function of the cube of the wind speed. Therefore if the wind blows at twice the speed, its energy content will increase eight-fold. Turbines at a site where the wind speed averages 8 m/s produce around 75-100 % more electricity than those where the average wind speed is 6 m/s, as not all the extra energy can be harvested.

2. Wind turbine availability

This is the capability to operate when the wind is blowing, i.e. the turbine is available to work. This is typically 98 % or above for modern European machines.

3. The way the turbines are arranged

Turbines in wind farms are laid out so that one turbine doesn't take the wind away from another. There are also landscape issues to consider. It is generally agreed that the ideal position for a wind turbine generator is a smooth hill top, with a flat clear fetch, at least in the prevailing wind direction.

3.2.2 Guidelines for control and operation

There are several characteristics of wind power that differ it significantly from other sources of power /5/.

First, locations of high wind potential are located in remote areas, far from population centers where transmission grids are inadequate for a power plant connection, or maybe not even existing. Therefore, new transmission network extensions are needed.

Second, generating systems are different from the synchronous generator used in conventional power plants, which can cause various difficulties in power system operation, as will be discussed later on.

Third, wind is hardly controllable and fluctuates randomly. Connected to this, there are two factors to be considered: wind generation prediction for load coverage and imbalances produced by turbulence and high wind speed.

To be able to predict the wind generation accurately is of course the most important objective of a wind generation forecast. Different weather conditions are associated with different uncertainties. This information could influence the day-ahead needed regulating capacity in the system. It could also have influence on the trading strategy.

Power fluctuations are induced by turbulence, which is a stochastic quantity that evens out when many turbines are considered. An exception, however, is formed by storm-induced outages that occur when the wind speed exceeds the cut-out value. These are not induced by stochastic turbulence but by storm fronts and can therefore affect a large number of turbines simultaneously.

3.2.2.1 Wind generating systems

There are three different types of turbines that are commonly used in a wind energy converter /3/:

Constant speed turbine with squirrel cage induction generator

Variable speed turbines with:

- Double fed (wound rotor) induction generator;
- Direct drive synchronous generator.

Squirrel cage induction generator

A squirrel cage induction generator is an asynchronous machine, composed by a squirrel cage rotor and a stator with three distributed windings which are directly coupled to the grid. The wind turbine rotor is coupled to the generator through a gearbox. Substantially this is a constant speed wind turbine because the power converted from the wind is limited by designing the turbine rotor in such a way that its efficiency decreases in high wind speed.

This kind of generators always consumes reactive power hence capacitors are necessary close to generators to avoid a voltage decrease because these generators cannot control and regulate the voltage level.

Double fed (wound rotor) induction generator

A double fed induction generator has a wound rotor that is connected to the grid through a back-to-back voltage source converter which controls the excitation system in order to decouple the mechanical and electrical rotor frequency and to match the grid and rotor frequency. The wind turbine rotor is coupled to the generator through a gearbox in the same way of the constant speed generator.

Direct drive synchronous generator

The most important characteristic of this wind generator is that it is completely decoupled from the grid by a power electronics converter connected to the stator winding. The converter is composed by a voltage source converter on the grid side and a diode rectifier (or a voltage source converter) on the generator side. The direct drive generator is excited by an excitation winding or permanent magnets.

3.2.2.2 Power system impacts

The wind power characteristics are reflected in a different interaction with the power system /5/. Local impacts of wind power are impacts that occur in the (electrical) vicinity of a wind turbine or wind farm and can be attributed to a specific turbine or farm. Local impacts occur at each turbine or farm and are largely independent of the overall wind power penetration level in the system as a whole.

System-wide impacts, on the other hand, are impacts that affect the behavior of the system as a whole. They are an inherent consequence from the application of wind power but cannot be attributed to individual turbines or farms.

Local impacts:

Wind power locally has an impact on the following aspects of power system:

- branch flows and node voltages
- protection schemes, fault currents, and switchgear ratings
- power quality: harmonic distortion and flicker

The way in which wind turbines locally affect the node voltages depends on whether constant-speed or variable-speed turbines are used. The squirrel-cage induction generator in constant-speed turbines has a fixed relation between rotor speed, active power, reactive power, and terminal voltage. Therefore, it cannot affect node voltages by adapting the reactive power exchange with the grid. To this end, additional equipment for generating controllable amounts of reactive power would be necessary. On the other hand, variable speed turbines have, at least theoretically, the capability of varying reactive power to affect their terminal voltage. Whether this is indeed possible in practice depends, however, on the rating and the controllers of the power electronic converter.

The contribution of wind turbines to the fault current also differs between the three main wind turbine types. Constant-speed turbines are based on a directly grid-coupled squirrel-cage induction generator. They therefore contribute to the fault current and rely on conventional protection schemes (overcurrent, overspeed, over- and undervoltage). Turbines based on the doubly fed induction generator also contribute to the fault current. However, the control system of the power electronics converter that controls the rotor current measures various quantities, such as the grid voltage and the rotor current, at a very high sampling rate (several kHz). A fault is therefore observed very quickly. Due to the sensitivity of power electronics to overcurrents, this wind turbine type is currently quickly disconnected when a fault is detected. Wind turbines with a direct-drive generator hardly contribute to the fault current because the power electronics converter through which the generator is connected to the grid is not capable of supplying a fault current. Normally, these are also quickly disconnected in case of a fault.

The third topic, power quality is divided in to subtopics: harmonic distortion and flicker. Harmonic distortion is mainly an issue in the case of variable-speed turbines because these contain power electronics, an important source of harmonics. However, in the case of modern power electronics converters with their high switching frequencies and advanced control algorithms and filtering techniques, harmonic distortion should not be a principal problem. Well-designed, directly grid-coupled synchronous and asynchronous generators hardly emit harmonics. Harmonic distortion is therefore not an issue for constant-speed wind turbines based on directly grid-coupled asynchronous generators.

Flicker is a specific property of wind turbines. Wind is a quite rapidly fluctuating prime mover. In constant-speed turbines, prime mover fluctuations are directly translated into output power fluctuations because there is no buffer between mechanical input and electrical output. Depending on the strength of the grid connection, the resulting power fluctuations can result in grid voltage fluctuations, which can cause unwanted and annoying fluctuations in bulb brightness. This problem is referred to as flicker. In general, no flicker problems occur with variable-speed turbines, because in these turbines wind speed fluctuations are not directly translated to output power fluctuations. The rotor inertia acts as an energy buffer.

System-wide impacts

Apart from the local impacts, wind power also has a number of system-wide impacts:

- power system dynamics and stability
- reactive power and voltage control
- frequency control and load following/dispatch of conventional units.

The impact on the dynamics and stability of a power system is mainly caused by the fact that, in wind turbines, generating systems are applied that are not based on a conventional synchronous generator. The specific characteristics of these generating systems are reflected in their response to changes in terminal voltage and frequency, which therefore differs from that of a grid-coupled synchronous generator. It is possible to comment on the impact of the three main wind turbine types on power system dynamics and stability in a qualitative sense by analysing their properties. Squirrel-cage induction generators used in constant-speed turbines can lead to voltage and rotor-speed instability. During a fault, they accelerate due to the unbalance between mechanical power extracted from the wind and electrical power supplied to the grid. When the voltage restores, they consume much reactive power, impeding voltage restoration. When the voltage does not return quickly enough, the wind turbines continue to accelerate and to consume large amounts of reactive power. This eventually leads to voltage and rotor-speed instability. Opposite to what applies to synchronous generators, whose exciters increase reactive power output at low voltage and thus accelerate volt-age restoration after a fault, squirrel-cage induction generators hence tend to slow down voltage restoration.

With variable-speed turbines, the sensitivity of the power electronics to overcurrents caused by voltage drops can have problematic consequences for the stability of the power system.

When the penetration level of variable-speed turbines in the system is high and they disconnect at relatively small voltage drops (figure 4.a), as is the case nowadays, a voltage drop in a wide geographic area could lead to a large generation deficit. Such a voltage drop could, for instance, be caused by a fault in the transmission grid. To prevent this, some grid companies and transmission system operators facing a high contribution of wind power in their control area are currently proposing more demanding connection requirements. They prescribe that wind turbines must be able to withstand voltage drops of certain magnitudes and durations, in order to prevent the disconnection of a large amount of wind power at a fault. In order to meet these requirements, manufacturers of variable-speed wind turbines are implementing solutions to reduce the sensitivity of variable-speed wind turbines to grid voltage drops.

The impact of wind power on reactive power generation and voltage control originates first from the fact that not all wind turbines are capable of varying their reactive power out-put, as stated above when discussing the local impacts of wind power. However, this is only one aspect of the impact of wind power on voltage control in a power system. Apart from this, there are two other issues that determine the impact of wind power on reactive power generation and voltage control. First, wind power cannot be very flexibly located when compared to conventional generation. As mentioned above, wind power affects the scenery and can hence only be constructed at locations at which this is not considered a major problem. Further, it must be erected at locations with a good wind resource. The locations that meet these two conditions are not necessarily locations that are favorable from the perspective of grid voltage control. When choosing a location for a conventional power plant, the voltage control aspect is often easier to consider because of the better location flexibility of a conventional plant. Second, wind turbines are relatively weakly coupled to the system because their output voltage is rather low and because they are often erected at distant locations. This further reduces their contribution toward voltage control. When the output of conventional synchronous generators is replaced by wind turbines at remote locations on a large scale, the voltage control aspect must therefore be taken into account explicitly.

The impact of wind power on frequency control and load following is caused by the fact that the prime mover of wind power is uncontrollable. Therefore, wind power hardly ever contributes to primary frequency regulation. Further, the variability of the wind on the longer term (15 minutes to hours) tends to complicate the load following with the conventional units that remain in the system, as the demand curve to be matched by these units (which equals the system load minus the wind power generation) is far less smooth than would be the case without wind power. This heavily affects the dispatch of the conventional generators.

Note that the aggregated short-term (<1 min) output power fluctuations of a large number of wind turbines are very much smoothed and are generally not considered problematic. These fluctuations are induced by turbulence, which is a stochastic quantity that evens out when many turbines are considered. An exception, however, is formed by storm-induced outages that occur when the wind speed exceeds the cut-out value. These are not induced by stochastic turbulence but by storm fronts and can therefore affect a large number of turbines simultaneously.

The impact of wind power on frequency control and load following becomes more severe the higher the wind power penetration level is. The higher the wind power penetration level, the larger the impact of wind power on the demand curve faced by the remaining conventional units, resulting in and fewer remaining units. Thus, the requirements on the ramping capabilities of these units must be stricter in order to match the remaining demand curve and to keep the fluctuations of the system’s frequency, caused by unbalances between generation and load, within acceptable limits. It is, however, impossible to quantify the wind power penetration level at which system-wide effects start to occur because of the differences in, for example, conventional generation portfolio, wind speed regime, and geographical spread of the turbines, demand curve, and network topology between various power systems.

3.3 Guidelines for R&D policy and decision makers

3.3.1 Wind technology development

There are three main lines of research connected to the wind power technologies:

- Basic Aerodynamics Research.
- Aerodynamic Improvement Devices.
- Offshore Wind Power Research.

3.3.2 Demonstration

Among the new RES technologies, wind power technology is the most widely used and has been extensively demonstrated.

3.3.3 Economic aspects

Wind power is used in a number of different applications, including both grid-connected and stand-alone electricity production, as well as water pumping. This section analyses the economics of wind energy primarily in relation to grid-connected turbines which account for the vast bulk of the market value of installed turbines.

The main parameters governing wind power economics include the following /4/.

- Investment costs, including auxiliary costs for foundation, grid-connection, and so on.
- Operation and Maintenance (O&M) costs.
- Electricity production/average wind speed.
- Turbine lifetime.
- Discount rate.

Capital costs of wind energy projects are dominated by the cost of the wind turbine. Table 1 shows the cost structure for a medium sized turbine (850 kW to 1,500 kW) sited on land and based on a limited data selection from the UK, Spain, Germany and Denmark. The wind turbine share of total cost is typically a little less than 80 %, but considerable variations do exist, ranging from 74 % to 82 %.

Table 1: Cost structure for a medium sized turbine

	Share of Total Cost, %	Typical Shareof Other Costs, %
Turbine (ex works)	74-82	-
Foundation	1-6	20-25

Electric installation	1-9	10-15
Grid-connection	2-9	35-45
Consultancy	1-3	5-10
Land	1-3	5-10
Financial costs	1-5	5-10
Road construction	1-5	5-10

The total cost per installed kW of wind power capacity differs significantly between countries. The cost per kW typically varies from approximately 900 €/kW to 1,150 €/kW. The investment costs per kW are almost at the same level in Spain and Denmark, while the costs were approximately 10 % to 30 % higher in the UK and Germany. However, it should be noted that these figures are based on limited data.

The calculated costs per kWh wind power as a function of the wind regime at the chosen sites are shown in Figure 1.21.3. As shown, the cost ranges from approximately 6-8 c€/kWh at sites with low average wind speeds to approximately 4-5 c€/kWh at windy coastal locations.

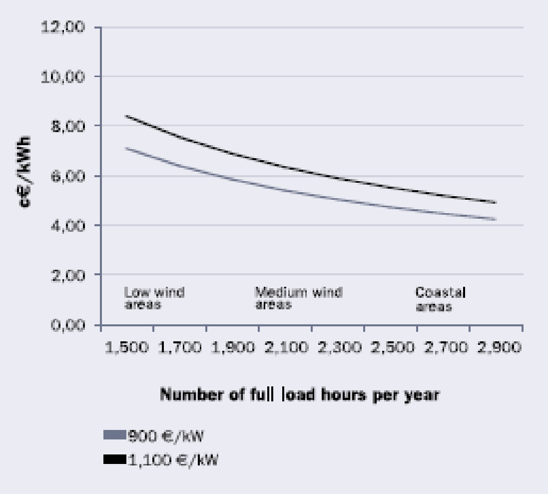

Figure 1.2 Calculated costs per kWh produced using wind power

Approximately 75 % of total power production costs for a wind turbine are related to capital costs, i.e. costs for the turbine itself, foundation, electrical equipment and grid-connection. Thus, wind power plants are a so-called capital-intensive technology compared with conventional fossil fuel-fired technologies such as a natural gas power plant, where as much as 40 %-60 % of total costs are related to fuel and O&M costs. For this reason, the cost of capital (discount or interest rate) is an important factor for calculating the cost of wind power.

3.3.4 Environmental aspects

As all power production facilities, wind turbines have environmental impacts. These can be divided into the following categories /6/:

- noise;
- visual impacts;
- atmospheric emissions during the materials processing and components production;
- birds;
- electromagnetic interference.

3.3.4.1 Noise

Noise from wind turbines can be of mechanical and aerodynamic origin, which have different characteristics and must be addressed separately. Aerodynamic noise is caused by interaction of the turbine blades with the surrounding air. Mechanical noise is due to the moving parts in the nacelle and it is transmitted to the environment both directly through the air and via the rest of the structure, including the tower /7/.

The noise problem is the most emphasized wind turbine environmental impact and should be given proper attention in the course of wind power plant project development. However, modern turbines are seldom heard at distances further than 300 m as background noise from wind in trees, for example, will be higher.

3.3.4.2 Visual impacts

The impact of wind turbines on visual amenity is the most controversial and difficult to quantify. In general, concern over visual impact is highest in areas of special importance and beauty and it is clear that care should be taken in the sitting and design of the turbines in other areas. Techniques for assessing visual impacts exist and are used within the planning process for wind power plants.

3.3.4.3 Atmospheric emissions

Although there are no direct emissions to the atmosphere caused by wind turbine operation, emissions from non-operational phases of the life cycle do exist. Historically, some of the major concerns about the environmental impacts of renewable energy generation technologies have been focused on energy use in materials processing and component production. However, it has been shown that atmospheric emissions from the wind fuel cycle are insignificant in comparison to those from fossil fuels /7/.

3.3.4.4 Birds

The major potential impact of wind turbines on birds are collision in flight with turbines and behavioral disturbance from blade avoidance. Although numerous studies show that birds rarely collide with rotor blades this is an issue sometimes raised.

3.3.4.5 Electromagnetic interference

Any large moving structure can produce electromagnetic interference. The electromagnetic signals may be reflected from the turbine blades, so that a nearby receiver picks up both a direct and reflected signal. Interference occurs because the reflected signal is both delayed (due to difference in path length) and Doppler shifted (due to the blade motion). However these problems can be minimized by careful sitting of a wind facility. Interference with a small number of television receivers can be easily and relatively cheaply rectified by a range of technical measures at the expense of the wind farm developer.

3.4 References

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4 PHOTOVOLTAIC

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4.1 General

Development of national and global economy is strongly associated with electrical energy production. There is a lack of electrical energy in the world, so the countries need to ensure the appropriate production of electrical energy to achieve economical independence.

The number of conventional power plants is not big enough to satisfy the need for electrical energy. Under the EU there are several programs to ensure electrical energy from renewable energy sources (RES). Those are representing an alternative to conventional energy sources. From among RES there is also the solar energy.

Production and application of solar systems is raising a lot. Trend of rising is foreseen in the future also. European market is very interesting for PV products, which application is rising. Also very interesting future market for PV products is a Balkan region.

4.2 Guidelines for planners, installers and students

4.2.1 Guidelines for design

4.2.1.1 The principles of photovoltaic

As the name suggests, the absorption of light - photons - in a semiconductor can, under certain conditions, create an electric current. The transformation principle is based upon the fact that in a semiconductor fixed electrons can be converted into freely moving conduction electrons. This simultaneously creates a positively charged “hole” and thus a second charge carrier with an opposing charge.

If a potential difference exists in the semiconductor material, whether due to a p-n junction or an appropriate surface charge, then this charge carrier can be forced to travel in an external circuit, i.e. an electrical current can be produced. In many cases, in particular in the case of crystalline silicon, the charge carriers that have been created can only reach this potential barrier because of thermal vibrations. No other force drives them in this direction. This means that the charged particles will have to exist until they reach the potential barrier. This lifetime or diffusion length (the average distance travelled) is one of the key factors for the efficiency of photovoltaic energy generation. Of course a multitude of other physical characteristics, such as cell design, help to determine functionality and efficiency.

4.2.1.2 The history of photovoltaics

The photovoltaic effect is the electrical potential developed between two dissimilar materials when their common junction is illuminated with radiation of photons. The photovoltaic cell, thus, converts light directly into electricity. The PV effect was discovered in 1839 by French physicist Becquerel. It remained in the laboratory until1954, when Bell Laboratories produced the first silicon solar cell.

It soon found application in the US space programs for its high power capacity per unit weight. Since then it has been an important source of power for satellites. Having developed maturity in the space applications, the PV technology is now spreading into the terrestrial applications ranging from powering remote sites to feeding the utility lines.

4.2.1.3 The importance of photovoltaics

The volume of solar cells currently produced world wide is approximately 100 Mega “peak watts” (peak watts are the capacity of a solar power plant at maximum sunshine of 1000 W/m^2). This order of magnitude is of course completely unimportant with regard to energy generation. However, there are numerous applications for which solar power brings great advantages. Thus, for example, many signal stations are driven by solar power. Another field which will grow significantly in the near future is photovoltaic power supplies for isolated houses, for which connection to the grid is very expensive. In the small appliance sector, e.g. power supplies for independent mobile equipment (meters, electrical tools, etc.), solar cells are becoming more popular.

Usage in the Third World will increase. Electrical lighting and the operation of fridges, etc. alone represent a large improvement in the standard of living in these countries. The operation of water pumps using photovoltaic is another viable application in this area, which is certain to become more and more common.

In the more distant future environmental concerns and the finite supply of fossil fuels make it certain that the sun, as the only inexhaustible energy source, will also be used for large scale power supplies. Just a fraction of the solar energy that falls upon the earth would cover our entire current energy demand. Thus, no restrictions are presented by the original energy supply.

- ***The PV cell***

The physics of the PV cell is very similar to the classical p-n junction diode. When light is absorbed by the junction, the energy of the absorbed photons is transferred to the electron system of the material, resulting in the creation of charge carriers that are separated at the junction. The charge carriers may be electron - ion pairs in a liquid electrolyte, or electron - hole pairs in a solid semi conducting material. The charge carriers in the junction region create a electric potential gradient, get accelerated under the electric field and circulate as the current through an external circuit. The current squared times the resistance of the circuit is the power converted into electricity. The remaining power of the photon elevates the temperature of the cell.

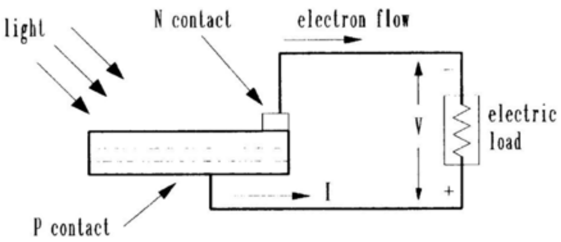

Figure 1: Photovoltaic effect converts the photon energy into a voltage across the p-n junction

The origin of the photovoltaic potential is the difference in the chemical potential, called the Fermi level, of the electrons in the two isolated materials. When they are joined, the junction approaches a new thermodynamic equilibrium. Such equilibrium can be achieved only when the Fermi level is equal in the two materials. This occurs by the flow of electrons from one material to the other until a voltage difference is established between the two materials which have the potential just equal to the initial difference of the Fermi level. This potential drives the photocurrent.

Figure 2 shows the basic cell construction. For collecting the photocurrent, the metallic contacts are provided on both sides of the junction to collect electrical current induced by the impinging photons on one side. Conducting foil (solder) contact is provided over the bottom (dark) surface and on one edge of the top (illuminated) surface. Thin conducting mesh on the remaining top surface collects the current and lets the light through. The spacing of the conducting fibres in the mesh is a matter of compromise between maximizing the electrical conductance and minimizing the blockage of the light. In addition to the basic elements, several enhancement features are also included in the construction. For example, the front face of the cell has anti-ref1ective coating to absorb as much light as possible by minimizing the reflection. The mechanical protection is provided by the cover glass applied with a transparent adhesive.

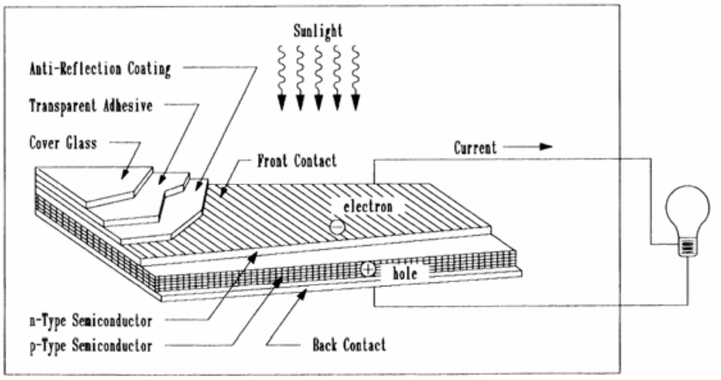

Figure 2: Basic construction of PV cell

- ***Module and array***

The solar cell described above is the basic building block of the PV power system. Typically, it is a few square inches in size and produces about one watt of power. For obtaining high power, numerous such cells are connected in series and parallel circuits on a panel (module) area of several square feet (Figure 3). The solar array or panel is defined as a group of several modules electrically connected in series-parallel combinations to generate the required current and voltage.

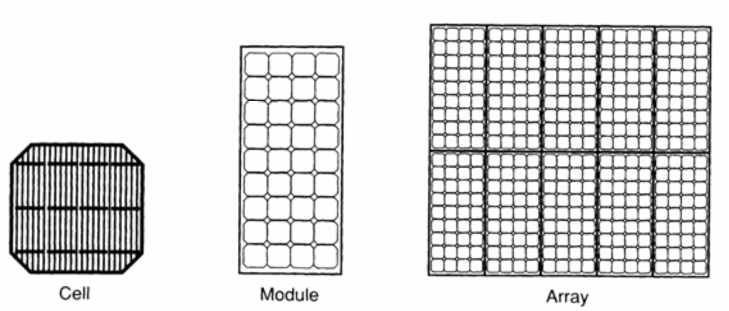

Figure 3: Several PV cells make a module, several modules make an array

Mounting of the modules can be in various configurations. In the roof mounting, the modules are in the form that can be laid directly on the roof. In the newly developed amorphous silicon technology, the PV sheets are made in shingles that can replace the traditional roof shingles on one-to-one basis, providing a better economy in the material and labor.

- ***Equivalent electrical circuit***

The complex physics of the PV cell can be represented by the equivalent electrical circuit shown in Figure 4.

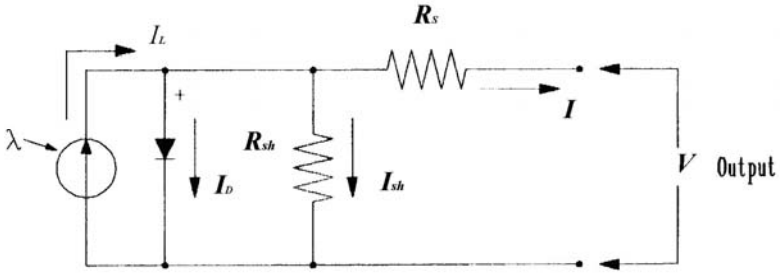

Figure 4: Equivalent electrical circuit of PV module, showing the diode and ground leakage currents

The circuit parameters are as follows.

The output-terminal current I (see Figure 4) is equal to the light-generated current I_L, less the diode-current I_D and the shunt-leakage current I_{sh}. The series resistance R_s represents the internal resistance to the current flow, and depends on the p-n junction depth, the impurities and the contact resistance. The shunt resistance R_{sh} is inversely related with leakage current to the ground. In an ideal PV cell, $R_s = 0$ (no series loss), and $R_{sh} = \infty$ (no leakage to ground). In a typical high quality one square inch silicon cell, R_s = 0,05 to 0,10 Ω and R_{sh} = 200 to 300 Ω. The PV conversion efficiency is sensitive to small variations in R_s, but is insensitive to variations in R_{sh}. A small increase in R_s can decrease the PV output significantly.

In the equivalent circuit, the current delivered to the external load equals the current I_L generated by the illumination, less the diode current I_D and the ground-shunt current I_{sh}. The open circuit voltage V_{oc} of the cell is obtained when the load current is zero, i.e., when $I = 0$, and is given by the following:

$$V_{oc} = V + IR_{sh}$$

The diode current is given by the classical diode current expression:

$$I_D = I_s\left(e^{\frac{QV_{oc}}{AKT}} - 1\right)$$

where:

I_s - the saturation current of the diode
I_D - diode current
Q - electron charge ($1{,}6.\ 10^{-19}$ C)
A - curve fitting constant
k - Boltzmann constant ($1{,}38.\ 10^{-23}$ J/K)
T - temperature on absolute scale (K)

The load current is therefore given by the expression:

$$I = I_L - I_s\left(e^{\frac{QV_{oc}}{AKT}} - 1\right) - \frac{V_{oc}}{R_{sh}}$$

The last term, the ground-leakage current, in practical cells is small compared to I_L and I_D, and can be ignored. The diode-saturation current can, therefore, be determined experimentally by applying voltage V_{oc} in the dark and measuring the current going into the cell. This current is often called the dark current.

- ***Stand-alone system***

The major application of the stand-alone power system is in remote areas where utility lines are uneconomical to install due to terrain, the right-of- way difficulties or the environmental concerns. Even without these constraints, building new transmission lines is expensive. A 230 kV line costs about 0,47 million EUR per kilometre.

The solar power output can fluctuate on an hourly or daily basis. The stand-alone system must, therefore, have some means of storing energy, which can be used later to supply the load during the periods of low or no power output. Alternatively, the PV can also be used in a hybrid configuration with diesel engine generator in remote areas or with fuel cells in urban areas.

According to the World Bank, more than 2 billion people live in villages that are not yet connected to utility lines. These villages are the largest potential market of the hybrid stand-alone systems using diesel generator with PV for meeting their energy needs. Additionally, the PV systems create more jobs per dollar invested, which help minimize the migration to already strained cities.

Because power sources having differing performance characteristics must be used in parallel, the stand.-alone hybrid system is technically more challenging and expensive to design than the grid-connected system that simply augments the existing utility system.

The typical PV stand-alone system consists of a solar array and a battery connection. The array powers the load and charges the battery during daytime. The battery powers the load after dark.

The inverter converts the DC power of the array and the battery into 60 or 50 Hz electrical power. Inverters are available in a wide range of power ratings with efficiency ranging from 85 to 95 percent at full load. The array is segmented with isolation diodes for improving the reliability. In such designs, if one string of the solar array fails, it does not load or short the remaining strings. Multiple inverters, such as three inverters each with 35 percent rating rather than one with 105 percent rating, are preferred. If one such inverter fails, the remaining two can continue supplying essential loads until the failed one is repaired or replaced. The same design approach also extends in using multiple batteries.

Most of the stand-alone PV systems installed in developing countries provide basic necessities, such as lighting and pumping water.

- ***Grid – connected system***

The photovoltaic power systems have made a successful transition from small stand-alone sites to large grid-connected systems. The utility interconnection brings a new dimension in the renewable power economy by pooling the temporal excess or the shortfall in the renewable power with the connecting grid. This improves the overall economy and the load availability of the renewable plant; the two important factors of any power system. The grid supplies power to the site loads when needed, or absorbs the excess power from the site when available. One kWh-meter is used to record the power delivered to the grid, and another kWh-meter is used to record the power drawn from the grid. The two meters are generally priced differently.

Figure 5 is a typical circuit diagram of the grid-connected photovoltaic power system. It interfaces with the local utility lines at the output side of the inverter as shown. A battery is often added to meet short term load peaks. In recent years, large building-integrated photovoltaic installations have made significant advances by adding the grid-interconnection in the system design.

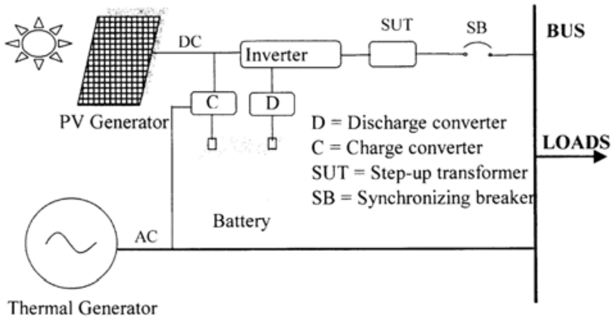

Figure 5: Electrical schematic of the grid-connected PV system

4.2.2 Guidelines for control and operation

Grid connected photovoltaic power plant normally operates fully automated. The power electronic circuits in photovoltaic power systems basically perform the following functions:

- convert DC into AC
- control voltage
- control frequency
- convert DC into DC

These functions are performed by solid state semiconductor devices periodically switched on and off at desired frequency. In terms of applications, no other technology has brought greater change in power engineering, or holds greater potential of bringing improvements in the future, than the power electronic devices and circuits results of a review on power electronic circuits used in modern photovoltaic power systems are shown below:.

Basic Power Electronic Switching Devices

A great variety of solid state devices is available in the market. Some of the more commonly used devices are as follows:

- bipolar junction transistor (BJT)
- metal-oxide semi conducting field effect transistor (MOSFET)
- insulated gate bipolar transistor (IGBT)
- silicon controlled rectifier (SCR), also known as the thyristor
- gate turn off thyristor (GTO)

For specific application, the choice depends on the power, voltage, current, and the frequency requirement of the system. A common feature among these devices is that all are three-terminal devices as shown in their generally used circuit symbols in Figure 6. The two power terminals 1 and 0 are connected in the main power circuit, and one control terminal G. In normal conducting operation, terminal is generally at higher voltage than terminal 0. Terminal G, known as the gate terminal, is connected to the auxiliary control circuit.

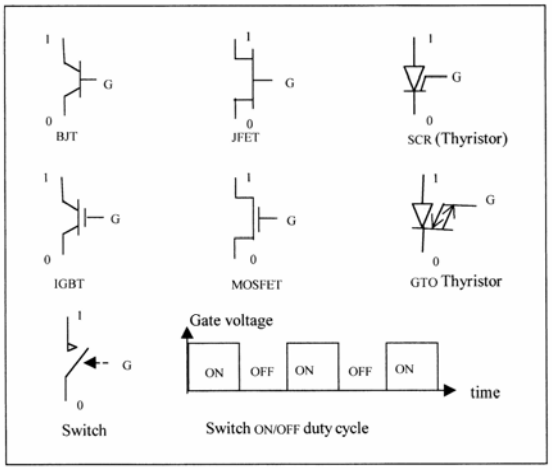

Figure 6: Basic semiconductor switching devices

Since the devices are primarily used for switching power on and off as required, they are functionally represented by the gate-controlled switch shown in Figure 6. In absence of the control signal at the gate, the device resistance between the power terminals is large, with the functional equivalence of an open switch. When the control signal is applied at the gate, the device resistance approaches zero, making the device behave like a closed switch. The device in this state lets the current flow freely through its body.

Table 1: Maximum Voltage and current Rating of Power Electronic Switching Devices

Device	Voltage Rating, Volts	Current Rating, Amperes	Remark
BJT	1500	200	Requires large current signal to turn on
IGBT	1200	100	Combines the advantages of BJT, MOSFET and GTO
MOSFET	1000	100	Higher switching speed
SCR	6000	3000	Once turned on, requires heavy turn-off circuit

The voltage and current ratings of the switching devices available in the market vary. The presently available ratings are listed in Table 1.

The switch is triggered periodically on and off by a train of gate signals of suitable frequency. The gate signal may be of rectangular or other wave shape, and is generated by a separate triggering circuit, which is often called the firing circuit. Although it has a distinct identity and many different design features, it is generally incorporated in the main power electronic component assembly.

In photovoltaic power systems, the DC power produced by the PV modules is inverted into 60 or 50 Hz AC power using the inverter.

DC to AC Inverter

The power electronic circuit used to convert DC into AC is known as the inverter. The term "converter" is often used to mean either the rectifier or the inverter. The DC input to the inverter can be from any of the following sources:

- DC output of the photovoltaic power modules.
- DC output of the battery used in photovoltaic power system.

Figure 7 shows the DC to three-phase AC inverter circuit diagram. The DC source current is switched successively in a 60 Hz three-phase time sequence such as to power the three-phase load. The AC current contains significant harmonics. Diodes secure the switch off function of thyristor. The fundamental frequency (60 or 50 Hz) phase-to-neutral voltage is as follows:

$$V_{ph} = \frac{2\sqrt{2}}{\pi}\cos\left(\frac{\pi}{6}\right)V_{DC}$$

The line-to-line AC voltage is given by $\sqrt{3}\cdot V_{ph}$.

