TYPES OF ENERGY

AND THEIR CLASSIFICATION

FEI STU

Jaroslav KULTAN

A BROCHURE FOR..

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Európska únia

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Types of Energy and their Classification

Zborník bol vydaný v rámci riešenia grantovej úlohy ....
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Energy is the ability to change one's condition, it is one of the life forms and its preservation is the basic sign of an intelligent approach to life.

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INTRODUCTION

This brochure is a follow-up to a series of articles which has been created through the support by resources provided by the European Regional Development Fund.

Energy is the ability of a physical system to carry out work. Today, we know five basic energy forms, however, the results of future research may unveil additional ones and the existence of new energy forms cannot be excluded.

At present, every human being is affected by the issues related to energy price and how energy is produced. The price of each product depends on the price of the energy consumed in the manufacturing process. Foodstuffs represent one of the most demanding products in terms of energy consumption, in particular during winter when there are not enough fresh vegetables and fruit. An ecologically clean and affordable energy would not only aid a well-balanced diet, it would also become a source of income for multiple rural households. The possibility to obtain cheap energy will help maintain comfortable temperatures without spending more and more money on heating and hot water. Another form of utilising energy of renewable sources is the operation of small wood driers. Lumber which otherwise would have to be stored for a long time to dry naturally or dried using expensive energy would be much more expensive then when long tunnel dry-kilns are used which can be used not only to dry wood but, if necessary, and with a suitable setup, also to dry fruit.

In this case, it is not only necessary to know how to utilise the energy, but also where to get it in an efficient way. We need to consider solar collectors, small hydroelectric power plants, wind power plants, as well as the energy of plants – burning of straw, wood, logging residue, etc. It is also necessary to focus on the production of briquettes from sawdust, plant leaves, and on sourcing biogas from animal waste, domestic biological waste and plant residue. The obtained gas is not only a source of heat but also a source of electricity.

The mentioned energy sources are known to a relatively small number of people who would be able to source energy from them. It is thus necessary to make this information available to the public and familiarise people with the basic technologies required to produce energy and use it. All the

involved manufacturers strive to acquire new know-how, improve the technological and economic parameters of their devices which will then lead to more systems being used, improved economy and a higher standard of living.

1. ENERGY CLASSIFICATION USING DIFFERENT CRITERIA

This section focuses on the formal classification of energy types. A proper understanding of energy classification makes it possible to seek new ways of obtaining energy and improving the utilisation of the available resources. Among the basic energy classification criteria, we should mention its origin, methods of obtaining, and the recovery and recuperation options.

1.1 Energy Types by Origin

The notion of energy describes the ability of a physical system to carry out work, i.e. it is a measure of all forms of matter movement. According to the relativity theory, mass and energy are equivalent, as suggested by Einstein's equation [1].

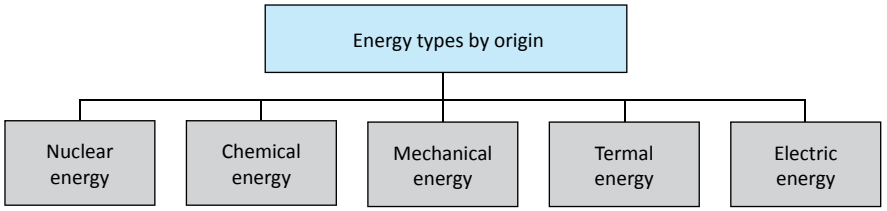


Fig. 1 Energy types by origin

Nuclear energy is the energy released in the process of heavy nuclei fission or light nuclei fusion. At present, the most frequently used heavy metals are uranium, thallium, and plutonium.

Fig. 2 Model of an atom

[1] $E = m.c^2$, where m is mass and c is the speed of light in the vacuum (299,792,458 $m.s^{-1}$

The basic precondition for light nuclei fusion is the mastery of technologies related to thermonuclear reactions of light elements, which usually use hydrogen, deuterium and tritium. The figure above (Fig. 2) shows a model of an atom with protons, electrons and neutrons. A large amount of energy can be released in the process of the decay or synthesis of such nuclei.

$$^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{236}_{92}U \rightarrow {}^{140}_{54}Xe + {}^{94}_{38}Sr + 2\,{}^{1}_{0}n + 200\ MeV$$ [2] (1)

The equation (1) represents the model of obtaining nuclear energy. (Fig. 3) shows the schematics of a nuclear power plant.

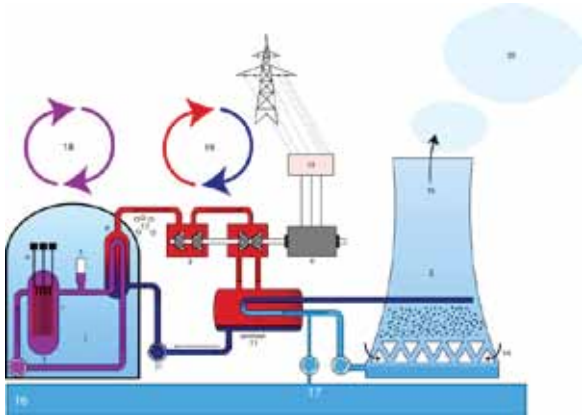


Fig. 3 Model of a nuclear power plant

Chemical energy is the energy of chemical bonds between atoms and molecules released in the process of transformation of electron envelopes of atoms. This energy is released during chemical reactions. The basic chemical energy carriers are fossil fuels (crude oil, natural gas) which release energy in the process of burning at the presence of an oxidising agent [3]. Other forms of obtaining chemical energy are processes producing heat, electricity and similar. An example of chemical energy sourcing is the hydrogen cell. The equation (2) is an example of methane combustion.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \quad (2)$$

[2] Splitting of the uranium nucleus

[3] E.g. oxygen (O_2)

Fig. 4 Gas combustion <http://www.equark.sk/index.php?cl=article&iid=670>

Mechanical energy is the energy of moving bodies or particles. It is the measure of the ability of a body to carry out work, i.e. apply force onto another body and move it along a certain path. In practical applications we differentiate between two basic types of mechanical energy - motion and stored. Motion /kinetic/ energy is the energy of a moving machine, object, etc. The kinetic energy of water is used in hydroelectric power plants, just as the kinetic energy of wind is used in wind power plants. Stored /potential/ energy is the energy of an object placed at a certain height. Potential energy is used, for example, in construction to drive pylons in the ground or in power plants with a tall dam. In this case, potential energy turns into kinetic energy which drives turbines.

$$E_k = 1/2\, mv^2 \tag{3}$$

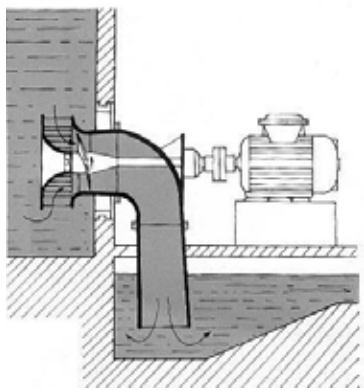


Fig. 5 A turbine transforming potential energy into kinetic <http://www.inforse.dk/europe/fae/OEZ/voda/voda.html>

Thermal energy or just heat [4] is the energy we observe as the demonstration of the disordered movement of particles (atoms and molecules) in matter. It is an internal energy which a body stores or transfers to another body in the process of heat transfer. Experiments are being performed to utilise the temperature gradient of seawater (temperature difference between the surface and deep water).

$$Q = c.m.(t - t_0) \tag{4}$$ [5]

Electric energy is the ability of an electric field to carry out work. It is most commonly transferred by an electromagnetic field in connection to the movement of conduction electrons in conductors. All bodies with an electric charge (electrically charged bodies) have electric energy. Its advantage is the suitability for transfer and distribution to consumers and it is thus used as an energy carrier. On the other hand, its major drawback is the impossibility of efficient storage (yet it is possible to transform it to other types of energy).

$$W_z = U_e Q = U_e I t = \frac{U_e^2 t}{R + R_i} \tag{5}$$ [6]

where U – voltage
Q – charge
I – current
R – resistance
t – time.

Equation (5) shows several ways of describing electric energy. In the first part, it describes the passage of a charge through a field with a potential difference U. In the second part, the charge is the product of current and time and, in the last part, current is the quotient of voltage and resistance.

All these types of energy can be obtained from renewable or non-renewable energy sources.

[4] Designation: Q, unit: J - Joule
[5] Calculation of the heat needed to increase the temperature of a body, where: Q – is heat [J], c – is the specific heat capacity [$J.kg^{-1}.K^{-1}$], m – is mass [kg] and $(t - t_0)$ – is the temperature gradient [K]
[6] Work of non-electrostatic force – is the measure of energy supplied by the source to a closed circuit, where W is work, U is the electric voltage, R is the conductor resistance, and t is the time during which current I flows through a conductor.

1.2 Energy Types by the Renewability of Energy Sources

The following energy classification focuses on origin (Fig. 6) with regard to whether the sources that it originates from are renewable or not.

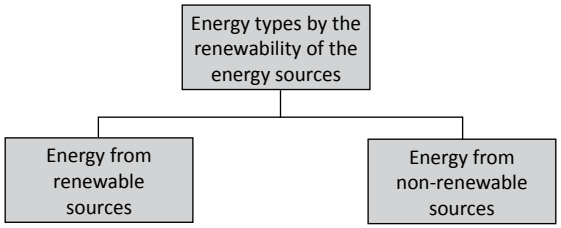


Fig. 6 Energy types by the renewability of energy sources

Energy from non-renewable sources is obtained by using non-renewable energy sources, such as fossil fuels (crude oil, coal, natural gas) and nuclear fuels (uranium, plutonium) the reserves of which are gradually diminishing.

Energy from renewable sources is won from sources which constantly recover naturally or through human activity and their stock is thus not diminishing. This is in particular solar energy, hydroelectric energy, wind energy, ocean energy, biomass energy, geothermal energy and others.

2. RENEWABLE SOURCES

This section analyses the best known ways of obtaining energy from renewable and ecological sources. These sources represent an alternative that can both help save the environment and decrease the complexity of production. Numerous publications on the subject of ecological energy sources speak of a very long return on investment when funding ecological energy sources. This is only true where the energy won is used in a traditional technological system which assumes utilisation of common technologies originating from the era when there was abundance of energy and its price was excessively low. Any energy production for the sake of production can be unprofitable due to the general basic properties of eco sources, such as:

- low energy concentration per unit of space (area), i.e. (kWh/m^2)
- low performance (output), i.e. (kW)
- more complicated energy production technology in comparison to the traditional ways.

The most important and best known sources of renewable and ecological energy, which can be used in our territory and have sufficient concentration level, are:

- energy of direct and diffuse solar radiation;
- wind energy in selected basins, valleys and elevations;
- the kinetic and potential energy of water in rivers, streams, lakes and dams;
- energy of waste generated by wood-working and wood-processing industry;
- energy from fast growing tree species;
- energy from animal excrement;
- energy from agricultural wastes and municipal waste;
- energy of the ambient environment.

