27

Energy Needs for Sustainable Buildings and Transportation

Rehan Khan, Suchit Deshmukh, and Ritunesh Kumar

Discipline of Mechanical Engineering, Indian Institute of Technology, Indore, India

27.1 Introduction

Energy is the key ingredient for the process of development of human civilization. All life on the planet earth is made possible by solar energy captured through plants and passed through ecosystems. The rise of human civilization is marked by innovation and development in utilizing and acquiring diverse sources of energy. The human population is increasing at a rapid pace, and it has achieved the present level of 7.2 billion (Pimentel and Burgess 2018). The rate of our development and its furtherance are unarguably dependent on how efficiently we can harvest and utilize energy obtained from different resources. Different forms of energy like electrical, thermal etc. are required for applications like buildings, transport, industries and agriculture. The energy demand has increased tremendously since the mid twentieth century because of urbanization and industrialization. According to Figure 27.1, energy consumption has increased sharply from 1990 to 2012 by approximately 114% with a mean increase of 11.87% in every year. The energy consumption increase rate was the highest (~34% increase) in 2000–2010 owning to the industrialization boom (Leahy et al. 2013). The total energy is mainly utilized in three sectors: buildings (residential and commercial), transportation and industry. Globally the energy utilized in the transportation and building sector was around 33% and 35% of the total energy intake in the year 2010 (Nejat et al. 2015). With the global increase in population, the demand for energy will increase gradually and so too the CO_2 emissions. The increasing demand for energy in the future can be met through sustainable means. Sustainability is defined as patterns of economic, environmental and social progress that meet the needs of the present day without reducing the capacity to meet future needs (Randolph and Masters 2008). The chapter gives a comprehensive review of the sustainable and renewable energy development and utilization in the two major sectors: buildings and transportation, as these two sectors cover the maximum primary energy consumption.

Sustainability: Fundamentals and Applications, First Edition.
Edited by Rao Y. Surampalli, Tian C. Zhang, Manish Kumar Goyal, Satinder K. Brar, and R. D. Tyagi

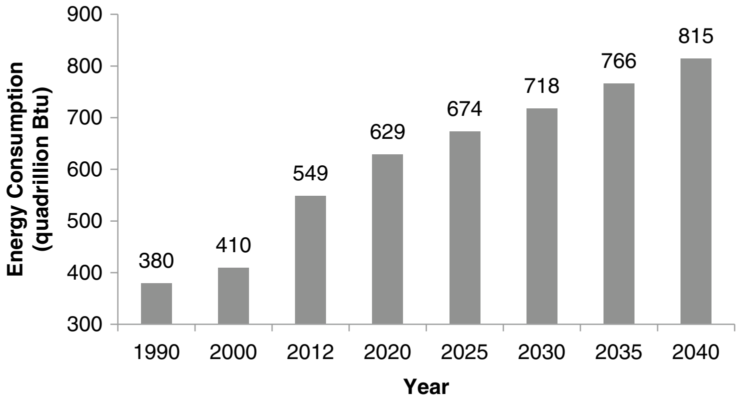

Figure 27.1 World energy consumption, 1990–2040 (Leahy et al. 2013).

27.2 Building and Energy

Building energy represents an indispensable part of the energy consumed globally. The energy intake for heating, cooling and ventilation accounts for approximately 15–20% of the energy consumed in buildings (Choudhury et al. 2010). Buildings are the largest energy-consuming sector in the world and account for an equal amount of CO_2 emissions (IEA 2013). With an expected increase in population, improvement in economy and standard of living, energy intake in the building sector is set to surge sharply, placing an additional burden on energy sector. Modern buildings consist of numerous advanced and sophisticated systems. These systems include structure, plumbing, lighting and heating ventilation and air conditioning (HVAC) systems. Air quality is one of the important parameters for maintaining productivity, health and comfort of occupants. The function of the HVAC system is to supply cool air during summer and warm air during winter. Development and promotion of low-energy buildings and zero-energy buildings is one of the emerging energy policies in many countries (Vanaga et al. 2018). The pursuit of sustainability has become the mainstream building design objective.

27.2.1 Solar Energy for Buildings

The largest demand for building energy is residential space heating and cooling followed by lighting. The design and orientation of building significantly affects the solar heat gain during summer and winter conditions. Use of window overhangs and window coatings that admit natural daylight and reject unwanted thermal gains are important techniques to minimize the cooling load and heating load.

27.2.2 Solar Angle to Help Design Overhangs

The sun rises in the east, reaches maximum height during the day time (solar noon) and sets somewhere in the west, and also the sun's height in the sky changes with latitude and with seasons. The length of overhang should be such that it allows the winter sun to enter our

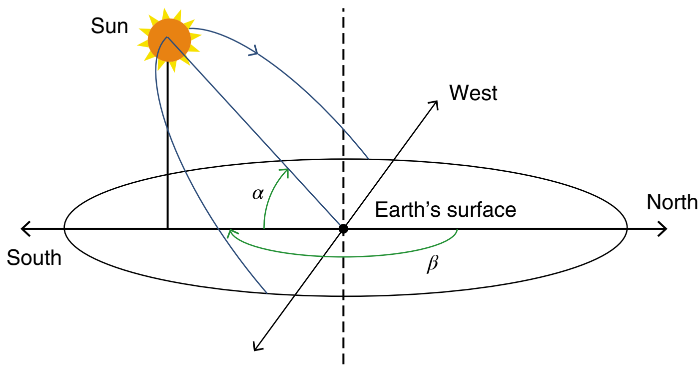

Figure 27.2 Solar angles: azimuth angle and zenith angle (Ferdaus et al. 2014).

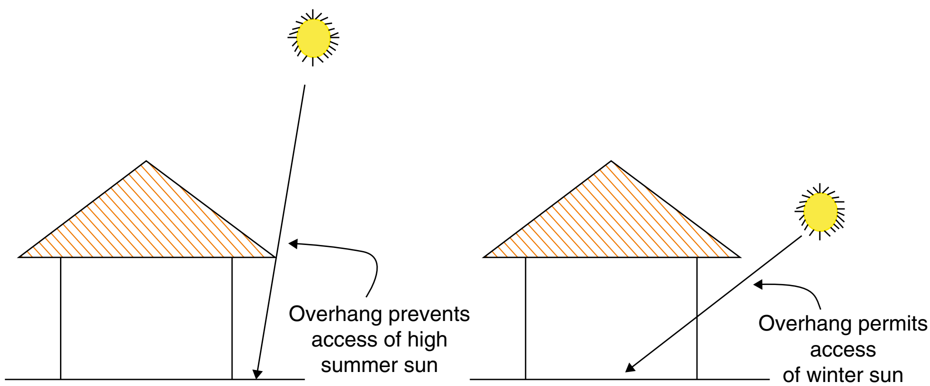

Figure 27.3 Overhangs.

home but blocks the summer sun's hot rays. The sun's height is at an angle called altitude (the angle of the sun height measured from the earth). Figure 27.2 shows the altitude and zenith angle of the sun (Ferdaus et al. 2014). The sun reaches its highest point in the sky around noon on the summer solstice (June 21, the longest day of the year) and lowest maximum height at noon on the winter solstice the shortest day of the year (December 21). To calculate the summer/winter sun altitude on the summer/winter solstice for any location the following equation is used: sun's altitude at noon on summer/winter solstice $= 90 \pm 23.5 - (\text{latitude})$. Figure 27.3 depicts that solar gains through south-facing windows are easy to control using overhangs, but east- and west-facing windows can cause overheating in the summer.

27.2.3 The Use of the Sun Path Chart

The sun path chart is a graph that shows the path of the sun as it moves across the sky during a typical day in each month. Figure 27.4 shows the sun path chart of the city of Indore. A sun path chart is essential for any site when designing building structures for light access, passive solar gain, and reducing glare and overheating. The abscissa is the azimuth or the direction that the sun is in from the observer. The ordinate is the sun's elevation or altitude.

