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Alternative Energy for Energy Sustainability

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Abstract: Energy has become a part and parcel of human survival and societal progress. In fact, per capita energy consumption has become a measure of a nation's progress. Just as air, water and food are the most important materials required for the survival of human life on earth, energy is essential for sustenance of the human race. Fear of depletion of fossil fuels, the main source of energy until now, has invigorated research for finding alternate sources. At the same time, fear of climate change and global warming is attracting attention of scientists to cleaner sources of energy. This paper presents a discussion of the various sources, the status of technology and their merits and demerits for application to daily life. The present day popular sources like solar, wind, biomass and geothermal are discussed in greater detail. The authors also present arguments to dub geothermal as the best renewable and clean energy source.

Key words: Solar energy, wind energy, geothermal energy, biofuels.

Sustainability is defined as progress made that increases the prosperity of mankind of the present day without reducing the capacity to meet future needs. Progress made can be in technology, economy, environment and society. Sustainable energy pertains to use of energy with the lowest total life-cycle cost. Life cycle includes all steps starting with identification, procurement of raw fuel to mining, manufacturing, processing, shipping to end-use, waste processing to final disposal. Full costs are captured in this analysis over a period of time (Randolph and Masters, 2008). Nobel laureate Smalley (2005) characterized mankind's quest for sustainability in the following ten prioritized problems: (i) Energy, (ii) Water, (iii) Food, (iv) Environment, (v) Poverty, (vi) Terrorism and War, (vii) Disease, (viii) Education, (ix) Democracy and (x) Population.

The availability of abundant energy that is readily available, affordable, clean, efficient and secure would enable the solution of all other 9 problems. Energy is needed to reclaim and treat water, grow food and to protect and preserve the environment. Energy is needed to eliminate poverty and disease and for expansion of education and communication. When basic needs are met, the root causes of terrorism and war can be tackled. Democracy can reach and touch more people in the world. Population needs to be stabilized. Energy holds the key in order to achieve a sustainable world order. The second law of thermodynamics states that matter and energy tend to degrade into an increased state of disorder and increased entropy. The flow of energy from hot reservoir to the cold reservoir with better quality can be used to create structure and preserve order. Global energy usage grew by 2% per annum from 1970 to 2002 and 4.1% from 2002 to 2005.

About 10.1% of the energy needed for household domestic consumption in the first quarter of 2010 in the United States came from alternate energy sources. Hydroelectric power plants are at present the largest producer of electricity from alternate energy sources (Shiva Prasad, 2008). An estimated 46 GW of electricity come from wind power and about 10 million households are served from windmills.

Figure 1 shows the DeSoto Next Generation Solar Energy Center, a photovoltaic solar power plant in DeSoto, FL. It can provide power to 3000 homes. President B. Obama commissioned this plant in October 2009. The capacity of the power plant is 24 MW. The solar power plant costs about $150 million to construct. Over 90,000 sun power solar panels with single axis trackers are housed in 180 acres of land. Over the next three years the President has set a goal of doubling the nation's supply of renewable energy sources.

NRG Energy and eSolar signed a contract to install new solar power plants in California and

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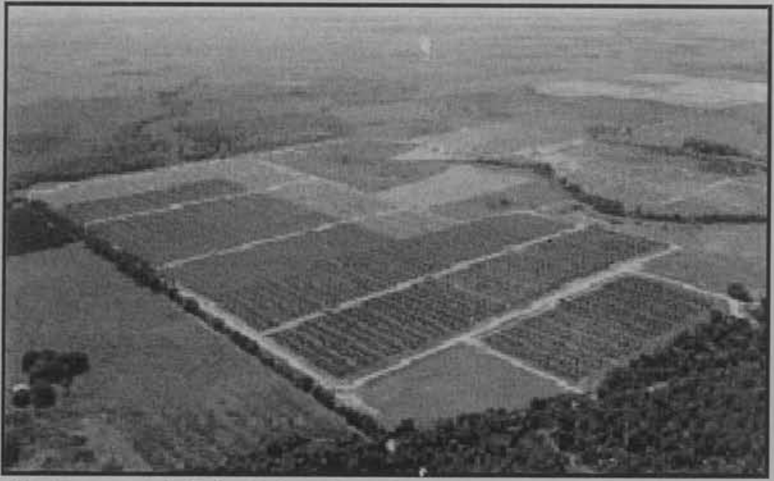