All listed energy sources are used in many countries around the globe and in many cases provide for a significant portion of energy consumed in the region where such systems are installed. These are especially solar collector systems in California, wind power plants in the Netherlands, hydroelectric power plants in the Scandinavian countries, plants for the processing of forestry residue in Austria and Switzerland, plants for straw combustion

in Austria and Germany, digestion towers for the production of biogas in the Netherlands, India and England and heat pumps, the number of which has recently increased also in the Czech Republic.

Table 1: Production of electric energy from RES **between 2002 and 2007**
Source: Renewable energy sources 1, Technologies for a sustainable future, FEI STU, Bratislava (2nd edition)

Years	2002	2003	2004	2005	2006	2007
Sources	[GWh]	[GWh]	[GWh]	[GWh]	[GWh]	[GWh]
Hydroelectric power plants total	5 483	3 671	4 207	4 741	4 399	-
out of that pumping	215	192	107	103	-	-
Hydroelectric power plants (without pumping)	-	3 479	4 100	4 638	-	4 500
Wind power plants	0	2	6	7	6	8
Biomass	159	84	3	4	368	-
Biogas	1	2	2	4	8	11
TOTAL	**5 428**	**3 567**	**4 111**	**4 653**	**-**	**-**
Share in the total electricity consumption	18,6%	12,4%	14,4%	16,3%	16,1%	16,5%

When listing these plants, many will remember that such plants can also be found in Slovakia or the former Czechoslovak Republic. Slovakia too has numerous manufacturers of solar collectors and wind power plants, there are small hydroelectric power plants in multiple locations, and wood fired boilers, devices for chipping wood residue and producing wooden briquettes are being developed. In the village of Bartka a plant for biogas production was put into operation, similar to those installed in numerous wastewater treatment plants. The number of manufacturers and users of thermal pumps and energy convectors converting energy from stables into hot water is naturally increasing in our territory too.

The following section focuses on issues related to individual renewable energy sources which humans can utilise. We describe the substance of each energy source and the possibilities of utilisation of these sources in the territory of Slovakia.

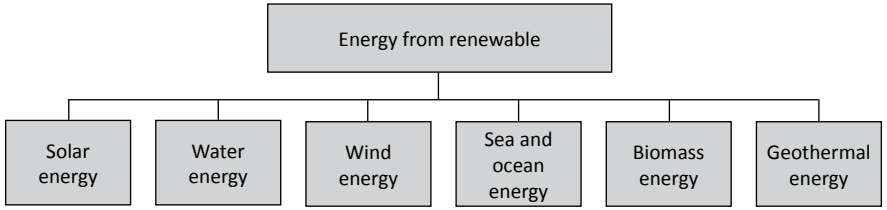


Fig. 7 Energy from renewable sources

2.1 Solar Energy

Solar energy is the energy sourced from the Sun, which reaches Earth in the form of solar radiation. Its two components, thermal and light energy, reach the Earth in the form of electromagnetic waves. The solar energy and its manifestations on Earth give rise to numerous other forms of renewable energy sources. The wind energy, for example, is being created through an uneven warming of the surface of the Earth by solar radiation. Solar energy is also the driving force behind the circulation of water on Earth. As you can see, solar energy has a huge potential. The trouble in using it is the uneven source distribution, whereas the solar radiation intensity is not sufficient in all regions all year round. Not all areas are, therefore, suitable for the installation of solar power plants. The decisive figure here is the total annual sunshine time [7]. In Slovakia, the sunniest part is the south-eastern half of the Danube basin with 2,000 to 2,200 hours of sunshine per year. [3] The amount of energy reaching the surface, however, varies throughout the year. During winter in Central Europe the average value is roughly 1.7 kWh/m^2 per day, yet during the summer months the average reaches up to 6.0 kWh/m^2 per day. On the global scale, the values range from 1,100 kWh/m^2 per year in Central Europe, over 1,700 kWh/m^2 per year in the Central Asia to more than 2,200 kWh/m^2 per year in some African countries. In Slovakia, these values are more or less the same as the values for Central Europe.

$$P\ (\text{kWh/deň}) = \text{kWp} \,.\, \text{kWh/m}^2\text{/deň} \,.\, \eta \quad [8] \qquad (6)$$

[7] No cloud cover.
[8] Where: kWp is the peak cell output in kW, kWh/day is the amount of solar radiation reaching the area of 1m^2/day and η is the efficiency of the entire system (usually 80% for systems connected to the power grid)

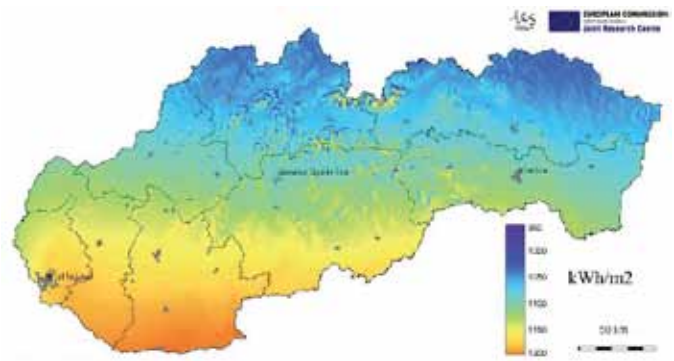


Fig. 8 Average annual amount of solar radiation reaching the territory of Slovakia

2.1.1 Energy of Direct and Diffuse Solar Radiation

The sum of direct solar radiation and radiation diffused by the atmosphere incident on a horizontal surface is called global insolation. Its intensity depends mainly on the position of the Sun, length of the day, elevation, atmosphere clearness and cloud cover, or the sunlight duration.

Measurements have shown that with clear skies the global insolation increases significantly with elevation, in particular within the layer of atmosphere closest to the Earth where the air contains large concentrations of air pollutants. From 4,500 metres above the sea level upwards the global insolation only shows small variations.

The average annual global insolation totals with clear skies in the territory of Slovak Republic range from around 1,945 kWh/m^2 in the southernmost areas to some 1,870 kWh/m^2 in the north of Slovakia. In the most elevated regions of the High Tatras the annual total for solar insolation can reach up to 2,165 kWh/m^2.

Under real conditions, the global insolation only forms part of the possible radiation which decreases as the cloud cover increases. The most significant deviations between the measured and possible values are in the northern districts where the average annual Q sums represent around 56% of the possible radiation. On the other hand, the smallest difference has been observed in the south where Q reaches 65 to 69% of the possible radiation. The following table (Table 2) shows the global annual insolation over a period of 30 years and the 5 year average. Next to the table is a graphical representation of these values. Based on that data it can be determined as

to what amount of energy can be obtained from collector systems with a specific surface area.

An inseparable constituent of global insolation is diffuse radiation. The flux intensity of diffuse radiation with clear skies depends on the position of the Sun and cloudiness of the atmosphere. Its values decrease with increasing elevation because higher up the Sun rays only have to travel a shorter distance through the Earth's atmosphere and the amount of particles causing diffusion is lower.

years	value	average
1	1,290	1,290
2	1,340	1,315
3	1,350	1,326.667
4	1,250	1,307.5
5	1,300	1,306
6	1,320	1,312
7	1,270	1,298
8	1,320	1,292
9	1,420	1,326
10	1,420	1,350
11	1,260	1,338
12	1,330	1,350
13	1,120	1,310
14	1,330	1,292
15	1,220	1,252
16	1,370	1,274
17	1,330	1,274
18	1,320	1,314
19	1,210	1,290
20	1,310	1,308

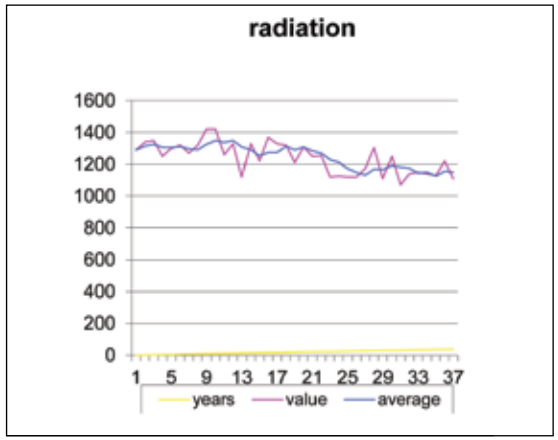
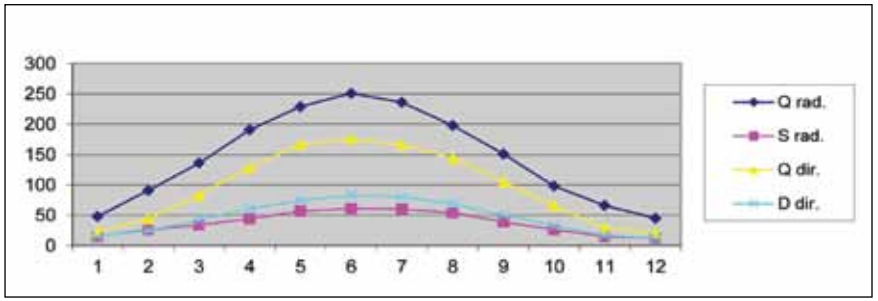


Fig. 9 Insolation energy

Table 2 Insolation values

Fig. 10 Energy of diffuse, direct and global radiation



Important information in trying to decide whether to use solar energy as a source of energy or not and calculating the needed surface area are the average monthly insolation values, which are listed in the following table. Based on the data shown and the necessary analysis of the ratio between solar and other types of used energy we can design an entire power-producing complex. It shows the global and diffuse radiation components in clear weather with average cloud cover.

When utilising solar energy in different branches of industry it is often necessary to know the amount of global insolation incident on surfaces with different inclinations. This is the sum of individual components of its fluxes, i.e. the direct radiation I_s, diffuse radiation D_s and reflected radiation R_s incident on a given surface.

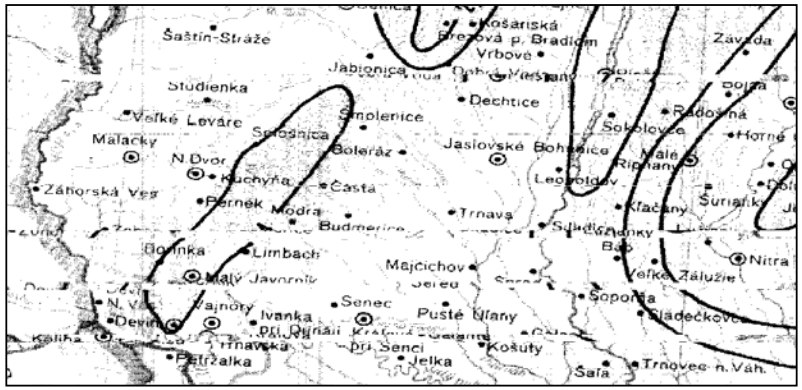


Fig. 11 Equipotential map of insolation in a given region

Table 3 Insolation values

	1	2	3	4	5	6	7	8	9	10	11	12	total
Q rad.	48	91	136	191	229	251	236	198	151	98	66	45	1,740
S rad.	15	26	34	44	57	61	60	54	39	26	15	12	443
Q dir.	23	44	83	129	167	176	166	145	105	66	29	20	1,153
D dir.	15	25	42	61	74	83	80	69	50	33	17	12	561

$$I_s = I_H \cos(\alpha) + I_v \sin(\alpha) \qquad (7)$$

$$D_s = D_H \cos^2(\alpha/2) \qquad R_s = R_H \sin^2(\alpha/2) \qquad (8)$$

Where the H index represents the energy component incident on a hor zontal surface and the V index on a vertical surface. The angle α represents

the inclination of the surface. Naturally the individual components are also a function of the azimuth of the inclination of that surface.