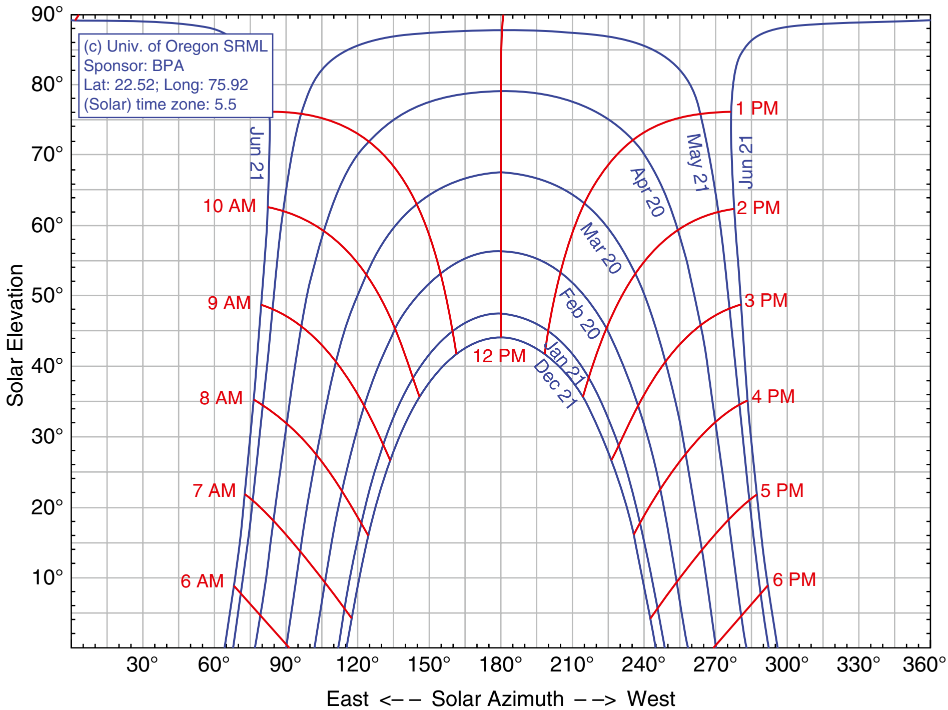

Figure 27.4 Sun path chart.

Each sun path chart is created for a specific location. To create a sun path chart for any location, the website http://solardat.uoregon.edu/SunChartProgram.html of the University of Oregon is especially handy. Sun path charts are helpful for doing quick site analysis to determine obstructions such as trees or building shadows in the proposed location.

27.2.4 Solar Radiation

Sun path and sun angle are useful, but in most cases it is essential to know the amount of solar radiation falling on a given location. The sun radiation intercepted by the earth varies according to the time, season and place. Solar radiation allows us to estimate the available solar energy for generating electricity, heating buildings and domestic water. Moreover, it is important to calculate the extra cooling load required during summer as much of the sunlight enters from the windows. Solar radiation (insolation) data have been compiled by the National Renewable Energy Laboratory in the US and are readily available on the internet.

27.2.5 Importance of Building Orientation

Wong and Fan (2013) suggested that it is vital to correctly orient a building so that it can receive a large amount of solar energy. Building location and orientation is a basic step to ensure that the building utilizes the available solar energy to the optimum. With rising

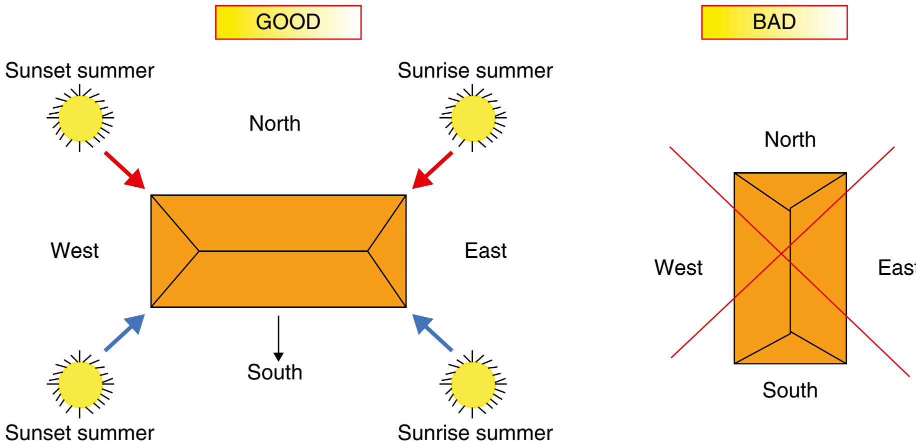

Figure 27.5 Building orientation along east–west direction (Randolph and Masters 2008).

energy costs it is becoming increasingly important for builders to orient buildings to capitalize on the sun's free energy. Properly oriented buildings will maximize the daylight through the building structure thereby minimizing the use of artificial light. Buildings that maximize daylight are ideal for implementing passive solar collection techniques to minimize electricity and enhance occupant comfort. A correct methodology can also reduce overheating and sun glare when sunlight is excessive. The relative position of the sun is a significant factor for thermal heat gain in buildings, which makes correct orientation of buildings a basis step in passive solar design. Figure 27.5 illustrates the importance of building orientation (Randolph and Masters 2008). A well-designed building makes the most of the available natural light without compromising energy efficiency. In summer it keeps cool and during winter it uses the sun's free energy to make it warm. The design and position of windows are critical to well-designed buildings. The fact that sun is higher in the sky during summer and lower in winter allows us to design and construct buildings accordingly. A building with its long axis along the east–west direction helps maximize solar gains in the winter while minimizing morning and afternoon solar exposure in the summer. Plants along the east and west sides can help control summer overheating without affecting winter solar gains. Abanda and Byers (2016) studied the impact of building orientation on energy consumption through various tools of Building Information Modeling (BIM). A correctly designed and oriented building can save a substantial amount of energy throughout its lifecycle. It was reported that a total annual energy cost saving of €878 for a period of 30 years with the best possible orientation of a building could be obtained.

27.2.6 Passive Solar Heating

Passive solar heating of building includes properly designed overhangs and reflective coated windows to provide comfort during the summer and cooling seasons. Passive solar heating is simple, cheap, reliable and affordable. It is simply encouraging the use of solar heat to pass through the window to gain the required heat. Passive solar heating maximizes the sun to the living area by aligning the length of the building along the east–west direction. This minimizes the need to heat rooms in winter and supplies more natural light. In summer when the sun is high in the sky, by designing the home with windows facing in the north direction and with proper overhangs, the home is covered with shade throughout the day. The sun does not stream into the north-facing windows, which keeps the room cool during summer. During winter the sun is at a lower height, meaning that it can penetrate through the window creating thermal gains and reducing the need for artificial heating. Once the design and orientation are right, it's important to shade it correctly so that in winter heat gain is obtained from the sun and in summer it is protected from the sun's hot rays. The basic design principles of passive solar heating are simple: (i) try to orient the building along an east–west axis to control solar gains; (ii) provide south-facing glazing systems to admit solar energy; (iii) provide well-designed overhangs to minimize natural daylight during summer; and (iv) provide adequate thermal mass to absorb excess solar energy in daytime.