Fig. 1. Florida Power and Light DeSoto Next Geneneration Solar Energy Center, DeSoto, FL.

the Southwest with a total capacity of 1.3 GW over seven projects. The power plant planned for Ivanpah, CA, near the Mojave Desert will begin construction later in 2010 and will begin production in 2013. The capacity of the plant is 100 MW. US Army plans to build a 500 MW solar thermal power plant at Fort Irwin, CA. Austin Energy has selected the San Francisco, CA based Gemini Solar development to install the solar array with 30 MW capacity. It can power up to 5000 homes and will use 300 acres of land in Webberville, TX. Another large. The largest urban solar power plant is in the south side of Chicago, IL, with 10 MW capacity. The photovoltaic plant is expected to cost $60 million and is scheduled for completion later in 2010. It shall use 39 acres of land by lease contract. The solar cells are built using thin-film solar technology.

The principles of Sustainable Engineering were developed at the Sandestin Conference of 2003 (Abraham and Nguyen, 2005). This ought to set the direction of engineers who work on developing sustainable alternatives to current engineering practices. Energy is considered a primary component of sustainable engineering. This is because of the pollution problems that arise from current methods of consumption of energy and the depleting reserves of fossil fuel such as bituminous coal, petroleum, peat, lignite, anthracite, oil shale, natural gas, etc.

Some harmful by-products of coal combustion are mercury and SO_2. Combustion of most fuel sources emits CO_2 (Carbon dioxide). Studies on the CO_2 cycle have shown that photosynthetic consumption of CO_2 by plants and trees and inhalation of oxygen by mammals and exhalation of CO_2 does not complete the cycle. A gradual increase in the concentration of CO_2 in the atmosphere has been observed. This leads to global warming. World temperatures have risen at an average of 0.5°C per 200 years since the late 1800s. Nearly 85% of the total energy consumption in the United States emanates from fossil fuels (DOE/EIA, 2003). Development of more fuel-efficient vehicles or energy integration in a chemical factory is within the scope of the field of sustainable engineering. It is important to consider whether the generation of electricity from combustion and gasification of fossil fuels are sustainable. A CEO of a Fortune 500 oil company said: "the Stone Age didn't end because we ran out of stones: the Oil age won't end because we ran out of oil". By the principles of engineering economy, and that of supply and demand, as the oil and fossil fuel reserves become meager in quantity their prices will rise steeply. The oil supply is forecast to peak sometime between 2021 and 2112. Environmentalists predict that oil reserves shall be depleted by the year 2050, natural gas by the year 2120 and coal by the year 3500.

Transport of fossil fuels can lead to disasters. In 1989 the Exxon Valdez dumped 11 million gallons of oil into the waters and onto the shores of Alaska. In 1994 a ruptured Russian pipeline spewed 85 million gallons of oil onto previously pristine Arctic tundra. In 1994 Exxon was ordered to pay $ 5 billion for Alaskan oil spill. 206 million gallons of oil was spilled in the recent deepwater horizon oil spill in the Gulf of Mexico by BP Americas. This was the worst environmental disaster ever in the history of technology. This was attributed to a rig explosion. The gusher was from the ocean floor.

In most formulations of sustainability the use of renewable energy resources is desirable. The Sandestin principle states that "Minimize depletion of natural resources". Renewable energy resources may be viewed as fuels that are produced at rates equal to or greater than the rates at which they are consumed. Thus there is no "net depletion" of the resources with the passage of time. For example, biomass production rates may jeopardize food supplies and hence have biomass fall out of the column of renewable resources and into the column of non-renewable energy resource. Sandestin principle of life cycle analysis may be applicable for evaluation of biomass as energy resource.

SOFC, solid oxide fuel cells and hydrogen may offer sustainable solutions. This may solve the environmental pollution problem. But the problem of depletion of energy source depends on the source and method of production of hydrogen. Energy use can have an impact on sustainability of the manufacturing process.

Renewable energy sources offer the long term solution to the energy security needs of the nation and myriads of pollution problems that arise from fossil fuel consumption. The different kinds of renewable energy sources are: (i) solar power, (ii) wind power, (iii) geothermal, (iv) biomass, such as plant material, (v) hydroelectric power, (vi) oceanic, (vii) biofuels such as ethanol, biodiesel, and (viii) hydrogen.