2.1.2 Utilisation of Solar Energy

Solar energy can be utilized in different ways. One of them is to transform solar energy into thermal energy (Fig. 12). Solar energy is used in this manner (conversion to thermal energy) by *solar collectors, solar furnaces and solar ovens*. In reality, though, only solar collectors are used.

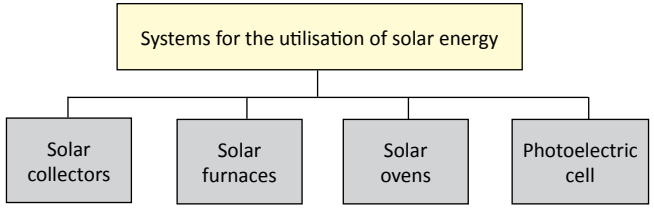


Fig. 12 Utilisation of solar energy

Solar radiation incident on a collector (Fig. 13) heats a heat carrier liquid which is then fed to a solar heat exchanger. Here, the heat is transferred to a different medium (e.g. water in a solar storage tank). The cooled heat carrier liquid then returns to the solar collector where the process of heating begins anew. The entire process repeats in this cycle.

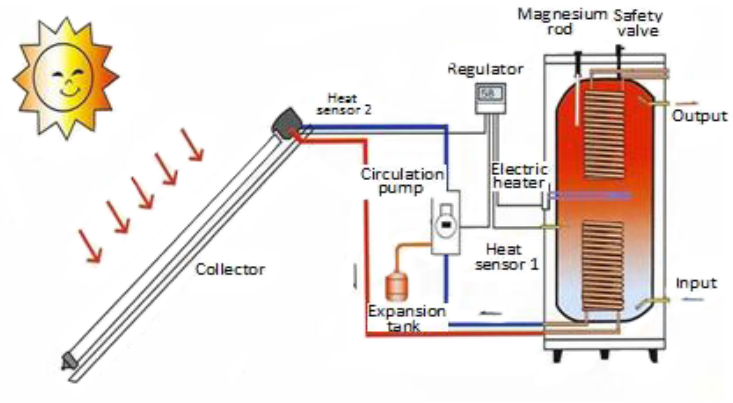


Fig. 13 Schematics of a solar collector connection
<http://www.efektivne.com/pictures/schema-01.jpg>

The other way of utilising solar energy is its direct transformation into electric energy. This is done in photovoltaic cells. Photovoltaics is a method of generating electric energy by converting solar radiation into direct current using semiconductors and the photovoltaic effect [9]. A photovoltaic or solar cell is a large-area semiconductor component capable of directly converting solar (light) energy into electricity using the photovoltaic effect. The practical applications for photovoltaic cells are very varied. They can be used to power small devices, such as calculators, but they are mainly used in places or situations where connection to a power grid is not possible - in satellites orbiting the Earth or in space probes. They are also increasingly used to produce electricity for households or the power grid.

In households, the energy produced by photovoltaic cells is modified in a converter and stored in accumulators. Electric appliances are then connected to these accumulators. There are also photovoltaic power plants which connect directly to the power grid. The energy that can be obtained from a photovoltaic cell in one day can be calculated as follows:

$$P\ (kWh/day) = kWp\ .\ kWh\ /\ m^2\ /\ deň\ .\ \eta \qquad (9)$$

Where kWp is the peak cell output in kW, kWh/day is the amount of solar radiation reaching the area of $1m^2$/day and η is the efficiency of the entire system (usually 80% for systems connected to the power grid)

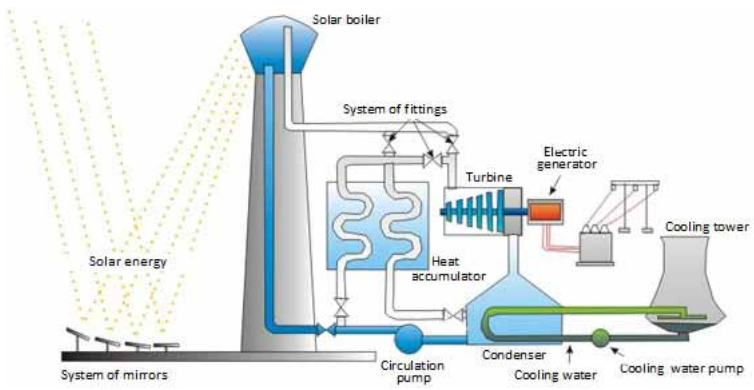


Fig. 14 Schematic of a solar power plant

[9] Absorption of the incident radiation creates positive and negative charge carriers in the semiconductor. The radiation must have a certain minimum intensity which depends of the type of semiconductor material used. To generate solar power the most suitable materials are those capable of capturing radiation and creating an electron – hole pair at microscopic thickness.

Ďalším spôsobom využívania slnečnej energie je výstavba slnečných tepelných elektrární (Obr. 14). Slnečná energie je smerovaná pomocou sústavy zrkadiel do slnečného kotla a následne je získanou energiou poháňaná turbína. Celkové zloženie elektrárne je podobné na zloženie tepelnej elektrárne s tým rozdielom, že je potrebné vytvoriť tepelný akumulátor. Potreba takéhoto akumulátora je vyzvaná nerovnomernosťou nahrievania.

2.2 Water Energy

Water as a source of energy has been used ever since the invention of a water wheel. The first water wheels were used in the East to power mills. In the eighteenth century numerous dams were built throughout Slovakia, the water from which was often used to drive mining equipment [10]. Utilisation of water energy made it possible to increase the production of ore and drive the overall development of mining in this region. Just like the other renewable energy sources, the energy of water too has its origin in the solar energy. In nature, water carries mechanical, chemical and thermal energy. When we speak of the mechanical energy of water, this can be the mechanical energy of atmospheric precipitation, the mechanical energy of glaciers, the mechanical (hydraulic) energy of watercourses or the mechanical energy of the sea. At present, we can only exploit the mechanical energy of watercourses to produce energy [11].

The power behind the movement of surface water in watercourses is solar energy, which constantly renews the watercourse energy making it inexhaustible. The amount of energy represented by a watercourse is determined by the flow rate and the fall. This energy is called the *hydro energy potential* [12]. The theoretical output of a watercourse can be calculated using the following formula:

$$Pt = 9.81\ .\ Q\ .\ H\ (kW,\ m^3.s^{-1},\ m) \qquad (10)$$

where Q – flow rate
H – fall
Pt – output
t – time
E – annual amount of energy

[10] Gold and silver mines around Banská Štiavnica
[11] Utilisation of the mechanical ocean energy so far is in the research stage, but there have not been any discoveries allowing for the efficient utilisation of this energy source.
[12] Hydro energy potential – HEP

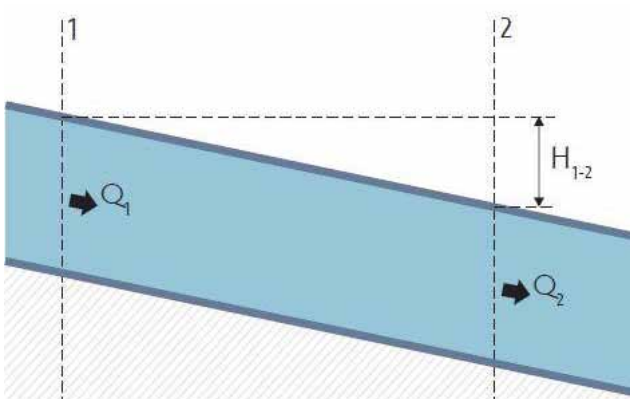


Fig. 15 Schematic for the calculation of water energy

For the production of electric energy the above calculated value is purely theoretical. The formula doesn't include a coefficient describing the efficiency of conversion of hydro energy potential into electricity – the coefficient in this case equals 1. Because in places where two watercourses meet the flow rate undergoes a step change, it is better to calculate the output of a given section of a watercourse as follows:

$$P_{1-2} = 9.81.\frac{Q_1 - Q_2}{2}.H_{1-2}\ (kW) \qquad (11)$$

The theoretical hydro energy potential of a given area will then be the sum of the theoretical outputs of all individual watercourse sections multiplied by time:

$$E = P_t\,.t\ (kWh, kW, h) \qquad (12)$$

In practical applications the hydro energy potential is usually specified as an annual value, which means the formula can be modified as follows:

$$E_{year} = \sum_{i=1}^{n} P_i\,.8760\ (kWh) \qquad (13)$$

Naturally, it needs to be said that the output of a watercourse is not constant all year long. For the purposes of energy generation it can be partially stabilised by building dams maintaining a constant water level. In such systems the flow rate can be partially regulated.

2.2.1 Kinetic and Potential Energy of Water in Rivers, Streams, Lakes and Dams

In many locations of Slovakia the energy of water is a little used source. This applies not only to energy concentrated in larger dams which not many could afford to build, but also to the energy of small sources with an output of 10 to 35 kW. These are the so-called micro power plants which can be built in places where in the past small sawmills and watermills had been built. There used to be a lot of these mills in the past – in some villages two or three. Naturally the surroundings of these streams have changed a lot and it is not possible to build head-races in the original stream-bed, or to dam the streams as they were in the past. Even so, after a detailed analysis of the terrain, it is possible to find places to build a micro power plant that would meet both the investor's and the ecological requirements. As shown in the following table (Table 4) of watercourses and locations where it is possible to install a watermill or where a watermill (sawmill) with the indicated output used to be installed in the past, there are numerous suitable locations in Slovakia. The table covers only a small output interval. The entire database includes more than 2,000 locations and still is not exhaustive.

Table 4 Sample list of streams and available energy

NAME OF STREAM	LOCATION	FLOW_ RATE	FALL	OUTPUT_ HP
Horská strouha	Vrútky	0.300	6.00	17.90
Belský potok	Výborná	0.940	10.00	18.00
Belský potok	Slovenská Ves	0.800	4.85	18.00
Belský potok	Bušovce	0.500	3.60	18.00
Biely Váh	Východná	1.260	5.20	18.00
Boca	Malužiná	0.803	2.50	18.00
Bratislava	Bučany	0.650	3.80	18.00
Červený potok	Matejovce	0.450	8.16	18.00
Križanský potok	Krivé	0.603	9.60	18.00
Likavka	Likavka	0.165	3.50	18.00
Nitra	Ondrochov	2.200	1.60	18.00
Nitra	Bánovská Kesa	1.150	1.50	18.00
Poprad	Maldur	1.200	1.85	18.00
Rajčanka	Stražov	1.200	1.80	18.00
Štítnický potok	Pašková	1.300	1.90	18.00
Choňkovský potok	Choňkovce	0.400	4.50	18.00
Lubický potok	Lubica	0.539	4.20	18.25

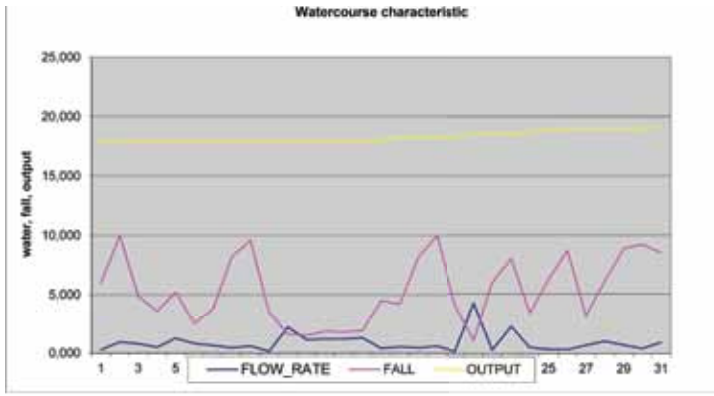


Fig. 16 Depiction of flow-rate, fall and output in selected locations

When analysing the hydro electric potential of a water source and calculating the installed output or amount of electric energy generated we can proceed according to the following tables (Table 5). Individual columns show different water flow rates and the lines show change in the water level. When creating an estimate it is necessary to consider the efficiency of the water source and of the electric generator. Then, we obtain the graphical relationship (Fig. 17 Relationship between output, fall and flow-rate) between the installed output and the water level and flow-rate.