27.2.6.1 Controlling Solar Gains with Better Windows

The design and selection of window glass should be such that it transmits the maximum light while blocking the thermal heat. Some of the solar radiation will bring visible light that helps to reduce the use of artificial light. The traditional approach in controlling solar heat gain in commercial buildings was to use either tinted or reflective glass. Tinted glass blocks the solar radiation by absorbing it making it difficult to sit next to it as it radiates heat; on the other hand, reflective windows eliminate the heating problem but unfortunately block most of the visible light wavelengths making it necessary to use artificial light. The most modern and sustainable approach for controlling solar heat gain is the use of smart windows. Several new windows made of different glass materials have been investigated by researchers (Alawadhi 2012; Liang et al. 2018). Liang et al. (2018) analyzed the performance of five different thermochromic windows for different climatic conditions of China. Thermochromic materials are temperature-sensitive materials that have the ability to regulate sunlight and thermal heat gain. When the temperature of the thermochromic materials becomes greater than its transition temperature, less solar radiation will enter the building. The authors reported that all different types of thermochromic windows could achieve both energy conservation and daylight. Alawadhi (2012) investigated the use of phase change material (PCM) in aluminum rolling window shutters through the finite element method. The motivation for using the PCM was to absorb solar radiation to minimize the solar heat gain. The performance of the PCM shutter was compared with aluminum foam shutters and it was found that the PCM shutter reduces heat gain by 23.29%.

27.2.6.2 Thermal Mass

Thermal mass is the ability of building material to absorb and store heat energy and radiate it when required (like a thermal battery). Heavy material has high thermal mass, which can be quite beneficial during a hot, sunny day. For example, concrete slab and masonry (high density material) walls absorb heat during hot sunny days and later on release it slowly by night, keeping the house comfortable. In winter time, thermal mass absorbs heat from the sunlight and releases it at night, keeping the home warm. It is particularly useful where there is a large difference between night and day ambient temperatures. Another promising approach to thermal mass is PCM where energy is stored as the phase changes. The state of the material changes from solid to liquid as it absorbs heat, and transforms back to liquid to give back the heat. PCM like hydrated calcium chloride absorbs 186 $kJ\,kg^{-1}$ when it melts at 27°C. It can store around 18 600 $kJ\,kg^{-1}$ when it changes phase at a density of 1500 $kg\,m^{-3}$ (Randolph and Masters 2008).

27.2.7 Climate Change and Buildings

In the past decade, there has been a sharp rise in CO_2 emissions due to various human activities. In the period between 2002 and 2011, CO_2 emissions rose by 54% because of human activities as compared to 1990 (Mazo et al. 2012). The increase in CO_2 emissions has created many hazardous situations like global warming, rises in sea level, increase in levels of ultraviolet radiation and change in rainfall patterns (Cellura et al. 2018). The energy consumption and carbon emissions of buildings are substantial. Therefore, efficient design of buildings will play a critical part in achieving low carbon emissions. According to the European Union (EU), 36% of CO_2 emissions are related to the building sector, which was addressed in the EU Directive on the energy performance of buildings. The lifetime of a building is approximately 50–100 years, which coincides with the timeline over which the climate is predicted to change; hence, in the future there is a need to develop more resilient and ecofriendly buildings.

27.2.7.1 Green Buildings

The amount of energy used for maintaining buildings is immense. Buildings use a large fraction of energy in heating, cooling, ventilation and lighting. Compared to green buildings conventional buildings are not as efficient in reducing the required amount of energy, while contemporary green buildings are superior both in carbon saving and cost saving. Green building uses 21% less energy than conventional building (Lin et al. 2016). The concept of green buildings has become popular worldwide. The harmful effect of construction on environment significantly promotes the concept of green buildings (Ding et al. 2018). These green buildings create less harm and do better, which creates a sustainable environment for all. The US Environment Protection Agency (EPA) says "Green building is the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's lifecycle: from siting to design, construction, operation, maintenance, renovation, and deconstruction." This practice expands and complements the classical building design concerns of economy, utility, durability and comfort. Green buildings are also known as sustainable or high-performance buildings. The features that can make a building green are: (i) efficient and economic use of energy, water and other resources; (ii) use of renewable energy such as solar energy and geothermal energy; (iii) comfortable and healthy indoor air quality; (iv) use of smart and non-toxic materials; (v) reduction in pollution, waste management and recycling; (vi) environment and ecological consideration in design, operation and construction of buildings; and (vii) sustainable design that can adapt with changes in the environment.

Green buildings are thermally more comfortable than conventional buildings. Hong et al. (2009) found that conventional buildings over 15 years old are half as comfortable as green buildings that are less than 15 years old. Building environment and indoor air quality affect the health of occupants. The primary cause of harmful ailments like asthma is indoor air quality and building environment (Singh et al. 2010). According to Abbaszadeh et al. (2006), green buildings have better indoor air quality compared to conventional buildings. More light obtained in green buildings increases the productivity and eliminates the need for artificial light. A study was conducted by Freed (2006) on how much sunlight enters the student-based classroom. The study concluded that student exam scores were 15% higher with classrooms lit by natural sunlight. The need for green buildings is felt globally more than ever; carbon emissions, increasing energy cost and human health are at stake. A strong environmental policy is needed to create good environments and to promote the rapid development of green buildings.

27.2.7.2 Advantages of Green Building

The advantages of green building include: (i) environmental benefits (e.g. reduction in energy consumption; reduce wastage of water and other resources; improved air quality; environmental and ecological protection); (ii) economic benefits (e.g. reduction in operating cost of systems; improvement in occupant productivity); (iii) social benefits (e.g. improvement in quality of life; better health and comfort of occupants).

27.2.7.3 Building Energy Ratings (BERs)

BER measures the energy performance of a building and is based on assessment of the energy use for space heating and cooling, ventilation and lighting for standard occupancy. The rating is expressed in the form of performance bands from A to G, with “A” being the most energy efficient and “G” being the least energy efficient.

Certain measures can be taken to improve BER and reduce annual energy bills. Some simple measures are: (i) insulating hot water tanks and pipes; (ii) installing energy-saving electrical equipment like compact fluorescent light bulbs; (iii) increasing insulation in walls and floor; (iv) replacing old inefficient systems with improved efficient systems (boilers); and (v) using renewable energy heating systems.

27.2.8 Heating Ventilation and Air Conditioning Systems

Although solar passive gains and improvement in structural design of buildings provide solar heating during winter and alleviate thermal gain during summer, still some kind of heating and cooling mechanism is needed to maintain the required comfort level. A major portion of the energy for cooling/heating load in many countries is expended in dehumidifying/humidifying the ventilation and infiltration air. Traditionally, the cooling and heating requirement is fulfilled by a vapor compression system. The fundamental components of a vapor compression system are condenser, evaporator, expansion valve and compressor. These systems are based on a closed-cycle system, where a fixed amount of working fluid known as refrigerant continuously flows through each component. A large amount of energy is consumed through the vapor compression system to achieve the required comfort condition. The energy intake for the heating and cooling system can be reduced effectively by integrating these systems with solar energy and geothermal energy.

27.2.9 Solar Collectors

Solar radiation can be utilized effectively to meet a portion of the hot water demand for domestic water heating. A solar thermal collector is a device that absorbs solar radiation and converts it into a more usable and restorable form. The solar collector transfers sun energy into thermal energy that can be used to heat water.

27.2.9.1 Flat-Plate Solar Collectors

A simple flat-plate solar collector is the heart of most hot water systems. The collector consists of a black absorber plate with a circulating tube attached at the back of the plate. The tube and the plate are kept in a casing and covered with glass to allow the ingress of sunlight. A pump or sometimes natural gravity causes the water to circulate from the storage tank to the collector. Solar flat-plate collectors tend to be more cost effective due to their simple design. Solar flat-plate collector may come with many possible options. They may have single glazing, double glazing or no glazing; or selective surfaces to absorb maximum solar radiation.

27.2.9.2 Evacuated-Tube Solar Collector

This new and quite exciting type of solar-evacuated collector consists of an absorber plate placed inside a cylindrical glass tube filled with a vacuum. The vacuum eliminates the conductive and convective loss from plate to glass, greatly improving the efficiency of the collector. To transfer thermal energy to circulating water these systems use a heat pipe filled with fluid. At higher temperatures the fluid evaporates and moves to the header position where heat is transferred to the water.