Fuels are primarily used for electricity generation. They are also used for heating/cooling of buildings, water heating, space explorations, transportation, rural agrarian activities, etc. Renewable energy source means that the supply is forever and will not be depleted. The categorization of fuels as renewable depends on thermoeconomic and socioeconomic issues (Shiva Prasad, 2010).

The basic knowledge and technology of most of the known renewable energy resources including water and hydrogen are quite old. However, this paper concentrates mainly on the more popular and established resources, namely solar, wind, biomass and geothermal. In fact, there is a big push in the US since the 80's for developing a clean hydrogen energy economy. In the automobile sector, BMW pioneered the development of a hydrogen car in 1960 (Solomon and Banerjee, 2006). Currently several companies are trying to use the more efficient route to hydrogen car using fuel cell technology instead of burning hydrogen inside the IC engine. Cost effective fuel cell technology development will help boost hydrogen energy usage. In addition, hydrogen production technology using clean renewable energy without any emission footprint needs to improve and become cost effective to be able to compete with other resources.

Electricity from water is also an ancient technology and per DOE estimates in 2009, it was supplying about 7% of electricity in the US. It is also a clean source and could be considered as more reliable than wind and solar, particularly if pumped storage systems are employed. Hence it could serve as a base load-generating source. However, its potential is limited in each country depending on the terrain and the rainfall. Several investigators are also pursuing development of devices for capturing the thermal and kinetic energy from the ocean water.

Solar

Solar power plant

Solar power plants can be expected to generate electricity at a lower cost. This is because the primary energy source is from the sun and it is for "free". It also is expected to provide a "zero emissions" alternate to the current fossil fuel-based power plants. The efficiency of conversion of sunlight to photovoltaic cell or useful energy continues to hover around 15%. New discoveries such as the CNT (carbon nanotubes) are expected to increase the photovoltaic efficiency of solar cells to over 40%. For now where the population density is sparse and sunlight is abundantly available for most of the year the solar power plants that come out with a positive PW (present worth) value end up using large area. The solar panels are not protected from birds and other forms of dust that degrade their operations. Lenses and mirrors can be used to concentrate the sunlight and energy storage devices can store the energy in useful chemical forms such as batteries for use at night and during rainy days. Some day technology in solar energy generation will be as technically efficient as that of the combined steam and gas cycle power plant. By use of both the steam and gas turbines the Carnot cycle efficiency has been increased from 30% to 50%. After nearly two centuries since the discovery of the steam engine by James Watt, from the point of view of thermodynamics that defines the limits of machines, what are the issues involved in solar power plant

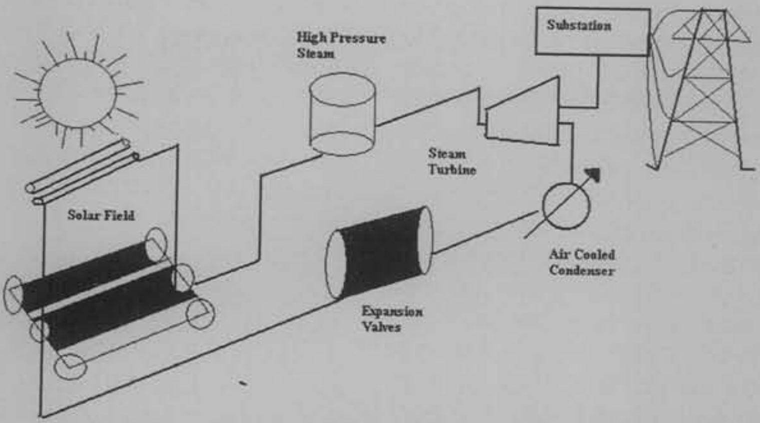

Fig. 2. Flow diagram of illustrative solar thermal power plant.

technology? How can a paradigm shift be effected from: "there is no such thing as a free lunch". Can solar energy be used to power a robot that can be used for transportation? What happens when this goes out of control? What are the hidden safety hazards in solar technology?

Solar energy may be tapped in three different ways; (i) solar thermal power, (ii) photovoltaic panels, and (iii) solar heaters.