Table 5 Calculation of output from flow-rate and water level

level/flow-rate	0.05	0.1	0.15	0.2	0.25	0.3	g	9.81
1	0.275	0.5494	0.824	1.099	1.373	1.648	turb. eff.	0.8
2	0.549	1.0987	1.648	2.197	2.747	3.296	gener. eff.	0.7
3	0.824	1.6481	2.472	3.296	4.12	4.944		
4	1.099	2.1974	3.296	4.395	5.494	6.592		
5	1.373	2.7468	4.12	5.494	6.867	8.24		
6	1.648	3.2962	4.944	6.592	8.24	9.888		
7	1.923	3.8455	5.768	7.691	9.614	11.54		
8	2.197	4.3949	6.592	8.79	10.99	13.18		
9	2.472	4.9442	7.416	9.888	12.36	14.83		
10	2.747	5.4936	8.24	10.99	13.73	16.48		
11	3.021	6.043	9.064	12.09	15.11	18.13		
12	3.296	6.5923	9.888	13.18	16.48	19.78		
13	3.571	7.1417	10.71	14.28	17.85	21.43		
14	3.846	7.691	11.54	15.38	19.23	23.07		
15	4.12	8.2404	12.36	16.48	20.6	24.72		

As you can see from the graphical depiction, to reach the same output it is possible to use locations with different water levels and flow-rates. A detailed analysis requires certain experience because a layman might not estimate the installed output exactly, which would cause the investment and watercourse potential go to waste.

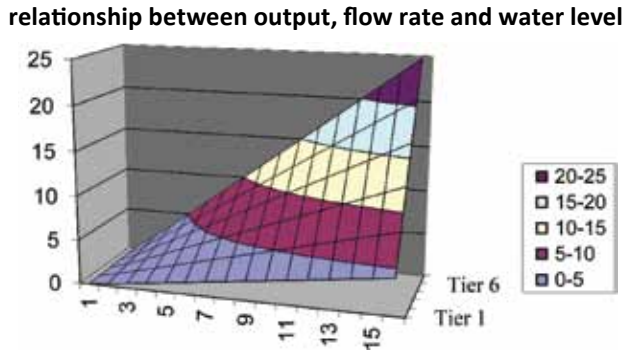


Fig. 17 Relationship between output, fall and flow-rate

Another required figure when deciding whether a small water power plant will be efficient or not is the estimated amount of produced electricity in relation to the daily number of hours in operation and the installed output. After substituting the current purchase price of electricity, the calculated result would represent the gross income for the energy supplied to the grid.

The efficiency of transforming the energy of water into electricity is the highest among all renewable energy sources - over 90%. The technically exploitable hydro energy potential of Slovakia represents almost 7,400 GWh per year. At present, almost 60% of that potential is being used in over 240 hydroelectric power plants.

The choice of the basic machinery for a power plant largely depends on the type of hydroelectric power plant. The classification of hydroelectric power plants by type is shown in Fig. 18

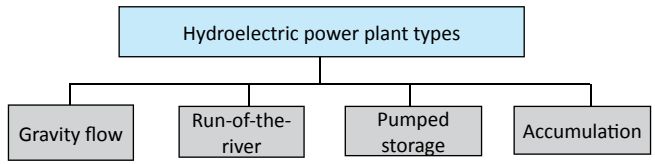


Fig. 18 Hydroelectric power plant types

There is still significant untapped potential at the following Slovak rivers: Hron, Poprad and the upper reaches of Váh. However, we should not neglect the potential of smaller, local streams which represent potential micro-sources. The cost of building a hydroelectric dam with a power plant [13] is around €2 to 4 million per MW, if the project is being built on an existing dam, the cost is around €1 to 2 million per MW [14]. Out of the total primary exploitable hydro energy potential about 1,200 MW can be exploited using small hydroelectric power plants.

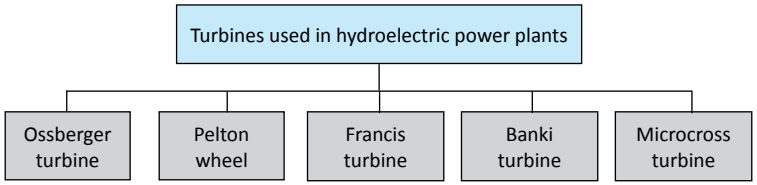


Fig. 19 Types of turbines used in hydroelectric power plants

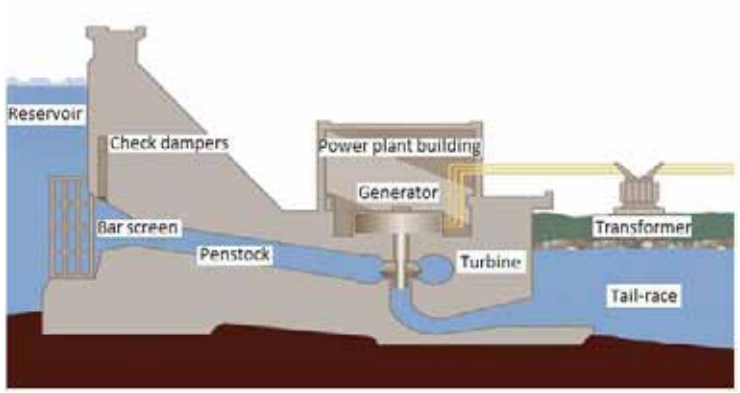


Fig. 20 Schematic of a hydroelectric power plant

A turbine is the basic piece of machinery needed to transform the energy of water into mechanical energy. The choice of the right turbine is a demanding process. Depending on the type of power plant it is possible to choose one of the types shown in the picture (Fig. 19). After choosing the right turbine it is possible to build a hydroelectric power plant similar to that depicted in (Fig. 20).

[13] Installed output 0.1 to 5 MW
[14] Source: Slovenské elektrárne a.s.

2.3 Wind Energy

Wind energy, just like water energy, originates from solar energy. A mass of air warmed by the Earth's surface tends to rise, because hot air is lighter than cold. This movement of air masses causes wind. Above the relatively flat surface of oceans, seas and coastal areas winds blow from a relatively constant direction which is why wind parks are being built out in the sea (Fig. 23). The near-ground wind above the land is strongly influenced by the relief of the Earth, which significantly changes its direction.

$$\textit{Wind energy} = 0.5 \,.\, D \,.\, d \,.\, v^3 \quad (14)$$ [15]

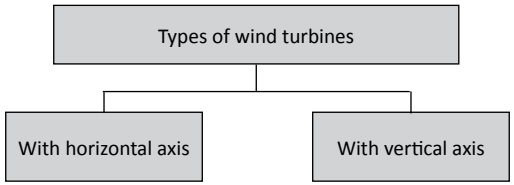


Fig. 21 Types of wind turbines

The wind energy potential of Slovakia as a continental country with quite a rugged relief is relatively low in comparison to coastal countries [16]. That is why in Slovakia there are only a few locations suitable for installation of wind turbines where the average wind speed is at least 5 m/s [17] and, moreover, many of them are located within protected natural areas.

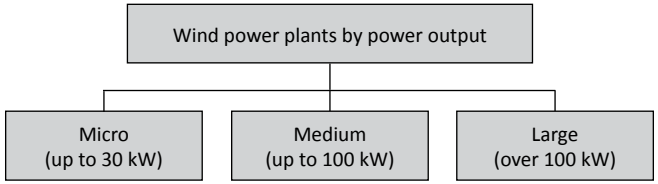


Fig. 22 Wind power plants by power output

[15] Where D is the area of the circle circumscribed by the wind turbine blades, d is the density of air and v is the wind speed.
[16] In the territory of Slovakia the total wind energy potential is roughly 600 GWh/year.
[17] According to: Slovenské elektrárne a.s.

The traditional representatives of wind energy users are wind mills [18], which were mainly used to pump water and mill and rough-grind corn.

Fir. 23
Wind turbine (built in the sea)

Fig. 24
Wind turbine (built in the sea, located on the roof of a family house)

Devices using wind energy to produce electric energy have undergone a long development, offer different outputs (Fig. 22) and different axis setups (Fig. 21). The most frequently used today are wind turbines rated around 500 kW with a diameter of more than 40 m. The current development suggests turbines rated between 750 and 1000 kW with a diameter of 50 to 55 m will be used. Due to the limitations of the existing infrastructure and construction complexity, development of larger and more powerful turbines [19] is currently at a standstill, but they may be used in the future.

It is estimated that in the future the use of wind energy as a power source will be much more common, as the capacities within the EU have by far not been exhausted and utilisation of wind energy is also part of the EU Energy Security and Solidarity Action Plan.

[18] Their wingspan is about 20 metres and output 5 to 10 kW.
[19] Rating of 1.5 to 2 MW

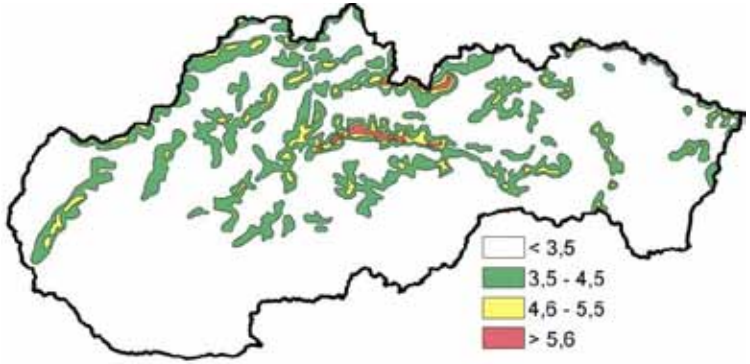


Fig. 25 The average annual wind speed 10 metres above the ground in m/s (Janíček, 2007)

If we want to use wind energy as a power source, the basic question is what specifically does the wind energy driving the wind turbine depend on? The following factors have an influence on the wind energy yield: the expected wind speed, the density of air in the given area and the area of wind turbine blades.