27.2.10 Solar Heat Pump System

The basic work of a solar collector is to absorb solar radiation in the form of heat. It comprises fluid running inside a pipe attached to the absorber plate. The working fluid absorbs the energy, which is transferred to a heat pump through an indirect intermediate heat exchanger. The heat pump transfers energy from a cooler region to a warmer region. In a heat pump cycle, the heating effect is obtained as the working fluid is cooled to a liquid state in condenser. Figure 27.6 shows the working of a solar-assisted heat pump. A Solar-assisted heat pump is the integration of a vapor compression heat pump and a solar thermal collector. The heat pump and solar collector are connected through an intermediate heat exchanger to transfer solar energy. The heat pump includes elements such as a condenser, expansion valve and evaporator (intermediate heat exchanger). The solar system comprises a solar panel, pump and intermediate heat exchanger. The working fluid in the solar system, e.g. water or glycol, feeds the solar energy to the refrigerant (R-134a) flowing in the evaporator of the heat pump. After evaporation, the refrigerant rejects heat during condensation in the condenser. The evaporator operates at higher temperatures, improving the coefficient of performance of the system. The advantage of combining a solar system with a heat pump is to improve the performance of the subsystem, which eventually increases the performance of the solar heat pump system as a whole. The system works in the presence of solar radiation; hence, in its absence, an auxiliary heat exchanger can be used.

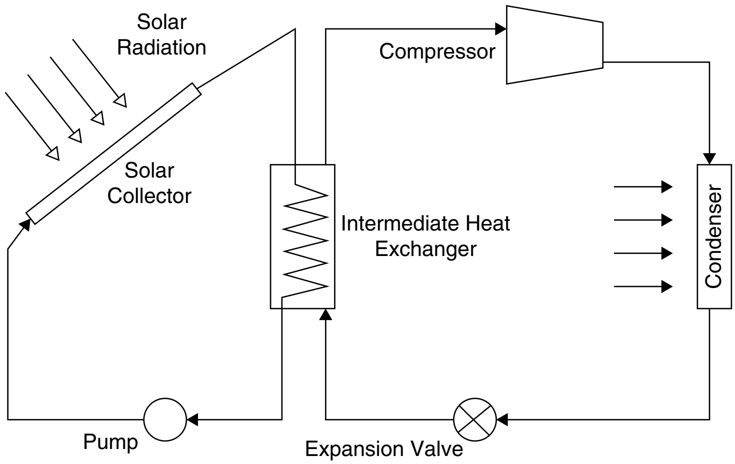

Figure 27.6 Solar heat pump.

27.2.11 Solar Domestic Water Heating

A solar water heater is a device used to heat water by trapping the infrared solar radiation. A number of options for solar heating system are available. The difference is how the water is transferred from solar collector to the storage tank. Figure 27.7 shows passive and active solar water heating systems. Thermosiphoning (passive) systems eliminate the use of pump and controller by placing the storage water tank above the solar collector. Cold water enters the collector while the hot water rises unassisted from the solar collector to the tank. The tank might be placed on the roof with the collector (closed-couple system) or within the roof cavity above the collector (gravity feed system). The system may consist of a simple flat-plate collector or an evacuated-tube collector. The evacuated-tube solar collector enjoys the advantage of receiving solar radiation orthogonally for most the day and, combined with their vacuum insulation, means better performance. The flat-plate collector, particularly used in a closed-couple system, is more affordable than evacuated-tube collectors. However, the prices of evacuated-tube collectors have decreased in recent years. In the active system, a small pump is used to move water from solar collector to tank. The location of the tank can be on the ground or within the roof. A passive system is space saving and has no moving parts, while an active system uses a pump with flexible tank position. During winter the solar collector needs to be protected when the temperature dips below the freezing point of water. The freezing water expands and can easily break the solar collector with potentially harmful consequences. Non-toxic antifreeze such as propylene glycol can be used to prevent freezing of water in winter conditions (Randolph and Masters 2008).

27.2.12 Geothermal Heating Systems

Geothermal energy means the energy available under the earth's surface. Geothermal energy is the thermal heat from the earth's crust. It is a clean and sustainable source of

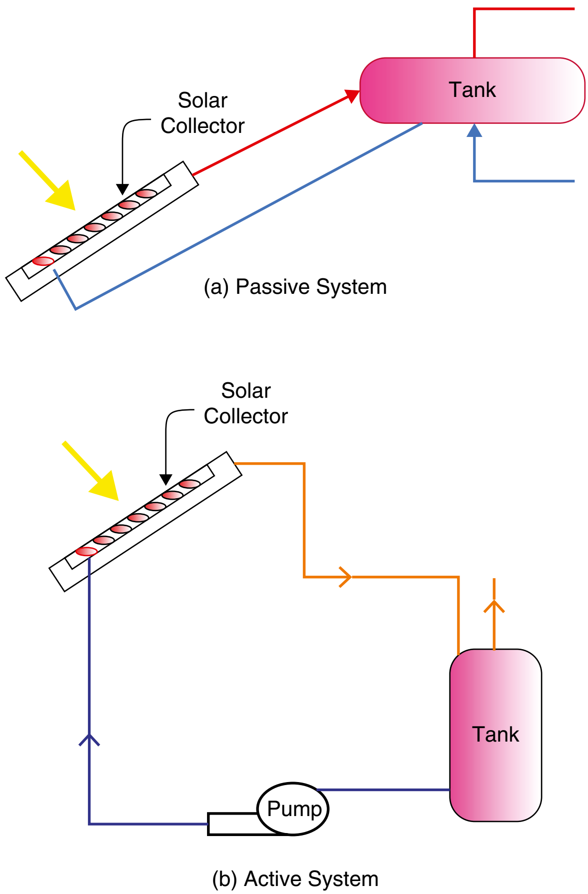

Figure 27.7 Passive and active system.

renewable energy, and it is constantly available. Heat from the earth's crust warms up the available underground fluid. In some places when the water becomes hot enough it can break through the earth's surface as steam or hot water. The atmosphere of the earth keeps on changing with respect to the weather conditions, but deep inside the layers of earth, the temperature is almost constant. Geothermal energy utilization in building will mitigate carbon emissions and will also save energy. Thus, geothermal energy can be effectively utilized to meet the future energy needs of the heating and cooling of buildings. One of the promising applications of geothermal energy is the earth-air heat exchanger. Figure 27.8 shows the schematic of an earth-air heat exchanger (ground-coupled heat exchanger). In this technology, a pipe is installed inside the earth up to certain depth. Air flows inside the pipe taking away the thermal energy from the earth, which is subsequently utilized for cooling and heating depending on the need. Depending on the requirement the fluid can be either air or water. In the case of air, it can be directly supplied to the conditioned space. The performance of the heat exchanger depends on the properties of soil (De Paepe and Janssens 2003).

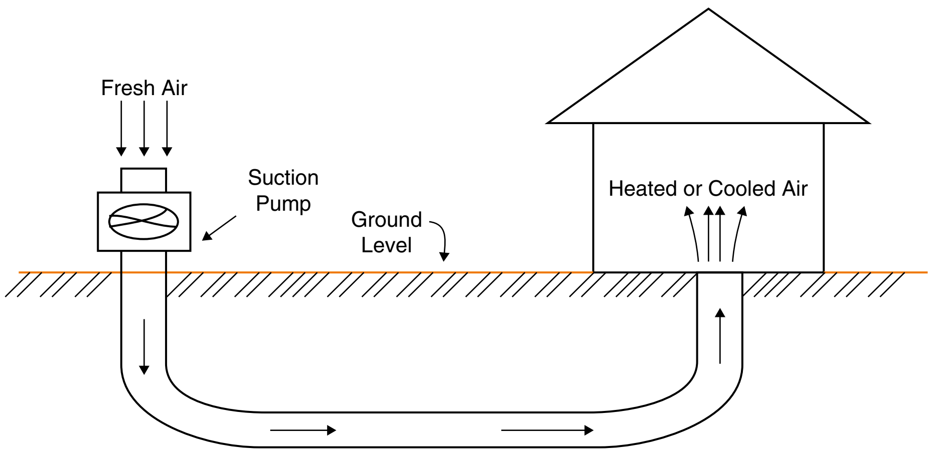

Figure 27.8 Geothermal heat exchanger.