In method (i) steam is generated in large boilers to turn turbines and generate electricity (Fig. 2), comparable in capacity to coal-fired boiler-based power plants. Photovoltaic panels can be used to convert directly the solar irradiance (W/m^2) into electricity. This technology is used to meet peak load needs and distributed power needs. Small power plants of up to 50 MW can be built using panels. The capacity of the recently commissioned De Soto Solar Power Generation Center in Florida is 24 MW and is less than 50 MW. Solar irradiance (W/m^2) is used to heat water or air and can be used for residential heating purposes.

Solar power plant technology can be used to produce base-load, large-scale power at low technical risk. These can replace coal-fired boiler-based power plants. Heat energy storage devices have been invented that can provide for uninterrupted services such as during the night hours, rainy days, etc. Lunar power can also be tapped into. Heat storage elements used are concrete, molten salts and pressurized water. The capital solar plant costs and the plant utilization factor continue to affect the bottom line. Spain has five such plants under development and two that have been already commissioned.

Investments have been made in several countries across the globe to advance the design of solar mirrors and lenses. These are used to gather the sunlight and focus on a fuel source to generate of electricity. Full scale commercial operations of such power plants with capacities in the range of 20-200 MW are expected by 2011. The cost per kWh is continuing to be the main concern. Optimization strategies could lead to significant cost reductions and may be expected to improve the overall output efficiency. Cost effective storage devices are also expected.

Present worth (pw) of solar power plants: A rapidly declining cost curve is seen in the photovoltaic cell technology (Khosla, 2008). The price of solar modules is expected to fall from around $2/W today to $1 in the near future. The price per watt installed is likely to fall from $6.0-$8.0 to $3.0 per watt. Dominant in the costs are power electronics and installation. With current incentives in the United States and European Union the cost of electricity generation using solar technology is in the range of the IGCC (Integrated Gasification Combined Cycle) power generation plants. In the state of California the cost of electricity from solar power plants is about 14-15 cents per kWh. This is against the 8-10 cents per kWh cost of electricity from IGCC power plants. By 2013 with some incentives from the federal government the cost of electricity from solar power plant is expected to fall to 10-12 cents per kWh. The per kWh cost is sensitive to the capital cost and the cost of materials of construction of the plant. Sequestration related carbon credits at $30 t^{-1} of CO_2 can affect a per kWh reduction of 3 cents. Government carbon tax, cost of capital are sensitivity parameters on the bottom line of solar power plants.

World wide, the solar thermal power capacity can grow at least 30% per year from 2010 to 2020 or 2030. 200 GW of new power plant capacity can be added each year. About 1-2 GW per year could be added in 2012. Solar technology is relatively simpler. The NREL, National Renewable Energy Laboratory, has identified potential for 6 TW (terra watts) of solar thermal power in the Southwestern US.

Solar concentrating systems can be made from: (i) parabolic troughs; (ii) parabolic dishes and; (iii) central receivers. Parabolic troughs are made from curved sheets of material that can reflect light. The sunrays are focused on a glass tube filled with a heat-conducting fluid. Parabolic dishes are bowl-shaped reflectors. These can be used to concentrate the Sun's heat on a receiver. The heat conducting fluid is allowed to pass through the receiver. Central receivers are made from 100s or 1000s of mirrors called heliostats. Molten salt circulating within the receiver is used to absorb the heat energy transmitted by the heliostats. The molten salt can be used to generate electricity and can be stored in insulated containers for later use. Solar Two was commissioned in the Mojave Desert near the town of Daggett, CA, by Department of Energy (DOE). 10 MW of electricity can be generated from this unit and can be used to power 10,000 homes.

Photovoltaic efficiency of PV cells is 8% for solar cells made from amorphous silicon. Their efficiency has increased now to 14%. This can be further increased to 20% by use of thin films that contain small amounts of crystals of silicon. Single crystal silicon can be used to make the "most efficient" solar cells with 30% efficiency. These PV cells are more expensive.