Unlike in BJT, MOSFET, and IGBT, the thyristor current, once switched on, must be forcefully switched off (commutated) to cease conduction. If the thyristor is used as the switching device, the circuit must incorporate additional commutating circuit to perform this function. The commutating circuit is a significant part of the inverter circuit. There are two main types of inverters, the line commutated and the forced commutated.

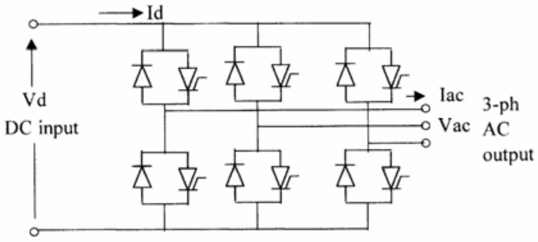

Figure 7: DC to three-phase AC inverter circuit.

The line-commutated inverter must be connected to the AC system into which they feed power. The design method is matured and has been extensively used in the high-voltage DC transmission line inverters. Such inverters are simple and inexpensive and can be designed in any size. The disadvantage is that they act as a sink of reactive power and generate high content of harmonics.

Poor power factor and high harmonic content in line commutated inverters significantly degrade the quality of power at the utility interface. This problem has been recently addressed by a series of design changes in the inverters. Among them is the 12-pulse inverter circuit and increased harmonic filtering. These new design features have resulted in today's inverters operating at near unity power factor and less than 3 to 5 percent total harmonic distortion. The quality of power at the utility interface at many modern solar power plants can exceeds that of the grid they interface.

The force-commutated inverter does not have to be supplying load and can be free-running as an independent voltage source. The design is relatively complex and expensive. The advantage is that they can be a source of reactive power and the harmonics content is low.

Grid Interface Controls

At the utility interface, the power flow direction and magnitude depend on the voltage magnitude and the phase relation of the site voltage with respect to the grid voltage. The grid voltage being fixed, the site voltage must be controlled both in magnitude and in phase in order to feed power to the grid when available, and to draw from the grid when needed. If the inverter is already included in the system for frequency conversion, the magnitude and phase control of the site voltage is done with the same inverter with no additional hardware cost.

Frequency Control

The output frequency of the inverter solely depends on the rate at which the switching thyristors or transistors are triggered into conduction. The triggering rate is determined by the reference oscillator producing a continuous train of timing pulses, which are directed by logic circuits to the thyristor gating circuits. The timing pulse train is also used to control the turn-off circuits. The frequency stability and accuracy requirements of the inverter dictate the selection of the reference oscillator. A simple temperature compensated R-C relaxation oscillator gives the frequency stability within 0.02 percent. When better stability is needed, a crystal-controlled oscillator and digital counters may be used, which can provide stability of .00l percent or better. The frequency control in a stand-alone power system is an open- loop system. The steady state or transient load changes do not affect the frequency. This is one of the major advantages of the power electronics inverter over the old electromechanical means of frequency controls.

Battery Charge/Discharge Converters

The stand-alone photovoltaic power system uses the DC to DC converter for battery charging and discharging.

Battery Charge Converter

Figure 8 is the most widely used DC-DC battery charge converter circuit, also called the buck converter. The switching device used in such converters may be the BJT, MOSFET, or the IGBT. The buck converter steps down the input bus voltage to the battery voltage during battery charging. The transistor switch is turned on and off at high frequency (in tens of kHz). The duty ratio D of the switch is defined as the following:

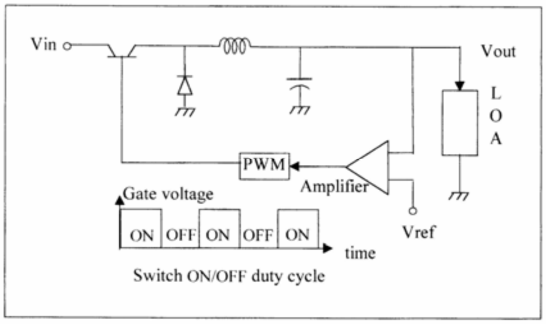

Figure 8: Battery charge converter for PV system (DC to DC buck converter)

Pulse-width modulation PWM in which the value of each instantaneous sample of the modulating wave is caused to modulate the duration of the pulse. The modulating frequency may be fixed or variable.

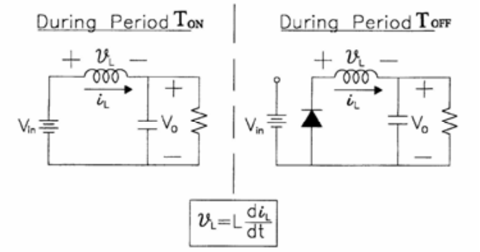

Figure 9: Charge converter operation during the switch on-time and off-time

$$Duty\ ratio\ D = \frac{Time\ on}{Period} = \frac{T_{on}}{T} = T_{on} \cdot Switching\ \ frequency$$

The charge converter operation during one complete cycle of the triggering signal is shown in Figure 9 During the on time, the switch is closed and the circuit operates as on the left. The DC source charges the capacitor and supplies power to the load via the inductor. During the off time, the switch is open and the circuit operates as on the right. The power drawn from the DC source is zero. However full load power is supplied by the energy stored in the inductor and the capacitor, with the diode providing the return circuit. Thus, the inductor and the capacitor provide short-time energy storage to ride through the off period of the switch.

Power Shunts

In stand-alone photovoltaic systems, the power generation in excess of the load and battery charging requirements must be dissipated in dump load in order to control the output bus voltage. The dump load may be resistance- heaters. However when the heaters cannot be accommodated in the system operation, the dissipation of the excess power can pose a problem. In such situations, shorting (shunting) the photovoltaic module to ground forces the module to operate under the short circuit condition, delivering I_{sc} at zero voltage. No power is delivered to the load. The solar power remains on the photovoltaic modules, raising the module temperature and ultimately dissipating the excess power in the air. The photovoltaic module area is essentially used here as the dissipater.

The circuit used for shunting the PV module is shown in Figure 10. A transistor is used as the switch. When the excess power is available, the bus voltage will rise above the rated value. This is taken as the signal to turn on the shunt circuits across the required number of photovoltaic modules. The shunt circuit is generally turned on or off by the switch controlled by the bus voltage reference.

Relays can perform this function, but the moving contacts have a much shorter life than the solid state power electronic switches. Therefore, relays are seldom used except in small systems.

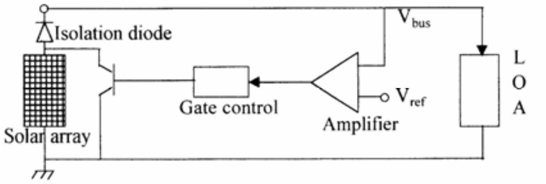

Figure 10: Power shunt circuit for shorting the module.

Another application of the power shunt circuit is in the PV module dedicated to directly charge the battery without the charge regulator. When the battery is fully charged, the module is shunted to ground by shorting the switch. This way, the battery is protected from overcharging.

For array with several modules in parallel, basic configuration shown in Figure 11-12 is used for each module separately, but the same gate signal is supplied to all modules simultaneously. For shunting large power, multiple shunt circuits can be switched on and off in sequence to minimize switching transients and electromagnetic interference (EMI) with the neighbouring equipment. For fine power control, one segment can be operated in the pulse width modulation (PWM) mode.

4.3 Guidelines for R&D policy and decision makers

4.3.1 RES-technology development

Electrical energy production with PV modules will rise at most in the future.

The importance of solar energy will rise as we can see on the Figure 11. On the PV market we can find different PV modules with solar cells.

The monocrystal solar cells have had greatest market share until 1998. Their efficiency is between 14 and 18 %, and will rise on 20 % by year 2010. In next 10 years the market share of monocrystal solar cells will be constantly dropping. From year 1997 to year 2000 it has dropped from 50 % on 31 % or on 27 % in year 2003. It is predicted that the market share will become stabile at 20 % in long term.

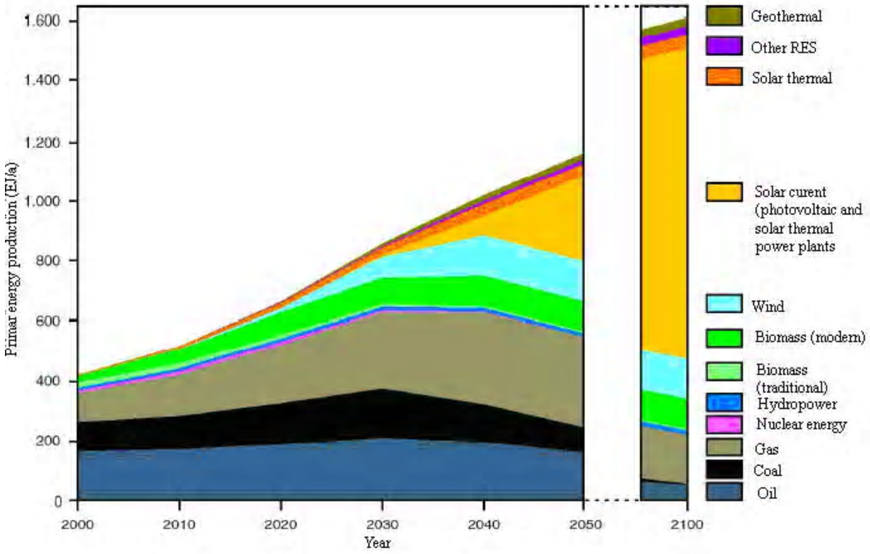

Figure 11: Trends of the global electrical energy production from RES.

Multicrystal solar cells have similar characteristics than monocrystal solar cells. Their production is chipper and easier than production of monocrystal solar cells. Efficiency of Multicrystal solar cells is between 14 and 17 %. Market share of multicrystal solar cells is constantly rising in the past years – from 49 % in year 2000 to 61 % in year 2003. Their market share will become stabile at 30 % in long term and it will be higher than market share of monocrystal (single crystal silicon) solar cells, ribbon & sheet, amorphous silicon, CIS, CdTe and concentrators solar cells (see Figure **Error! Not a valid link.**).

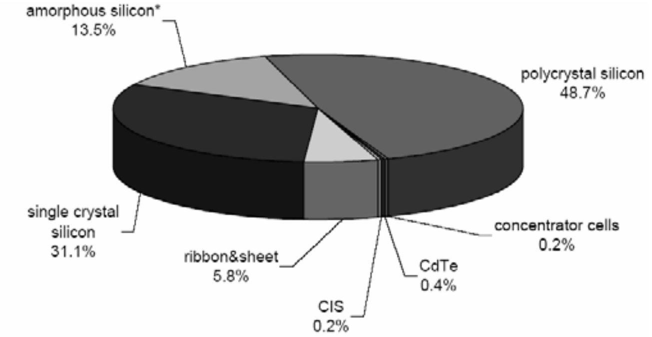

Figure 12: Market share of different solar cells in year 2010.

Technological process of production of ribbon sheet solar cells is improved process of solar cell production without slicing and other desertion. Their efficiency is low. The market share of ribbon sheet solar cells will rise because their low production costs. Their market share will become stabile at 20 % in long term.

Efficiency of solar cells can be raised up to 25 % with use of concentrator cells. Selling price of these cells is still extremely high, but it will drop. Concentrator cells are appropriate for large solar systems (solar area) (> 100 kW). The market share of concentrator cell will rise constantly.

Many years have been set up, that the amorphous solar cells will be the right alternative to crystal solar cells. 2/3 from all laboratory researches has been directed to this field. In comparison to the crystal solar cells the amorphous solar cells does not have a crystal structure, they have amorphous silicon, gained with several technologies. The efficiency of amorphous solar sells is low, about 8 %. Great advance of amorphous solar cells is their low selling price. Market share of those solar cells will be constantly rising and will stabilize at 20 % in 2010.

The advantage of CdTe and CIS solar cells is that the semiconductor material in this case is not silicon, but a complex layer of some alloy metal. These alloys are much easier to provide than silicon. The efficiency of these cells is about 7 %, but laboratory researches are predicting that it will rise up to 14 % in year 2010. The problem of those cells is long term unreliability. The market share of those solar cells will stabilize at 3 or 4 % in year 2010 (see figure 13).

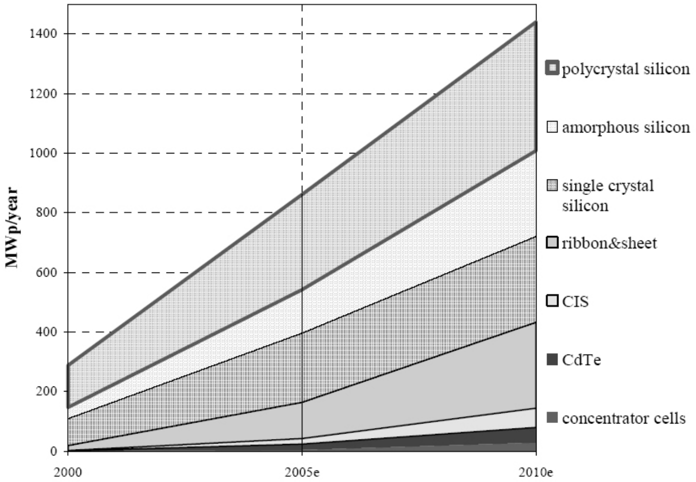

Figure 13: Forecast of different solar cells options from 2000 to 2010

The production of the PV products has rise up to 32 % in year 2003. From year 1997 to 2002 it has rise for 27 % each year. At year 2004 was the total global production of PV modules 3145 MW. Total installed capacity of PV modules to year 2004 was 1,8 GW. The production of PV modules will rise for 30 % yearly until year 2010, and for 25 % after year 2010 (Figure 14). The reasons for such big step in PV production are the improvements of production technologies and used materials and several state initiatives. The global production of PV modules will rise up to 300 GW per year in year 2030.

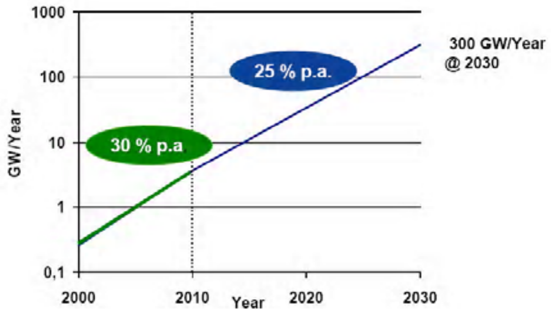

Figure 14: Predicted rise of global PV modules production

Very perspective future market for PV systems it will also be Balkan region. This region has low electrification. To enable the future economy growth for this region, this region will have to improve its electricity supply. Therefore Western Balkan Countries should begin with several projects to promote electrical energy from RES. So there is also always a possibility to install PV systems.

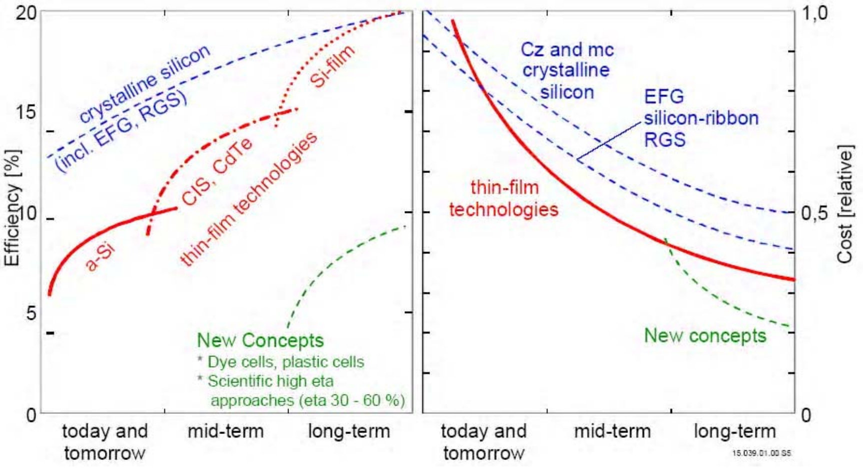

Figure 15: Solar cells development trends

In Figure 15 it can seen that the efficiency of different solar cells will rise and the production costs will significantly fall on the long time period. Installed capacities in these countries are much lower than installed capacity in European countries. There should be activated several projects to achieve much higher share of electricity, produced from photovoltaic, which are:

- Programs which gained special attention should be also for Western Balkan countries “Sun at School” and “PV Enlargement”
- Legislation and promoting programs for PV systems (subsidy for produced electricity).
- Improvement of DC-AC converter technologies
- Improvement of Si feedstock production routes
- Improvement of efficiency and production process of solar cells and solar module

In Figure 16 it can that the there are possibilities to improve the Si feedstock production. Green lines show the today normal production line of SoG-Si, and the yellows possible improvements.

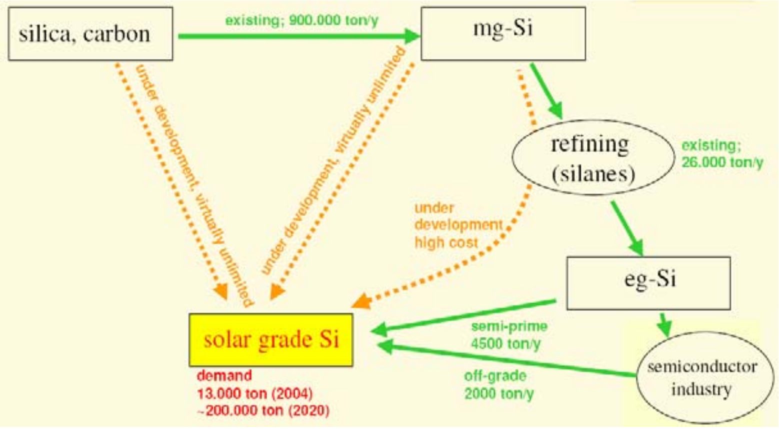

Figure 16: Possible development Si feedstock production routes.

4.3.2 Demonstration

According to a great success of program to promote PV products for housekeeping in Germany, the governments of Western Balkan countries should managed to make a step forward in the RES energy legalization (Feed-in Law). The feed-in tariff of 1 kWh of electricity from PV modules in Germany is between 0,45 and 0,62 EUR. Similar model for increasing of PV systems installation exists also in Spain, Portugal, Austria, Netherlands, France, Slovenia, Italy.

Further advantages of PV market in Western Balkan countries should be simplicity of administrative and technological procedure of incorporation of PV systems in the national electrical grid. The inquiry for PV systems will also grow with new PV power plants on mountain hut; ski lodge, schools, on air conditioning facilities, parking houses for (hybrid driven) vehicle, low emission houses etc.

The investment costs for these demonstration plants have to be subsidized due to the environmental friendly technology.

An interesting example of a subsidized demonstration project in Slovenia, on University of Maribor, is photovoltaic, wind and fuel cells hybrid power plant. Lots of experiences and data will come out of this application, which will help to improve the components of the aggregate and to enlarge the effectiveness of the plant by an advanced control system.

4.3.3 Economic aspects

A good economical overview on the photovoltaic power plant can be gained by a comparison with the conventional and other power plants based on RES.

Table 2: Investment and production costs of some power generation technologies (technologies printed in **bold** are suitable for dispersed generation, renewable technologies are printed in *italic*)

Technology	Usual size MW]	Investment costs [EUR/W]	Production costs [EUR/kWh]
CHP – fossil	10 – 40	0,43 – 0,80	0,04 – 0,05
CHP – biomass	0,7	2,0 2,3	0,05 – 0,07
CHP – fuel cell	0,2	1,00 – 1,47	0,07 – 0,10
Wind turbines	1,5	0,80 – 1,20	0,04 – 0,09
Small run-of-river hydro PP	5	0,80 – 5,10	0,02 – 0,03
Gas turbines	5	0,73 – 0,80	0,02 – 0,05
Gas motors	5	0,43 – 0,73	0,03 – 0,04
Photovoltaic cells	5	5,67 – 8,67	0,33 – 0,92
Micro motors	0,05	0,57 – 1,47	0,07 – 0,14
Micro turbines	0,05	0,27 – 0,33	0,03 – 0,05
Fuel cells	0,05	0,80	0,08 – 0,14
Thermal PP – coal fired	450	0,47– 2,60	0,03
Combined cycle	500	0,44 – 4,17	0,03
Hydro power plants	350	1,46 – 2,60	0,02

Technology	Usual size MW]	Investment costs [EUR/W]	Production costs [EUR/kWh]
Nuclear power plants	600	0,83 – 3,65	0,03
Solar collectors	150	1,98 – 2,58	0,04

The energy pay-back time represents that time period over which a PV module generates the amount of energy that was required to produce it. It is thus a parameter that particularly in view of environmental considerations ought to be considered. While it is obvious that these time periods depend on the cumulated isolation and hence on the geographical location of the solar module installation (i.e. longer energy pay-back items at larger geographical latitudes), a comparison of the absolute values requires a clear definition of the energy consumptions that are to be taken into account for manufacturing the solar module. In Figure 18 the energy requirements needed to produce a frameless solar module are compiled for two scenarios, that either take into account only the energies needed for the immediate steps to produce a module (silicon feedstock, wafers, cells, and modules), or additionally include the energy requirements to produce the raw materials needed (e.g. glass, plastics etc.).

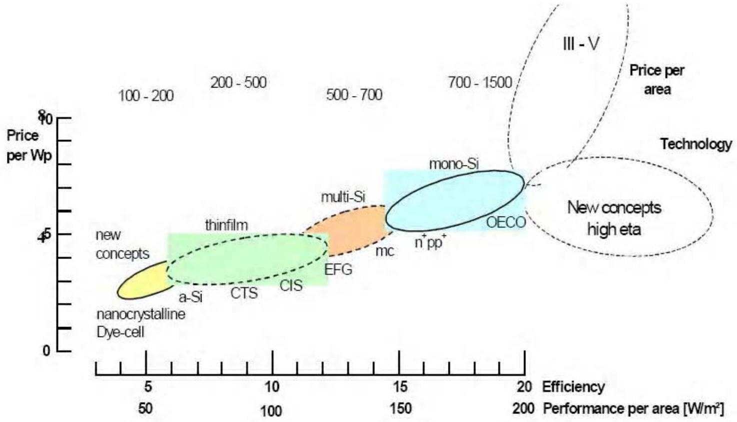

Figure 17: Area Related Price and Power Output for Various Technologies

In the latter case, all electricity needs are changed into primary energy. The conversion factor electrical to primary energy typically is assumed to be 0.35. At 1 kWh/Wp year insolation, roughly Central Europe, the energy need, expressed as kWh/Wp, equals the energy pay-back time in years; for Southern Europe at about twice the insolation, the energy pay-back time corresponds to about one half the energy needs. While these data significantly may vary depending on the accuracy of data collection, it is safe to state that the energy pay-back times are far below the anticipated service life of modules. Hence PV must be considered as an environmentally meaningful way of electricity generation.

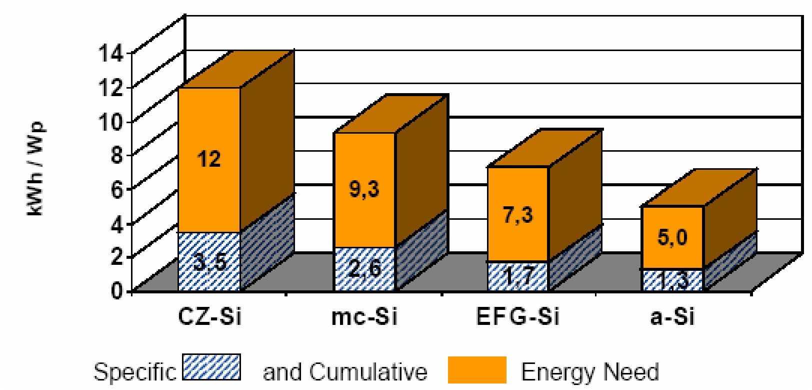

Figure 18: Energy need for PV module production

In Figure 18 it can be seen that the specific and cumulative electrical energy consumption are the greatest for monocrystal solar module production (CZ-Si). The lowest energy consumption is appearing in case of amorphous solar cell - modules production (a-Si). The optimum is representing the specific and cumulative electrical energy consumption for multicrystal (mc-Si) solar module production. The edge-defined film fed growth solar cells (EFG-Si) are between of above mentioned solar cells.

4.3.4 Environmental aspects

RES are wide geographical spread, so they can be generated near the load centers, thus simultaneously eliminating the need of high voltage transmission lines running through rural and urban landscapes. The present status and benefits of the renewable power sources are compared with the conventional ones in Tables 3 and 4, respectively.

The renewals compare well with the conventional in economy. Many energy scientists and economists believe that the renewals would get much more federal and state incentives if their social benefits were given full credit.

Table 3: Status of Conventional and Renewable Power Sources

Conventional	Renewals
Coal, nuclear, oil, and natural gas Fully matured technologies Numerous tax and investment subsidies embedded in national economies Accepted in society under the' grandfather clause' as necessary evil	Wind, solar, biomass geothermal, and ocean rapidly developing technologies Some tax credits and grants available from some sate governments being accepted on its own merit, even with limited valuation of their environmental and other social benefits

Table 4: Benefits of Using Renewable Electricity

Traditional Benefits	Non-traditional Benefits Per Million kWh consumed
Monetary value of kWh consumed U.S. average 9 EUR cents/kWh U.K. average 7.5 pence/kWh EU average 10,5 EUR cents/kWh Slovenia average 7,9 EUR cents/kWh	Reduction in emission 750-1000 tons of CO_2 7.5-10 tons of SO_2 3-5 tons of NO_x 50,000 kWh reduction in energy loss in power lines an quipment Life extension of utility power distribution equipment Lower capital cost as lower capacity equipment can be sed (such as transformer capacity reduction of 50 kW per MW installed)

The most used materials by solar module production are glass, EVA foil and aluminum. Other materials which are used in this process are raw materials, which are used for metallurgical process of silicon refinement and wafer slicing (mineral oils, SiC). Special attention needs to be dedicated to great amount of HCl, which is used in carbon and silicon purification process.

The greater emissions in the life time of the solar module appear in solar module production phase. Environmental aggravating substances, used in production, are fluorine (F), chlorine (Cl), nitrate (N_x), isopropyl, SO_2, CO_2 and evaporated parts of silicon and smelter.

Many of these substances can cause acute or/and conical illnesses of the employees (caustic, acids, smelters…). Most of materials, used in multicrystal solar cells and module production are not poison and are not harmful for the employees.

Chemicals, which are used in the production process, can be separate on cancerous or uncancerous chemically. Uncancerous chemically can cause specific damages to defined organs, reproduction ability, nerve system, immune system, decreasing of growth and appetite.

Cancerous chemically cause or accelerate growth of tumors in the human body and/or animals. Cancerous chemically are arsenic, cadmium and trichlorineethyl. Harmful, but not cancerous chemicals are phosphates, FCl_3, HCl and H_2SO_4.

Emissions of GHG will reduce in next then years because of increasing number of PV system installations. Emission of CO_2, which appear at solar module production, is 20 times lower than emissions of CO_2 at conventional electricity generation. Emission of the acids, which are related with electricity generation, are 16 times lower, than emissions of the same acids, which are related with conventional electricity generation. Emissions of GHG can be reduced up to 60 % with use of solar modules for electricity generation.

In view of the points of attention that were identified in the environmental assessment of multicrystal solar cell modules, the following recommendations can be formulated:

- The possibilities for recycling silicon wafers, both from production waste (rejected cells) and from decommissioned modules, should be investigated;
- Possibilities for using secondary aluminum for producing module frames should be assessed;

- Methods should be investigated to reduce the emission of fluorides in water, but also the emission of fluorides as solid waste. Alternative methods to etch the emitter without use of HF enchants should be considered;
- The CF_4 gas which is used in the plasma etching process has a large Global Warming Potential. Therefore routine or incidental emissions of this gas should be avoided;
- Emissions of volatile solvents and alcohols should be avoided;
- The possibilities for reuse of silicon carbides (sawing slurry) and argon should be given attention;
- The use of silver for contacts should be reduced to avoid problems with resource availability and problems with the management of waste from decommissioned modules.

The additional quantities of the other material, needed at the solar module production can be reduced with recycling methods for solar modules. The biggest recycling problems appear at EVA foil and glass recycling. From the structure aspects, the EVA foil is not purpose for recycling. The glass from solar modules contains far too much plastic, so it can not be recycled by glass recycling centers. Therefore the special methods are required to remove foil form the glass. Material, which is very easy to recycle, is aluminum.

The process of solar module recycling is very complex, because of very long life time of the solar module and low concentrations of valuable materials and global despoliation of the solar modules.

Module recycling costs are about 0,1 EUR/W, at quantity of 150000 solar cells per year. The production costs for new solar cell are 2 EUR/W. The global amount of exploited solar modules was 9500 ton in year 2003. The advantage of solar module recycling is very large energy saving, by production of solar module from recycled solar cells can be saver up to 80 % of energy.

4.3.5 Potentials in the WBC

The objectives of the discussion about potentials of technologies are finally the quantification of possibilities. Potentials have to be discussed in detail for discovering the obstructions for a broad application of the RES technologies. The analysis of potentials leads to the following detailed investigations.

- Theoretical potential: It covers the whole energy content, which can be delivered by an energy conversion technology in the WBC.
- Physical potential: It covers that part of the whole energy content, which is limited by the today known physical properties of a process..
- Production-engineering potential: It covers that part of the whole energy content, which is not limited by the production capacity in the WBC
- Ecological-topographical potential: It covers that part of the whole energy content, which is not limited by environmental factors, like pollution of air, water, soil, as well as noise and unfavorable optical changes of the environment.

- Economic potential: It covers that part of the theoretical potential, which can be compared in view of costs with the conventional technique. The application of conversion processes, based on fossil fuels, release pollutant substances, like SO_2, NOx, CO, CO_2, CxHy and dust, which causes damages on human and environment. Politico-economical costs, the so-called external costs, arise and have to be considered too.

In this general part of "Guidelines for RES-technologies" no quantification of potential will be done. This will follow later on for the different RES-techniques.

4.3.6 Subsidy needs

After the demonstration of the environmental friendly, RES-photovoltaic power plants, the broad applications have to be prepared by suitable decisions of the policy makers and politicians. Subsidies developing programs and administrative facilities for photovoltaic power plants have to make available in a suitable level, so that customers will be encouraged to invest their money for RES-photovoltaic power plants with equal costs and benefits, as they have to pay for the market available electricity produced by other sources.

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5 BIOMASS-FIRED ORC-POWER GENERATION

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5.1 General

Biomass is an extremely important renewable energy source, available nearly everywhere. It is often preferable to produce electricity from biomass by means of relatively small generation units, in order to get biomass from a single source or from a number of sources located in a limited area, without a complex biomass gathering organization and without the additional commercial, transport and storage costs. Power plants based on Organic Rankine Cycle (ORC) are very promising solution for biomass co-generation with nominal ratings between 450 and 1500 MW electric per unit. The ORC is a thermodynamic cycle that uses an organic working fluid (rather than steam) to generate electricity. Seven years after the commissioning of the first industrial installation of a biomass cogeneration plant based on an ORC turbo-generator and thermal oil boiler several reference plants are running successfully in Europe with continues and unattended operation.

Figure 3.1: Biomass fired ORC co-generative district heating plant in Lienz, Austria /1/

The advantages of this technology in terms of high availability, low maintenance costs, completely automatic and unmanned operation and high electric efficiency have been confirmed in practice.

Typical applications are co-generative district heating systems and co-generation in wood manufacturing industries, where this technology is experiencing a fast growing number of installations.

5.2 Guidelines for planners, installers and students

5.2.1 Guidelines for design

5.2.1.1 Thermodynamic background

A Rankine cycle is usually known as a closed circuit steam (water vapor) cycle. An "organic" Rankine cycle uses a heated chemical instead of steam as found in the original Rankine Cycle. Chemicals used in the Organic Rankine Cycle include freon, butane, propane, ammonia and the new environmentally-friendly" refrigerants and as well as oils. Such of working medium boils at a temperature below the temperature of frozen ice. Solar heat, for example, of only 65 ^{0}C from a typical rooftop solar hot water heater, will furiously boil a refrigerant. The resulting high-pressure refrigerant vapour is then piped to an organic Rankine cycle engine. The first ORC plants have been used to convert solar and geothermal heat into electricity almost fifty years ago. The working principle and the different components of the ORC process are shown in Figure 3.2 and Figure 3.3

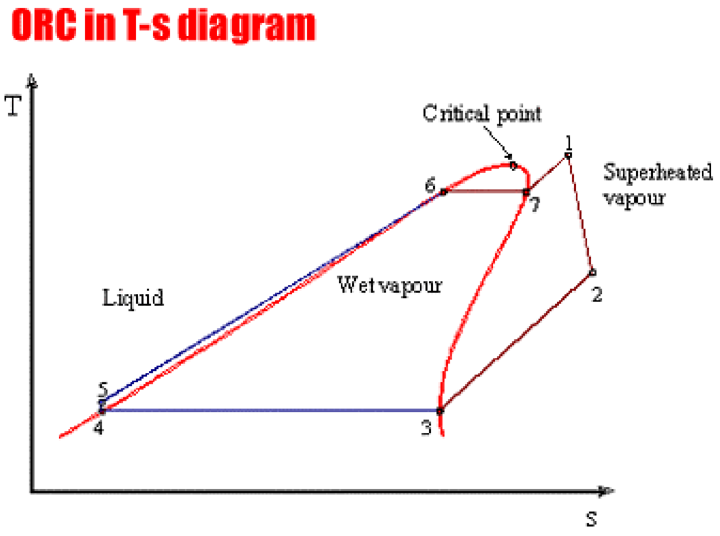

Figure 3.2: Organic Rankine Cycle in basic thermodynamic diagram /2/

The selected working fluid for biomass fired ORC plants is silicone oil. This approach allows exploiting efficiently low temperature heat sources to produce electricity in a wide range of power outputs (from few kW up to 3 MW electric power per unit) /3/.

The silicone oil is heated, vaporized and slightly pre-heated in the evaporator by getting heat from the thermal oil (lines 5→6→7→1). The vapor is then expanded into appropriately designed axial turbine (line 1→2). The exhaust vapor flows through a regenerator (line 2→3) where it heats the organic fluid. The vapor is then cooled by the water flow and condensed in condenser (line 3→4). The organic fluid liquid is finally pumped (line 4→5) by silicone oil pump to the regenerator and then to the evaporator, thus completing the sequence of operations in the closed-loop circuit. The cooling water inlet/outlet temperatures is a range of 60/80 ^{0}C, thus the ORC plant could be directly connected with district heating system or process heat consumer in order to produce combined heat and power (CHP). In places where appropriate heat consumers are not available, the ambient air can be used for cooling. In this case large air-cooling facility has to be available. The cycle has got relatively high electric efficiency (=net electric power produced/thermal power input) of approximately 18 % /4/.