27.3 Energy for Transportation

For sustainable development, the transport sector plays a vital role from the viewpoint of energy security as well as emission concerns. A lot of investment is being made in this sector as energy demand will rise at a faster pace because of the increasing need for transportation in the developing world. The transport sector energy demand is expected to increase to 3400 million tons of oil equivalent (mtoe); more than 80% of this energy need will be satisfied by oil as a primary source. It can be seen from Figure 27.9 that the share of oil was highest (31%) in terms of global energy demand compared to other sources (International Energy Agency 2016). It will reduce to almost 27% in 2040 but still maintaining its highest consumption status. The other renewables will see the highest relative growth in future energy scenarios. The demand for oil will rise to 103.5 mb day^{-1} in 2040 from 90.6 mb day^{-1} in 2014, out of which, around 55% was used for the transport sector in 2014 (Figure 27.10) (International Energy Agency 2016). This grows to 58% in a future scenario, with 60.4 mb day^{-1} of oil required for transport alone. Most of the increase in energy demand of the transport sector is due to road transport, though other modes of transport like rail or aviation continue to grow at a steady pace.

Crude oil is readily available fuel. There are well-established facilities for its extraction and processing. However, there is a rising concern about its availability in the near future considering its non-renewable nature, environmental and health problems due to the emissions. In addition to this, countries like India have to rely on a select few crude oil-exporting countries that control the per barrel rate of crude oil. There is a lot of debate going on regarding the future of the transportation energy supply. This brings us to the idea of sustainable development of the transportation sector. Sustainability analysis is necessary to assess the ability of different fuels to satisfy current and expected energy needs without compromising the ecological balance. This assessment should consider the environmental, economic, social and technological aspects. Efforts are being made to find new and renewable alternative fuels that not only can contribute to the demand–supply equation but also

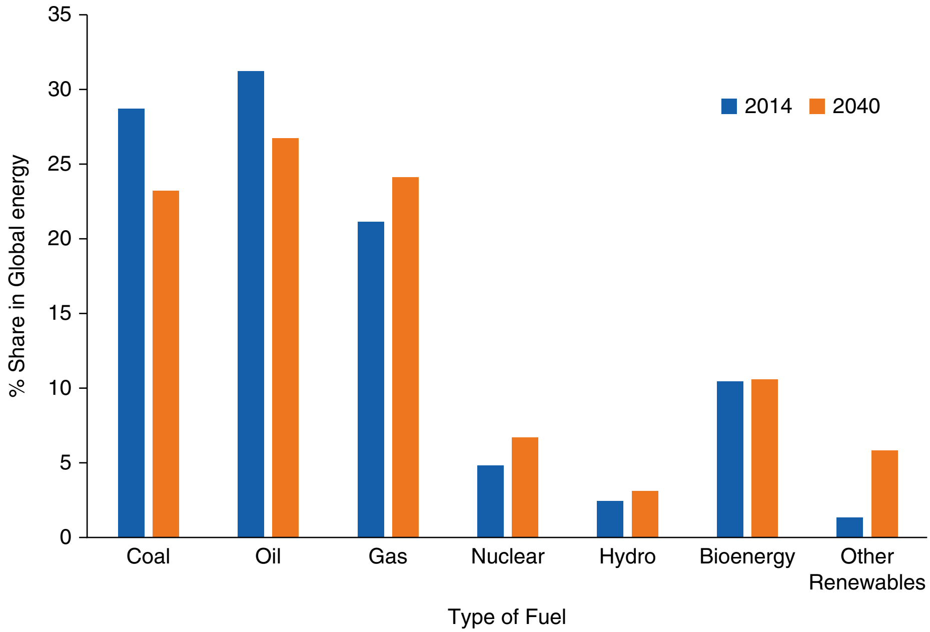

Figure 27.9 Percentage demand for different sources of energy.

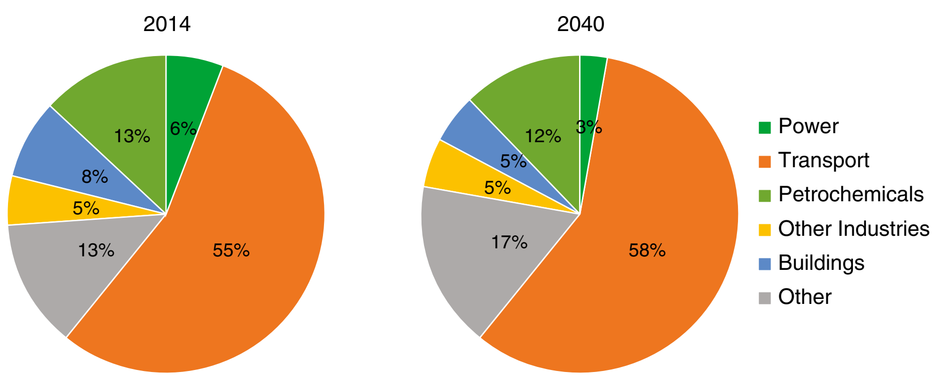

Figure 27.10 Use of oil in different sectors.

will be sustainable in nature. The government policies in this regard are crucial factors in the support of biofuel programs in countries. The demand for biofuels is expected to grow to 4 million barrels of oil equivalent (mboe)/day in 2040 – almost three times the current use. Keeping this in mind, the following paragraphs discuss different alternative sources of fuels for the transport sector considering mainly road transport. Battery-operated vehicles have also been covered briefly as they are being considered as the next big thing in the automobile industry. The pros and cons of them will help in comparisons of the future of the transport sector.

27.3.1 Biodiesel

Biodiesel is a mono alkyl ester of long chain fatty acids obtained from edible and non-edible oils as well as animal fats. It is an alternative fuel to diesel owing to similar thermo-physical properties. It is a clean, renewable fuel with less carbon monoxide, unburned hydrocarbon and smoke, net carbon dioxide and sulfur emissions (Atabani et al. 2012). It is not entirely new technology as Rudolf Diesel himself tested his engine with vegetable oil. However, cheap and readily available petroleum products became favorable, and the use of vegetable oil as a fuel remained just an idea. The current increase in crude oil prices and fear for their long-term availability has brought back the concept of use of oils as a fuel. As the oil has high viscosity compared to diesel fuel, a reaction called transesterification is used to convert oil into biodiesel. It is a reaction of triglyceride with methanol in the presence of a catalyst (acid or base), which form biodiesel and glycerol as a byproduct. The use of acid (H_2SO_4) or base (NaOH) catalyst mostly depends on the content of free fatty acids (FFAs) in the oil or animal fat. The reaction is carried out at around 60°C with continuous stirring. The conversion efficiency of oil to biodiesel is fairly high when the reaction is properly optimized for various parameters, namely ratio of alcohol to oil, catalyst used, time, temperature and mixing intensity (Meher et al. 2006).

As already stated, chemically, biodiesel is a mixture of different fatty acid methyl esters. The fatty acids can be divided broadly into saturated and unsaturated fatty acids based on whether they contain a double bond or not. The fatty acid chain length in biodiesel also varies from 12 to 24 carbon atoms. Physical properties like viscosity, density heating value, etc. will be dissimilar for different fatty acids. Saturated and unsaturated fatty acids have both favorable and unfavorable properties (Knothe 2005). Therefore, biodiesels have varying thermo-physical properties that depend on their fatty acid composition. These properties determine how well the fuel can be utilized in the diesel engine in terms of combustion as well as emission parameters. For example, biodiesel obtained from palm oil has a large percentage of palmitic acid (C16 : 0) so the saturated fatty acid content is very high. Therefore, palm biodiesel has better cetane number, density and oxidation stability but has inferior viscosity because of the higher saturation content.