Increasing the efficiency of photovoltaic conversion: A team of scientists from CIT, California Institute of Technology, Pasadena, CA, developed flexible solar cells that enhance the absorption of sunlight and hence the photovoltaic efficiency using fraction of expensive semi-conductor material. According to Harry Atwater, director of Caltech's Resnick Institute that focuses on sustainability research, "these solar cells have, for the first time, surpassed conventional light-trapping limit for absorbing materials" (Oliwenstein, 2010). They built their solar cells using silicon wires embedded within a transparent, flexible polymer film. Black paint can absorb light well, but may not generate electricity. These solar cells convert most photons absorbed into electrons. These wires have what is called a near perfect internal quantum efficiency. A high-quality solar cell is built for high absorption of light and good conversion of photons to electrons. These wires are painted with anti-reflective coating prior to being embedded into the transparent polymer. Each wire is about 1 μm in diameter and 30-100 μm in length. 2% of the material is silicon and 98% polymer. This brings down the cost of the solar cell. These solar cells are also flexible.

Photovoltaic cells respond only to a narrow part of the sun's spectrum. In order to circumvent the lower efficiency on account of absorption of narrow part of the spectrum some developers prepare layered materials. The efficiency goes up, but the material becomes expensive as well. Cloudy days may lower the efficiency. Emspack, 2009 from Ohio State University developed a doped polymer, oligothiopene. The resulting substance was responsive to wavelengths from 300 nm to 1000 nm. The spectrum of near ultraviolet (UV) to far infrared is spanned in this range. The doped polymer both fluoresces and phosphoresces. Fluorescence emanates from electrons that get excited by incident rays of sunlight travel from a higher energy state and drop back to a lower energy state. Some light is emitted. The wavelength of the emitted light is in infrared range and not visible. This emitted light is seldom reused. Reuse of emitted light may improve the photovoltaic efficiency. These polymers are cheaper to produce compared with silicon. Hence they can be considered even if their photovoltaic efficiencies are lower. The relaxation time (Sharma, 2005) of these electrons during fluorescence of the doped polymer comes up from a few picoseconds in other solar materials to a few microseconds.

A full spectrum solar cell that absorbs the full spectrum of sunlight from the near infrared and far ultraviolet to electric current can be prepared from an alloy of indium, gallium and nitrogen (Wu *et al.*, 2002). This was made possible by a serendipitous observation by researchers at Lawrence Berkeley National Laboratory interacting with the crystal-growing research team at Cornell University and Japan's Ritsumeikan University. This observation was that the band gap of the semiconductor indium nitride is not 2 eV as previously thought, but instead is a much lower 0.7 eV. Solar cells made from this alloy would be the most efficient and can be lower in cost as well.

The efficiency of photovoltaic cells is limited because of a number of factors. Some light energy that gets absorbed is rejected as waste heat. There exists a band gap in semi-conductor materials that the solar cells are made out of. Incoming photons of the right energy knock electrons loose and leave holes and migrate in the np junction to form an electric current. Photons with less energy than the band gap slip right through. Red light photons are not absorbed by high-band-gap semi-conductors. Photons such as blue light photons that posses higher energy than the band gap are absorbed. Excess energy is dissipated as heat. There is a maximum efficiency limit for a solar cell made from a single material for converting light into electric power. This is about 30%. In practical applications it is about 25%. Stacks or layers of different materials are attempted in order to increase the efficiency.

CIGS, $CuIn_xGa_{1-x}Se_2$ based photovoltaic thin films can deliver sunlight to electricity conversion performance greater than that of CdTe or silicon based thin films. Nanosolar (Contreras *et al.*, 2006) has developed a process with high-throughput, high-yield printing of nanoparticles onto low-cost substrates and formation of solar cells. CIGS based PV thin films can deliver sunlight to electricity conversion efficiencies of 19.5% (Hegedus, 2006). NREL has certified the solar cell efficiency of 14% achieved by nanosolar with lower cost materials using nanotechnology. CIGS based thin films result in higher efficiencies. They are coated with a homogeneously mixed ink of nanoparticles using wet coating techniques. CIGS roll-printing technology developed by nanosolar uses a combination of high-speed, high-yield, non-vacuum, wet coating of nanoparticles onto low cost per unit area of metal foil substrates with RTP (Rapid Thermal Processing) techniques. Nanosolar's rapid thermal processing of nanoparticle-based coatings resulted in solar-cell efficiencies confirmed by NREL (National Renewable Energy Laboratory) to be 14.5%, which amounts to a world record for any printable solar cell.