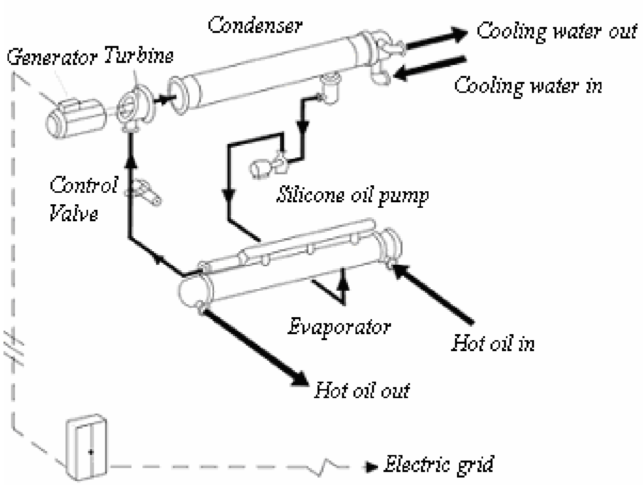

Figure 3.3: Main components of ORC unit /3/

The ORC has several advantages over conventional steam plant technology for small and medium scale biomass fired power generation:

- The organic fluids have a lower specific volume than steam. This results in smaller turbines, smaller diameter exhaust piping and smaller size of the condenser.
- Due to the low acoustic velocity of organic fluids, compared to steam, favorable aerodynamic matching is achieved at low blade speed. This yields high turbine efficiency at 50 Hz (1,500 rpm) without a gearbox.
- Organic fluids condense at higher pressure than steam. By operating at condensing pressures near atmospheric, the ORC turbine requires smaller blades, fewer stages and the ingress of air into the system is significantly minimized. The latter feature mitigates the need for vacuum maintenance.
- Unlike steam, silicone oil remains dry during the expansion from high to low pressure—a consequence of the organic fluid's thermodynamic properties. This eliminates the possibility of moisture formation and the likelihood of erosion damage when high-speed droplets collide with the turbine's buckets and nozzles. Thus, the ORC can accommodate part load operation and large transients more effectively than steam turbines, without requiring a super-heater.
- No water treatment necessary;
- The ORC turbo-generator (up to about 800 kW$_{el}$) consists of a single skid-mounted assembly, containing all the equipment required for the turbo-generator to be operated (i.e. heat exchangers, piping, working fluid feed pump, turbine, electric generator, control and switch-

gear). Larger units are composed of multiple modules, pre-assembled at the factory. Hence the units are easy to transport and to install, and they are easy to interface with the hot and cold sources on site.

There are also other advantages, such as simple start-up/ shout-down procedures, quiet operation, minimum maintenance requirements and good partial load performance.

5.2.1.2 Biomass fired ORC plant basic design features

The biomass fired ORC-power generation is based on the following main steps:

A. Biomass is burned in a combustion chamber made according to the well-established techniques in use also for hot water boilers. These facilities with their set of accessories (filters, controls, automatic ash disposal and biomass feed mechanism etc.) are nowadays safe, reliable, clean and efficient.

B. Hot thermal oil is used as primary heat transfer medium, giving a number of advantages, including low pressure in boiler, large inertia and insensibility to load changes, simple and safe control and operation. Moreover, the adopted temperature (about 300 ^{0}C) for the hot side ensures a very long life of the oil. The utilization of a thermal oil boiler also allows operation without licensed operator required for water vapor systems in many European countries;

C. An Organic Rankine Cycle turbo-generator is used to convert the available heat to electricity. Thanks to use of properly formulated working fluid (silicone oil) and to the optimization of machine design both high efficiency and high reliability are obtained. The residual heat of the cycle (heat of condensation) is used to produce hot water at typically 80-90 ^{0}C level, a temperature range suitable for district heating and other low temperature needs (like wood drying and cooling through absorption chillers etc.)

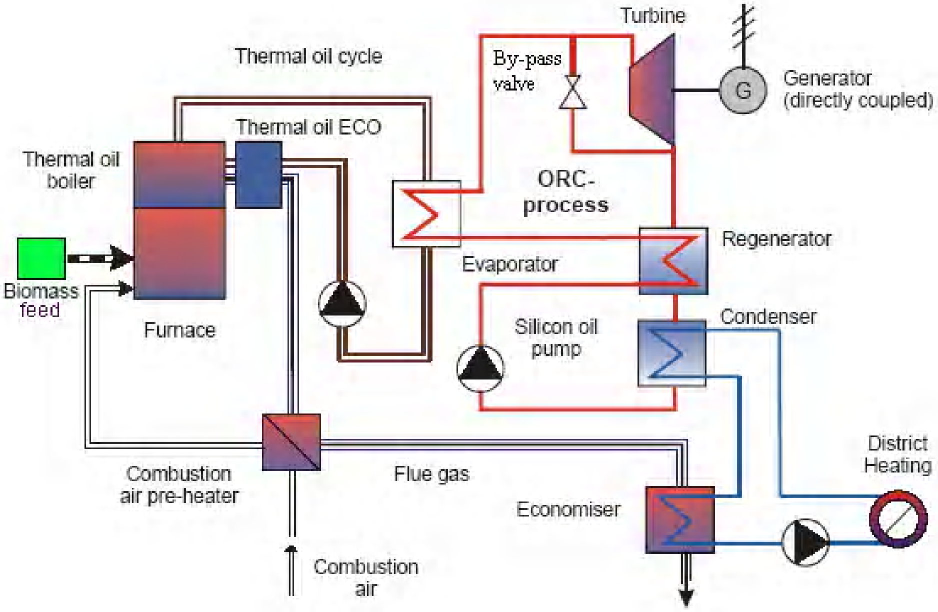

Figure 3.4: Layout of biomass fired ORC plant for combined heat and power generation in Lienz, Austria /1/

As it shown on the Fig.X.4 a biomass fuelled ORC power plant is composed of the following items:

- An automatic biomass feeding system, suitable to automatically operate the boiler adapting to the available biomass;
- A biomass boiler consisting of a combustion chamber with fixed or sliding grates, air or water-cooled according to the biomass to be burned. On the top of the combustion chamber, a hot gas/thermal oil primary heat exchanger is installed. Normally, this heat exchanger is composed of a single pass coil in which a relatively high thermal oil speed is assured, in order to avoid oil stagnation. In fact, it is essential to avoid hot spots in thermal oil tubes, as this would lead to its overheating and as a result a reduction of its lifetime.
- Due to relatively high thermal oil inlet/outlet temperatures (250 ^{0}C / 300^{0}C) the exhaust gas temperature is high enough to allow installation of hot gas/thermal oil economizer, combustion air pre-heater and flue gas/district heating water economizer. Using these approach, the thermal efficiency of the biomass fired thermal oil boiler reaches 82% (= thermal power output/fuel power input), which is about 10% higher than corresponding values from conventional biomass-thermal oil boilers. This increased thermal efficiency, subsequently changed the over all electric efficiency of the CHP plant (= net electric power produced/fuel power input into the biomass-fired boiler) to about 15%, Fig. 6.5.
- A thermal oil circulation system driven by a pump provides heat exchange between the boiler and ORC turbine. Normally two pumps are installed (one in standby), in order to assure in any case circulation of thermal oil through the boiler. In case of malfunction of the first pump, the second one is automatically started. If a grid failure occurs, then an UPS supplies electric power to the pumps.
- An evaporator using heat from the thermal oil to vaporize and slightly to pre-heat the organic fluid
- A direct cooling by-pass, suitable to transfer heat from the thermal oil circuit to the cooling water circuit This by-pass valve is useful tool during turbo-generator start-up or shut-down procedures.
- An Organic Rankine Cycle unit. The key component of the whole biomass fired ORC-power generation plant is an axial turbine that drives directly coupled generator. It allows heat to electricity conversion with good efficiency and reliability from thermal oil at relatively low temperature of 300^{0}C.

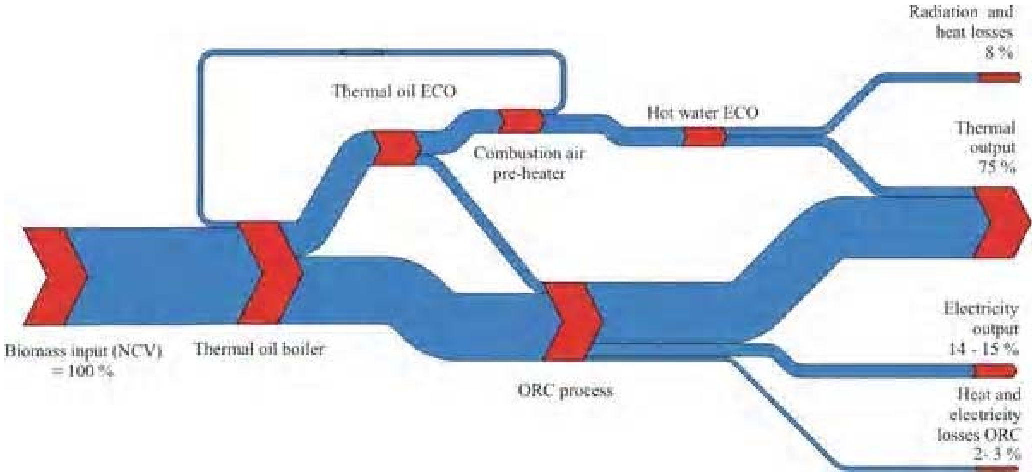

Figure 3.5 Energy balance of the biomass CHP plant in Lienz, Austria /1/

The adoption of an intermediate Heat Transfer fluid (i.e. the thermal oil) between the biomass furnace and the ORC turbo-generator gives a number of advantages, mainly:

- Absence of a high pressure 'vapor generator' inside the boiler (in a thermal oil boiler a liquid is heated, without phase changing). The presence on site of a licensed 'boiler operator' is not required.
- Simple and easy-to-clean heat exchanger geometry (a thermal oil boiler is basically a coiled pipe, while in a steam generator the geometry is more complex. Furthermore, in case of the presence of a steam super-heater, the tube wall temperatures are higher and melting problems of ashes can occur, with the consequence of severe scaling or even clogging of the flue gas path. Moreover, the high wall temperature of a steam super-heater involves corrosion problems, due to the acid components of the biomass combustion gases. Between the main scheduled cleaning sessions, a thermal oil boiler is automatically and effectively cleaned by suitable compressed air blows;
- Clear and simple interface between the furnace and the ORC turbo-generator. By measuring thermal oil temperature and flow it is easy to compute the recovered thermal power, hence to clearly define the performance of the boiler and the performance of the turbo-generator;
- Easiness of in providing an auxiliary cooling of the furnace exhausts loop (in case of turbo-generator shut down or during start-up) by installing a relatively small thermal oil-water heat exchanger. In most applications, the exhausts have to be cooled in any case before entering the filtering system.
- Operation simplicity. Partial load conditions are obtained by modulating a three- way valve on thermal oil side or by changing the thermal oil temperature, like in a standard water boiler
- Automatic, unattended operation of the boiler and of the turbo-generator;
- Easy of control of the maximum thermal oil temperature feeding the turbo-generator. Hence, the adopted working fluid inside the ORC turbo-generators, besides having a very good thermal stability is protected from over-temperatures. As a consequence the operational life of the working fluid is unlimited. Should the working fluid be put directly in a biomass boiler, higher temperature spots (hot- spots) could not be avoided in all operating conditions
- Long life and low maintenance of all the system components

5.2.2 Guidelines for control and operation

Due to strong fluctuations of the fuel quality and the heat demand in a district heating plant an optimized process control system of the CHP plant is of importance. It order to be profitable the whole ORC plant is heat controlled. It means that the current heat load of the plant defines the ORC unit's capacity. In this way all residual heat coming from the ORC condenser is entirely used to satisfy process heat and/or district heating demand.

5.2.2.1 Control of the ORC unit.

The ORC unit operation is fully automatic and controlled by a means of a programmable logic controller (PLC). When engaged, the control automatically diverts the thermal oil boiler exhaust to the Evaporator, controls the acceleration of the turbine generator to synchronous speed and then synchronizes the generator to the bus. Following synchronization, the control system controls the operation of the ORC module. Pressure, temperature, voltage, speed, currents and power, etc, are checked and monitored during each scan of the PLC and compared with preset values in the program.

The PLC then makes the necessary adjustments in the ORC unit operation. The smooth load control is guided the feed water temperature at the condenser outlet between 10 and 100 % of the nominal load. Detection of a warning or failure condition is performed by the PLC, and then sent to a remote, manned station where it is analyzed. In the event of a failure within the system, the unit is disconnected from the bus in a pre-programmed sequence.

The ORC control system is equipped with a user-friendly, human-machine interface (HMI) system located in the biomass fired plant control room, allowing easy monitoring and control of the unit.

Due to this fully automatic operation, the personal demand is reduced to checking and maintenance work, which do not exceed 5 hours per week on average. Possible malfunctions of the process are visualized, automatically stored and forwarded tot the operator via telecommunications.

5.2.2.2 Control of the biomass boiler

Regarding constant thermal oil feed temperature the biomass-fired boiler is more difficult to control. As the thermal oil feed temperature directly influences the load of the ORC unit, a newly developed Fuzzy Logic control system for biomass CHP plants has been installed, with aim of stabilizing and smoothening the operation of the biomass combustion plant and consequently of the entire CHP plant. This system is in its test phase at the moment. Due to the fact that the biomass furnace is coupled with thermal oil boiler operated at atmospheric conditions no steam boiler operator is needed and the steam boilers law is not applied. In this way, the personal costs are reduced in comparison to steam boilers.

The silicon oil used as working medium in the ORC unit is environmentally friendly, but it is flammable. As a result, the ORC process is equipped with a special detection system for organic compounds whereby a small amount of air over all the flanges is sucked in and subsequently analyzed using flame ionization detector, through this safety measure the ORC is monitored continuously for leaks

5.3 Guidelines for R&D policy and decision makers

5.3.1 ORC-technology development

The ORC process has already attained a high level or development. At present, the ORC technology represents state of the art and is available on the market. Compact ORC modules are available in container size with nominal capacity between 500 and 1500 kW_{el}.(Table 6.1)

By comparing the specific power generation costs calculated for with the feed-in tariffs granted in different central European countries, an economically viable operation of biomass fired ORC plants is possible in Austria, Germany, Switzerland and Northern Italy if the framework conditions pointed out are fulfilled (heat controlled operation and high capacity utilization)/3/. This conclusion is confirmed by the growing number of plants commissioned already or under construction in the moment (Table 6.2)

Most of the newly erected ORC units are located in CHP biomass plant burning virgin wood. The discharged thermal power is mainly used for wood drying chambers and in wood presses.

The ORC technology becomes feasible also for some East Europeans countries that have adopted power generation legislation uniform with the EU one /8/.

Table 6.1 Data sheet of ORC units manufactured by TURBODEN

	T500-CHP	T600-CHP	T800-CHP	T1100-CHP	T1500-CHP
Heat source	Thermal oil in a closed circuit				
Thermal oil nominal temperature (In/Out)	300/250 ^{0}C				
Thermal power input from the thermal oil	2900 kW	3500 kW	4500 kW	6200 kW	8700 kW
Thermal oil flow (about)	23.6 kg/s	28.3 kg/s	36.3 kg/s	51 kg/s	70.9 kg/s
Cooling water temperature (In/Out)	60/80 ^{0}C				
Water flow	28.1 kg/s	33.9 kg/s	43.3 kg/s	60.2 kg/s	84.5 kg/s
Thermal power to the cooling water loop	2320 kW	2800 kW	3580 kW	4970 kW	6975 kW
Net active electric power output	500 kW	600 kW	800 kW	1100 kW	1500 kW
Electric generator	Asynchronous 3 phase, L.V., 650 kW	750 kW	930 kW	Asynchronous 3 phase, L.V., 1250 kW	1650 kW
Over all dimensions (LxWxH)	13x3x3	13x3x3	13x3x3	12.5x6x5.8	13x7x4.5

Table 6.2 ORC plants distribution over central European countries

Country	ORC units in operation	ORC units under construction	Total number of ORC units
Austria	6	11	17
Czech Republic	0	1	1
Italy	2	1	3
Germany	3	7	10
Switzerland	2	0	2
Total number of ORC units	13	20	33
Total ORC plants capacity	12050 kW_{el}	21500 kW_{el}	33550 kW_{el}

5.3.2 Demonstration

The first ORC technology demonstration project funded by the European Union is located in Admont, Austria. This is biomass CHP plant fed by saw dust produced within the STIA HOLZINDUSTRIE GmbH in Admont /6,7/. The plant has nominal electric capacity of 400 kW and nominal thermal capacities of 3.2 MW (thermal oil boiler) + 4.0 MW (pressurized hot water boiler) + 1.5 MW (flue gas condensation unit). Hot water produced at the ORC condenser is used for wood drying and for district heating (Benediktinerstift Admont).

This plant has reached 30000 hours of trouble-free operation in August 2003. The project has been awarded the contribution from UE Thermie contract BM./00120/98.

The next demonstration project is a biomass CHP plant based on an ORC cycle and a newly developed Fuzzy Logic control system - Stadtwärme Lienz, EU-THERMIE demonstration project (Tyrol, Austria). The water heated by the ORC condenser (from 60°C to 80 °C) feeds the Lienz district heating circuit. The plant has nominal thermal capacities: 7.0 MW biomass pressurized hot water boiler + 6.0 MW biomass thermal oil boiler + 1.5 MW flue gas condensation unit; nominal electric capacity: 1.1 MW ORC process; start of operation: 2001.

The latest demonstration project is a biomass CHP plant based on an ORC cycle and absorption chillier for power generation and cooling, fired with 100 % waste wood. This is Austrian national funded project located at BIOSTROM, Fussach site, Vorarlberg. The plant has the following technical data: Nominal electric capacity: 1,100 kW; Nominal thermal capacities: 6.2 MW (thermal oil boiler + thermal oil ECO) +1.0 MW (pressurized hot water economizer) Nominal chilling capacity - absorption chiller: 2.4 MW, Start of operation: 2002.

This is the first biomass CHP plant based on an ORC cycle combined with an absorption chiller for power production and cooling worldwide. The plant has also some important innovations like:

- Waste wood treatment with metal and non-metal separation;
- Low-NOx waste wood furnace with CFD optimized geometry;
- Thermal oil boiler with separate radiative and convective sections and an automatic cleaning system;
- Highly efficient fibrous filter with integrated dry sorption;

- Production of electricity from waste wood;
- Optimized coupling of the ORC cycle and the absorption chiller.

All these demonstration projects are reported as very successful /3,4,5,6/. As a result the biomass based ORC –power generation technology reached high degree of maturity.

5.3.3 Economic aspects

Based on the project in Lienz, Austria and on the experience with other biomass CHP applications comprehensive investigations concerning the economy of biomass fired ORC-power generation plants have been performed. The calculation of the production costs for electricity generated by CHP plant is usually based on VDI guideline 2067. This cost calculation scheme distinguishes four types of costs:

- Capital costs (depreciation, interest costs);
- Consumption based costs (fuel, consumables);
- Operation-based costs (personnel costs, costs of maintenance) and
- Other costs (administration, insurance).

The capital costs are based on additional investment costs, an consider only surplus investment costs of ORC plant in comparison to a conventional biomass fired plant with a hot water boiler and the same thermal output. The additional investment costs form the correct basis the correct basis for the calculation of the electricity production costs of CHP plants. This approach is reasonable because decentralized biomass fired plants primarily produce process heat or district heating. Electricity–controlled operation of decentralized biomass fired plants is neither economically nor ecologically justified due to the limited electrical efficiency achievable with such of systems. In contrast, the overall efficiency of a heat-controlled biomass CHP plant can be very high (up to 90 %). Therefore, electricity production is an alternative and its implementation depends mainly on the profitability of the additional investment necessary. This approach makes possible clear comparisons of costs for heat only and CHP applications and forms the basis for a correct calculation of the electricity production costs.

The capital costs based on additional investment for a 1000 kW_{el} ORC plant are about 2000 Euro/ kW_{el}. As shown in Figure 3.6 the specific electricity generation cost calculated for Lienz reference is case is about 120 Euro/MWh (el).

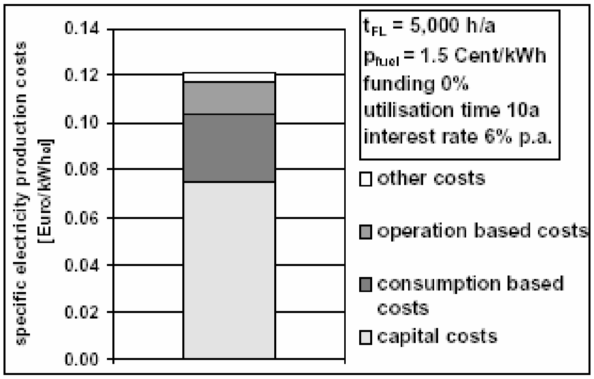

Figure 3.6: Specific electricity generation costs of biomass-fired ORC-power generation plant /4/

This result is based on the following assumptions:

- The average fuel price is set at 15 Euro/MWh. This figure represents of a mixture of bark, industrial wood chips and forest wood chips, taking a secured long-term availability into consideration. Only the amount of additional fuel needed for electricity production is taking into account.
- The capacity utilization of the ORC plant influences the electricity production costs to a high extent and represent the most important influencing variable (Figure 3.7). 5000 full-load operating hours per year are recommended as a minimum value for economic operation. In heat controlled CHP systems this requirement makes a correct design of the plant capacity, based on annual heat output line, very important. Of special interest are decentralized biomass CHP units for the wood processing and wood manufacturing industry (where high amounts of process heat are required) as well as for larger biomass district heating plants (where the base load boiler could be changed to a ORC unit). A good example for almost a year full-load operating hours case is the project in Fussach, (Vorarlberg, Austria). This is the first biomass CHP plant based on an ORC cycle combined with and absorption chillier for power generation, district heating and cooling worldwide.
- The annual costs for consumables (such as lubricants and sealings), maintenance and other expenditures are calculated as percentage of the additional investment costs based on operational experience;
- The personal costs and the amount of electricity needed for thermal oil circulation are derived from experience already gained from the Lienz CHP plant and other plants.

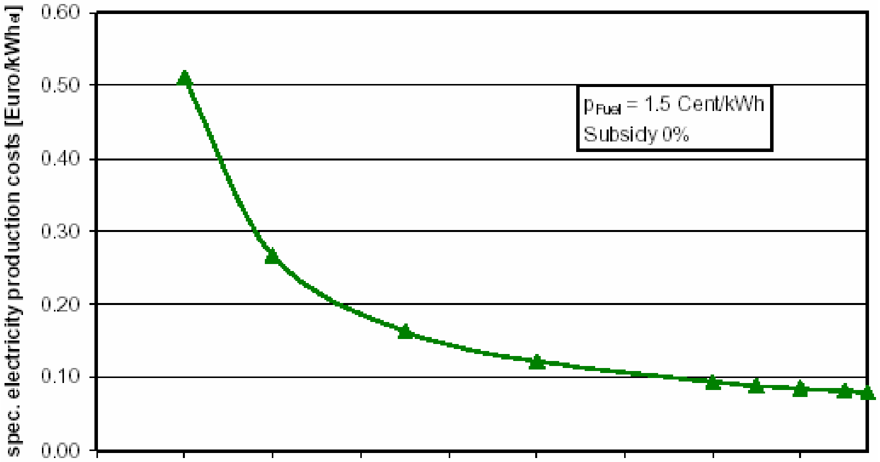

Figure3.7: Specific power generation costs versus capacity utilization (full-load operating hours) /5/, /6/

Another important factor influencing the electricity production costs is the fuel price (Figure 3.8).

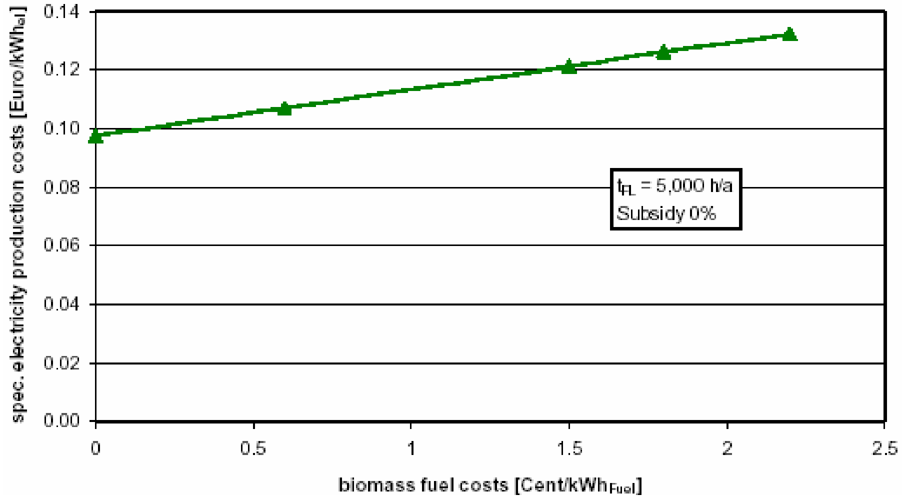

Figure 3.8: Specific power generation costs versus the biomass fuel costs /5/

Concerning future biomass fired ORC-power generation deployment; a decisive factor will be sustainable reduction of the investment and operational costs.

5.4 Environmental aspects

5.4.1 Technology impact

5.4.1.1 ORC unit environmental impact

The thermal utilization of biomass corresponds to the criteria of actual environmental protection, since biomass is renewable and CO_2 neutral source of energy. The enhanced production of electricity from biomass is a clear objective of the European environmental and energy policy. All biomass fired ORC-power generation project contribute to the achievement of the CO_2 reduction target planed in the Kyoto protocol.

The ORC cycle does not cause any solid, liquid or gaseous emissions; since it is completely closed (no losses of the working medium occur). ORC plants are relatively silent (the highest noise emissions occur at the encapsulated generator and amount to 75 dBA in a distance of 1 m). Silicone oil is not toxic not depleting the ozone layer, not explosive but is flammable with a flame point of 34°C. The thermo-oil cycle demands higher security measures regarding leakage than water or steam cycles.

5.4.1.2 Biomass combustion environmental impact

The combustion of biomass fuels (bark, wood chips and saw dust) implies the production of residues, the ashes. Several ash fractions can be distinguished which are collected at different stages. These fractions are the bottom ash (which is precipitated on the grate), the cyclone fly ash (which is precipitated in the boiler section and the multi-cyclone) and the filter fly ash (which is precipitated in the wet electrostatic precipitator and within the flue gas condensation unit).

The mixture of bottom ash and cyclone ash representing about 90 % of the total ash produced, can be defined as usable ash, because the mixture of these two ash fractions have got very low heavy metal concentrations for ash utilization on soils. Therefore the usable ash from biomass (virgin wood) fired ORC-power generation plants can be used as a soil amending and fertilizing agent for agriculture and forest soils as well as for compost production.

In contract to the usable ash, the filter fly ash contains considerably higher fractions of heavy metals and it has to be separately collected and disposed. Following this approach, the mineral cycle in the course of thermal biomass (virgin wood) utilization can be almost closed and the heavy metals, accumulated in the ecosystem by environmental pollution, can be effectively extracted.

The gaseous emissions released by the biomass fired ORC plant in form of CO, NO_x, C_xH_y and dust are clearly kept under the prescribed limiting values in all three-demonstration projects in Austria.

5.4.2 Potentials for Biomass fired ORC-power generation in the WBC

The biomass potential in West Balkan Counties is abundant but not quantified well yet /9/.

5.4.2.1 Albania

Biomass has not been considered in Albania and its use for power generation would require further feasibility studies. Studies undertaken to date indicate that agricultural residues reached 130 toe/year in 2001 and fuel wood reserves were estimated at about 6 Mtoe.

5.4.2.2 Bosnia and Herzegovina

Apart from the traditional use of firewood and the recycling of wood waste in the wood-processing industry, there is no reliable data on the potential for using biomass in Bosnia and Herzegovina. If studies have been carried out at the canton level, the results are not accessible. It can be assumed, however, that there is considerable potential for the use of biomass from the forestry and agricultural sectors. Roughly 50 percent of the land area of Bosnia and Herzegovina is wooded and the country has a relatively developed forest industry, including sawmills and wood processing, from which residues are currently dumped in the open. According to a study conducted by Innotech HT GmbH, Berlin, in 2003 on behalf of the GTZ, there is an unexploited potential of approximately 1 million m3/a of residual wood and wood waste, which could be used to provide heat to 130,000 residences or 300,000 inhabitants. Wood is also used heating in rural areas and for conversion into electrical energy in some steam power plants, such as in the state-owned Krivaja factory in Zavidovici, which manufactures furniture and timber houses. With a maximum thermal output of 15 MW, 4.5 MW of electricity is generated for the factory's on-site peak power needs.

There are also plans with the local authority for a group heating scheme nearby, but because of lack of funding it has not been possible to put this idea into practice.

5.4.2.3 Croatia

There is significant potential for the utilization of biomass in Croatia. The biomass technology, is commercially proven, and has already attracted the interest of private developers in Croatia. A demonstration project of a total of 5 MW and an estimated value of 5.2 Million Euros will be implemented by the Global Environment Fund's renewable energy program. The goal is to catalyze the market for biomass energy. A pilot biomass fired ORC project could be proposed for the wood processing plant Drvoproizvod d.d. located in Jastrebarsko. There is already thermal oil boiler with 2.500 kW thermal capacities installed at this site.

5.4.2.4 Macedonia

In general, there is lack of updated and reliable data on the potential for biomass production in Macedonia. Biomass, in the form of wood and charcoal is almost exclusively used in the domestic sector. Industrial or other uses are very small and represent less than 1 percent of the total biomass final energy consumption.

Agricultural residues have negligible contribution since most of the straw is used as fertilizers and animal fodder. The theoretical potential for Forests and Forest Residues utilization is as follow on: Theoretical Potential 6000 GWh and Technical Potential 2660 MWh.

Forests cover over one million ha of which 90 % is owned by 30 major forestry companies. The forestry industry is currently under recession, which has resulted in reduced logging and production volumes. Out of 900,000 m3 of wood, 750,000 m3 is used for domestic heating purposes and the rest is provided to the wood processing industry. An additional 150,000 m3 of wood waste, equal to 100,000 tons of wood waste (density 650kg/m3), is produced during the logging process. It is possible, therefore, to increase the energy segment deriving from forest biomass by:

- Increase logging for domestic heating
- Utilize the produced wood wastes which remain unexploited

The wood processing industry faces similar problems and is presently running at 30 percent of its capacity. Each year, the wood processing industry utilizes 150,000 m3 of wood and produces nearly 70,000 m3 of waste (45,000 tons). Reports indicate that wood processing companies and sawmills produce a substantial amount of waste, whereas waste from furniture companies is considerably less. Some firms have installed wood boilers, the majority of which are old and inefficient, but most of the produced wood waste is left unexploited and land filled. It is possible to:

- Make use of the remaining wood waste, which is mostly produced from the sawmills and wood processing companies;
- Install new wood waste fired

5.4.2.5 Serbia and Montenegro

Biomass has been recognized as the highest renewable potential in Serbia. The identified energy potential from agricultural and forest biomass sources is estimated by the ministry to 110 000 TJ.

There are no studies on the potential for biomass use in Montenegro. However, considering the large size of forest areas in the country there is likely more scope for further investigation of biomass.

5.4.2.6 UNMIK Kosovo

No studies have been undertaken to determine the potential for using biomass for energy generation in Kosovo. Biomass/wood is an important resource used for heating in individual houses. The total wood area in Kosovo is more than 4,000 km2, with a wood stock of 30 million m3. The yearly growth of the wood stock is around 1.0 million m3, compared with an estimated yearly consumption (year 2000) of around 1.0 million m3 of firewood alone. More timber is cut for lumber in the booming construction sector.

The biomass potential for ORC-power generation in West Balkan Countries is significant, but the overall political and economical conditions have to be done more favorable the construction of pilot and demonstration plants

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6 BIOMASS STIRLING CHP

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6.1 General

The following items inform about steps of development on the Stirling principle, starting with the invention by Reverend Robert Stirling in Scotland up to now. It is worth to mention that the biomass fired Stirling combined heat and power (CHP) production gains importance in the small capacity range as an excellent RES technology for decentralized applications.

1816 After extensive preparatory work Reverend Robert Stirling takes out a patent for the first hot air engine with external combustion. Figure 1 shows the patent specification. Even then the proposed principle contains all components of a modern Stirling engine – also the regenerator as an economizer. Until the invention of the Stirling engine above all steam engines are used for the different tasks, e.g. for pumping the water out of mining systems. But steam is a dangerous medium. So, the Stirling engine was a desirable alternative.

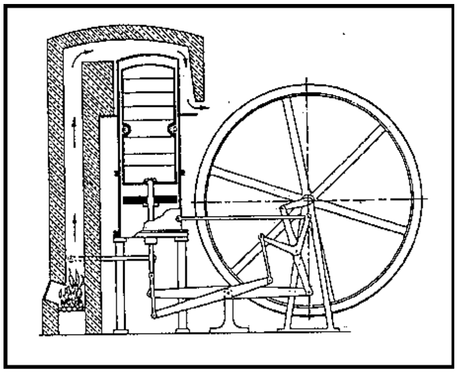

Figure 4.1 Stirling´s hot air engine, facsimile of fig. 8 of the Patent Specification of 1817. Courtesy of the Scottish Record Office /4/.

1816 The first engine following the Stirling principle was put in operation for water pumping in Scotland.

1824 Sadi Carnot published the “Carnot-Process“. It was defined at first by this discovery that a heat power engine only can work between two temperatures. The heat is supplied at the higher temperature and a part of the supplied heat has to be rejected at the lower temperature. The difference between the supplied and the rejected heat is converted into mechanical work. These theoretical basics were unknown as Robert Stirling invented his engine.

1840 Robert Mayer calculates the „Mechanical Heat Equivalent“

1872 Ericson constructed the first “Solar Engine“. The Stirling engine was fixed in the focus of a parabolic mirror. It is worth to mention that Mr. Ericson and Mr. A. Mouchot (see “Guidelines on Absorption Refrigeration”, Figure 6.1) do have a patent wrangling about the first solar driven engine.

1876 The Otto engine was invented. The Stirling engine was produced up to this time in large numbers. But by the invention of the Otto engine as well as the Diesel engine (1896) and the electrical engine the Stirling engine was edged out.

1938 The first revival of the Stirling engine technique takes place in the Philips Research Labatories in Eindhoven. The first objective of theses developments on high performed Stirling engines was the replacement of the Otto- and Diesel engines in cars. But these targets could not be reached because the Stirling engines are more expensive than internal combustion engines. The only business for Philips was a gas refrigeration machine for the production of liquid air, which is constructed up to now in a similar shape.