Despite the various advantages of biodiesel, the source of oil for biodiesel is key in making the fuel viable as an alternative to diesel. Table 27.1 presents the potential yield of different sources of biodiesel. The biodiesel source should not only provide biodiesel in abundance so that the growing need for energy is satisfied, but also the quality of the produced biodiesel should be in accordance with the established norms like ASTM D675 or EN14214.

Initial biodiesel sources are called first generation sources of biodiesel. They are mainly edible oil plants like soybean, sunflower, etc. Since they pose a problem of food vs fuel security, it was later decided to switch to second-generation biodiesel sources like Jatropha, *Pongamia pinnata*, etc. They have the advantage that they are non-edible oil sources and can grow on waste land, therefore do not compete with food crops. They also produce biodiesel with a good mix of saturated and unsaturated fatty acids making them favorable for most of the properties. However, researchers have reported that second-generation biodiesel sources do not have the potential to satisfy the demand–supply equation of diesel vehicles. Recently, microalgae have been regarded as a third-generation source of biodiesel with vast potential to replace fossil fuel consumption

Table 27.1 Estimated oil yield from different feedstocks (Atabani et al. 2012).

Feedstocks	Oil content (%)	Oil yield (l (ha year^{-1})$^{-1}$)
First generation		
Sunflower	25–35	952
Soybean	15–20	446
Palm	30–60	5950
Second generation		
Jatropha	35–40	1892
Jojoba	45–50	1818
Calophyllum inophyllum	65	4648
3rd generation		
Microalgae	30 (low oil content)	58 700

because of the high growth rate and high oil-yielding potential. Figure 27.11 shows the main stages of biodiesel production through microalgae. Table 27.2 presents the oil content of different species of microalgae. The photosynthetic ability of microalgae is very high, consuming CO_2 at a very high rate. Thus, they help in reducing atmospheric CO_2 emitted from industries and power plants. They can be grown in water in tanks or specially designed photo bioreactors. Simultaneously, they can be grown in wastewater for phycoremediation. Such a beautiful scenario of microalgae biodiesel is hindered by some challenges in the efficient biodiesel production process. Even though the growth rate is high, harvesting of the biomass from water is difficult. The harvested biomass needs to be dried before oil extraction, which itself needs innovative techniques as the conventional expeller press oil extraction technique will not work in the case of dried microalgae powder. The advanced techniques that are applied for microalgae

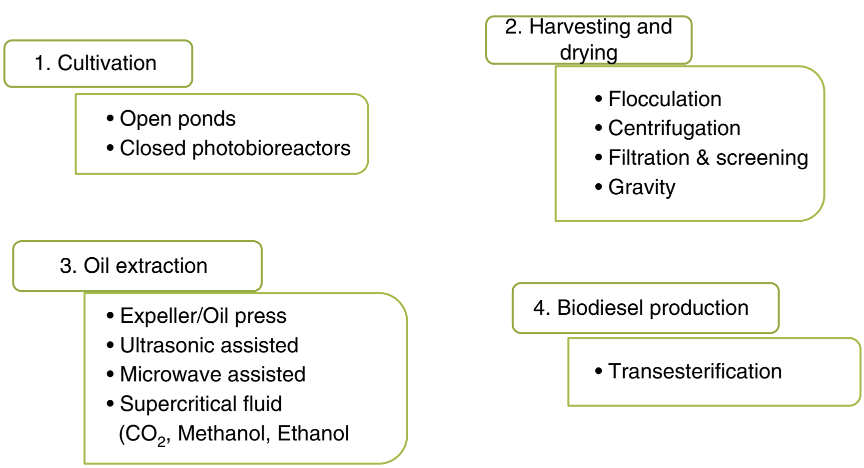

Figure 27.11 Microalgae biodiesel production process.

Table 27.2 Oil content in different microalgae species (Illman et al. 2000; Mata et al. 2010; Rodolfi et al. 2009; Yoo et al. 2010).

Microalgae species	Oil content (%)
Botryococcus braunii UTEX 572	20.8
Chaetoceros calcitrans CS 178	39.8
Chlorella vulgaris CCAP 211/11B	5.4–14.9
Chlorella emersonii CCAP 211/11N	8.1–49.9
Chlorella sorokiniana IAM-212	44.7
Isochrysis sp. (T-ISO) CS 177	37.7
Nannochloropsis CS 246	49.7
Scenedesmus sp. KCTC AG20831	20.7
Ankistrodesmus sp.	24.0–31.0
Chlorococcum sp.	19.3
Dunaliella salina	6–25
Pavlova salina	30.9

oil extraction include the use of ultrasonication, microwaves, supercritical fluid like CO_2 and ionic liquids. These processes, along with harvesting, require additional energy, which can make the net energy output of the microalgae biodiesel production process negative. Many companies are doing research and many of them are making claims about the high yield potential of microalgae biodiesel and that they can produce it economically. But almost all of them are still not able to commercialize the product to a satisfactory level. The microalgae biodiesel production process will be economical only when it is combined with other applications such as wastewater treatment, CO_2 sequestration from flue gases and production of other valuable products such as pigments.

From the sustainability point of view, many lifecycle analysis studies have been carried out to determine the net energy output of the biodiesel production process. Lardon et al. (2009) studied the microalgae biodiesel production process with normal fertilizer and nitrogen stress conditions. They also considered dry and wet oil extraction methods. They underlined that microalgae biodiesel seems promising but only if we reduce fertilizer cost and energy required for the oil extraction process. Out of the total energy consumed in the biodiesel production process in their work, about 70–90% was utilized for the oil extraction process alone. Dutta et al. (2016) also carried out a lifecycle analysis study of microalgae biodiesel and stressed the idea of reducing cost by using wastewater for microalgae growth and production of value-added co-products along with biodiesel. Oil extraction and recovery of solvent also play a crucial role in economics as well as in greenhouse gas emissions. A lot of technological advancement is needed to produce microalgae biodiesel at a large scale economically, which should also address the environmental concerns. Already stiff competition has arisen in the form of battery-operated vehicles wherein government policies and investment from many automobile companies are overshadowing biodiesel's viability.

27.3.2 Ethanol

Ethanol or bioethanol is obtained from biomass by fermentation of sugar. Its applications include use as a solvent, as an intermediate material for production of chemicals and use in the beverage industry. It is also used as a raw material in the cosmetic and plastic industries. Notably, it is one of the chemicals used in very large volumes. It is a clean-burning chemical with a high octane rating owing to the presence of oxygen. As it can be obtained from biomass, bioethanol is a renewable source of energy. Its easy miscibility with gasoline fuel makes it a suitable candidate for use as a blend in gasoline-powered vehicles. Blending 10% ethanol in gasoline will increase its octane rating by three (Sakthivel et al. 2018). This will also offset the reduced energy output because of the lower heating value of ethanol. This will make a considerable saving in fuel and allow the gasoline engine to operate at a higher compression ratio (CR) just like its diesel counterpart. The improved combustion due to ethanol addition results in lower emissions; hence, the blend is suitable for recent stringent emission norms. In current engines, up to a 20% ethanol blend in gasoline does not require any modifications. Complete replacement with ethanol as a fuel in gasoline engines will require some changes to the engines. Rather than modifying the existing engines, it is advised to specially design engines to run on ethanol fuel. Interestingly, ethanol can also be used in diesel engines, and many researchers are exploiting the use of diesel–biodiesel–ethanol blends in engines for possible reduction in emissions (Zhu et al. 2011). The miscibility of ethanol in biodiesel makes the above blend easy to form, and it remains stable for a sufficient amount of time depending on the concentration of ethanol and biodiesel. The low viscosity and low vapor pressure of ethanol lowers the overall viscosity and vapor pressure of the blend compared to that of a diesel–biodiesel blend. Therefore, it improves the fuel spray and atomization characteristics and helps in complete combustion and reducing emissions.

