1 Survey of renewable energy

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1.1 Introduction: Renewable energy in the past, at present and in the future

Before industrialization renewable energy had been the only source of energy available:

- Firewood to provide heat;
- Biomass for food, for horses and other animals for hauling transportation vehicles;
- Wind for propulsion of sailing boats;
- Wind and water power to run mills.

The onset of industrialization − about 300 to 200 years ago − caused an extraordinarily fast rise of the demand on energy and a severe shortage of firewood in many countries. Fossil fuels soon became the dominant source of primary energy. The abundant and steady availability of fossil fuels and especially their low cost satisfied the newly arising additional demand on energy to provide any required fast rising amount of

- heat,
- electric power and
- fuels for propulsion in the transportation sector.

At present, renewable energy can be used to provide only a rather limited amount of secondary energy, as shown in Table 1.1. A more extended use of renewable energy at present is mainly handicapped by

- restricted availability (e.g. hydro power, biomass),
- strongly fluctuating and intermittent availability of hydro river and wind power and of sunlight,
- comparatively high investment cost and cost of energy provided (e.g. sunlight, geothermal energy).

On the other side, it is of utmost importance to fight climate change caused by further greenhouse warming due to the increasing content of carbon dioxide in the atmosphere from the exuberant burning of fossil fuels [91IPC]. All these implications should be regarded as a challenge for proper R&D of renewable energy technologies making best uses of

- interdisciplinary science and technology and
- nano sciences and nano technologies for design and production of new materials

to achieve economically attractive solutions like e.g. photovoltaics, storage of electric energy in batteries, production of hydrogen par example via (solar-) thermal catalytic water splitting, fuel cells, conversion of hydrogen together with CO_2 extracted from the atmosphere to a synthetical hydrocarbon fuel.

Table 1.1. Use of renewable energy as secondary energy [03BWT], [99STK], [02IEA].

Secondary energy	via	Percentage of global demand [%]	
Electric energy	hydro power	18	20%
	wind power	0.3	
	biomass	1	
	geothermal	0.3	
	sunlight	0.02	
Fuels	ethanol	about 1	2%
Transportation sector	biodiesel	about 1	
Heat (mainly for cooking in developing countries)	burning non commercial biomass (mainly firewood)	about 7% of the total global demand on primary energy	

1.2 Worldwide demand on energy and potential of renewable energy

Actually, renewable energy available in total worldwide (see Table 1.2) could satisfy the *total worldwide demand on primary energy* (see Table 1.3) which at present amounts annually to

about 400 EJ	to provide heat, electric power and fuels in the transportation sector [03BWT], [99STK], [02IEA],
and in addition about 700 EJ	of primary biomass to provide about 20 EJ of food consumed in total by 6 billion of humans,

which in future, within some decades, may amount annually to

about 500…700 EJ	to provide heat, electric power and fuels in the transportation sector,
and in addition about 800...1000 EJ	of primary biomass to provide about 30 EJ of food to be consumed by about 8 to 10 billion humans.

Concerning the survey of the potential of renewable energy as shown in Table 1.2, the following definitions are used:

- *Theoretical potential*: total potential available in nature embedded in all kinds of natural processes and cycles within the biosphere;
- *Technical potential*: restricted part of the theoretical potential which could at least in principle be used by mankind with proper energy technologies to satisfy its demand of energy (without paying attention to the cost of relevant technologies);
- *Economic potential*: restricted part of the technical potential which can be realized economically in competition with the use of other energy sources, like fossil fuels.

As shown in Table 1.3, renewable energy at present contributes only a small fraction to satisfy the total demand on “technical” energy (not including “natural” energy in form of primary biomass to be finally converted to food), mainly using hydro power to generate electricity and burning biomass, especially leftovers and waste, to produce heat and electricity. The major part of the present demand on “technical” energy is satisfied with fossil energy – coal, oil and natural gas – because of their ample, steady and comparatively cheap availability, their easy storage and easy distribution. The technical potential of renewable energy in total (see Table 1.2) would allow to enlarge its contribution to the still rising worldwide demand on “technical” energy. But in many to most cases, the cost, especially the investment cost of the relevant energy technologies, are noticeably higher than the present cost to provide electricity, heat and fuels for the transportation sector by making use of fossil fuels.