1990 The second revival of the Stirling technology has been started. The environmental protection changes the thinking of the people, politicians and decision makers recommend subsidizing the RES technologies for decentralized production of heat and power. The Stirling engine has the advantage - like the steam engine – that it can use directly different kinds of renewable fuel, like wood chips or wood pellets. So, gasification or liquefaction of biomass can be avoided.

6.2 Guidelines for planners, installers and students

6.2.1 Guidelines for design

6.2.1.1 Thermodynamic basics of the Stirling process

Basics of a heat engine: The main task of a heat engine is to convert heat in power. Since the discovery of Carnot (1824) it is well known that a heat engine works between two temperatures. The heat which should be converted is received at the upper temperature and a part of it is rejected at the lower temperature. The difference is converted into mechanical energy and can be used at the turning shaft of the heat engine.

Efficiency of the process: Carnot found, that the height of the upper temperature and the difference between the upper and the lower temperature do have a significant influence on the relation of the mechanical energy on the shaft and the heat input at the upper temperature. The Carnot law is given by the following equation

$$\eta_c = 1 - T_{LOW} / T_{HIGH} = \Delta T / T_{HIGH}$$

T_{LOW} ... low temperature (K), T_{HIGH} ... high temperature (K)
η_c .... Carnot efficiency

Example 1: T_{HIGH} = 600 °C = 873 K; T_{LOW} = 27 °C = 300 K; η_c = 0,65
Example 2: T_{HIGH} = 80 °C = 353 K; T_{LOW} = 27 °C = 300 K; η_c = 0,15

The Stirling process is an isothermal process and do have the same theoretical efficiency than the Carnot process. Therefore it can be calculated with equation (1).

Process display in the p,V-diagram: All thermodynamic processes can be displayed e.g. in the pressure (p), volume (V)-diagram, which can be easily derived from the general gas equation. Figure 4.1 shows the theoretical Stirling process diagram as a basis for a realization of the thermodynamic closed process. It is worth to mention, that every area in p,V-diagram is physical work (Nm, Ws or J) independent on the surrounding closed lines. Figure 4.2 displays the principle arrangement of a cylinder with two pistons, a hot and a cold heat exchanger space and a regenerator consisting of a thin steel wire mesh as heat storage within a thermodynamic cycle.

Theoretical process: Figure 7.3 displays the motion of the pistons and the displacements of the volumes between the pistons. For understanding the process it is necessary to use figure 7.1, Figure 7.2 and Figure 7.3 (thin lines). The process is divided in four steps. The explanation of the theoretical process starts at point 1. In this process state the expansion piston is at the upper death centre and the compression piston at lower one. Between process point 1 and 2 only the compression piston moves from the lower death centre to the upper one and compresses the enclosed gas, e.g. air. In the theoretical process an ideal isothermal compression takes place and TC is constant between 1 and 2.

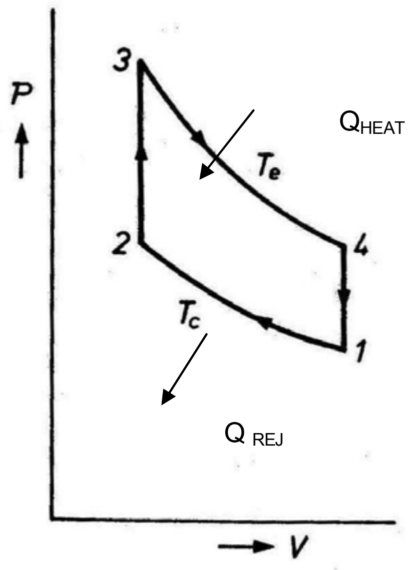

Figure 7.1 Theoretical Stirling process in the p, V-Diagram

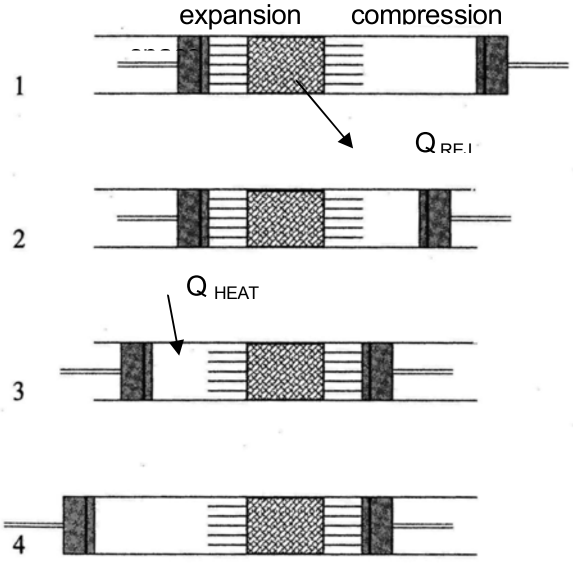

Figure 7.2: Displacement of volumes for the theoretical Stirling process,

Therefore the heat Q_{REJ} has to be rejected out of the process by a gas cooler. Before the compression piston reaches its upper death centre at process point 2, the expansion piston starts moving from its upper death centre towards the lower one and the compressed gas is displaced at constant volume through the regenerator from the cold space into the hot space. Between the process point 2 and 3 the gas is heated up by the stored heat in the regenerator so that the gas pressure between the two pistons rises steeply. The compression piston arrives the upper death centre at the process point 3. At the process point 3 the expansion piston has covered already half of its way from the upper to the lower death centre. Its worth to mention that the expansion takes place at higher pressures than the compression as an isothermal expansion too. Heat from outside must be supplied to avoid a temperature drop during the expansion phase. The expansion is finished in process point 4. During the last process step from 4 to 1 the hot working gas is displayed at constant volume from the hot space through the regenerator in the cold space. If the working gas flows through the regenerator, its heat is stored in the steel wire mesh and the gas leaves the regenerator at low temperature entering the compression space (see Figure 7.4).

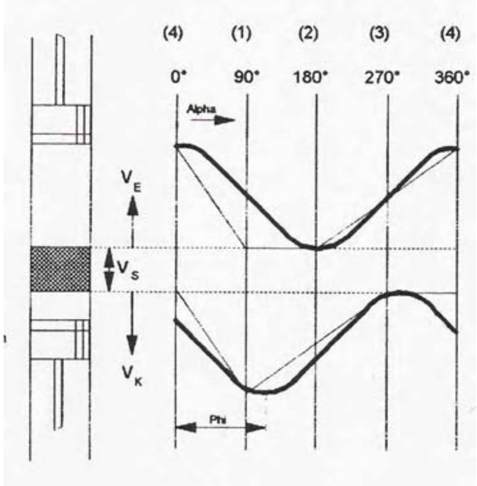

Figure 7.3: Continuous and discontinuous motion of the pistons and displacement of the volumes.
theoretical process: discontinuous thin lines
practical engine: continuous bold lines

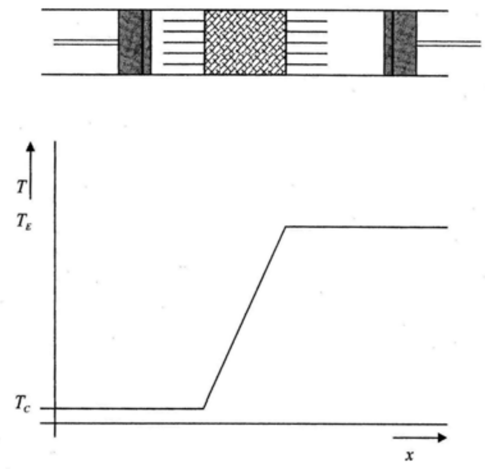

Figure 7.4: Absolute gas temperature in the working space as a function of the way x;
T_C *... temperature in the compression space (cooler),*
T_E *... temperature in the expansion space (heater)*

Sinusoidal process: Engineers do not like discontinuous motions of pistons and shafts in mechanical engines due to the big mass forces. The theoretical process is therefore transferred in a continuously working process with continuously turning crank shaft and sinusoidal moving pistons. The two pistons are therefore connected with a crank mechanism which is so designed that the hot piston reaches at first the upper death centre and the cold piston is running behind with a phase shift of 90°. Figure 4.3 shows the motion of the two pistons and the displaced volumes VE and VK by the bold sinusoidal lines. VS is the gas volume of the regenerator and remains therefore constant.

Efficiency drop: The area inside the closed process lines in the p,V-diagram shrinks if the technical process with the sinusoidal motions of the pistons is realized. As it was mentioned above, the area inside the closed process lines is physical work. This leads to a efficiency drop of the technical process in relationship to the theoretical one. Figure 7.5 shows this connection.

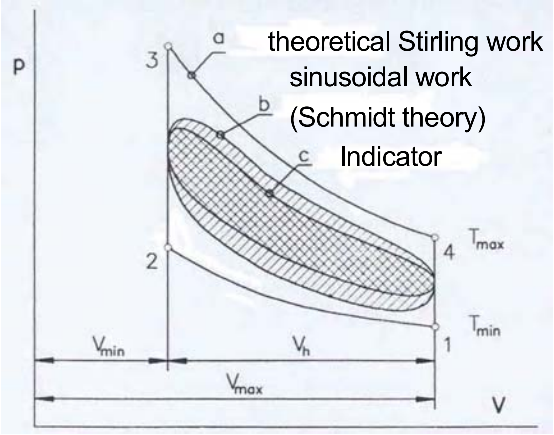

Figure 7.5: Mechanical work of the Stirling process in the p,V-diagram.

Curve a (1,2,3,4): Theoretical Stirling work, limited by V_{min}, V_{max} and T_{min}, T_{max}.

Curve b. Continuous turning shaft and sinusoidal motion of the pistons leads to a banana shaped area (Schmidt theory 1862).

Curve c: The curve c for the indicator work takes additional losses of the Stirling process in consideration which reduces the work on the shaft further.

Regenerator: A very important part of the Stirling engine is the regenerator. If the working gas is displaced during the step 4 to 1 in figure 4.1 and figure 4.2 from the hot space in the cold space, the sensible heat is stored in the regenerator. The working gas enters the regenerator with a temperature of about 600 °C and leaves it with a temperature of about 80 °C. The heat of the working gas is stored in the steel wire mesh of the regenerator. The wire mesh consists of some thousands meter of heat resistant steel wire with a diameter of about 0,05 to 0,1 mm. It has the largest heat exchanger surface in the engine. In the process step 2 to 3 the cold working gas returns from the cold space to the hot space and enters the regenerator in the theoretical process with 80 °C and is heated up by the stored heat to 600 °C. So, the cold heat exchanger has only to reject the compression heat of the isothermal compression (step 1-2) and the hot heat exchanger receives from the heat source only the necessary heat for the isothermal expansion (step 3-4). In practice the efficiency of the regenerator is not 100 %, but 95 to 98 % can be reached. The missing heat have to be delivered by the heat source and the surplus must be rejected by the cooler.

6.2.1.2 Types of Stirling engine

After the invention of Robert Stirling (1816) many thousands engines have been constructed and used for private and commercial applications. In time above all three types of Stirling engines are designed. They are called alpha type engine (α), beta type engine (β) and gamma type engine (γ).

α-type Stirling engine: This engine type is characterized by a cold and a hot piston, a hot and a cold heat exchanger and a regenerator. A crank mechanism steers the sinusoidal motion of the pistons (Figure 7.7) and the displacement of the active volumes following the principle shown in figure 7.6. It is worth to mention that both piston seals are not lubricated and have to resist against the full dynamic pressure of the working gas.

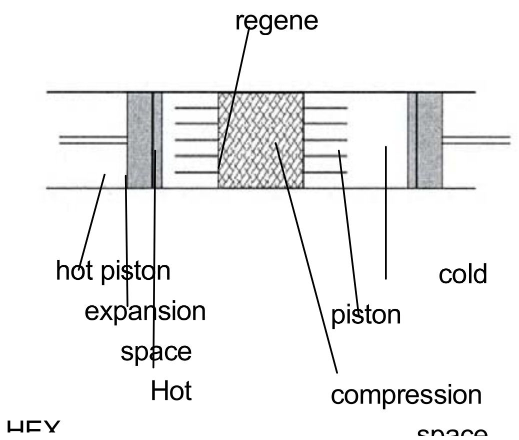

Figure 7.6: Principle sketch of a α-type Stirling engine, motion of pistons and displacement of volumes, see fig. 4.1 to fig. 4.3

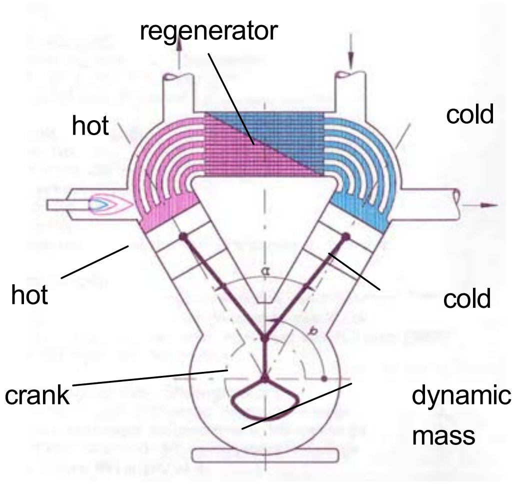

Figure 7.7: α-type Stirling engine, designed as a V-engine.

<u>β-type Stirling engine:</u> Figure 4.8 shows how the main parts of the β-type Stirling engine are arranged. The β-type engine is characterized by one piston and one displacer in one cylinder. The task of the displacer is to displace with a sinusoidal motion the working gas from the cold space through the regenerator in the hot space and back. Thereby the working gas is heated up and cooled down in one process cycle whereby the dynamic pressure variations are generated. At the same time the piston moves also sinusoidal but with a constant phase difference. The piston reaches the dead centre 90° later than the displacer. The phase shift between the displacer and the piston is necessary, because the dynamic pressure presses the piston on its way from the upper death centre to the lower one and the crank mechanism accepts mechanical energy from the thermodynamic process. The same happens on the way of the piston from the lower death centre to the upper one, because in this phase of the motion the dynamic pressure above the piston is lower than the pressure under the piston. The working gas pressure under the piston is every time nearly constant. The dynamic, nearly sinusoidal pressure variations takes place only in the space above the piston and are theoretically equal above and under the displacer at the same time. The displacer have to have only a simple seal for displacing the working gas from the hot space through the regenerator to the cold space and on the same way back. The figure 4.5, which shows the work output, is also valid for the β-type engine.

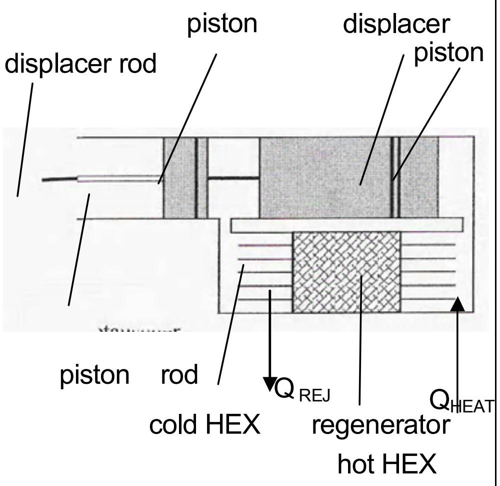

Figure 7.8: β-type Stirling engine (principle)

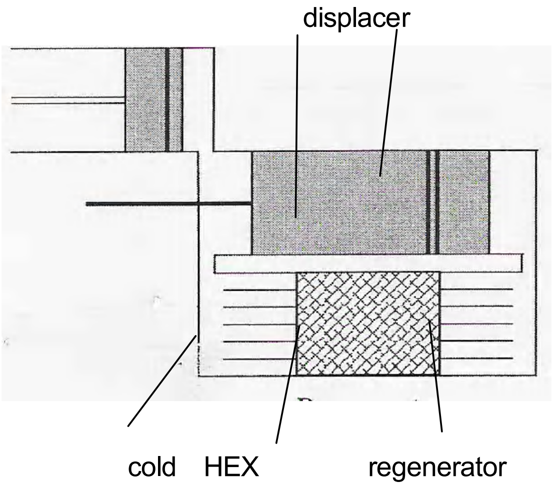

Figure 7.9: γ-type Stirling engine (principle)

γ-type Stirling engine: Figure 7.9 shows the main parts of the γ-type Stirling engine. The γ-type engine is characterized by one piston and one displacer in two separate cylinders. The task of the displacer to displace with a sinusoidal motion the working gas from the cold space through the regenerator in the hot space and back. Thereby the working gas is heated up and cooled down in one process cycle, whereby the dynamic pressure variations are generated. The piston moves at the same time also sinusoidal, but with a constant phase difference. The power piston reaches the dead centre 90° later than the displacer. The phase shift between the displacer and the piston is necessary, because of that the dynamic pressure presses the piston on its way from the upper death centre to the lower one and the crank mechanism receives mechanical energy from the thermodynamic process. The same happens on the way of the piston from the lower death centre to the upper one, because in this phase of the motion the dynamic pressure above the piston is lower than the pressure under the piston. The working gas pressure under the piston is every time nearly constant. The dynamic, nearly sinusoidal pressure variations takes place only in the space above the piston and are theoretically equal in the space above the piston at the same time. The displacer is equipped only with a simple seal for displacing the working gas from the hot space through the regenerator to the cold space and on the same way back. The figure 4.5, which shows the work output, is also valid for the γ-type engine.

6.2.2 Guidelines for operation and control

6.2.2.1 Starting procedure

For the operation of a Stirling engine a lot of conditions have to be fulfilled. The following items must be ensured before the engine can start.

- *Working gas:* The working gas could be air for low pressure Stirling engines up to 10 bar middle pressure and about 500 rpm. If the engine should work at higher middle pressures as

10 bar, nitrogen can be used. For high middle pressures and 1.000 to 1.500 rpm helium or hydrogen must be used as a working gas, due to their more suitable physical properties.

- *Pressure management:* Before the engine is started the working space under and upper the piston (s) have to be pressurized by filling in the working gas up to the middle pressure level. Normally air and nitrogen engines can be started at 3 to 10 bar and helium engines between 15 and 30 bars.
- *Heat source:* A heat source with a suitable heat capacity and temperature has to be switched on and the hot heat exchanger of the engine should be heated up slowly.
- *Heat sink:* The cold heat exchanger must be cooled continuously with air or water to reject the low temperature heat out of the engine.

6.2.2.2 Shaft power expected

Cheap as well as expensive computer programs are available for a design of the engine which allows calculating the thermodynamic process and the mechanical power which can be expected on the shaft of the engine. But also some simple equations can be used for a roughly determination of the shaft power.

$$P = 0{,}013 \,.\, p \,.\, V \,.\, f \qquad \text{(Watt)}$$

(equation of Prof. Beal)

P ... shaft power in Watt
p ... middle pressure in bar
V ... swept volume of the expansion piston in cm^3
f ... frequency of the shaft in rps

Example: p = 32 bar, V = 840 cm3, f = 600 rpm = 10 1/s; result: P = 3.500 Watt

For this calculation it assumed, that the hot space of the engine is heated up to 650 °C the cold space is cooled down to 65 °C and the phase shift is 90 °.

Higher accuracy can be expected with the aid of the equation of Colin West. In this equation the temperatures of the cold and the hot space are considered too.

For higher comfort and accuracy computer programs have to be used. Lots of curves for shaft power, mechanical moment, efficiency, heat transfer values as a function of engine speed are calculated automatically.

6.2.2.3 Power control

The Beal equation show that the shaft power depends directly on the middle pressure of the working gas in the engine. One of the simple way to control the shaft power of the engine is therefore the variation of the middle pressure which can be done by small auxiliary working gas compressor and a high pressure steel bottle and some valves. In figure 4.10 two examples are displayed which show very clear that the work of one process cycle can be enlarged if the middle pressure is increased. As it was mentioned above, the closed area in the p,V-diagram is work in Ws, Nm or J.

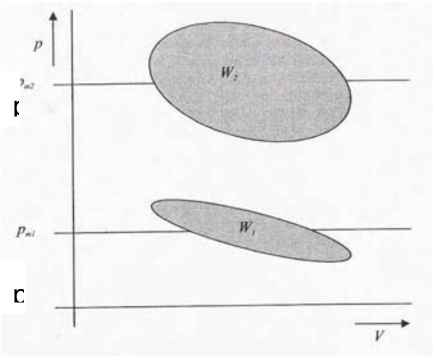

Figure 7.10: Shaft power control by variation of the middle working gas pressure in the engine.

Example 1: $p_{w1} = p_1 = 10$ bar $T_1 = 373$ K, $T_2 = 873$ K, active gas volume is constant.
$p_2/p_1 = T_2/T_1$; therefore $p_2 = 23{,}4$ bar

Example 2: $p_{w2} = p_2 = 50$ bar $T_1 = 373$ K, T2 = 873 K, active gas volume is constant.
$p_2/p_1 = T_2/T_1$; $p_2 = 117{,}0$ bar

6.3 Guidelines for R&D policy and decision makers

6.3.1 RES-technology development

6.3.1.1 State of the Art

The first revival of the Stirling engine technology takes place in and after the Second World War. Lots of high effective Stirling engine have been constructed. Companies like United Stirling Sweden, Philips in The Netherland, Ford in USA and MAN in Germany tried to develop Stirling engines which are powered by fossil fuels as a competition to internal combustion engines in cars. At this time high effective engines were constructed and lots of experience gained. These engines were designed above all for the fuel natural gas. Natural gas has a high flame temperature of 1.600 to 1.700 °C. This results relatively light and small Stirling engines in relation to those for the fuel biomass which has a flame temperature of only about 1.000 °C.

In Figure 7.11 a early model of a V160 is shown. This α-type Stirling engine is originally developed in Sweden between 1960 and 1970 and was used there for military purposes as a emergency generator. After that Stirling Power Sweden (SPS) goes to USA and the engine was improved step by step. All together about 34 different prototypes were constructed and tested over about 40.000 hours. After bankruptcy of SPS the German company Bergermann, Schlaich and Partners purchased all rights on the engine and the company SOLO in Sindelfingen constructs since 1995 lots of gas fired V160 as Mini-CHP, solar dish applications and others.

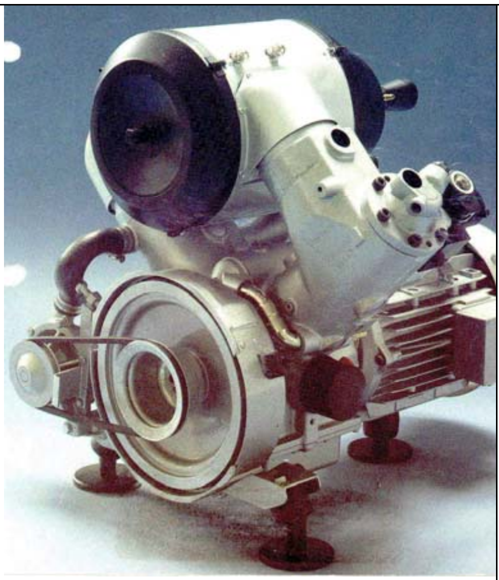

Figure 7.11: Natural gas powered V160, 9 kW at 1.500 rpm and 150 bar. (Courtesy of Stirling Power System, Sweden)

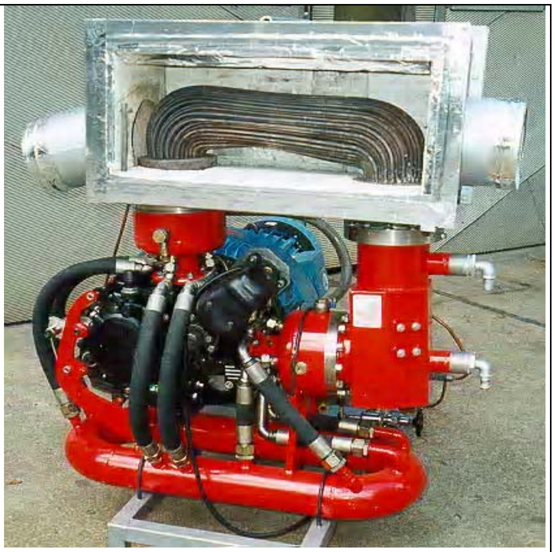

Figure 7.12: Prototype of biomass powered Stirling engine, 3 kW, at 540 rpm, and 30 bar (Courtesy of Joanneum Research, 1998)

6.3.1.2 RES-Stirling engine development

In principle a Stirling engine for RES fuel can be designed by following the above discussed types (alpha, beta or gamma). But the following main questions have to be answered before making basic design decisions:

- Could we expect a mass production of biomass Stirling engines comparable to the car engines? “No, but a group production could be expected.”
- Should the engine be designed for the common maximum flue gas temperature of 1.000 °C which is usual in wood chip furnaces or for higher flue gas temperatures of a specific furnace?. For 1.000 °C, because there we can expect the maximum of applications.
- Could the biomass flue gas be cleaned at the high temperature level of 1.000 °C. “No, because hot gas cleaning is technical insecure and too expensive.
- The answers lays the basics for the design guidelines
- For the alpha type Stirling engine lots of components can be found at the market of the serial production of compressors or internal combustion engines, like the crank case including the crank mechanism and lubrication system.
- The market expectations (reduced flue gas temperatures) leads to Stirling engines with a large heat transfer surface due to the reduced temperature for the heat transfer from the flue gas to the working gas (compared with natural gas Stirling engines). Therefore the cylinders of a biomass fired Stirling engine must be designed with larger diameter. So, all together the biomass fired engine will be bigger and more heavy.
- For the management of the not purified flue gas in the heater section the hot heat exchanger have to be made with smooth surfaces, like tubes without fins. This measure leads to a further enlargement of the death space in the active volume of the engine.

Following that basic strategy a biomass fired Stirling engine, like it is shown in Figure 4.12, can be designed and constructed. A crank mechanism of a serial produced motorcycle of the company DUCATI including lubrication system, crankshaft, piston rod and cross heads is used for the design of a 3 kW alpha type Stirling engine. The water cooled cylinders of the Stirling part do have larger diameters (140 mm). The hot heat exchanger is designed with smooth, heat resistant tubes and can manage a flue gas with certain ash content without obstacles. Time by time the hot heat exchanger must be cleaned.

Further important parts of the engine are the rod seals which are necessary to seal high pressures active space from the crank case, which must work at ambient pressure. The rod seals follow the Leningrader principle. The seal are lubricated by the oil of the crank mechanism and uses the hydrodynamic effect of an annular conical gap. The technical data of the biomass Stirling engine in Figure 7.12 are displayed in Table 7.1:

Table 7. 1: Technical data of the biomass Stirling engine in Figure 7.12

Expansion volume:	*840*	*cm^3*
Compression volume	*840*	*cm^3*
Temperature of the flue gas inlet	*1.000*	*°C*
Temperature of flue gas outlet	*750*	*°C*
Cooling water temperatures (inlet/outlet)	*45/55*	*°C*
Middle pressure (minimum/ maximum)	*5/32*	*bar*
Rotation per minute of crankshaft	*540*	*rpm*
Shaft Power	*3,2*	*kW*
COP (shaft power/heat received)	*25*	*%*
Crank mechanism	*DUCATI motorcycle*	

6.3.2 Demonstration of the biomass fired Stirling CHP

Energy policy maker are not able to make decisions for a subsidized broad application of a new RES technology. Therefore demonstration plants are necessary to convince the decision maker that the new RES technology proposed will be a benefit for the isolated region and the people. Figure 7.13 shows the principle arrangement of a decentralized CHP production at a district heating system as the “Application 1”. The main task of this application is the production and sale of heat for the district heating contractors. Besides of this business a part of the heat produced by the biomass furnace is used in a Stirling engine to produce power. The heat rejected by the engine is transferred to the district heating plant and purchased. The electricity produced is used for own demand, especially to drive the pumps of the district heating plant. The aim of this power production is the avoidance of electricity consumption from the grid. Figure 7.14 displays the energy flow for “Application 1”

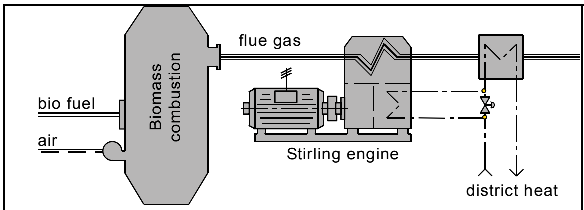

Figure 7.13 : Application 1: Principle sketch of a CHP-production in a biomass district heating plant

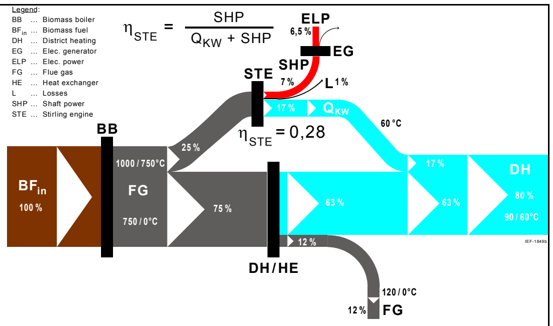

Figure .14 : Energy flow for figure 4.13

Figure 7.15 shows the principle arrangement of a decentralized CHP production for a isolated region as the "Application 2". The main aim of the "Application 2" is the maximum production of power and electricity out of 1 kg biomass. "Application 2" do have therefore a heat recovery HEX to reduce the heat production and to increase the share of power. An additional HEX for heating up the combustion air to about 600°C is necessary. Figure 7.16 displays the energy flow of the arrangement in figure 7.15. The maximum output on electricity is about 20 % of the low heating value of the biofuel.

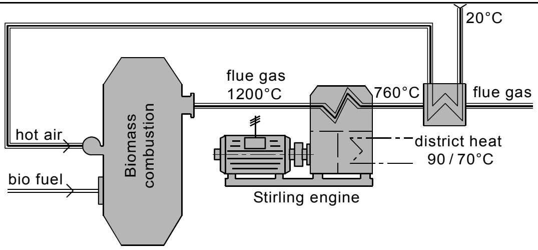

Figure 4.15 : Application 2 : Principle sketch of a CHP-production with a maximum on power and reduced heat

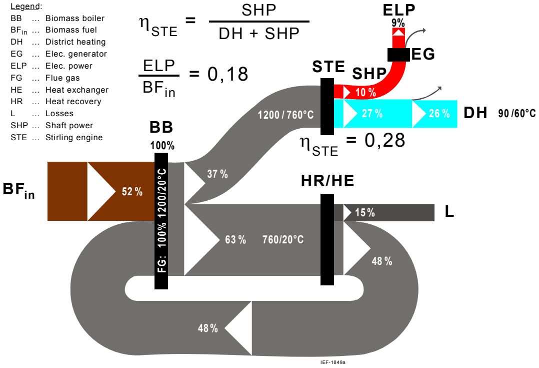

Figure 4.16 :Energy flow for the plant following the sketch in figure 4.15

6.3.3 Economic aspects of biomass fired Stirling CHP

The presented economical results belongs to the "Application 1" of a Stirling CHP-production in a biomass district heating plant with a biomass furnace of 1 MWth. The electricity production costs, the net present value and the payback times were calculated for different financing models.

6.3.3.1 Electricity production costs

The part load operation of the plant is analyzed through simulation of CHP operation under real conditions, i.e. based on measuring data from a typical biomass district heating plant. This results in different annual electrical outputs for different rated capacities of the power production unit (Stirling engine/generator). If the rated capacity of the Stirling engine is too high, electricity production can be maximized, but on the other hand operating costs, and in particular annual repayments, will also increase. If the rated capacity of the power production unit is too low, the possible annual electrical output cannot be achieved, quite apart from the fact that the specific investment costs of a smaller engine are also higher. The mathematical formulation and evaluation of these functions yield the actual annual electrical output, from which the costs as a function of engine size can be determined. Figure 4.17 shows this calculation of electricity production costs on the basis of plant data measured at part load.

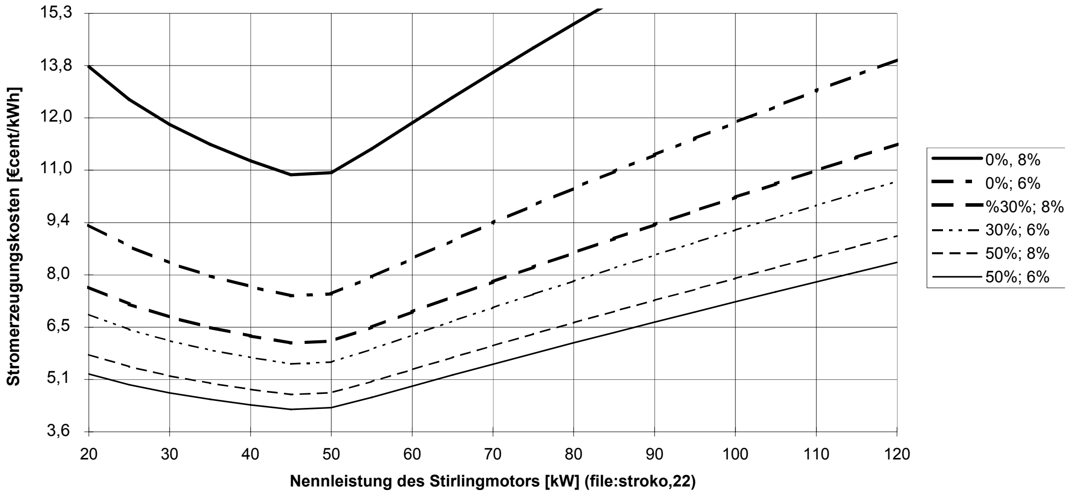

Figure 4.17: Electricity production costs using Stirling engines at rated capacities from 20 to 120 kWe; specific investment costs 1.600 € /kWe for a 100 kW Stirling engine; subsidies 0, 30 and 50%; interest rate 6 and 8%; heating plant capacity 1 MWth, /9//.

6.3.3.2 Payback time

For economic reasons, the payback time for the investment costs of a technical plant should not exceed half the plant life, or else the investment becomes too risky. Fluctuations in electricity prices may result in changes in the annual revenue and thus negatively affect payback time, extending it beyond the assumed plant life. Figure 4.18 shows one example of the many calculation results in /9/, which clearly shows the effects of changes in the parameters of ‘financing’ and ‘electrical output’ on payback times.

An important measure of plant design is the adaptation of the rated Stirling engine capacity to the combustion capacity. As the optimum Stirling engine capacity for this case of a district heating plant with a thermal capacity of 1000 kW_{th} an engine with 45 kW_{el} was found. An enlargement or a reduction of engine capacity leads in every case to an increase of the pay-back period. For the optimum case the calculated pay-back period covers 5 years, this is 25 % of the plant living time. It is worth to mention, that the pay-back period without governmental incentives lies above the plant live time.