In India, in order to reduce the strain on foreign currency reserves and to reduce the pollution levels of highly populated cities, the government has recognized the potential of ethanol as an alternative fuel at the start of this century and accepted an ethanol-blended petrol program since 2003. Brazil adopted an ethanol fuel policy a long while back and has achieved phenomenal statistics since then. It’s a leading country in terms of the use of ethanol as a fuel, with the primary source being the sugarcane industry. The USA is also a top manufacturer of ethanol; together these two countries produce 86% of total ethanol production in the world (Sakthivel et al. 2018). The total capacity of India’s ethanol production is 2.3 billion l as of 2015 according to the Indian sugar mills association, lagging behind the top producing countries by a large margin. Out of this, only around 30% is used for gasoline blending. With this statistic, the country’s aim of reducing oil imports by use of alternative fuels seems a distant dream.

The technology to produce ethanol is not new as it has been known for thousands of years. Ethanol is produced mainly by fermentation of sugar. Therefore, it requires a resource that has sugar, which includes material like sugar cane. Apart from this, a material like starch or cellulose can also be used for ethanol production by converting it first into sugar and then fermenting it into ethanol. This includes feed stocks like corn or grains. This requires an additional step called hydrolysis. Even though the fermentation is a simple and well-established process, use of ethanol as a fuel produced by this process is ill-advised because the raw material is costly and also it will give rise to the food-versus-fuel issue. An integrated approach where, along with ethanol, other products are also produced is a key to make the process beneficial. The fermentation requires specific microorganisms and the reaction slightly differs based on what sugar molecule is used. One mole of glucose gives two moles of ethanol and two moles of CO_2. The reaction of xylose is not straightforward and can proceed in different pathways. One mole of xylose can give two moles of ethanol, one mole of CO_2 and one mole of water. Other possible pathways are: three moles of xylose produce five moles of ethanol and five moles of CO_2; or three moles of xylose can also produce four moles of ethanol and seven moles of CO_2. Any material containing cellulose can be used for the above process. The efficiency of the production of ethanol of the above processes ranges from 40–60% on mass basis, but it also produces CO_2, whose disposal can lead to further problems as it is a greenhouse gas. The other feedstock that can be used for the above process is waste from agriculture and industries that contain sufficient amounts of cellulose or starch. The amount of such waste produced in the world is tremendous.

The other method of ethanol production uses lignocellulose material. It is a cheap source as it consists of material mostly obtained from agricultural residue and waste, forest residue and waste, industrial and municipal waste, but the conversion to sugar is complex because of the structure of lignocellulose. It consists of three components, namely crystalline cellulose, hemicellulose and lignin. The first two components, which are used for ethanol production, are attached to lignin by different bonds. This makes the structure complex and difficult to depolymerize. The lignocellulose biomass is first processed for preparing slurry by the addition of water. Drying or grinding is done if necessary. The slurry is pretreated by biological, chemical or physical means to break the complex structure to separate cellulose, hemicellulose and lignin so that the former two are available for hydrolysis. This step is expensive but essential otherwise the complex structure of lignocellulose does not permit hydrolysis easily. The hydrolysis breaks the cellulose and hemicellulose into sugars and then the production of ethanol proceeds by fermentation. Compared to the use of material like sugarcane or corn, use of lignocellulosic biomass does not produce the fuel-vs-food issue, and separate land requirement is also not necessary. The potential of lignocellulosic biomass is high for bioethanol production with an estimated value of 442 billion l every year including forest residue (Zabed et al. 2016). Still, due to lack of technological advances, use of lignocellulosic biomass for ethanol production needs further research. The production of ethanol can be summarized in Figure 27.12.

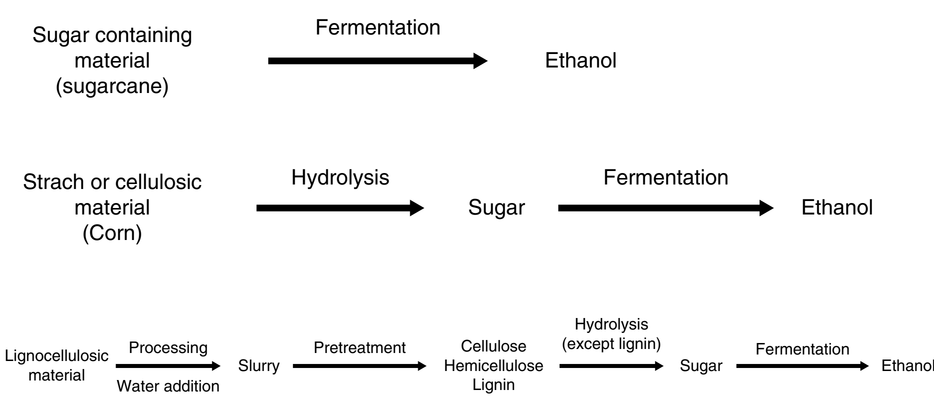

Figure 27.12 Ethanol production pathways from different feedstocks.

To make ethanol a viable alternative fuel, the energy requirement of the production process is a key factor. Lifecycle analysis studies done in the past propose ambiguous results with some expecting net energy output of the process to be positive while others are suggesting some additional steps for the process to yield positive net energy. The cost required for transport of raw material is also important as reducing it would drastically reduce the production cost of ethanol. More studies with the complete scenario considered could help solve these problems.

27.3.3 Electric Vehicles

Electric vehicles (EVs) are an alternative to traditional gasoline- or diesel-powered vehicles. A significant and straightforward advantage of EVs is an emission-free and noiseless drive as compared to traditional vehicles. It has very few moving parts, does not require frequent oil change and lubrication. This reduces the maintenance cost drastically.

The EVs are of two types, namely all-EVs and plug-in hybrid vehicles. All-EVs use only electricity as a fuel source with a battery and electric drive as two main components. The plug-in hybrid EVs use both electricity and conventional fossil fuels. Electricity can be used for the required range and when the battery is about to be fully discharged, international combustion engine mode can be switched on and the vehicle now runs as a conventional vehicle. In both these types, the battery needs to be charged by connecting it to external power source or grid. The charging time depends on what type of charger and battery the owner of the car is using. The current technological advancement in the area of battery technology is driving the vehicles to go all electric instead of hybrid vehicles. Tesla motor is doing pioneering work in this field with many of its all-electric models currently running successfully in most areas of the world. To fulfill our future energy demands for road transport, EVs are claimed to be the only possible solution by many experts and researchers. This is not only because of the development in electricity generation capacity of many countries, but also because of the mere simplicity of the EVs. After the initial hiccups, the EV industry is now taking a big leap. The power required for EVs is in the form of electrical energy. Currently, in India, most electricity generation is done by using coal. However, even if we consider that energy for EVs is coming from coal thermal power plants, the types of emissions produced are still different; their place and timing is beneficial to us considering the pollution of vehicles in the middle of the city. Environmental concerns are forcing the use of cleaner unconventional sources of energy for the generation of electricity. These sources include solar, wind, nuclear and hydropower. In a scenario in which these cleaner energy sources are used for electricity and this electricity is used for charging of EVs, the emissions of the process are near zero.

Including the maintenance cost, the operational cost of EVs is actually less than that of internal combustion engine-powered vehicles. Also, the better torque speed characteristics of the electric motors make them more responsive to drive. However, there are still some glitches that need to be addressed. The current capacity to produce batteries in the world is not sufficient to replace all the conventional vehicles. The Giga factory of Tesla may help solve this issue. The extraction of raw material used for the production of lithium ion batteries produces certain issues like land and policy conflicts, environmental problems and local labor issues. Hybrid EVs seem to be a promising alternative for now until we are ready to completely shift to fully EVs.