2.3.1 Wind Energy in Selected Basins, Valleys and Elevations

When analysing the possibilities of using wind energy for power generation, numerous works examining the flow of air in our country are taken into account. These are mostly documents prepared by the Slovak hydrometeorological institute and similar organisations in other countries. They include information about the average wind speed and frequency graded by speed, time of year and seasons. The prevailing airflow above central Europe is the zonal western flow which may alternate with meridian flow from north to south or vice-versa. The wind speed and direction are also influenced by the frontal position and the wind direction can quickly change by up to 180 degrees. Depending on the frontal zone, the zonal flow can be in balance with components of the meridian flow. Here, we speak of a mixed type of air circulation. Besides the global meteorological conditions, wind speed and direction are to a large extent also influenced by the shape, orientation, and inclination of mountains and valleys. A flow of air corresponding completely only to the circulation conditions is very rare in the rugged

terrain of Slovakia and only occurs on the open plains or on mountain tops. The following figures show fragments of maps (Fig. 26) depicting the average wind speeds in certain locations. Individual curves connect places with the same average wind speed.

When choosing a spot for the installation of a wind power plant, its parameters, i.e. height, output and similar, return on investment or interaction of the power plant with other alternative energy sources, it is necessary to consult professionals who will evaluate the energy balance of each particular location. We need to realise that wind energy complements solar energy very well, because the months with little sunshine and a lot of clouds are usually very windy. Thus, if solar panels fail to provide energy we can source it from the wind power plant. In the decision making process it is possible to plan for a smaller solar power plant that will only take advantage of the sunny days and a smaller wind power plant that takes advantage of the faster wind speed, which will in total give us a cheaper energy source all year round.

Fig. 26 Equipotential map of wind speed

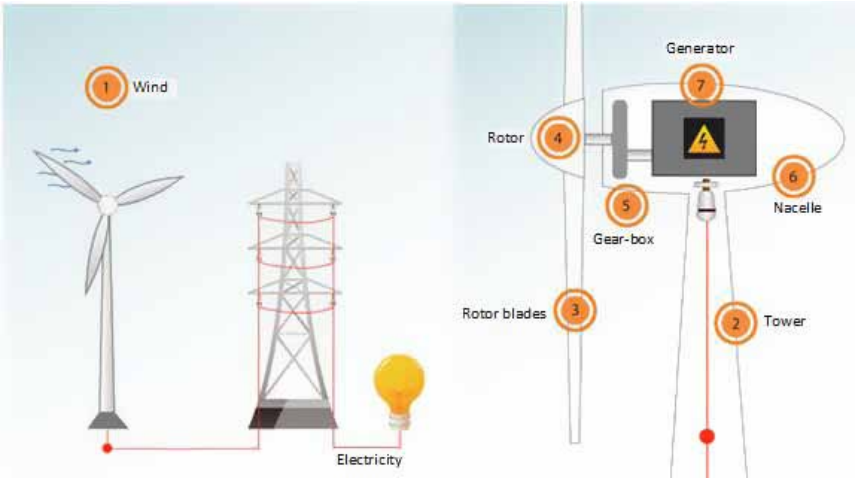


Fig. 27 Schematic of a wind power plant

The basic constructional and functional components of a wind power plant are the turbine, gearbox, generator and distribution box. The entire power plant, except the distribution box, is located on a tower. The higher the tower the higher the output achieved with the same turbine blade diameter.

2.4 Energy of Seas and Oceans - Tidal Energy

Tidal energy is one of the renewable energy sources. The tide is caused by tidal forces, i.e. the gravitational pull of the Sun and Moon on the mass of water, which causes the rise and fall of the sea level[20]. The tide repeats every 12 hours. Depending on the mutual position of the Earth, the Sun and the Moon we differentiate between spring *tide*[21] and neap *tide*[22] which is not as strong as the spring tide. Systems capable of using the tidal energy consist of a dam built in a bay. The dam has openings through which the water can pass. Water turbines are installed in these dam openings. These power plants are best built in places where the difference between high and low

[20] so-called oceanic tidal effects
[21] the Earth, the Moon and the Sun aligned
[22] the Earth, the Moon and the Sun unaligned

tide is at least 4 metres. Because Slovakia is not a coastal country, we are not going to explore this issue any deeper.

2.5 Biomass Energy

Biomass represents a huge source of renewable energy worldwide. Biomass consists of material of animal or plant origin suitable for energy uses. This material can be either of natural origin or produced by human activity (Fig. 29). The biomass energy, once again, originates from solar energy, which plants have converted to organic matter using photosynthesis. This energy is, so to say, embedded in the organic matter. When a suitable conversion method is used, it can be used in many different ways (Fig. 28). It can be used to generate electric energy, produce heat as well as liquid fuels for motor vehicles. Biomass is perceived as a possible replacement for the most significant energy source - fossil fuels. Its huge advantage is that biomass production is not as limited by the natural conditions of the land as the other renewable energy sources. The significance of biomass lies not only in its energy potential, it also has a positive social and economic impact, because it creates new employment opportunities both in towns and in rural areas (growing, harvesting and storage of biomass). It is expected that biomass will be used as an energy source in the long term, thus the longevity of companies using biomass as an energy source is basically guaranteed and so are the jobs in such companies. It is expected that in the final stage of biomass utilisation as an energy source it will account for up to 40% of all energy obtained from renewable energy sources.

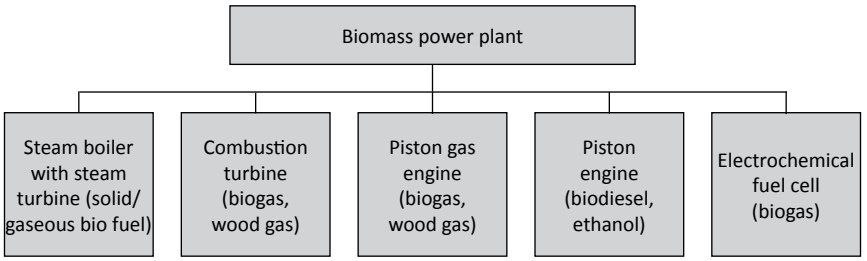


Fig. 28 Classification of biomass power plants by the type of fuel and system used to convert bioenergy into electric energy

When it comes to the utilisation of biomass as an energy source, Slovakia lags significantly behind the old EU member states [23]. According to the Ministry of Economy of the Slovak Republic, its usable annual potential represents almost 49% of the technically exploitable potential of all renewable energy sources. Out of the total biomass potential, Slovakia currently barely uses 20%, which represents around 1 to 1.5% of the primary energy source consumption. According to existing predictions, the climatic conditions prevailing in Slovakia allow to cover 6 to 12% of our energy needs from biomass. Residual biomass is mainly used for the production of heat in the timber industry, and even here the use is only marginal. Biomass originating from agriculture remains almost completely unused, and there is also no utilisation of straw or fast-growing energy plants [24].

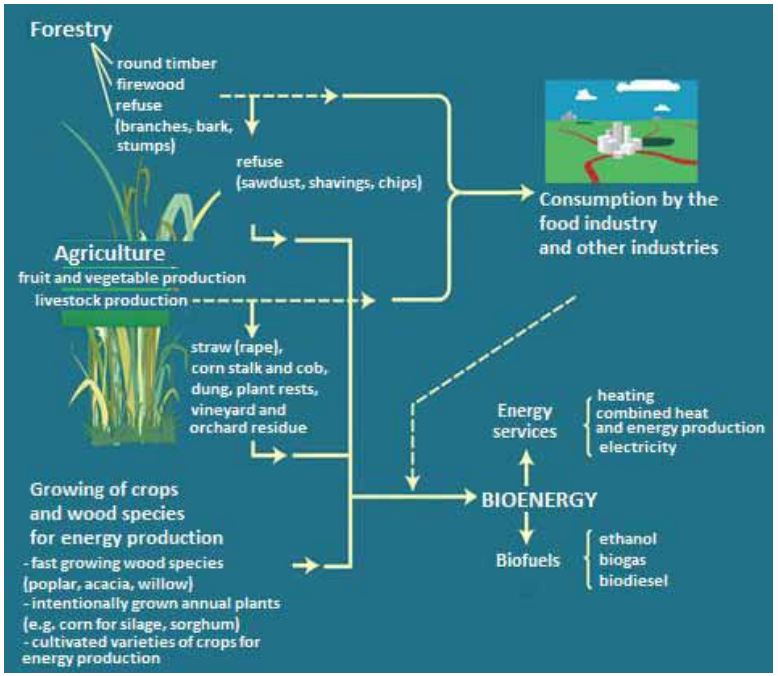


Fig. 29 Biomass and its utilisation <http://www.greenprojekt.sk/biomasa.html>

[23] EU 15 – Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden and United Kingdom
[24] Fast-growing tree species: willow, poplar; fast-growing plants: hemp

In terms of CO_2 emissions, biomass is considered a neutral fuel. When combusted, the quantity of CO_2 released in the air is equal to the quantity received by the plant while growing. By origin, biomass can be divided as follows:

- forest biomass - fuel wood, branches, stumps, bark, sawdust
- agricultural biomass - grain and rape straw, hemp, animal excrements, wastes
- wood-working industry wastes - cuttings, shavings, sawdust
- municipal refuse - solid combustible waste, landfill gas, sludge gas

High-grade biomass products are:
- solid fuels - wooden chips, pellets and briquettes
- gaseous products - wood gas, biogas
- liquid biofuels - biodiesel, bioalcohol [25]

The basic sources of energy are biological materials of plant origin that can be found in nature or have been produced by human activity. The main sources of such energy are trees and wooden residue of traditional technological production plants, plant waste from agriculture, animal waste and wastes from other industrial and municipal human activities.

[25] Source: Slovenské elektrárne a.s.

2.5.1 Energy of Refuse Generated by Wood-working and Wood-processing industry

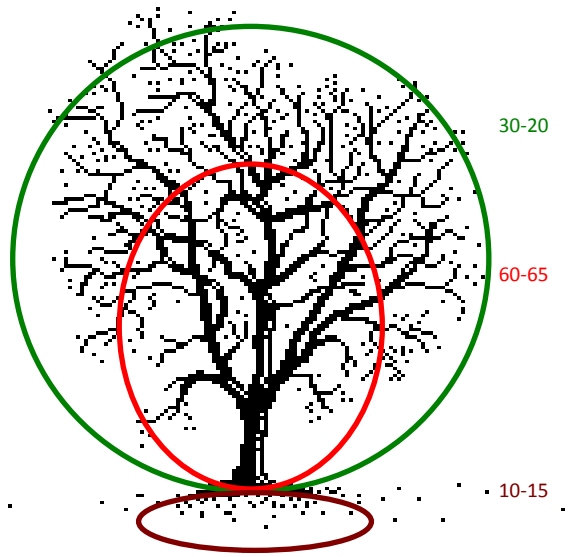


Fig. 30 Use of the wood substance of trees

Wood – biomass in the form of plants grown specifically for combustion in particular in the foothills and rural areas. Along with the residual wood from furniture making, paper making and wood-working industries it can be used as an alternative to fossil fuels. Wood and wood residue can be directly combusted or first converted to high-grade solid or gaseous fuels suitable for the existing types of furnaces (Fig. 31).