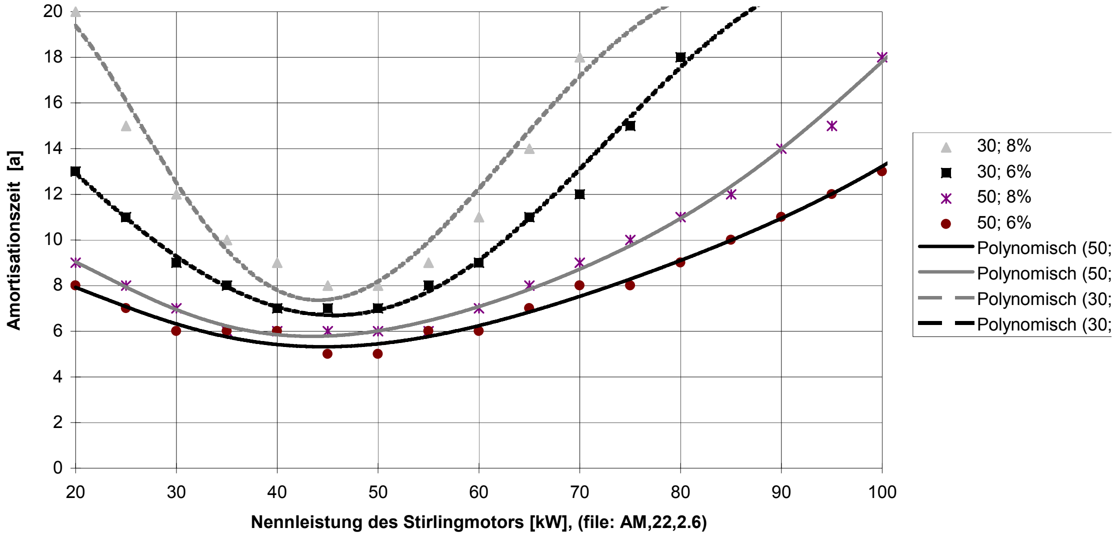

Figure 4.18 :Payback times for Stirling engines as a function of engine capacity. Specific investment costs: 1.600 € /kW (100 kW Stirling engine); electricity price: 0,189 € /kWh; subsidy 30 and 50 %; interest rate 6 and 8%; heating plant capacity 1 MWth, /9/.

6.3.4 Environmental aspects on biomass fired Stirling CHP

Energy conversion processes could be open or closed. Most of the power generation processes are closed. A working medium is closed in a certain volume which consists of components, like vessels, tubes, heat exchangers, turbines, expanders, compressors, valves and pumps. The working medium could be a chemically produced medium (ORC-process) or a substance of the bio sphere (steam, nitrogen, helium). Chemically produced working mediums do have a depletion effect on the ozone layer in the stratosphere or/and a contribution to the global warming. Both influences can be quantified by numbers which express the relation to the refrigerant R 11.

6.3.4.1 Definitions

The definition of Ozone Depletion Potential (ODP), the Global Warming Potential (GWP), the Indirect Global Warming Potential (ID-GWP) and the Total Equivalent Warming Impact (TEWI) are given in detail in the contribution Number 6. “ABSOPTIN REFRIGERATION” of this report and should not be repeated.

6.3.4.2 Environmental related comparison

The following Table 4.2 displays the comparison of a fossil fuel fired small steam power station in comparison to a biomass fired Stirling engine plant as an example of a RES-technology in isolated areas. It should be mentioned that the auxiliary drives, e.g. pumps, water treatment, are supplied by the power produced and energy effort of the production of nitrogen is neglected.

Table 7.2: Environmental impact of power production processes

PROCESS	ODP	GWP	ID-GWP	COP	APPLICA-TION	WORKING-MEDIUM
			Kg CO2/ kWh	---		
biomass fired Stirling plant	0	0	0,0	0,25	electricity	nitrogen
small steam power station	0	0	2,15	0,13	electricity	water

Legend:

ODP	Ozone Depletion Potential (relation: R11 =1),
GWP	Global Warming Potential (relation: R11=1),
ID-GWP	Indirect Global Warming, (kg CO2 per kWh cold work); For fossil heat driven processes: 7.800 kg CO_2/TJ = 0,28 kg CO_2/ kWh; For electrical drives: if thermal power generation: factor 3 to 7,7; if hydro power generation: factor 0; In practice: “country specific factor” as a mix of several kinds of generation from 0 to 3.
COP	Coefficient of performance, for RES-Stirling: COP = kWh at engine shaft / kWh driving heat

6.3.5 Potentials in the WBC

The objectives of the discussion about potentials of technologies are finally the quantification of possibilities. Potentials have to be discussed in detail for discovering the obstructions for a broad application of the RES technologies. The analysis of potentials is made in this Final Report on Workshop 1 of the WP 1 in a special contribution.

6.3.6 Subsidy needs

After the demonstration of the environmental friendly, biomass fired Stirling technique, the broad applications have to be prepared by suitable decisions of the policy makers and politicians. Subsidies have to make available in a suitable level, so that customers will be encouraged to invest their money for decentralized biomass fired power plants with equal costs and benefits, as they have to pay for the market available conventional power technology.

The highest competition is given by the gas or diesel fired internal combustion engines which are available as a serial product with about 1.100 €/kW in the 100 kW power range. Following the results of he economic evaluation of biomass fired Stirling technique in the Figures 7.17 and 7.18, the RES technology is available with about 1.560 to 2.000 €/ kW. That means the double investment costs.

This costs shows clearly that public subsidies have to be placed to customer's disposal. There are different ways to support this new technology which will make the market penetration easier. Both the investment costs and the green electrical energy produced can be subsidized by higher tariffs. This will be the task of policy makers and politicians, which should be supported by the "Guidelines on RES technologies".

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7 SMALL HYDRO POWER PLANTS

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7.1 General – water flows as energy sources

Since the beginning of electric power production, waterpower has been, and still is the leading, renewable source for the electric power production. Nowadays, the electric energy produced by waterpower represents 13 % of total electric energy production in the European Union countries. In this way, the annual emission of CO_2 is reduced for more than 67 mil. tons.

Taking into account that, so called medium and large hydro power plants, usually demand extended flooding of agriculture lands, with serious consequences to environment, well-designed small power plants represent a good alternative.

Small scale hydropower plants and small reservoirs, unlike medium and large ones, fit into the environment much more harmoniously, and cause fewer hazardous environmental impacts. Small scale hydropower plants are used for power production, municipal supply with potable and industrial water, or irrigation. They participate in balancing the naturally non-regulated waters and silting-up prevention, thus prolonging the duration and increasing the extent of utilization and profitability of the large ones. Generally the small scale hydro power plants and reservoirs are constructed for the purpose of preventing or reducing erosion, floods and droughts, improvement of agricultural and small scale economy development (timber processing, sawing mills, stone crushing and grinding plants, etc.), as well as development of cattle breeding, fish breeding, sports, recreation and tourism, provision of biological minimum and prevention of migrations from underdeveloped into densely inhabited industrial zones.

Definition of small hydro power plant

Generally speaking, there is no such thing as a unified attitude regarding the definition of small power plants. Some countries, like Portugal, Greece or Ireland, have set the 10 MW of installed power as the upper limit; some others, like Italy, set the limit of 3 MW, while France has a limit of 8 MW and in Great Britain, it is 5 MW. Therefore, it is implied that the small hydro power plant is a production facility that has small installed power, which differs from country to country, from region to region.

Regarding the effective head, the systems can be classified in three categories:

- high head of 100 m and more
- medium head of 30 to100 m

- low head of 2 to 30 m.

The next hydro plant categories can be considered in power systems:

- up to 100 kW – micro plant
- up to 5.000 kW – small plant.
- up to 10.000 kW – medium plant

Hydro power plants, in general, use the effective head of water, that is, potential water energy, transforming it into kinetic energy and at the end into electric energy. Small hydro power plant, in general, consist of civil construction on the water flow and installations on it; of derivative or/and pressure pipeline, and the machine facility where the equipment for electric power production. Electric power production facility consists of turbine, generator, transformer, control and other necessary equipment.

To enable the electric power production, by using small hydro power plants, it is necessary to have certain natural preconditions, Fig.1. They include the existence of river or water flow with the sufficient water discharge and effective head, so that the construction of small hydro power plant would be techno-economically justified.

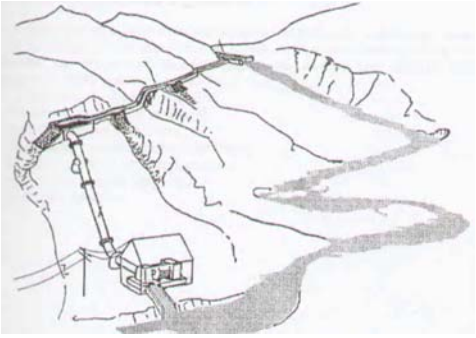


Fig. 1. Situation of small hydro power plant

7.2 Water resources and their potentials

7.2.1 Preconditions

Water resources and their potentials

Fig. 2. shows that the water, flowing from point A to point B, regardless of its different paths (whether it is through its river bed, open channel or pipeline) contains always the same amount of energy, which can be expressed by the formula:

$P = Q \times H \times \rho \times g$

where:
P - Power in kW contained in water,
Q - Discharge rate in m^3/h,
H - Effective head in m,
ρ - Density of fluid (liquid) - for water p = 1000 kg/m^3,

g - Acceleration due to gravitation, 9,81 m/s^2

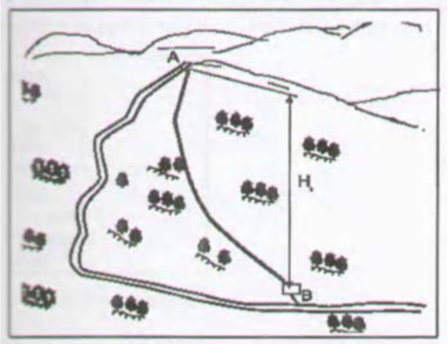


Fig. *2. Water flow, from point A to B*

Water can flow in its bed losing the energy on the way, through the friction and turbulences, or it can flow from point A to point B through the pipe where, on its lower end, there is a turbine.

In the second case, energy in the turbine will be transformed into mechanical energy, and later on, in generator, into electric energy.

The intention of good design is to reduce the amount of energy, lost from point A to point B.

Evaluation of the water flow by measuring the flow rate

If it is impossible to find adequate information for the flow rate, it should be measured directly during a year. The reason for such extended measurements is that it should encompass all typical periods, from the rainy springs' and falls' to dray summers' and winters' periods. That is the only way to obtain reliable data of water discharge. In case that the initial data, expressed in average discharge in m^3/h, are not precise, significant mistakes in planning and later exploitation are possible. In planning, the mistake is reflected in non-optimum dimensions of pressure pipeline, turbine. When it comes to exploitation, the mistake in evaluation of discharge is reflected in the lesser production of electric energy, or in inefficient usage of the facility.

The following methods can be used for the discharge measurements:

- method of speed and surface,
- method of dilution,
- method of dam.

The method of speed and surface

This is a conventional method for the discharge measurement of big and medium rivers. The method includes the cross section measurement of the river and the measurement of water speed in this cross section. It is necessary to choose the appropriate measurement point on straight, slow part of the river, as it is shown in Fig. 3. At this point, the river should have the well-balanced width, which is clearly defined and clean. As the discharge rate varies, the water level goes up and down. The water level is monitored every day at the gauging board.

Using the set of data for discharges and water levels (effective heads) we get *Q-H* diagram, shown in Fig. 4. *Q-H* curve can be represented by the expression:

$$Q = a\,(H+B)^n$$

where:

- a and n are constants,
- H – river level (measured or entered previously) and,
- B – correction factor.

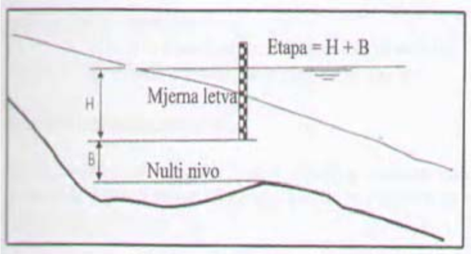


Fig. *3. Discharge measurements at the station*

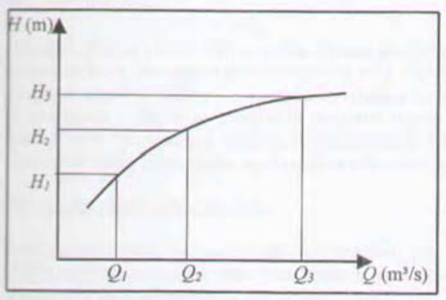


Fig. 4. Q-H curve

Measurement of cross section

To measure the cross section of natural water flow, it has to be divided into a series of trapezoids, as it is shown in Fig. 5. The area of the cross section can be gotten by the simple formula.

Measurement of the flow speed

It is necessary to measure the flow speed at several points, in order to get the average value. There are several ways of doing it.

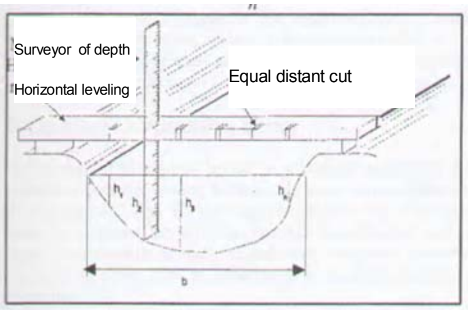


Fig. 5. Measurement of cross section

With the float

The flowing object, the float, which is mostly under the water, i.e., wooden stick or half-filled bottle, is located in the middle of the stream. The measured values are time t, in seconds, needed the float pass over a given distance L. The surface speed, measured in m/s should be averaged with the corrective factor, which varies between 0,60 – 0,85, depending on the water flow and uneven area of the river bed and banks.

With the propeller surveyor

The small propeller rotates over horizontal axis, which is placed parallel with the natural river flow. The instrument is loaded in order to be kept, as much as possible, directly beneath the observer. Each turn of the propeller is recorded by the electric signal through the cable that leads to the observer, who records the number of turns. It can also be recorded automatically, in short intervals. These data are used to form the curve for the water speed, marked on the instrument.

The other version of the instrument has a ring made of small conical dishes, arranged horizontally on the axis, as shown in the Fig. 6. It is possible to draw even the complete map of the cross section speed, and measure out the discharge, by moving the counter vertically and horizontally into many positions.

With the electromagnetic surveyor

Electromagnetic speed surveyor is electric, inductive measuring instrument, without movable parts, placed inside the sealed probe. The probe might be placed on the stick, or might be hanging from the cable. Electromagnetic measurement devices are smaller and do have a wider measuring range than propelling counters. It is of a special importance for flows with very little speeds, where the signal of propeller counters is unreliable.

The easiest way to get the discharge through certain cross section is to enter the measured speed on a cross section at the measuring point. The contours of equal speeds are entered afterwards and the related areas are measured, as shown in Fig. 7.

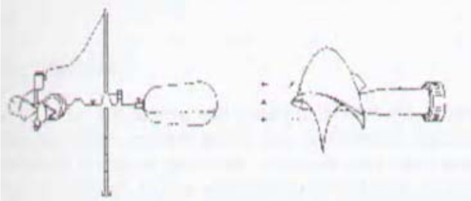


Fig. 6. Propeller surveyor

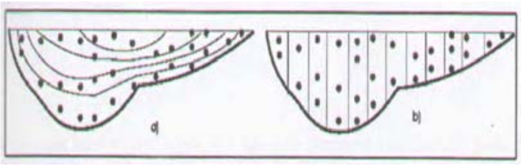


Fig.7. Measurement results of electromagnetic surveyor

The method of dilution

This method is especially suitable for small, turbulent flows where depth and discharges are not suitable for the flow surveyors, and the floats would represent unnecessary expenses. The method consists of syringing of the chemical into the flow and collecting the samples of water down the flow after the chemical is completely mixed with water. The chemical can be added to the water by constant syringing until the collected sample does not show the constant level of concentration. The other way is to apply individual dosing. In the other case, the samples in a period exclude the connection of concentration of the time. In both cases the concentration of the chemical in the samples is used for measuring of dissolvent, where it is possible to get the flow rate of the particular flow.

The method of dam

If the water flow is reasonably small (let us say, less than 4 m^3/s) it is possible to built up the temporary dam with the pass for the water. It is enough to measure the water level upstream to calculate the flow rate (at least 4 levels). Several types of passes can be used, shown in *Fig. 8*, and they are:

- square
- trapezoidal
- V-pass

V-pass is the most precise at very high flow rates, but the trapezoidal or square passes are suitable for wider range of flows.

Characteristics of the stream flow

Procedure of stream flow measuring in the given area, through a period of several years, will produce the table of discharges. In order to make it useful it has to be organized in applicable form.

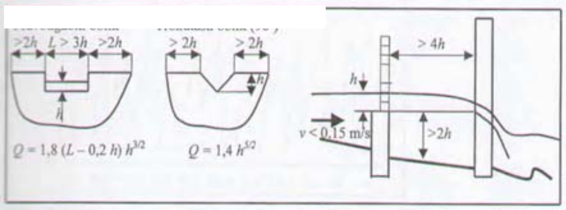


Fig. 8. Different shape of passes

Hydrograph

One of the ways to do this is to enter the data in the form of hydrograph which shoes the discharges chronologically, depending of time, as it is shown in *Fig. 9*.

The discharge duration curve

Another way to organize the data is to get the discharge duration curve which shows the percentage of time during which the discharge equals or surpasses the set values, in a certain river location. From the hydrograph data can be organized according to size, instead chronologically. In *Fig. 10.* data from *Fig. 9.* are organized in descending order.

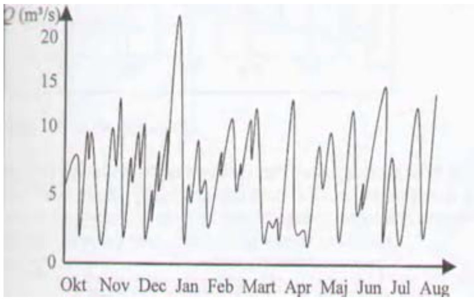


Fig. 9. Hydrograph

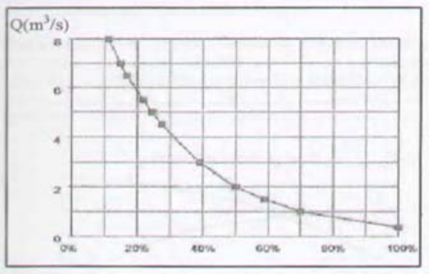


Fig. 10. The discharge duration curve

Measurement of gross and net heads

Gross head is the vertical distance between the upper and lower water level. In the past, the best way for measuring the gross head was gradual manual measurement, but the process was very slow. Nowadays it is done digitally, which has simplified the process.

After the gross head is known, it is necessary to find the losses in the flow (local losses), as well as the losses made by friction in the pipes. Gross head diminished for the sum of all losses represents the net head.

Facility capacity evaluation

The discharge duration curve is a mean for the right turbine design. Taking into consideration residual and minimal technical rate, the capacity of the facility may be decided as well as average annual production of energy.

In all calculation for Q is taken $Q_{available\ flow\ rate}$. It is found when the residual discharge is taken from the $Q_{real\ flow}$. Uncontrolled flow of water to the turbine can produce serious consequences. To avoid this, the law prescribes certain water rate which must stay in the river bed, and it is called residual or reserved flow, i.e., biological minimum as it is shown in *Fig. 11*. The area, under the curve in *Fig. 12*, is available energy for the emergency during the year.

In the most of countries, biological minimum is about 10 % of medium annual flow rate.

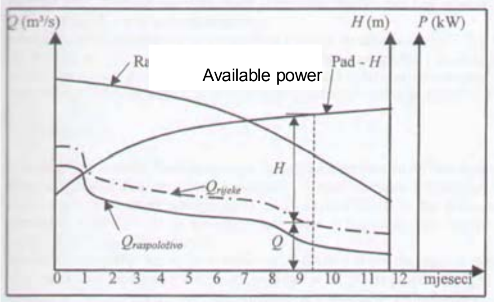


Fig. 11. Curve of a flow rate with Q, H and P

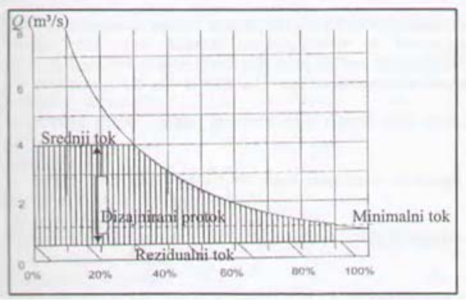


Fig. 12. Curve of a flow rate in percents of flow duration

7.3 Terrain evaluation methodology

Head and discharge as described before are necessary requirements for exploitation of potential energy. The choice of the location for the small hydro power plant is conditioned by those requirements.

However, the choice of the most suitable technical solution for the given location will be the result of long-lasting, interactive process where the most important factors are topography and ecological sensitivity of the terrain. Methods of evaluation of mentioned factors are getting more advanced and by using them, it is much easier to construct suitable schemes for small hydroelectric plants at reduced costs.

Cartography

The needed maps are usually available in industrialized countries. In case that map cannot be found, it is possible to use the topographic photographs of the territory. However, the photographs differ from the maps since they do not have uniformed rate. Also, the territory photographs cannot be presented in stereoscopic way or in three dimensions. Stereoscopic effects enable geologists to identify the type of the rock, the geologic structures and the instability of the slope. They offer the necessary information for the dam construction, the construction of open channels and the pressure pipelines to the engineers.

Geotechnical studies

The need for detailed geological studies of terrain is often neglected. Wrong evaluation of geological structure can cause leaking under the dam, sliding of open channels, etc. Good geological maps are the basis for the dam foundation, the stability of the slope, and absorbability of the terrain. However, sometimes general data have to be complemented by soil drilling and analyzing the samples.

In the geology, there is a spectrum of geomorphologic techniques, which can be used, and the following are the most common:

Photo geology

In the scales from 1:10000 to 1:5000 it offers possibility to detect the type of rocks in order to decide of geological structure and the stability of incline.

Geomorphologic map

Produced in a scale from 1:10000 to 1:5000, they show the surface formations that can influence the hydraulic structures.

Laboratory analyses

The traditional laboratory tests, like analysis of the soil, can supply additional information to the previous maps.

Geophysical studies

Geophysical research contributes to better understanding of the thickness of surface formations. They enable to locate the slide sites, underneath waters, and unstable formations.

Geological structure analyses

When the channels are laid in tunnels and the leaking in foundations of hydraulic structures are the problems, this methodology can help to solve it.

Direct drilling research

The drilling program and laboratory tests on drill samples are very important, when the dam should be constructed on unstable soil. That kind of measurements are not usual for design of small hydroelectric plants but it could be helpful in this case.

Dam

The law requires that the stability of the foundations must be analyzed, if there is a possibility of damage, due to sliding or when the sliding is possible along the joints. If it is necessary, the rock mass has to be stabilized additionally. The variations of the water level can influence the stability of the lake shores, if the dam must be built on unstable soil.

Open channel

Many geomorphologic characteristics can unfavorably influence the channel, along side the chosen line and could lead to instability. A geological study should be conducted in order to prevent the layers in the channel and to drain them so that the pressure of the water under the channel is reduced. The foundations of the channel must be stable and the channels should be fixed on a firm structure.

Channel in the tunnel

When it is needed to build the channel in the tunnel, the construction must be in accordance with the following:

- the digging is conditioned by the geological composition, whether it goes through the mass of rocks, or surfacing formations
- the tunnel for the hydraulic channel, must be stable and waterproof. Therefore the geological composition of the ground through which the digging is done, must be known in detail.

Engine facilities

Due to huge and heavy equipment within the facility, the stability of it must be totally secured. If the geological composition of the ground cannot guarantee the stability of foundations then it must be fortified. If the facility is founded on the rock then preliminary works should eliminate the surfacing unstable layer, leaving the firm rocky base. If the engine facility is located on the river terraces, which are not stable, than again the foundations must be fortified.

The traditional cementing procedure can cause difficulties, and in any case, it is never satisfying when the terrain is heterogenic, which usually is at the river terraces. The new technique of the syringing the cement by the beam under the ground surface, can guarantee consolidation, but it is very expensive at the moment.

7.4 Hydraulic structures, turbines and generators

7.4.1 Structures for drainage and water gathering

The dam

The dam represents a basic element for conventional hydraulic systems and is used for creating reservoirs for water gathering and level increase. At the relatively flat terrain, the dam can create needed altitude difference, necessary for the production of energy. It can, also, be used for water gathering during seasons with high water levels, in order to provide energy production in dry seasons.

Due to high costs of dam construction, they are seldom used for small hydro electric plants. Where the reservoir is made for other purposes, like irrigation or water supply to towns, it is possible to produce energy, if the engines are installed at bottom end of dam, as additional benefit.

Sluice

With majority of small hydro power electric plants, the part of the flow rate, bigger than minimum needed for functioning of turbine, is used. Building such systems, the low structure is made in the riverbed, to redirect quantity of water needed for the work of turbine, while the rest flows over. When the system is big enough, this redirecting structure becomes smaller dam, whose role is not gathering, but rising of the water level, so that the flow is directed into the drain opening. Sluices should be built on the rocks, and in its simplest version they consist of several lumps lied transversal on the flow, like in *Fig. 13a*. It is also possible to use a threshold made of steel bags filled with sand, as it is shown in *Fig. 13b*.

With bigger structures, sluice can be a smaller dam with the waterproof core, which continues into waterproof foundation, located in the central part of the sluice, like in *Fig. 13c*. This core is usually made of pressed clay material, and if such material is not available, upstream embankment must be covered with geo textile material, in order to secure impermeability. If gravel and sand are available on the spot, instead of clay material, the building of the concrete dam should be considered.

If the flow is liable for sudden floods, demanding big drain openings that are expensive to build on clay dams, it much better to build concrete dam, where the drain openings are easier to integrate. However, if the system is located on stirring area, the firm structures, like concrete dams, should be avoided. In cold climates, the needed precautious measures undertaken with fresh concrete can be so expensive to prevent the building of the concrete dam. The majority of small dams in small hydroelectric plants are of gravitational type, built on the solid rocks, where the stability of the dam is achieved by its own weight.

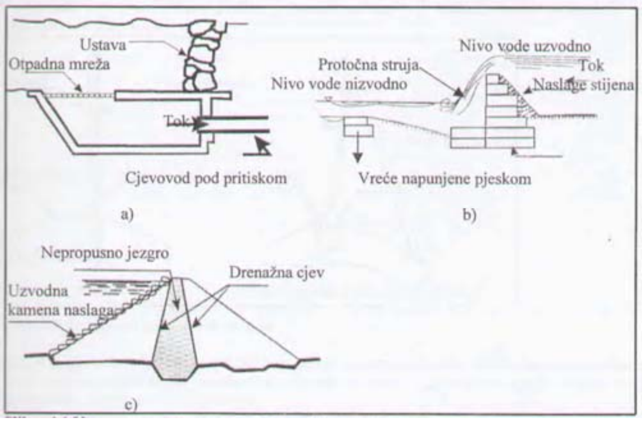


Fig. 13. Sluices

Drainage

In the area with clear difference between wet and drain seasonal flows, the floods can have catastrophic effects on any structure built along the flow. To avoid damage, the surplus of water must be safely taken over the sluice or the dam. Therefore, carefully designed passes for too big flows are united with dams and are called drainages.

The basic type is gravitational, surpassing drainage. It is an open channel with steep banks and opening at the entrance. To reduce the pressure on the surface of drainage, the profile of it must follow the ecliptic curve that overflows the sharp rim of the dam. This ecliptic depends on opening, so the profile of the rim suits only to designed entering. If the flow is bigger than designed, the zone of the sub pressure is developed on the surface and it may lead to cavitations.

The discharge can be calculated according to formula:

$$Q = C \times L \times H^{3/2}$$

where: C – discharge coefficient, L - length of drainage rim, H - head.

Discharge coefficient C should be chosen by means of model testing. The normal values are between 1,66 for the wide rims to 2,2 for optimally designed rims.

Shallow drainages in small hydroelectric plants are used for draining, for cleaning of the reservoirs, in the case of emergency, or for maintenance purposes. Generally, shallow drainage with wedge-shaped valve at the exit, or sliding gate at the entrance, is enough for this function. Flow out from the opening is often critical and can cause serious erosions on the dam, especially if the riverbed is clay or muddy. The surpass structure must be made to avoid such a damage. It is known as a calming pool, which leads to forming the hydraulic leap where the water flow changes from over critic to sub critic.

7.4.2 Structure for water transport

The water intake

Water Intake is defined as a structure that directs water into a pipeline leading to the engines. The intake must direct the needed quantity of water into a pipeline under the pressure and without negative influences to environment and with minimal losses. Clutch serves as a trespass between the movable flow, from the creek to torrent, and controlled water flow.

The designer of the supply pipe opening should consider three criteria:

- hydraulic and structural criteria common for all types of clutches,
- functional criteria, i.e. the percentage of supply pipe flow, cleaning the sediment and litter, etc., that is different from one to another supply pipe opening, and
- ecological criteria.

Pipeline under pressure

The purpose of a pipeline under pressure is to lead the water from the intake to engine. However, it is not simple to select the most economical arrangement for such pipes. Pipelines under pressure can be placed on or under the ground, depending on the factors like natural conditions (ground structure), material of pipes, temperature of environment, etc.

Flexible PVC pipelines of small calibre can be placed on the ground following the line with minimum of preparation. On the other hand, pipelines of bigger calibres must be placed under the ground with minimum of digging.

Steel underground pipelines must be carefully protected to prevent corrosion. It is also important not to damage the protection layer during the instalment, in order to minimise additional maintenance. From the environmental point of view, this is optimum situation because the earth can recover its initial form, so the pipelines do not represent the obstacle for flora growth. Pipeline on the ground can be designed with or without joints. Variations in temperature are important if turbines do not constantly work, or when the pipelines are emptied for, i.e. repairing. The consequence of stated variation is expansion or contraction.

Pipelines on the ground are mostly made in a straight or almost straight line with the concrete anchor blocks at every curve and with the joints between every part of anchorage, as shown in *Fig. 14.* The straight parts of pipeline are placed in, so called, saddles fitting to the pipe.

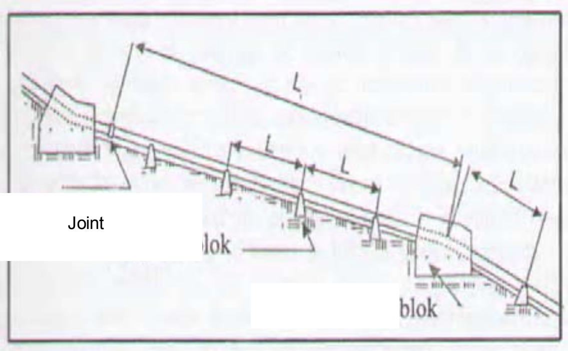


Fig. 14. Pipeline under pressure

The basic characteristics of the pipeline are material, calibre, the width of the wall, and the type of joint. Material is chosen on the bases of ground conditions, weight, joint system and price. Calibre is chosen in order to reduce losses due to friction within the pipeline, up to the acceptable level. The width of the wall is chosen so that it can endure maximal inner hydraulic pressures.

Pipeline diameter

Pipeline diameter is chosen on the basis of balance between the price and the loss in power. Power P is calculated from discharge Q multiplied by the maximal head H and is given by the next equation:

$$P = Q\,H\,\gamma\,\eta \ (kW)$$

where: Q – discharge in m^3/s,
H – maximal head in m,
γ - specific weight of water in kN/m^3
η - global efficiency.

The network pressure is equal total pressure minus sum of all losses in the pipeline. They are approximately proportional to the square of water speed in the pipe. Pipes with smaller calibres demand higher water speeds, so the losses are higher compared with a larger calibre of the pipes. The cost can be reduced, if the smallest possible pipe calibre is chosen, but the losses in discharge are increased.

7.4.3 Turbines classifications

Discharge through the turbine

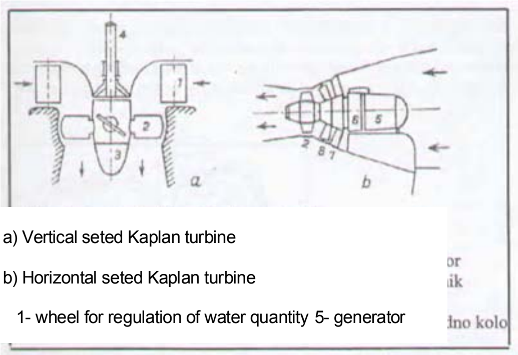
Turbines are engines, which transform potential and kinetic energy of water into mechanical work. Turbines can be, according to the way of transporting the water to working wheel, reactive and impulse turbines. In reactive turbines, the pressure transforms into kinetic energy in transporting elements in front of working wheel, and the other part of sub pressure energy is transformed from sub pressure to kinetic energy in the working wheel. With this type of turbine, immediately in front of the working wheel, the water pressure is big and because of that these turbines are called reactive. They have immobile transporting wheel, or the mobile spades and the working wheel that rotates with the axes of turbine. The relative stream of liquid accelerates passing through working wheel, therefore the grate of the working wheel rotates.

If the total portion of working wheel thrust energy is transformed into kinetic energy, then we are talking about impulse turbine, that is, the turbine of equal pressure. Thrust energy transforms into kinetic energy in the spout, the reason we call it impulse turbine. With impulse turbine water stream hits the board, and with the reaction ones the water stream flows out like from the dish. Therefore, turbines can be:

- impulse (with a free spout): Pelton, Banki (Crossflow)
- reactive (with overpressure): Francis, Propeller and Kaplan

Kaplan turbine

Kaplan turbine is a reactive axial turbine used for single rate work from 15-50 J/kg and for discharges in the range of 0,01-50 m^3/s. Depending on single rate work the number of spades can be from 3-10 (less number for smaller discharges). The conveying apparatus can be made as cylindrical conveying one, when the conveying apparatus circular motion axis of the spades is crossed with the axis of working wheel axis. The basic characteristic of Kaplan's turbine is that the working wheel spades are mobile around its axes, depending on turbine working regime. They are made with a vertical axis, while the pipe Kaplan turbines are made with a horizontal axis. They are usually applied at low pressure power plants (3 m < H < 55 m), where the discharges are significant.



a) Vertical seted Kaplan turbine

b) Horizontal seted Kaplan turbine

1- wheel for regulation of water quantity 5- generator

Fig. 15. Kaplan turbine

Francis turbine

Francis turbine is also reactive, radial-axis one. It is because the water enters the turbine and the working wheel radially and leaves it axially, as it is shown in Fig. 16. Parameters, for which those turbines are built, are single rate work 120 J/kg and discharges from 0,45-25 m^3/s. Such a solution decreases the price of turbine up to 20 % compared to all other solutions. Turbine wheel redirect water from radial to axial direction. They are made for heads from 10-350 m and have the specific number of turns from several tens to 500 per minute. Water is brought to Francis turbine by a conveying wheel who's spades regulate the water quantity. From the working wheel, water flows to diffuser who's role is to further convey water without whirling.