Solar energy for buildings: The three largest demands for energy in the building sector in order of size are: (i) residential space heating; (ii) lighting for commercial buildings; and (iii) residential water heating. Solar energy can be used to meet a significant portion of these energy needs. Overhangs can be used to shade windows to minimize the impact of undesired solar gains in the hot summer months. The selection of window coatings that permit sunlight and reject undesired thermal gains can also be made use of.

The position of the sun can be tracked at various times in the day. It rises in the east, reaches some maximum height in the sky at a time called solar noon and sun sets in the west. Figure 3 shows the two angles of interest: (i) altitude angle, β and; (ii) azimuth angle, φ-.

The altitude angle during solar noon is of particular interest. The altitude angle may vary from season to season, region to region, etc. An equation can be written for the altitude angle as follows;

$$\beta_N = 90 - L_a + \delta \qquad ...1$$

where, β_N is the altitude angle of the sun at solar noon, L_a is the local latitude and δ is the solar declination. The solar declination is the line of latitude over which the sun appears to move on account of the earth's revolution about the sun on a given day. During the course of the day as the earth revolves around the sun the sun would appear to revolve along an arc. The line parallel to this on the earth is called the line of latitude. The equation for solar declination, δ can be written as:

$$\delta = 23.5 \sin\left(\frac{360\$}{365\$}(n - 81)\right) \qquad ...2$$

The solar declination, δ, varies periodically between 23.5 on the spring equinox day, i.e., day # 81 or March 21st and 0 at which point the sun appears directly above the equator. Sun reaches its maximum height at solar noon on June 21st the summer solstice and its minimum height on December 21st the winter solstice.

The model equations used to locate the sun at any time of day, any day, any day of the year are tedious. Sun path diagrams can be generated using the internet. Software to generate sun path diagrams may be accessed at the website maintained by University of Oregon Solar Radiation Monitoring Lab (1999). The Sun path diagram for Cypress, TX with Zipcode 77429 was generated using this software is and the results are shown in Fig. 4. Sun-path diagrams can be used to perform site-analysis to find out whether the obstructions may cause shadows on the proposed location. The altitude and azimuth angles of potential obstructions can be measured using a protractor and bob and a compass. The fraction of solar energy that is available for generation of electricity

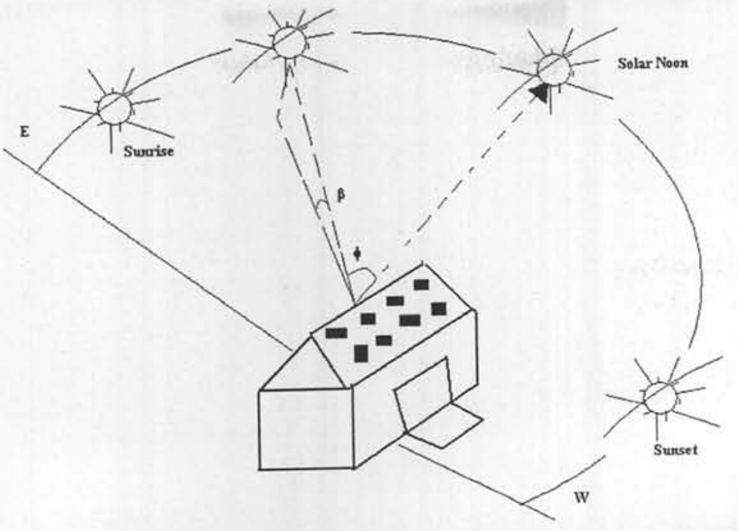

Fig. 3. Sun's positions during the day and azimuthal and altitude angles.

can be estimated. The incident solar radiation on a collector or insolation is measured in kW.

The passive solar systems are simple, reliable and low in cost. Sunrays are allowed to pass through the windows to provide the necessary heat (Balcomb *et al.*, 1983; Dunlop, 2012; Swisher, 1985). Active solar systems are designed with special collectors, and storage devices. These are higher in cost. Passive solar systems can be designed to maximize solar efficiency. The building needs to be oriented along an east-west axis to control solar gains. South-facing solar systems are provided to permit solar energy. Overhangs are designed to secure the south-facing windows in summer. Sufficient thermal mass is provided to absorb solar energy in excess of needs during the day.