In the climate of Slovakia, wood residue in forests represents a significant energy potential. In many areas of Slovakia, the annual increment of wood residue exceeds the energy consumption of those areas. Savings of fossil fuels, independence from fuel imports and new job opportunities can also be mentioned among the advantages of this energy source.

Until now, only thick wood of 7 and more centimetres (Fig. 30) has been supplied and included in reports. This kind of wood, however, only accounts for 60 to 65% of the entire mass of wood in a tree above and below the ground. Smallwood in the treetops accounts for additional 15 to 25%,

the mass of the stump and roots for 10 to 15% and the rest are leaves. A significant amount of residue - sawdust - is being created in small carpentry shops which often have problems with its disposal.

One of the ways of using this residue is to produce briquettes out of sawdust and chips used for heating in fireplaces and stoves both at homes and in boilers-rooms with a larger output capable of supplying heat to entire blocks of flats. Briquettes can be created out of sawdust, shavings, ground bark or small chips.

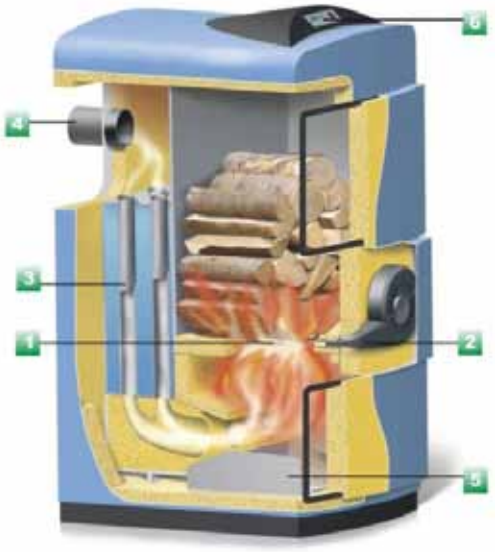


Fig. 31 Wood gasification boiler

Another form of dendromass processing is partial pyrolysis and the production of wood coal. By exposing the raw material to heat without letting air in, dry distillation takes place - a chemical reduction of organic matter - decomposition of wood. Heat decomposition (pyrolysis) is used to obtain wood coal and some other by-products.

An intermediate product in the production of wood coal is the so-called roast coal. It is produced using the process of partial pyrolysis, but

the production of roast coal ends at the beginning of the exothermic stage at a temperature of 270°C. The heating value of roast coal is 23 MJ/kg. If we compare this with brown coal (14 MJ/kg) or black coal (23 MJ/kg) we can see that this is a high-quality energy source.

Another form of wood mass processing is gasification, the product of which is wood gas. Gasification is a process during which the combustible fuel component turns into a gaseous fuel under high temperature. The obtained wood gas was used to power motor vehicles already during the second world war. Such devices suffered from certain issues, such as a very small range on one filling, low ride comfort and similar. Wood gas is more suitable for powering engines which drive power generators. This provides a power source in remote and secluded areas with abundance of wood and no connection to the power grid.

Out of the resources available in Slovakia it is possible to use up to 293,620 m3 of broad-leaved and coniferous raw material per year. The said resources do not include dendromass originating from pruning and stump extraction. By using all available wood mass, in one year it would be possible to replace around 85,000 tonnes of brown coal or 7,000 tonnes of black coal, or up to 31 million cubic metres of natural gas.

2.5.2 Energy from Fast Growing Tree Species

In a similar way, not only the dendromass of the existing forests, but also trees planted specifically for these purposes can be used. It is in this way that it is possible to use land resources, which due to contamination (e.g. high levels of nitrogen and other fertilisers) are not suitable for use in the food chain. At the same time, the quality of land resources improves. The leaves mass can be used to prepare compost.

Ethyl alcohol has been manufactured from biomass for technical purposes since the 1930s. Plants most suitable for the production of alcohol are corn, potatoes, sugar beet and other. Even though not all material is used to produce biofuels, in the process other valuable by-products are created which can be used as a replacement for protein feedstuffs and improve the overall economic balance of the project.

Biodiesel production consists of rape oil pressing followed by oil separation (etherification) into biodiesel and glycerine. Glycerine as a by-product of this production process is suitable for use in the chemical industry. The leftovers from pressing can be used as feedstuffs.

Besides growing the mentioned plants, increased attention is also being paid to wood species which can be burned directly. These are, for example, some varieties of poplar, alder, willow and similar. In Slovakia, it seems, the most suitable wood species is the Salix viminalis willow which has several strong-points, such as quick growth, little need for grower interaction, simple application in areas threatened by erosion, usability for wastewater treatment and treatment of heavy metal contaminated soil. Under good conditions it is possible to obtain up to 15 tonnes of dry matter from one hectare. In the fourth year after planting it is possible to obtain 40 to 65 tonnes of dry matter from one hectare depending on the conditions and treatment.

2.5.3 Energy from Animal Waste

Animal waste is one of the possibilities to obtain energy where, besides energy, we also obtain high-quality fertilisers. A significant advantage is also gradual disposal of waste which could contaminate soil and groundwater and make life in the proximity of farms quite unpleasant.

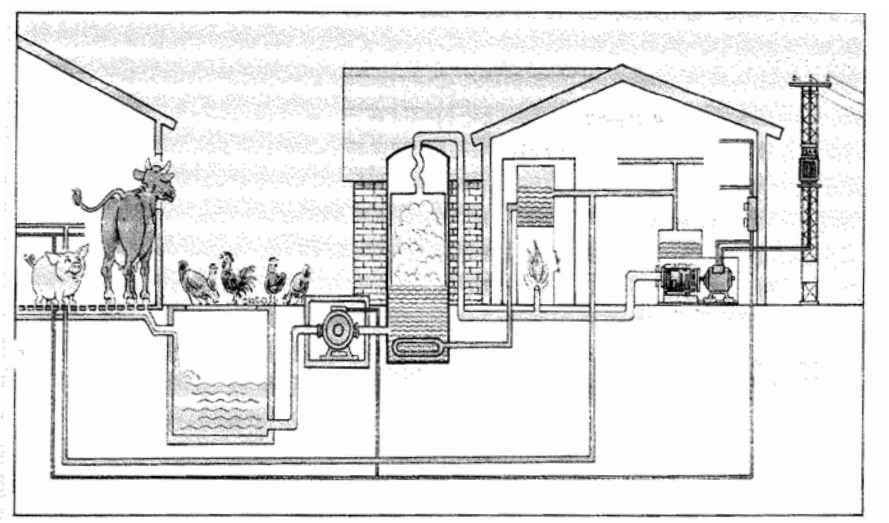


Fig. 32 Use of excrement from livestock production

When farming animals are bred on a large scale, a large quantity of biologically active material is being produced, which can be used in biogas production. In terms of efficiency we can mention some results listed in numerous publications focusing on this topic. On average the waste produced by one cow per day can generate an amount of biogas which produces 15 to 20 MJ of energy. In poultry raising 24.7 to 26.2 MJ can be produced which in average represents an output of 300 W in poultry raising and 200 W in stock raising. In terms of power output this represents 4.5 to 7 kWh a day. With a herd of 200 cows it is possible to obtain 900 kWh of energy per day. The annual energy production then equals 900 kWh/day times 365 days = 328,000 kWh. The obtained energy can then be used in accordance with the concept of complex energy utilisation in greenhouses, in biohumus production or in electricity production.

The basis of biohumus production is the technological process described in (Fig. 33). This schematic shows the basic technological process, the exact composition of which needs to be adjusted with regard to the existing technology, current use of biological material originating from livestock production and fruit and vegetable production. At present, numerous components of this technology can be found in many farms. The basis for implementation of this technology is the harmonisation of the potential of the given location, available biological materials, need to generate new energy, possibilities to consume the energy obtained and available funds. The basic precondition of a successful functioning of this technology is the right concentration of biological material, a constant supply of decaying material, and the removal of the used material. The system efficiency decreases in the winter months due to the need of material warming and increases in the summer months. In the summer, the excess energy can be used to produce electricity which can be sold to the power grid or used for other activities.

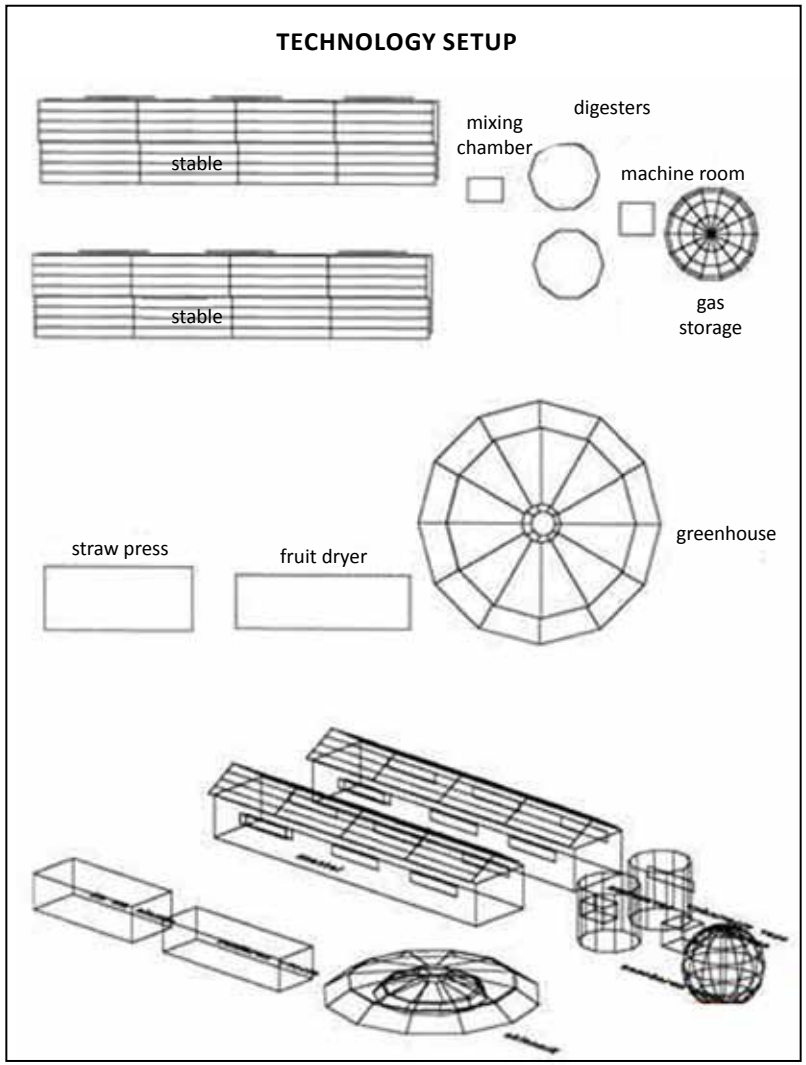


Fig. 33 Technology layout schematic

Biogas can be used as a direct fuel in boilers, dryers, to produce electric energy in gas turbines, and in dual-fuel engines and gas engines to power cars. The most efficient form of biogas processing is the combined production of heat and electric energy and its utilisation in production facilities.