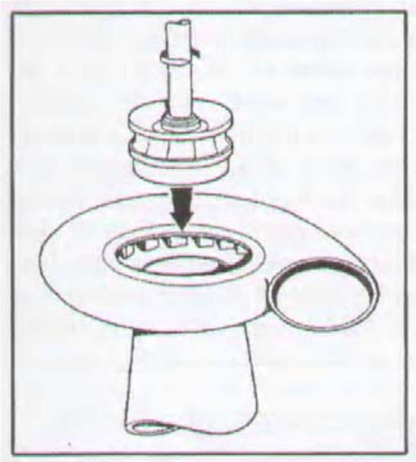


Fig. 16. Francis turbine

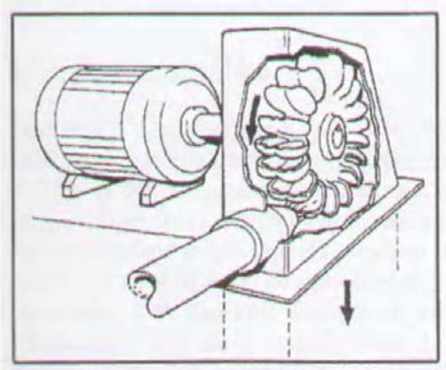


Fig. 17. Pelton turbine

Pelton turbine

Pelton impulse working turbine is most frequently used in small hydro power plants. The advantage of it is that Pelton turbine is relatively the simplest, in constructive and hydraulic way. The application range for small hydro power plants is from heads of 300 m and more, and are made for specific number of turns from 10-30 turns per minute, and discharges from

0,01-2 m^3/s. In a Pelton turbine water is brought through, so called, nozzle (mouth-piece), directed on shell shaped spades, which have nozzles on its ends. Working water is brought under the pressure. The number of spouts is from 1-4. By the position of needle in the nozzle, the quantity of water is regulated. They are often built with horizontal axis. Pelton turbines work on the principal of active hit of water stream on working wheel spouts. The water stream from spout hits the spade tangential and rotates the turbine by that pressure. It is used with the high-pressure power plants where the discharges are relatively small.

Other turbines

Apart from the stated ones, today also are in use:

- Banki or Crossfow turbine,
- Propeller turbine

as well as number of other turbines of different constructions for different conditions.

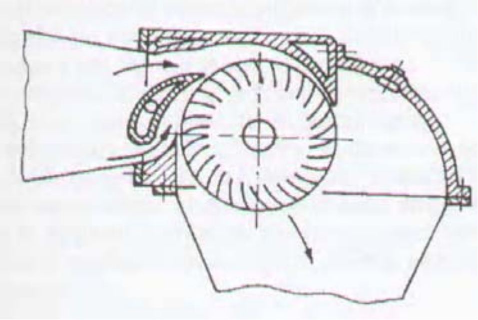


Fig. 18. Banki (Crossflow) turbine

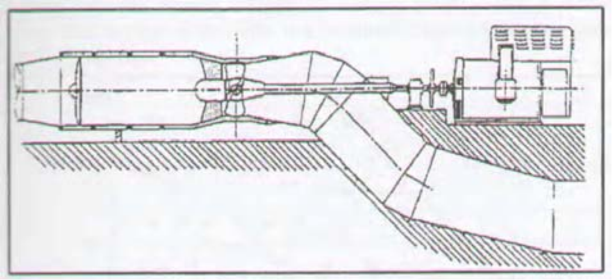


Fig. 19. Propeller turbine

The choice of turbine

On the basis of head

When speaking of simple solutions for turbines and its constructive variations, as it is shown in *Tab. 20*, regardless of application scope, at the first place techno-economical criteria must be considered. Before the final decision, several variations should be analyzed, and then the most acceptable one should be chosen. All these solutions and the prices have to take in consideration the investment costs per one kW of power and the production costs of one kWh of electric energy, because these two values are determine performance of the small hydro power plant.

Turbine type	Head
Kaplan	3 < H < 55
Banki	3 < H < 200
Frnacis	10 < H < 350

Pelton	50 < H < 1300

Tab. 20. Choice of turbine type according to the head

On the basis of discharge

From the diagram given in Fig. 21, it can be noted that Kaplan and Banki turbines are of low pressure, Francis turbine is of middle, while the Pelton turbine is of high pressure. The selection of the type of turbine is defined after the decision on installed discharge, available head and the number of generators.

Besides the stated methods for the choice of turbine, the methods based on specific speed are also in use.

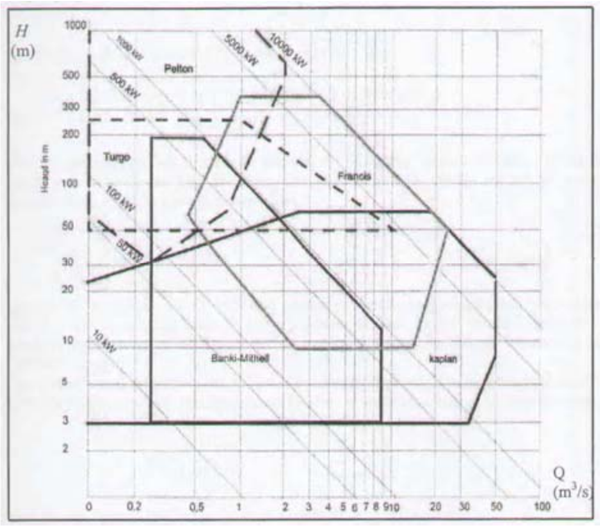


Fig.21.Choice of turbine type according to Q and H

Efficiency of turbines

It is defined as a ratio of the power on the turbines axis and absorbed power (hydraulic power equivalent to measured discharge). It should be mentioned that the pressure is measured at the point of stream hit for impulse turbines (Pelton and Banki), which is always above water level downstream. This causes decrease of pressure. The difference is not disregarding for low-pressure schemes.

In *Fig. 22.* medium efficiency, guarantied by the producer for several kinds of turbines is shown.

To define total efficiency, we multiply the turbine efficiency with accelerator (if there exist) and generator efficiency. Turbine is designed to work with the best efficiency, or approximately the best, mainly with 80 % and more of maximal discharge; as the discharge declines from that specified value the hydraulic efficiency of turbine declines.

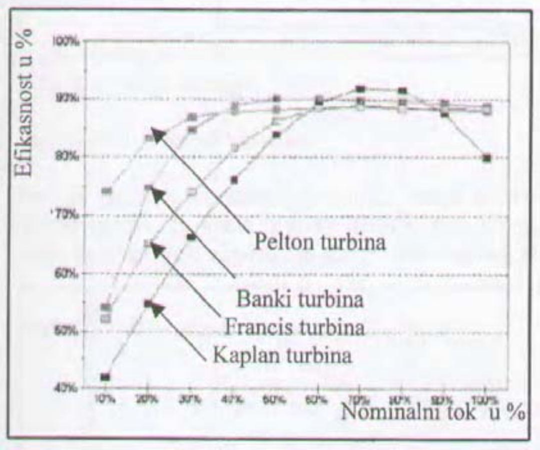


Fig. 22. Medium efficiency for turbines

Generator – turbine connection

The most frequent connection between turbine and generator is done by an elastic joint bar, if the turbine and generator have the same turn speed. If the turn speeds of a turbine and generator are not correspondent (in small hydro power plants the generator turn speed is almost always higher than the turbine turn speed), then for the turbine-generator connection, the belt transmission or multiplier can be used.

If the turbine power is from 250 -2000 kW, and transmission ratio is 2-6, the transmitter with cylindrical cogwheels is used. The use of conical, cochlear and planetary transmitters is not recommended.

To decide on a choice of turbine generator connection one should consider economical aspects also.

Generators

Generator transforms mechanical into electrical energy. Three-phase alternating current generators are in use nowadays. Depending on a network supply characteristics, the producers may choose between synchronous and asynchronous generators. Synchronous generators are more expensive than asynchronous and are used in power systems where the output from generator is in accordance with the load of power system.

Synchronous generators

Synchronous generators are supplied with an excitation system (rotational or static) together with a voltage regulator which provides possibility for voltage regulation. It also can deliver some reactive energy, which in many regimes is required by external network. Synchronous generators can work isolated from the external network and produce energy, since their excitation does not depend on the external network.

Capacity of synchronous generators
Power: from 10-500 kVA,
Voltage: 400/230 V,
Frequency: 50 and 60 Hz,
Power factor: 0,8 cos φ
Rotation speed: 1500 rpm

Asynchronous generators

Asynchronous generators are simple inductive engines without possibility to regulate voltage and they operate with the speed directly connected to the frequency of external network. They use the external network for magnetizing needs. They cannot operate when they are disconnected from the network because they are unable to supply themselves with magnetizing current. These generators are cheaper and are in operation within extended networks, where their output is insignificantly proportional to the power system load. Their efficiency is from 2-4 % lower than the efficiency of synchronous generators.

Lately, system of variable speed and constant frequency, where the fluctuation of turbine speed is allowed in a wide range, while voltage and frequency stay constant, entered the market. This system can even synchronize units to the network before it starts running. The key of the system is the use of transformer with serial resonance.

Operating voltages of generator varies with power. The standard voltages are 380 V or 430 V for generator sizes of up to 1400 kVA. The stated voltages allow the usage of standard distribution transformers (as well as standard step-up transformer) and the usage of generated power within the power plant (local system).

Capacity range of asynchronous generators:
Power:: 15 -315 kVA
Voltage: 3x380 V,
Frequency: 50 Hz,
Power factor: cos φ = 0,8 - 0,9
Rotation speed: 600 -1500 rpm

Other machinery

Beside the stated, the main machinery for the successful work of small hydro power plant in the engine room is:

- Power transformer,
- Self-consumption transformer,
- Medium voltage machinery,
- control system,
- DC supply
- signalization and alarms
- grounding system

7.5 Cost-Efficiency and Characteristics of Small Scale Hydropower Plants

Small scale hydropower plants have important advantages in comparison with the medium and large hydro plants because they fit into the environment and cause fewer hazardous environmental impacts. Those are structures of smaller size, smaller reservoirs, and therefore, causing less floods in the surrounding land. Sometimes, there is no reservoir at all, and the whole process takes place in the river bed, or it is a run-of-the-river plant.

Utilization of water potential represents the most important alternative to the energy gained from fossil fuels, because otherwise, the water flow energy gets irrevocably lost. It is an inexhaustible source of energy, and from the aspect of environmental protection it represents the cleanest mode of utilization.

One of the major elements of cost-efficiency of small scale hydropower plants construction is the short construction period. This refers particularly to execution of civil works, as the prices of construction materials, manpower and equipment constantly change. The largest effect of short construction period is the fast commencement of operation - quick return of invested assets and increase of utilization of available resources of cheap and replenishable energy.

Average price of a kW of installed capacity or generation of electric power in small scale hydropower plants, should be higher than in large ones. However, if the small scale hydropower plants should be constructed on multipurpose structures, the investments in small scale hydropower plants may be expected to be lower than in large ones.

The scope of civil works significantly influences the costs of small scale hydropower plants construction, and consequently the price of generated electric power. Therefore, especially in the beginning, small scale hydropower plants should be constructed on locations with previously completed, or at least partially completed civil works. Adaptation of the existing mills and old deserted locations of small scale hydropower plants, due to the existence of civil structures, reduces the investments per 1 kW of installed capacity. Civil and hydraulic structures of mills are well preserved, and with small reconstruction could be adequately adapted and used for small scale hydropower plants construction.

Some of the small scale hydropower plants could be refurbished, with low investments, so that they can be used more extensively.

Construction of small scale hydropower plants in the consumers' immediate vicinity (otherwise remote from the main distribution network) and with the exclusive purpose to meet the requirements of those consumers, involves notably lower investments for generation of a kWh of electric power than it would be the case with large scale hydropower plants, as there are no transmission lines expenses, nor losses of electric power transmission.

The advantage of small scale hydropower plants in comparison with the large ones, lies in the vicinity of construction and utilization, low maintenance costs, there is no permanent staff, and owners and co-owners, apart from state owned enterprises and local authorities, may also be the private ones.

Multipurpose utilization of hydro potential of small water flows represents the optimum concept of construction, cost efficiency and utilization of small scale hydropower plants: Main purpose of small scale hydropower plants is electric power generation. It is usually aimed for some local consumers (sawing mills, timber industry, tread mills, stone crushing and grinding plants). Implementation of small scale hydropower plants and small reservoirs would provide rather cheap electric power. Each kWh of generated electric power in small scale hydropower plants represents saving of 1,6 kg to 2,2 kg of coal (depending on the kind and quality) or approximately 0,25 kg of oil.

Small reservoirs are also used for agricultural lands irrigation. It is particularly important that they are most often constructed in underdeveloped, hilly and mountainous areas, in which water is necessary for agricultural development (cultivation and cattle breeding). This has indirect and favorable influence on the development of those underdeveloped regions.

Municipal and industrial water supply is another purpose of small reservoirs, influencing improvement of local population standard and agriculture, and subsequently, reducing migrations from villages into towns.

Small reservoirs perform flood retention, and therefore, protection of human lives and material goods against water power. Small scale hydropower plants construction within water resources management regulation of water flows has particular importance if they are constructed as additional structures to some water resources management regulations of river catchments.

Such reservoirs participate in land protection against erosion, prevent silting-up in the existing downstream, larger reservoirs, and thus prolong their duration.

Small reservoirs, and small scale hydropower plants, provide water for enrichment of small discharges in dry seasons downstream from the dam. Providing the guaranteed minimum, they participate in water regime regulation and thus contribute to environmental protection.

Fish breeding and production are very favorable in small rivers and streams, with less pollutants and water much cleaner than downstream.

Small reservoirs contribute to the development of tourism, sports, and recreation. Lately, running away from polluted towns, people increasingly return to the nature, and countryside tourism in our country has expanded in the recent years.

Nowadays, with a number of already constructed small reservoirs and the necessity of considering extensive construction of these structures, the possibilities for construction of small scale hydropower plants are rather increased. In the domain of small scale hydropower plants construction, the following activities are taking place:

- reconstruction and refurbishment of the existing small scale hydropower plants;
- automation of small scale hydropower plants which already operate;
- adaptation of the existing mills into small scale hydropower plants;
- additional housing of new units with installed capacities up to 10 MW within the existing hydropower plants, for additional utilization of the available hydropower potential; and
- Construction of new plants as separate structures.

In order to turn the existing hydropower potential in small scale hydropower plants the standardization of projects and equipment for small scale hydropower plants becomes more important.

Construction of standard civil structures is the first step towards standardization of the required electro-mechanical equipment, which implies faster and easier installation of automatic control system in small scale hydropower plants without crew. At the same time, those are the right moves to make the equipment manufacturing for small scale hydropower plants financially attractive and cost-efficient for our country's industrial production.

Small scale hydropower plants with the latest standard structural solutions are easy to be constructed, operated and maintained. With standardized electro-mechanical equipment and uniform civil works, they require minimum technical and organizational conditions, they have reduced costs of construction and maintenance and rapid return of invested capital.

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8.1 General

The large field of applications of the sorption cooling technology, which uses heat as the driving energy for the cooling process, is the oldest cooling technique. It’s worth mentioning, that the first artificial cooling device of Edmond Carré follows the periodical absorption cooling principle and was put in operation around 1850. The period from 1850 to 1880 in France was marked by an energy crisis caused by a tremendous increase of costs of the conventional fuel (wood, coal). The reason for that was the industrial development and a shortcoming extension of coal mining in France. For one ton of steel about seven to ten tons of char coal were needed and the prices for energy raise about 10 % per year. The government of France decided to subsidize the development of solar applications. It is only little known and should be therefore mentioned, that at that time (1850 to 1880) in France all solar technologies, except the photovoltaic applications, were practiced by using the available techniques (A. Mouchot: “La chaleur Solaire et ses Applications Industrielles”, 1879).

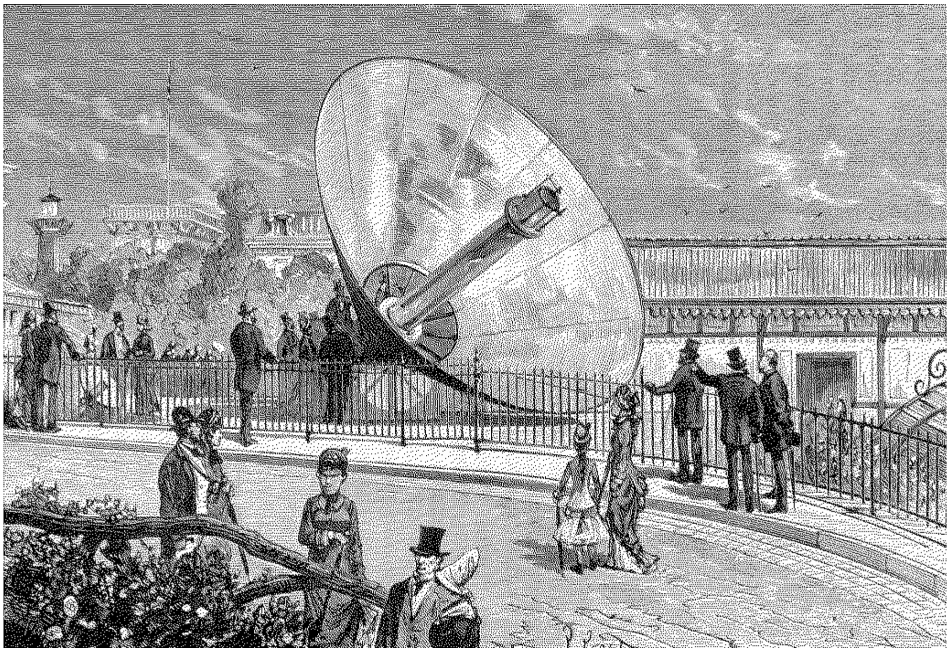

Figure 9.1: World exhibition 1878 in Paris /1/. On September 29 Augustin Mouchot produces the first ice block with solar energy using a periodical absorption machine of Edmund Carré (Courtesy of Olynthus).

The continuous increase of the man made CO_2 emission in the 20th century and the environmental pollution by the energy conversion promote the utilization of renewable energy sources (RES) like solar and biomass to meet air-conditioning and refrigeration needs by heat driven systems. The electricity production and the grid can be relieved too.

8.2 Guidelines for planners, installers and other professionals

8.2.1 Guidelines for design

8.2.1.1 Sorption refrigeration systems

A large variety of sorption processes are well known and most of them can be assigned to the structure in Figure 6.2, which shows a compilation of the most important groups of the processes. The different sorption processes can be generally divided in two branches:

- Periodical Sorption Refrigeration and
- Continuous Sorption Refrigeration processes.

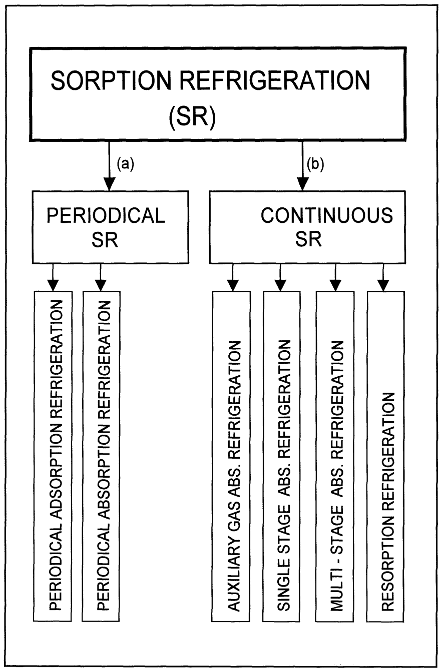

Figure 9.2: Arrangement of sorption refrigeration processes.

8.3 Continuous absorption refrigeration

This group of sorption processes uses liquid absorbents and do have a continuously working thermal compressor. It replaces the mechanical compressor of conventional vapour compression cooling system. Figure .3 shows the main components of the system (b) and the energy graph above (a).

The single stage, continuous absorption refrigeration process is the basic process of all systems in the group (b) and works as follows:

The working fluid (WF), mainly ammonia and water is boiled in the generator G, which receives heat from the solar collectors at temperatures in the range of 65 to 80°C. Mainly ammonia - but also a small quantity of water - leaves the generator as vapor and is condensed at the water cooled condenser C, e.g. at 25 to 35°C. The ammonia, which leaves the generator G, leads to a decrease of the ammonia concentration in WF of the generator, and so the boiling working fluid in the generator has to be exchanged continuously. This is managed by the working fluid pump P, which delivers strong working fluid with a concentration of, e.g. 40 % ammonia, from the absorber A via the working fluid heat exchanger (WFHE) to the generator G. The WFHE heats up the strong WF from the absorber temperature, e.g. 30 to 35°C, by heat recovery to about 50 to 65°C. The WF enters therefore preheated the generator G and starts boiling by receiving additional heat from the collectors. After boiling of the WF in the generator the concentration is decreased, e.g. from 40 to 35 %, and it is led back as weak WF via the WFHE to the absorber A. The weak WF leaves the generator with an outlet temperature of about 80°C, enters the WFHE and is cooled down by the cold, strong WF, which comes from the absorber A with a temperature of about 35°C. The WF control valve (WFCV) is controlled by the WF level in the generator and ensures that the same volume of WF leaves the generator as it is delivered by the WF pump P into the generator.

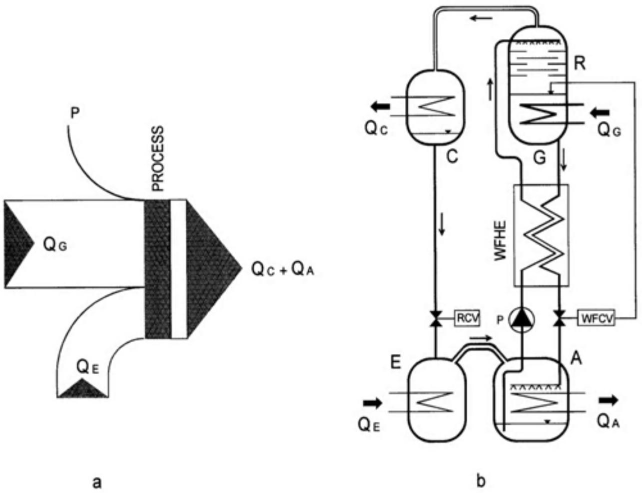

Figure 9.3: Single stage, continuous absorption refrigeration system; A … Absorber, G … Generator (Expeller), E .. Evaporator, C … condenser, WFHE .. working fluid heat exchanger, P ... WF pump; RCV ... refrigerant control valve, WFCV ... working fluid control valve, QG ... heat received at generator, QC ... heat rejected at condenser, QE ... heat received at evaporator, QA ... heat rejected at absorber.

The condensed refrigerant ammonia leaves the condenser C and is injected into the evaporator E by the refrigerant control valve RCV. The evaporator E is working at the low pressure level, e.g. 2 to 4 bars, and the refrigerant boils and evaporates at low temperature in the evaporator depending on the cooling water temperatures. The cold evaporated ammonia vapor leaves the evaporator E and flows into the absorber A, which absorbs the refrigerant vapor and therefore it has to be cooled continuously.

The thermal coefficient of performance ($COP_{thermal}$) describes the relation between the profit (cooling capacity) and the expense (heat from the collectors):

$$COP_{thermal} = Q_{cooling} / Q_{heating}$$

8.4 Results of process design

The thermodynamic properties for the ammonia water mixture are well known. The tools for the process configuration in principle are the lgp,1/T diagram and, if higher accuracy of the calculation results is desired, the table of Merkel-Bosnjakovic should be used (Niebergall 1959, Bogard 1980) /2/, /3/. The big advantage of the working pair ammonia/water is the option of multi-purpose application from the evaporation temperature of +5 to –50 °C.

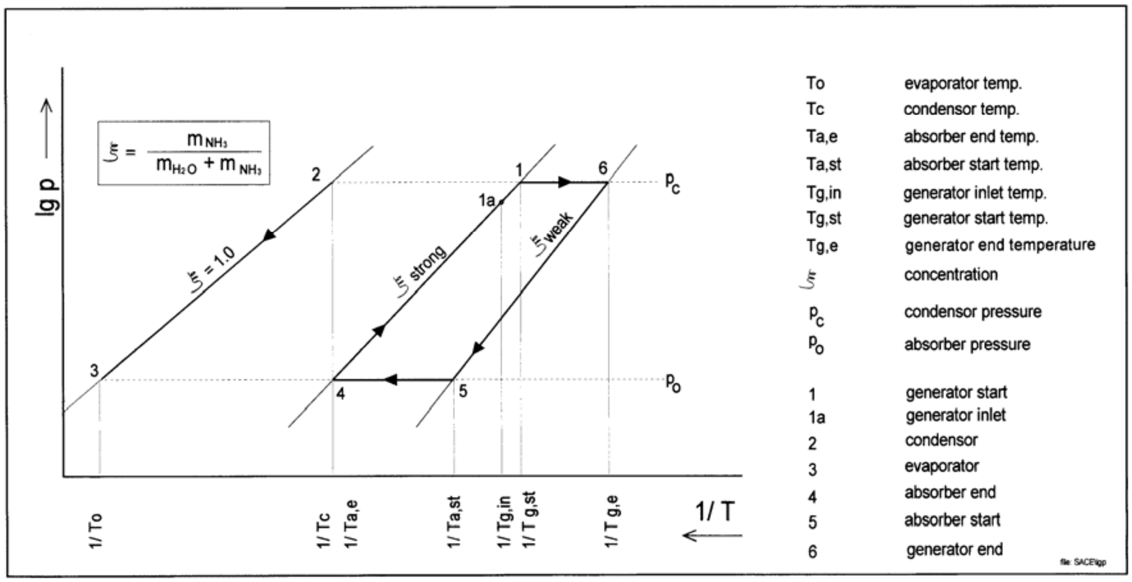

Figure 6.4: Basic design of a single stage, continuous absorption refrigeration process in the lgp,1/T-diagram for working fluids with positive heat of the chemical reaction /2/.

For the basic design of a refrigeration process the following items have to be determined:

- Working pair (NH3/H2O or H2O/LiBr)
- Evaporation temperature (To)
- Temperature of cooling water (heat is rejected at Ta,Tc)

The data in the Table 6.1 show a comparison of the thermodynamic behavior of three different applications using an ammonia/water mixture as the working fluid.

For the model - process, which is characterized by circulating of 1 kg refrigerant and f kg WF, the corresponding heats can be determined and are shown as the results of the process design in Table 9.1.

Table 9.1: Characteristic data of the single stage, continuous absorption refrigeration model-machine for a circulation of 1 kg refrigerant (NH_3) Evaporation at +5, -10 and -34 °C.

Element		App.1	App. 2	App. 3	Units
Evaporation temp.		+5	-10	-34	°C
Cooling water temp.		27/33	25/30	23/28	°C
Generator	$q_{K(E)}$	1782	2149	3038	kJ/kg
Evaporator	q_0	1116	1058	1210	kJ/kg
Absorber	q_A	1595	1750	3046	kJ/kg
WFHE	q_{WF}	940	2020	6005	kJ/kg
Condenser	q_C	1303	1462	1213	kJ/kg
WF pump	q_P	5,4	6,3	19,0	kJ/kg
Condenser pressure	p_C	12	10	12	bar
Absorber pressure	p_A	5	1,85	1	bar
Concentration weak WF	ξw	48	26	18	%
Concentration strong WF	ξs	54	36	23	%
Concentration difference	$\Delta\xi$	8	10	5	%
Specific WF-circulation	f	6,62	7,4	16,4	-
Heat ratio COPth	COP_{thrm}	0,62	0,492	0,397	-

Application 1: Air conditioning at an evaporation temperature of +5 °C (low temperature solar application with flat plate collectors).

Application 2: Brine cooling at –10 °C

Application 3: Deep freezing at – 34 °C for a food storage

The $COP_{thermal}$ – the relation between the enthalpy difference at the evaporator and at the generator - is relatively high (0,62) for air-conditioning and significantly lower at deeper evaporation temperatures.

8.5 Rectification

Of the different working fluids of absorption cooling machines there is to make a distinction between absorbents which have their own vapor pressure in case of boiling, e.g. water, and absorbents, which don't have a measurable vapor pressure, e.g. Lithium Bromide. If 0.5 kg of the refrigerant ammonia and 0.5 kg of the absorbent water is mixed, the concentration is 50 %. Assuming that such a mixture of the WF is filled in the generator and boiled at 65 °C and 11,5 bar, the vapor, which leaves the generator, consists of 98 % of ammonia and 2 % water. For brine cooling at minus 10 °C the generator temperature have to be raised to about 90°C and the share of water steam in the vapor raises to about 5 %, thus, the ammonia vapor concentration falls to 95 %. In the deep freezing sector (evaporation at –30 to – 40°C) the boiling WF temperature has to be enlarged to about 120°C and the ammonia concentration in the vapor above the boiling WF falls down to about 90 % and lower and the vapor contents 10 % of water as steam. This large content of water leads sometimes to serious disturbances in the evaporator, especially for deep-freezing applications. Since the water has to be removed out of the refrigerant vapor. The rectification facility is a well-known equipment in the process engineering and has to fulfill the task to enlarge the concentration of the refrigerant in the vapor to the range of 99 to 99.5 %. The principle of this procedure is generally quite simple: Ammonia/water vapor raises out of the generator and contacts the strong working fluid, which has a temperature only few below the boiling point, at large surfaces. For that purpose the strong WF is pumped to the top of the generator, is distributed on the cross section and drips, e.g. through a “Raschig-ring” set, with a large surface. A “Raschig-ring” set is a simple rectification facility and consists, for example, of heaped up steel or glass tubes (approximate dimensions: diameter 20mm, length 20 mm). In counter flow to the strong WF, which drips from the top to the bottom of the “Raschig-ring” set, the ammonia/water vapor raises from the bottom to the top. At first water of the ammonia/water vapor condenses at the surface of the strong WF and at first ammonia evaporates out of the boiling strong WF on its way from the top to the bottom. The one after the other following steps of condensing and evaporating result a significant higher concentration of ammonia in the vapor, which enters the condenser. But the rectification needs also additional heat for the same evaporation capacity as without rectification. Thus, the thermal COP is lower with rectification than without but deeper evaporation temperatures could be reached and disturbances in the evaporator avoided.

Small absorption refrigeration machines, with evaporation temperatures around 0°C, therefore normally have very simple rectification systems. Also the top of a falling film generator could be designed as a simple rectification system adjusted to the WFHE. Rectification facilities for large absorption refrigeration plants at evaporation temperatures of minus 30 to minus 50°C have a high cost.

8.5.1 Guidelines for control and operation

The control system of the RES assisted absorption refrigeration plant uses commercial control facilities, like the common Direct Digital Control (DDC) technique with a large variety of soft ware tools or a Programmable Logic Controller (PLC). The control strategy, which has to be developed for the different applications in the private, commercial and industrial sector, consists of a basic strategy for the following control tasks:

1. *Control of the RES heat production:* control of the primary and secondary circuit by measuring the temperatures and switching the speed controlled pumps.
2. *Storage management*: Charging and discharging the hot water storages depending on heat consumption and heat production.
3. *Cooling tower management*: Speed control of the fan, measuring the water quality and control of the drain off rate. Automated emptying in case of frost danger and automated refilling.
4. *Control of the absorption refrigeration machine:* Speed control of the working fluid pump to adjust the concentration difference of the strong and the weak working fluid. Control of the working fluid circuit in dependence of pressure variations due to the temperature variations in the storages. Evaporation capacity control by measuring the temperatures at the inlet and outlet of the evaporator and control of the ammonia injection valve.
5. *Filling with working fluid and refrigerant:* There are a lot of possible procedures of filling the absorption refrigeration machine with ammonia and water. In any case one has to pay attention to the regulations of handling with ammonia. It is recommended to fill the machine at first with an ammonia water mixture of 24 %, which is available on the market. The rest of the necessary refrigerant should be filled directly and slowly in the evaporator, while the generator is heated softly and the WF pump is turning slowly.
6. *First operation*: If enough water and ammonia is filled in the machine, the generator can be heated up slowly to the designed generator temperature. During this procedure the cooling water circuit with the cooling tower is put in operation and the evaporator should be loaded. The refrigeration capacity could be determined by measuring the ammonia flow rate.

8.6 Guidelines for R&D policy and decision makers

8.6.1 RES-technology development

Small absorption refrigeration machines, which can be connected in a simple manner with Renewable Energy Sources (RES), like solar collector fields and/or biomass wood chips or pellets combustors as well as different waste heat sources, due to a sustainable production of cooling capacity in a wide temperature range for several applications, are at present not available on the market. The principle knowledge of design – as demonstrated above – can be easily transferred from the large range of the absorption refrigeration technique. The design and construction methods of the components for the mass and heat transfer, like generator, absorber, condenser and the working fluid heat exchanger can be used in principle also for the small capacity range. The disadvantage by doing this is the high costs, due to the large weight and the expensive manufacturing of the components.

Therefore new ways have been searched for the design of the apparatuses and facilities. Special interest and efforts were focused on the adaptation and improvement of the key components of small absorption machines, which are:

- Reliable, low cost pressure independent WF mass flow control.
- Reliable, low cost working fluid (WF) oil piston membrane pump.
- Reliable, low cost fluid level detectors.
- Enhancement of heat and mass transfer by falling film technique.
- Effective, low cost rectification especially designed for small machines.
- Significant simplification of the system design.

Especially in the industrial and commercial sector cooling capacity below 0 °C are necessary and RES driven absorption refrigeration plants could be used as an environmental friendly alternative to the common vapor compression technique.

8.6.2 Demonstration

Some interesting ideas on component design have been realized already. A broad demonstration of small, heat driven absorption refrigeration machines, which are able to run with RES

- in air-conditioning plants, or
- at higher generator temperatures for brine cooling, or
- in the freezing sector from –20 to –40 °C

have to be started by a political decision. The investment costs for these demonstration plants have to be subsidized due to the environmental friendly refrigeration technology by using RES, like solar and biomass. An interesting example of a subsidized demonstration project in Austria, State Styria, is a solar/biomass heat driven ammonia/water cooling machine in a private winery. Lots of experiences and data will come out of this application, which will help to improve the components of the aggregate and to enlarge the effectiveness of the plant by an advanced control system. The RES driven absorption refrigeration plant with 100 m^2 of solar flat plate collectors is used for the following different tasks in the winery.