The heating demand can be reduced below current building codes by provisions for more insulation, better windows, tighter ducts and more efficient heating and cooling systems. Passive heating systems can drive the heating demand to near zero levels. Cooling loads for building use can be kept under target by better building orientation, use of overhangs, natural ventilation, spectral windows, and better roofing materials. Building orientation has been known since the days of Vastu Sastra in ancient India during the Ṿedic age. The concept of Whole-building Life-Cycle assessment including all the energy required starting from site selection, through construction through use and disposal. Solar energy can be used for water heating. Zero-energy, zero carbon buildings can be expected in the future.

Future trends: Over the next decade or two, research is expected to result in hybridization of solar thermal power plants with natural gas plants. This would allow for backup power during poor weather conditions such as rain, nightfall, etc. Solar and wind are proposed to be merged with each other. This can result in less cost. Dish concentration with Stirling engine power generation is being developed.

The fundamentals of photovoltaic physics have to be better understood. How the solar cells work may make a popular science topic. The unification of gravitation and electromagnetism was a goal envisioned by Sir Albert Einstein during his last days. Better theory is needed to describe how electrons speed up on receiving energy from the sunlight in terms of photons. The influence of collector orientation has to be better quantified. Solar array sizing the economics of solar power plant needs to be better understood. The use of large land areas and the social consequences of it need to be spelled out. In the future the customer can choose from silicon photovoltaic systems and plastic photovoltaic systems with different levels of efficiency. In locations where the sun shines more, the tax credits, utility rebates, tax-deductible interest on loans can make photovoltaic systems comparable in cost with the integrated gasification and combustion combined cycle power plants, that have higher thermodynamic cycle (IGCC) efficiency. Solar power plants may be of interest to customers with high marginal cost of utility of electricity.

Biofuels

Biodiesel

Biodiesel is becoming increasingly attractive as an alternate source of energy on account of the