27.4 Conclusions

Energy security is vital for both the building and transport sector as fossil fuels do not fall under the category of renewable and sustainable fuels. The aforementioned sources of energy (biofuels, batteries, geothermal and solar energy) are slowly making their way into the energy demand for building and transport. However, there are some challenges and hurdles to overcome. The world is skeptical about whether biofuels and solar energy can actually meet our energy demands at affordable rates. The concept of green building is promising but at a fairly large capital cost. In the case of third-generation biofuels like microalgae, the economic analysis of its production stages illustrates discouraging statistics. The space requirement for solar equipment installation and biofuel production is tremendous. Therefore, we cannot afford to lose too much land to producing biofuels and renewable energy. Certain concrete steps, both research- and government policy-driven may help solve our energy problems by use of biofuels and renewable energy. EVs also have their share of disadvantages such as the battery weight is quite high for high-powered vehicles, current lack of charging infrastructure, battery production capacity and need of thermal management as batteries tend to overheat. The use of solar collectors and passive solar heating are efficient to alleviate the electricity consumption. Overall, sustainable development of the building and transport sectors is possible but there are still many miles to cover before we reach our desired goals.

References

Abanda, F.H. and Byers, L. (2016). An investigation of the impact of building orientation on energy consumption in a domestic building using emerging BIM (building information modelling). *Energy* 97: 517–527.

Abbaszadeh, S., Zagreus, L., Lehrer, D. and Huizenga, C. (2006). Occupant satisfaction with indoor environmental quality in green buildings. Proceedings of Healthy Buildings 2006, Lisbon, 3, pp. 365–370.

Alawadhi, E.M. (2012). Using phase change materials in window shutter to reduce the solar heat gain. *Energy and Buildings* 47: 421–429.

Atabani, A.E., Silitonga, A.S., Badruddin, I.A. et al. (2012). A comprehensive review on biodiesel as an alternative energy resource and its characteristics. *Renewable and Sustainable Energy Reviews* 16 (4): 2070–2093.

Cellura, M., Guarino, F., Longo, S., and Tumminia, G. (2018). Climate change and the building sector: modelling and energy implications to an office building in southern Europe. *Energy for Sustainable Development* 45: 46–65.

Choudhury, B., Chatterjee, P.K., and Sarkar, J.P. (2010). Review paper on solar-powered air-conditioning through adsorption route. *Renewable and Sustainable Energy Reviews* 14 (8): 2189–2195.

De Paepe, M. and Janssens, A. (2003). Thermo-hydraulic design of earth-air heat exchangers. *Energy and Buildings* 35: 389–397.

Ding, Z., Fan, Z., Tam, V.W.Y. et al. (2018). Green building evaluation system implementation. *Building and Environment* 133: 32–40.

Dutta, S., Neto, F., and Coelho, M.C. (2016). Microalgae biofuels: a comparative study on techno-economic analysis and life-cycle assessment. *Algal Research* 20: 44–52.

Ferdaus, R.A., Mohammed, M.A., Rahman, S. et al. (2014). Energy efficient hybrid dual axis solar tracking system. *Journal of Renewable Energy* 2014 Art. No. 629717.

Freed. E.C. (2006). As the green architect: why should I care about green building anyway? https://blogs.umass.edu/natsci397a-eross (accessed November 2019).

Hong, S.H., Gilbertson, J., Oreszczyn, T. et al. (2009). A field study of thermal comfort in low-income dwellings in England before and after energy efficient refurbishment. *Building and Environment* 44 (6): 1228–1236.

IEA (2013). Transition to sustainable buildings. Paris: IEA. https://www.iea.org/publications/freepublications/publication/Building2013_free.pdf (accessed November 2019).

IEA (2016). World energy outlook (2016). Paris: IEA.

Illman, A.M., Scragg, A.H., and Shales, S.W. (2000). Increase in Chlorella strains calorific values when grown in low nitrogen medium. *Enzyme and Microbial Technology* 27 (8): 631–635.

Knothe, G. (2005). Dependence of biodiesel fuel properties on the structure of fatty acid alkyl esters. *Fuel Processing Technology* 86 (10): 1059–1070.

Lardon, L., Helias, A., Sialve, B. et al. (2009). Life-cycle assessment of biodiesel production from microalgae. *Environmental Science & Technology* 43: 6475–6481.

Leahy, M., Barden, J. L., Murphy, B. T., Slater-Thompson, N. and Peterson, D. (2013). International energy outlook 2013. Washington, DC: EIA. https://www.eia.gov/outlooks/ieo/pdf/0484(2013).pdf (accessed November 2019).

Liang, R., Sun, Y., Aburas, M. et al. (2018). Evaluation of the thermal and optical performance of thermochromic windows for office buildings in China. *Energy and Buildings* 176: 216–231.

Lin, B., Liu, Y., Wang, Z. et al. (2016). Measured energy use and indoor environment quality in green office buildings in China. *Energy and Buildings* 129: 9–18.

Mata, T.M., Martins, A.A., and Caetano, N.S. (2010). Microalgae for biodiesel production and other applications: a review. *Renewable and Sustainable Energy Reviews* 14 (1): 217–232.

Mazo, J., Delgado, M., Marin, J.M., and Zalba, B. (2012). Modeling a radiant floor system with phase change material (PCM) integrated into a building simulation tool: analysis of a case study of a floor heating system coupled to a heat pump. *Energy and Buildings* 47: 458–466.

Meher, L.C., Dharmagadda, V.S.S., and Naik, S.N. (2006). Optimization of alkali-catalyzed transesterification of *Pongamia pinnata* oil for production of biodiesel. *Bioresource Technology* 97 (12): 1392–1397.

Nejat, P., Jomehzadeh, F., Taheri, M.M. et al. (2015). A global review of energy consumption, CO_2 emissions and policy in the residential sector (with an overview of the top ten CO_2 emitting countries). *Renewable and Sustainable Energy Reviews* 43: 843–862.

Pimentel, D. and Burgess, M. (2018). *World Human Population Problems. Encyclopedia of the Anthropocene*. Amsterdam: Elsevier Inc.

Randolph, J. and Masters, G. (2008). *Energy for Sustainability: Technology, Planning, Policy*. Washington, DC: Island Press.

Rodolfi, L., Zittelli, G.C., Bassi, N. et al. (2009). Microalgae for oil: strain selection, induction of lipid synthesis and outdoor mass cultivation in a low-cost photobioreactor. *Biotechnology and Bioengineering* 102 (1): 100–112.

Sakthivel, P., Subramanian, K.A., and Mathai, R. (2018). Indian scenario of ethanol fuel and its utilization in automotive transportation sector. *Resources, Conservation and Recycling* 132: 102–120.

Singh, A., Syal, M., Grady, S.C., and Korkmaz, S. (2010). Effects of green buildings on employee health and productivity. *American Journal of Public Health* 100 (9): 1665–1668.

Vanaga, R., Blumberga, A., Freimanis, R. et al. (2018). Solar facade module for nearly zero energy building. *Energy* 157: 1025–1034.

Wong, K. and Fan, Q. (2013). Building information modelling (BIM) for sustainable building design. *Facilities* 31 (3/4): 138–157.

Yoo, C., Jun, S.Y., Lee, J.Y. et al. (2010). Selection of microalgae for lipid production under high levels carbon dioxide. *Bioresource Technology* 101: 71–74.

Zabed, H., Sahu, J.N., Boyce, A.N., and Faruq, G. (2016). Fuel ethanol production from lignocellulosic biomass: an overview on feedstocks and technological approaches. *Renewable and Sustainable Energy Reviews* 66: 751–774.

Zhu, L., Cheung, C.S., Zhang, W.G., and Huang, Z. (2011). Combustion, performance and emission characteristics of a DI diesel engine fueled with ethanol-biodiesel blends. *Fuel* 90 (5): 1743–1750.