- Cooling of the large wine tanks in the fermentation period
- Extraction of the tartar (wine crystals) and
- Cooling and humidification of the wine bottle storage.

8.6.3 Economic aspects

A good economical overview on the RES driven absorption refrigeration can be gained by a comparison with the conventional electrical driven vapor compression technique. This is done with the help of the known cost of the above mentioned RES driven absorption refrigeration plant in the winery, which was put in operation in 2003.

Methodology of the costs comparison

At first the investment costs was evaluated in detail. Only 80 % of the investment costs of the solar collectors were calculated due to the contribution of room heating in winter time. The cost of the biomass furnace for room heating in winter is neglected because it exists already. The RES driven absorption refrigeration plant is compared with a air cooled vapor compression plant. It is assumed that the investment capital is raised on the capital market with an interest rate of 6 % over 20 years. An important part of the annual operational costs are therefore the annual repayment which is calculated with the Time Value of Money method (TVM). Other operational costs are the costs for electricity, bio fuel and service.

The Table 9.2 shows the investment and operational costs as an example for a comparison of the RES driven absorption refrigeration with a conventional electrical driven vapor compression technique.

Table 9.2: Comparison of costs of RES driven absorption refrigeration with conventional electrical driven vapor compression cooling technique

Refrig. Capacity: 10 kW, 50 m2 solar collectors	RES absorption refrigeration	Electrical vapor compression technique	Remark
1. Investment costs	Euro	Euro	
Absorption refrigeration	20.500	15.500	incl. re-investment
Solar collectors, 50m2	8.000	0	80 % for cooling
Solar installation	12.316	0	labor
Cold installation	7.650	8.900	
E-engineering & Control	11.000	11.500	incl. visualization
Sum of investment costs	**59.466**	**35.900**	
2. Costs per year			
Repayment 20a/ 6 %	5.185	3.130	
Costs of electricity	110	1.886	Commercial tariffs
Wood fuel	137	0	Own wood
Service	150	500	
Sum: of annual costs	**5.582**	**5.516**	

Results of the costs comparison

The cost comparison in the Table 6.2 shows that the annual costs depend significantly on the repayment which is higher for the RES technology than for the vapor compression technique. On the other side especially the costs for electricity influence the annual costs of the conventional cooling system. Advantages for the RES technology can be discovered if the solar collector area is reduced and the missing heat is delivered by the automatically working biomass furnace. This is especially valid if the bio fuel is produced in the own forest. The results show that the annual costs for the both compared systems are almost equal if the solar collector area is 50 m2.

8.6.4 Environmental aspects

Energy conversion processes could be open or closed. Most of the cooling processes are closed processes. A working medium, named the refrigerant, is closed in a certain volume which consists of components, like vessels, tubes, heat exchangers, valves, pumps and compressors. The refrigerant could be a chemically produced medium or a substance of the bio sphere. Chemically produced refrigerants, like the so called “security refrigerants”, do have a depletion effect on the ozone layer in the stratosphere or/and a contribution to the global warming. Both influences can be quantified by numbers which express the relation to the refrigerant R 11 /4/.

8.6.5 Definitions

Ozone Depletion Potential (ODP): The influence on the ozone layer depletion is defined by the relative Ozone Depletion Potential which gives the relation between the selected substance and the refrigerant R11. The numbers for the ODP for all refrigerants are listed in the refrigeration engineering literature /4/.

Global Warming Potential (GWP): The influence on the green house effect is defined by the GWP which gives the relation between the selected substance and the refrigerant R11 for a period of 100 years. The numerical values for the GWP are listed in the refrigeration engineering literature. Sometimes for GWP also the relation to CO_2 instead of R11 is used. The following formula shows, how the numerical values can be converted:

$$1 * \mathrm{GWP}\ (\mathrm{R11};\ 100\ \mathrm{a}) = 4.000 * \mathrm{GWP}\ (\mathrm{CO_2},\ 100\ \mathrm{a})$$

Indirect Global Warming Potential (ID-GWP): Most of the energy conversion processes do have auxiliary devices, which need electrical power. Therefore the CO2 of the power production have to be taken into consideration. This is done by the Indirect Global Warming Potential (ID-GWP) which defines, how many kg CO2 are emitted, if 1 kWh electrical energy is produced. The mass of CO2 emissions of a heat source which use fossil fuels, amount to 0,28 kg CO2/kWh of produced heat. About 3 kWh of heat is needed for 1 kWh electrical energy, if the electrical energy is produced in thermal power stations.

Total Equivalent Warming Impact (TEWI): Especially for vapor compression technique the TEWI is sometimes used which describes the total environmental impact of a refrigeration plant during its whole life time. The TEWI is defined as follows.

$$\mathrm{TEWI} = \mathrm{GWP} * L * n + \mathrm{GWP} * m * (1-\alpha_R) + n * Ea * \beta$$

L	leakage of working medium per year	kg/a
n	years of operation	a
m	filled mass of working medium	kg
α_R	recovery factor after n years	-
Ea	energy consumption per year	kWh/a
β	CO_2-equvalent emission factor	kg CO2/kWh (see ID-GWP)

($\beta = 0$, if only hydro power; $\beta = 3*0{,}28$ kg/kWh, if only thermal power)

8.7 Environmental related comparison

The table 9.3 shows the environmental related comparison of the RES-absorption refrigeration technique to the conventional vapor compression process. RES-absorption refrigeration technique uses ammonia and water; both are substances of the atmosphere, and the conventional vapor compression cooling circle works with the refrigerant R134a.

Table 9.3: Environmental impact of cooling processes /5/

PROCESS	ODP	GWP	ID-GWP	COP	APPLICA-TION	WORKING-MEDIUM
			kgCO2/ kWh	---		
RES-absorption refrigeration	0	0	0,04	0,61	–10°C	H2O/NH3
Elect. vapor compression	0	0,25	0,45	2,3	–10 °C	R134a

Legend:

ODP	Ozone Depletion Potential (relation: R11 =1),
GWP	Global Warming Potential (relation: R11=1),
ID-GWP	Indirect Global Warming, (kg CO2 per kWh cold work); For fossil heat driven processes: 7.800 kg CO_2/TJ = 0,28 kg CO_2/ kWh; For electrical drives: if thermal power generation: factor 3; if hydro power generation: factor 0; In practice: “country specific factor” as a mix of several kinds of generation from 0 to 3.
COP	Coefficient of performance, for RES-abs. refrigeration: COP = kWh cold / kWh driving heat for electrical vapor compression: COP = kWh cold / kWh electrical

8.7.1 Potentials in the WBC

The objective of the discussion about potentials of technologies is the quantification of possibilities. Potentials have to be discussed in detail for discovering the barriers for a broad application of the RES technologies. The analysis of potentials leads to the following detailed investigations.

- *Theoretical potential:* It covers the whole energy content per year, which can be delivered by an energy conversion technology in the WBC.
- *Physical potential:* It covers that part of the theoretical potential, which is reduced by the physical properties of a process, like the COP.
- *Production-engineering potential:* It covers that part of the theoretical potential, which is not limited by the production capacity in the WBC
- *Ecological-topographical potential:* It covers that part of the theoretical potential, which is not limited by environmental factors, like pollution of air, water, soil, as well as noise and unfavorable optical changes of the environment.
- *Economic potential:* It covers that part of the theoretical potential, which is competitive with the conventional technique. The application of conversion processes, based on

fossil fuels, release pollutant substances, like SO2, NOx, CO, CO2, CxHy and dust, which causes damages on human and environment. Politico-economical costs, the so-called external costs, arise and have to be considered too.

In this general part of "Guidelines for RES-technologies" no quantification of potential will be done. This will follow later on for the different RES-techniques.

8.7.2 Subsidy needs

After the demonstration of the environmental friendly, RES-absorption refrigeration technique, the broad applications have to be prepared by suitable decisions of the policy makers and politicians. Subsidies have to make available in a suitable level, so that customers will be encouraged to invest their money for RES-absorption refrigeration plants with equal costs and benefits, as they have to pay for the market available vapor compression technique.

8.8 References

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9 GEOTHERMAL

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9.1 General

What is geothermal energy?

Geothermal energy can be defined as the thermal energy that is produced in the earth's interior layers. This energy is massive and is estimated to be 4.87×10^{25}GJ (1.16×10^{28}kWh). Geothermal energy is conveyed through various fluids, mainly water that either discover channel from the interior of earth to the surface or are forced to move towards the surface of the earth with drills and pumps.

How does geothermal heat get up to earth's surface?

The heat from the earth's core continuously flows outward. It transfers (conducts) to the surrounding layer of rock, the mantle. When temperatures and pressures become high enough, some mantle rock melts, becoming magma. Then, because it is lighter (less dense) than the surrounding rock, the magma rises (convects), moving slowly up toward the earth's crust, carrying the heat from below.

Sometimes the hot magma reaches all the way to the surface, where we know it as lava. But most often the magma remains below earth's crust, heating nearby rock and water (rainwater that has seeped deep into the earth) - sometimes as hot as 300 degrees C. Some of this hot geothermal water travels back up through faults and cracks and reaches the earth's surface as *hot springs* or *geysers*, but most of it stays deep underground, trapped in cracks and porous rock. This natural collection of hot water is called a *geothermal reservoir*.

How have people used geothermal energy in the past?

From earliest times, people have used geothermal water that flowed freely from the earth's surface as hot springs. The oldest and most common use was, of course, just relaxing in the comforting warm waters. But eventually, this "magic water" was used (and still is) in other creative ways. The Romans, for example, used geothermal water to treat eye and skin disease and, at Pompeii, to heat buildings. As early as 10,000 years ago, Native Americans used hot springs water for cooking and medicine. For centuries the Maoris of New Zealand have cooked "geothermal," and, since the 1960s, France has been heating up to 200,000 homes using geothermal water.

How do we use geothermal energy today?

Today we drill wells into the geothermal reservoirs to bring the hot water to the surface. Geologists, geochemists, drillers and engineers do a lot of exploring and testing to locate underground areas that contain this geothermal water, so we'll know where to drill geothermal *production* wells. Then, once the hot water and/or steam travels up the wells to the surface, they can be used *to generate electricity in geothermal power plants or for energy saving non-electrical purposes*.

How is electricity generated using geothermal energy?

In *geothermal power plants* steam, heat or hot water from geothermal reservoirs provides the force that spins the *turbine generators* and produces electricity. The used geothermal water is then returned down an *injection well* into the reservoir to be reheated, to maintain pressure, and to sustain the reservoir.

There are three kinds of *geothermal power plants*. The kind we build depends on the temperatures and pressures of a reservoir.

1. A "dry'" steam reservoir produces steam but very little water. The steam is piped directly into a *"dry" steam power plant* to provide the force to spin the turbine/ generator unit. The largest dry steam field in the world is The Geysers, about 90 miles north of San Francisco. Production of electricity started at The Geysers in 1960, at what has become the most successful alternative energy project in history.
2. A geothermal reservoir that produces mostly hot water is called a "hot water reservoir" and is used in a *"flash" power plant*. Water ranging in temperature from more than 150 degrees C is brought up to the surface through the production well where, upon being released from the pressure of the deep reservoir, some of the water flashes into steam in a 'separator'. The steam then powers the turbines.
3. A reservoir with temperatures between 90 - 150 degrees C is not hot enough to flash enough steam but can still be used to produce electricity in a *"binary" power plant*. In a binary system the geothermal water is passed through a *heat exchanger*, where its heat is transferred into a second (binary) liquid, such as isopentane, that boils at a lower temperature than water. When heated, the binary liquid flashes to vapor, which, like steam, expands across and spins the turbine blades. The vapor is then recondensed to a liquid and is reused repeatedly. In this close loop cycle emissions to the air are avoided.

What are some of the advantages of using geothermal energy to generate electricity?

- *Clean*. Geothermal power plants, like wind and solar power plants, do not have to burn fuels to manufacture steam to turn the turbines. Generating electricity with geothermal energy helps to conserve nonrenewable fossil fuels, and by decreasing the use of these fuels, we reduce emissions that harm our atmosphere. There is no smoky air around geothermal power plants -- in fact some are built in the middle of farm crops and forests, and share land with cattle and local wildlife.
- *Easy on the land*. The land area required for geothermal power plants is smaller per megawatt than for almost every other type of power plant. Geothermal installations don't require damming of rivers or harvesting of forests -- and there are no mine shafts, tunnels, open pits, waste heaps or oil spills.

- *Reliable.* Geothermal power plants are designed to run 24 hours a day, all year. A geothermal power plant sits right on top of its fuel source. It is resistant to interruptions of power generation due to weather, natural disasters or political rifts that can interrupt transportation of fuels.
- *Flexible*. Geothermal power plants can have modular designs, with additional units installed in increments when needed to fit growing demand for electricity.

What are some non-electric ways we can use geothermal energy?

Geothermal water is used around the world, even when it is not hot enough to generate electricity. Anytime geothermal water or heat are used directly, less electricity is used. Using geothermal water 'directly' *conserves energy* and *replaces the use of polluting energy resources with clean ones*. The main non-electric ways we use geothermal energy are direct uses and uses via Geothermal Heat Pumps (GHP).

Direct uses can provide services like

- *Heating*: Earth's heat (the difference between the earth's temperature and the colder temperature of the air) is transferred through the buried pipes into the circulating liquid and then transferred again into the building.
- *Cooling*: During hot weather, the continually circulating fluid in the pipes 'picks up' heat from the building - thus helping to cool it - and transfers it into the earth.
- Geothermal Heat Pumps (GHP) use very little electricity and are very easy on the environment.

Nisyros Island presents a rich geothermal energy potential for a wide range of applications. A map of Nisyros Island is shown on Figure 10.1. The proposed relevant applications are presented on Table 10.1.

Figure 10.1:*Map of Nisyros island*

9.2 Guidelines for planners, installers and other professionals

9.2.1 Applications proposed

Applications proposed for the available geothermal energy of 250 m^3/h flow-rate at 99^oC, the Nisyros island geothermal field. Geothermal applications proposed to be realised on Nisyros island are shown on following Table 10.1, while the relevant flow diagram is shown on Figure 10.2.

Regarding the proposed applications Table 10.2 presents columns for the power produced, the load factor and selected remarks if they are available otherwise they are marked as not available (n/a). The load factor is defined as the fraction of total hours of operation annually over the total hours of the year. TDS stands for Total Dissolved Solids, referring to the quality of the produced water.

Table 10.1: Applications proposed at the Nisyros geothermal field

Application proposed	Power	Load factor	Production	Remarks
Rankine cycle electricity production	700 kw_e	95 %	5.825.400 kwhe (annually)	N/a
Thermal desalination	2,3 mw_{th}	90 %	20 m^3/h	480 m^3 per day of desalinated water with tds < 50 ppm
Geothermal greenhouses (or equivalent space heating)	5,1 mw_{th}	20 %	30.000 m^2	Heating
Heating/cooling with heat pumps (cooling is gained through absorption method, best described on the solar refrigeration report)	2,1 mw_{th} copth 4,2 (heating) Copc =?	40 %	10 kw_{th} = 100 m^2 Total 21,000 m^2 of space	1,6 mw_{th} from geothermal energy 0,5 mw_e from electricity

The availability of 250m^3/h of geothermal water at 99ºC provides the energy needed for the applications described on Table 10.1: a) Binary cycle electricity production, b) desalination of seawater, c) heating of greenhouses or other spaces and d) district heating with the aid of heat pumps. During summer, cooling will be provided with the use of groundwater from either a very shallow shaft or seawater.

Based on geological, geochemical, geophysical, drilling logging data and the geothermal reservoir conceptual model of Nisyros Isl. (Geotermica Italiana-PPC 1984) the temperature of 99ºC for the entering geothermal temperature (well-head temperature) seams to be feasible especially in the region of the crater and possibly at numerous points of the rest of the island at depths of 350-400 m. Therefore 2 boreholes (geothermal boreholes of at least 350m) with final diameters of 12-14” should be drilled. However, the possibility of the utilization of hot-spring waters should also be examined in this case.

In order to improve the sustainability of the subsurface geothermal system and eliminate any environmental consequences that may arise from the disposal of the geothermal water, after delivering its heat, the geothermal water is disposed within the same deep subsurface horizons it originated from, through a reinjection well. For maintenance purposes during operation, in order to minimize possible scaling and/or corrosion problems that may be associated with the geothermal water, the piping that conveys the geothermal water must have the minimum possible length. This is achieved by:

- Having a secondary piping system conveying water of non-corrosive and non-scaling tendency as a heat transfer media to the energy users.

- Locating heat exchangers close to the production well.
- Placing the reinjection well at a distance up to 500 m from the production well. This is considered as a safe distance in order to avoid cooling of the geothermal system close to the production well.

The production wells, the reinjection wells, the heat exchangers and the piping conveying geothermal water compose the geothermal circuit and will be located either near “Paloi” village or near the location “Loutra”. The Greenhouses will be located near “Paloi” village and the district heating system near “Loutra” in order to cover the heating/cooling needs for the spa centre.

In order to minimize capital costs by reducing the necessary number of wells and piping diameter, the flow rate of the geothermal water must be minimized. This is achieved by placing the energy users in cascade (series), which results in maximizing temperature drop and consequently the energy extracted from a given flow rate of geothermal water. Flexibility of the systems in terms of energy consumers location and operating parameters, is facilitated by having different heat distribution networks (and heat exchangers) for each type of energy user, namely for the electricity production units, the desalination units, the greenhouses and the heat pumps which serve the buildings. In addition, a seawater supplying system is needed, in order to supply the desalination units and to provide a heat sink to the heat pumps during summer with the aid of a heat exchanger.

9.2.2 Analysis of the system components

Geothermal water is produced from the wells by submersible pumps, the flow rate of which is controlled by a variable speed drive (frequency converter or “inverter”), according to the energy requirements (expressed in temperature level and requested flow-rates) of the entire cascade system. Plate heat exchangers are selected, because they can be dismantled easily for scale removal, and have higher overall heat transfer coefficient compared with shell and tube heat exchangers of the same size. They may be constructed from stainless steel or titanium alloys depending on corrosive tendency of the fluids.

Materials selection is based on the physical and chemical properties of the fluid. Most common materials used for piping equipment are mild steel with low carbon content and polypropylene for fluids of temperature higher than 40ºC, and PVC or polyethylene, for lower temperatures. In case the geothermal fluid is conveyed in steel pipes, specific actions or protection methods are necessary, in order to avoid or minimize any corrosion problems. These include use of heavy weight pipes with thick walls, in order to elongate their life span. They also include proper design so that, on the one hand, the oxygen content in the fluid is minimized and, on the other, when the pipes are emptied for some reason, no water remains in their internal surface. Moreover, use of anti-corrosive methods can be employed when the fluid has a corrosive tendency.

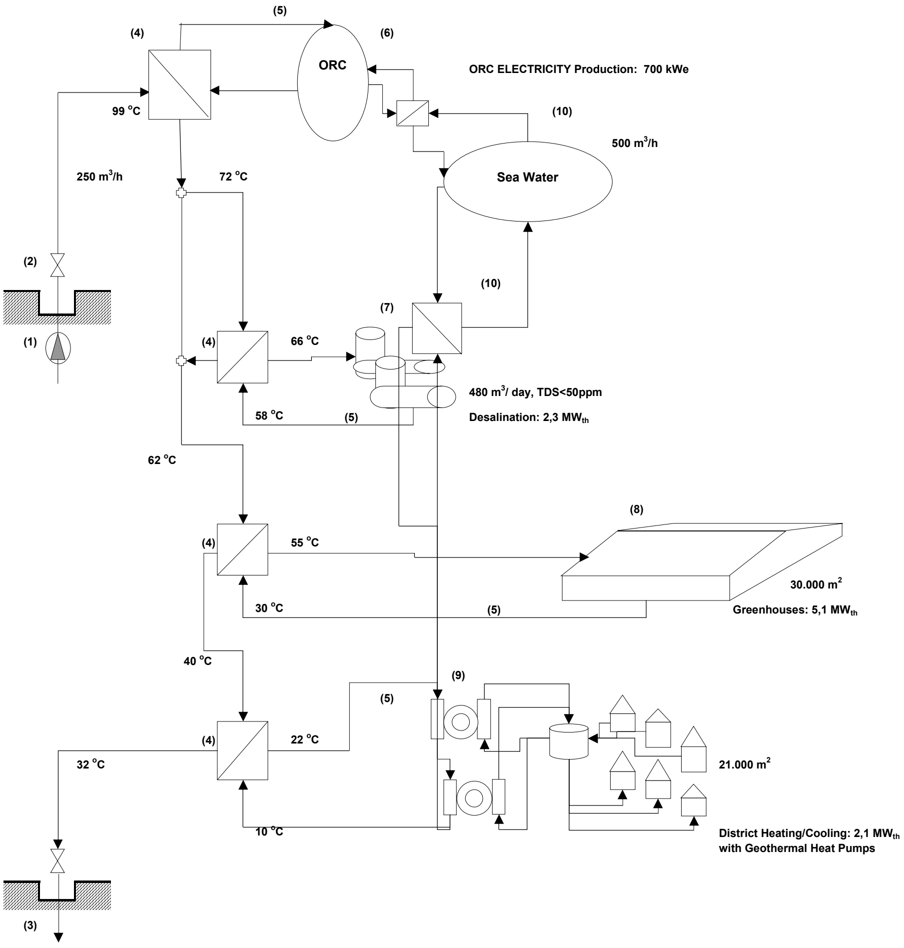
System components include (see also Figure 10.2 – Nisyros applications flow diagram):

a. *Geothermal Energy Production (1 to 3)*
   Geothermal production wells (at least 3) (1) drilled to a maximum depth of 400m
   Geothermal springs (2)
   Reinjection well at least 2 production wells (3)
b. *Heat Exchangers Centre (4)*
c. *Secondary Energy Transportation Circuits (5)*
d. *Binary Cycle Electricity Production Unit 700 kWe (6)*
e. *Thermal Desalination Unit using either the method of Mulitiple Effect Distillation (MED) or that of Multi Stage Flash Effect Distillation (MSF-ED) capable to produce 480 m^3 per day (7)*
f. *Greenhouses fully equipped for heating,, automations, etc. 30.000 m^2 (8)*
g. *Heat Pump Units of 2,1 MWth for heating and cooling of 21.000 m^2 (10 kWth for heating and 8 kWr for cooling per 100 m^2) (9)*
h. *Sea water system for the desalination units and the heat pumps: 600 m^3/h (maximum) at a distance of 500 m maximum (10)*

The whole network has been designed in order to minimize electricity consumption and in order to achieve sustainability by minimizing geothermal water use.

9.2.3 Flow diagram for the proposed applications

On Figure 10.2 the flow diagram of the proposed geothermal applications on Nisyros island geothermal field is shown. It presents the route of the geothermal fluid through the applications proposed with the relevant temperatures up to its final reinjection to the geothermal basin.



Karytsas-CRES (MAR. 2005)

Figure 10.2: Flow diagram of the Nisyros proposed geothermal applications

9.3 Guidelines for R&D policy and decision makers

9.3.1 Economic aspects

On Table 10.2 cost estimate of the proposed applications is presented. The numbers following each application refer to Figure 10.2. There are columns referring to the units themselves as well as to the peripheral equipment and studies so as to include all the costs involved.

Table 10.2: Cost estimation of applications proposed at the Nisyros geothermal field

Cost of application In euro	Geothermal circuits (1,2,3, and 4)	units (6,7,8 and 9)	Peripheral equipment and studies (6 and 10)	Total cost (1 to 10)
Binary cycle Kalina or orc (6)	200.000	1.400.000	150.000	1.750.000
Thermal desalination (7)	100.000	600.000	100.000	800.000
Geothermal greenhouses (8)	150.000	150.000*	250.000	550.000
Heating/cooling heat pumps (9)	100.000	600.000	200.000	900.000
	550.000	2.750.000	700.000	4.000.000

* Only the cost for the geothermal greenhouse energy supply system cost 5 € per m^2 of greenhouse, the cost for the construction of greenhouses is not included

On Table 10.3 an analysis of the energy and environmental benefits through the applications is presented. More specifically, one can see columns of the energy produced in toe's and the mass of CO_2 emissions avoided.

Table10.3: Energy produced, avoided CO_2 emissions annually

Application	Load Factor	Energy Substituted annually in mwh_{th}	Energy annually in toe*	Emissions of co_2 not emitted
Binary cycle Kalina or orc	95 %	74.989	8.062	25.798
Thermal desalination	90 %	18.133	1.949	6.237
Geothermal greenhouses	20 %	8.935	961	3.075
Heating/cooling with heat pumps	40 %	7.359	791 (602,5 from geothermal)	2.531
Total from geothermal energy		109.416	11.763	37.642

* 1 TOE is equal to 9.302 kWh_{th} and 1 TOE is estimated to produce 3,2 TCO_2

An analysis of the energy production cost of the proposed applications are presented on **Table 10.4. Relevant categories include equipment maintenance, geothermal license, thermal and electrical** energy production costs.

The ORGANIC RANKINE CYCLE or KALINA unit covers its own electricity needs, including the proportion corresponding to geothermal primary loop and sea-water cooling loop related to the ORC unit.

The energy production cost for the electricity production of the ORGANIC RANKINE CYCLE or KALINA unit is estimated to be 0,0314 EURO/kWh$_e$.

Table 10.4: Energy production cost

Category	Binary cycle kalina or orc	Thermal desalination (total energy cost)	Greenhouses cost of heating system)	Heat pump system (total cost)	Total energy production cost
Personnel (7 man-years) 1 man-year = 20.000 euro	40.000	30.000	30.000	40.000	140.000
Energy supply 1 kWhe = 0,07 euro	0	49.056*	30.660**	153,607****	233.323
Equipment maintenance (~3 % of capital cost)	52.500	24.000	16.500***	27.000	120.000
Geothermal license 1 toe = 10 euro	80.620	19.490	9.610	6.025	115.745
Miscellaneous	10.000	10.000	5.000	10.000	35.000
Total annual production cost	183.120	132.546	91.770	236.632	644.068
Energy substituted in MWh$_{th}$ (annually)	74.989	18.133	8.935	7.359	109.416
Electricity produced, MWhe (annually)	5.825,4	N/a	N/a	N/a	N/a
Energy production cost in euro per kWh$_{th}$	0,0024	0,0073	0,0103	0,0322	0,0059
Electricity production cost in euro per kWhe	0,0314	N/a	N/a	N/a	N/a

Legend of Table 10.4

- *Total electricity required for desalination 100 kW or 700.800 kWh$_e$ annually
  - Desalination electricity requirement 1 kWh per m^3 produced or 20 kW
  - Sea water transportation electricity system 30 kW
  - Geothermal circuit 30 kW
  - Secondary circuit requirement 20 kW

(this corresponds to an electricity cost per desalinated m^3 of 0,70 euro or 10 kWh per m^3 when a price of 0,070 euro is given per kWh)

- **Total electricity required for the heating supply system of the green houses of 30.000 m^2 (30 stremmata**)** 250 kw or 438.000 kWh$_e$ annually

- geothermal circuit 50 kW
- secondary circuit requirement 200 kW

- ***Only for greenhouse heating equipment or 3 % on 720.000 euro (16.500 euro/annually)

- ****Electricity requirement for geothermal heat pump system 2.194.380 kWh$_e$ per year [for 140 buildings/houses of 150 m^2 or 15.674 kWh$_e$ per building per year (1.097 euro for heating and cooling) per year

  - Electricity for heat pumps
    - Heating mode cop = 4,2 / 25 % of year / compressor of 0,50 mw (1.095.000 kWh$_e$ / Year)
    - Cooling mode cop = 3,2 / 15 % of year / compressor of 0,65 mw (854.100 kWh$_e$/ Year)
  - Geothermal circuit 20 kW
  - Secondary circuit requirement 50 kW

9.3.2 Environmental aspects

According to relevant studies on the environmental aspects of geothermal energy, geothermal energy is a renewable as well as a “clean” source. In general, the low enthalpy geothermal fluids do not produce any serious problems provided that a thorough research regarding the disposal of discharged exploited fluid is preceded. According to one study, implicit environmental effects should be outlined that may derive from alkalinity and salinity hazards that are caused due to the water-soluble chemical content of the fluids. Knowledgeable methods of dealing with such problems are the drainage, the soil-recipient washing, the selection of appropriate cultivations, the frequent irrigations, the mixture of the geothermal brine with rain water and the appropriate time of fertilization (G. Martzopoulos et al., 1999). Regarding the exploitation of high enthalpy geothermal fluids, there is significant international expertise on the dealing of pollution problems and the environmental effects that may be produced. Gaseous pollutants, for example, that are emitted by any geothermal unit, such as H_2S, can be disposed by the assistance of special direct contact condensers. The liquid pollutants which are moderately overloaded in the high enthalpy fluids, can be faced by using the method of the fluid reinjection into the geothermal basin, so as to avoid the pollution of the “clean” subterranean water. Furthermore, technical problems are related to the oxidation and corrosive attributes of the geothermal fluid, as well as the phenomenon of sludge during the discharge of these fluids. These technical problems are solved by using heat exchangers and appropriate selection of materials used as the geothermal energy exploitation plants.

9.4 References

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/2/ Karytsas C., Mendrinos D. (February 2003) Nisyros low enthalpy geothermal energy utilisation in ge-islebar: removal of barriers to the development of thermal resources in European peripheral islands – final report, ENERGIE DG-TREN
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10 BIOGAS

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10.1 General

10.1.1 Principles of anaerobic fermentation

Biology (bacteria, steps of decomposition)

Methanogenetic bacteria already populated the surface of the earth at an age, where the atmosphere did not contain any oxygen - some 3.5 Billion years ago. They are not able to use oxygen but it is toxic for them. In nowadays atmosphere they only can survive in places where no air access is possible, ore where oxygen is consumed much more quickly than produced: Deep marshes, organic bottom layers of deep lakes, and - very important - digestive tracts of men and animals. However, also “anthropogenic” tanks might be kept under anaerobic conditions: Biogas fermenters. Most important representatives are methanobacterium formicicum, methanobacterium bryantii, methanobrevibacter arboriphilus, methanobacterium mobile, methanospirillum hungatei, methanosarcina barkeri, methanococcus mazei, methanococcus vanielii, Methanococcus voltae, methanothrix soehngenii (Scheucher P., 1984).

Metabolisme of bacteria is responsible for any decomposition of organic material. For anaerobic fermentation, in principle 3 steps of decomposition have to happen, whereby different kind of bacteria are active:

a) Hydrolysis (fermentative bacteria decompose biopolymeres into fatty acids, H_2 and CO_2)

b) Acetogenesis (acetogenetic bacteria decompose fatty acids and form acetic acids)

c) Methanogenesis (methanogenetic bacteria decompose acetic acids and form CH_4 and CO_2)

The different steps of decomposition have to happen well balanced in terms of biochemical boundary conditions: Imbalance of one of the bacteria types may change the “environmental” condition in the material in a way, that the others die out: No methane will be produced, but tons of “vinegar”, which must be disposed from the fermenter. This has to be respected in technical anaerobic fermentation, especially in non stationary operation conditions of a biogas plant, e. g. starting of the fermenter.

Composition of biogas

Biogas consists of the following components:

Methane (CH_4)	40 - 75 vol. %
Carbon monoxide (CO_2)	25 - 55 vol. %

Water (H_2O)	0 - 10 vol. %
Oxygen (O_2)	0 - 2 vol. %
Hydrogen (H_2)	0 - 1 vol. %
Ammoniak (NH_3),	0 - 1 vol. %
Hydrogen sulfide (H_2S),	0 - 2 vol. %

Behavior of biogas

Some physical properties of biogas are given below:

Specific gravity:	1,2 kg/m_N^3 *
Ignition temperature:	700 °C
Ignition concentration in air:	6 - 12 vol. %
Calorific value of methane (CH_4):	39,8 MJ/m_N^3
Calorific value of biogas with 60 vol. % methane	23,7 MJ/m_N^3
Thermal value of methane (CH_4):	35,8 MJ/m_N^3
Thermal value of biogas with 60 vol. % methane	21,6 MJ/m_N^3

Fermentable material

In principal, all organic material is fermentable. In a technical viewpoint, the following materials are the most important:

Municipal waste water and solid waste (degradation before disposal)

Agricultural residues (animal manure, growing residues)

Industrial organic waste (chemical industry, food industry)

Slaughterhouse residues

Kitchen residues (catering trade)

Energy crops (maize, corn, grasses.....)

10.1.2 Reactor principles

Batch reactor

A batch reactor is discontinuously completely loaded and emptied after the retention time. Batch reactors for energy production are used in development countries only. However batch reactors are use in laboratory to study fermentation of different material under different conditions. Fig. 8.1 exemplary shows results of batch fermentation tests with cow manure at different temperatures (left) and maize at 40 °C (right).

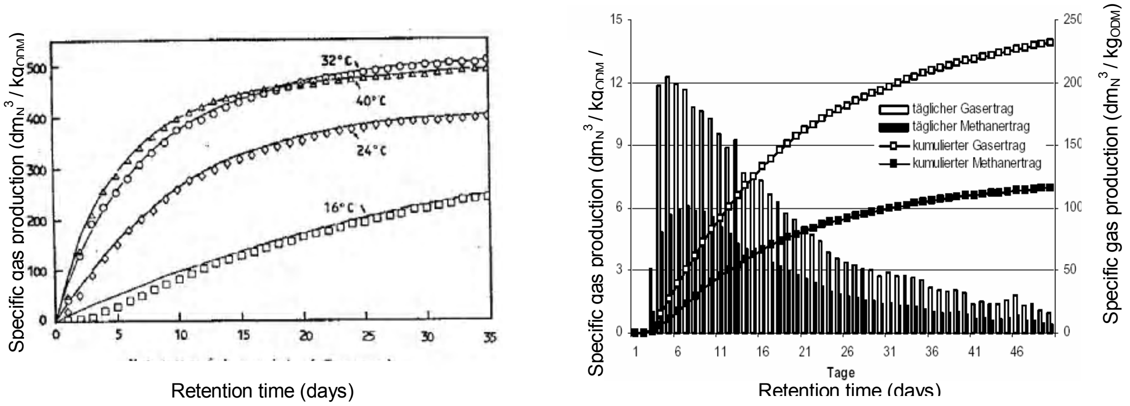

Fig. 11.1: Results of batch fermentation tests wi ow manure at different temperatures (left) and maize at 40 °C (right).

ODM ...... Organic dry matter

If the substrate is sufficiently inoculated with bacteria, the fermentation immediately starts and empirically shows the results of a reaction of 1st order. In this case the gas production rate can be easily described by equations of the form

$$\mathbf{g'_{batch} = G'_{max,\ batch} / \tau_{batch} * exp(-t / \tau_{batch})} \qquad (1)$$

g'_{batch} ... Gasproduction in batch experiment [m_N^3 / (d * kg_{ODM})]

τ_{batch}......time constant of reaction in batch experiment [d].