2.5.4 Energy of Agricultural Wastes

One of the forms of agricultural waste utilisation is the use of straw for energy production (Fig. 34). Corn residue - straw - can be collected using commonly available technologies and then efficiently converted into ecologically clean energy. To cover the heating needs of one medium-sized household for one year, it is necessary to collect straw from an area of about six hectares. Naturally, the energy utilisation of straw must not be done at the cost of returning nutrients to the soil. Despite the straw being an important constituent of fertilisation, at present too much of it remains in our fields without any use. To improve the quality of soil, ashes created in the process of burning can be used.

Another source of producing energy is the grass mown in parks, which can be used for the production of biogas in bioreactors. Fallen leaves and other plant residue, that can be ground to small particles and used in bioreactors, can also be used for these purposes.

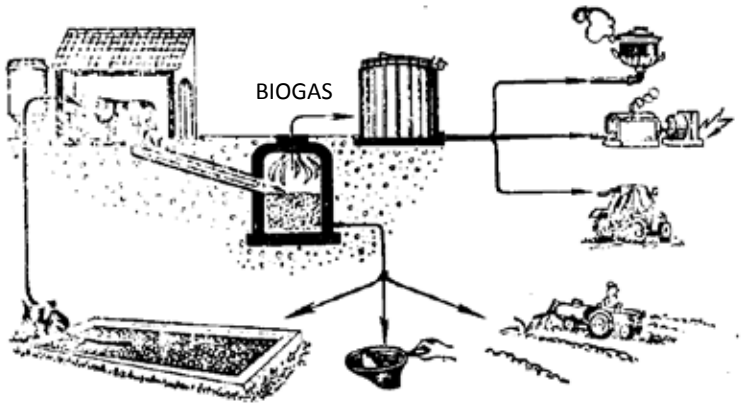


Fig. 34 Biogas utilisation in agriculture

Human activity produces a lot of waste which pollutes the environment. This is mainly waste from canning plants, processing industry and other technologies. Ground plant rests can be used in digestion or fermentation tanks. In the process of digestion biogas can be created, fermentation, on the other hand, produces alcohols which can be used as engine fuel.

An interesting possibility to obtain energy is the waste from small and larger distilleries. Even though this is a seasonal source of material, both the thermal energy of the hot waste can be used and certain alcohol components which can be burned to obtain thermal energy to heat the new material for the production of alcohol.

In towns and villages, there are often wastewater treatment plants. Many of them are currently using digesters where biogas is generated in an anaerobic process. This gas can be used to heat the surrounding buildings, to keep the digestion process going, or to produce electric energy.

2.6 Geothermal Energy

Geothermal energy is the manifestation of the thermal energy of the Earth which originates from the decay of radioactive matter and tidal forces. The Earth's geothermal energy manifests on the surface in volcano eruptions, geysers, hot springs and steam outbursts. The most frequently used medium for the transfer of geothermal energy is thermal water or hot steam (Fig. 35). Reserves of geothermal water can be divided into replenished and non-replenished. With the replenished ones, energy can be won through a single well. After the water cools down it is drained into watercourses. The non-replenished ones need to be regularly replenished which requires a second (so-called reinjection) well through which the geothermal water is pumped back underground after giving off its heat, which ensures a constant circulation.

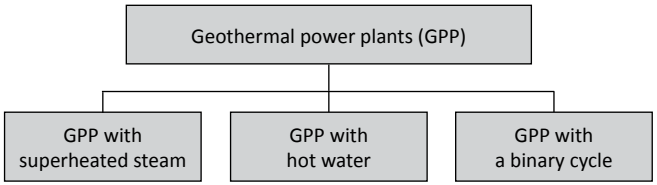


Fig. 35 Geothermal power plants

Within the EU, geothermal energy is the concern of the EGEC (the European Geothermal Energy Council). EGEC has set the following objectives

for the European Union when it comes to geothermal energy utilisation: in 2020 around 5,000 MW of installed power output, and later (until 2030) up to 15,000 MW of installed power output. It is apparent that the EU supports the utilisation of geothermal energy as an important energy source on its way to achieving the objectives of the EU Energy Security and Solidarity Action Plan.

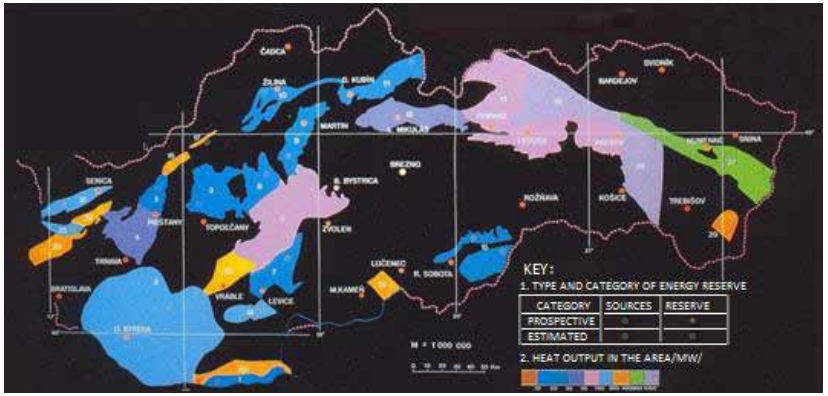


Fig. 36 Geothermal potential of the SR (Slovgeoterm)

In Slovakia (Fig. 36) the geothermal water temperature ranges from 45 to 130°C which means it is particularly suited for heating. In Slovakia, there are about 25 areas with a geothermal water temperature of up to 150°C and source depth of up to 5,000 m which could be utilised. The most important of these locations is the Košice basin where Geoterm Košice, a.s. plans to build a geothermal power plant near the villages of Ďurkov and Svinica [26]. Besides producing electricityfrom geothermal water using ORC cycles, the investor also plans to use geothermal energy to heat some town districts of Košice.

Besides the traditional ways of utilising geothermal energy, where geothermal water is being used directly, a new method is being introduced, which does not require the presence of geothermal water. This method of geothermal energy utilisation is called *Enhanced Geothermal System* (Fig. 37) (or *Hard dry rock geothermal energy* – which almost precisely describes how geothermal energy is obtained).

[26] The area belongs to the cadaster of the village of Svinica.

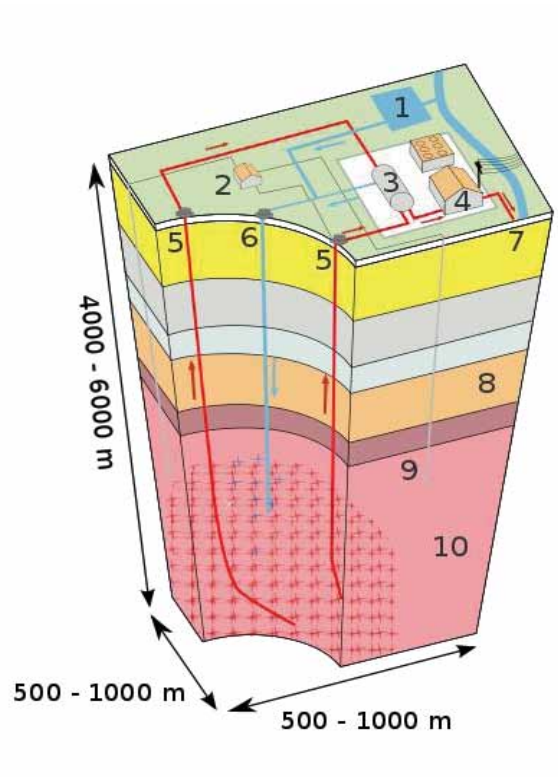


Fig. 37 EHC – Enhanced Geothermal System

This method does not require the presence of natural hydrothermal sources. Water is injected in the ground where it is being heated in contact with hot rock and returns to the surface through production wells. The basic precondition, however, is sufficient soil permeability - through faults or porosity of mineral grain.

Geothermal energy is significant especially as a local energy source. Research work shows that the geothermal potential of the SR is estimated to some 5,538 MWt (Energy policy of the SR). Slovakia has good conditions for the development and use of this renewable energy source. So far, in Slovakia, more than 70 geothermal boreholes have been made (most of them in the Danube basin) with a total discharge of 1,000 l/s and a temperature of 20 to 129°C and a thermal output of around 220 MW

(Chyba! Nenašiel sa žiaden zdroj odkazov.). Using thermal pumps this output can be further increased. The amount of heat supplied by thermal streams is about 70 MW/m^3. The geothermal gradient of sources in Slovakia is on average 37 K/km, which is more than the worldwide average (30 K/km). The water temperature is suitable for heating of houses, for use in industry, agriculture and tourism. Besides numerous swimming pools, thermal water is also used in some locations for heating of buildings (e.g. the Sever housing estate in Galanta) and greenhouses. Around some of the proven geothermal springs in some locations, tourism centres of international significance have been built.

At present, only 5.4% of the identified technically exploitable geothermal energy potential is being used, mainly for heating. The technically exploitable potential for electricity production represents only 60 GWh per year. At present, only one geothermal source is used for electricity production. It is located in the town of Komárno and has an annual output of 3.5 GWh. The plant uses two small cogeneration units each with an output of 44 kW. These units burn natural gas (methane) released from a geothermal source. The table (Table 6) shows the estimated potential of geothermal waters in the SR divided into regenerating and non-regenerating water.

Table 6 Energy potential of geothermal water in Slovakia (MWt)

Regenerating water			Non-regenerating water		
probable	verified	assumed	probable	verified	assumed
321	147	85	4511	29	445
Total Potential of Usable Geothermal Energy: 5538 MW_t					

Low Potential Geothermal Waters

The most important area with geothermal sources is the central depression of the Danube basin. The geothermal water sources in this area have an estimated yield of 1,027 l/s with an average temperature of 60°C and an average water level depth of 1,500 m, which represents a potential of 193 MW. So far, 64 geothermal boreholes have been made, some going up to 2,100 m deep.

In other prospective areas of Slovakia, wells have been drilled in the Komárno block (4 wells, out of which two in Komárno and Štúrovo are being used), in the Levice block (Podhájska), in the Poprad basin (Poprad, Vrbov, Stará Lesná), in the Liptov basin (Bešeňová, Liptovský Trnovec, Liptovská Kokava), in the Skorušiná pool (Oravice), in the Záhorie lowland (Lakšárska Nová Ves, Šaštín - Stráže) and in the Topoľčany bay (Bánovce nad Bebravou). Some of them are being used in tourism, to heat greenhouses and swimming baths, or in fish farming (Vrbov). Other projects for drilling geothermal wells are being prepared in the Turčianska basin (Martin) and in the east of Slovakia (Zemplín).

Medium and High Potential Geothermal Waters

A prospective area in the Košice basin (in proximity of the village of Ďurkov) has an area of 200 km^2. The source supplies geothermal water with a temperature of 115 to 130°C, water collectors have been discovered at the depths of 2,100 and 3,200 m. The first three wells have been drilled in 1999 and confirmed the presence of geothermal water in the carbonates of the Košice basin. Geothermal water with a surface temperature of 150°C and more can be extracted from a depth of over 4,000 m.

All these sources make it possible to obtain energy which may be used to replace the traditional fossil fuels, to lower the amount of CO2 in the air and to reduce the country's energy dependency on imports of the basic types of energy carriers.