Especially the energy production of photovoltaic powerplants is hampered by the daily and seasonally more or less restricted and more or less fluctuating availability (see Fig. 1.1). To further compensate these restrictions and fluctuations, more or less expensive energy technologies have to be provided, either to store electric energy or to fill the power gaps by means of further powerplants which can be turned on and off sufficiently fast. Concerning biomass, a further increasing use of it by large as “technical” energy (e.g. to produce biofuels for the transportation sector) may be severely restricted by the rising demand on primary biomass to provide sufficient food for the still rising world population. From all kinds of renewable energy to satisfy the demand on “technical” energy in future, sunlight is the richest energy source.

Table 1.2. Annual Potential of Renewable Energy in units of exajoule, EJ [99STK], [02IEA], [91IPC].

Source			Theoretical potential	Technical potential	Economical potential realized in 2000
Sunlight	Insolation from sun onto earth		5,500,000	8,000 [1])	0.1
Wind	Wind energy all around the globe		100000	10 to 20	0.1
Hydro	Water runoff from precipitation on land into ocean		120	15 to 20	10
Biomass	Heating value of biomass grown annually on land and in oceans				
	on land:	forests	1100 to 1700	about 300	about 100 [2])
		grassland	550 to 850	400 to 600	about 350
		agricultural areas	350	350 to 450	350
	on land in total		2000 to 2900	about 1200	about 800
	in the oceans		about 1000	?	about 40 [3])
Heat from earth interior	Stored in upper 10 km of earth crust		600 Million	1 to 4	1
Heat from air, water and soil	To be pumped with heat-pumps to higher temperature		10000	10 to 30	about 3

[1]) Insolation onto the surface of any kind of human settlements (10 million km²) and of all proper arid/desert areas (20 million km²) sums up to 165,000 EJ. In order to avoid undue regional climate change, only 1 percent of the absorbed light should be converted e.g. to electric energy – to be then often transferred over long distances. With an assumed conversion efficiency of 20 percent, the technical potential of light to be converted to electrical energy is limited to about 8000 EJ.

[2]) Including about 30 EJ of wood for non energetic use (timber).

[3]) Primary biomass food for 100 million tons of fish harvested annually.

Table 1.3. Annual worldwide demand on energy in units of EJ [91IPC].

Year	Energy sources	Primary energy	Secondary energy					
			Food	Total	Electricity	Liquid fuel transp. sector	High temp. heat	Low temp. heat
2000	"Natural": Biomass	700	20					
	"Technical": Total commercial and non commercial	415		300				
	- Commercial	385		295	55	63	87	90
	- Fossil				36	62	75	85
	- Nuclear				9	-	-	-
	- Renewable				10	1.3	12	5
	- Non commercial (Renewable: Firewood etc.)	30		5			5	
2050	"Natural": Biomass	800…1000	30					
	"Technical": Total commercial	500…700		400…500	70…90	90…100	120…150	120…150