Numerical values for **$G'_{max,\ batch}$** and τ_{batch} are available for different fermentation material and for different fermentation temperatures (Padinger R., 1987)

Plug flow reactor: Substrate is loaded quasi continuously and is fermented without any internal mixing (as it is for example in an animal intestine)

Fully mixed reactor: Substrate is loaded quasi continuously and is fermented under full internal mixing (as it would be in a kitchen mixer)

Partially mixed reactor: Substrate is loaded quasi continuously and is fermented under partial internal mixing conditions

10.1.3 Reactors for biogas production (Fermenters)

In practical operation a compromise between advantages and disadvantages of plug flow and mixing characteristic has to be found:

- Mixing is disadvantageous because partially fermented material reaches the fermenter outlet.
- Mixing is necessary to inoculate fresh material with bacteria for a quick process start.
- Mixing is further necessary to avoid segregation of liquid and solid material.

The consequences of this discrepancy are:

- Biogas fermenters are mainly mixing reactors with internal mixers or external remixing.

- Cascades of 2 or 3 mixed reactors may use the advantages of mixing but partially avoid

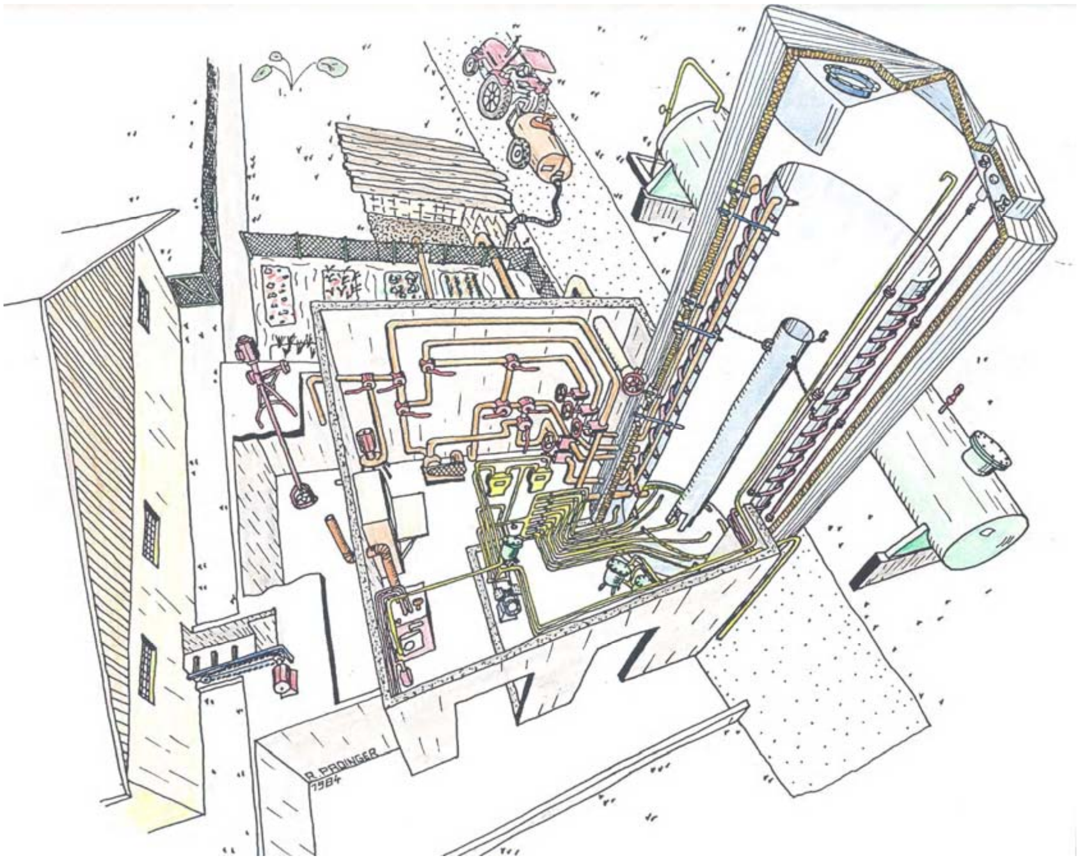

Fig. 11.2 shows a sectional drawing of the Austrian biogas plant “Harrer” as an example of a very small scale biogas plant for cow manure.

Fig. 11.2 shows on the right the fermenter, consisting of to concentric big tubes. Substrate is conveyed from the cowshed (left) into a mixing tank, where it is mixed with the back flow from the fermenter in a ratio of $1_{fresh} : 4_{fermented}$. Through a system of tubes and pumps, the substrate is fed into the inner fermenter of the reactor. It is necessary to heat up the reactor to the optimum temperature of 37 °C. Therefore the fermenter is equipped with a heating system on the inner cylinder and a isolation against heat losses on the outside for all year operation. On the bottom of the fermenters, gas injection tubes are installed in order circulate the substrate with the aid of the Mammut Pump (small vertical tube in the center of the cylinder). The produced biogas is stored in a steel tank (right) at a pressure of some 10 bar. The fermented substrate is stored in a open well, where it can be pumped by a tractor pump in a transport vessel and brought back to the fields and used as a natural fertilizer. The content of Nitrogen as the fertilizer is not reduced by the fermentation process.

10.2 Guidelines for planners, installers and other professionals

10.2.1 Guidelines for design

10.2.1.1 Basic biotechnological parameters:

- Active fermented volume: $\mathbf{V_F}$ [m^3]
  Volume of space in the fermented, where reactions take place
  = Total fermented volume, minus gas volume and minus possible dead volume in the substrate
- Substrate mass flow: $\mathbf{m_s}$ [kg/d], [t/d]
  Mass loading rate per unit of time (in biogas technology normally daily)
- Substrate volume flow: $\mathbf{v_s}$ [m^3/d]
  Volume loading rate per unit of time

$$\mathbf{v_s}\,[m^3/d] \approx \mathbf{m_s}\,[kg/d] * 1.000 \qquad (2)$$

- Dry matter concentration: $\mathbf{C_{DM}}$ [kg_{DM}/kg_{total}], [$\%_{DM}$], [kg_{DM}/m^3_{total}]
- Organic dry matter concentration: $\mathbf{C_{ODM}}$ [kg_{ODM}/kg_{total}], [$\%_{ODM}$], [kg_{ODM}/m^3_{total}]
- DM-massflow: $\mathbf{m_{DM}}$ [kg_{DM}/d]
  Mass loading rate of dry matter per unit of time
- ODM-massflow: $\mathbf{m_{ODM}}$ [kg_{ODM}/d]
  Mass loading rate of organic dry matter per unit of time

$$\mathbf{m_{ODM}}\,[kg_{ODM}/d] = \mathbf{v_s}\,[m^3/d] * \mathbf{C_{ODM}}\,[kg_{ODM}/m^3_{total}] / 1.000 \qquad (3)$$

Due to the fact, that biogas is produced from organic dry matter only, ODM-massflow is the most relevant parameter for the design of a biogas plant.

(m^3_{Biogas}/d) / (kg_{ODM}/d) = m^3_{Biogas} / kg_{ODM})

- Recirculation rate ($kg_{fermented}/kg_{fresh}$)
- Gas production: $\mathbf{g}$ [m^3/d]
  Cubic meter biogas per day, at given gas temperature and pressure
  - Gas production in normal cubic meter: $\mathbf{g_N}$ [m_N^3/d]

  Cubic meter biogas per day can be converted into normal conditions as follows:
  101,325 kPa (= 760 Torr),
  273,15 K (= 0 °C) (following DIN 1343) or
  288,15 K (= 15 °C) (following ISO 2533)

  Conversion formula following DIN 1343:

$$g_{N\left(m_m^3/d\right)} = g_{\left[m^3/d\right]} \cdot \frac{273{,}15}{273{,}15 + T\left[^\circ C\right]} \qquad \frac{p\left[\mathrm{kPa}\right]}{101{,}325} \qquad (4)$$

T....gas temperature [°C]

p....gas pressure [kPa]

Conversion formula following DIN ISO 2533:

$$g_{N\left(m_m^3/d\right)} = g_{\left[m^3/d\right]} \cdot \frac{288{,}15}{273{,}15 + T[°C]} \quad \frac{\mathrm{p}[\mathrm{kPa}]}{101{,}325} \tag{5}$$

10.2.1.2 Derived biotechnological parameters

The parameters below are used to evaluate an to compare biogas plants / processes:

- Specific biogas production m_N^3 gas/d per kg_{ODM}/d (= m_N^3 gas per kg_{ODM})
- Specific energy production. The specific energy production shows, how much energy is produced from 1 kg of organic dry matter of the substrate.
  kJ/kg_{ODM}, kWh/kg_{ODM}
- Daily loading rate. The daily loading rate describes, how much organic dry material is daily loaded per cubic meter of active fermented volume kg_{ODM}/d per m^3 fermented volume. The limit of daily loading rate in biogas technology is some 4 - 8 kg_{ODM}/d per m^3 fermented volume
- Retention time (**t_R**)
  m^3 fermented volume per m^3/d substrate volume rate unit: $m^3/(m^3/d)$ = d (days)

$$t_R = \frac{V_F\left[m^3\right]}{V_s\left[m^3/d\right]} \tag{6}$$

t_R........ Retention time [d]

V_F...... Fermented volume [m^3]

v_S........Substrate volume flow [m^3/d]

- Reactor characteristics

The main parameter to describe the reactor characteristic is the internal and external residence time distribution (RTD). The internal RTD function is a graph, showing how much material in the reactor is more than a certain age old (age distribution). The external RTD function is a graph, showing the age distribution of the material in the outflow. The external RTD function is the mathematical derivation of the internal RTD. The external RTD can be easily find out by measuring the outflow concentration of an introduced pulse of a tracer material. In biogas technology, Lithium or *bacillus globigii* is used as a tracer material. (For further information please refer to http://www.ktbl.de/aktuell/hygiene.pdf).

The left graph of Fig. 8.3 shows the external, the right graph the internal RTD of 6 different biogas plants together with the external RTD of the ideal mixing reactor (starting at the value of "1")

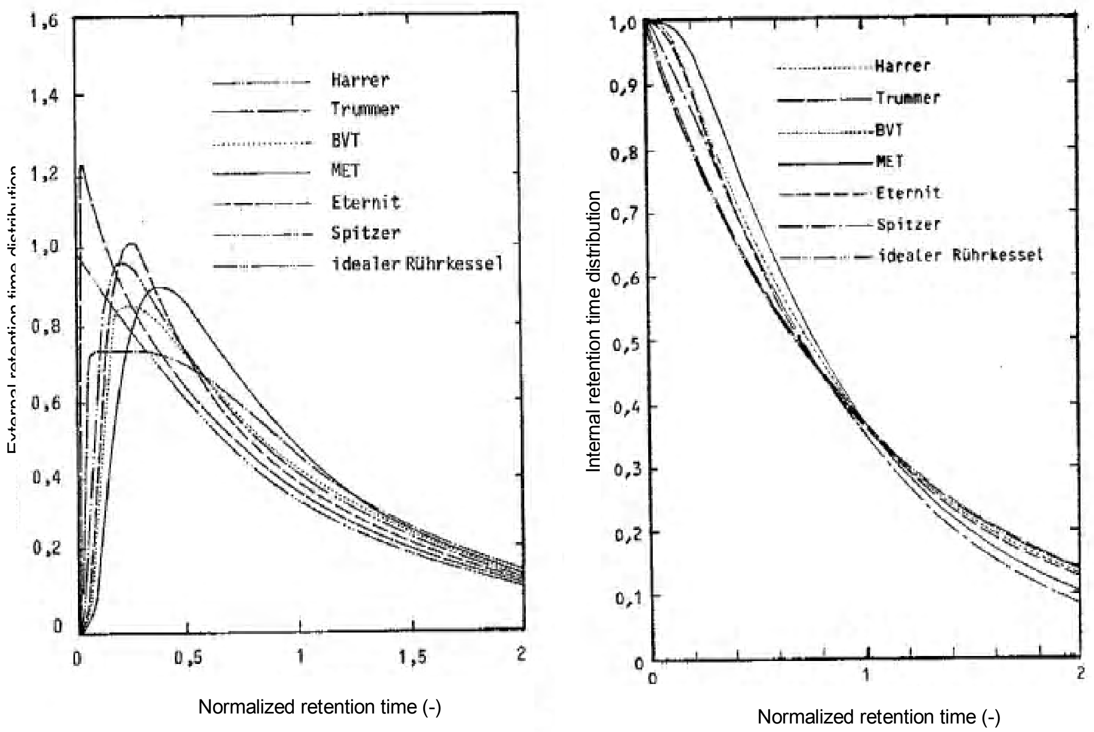

Fig. 11.3: External (left graph) and internal RTD (right graph) of 6 different biogas plants in Austria together with the external RTD of the ideal mixing reactor, (Padinger, 1987).

If the RTD of an industrial fermenter and reaction characteristic from a batch fermentation experiment are known, on can easily calculate the gas production of the industrial fermenter.

On can see, that the RDT of the biogas plants is very similar to the RTD of an ideal mixing reactor. More about in chapter 8.2

The intenal RTD of a mixing reactor can be calculated as

$$I(t) = \exp(-t / t_R) \tag{7}$$

I(t)........ Internal retention time distribution (RTD)

t_R ....Average retention time [d]

10.2.1.3 Calculation of the biogas production

With the following equations it is possible to calculate the amount of produced biogas:

$$g = v_s \cdot C_{ODM} \cdot \int_t \left[g'_{batch}(t) \cdot l(t) \right] \cdot dt \tag{8}$$

g......... Biogas production [m^3/d]

v$_S$........ Substrate volume flow [m^3/d]

C$_{ODM}$... Concentration of organic dry material [-]

g'$_{batch}$.....Specific gas production in a batch fermentation test [m3/(d * kg$_{ODM}$)]

I(t).........Internal retention time distribution (RTD)

/6/ In case of a mixed reactor with **I(t) = exp(- t / t$_R$)** following Eq. 7 and a 1st order process with **g'$_{batch}$ = G'$_{max,\ batch}$ / τ_{batch} * exp (- t / τ_{batch})** following Eq. 1, Eq. 8 has becomes as follows:

$$g_{mixing\ \mathrm{reactor},1^{st}\ order} = v_s \cdot C_{ODM} \cdot \int_t \left[G'_{\max,batch} / \tau_{batch} \cdot \exp(-t/\tau_{batch}) \cdot \exp(-t/t_R) \right] \cdot dt \tag{9}$$

g$_{\text{mixing reactor, 1st order}}$.Biogas production in a mixing reactor, 1st order process [m^3/d]

v$_S$.................... Substrate volume flow [m^3/d]

C$_{ODM}$............... Concentration of organic dry material [-]

G'$_{max,\ batch}$........ Specific maximum gas production in a batch fermentation test [m_N^3/kg_{ODM}]

I(t).................. Internal retention time distribution (RTM)

τ_{batch}................Time constant of reaction in batch experiment [d].

t$_R$....................Average retention time [d] = **V$_F$/v$_S$**

The solution is:

$$g_{mixing\ \mathrm{reactor},1^{st}\ order} = v_s \cdot C_{ODM} \cdot {}^{V_F}\!\!\diagup\!{}_{V_S} \cdot \frac{G'_{\max,batch}}{V_F / V_S \cdot \tau_{batch}} \tag{10}$$

This is suitable to calculate the expected amount of biogas for industrial plants for the following boundary condition:

- The reactor is nearly a mixing type (normally fulfilled for industrial biogas plants)
- The fermentation process nearly follows a reaction of 1st order (normally fulfilled for the relevant substrates if they are sufficiently inoculated)

Validity of equation has been successfully checked for several plants, substrates, and boundary conditions /2/.

Example: The following example shows how the gas production of a biogas plant can be calculated with the help of the Equation 10

Input data for the calculation:

$\mathbf{v}_S$.............. Substrate volume flow = 250 [m^3/d]
$\mathbf{C}_{ODM}$......... Concentration of organic dry material = 0,075
$\mathbf{G}'_{max,\ batch}$...Specific maximum gas production in a batch test = 0,48 [m_N^3/kg_{ODM}]
τ_{batch}............time constant of reaction in batch experiment = 5 [d].

Results:

$\mathbf{g}_{mixing\ reactor,\ 1^{st}\ order}$.. biogas production in a mixing reactor, 1st order process = **6.050 [m^3/d]**

The daily gas production corresponds to a produced energy of 6.050 m^3/d * 21,6 MJ/m^3 = 130.600 MJ/d = 36.300 kWh/d.

10.2.2 Guidelines for control and operation

Industrial biogas plants exists over about more decades in Europe especially in Germany and Austria. Lots of basic experience could be collected especially concerning automatically controlled operation. However, further research and development efforts are still needed to optimize process control under specific conditions (see chapter 8.3.1). The most important parameters for standard control strategies are given below.

10.2.2.1 Biotechnological control parameters

The most important biotechnological control parameters are:

- Concentration of volatile fatty acids of the substrate in the fermenter
- Methane concentration of the biogas (should be not less than 40 %)

10.2.2.2 Technical control parameters

The most important technical control parameters are:

- Retention time (should be not less than some 12 - 15 days)
- Fermentation temperature (between 30 and 40 °C)

10.3 Guidelines for R&D policy and decision makers

10.3.1 RES-technology development

Anaerobic fermentation technology is more or less state of the art. However individual aspects in terms of using special substrates or special gas application technologies have still to be optimized by RTD:

- Co-substrate fermentation
- Biogas cleaning and methane enrichment
- Biogas as fuel for motor vehicles
- Biogas feeding into a natural gas grid
- Biogas for fuel cells
- Optimized planning and operation of biogas plants
- National / international monitoring and evaluation of biogas projects

10.3.2 Demonstration

Demonstration of anaerobic fermentation technology is needed to spread excellence and to encourage people to use this very important renewable energy source. Since some decades, about 150 biogas plants have been installed in Austria.

10.3.3 Economic aspects

Biogas technology is suitable to get energy (heat and power) from agricultural products and from biogenic residues. Due to decreasing world market price of agricultural food products on the one hand and due to increasing disposal costs on the other hand, these aspects becomes more and more important. EU-subsidies for non food production and national subsidies for electricity from renewable energy sources help to make biogas technology economic in several countries.

10.3.4 Environmental aspects

Biogas technology helps to avoid non controlled green house gas emissions from agriculture and therefore contributes to reach national and international climate protection conventions (Kyoto protocol).

However, the CO_2 equivalent of methane is 21. This means that the biogas plants have to be carefully designed in the viewpoint of avoiding any methane leaks. Fermenters and other substrate stores must be tightly covered.

10.3.5 Potentials in the WBC

Potentials of fermentable biomass is discussed in a special chapter of the report D 1.1.

10.3.6 Subsidy needs

After the demonstration of the environmental friendly biogas production technique, the broad applications have to be prepared by suitable decisions of the R&D policy makers and politicians. Subsidies have to make available in a suitable level, so that customers will be encouraged to invest their money for biogas production plants with equal costs and benefits, as they have to pay for the market available fossil energy.

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/6/ Moser F. (1980)

11 WOOD PELLETS

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11.1 Abstract

Modern use of wood for domestic heating are pellets. Upgraded fuel improves significantly cleanliness, availability and convenience for use of wood fuels.

Wood pellets are produced from sawdust, shaving and chips. Generally, raw material is hard or soft wood, free of bark with ash content of 0,8% or less. Fuel pre-treatment and processing includes all the steps necessary to produce an upgraded fuel from a harvested biomass resource. Fuel characteristics: material of uniform size and structure, dense, large surface, and low water contents enables high efficiency of conversion process.

Pellets, used in special pellets boilers are characterised by high combustion efficiency, low air emissions, very low ash production and fully automatic fuel charging. In addition technical complexity and investment costs are reduced in comparison of wood chip boilers.

The article presents fuel physical and chemical characteristics, existing standards in Europe and briefly its production. Technical, economic and environmental characteristics of wood pellets domestic heating are described. As well the important elements of its design and selection.

11.2 General

Wood energy is gradually penetrating energy markets as a clean, cost-effective and locally available source of energy. Biomass is the oldest fuel known to man, wood pellets are the modern form used mostly for domestic heating. Industrial pellet production started in the mid 1980s after the development of residential wood pellet stove. In comparison to conventional wood heating it improves significantly cleanliness, availability and convenience for use of wood fuels. Wood pellet boilers are considered as modern heating systems which can be used also in areas with high building density.

Wood pellets are preprocessed biomass fuel which is dry, small in diameter and length and clean – made of natural wood. Used in special pellets boilers combustion is of high quality, with low environmental emissions. Fully automatic fuel charging enables comfort of heating systems comparable to conventional oil fuelled boilers.

By introduction of wood pellets several obstacles related to the other wood fuels has been overcome. Automatic fuel feeding is available also for small scale boilers. Ash contents in low, thus its removal is easier. The other environmental emissions are also much lower. Fuel characteristics: material of uniform size and structure, dense, large surface, and low water contents enables high efficiency of conversion process. Technical complexity of pellet feed, conveyors and storage is reduced, thus boilers are more efficient and cheaper in comparison to woodchips fuelled machines.

11.2.1.1 Wood fuel statistics

The share of fuel wood in total energy requirements in Europe reaches 1,2 %. However, in Austria, Sweden and Finland wood energy provides 12 to 18 % of their total energy supply. Worldwide wood share was 5 % of total primary energy supply and 34,8 % of total renewable sources supply /1/.

The data on solid fuel production are as follows: Canada 3560 TJ; Denmark 2217 TJ; Finland 1800 TJ. A considerable amount of wood fuels (pellets, wood chips) is locally and internationally traded today. In Europe wood fuel trade has reached a level of almost 50 PJ/year in 1999.

In Europe 23 % of wood removals are used for energy purposes in 2002.

At present the use of wood fuel in WB countries is as follows /1/: In Albania 0,3 Mio t, Bosnia and Herzegovina 0,5 Mio t, Croatia 0,9 Mio t and in Republic Macedonia 0,5 Mio t.

11.3 Guidelines for planners, installers and students

Biomass material properties and characteristics are quite varied, depending on the plant species, the nature of the resource material and its moisture content , which can range from around 10 % for straw to even 95 % for sewage sludge material (wet basis).

Technologies for biomass to energy conversions are largely determined by the fuel used, and each of them has specific requirements concerning dry matter content, shape, size, and particle consistency of the raw material. Other then the moisture content and the energy content, properties of biomass fuels are defined by their physical structure, weight, volume, density and ash content.

11.3.1 Pellets

Wood pellets are a compressed biomass fuel made exclusively out of wood (Figure 9.1).

Raw material features for pellet production is:

- Hard or soft wood
- It is free of bark
- It can be sawdust, shaving and chips
- Its ash content is lower than 0,8 %.

Figure 9.1: Wood pellets

11.3.2 Pellets production

Fuel pre-treatment and processing includes all the steps necessary to produce an upgraded fuel from a harvested biomass resource. The manufacture of wood pellets involves the following processes:

1. Hogging/grinding
2. Drying
3. Pelletising
4. Cooling
5. Fines separation
6. Bagging and sorting

Plants are usually stationary, using piston or roller press with perforated dies. Various factors (raw material type, water content, degree of contamination, type of press die and others) affect pelletising parameters as costs and quality of output /2/.

11.3.3 Pellets characteristics

Pelletisation process affects the physical characteristics:

- Bulk density
- Uniform size
- Low moisture contents and
- Low ash contents.

These characteristics affects significantly quality and cost of its use /2,3,4/:

- Relatively high bulk density enables easy and less expensive transport, storage and handling costs.
- Pellets are suitable also for different size of burners. It is the only wood fuel which can be charged automatically in small scale boilers. Technical and economical advantages of wood pellets are as well at larger boilers. Due to fuel size, its uniformity and the uniformity of the moisture distribution the parameters of combustion are easier to control (moisture control, fuel charging). Technical complexity of the fuel charging system and the moisture control is reduced. Actually, no moisture control is needed and both pellet feed and conveyor are simpler. Plant’s investment costs, maintenance and personnel costs are reduced.
- Ash removal is easier due to the low quantities of ash produced.
- The other fuel environmental characteristics and impacts are described in chapter 9.3.

The report /2/ gives an excellent overview on wood pellets in general terms and both physical and chemical characteristics. Its impacts are:

Water contents:	storability, calorific value, losses
Calorific value:	fuel utilisation, plant design
Ash content:	particle emissions, costs of ash disposal
Bulk density:	transport & logistical planning
Share of fines:	dust formation, usage: transportation losses,
Cl contents:	HCl, dioxine/fourane emissions
Heavy metals:	use or disposal of ashes
K, Mg, Ca, P contents:	corrosion

11.3.4 Pellet quality standards

Fuel quality standards exist in few countries in Europe. Austria (ONORM M 7135); Sweden (SS 187120); and Germany (DIN 51731) have national standards. Table 9.1 gives parameter limits in Austrian and German standards. A harmonised European standard for biomass fuel is in preparation by the European Committee for Standardization.

Table 12.1. Limit values for wood pellets in Austrian and German standards /2/

	AUSTRIA ONORM M 7135	GERMANY DIN 51731
Unit density	>= 1,0 kg/dm3	1-1,4 g/cm^3
Water content	<= 12 %	<= 12 %
Ash content	<= 0,5 % (rel. to dry matter)	<= 1,5 %
Lower calorific value	>= 18 MJ/kg (rel. to dry matter)	17.5-19.5 MJ/kg (water and ash free)
Sulphur	<= 0,04 % (rel. to dry matter)	<= 0,08 %
Nitrogen	<= 0,3 %	<= 0,3 %
Chlorine	<= 0,02 %	<= 0,03 %
Impurities	Made only from uncontaminated wood	
Binding agents	Forbidden	
Arsenic (As)		<=0,8 mg/kg
Cadmium (Cd)		<=0,5 mg/kg
Chromium (Cr)		<=8 mg/kg
Copper (Cu)		<=5 mg/kg
Mercury (Hg)		<=0,05 mg/kg
Lead (Pb)		<=10 mg/kg
Zinc (Zn)		<=100 mg/kg
Extractable organic halogens		<=3 mg/kg

11.3.5 Pellets distribution

Figure 12.3: Several kind of bags

Figure 12.2: Delivery of wood pellets.

Used for various purposes, pellet might be distributed:

- By truck-tank and by pneumatic filling of consumers storage,
- In small 15 kg bags for use in pellet stoves,
- In big bags (ca 1 t).

11.4 Technical and economical aspects of heating systems

11.4.1 Technical aspects

Wood pellet fuel is used in variety of types of heating systems, as:

- Small to medium scale district heating systems
- Micro networks
- Central heating systems of individual buildings
- Central heating for single family houses
- Chimney ovens and stoves.

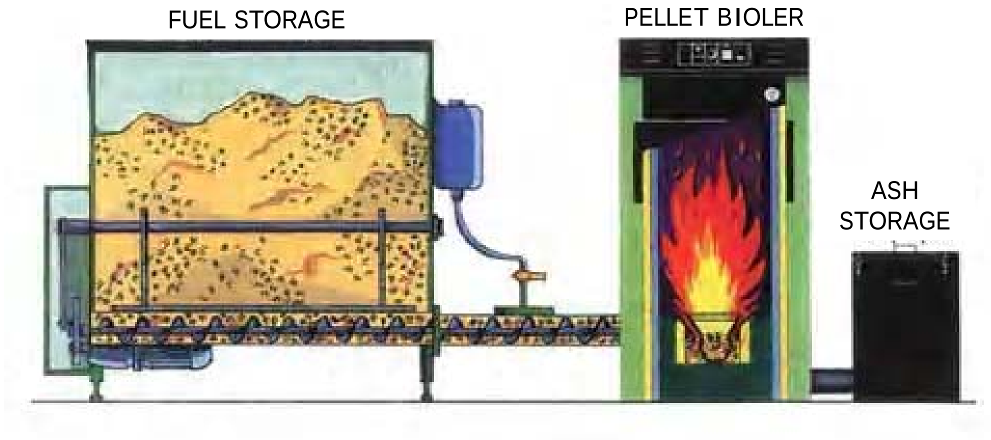

Figure 12.4 . Schematic representation of wood pellet heating system for a single family house /8/.

In different countries completely different size of wood pellet heating systems are dominating: in Italy small devices – room stoves, in Austria small to medium boilers for single family houses and micro-grids and in Finland there are as well larger district heating systems.

Most modern plants system characteristics are low operation costs, high combustion efficiency low emissions. The machines differ from each other but their technical solutions are similar or even universal.

Process control systems supports fully automatic system operation. Most of machines features are:

- Electric ignition to control start and stop on demand or linked to modern building automation systems
- Automatic ash removal systems, with capacity of two weeks or higher, at larger machines. Small machines are with manual de-ash systems
- Capacity control systems allowing to modulate output generally between 100 % to 20 % to match load served, which is an advantage over common fossil fuel burners
- A lambda oxigen monitoring sensor in the flue gases channel is used for combustion control system
- Modern machines reaches an efficiency level of over 90 %.

Various combustion systems are used for pellet fuel, one of the most common solutions for domestic heating systems is fixed-bed combustion with underfeed stokers /4/. Underfeed stokers represent a cheap and operationally safe technology for small- and medium-scale systems up to a nominal boiler capacity of 6 MW_{th}. They are suitable for biomass fuels with low ash content (wood chips, sawdust, pellets) and small particle sizes (particle dimension up to 50 mm). An advantage of underfeed stokers is their good partial-load behaviour and their simple load control. For the other biomass fuels with a high moisture content, varying particle sizes and high ash content various designs of grate furnaces are used.

11.4.2 Heating system dimensioning

For selection of an efficient and economic heating system the following tasks need to be completed:

1. Determine the load to be served and its dynamics. In case of a district heating or a micro network system the factor of simultaneous use needs to be determined. Load duration curves are a simple tool to determine the daily and annual base load heating requirements.
2. Check the costs and availability and compare the results with other choices. For medium and large scale systems check the need for alternative back up systems for part year loads and system down time. Determine base-load biomass boiler and fossil fuelled peak-load boiler. In any case avoid summer operation of biomass boiler.
3. For larger scale systems: it is recommended to check CHP option,
4. Determine fuel storage requirements: size, location, accessibility for delivery, fire risk, shelter from the external elements,
5. Check compliance with national regulation and environmental performance of device (fire control; emissions, permissions, licences, monitoring),
6. Check system controllability options.

- ***Heat costs***

Economic comparison of different options should consider actualised life time costs including:

- Fuel costs, including taxes and delivery costs
- Investment costs including capital costs
- Personnel costs for heating system operation
- Maintenance costs (can be determined according to VDI 2067 standard).

Figure 12.5 gives a comparison of costs for heating served by wood pellet and fuel oil boiler. The annual heat load assumed to be served is 17250 kWh and a capacity needed is 15 kW.

Important items for pellet heat production are:

- Investment costs:: 7500 €
- Labour costs is virtually zero for domestic heating
- Pellet costs: 120 €/t is equal 25 €/MWh

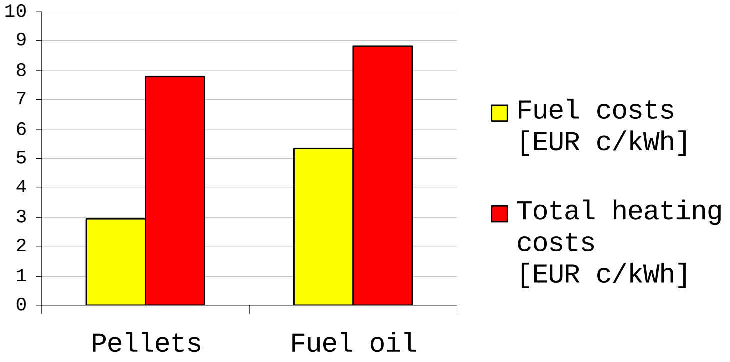

Figure 12.5. Comparison of fuel costs

11.5 Wood pellet heating - a sustainable energy option

11.5.1 Environmental issues

The key environmental characteristics of wood pellet use for heating are:

- Wood pellets are produced entirely form natural wood,
- Burning of biomass do not produce extra carbon dioxide emissions, thus it help to combat the climate change. (CO_2 which was absorbed from the air while the plant was growing, is released back into the air when the fuel is burned)
- Quantities of ash produced are very low, (0,5 to 0,75 %) by weight of input fuel. A mean/source for ash disposal is needed. Fly ash can not be spread on the ground because of high heavy metal contents, while bottom ash can.
- Air emissions are low in comparison to other fuels: particularly NO_X and particles emissions are low. Due to high quality of combustion process, carbon monoxide in the flue gases is low.

Table 12.2. Comparison of air emissions in the flue gases /2/

	CO	NO_X	Particles
	mg/m^3	mg/m^3	mg/m^3
Boiler lambda control (log wood)	240	150	35
Automatic boiler (wood chips)	154	131	49
Pellet boiler	97	114	16

The life cycle analysis is a valuable tool for considering the environmental aspects of the heat production. The whole chain from harvesting, fuel production, transportation and use, the production of the heating devices and the pellet storage construction, the plant decommissioning and the ash disposal need to be considered.

11.5.2 Social aspects

Wood production systems are job creating. Wood energy is the most labor intensive technology and has the highest job creation potential among the renewable energy options. Most of the jobs are created in rural areas /9/.

11.6 Conclusions

Wood pellets heating is a sustainable energy option.

It is a modern fuel which can be used with high comfort. There are several advantages over other wood fuels: it is cleaner, technologies are cheaper, and can be used as well in densely populated areas.

In different countries completely different size of wood pellet heating system are dominating: in Italy small devices – room stoves, in Austria small to medium boilers for single family houses and micro-grids and in Finland there are as well larger district heating systems. Wood pellets are used in The Netherlands for co-combustion at large coal power stations (600 MW_{el}). Pellets are purchased from Canada, Sweden and the Baltic countries. Various subsidy systems directs penetrations of technologies in various countries.

The opportunities for pellet use in Balkan region can be found in pellet production, its use for heat production and also in production of heating technologies.

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11.7.1 Selected internet links

- Network of Excellence Overcoming Barriers to Bioenergy
http://www.bioenergy-noe.org/
- Energytech.at - the platform for innovative technologies in the area of energy efficiency and renewable
http://www.energytech.at/(en)/biomasse/portrait.html
- energy from biomass; r&d in at;
http://www.bmvit.gv.at/biomasse/e/frameset.htm
- IEA BIOENERGY
http://www.ieabioenergy.com/ourwork.php?t=32#32
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- IEA BIOENERGY TASK 32
http://www.ieabcc.nl/

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