3. COMBINED USE OF RENEWABLE ENERGY

Obtaining energy from renewable sources has several disadvantages inherent to the nature of these sources, such as their instability, difficult predictability, low concentration, or dependency on weather conditions.

3.1 Combined Production of Energy from Biomass

The production of energy from renewable sources is a demanding process both in terms of technology and economy. Provided that there are suitable energy sources at our disposal, it is necessary to use them to obtain multiple types of energy, which makes the process more profitable.

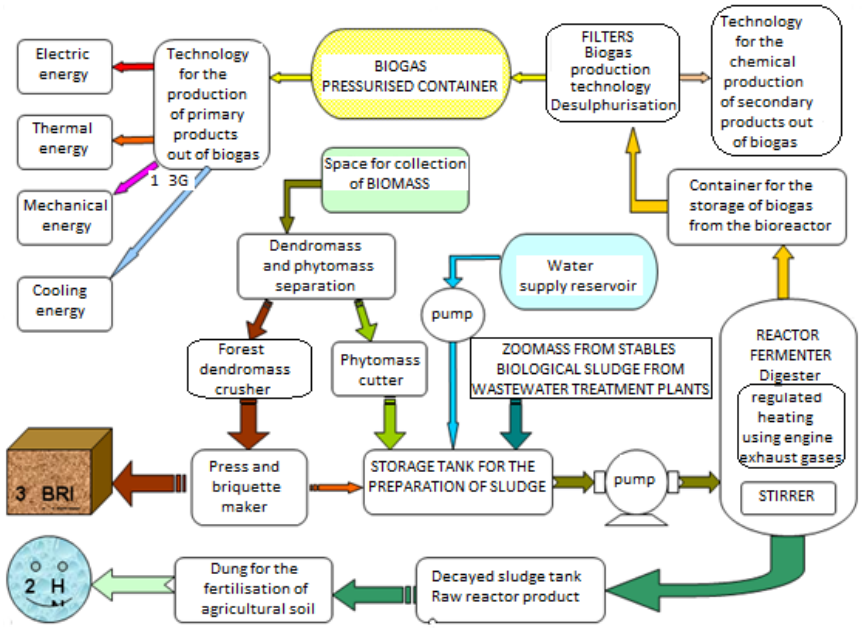


Fig. 38 Ways of biomass utilisation

The picture (Fig. 38) shows a schematic of the complex utilisation of biological material not only to produce energy but also to gradually refine biological waste. Such a complex system may produce several types or energy and products which may be used in other branches of industry.

The obtained products/briquettes, pellets, or bales of straw may be burned in different energy production facilities. After a preliminary treatment before the entry to the burner chambers such products can be used to obtain quality energy - electric, thermal for heating or preparation of hot water.

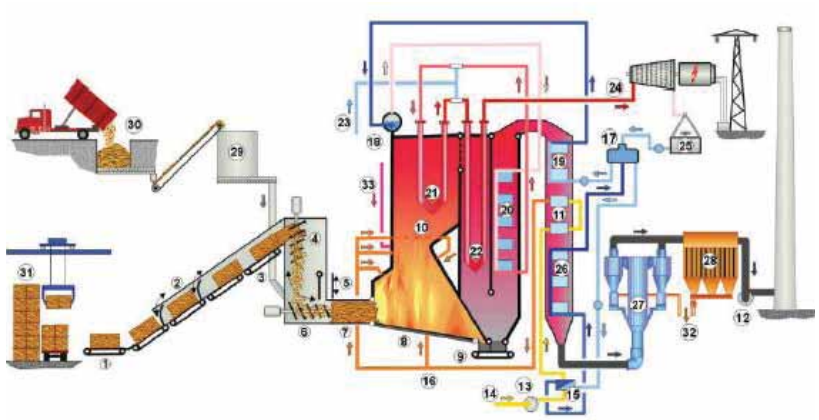


Fig. 39 Ways of burning straw

The technological equipment in power plants for burning biomass is frequently combined to be able to accept several types of biomass in different packaging. The product of such an energy system is not just electricity, but thermal energy as well. The figure above shows a system processing bales of straw and wood chips supplied from hoppers. The product is electric energy produced using a high temperature, high pressure carrier - steam. Steam is used mainly for the production of electricity and also in medium- and low-potential devices for the heating of buildings and houses.

3.2 Combined Use of Solar and Wind Energy

Recently, several studies have been carried out which have confirmed that regardless of the variability of solar and wind energy, it is still possible to find a very good correlation between them. Frequently, when the intensity of solar radiation decreases the wind speed increases. This situation is described in (Fig. 40). The measurements have shown a large negative correlation.

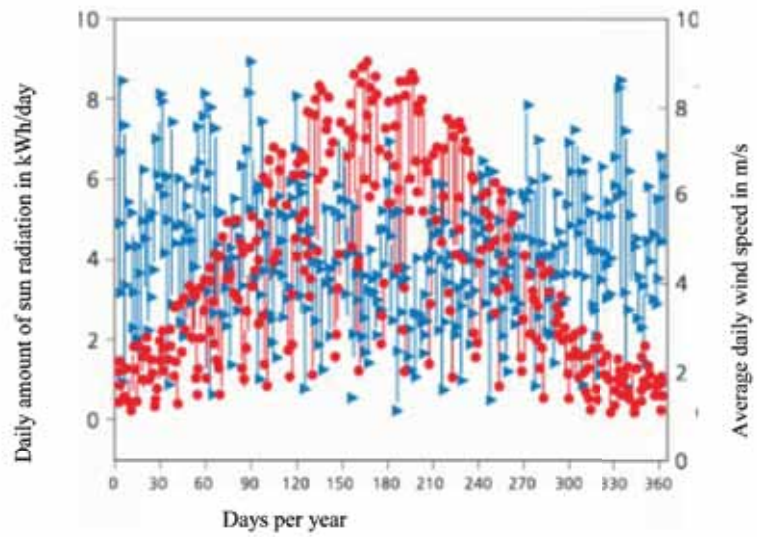


Fig. 40 Mutual correlation of solar and wind energy

This dependency makes it possible to create systems utilising both forms of energy with a lower individual outputs, but higher total energy gain. When considering a single source of energy, e.g. wind, the increase in the price of energy production is linear to the price of the equipment used (Fig. 41). However, because the frequency of high-energy winds is low, the overall utilisation of the installed output is lower compared to a lower output system (Fig. 42).

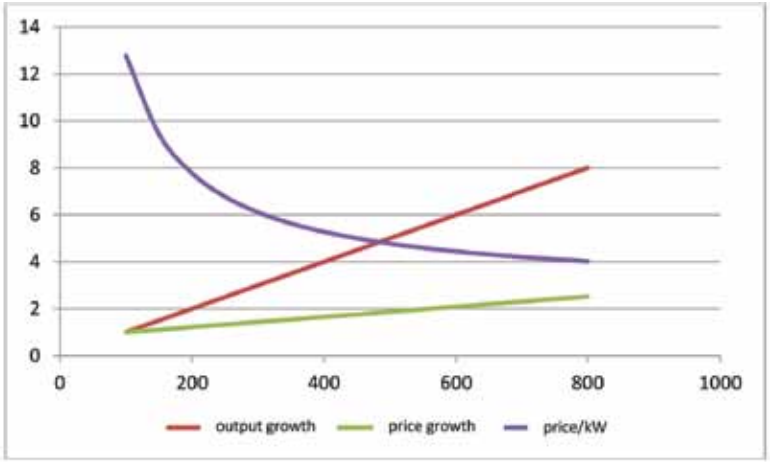


Fig. 41 Relationship between the price of system, output and unit price of output

We can state that the overall profit generated by a high-output energy system that only operates for a few hours is in general lower than that of the profit generated by two separate systems with lower outputs. Their advantage is that while one system operates, the other may be idle. When utilising the energy from the wind and sun, the total combined time in operation will be longer and the profit generated by such a system will be higher.

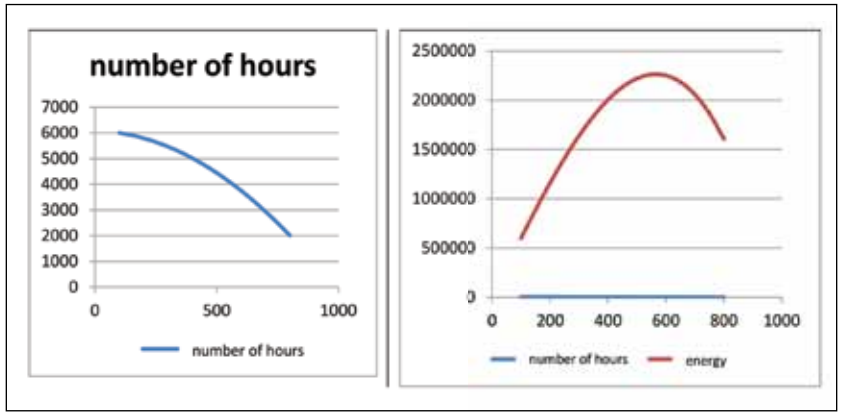


Fig. 42 Relationship between the number of hours, energy produced and output

The following graph (Fig. 43) shows the possible energy gain. You can see that by installing two systems, part of the energy is generated by the wind turbine e1 and part by the wind turbine e2 with an output of around 300 kW each. These two systems will produce more energy than a single turbine with an output of say 700 kW.

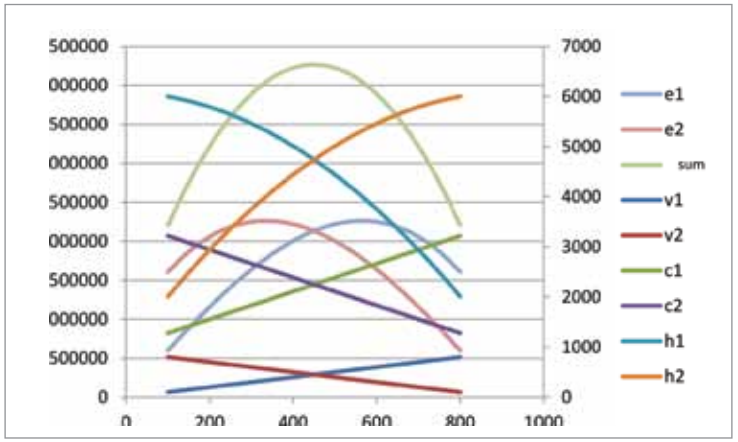


Fig. 43 Relationship between selected parameters and output

e1, e2 – amount of produced electricity
v1, v2 – output of individual devices
c1, c2 – price of individual devices with the given output
h1, h2 – number of hours during which individual devices are in operation
total – the total amount of energy generated

The graphs above suggest that in terms of energy generation it is better to use multiple types of devices with lower outputs than a single device, the purchase price of which is relatively high and which can only operate for a limited number of hours.

CONCLUSION

This brochure includes a brief overview of individual energy sources which helps the readers find their bearings in the issues related to obtaining energy. A correct understanding of the energy source classification provides a good basis for getting to know the individual sources and technologies. Furthermore, we present individual types of energy and the technologies used to derive energy from these sources. The detailed description of individual sources also includes information about how both large companies and small users can use them in an efficient manner.

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* Dr. Ing. Kultan Jaroslav, PhD
STU v Bratislave