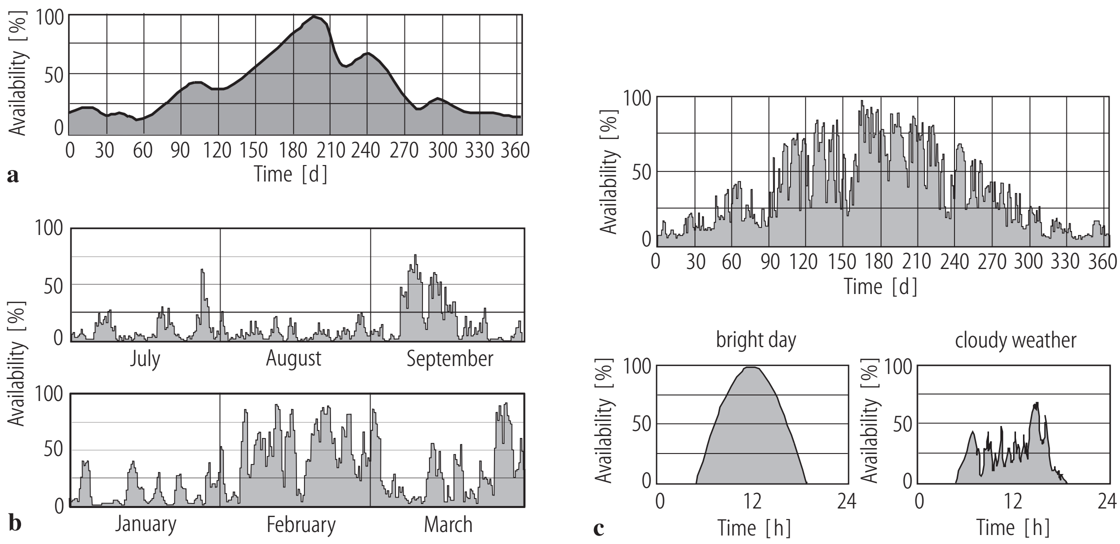

Fig. 1.1. Availability of electric power from different energy sources, restrictions and fluctuations in time. **(a)** River Hydro (Germany), see Sect. 2.2. **(b)** Wind (Germany: Coast to North Sea), see Chap. 3. **(c)** Photovoltaic Powerplants (Freiburg, Germany), see Sect. 4.2.

1.3 Technologies to convert renewable primary energy

As shown in Table 1.4, energy technologies – partially already available and partially still to be developed along the whole chain from basic scientific research via development and test to finally mature technologies – can offer a rich variety to convert most kinds of renewable energy into electricity, a decent variety to convert some kinds of renewable energy into heat and restricted possibilities to convert renewable energy directly into liquid fuels for the transportation sector (with some additional option to make use of electric energy and/or thermal energy and/or light to produce hydrogen as fuel by water splitting). Energy technologies still to be developed in basic and applied science are for instance

- low cost photovoltaics (aiming for investment cost of 0.5 US$/$W_{peak}$ and cost of electric energy of few to some cents/kWh);
- low cost hydrogen production possibly by means of photo chemical, photo biological or (solar) thermal catalytic splitting of water (aiming for H_2 fuel cost of 1US$/10 kWh heating value, i.e. similar price to 1 l of gasoline);
- low cost batteries to store electric energy (aiming for storage density of 1 kWh/kg battery and for investment cost of 5 US$/kg battery). Achieving this goal would allow to equip wind and photovoltaic power plants with their discontinuous power production to self sufficient systems of continuous provision of electric power;
- conversion of (low cost) hydrogen to (low cost) synthetic methanol as fuel in the transportation sector, which can easily be stored, distributed and kept on board of the vehicle;
- sufficiently low cost fuel cells (aiming for investment cost of 500 to 1000 US$/$kW_{el}$ for stationary power production and of 100 to 200 US$/$kW_{el}$ for mobile power production on board of vehicles) [see LB VIII/3A, Chapter 7: Fuel Cells];
- cheap desalination and purification of water (aiming for cost of 1 US$/ton of water) to allow enhanced growth of biomass for food and fuel by means of artificial irrigation.

The economic potential of renewable energy realized until 2000 is comparatively small reflecting both the limited availability (sunlight, wind) and the more or less prohibitively high cost for the relevant technologies compared to the provision of energy making use of fossil fuels. But there is hope for future breakthrough in the further development of new energy technologies, e.g. listed in Table 1.4. In the past,

Table 1.4. Survey of technologies to convert renewable energy into final energy demanded (■ technology available, □ technology to be developed).

Energy source		Conversion technology	Final energy			
			Electricity	Liquid fuel	High temp. heat	Low temp. heat
Hydro		Water storage powerplant	■			
		River powerplant	■			
		Tidal powerplant	■			
		Ocean waves powerplant	□			
		Ocean currents powerplant	□			
Wind		Rotor generator	■			
Sun	Non-focus. light	Conversion to heat				■
		Desalination of water ■□				
		Photovoltaics	■□			
		Photo chem. cat. H_2O splitting		□ (H_2)		
		Photo biological H_2O splitting		□ (H_2)		
		Thermal cat. H_2O splitting		□ (H_2)		
	Focus. light	Solar thermal powerplant	■			
		Solar chemistry			□	■
Biomass		Leftovers and waste	■		■	■
		Plants and trees	■	■	■	■
Earth heat		Natural Aquifers, natural wells	■			■
		Artificial boreholes	□			■
Soil/water heat		Heat pump				■
Electrical energy		Electrolysis of water		■ (H_2)		
Discontin. provision of electr. power by photovolt.		Storage of electricity in batteries (high electrical density at low cost)	□			
Hydrogen		Production via electrolysis		■		
		Production via catalytic H_2O splitting		□		
		Storage by liquification		■		
		Distrib. and transp. on board of vehicles		□		
		Conversion to synthetic fuel		□		
Hydrogen,		Fuel cells	■□			
Methanol			■□			

we had to rely on bright ideas and on materials provided by nature respectively mixed by experience or trial and error. There wasn't much knowledge of the micro and nano structure of the materials.

Nowadays we still need bright ideas, and hopefully some of these ideas may be triggered by learning from nature, especially from relevant processes of the metabolism of biological organisms. In addition, we start to have the scientific capacity to investigate the micro and nano structure of any type of material, even their properties under any type of stress. Furthermore we are able to develop powerful mathematical methods and can make use of computers e.g. to simulate new, really artificial materials and material compounds with the best desired properties up to the limits imposed by well known micro- and nanophysics of the materials, see [03Sie]. The properties of these new materials (e.g. heat conductivity and insulation, transport of electrolytes or catalytic efficiency) thus excel those of natural materials, which were not designed to comply with modern technical requirements but with natural needs.

1.4 Possible utilization of the different kinds of renewable energy

1.4.1 Hydropower to produce electricity

Only about 10 percent of the total water running off from the continents into the oceans could be used to generate electricity, and already half of it has been realized by now. Any realization of this potential has to be judged carefully by its positive and negative environmental impacts (see Sect. 2.1 to Sect. 2.4 and Sect. 2.7). Further possibilities of hydropower are tidal power, ocean waves and ocean currents. Tidal power offers a potential rather limited in size and location and restricted by high investment cost (see Sect. 2.5). Ocean waves and currents offer in principal a huge potential, but have a rather restricted energy density. Until now, any realization has been barred by the required enormous technical expenditures.

1.4.2 Wind energy

From the enormous potential of the wind blowing more or less steadily all around the globe within the atmosphere up to about 10 km height and more, only a small portion, mainly in coastal regions on- and off-shore up to about 100 m height, is accessible for use to generate electricity (see Chap. 3).

The main obstacle for any realization of the use of wind power is its intermittent availability: in most cases the temporal availability of wind power in coastal regions is limited *on shore* to around 20 percent of the total time, and *off shore* up to about 40 percent of the total time. A possible direct storage (see LB VIII/3A, Chapter 6: Batteries) or indirect storage (hydrogen, pumpwater storage, see Sect. 2.6) of electric energy can be realized only in more or less restricted amounts and at comparatively high cost.

1.4.3 Sun light

Insolation offers by far the largest potential of renewable energy to be used for producing heat (see Sect. 4.3), electricity (see Sect. 4.1 and Sect. 4.2) and fuels (see Chap. 6 and Chap. 7). But the energy density of insolation is relatively low (1 kW/m^2 at most), further strongly restricted by cloud coverage and by its daily and – outside equatorial regions – its annually temporal intermittency. Because of its temporal intermittency, using sun light as a source of primary energy to produce heat, electricity and fuels requires storing of the produced energy over daily (respectively annual) intervals which is rather expensive in most cases (see remark concerning storage in Sect. 1.4.2).

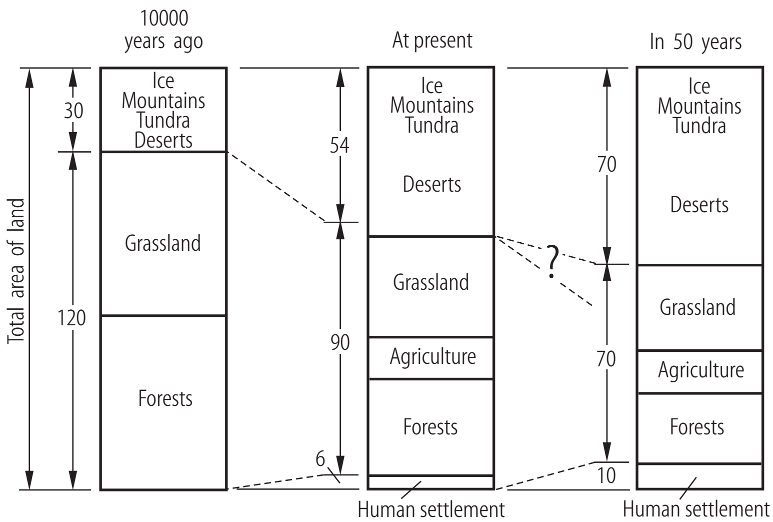

Fig. 1.2. Biomass: Available area of land (in million km^2).

1.4.4 Biomass

Biomass, more or less steadily growing in forests, grassland and cultivated land, is a rather appealing source of primary energy, more or less available everywhere and easy to be stored and distributed (see Sect. 5.1, Sect. 5.2 and Chap. 6). But the potential of biomass as a source of primary energy is strongly limited by the fact that the total "green earth" is already nearly entirely in use by mankind to provide food from grasslands/agriculture and timber, cellulose and firewood from forests (see Fig. 1.2).

Because of climate change, unsustainable management and overuse, the available size of "green earth" is expected to shrink further within the near future [00UNC]. Considering the rising demand of food and wood products by a still rising world population, biomass can therefore only become a growing source of primary energy if the present rise of desertification of "green earth" is stopped and arid zones are now recultivated.

The potential of biomass as a source of primary energy available at present is restricted mainly to biological waste and leftovers from forestry, wood industry, agriculture and food industry, which in total may contribute up to around 10 percent of the present demand of primary energy. Any further 10 percent contribution from biomass to the present worldwide demand of primary energy of 400 EJ would require harvesting biomass from about 150 to 300 million hectares of cultivated land. This area is equal to 10 to 20% of the present size of worldwide cultivated land.

1.4.5 Heat from earth interior

The potential of heat partially produced and stored in the earth crust of some 10 km thickness is extremely high. But the profile of temperature, rising on average only about 30°C per 1 km depth, is low. To harvest heat at temperatures of at least 100 to 200°C to be used for generating electricity in thermal powerplants, drilling down to many kilometers depth would be required. As this is rather expensive, the use of heat from the earth interior is still limited to natural wells of steam and hot water and to the harvest of heat at temperatures up to about 100°C from artificial boreholes in mostly deep aquifer layers (see Chap. 8).

1.4.6 Heat from water, soil and air

Heat from water, soil and air stored at rather low temperatures around 10 to 20°C can be harvested and pumped to useful higher temperatures around 20 to 40°C (especially for room heating) with heat pumps, operated by electric motors or by fuel burning engines (see Chap. 9). This way, the total amount of heat provided at the raised temperature level is about 2 to 3 times higher than the amount of energy spent to operate the heat pump.

1.4.7 Survey of main obstacles to increase the use of renewable energy by large

At present, the users' high demand of electricity, heat and liquid fuels at any time during day and night, in summer as well as in winter and everywhere at least in industrialized countries can be satisfied much more easily with fossil fuels than renewable energies with their often low energy density, their regionally and temporally restricted availability and the comparatively high cost for provision, storage and distribution of energy. Especially difficult is the provision of a sufficient amount of innovative liquid fuels for the transportation sector from primary renewable energy sources:

- To produce *hydrogen* as one of the two major options calls either for an additional amount of electric energy of the order of the total amount of electric energy consumed at present or for an equivalent amount of high temperature solar heat, which could be made available only in desert regions of high insolation at latitudes around the equator (see Chap. 7).
- To produce *methanol* as the other major option would require either an enormous amount of biomass to be harvested from areas as large as a major fraction of present day worldwide agricultural land (not available at present for this purpose) or the expensive synthesis of methanol from hydrogen and carbon dioxide (see Chap. 6).

1.5 Synergy effects of extensive use of renewable energy

Biomass and sunlight could be used in an interlaced way to provide

- food,
- water for drinking and artificial irrigation,
- timber and cellulose,
- energy.

Solar light (respectively heat) can be used to directly produce electricity and hydrogen fuel and furthermore to desalinate sea water and to purify contaminated water. This provides not only drinking water but also water for artificial irrigation to help stopping desertification and to allow recultivation of arid soils. This way, the production of biomass could be increased to provide ample food, timber, cellulose and fuel, especially for the transportation sector, to an extent sufficient to satisfy the needs of a still rising world population. But the necessary investment cost for such a worldwide enterprise would be high (a few times the amount of money spent today for the worldwide exploration and exploitation of natural oil and gas within a period of some decades), and a profit could only be realized within a time frame of many decades.

1.6 References for 1

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