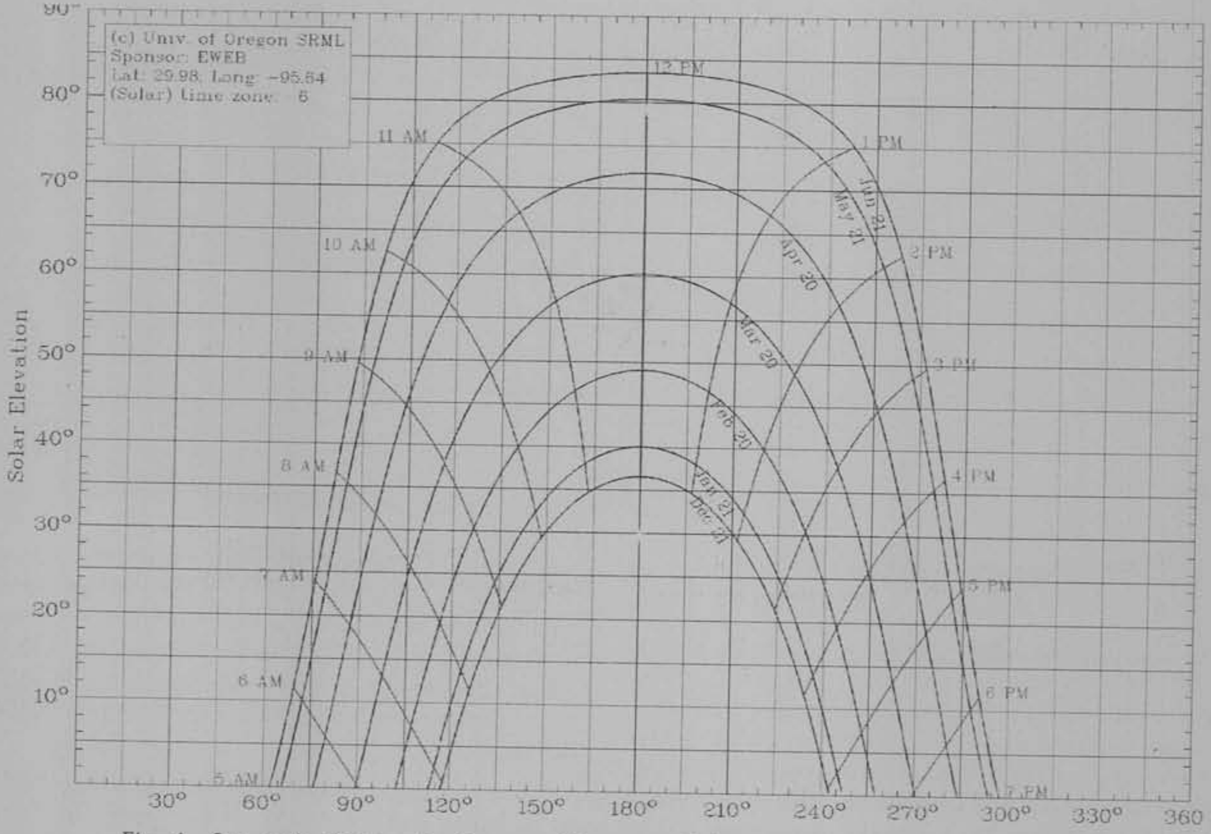

Fig. 4. Sun path diagram for Cypress, TX generated by University of Oregon Website http://solardat.uregon.edu/SunChartProgram.html

environmental benefits that come from its use. It is made from renewable biological sources such as vegetable oils and animal fat. Its commercial use as a substitute for diesel started in Europe in the late 1980s. Use of biodiesel can alleviate the air pollution problems that are currently becoming more of an issue from the fossil fuel based power plants. The CO_2 emissions can also be lowered. Volatile organic compounds, VOCs, NO_x, SO_x are the predominant pollutants from current power plants.

Biodiesel comprises of FAMEs, fatty acid methyl esters. It can be obtained by four routes; (i) Blending of oils and direct use, (ii) Microemulsions of oil, (iii) Pyrolysis of vegetable oil, and (iv) Transesterification of oil.

The common methods adopted in different parts of the world such as Taiwan is the transesterification of vegetable oil. Vegetable oils used as soybean, rapeseed, sunflower, palm, coconut, tung and waste cooking oils. Investigations on generation of oils using microorganisms such as algae, bacteria and fungi have been undertaken (Shay, 1993). Transesterification is the chemical reaction between triglycerides present in the vegetable oil and an alcohol to form esters and glycerol. A catalyst is usually added to improve the transesterification rate of reaction and yield of product and by-product. Glycerol is used as a by-product.

It can be seen that from the AW (annualized worth) analysis below that the sales of glycerol made the manufacture of biodiesel profitable in a plant in Taiwan (You *et al.*, 2008).

Biodiesel is produced by transesterification reactions. Triglycerides present in virgin soybean oil are reacted with anhydrous alcohol such as methanol, ethanol, propanol, etc., to form fatty acid methyl esters (FAME), or biodiesel and glycerol. The alkali catalyst used was sodium hydroxide (NaOH). Biodiesel is an attractive fuel due to its environmental benefits it has to offer. It is prepared from renewable energy resources such as vegetable oil. Using the information provided in Table 1, AW (annualized worth) of the biodiesel plant was calculated (Sharma, 2011).

***Table** 1. Cost and revenue data for biodiesel production in Taiwan*

Acitivity	Amount
Systems Transesterification reactors, Distilation columns, Pumps, Heat exchangers, Separator, Vaccum systems	$ 765,000
Materials Soybean feedstock, Catalyst, Solvent, Methanol	$ 798,000
Labor, utilities and overhead	$ 1,119,000
Revenue form Biodiesel Sales, Glycerin by-product	$ 9,883,000

The plant is expected to last for 20 years. The interest rate for equivalence calculations can be taken as 3.0%. The main cost in these plants is the raw material cost.

The AW calculated is shown in Table 2. The capital cost is obtained by adding the costs of reactors, washing column, distillation column, heat exchangers, pumps, vacuum systems. The capital cost of $765,000 is amortized over 20 year period (Turton *et al.*, 2003) by using the capital recovery factor. The capital recovery factor is obtained from Table A-7 in Sharma (2011). The materials costs include the soybean oil, methanol, catalyst and solvent. The Annual costs are obtained by adding the materials cost, labor costs, utility costs and overhead costs. The annual revenue is obtained by adding the sales of biodiesel and glycerin. The AW was calculated as shown by plugging the information available into Eq. below:

$$AW = R_k - E_k - \text{Capital Recovery Factor} + \text{Sinking Fund Factor} \quad ...(3)$$

where, R_k is the revenues accrued in the k^{th} year and E_k is the expenses incurred in the k^{th} year. The Capital Recovery factor and sinking fund factor calculations are shown in Sharma (2011). The AW is about $1.915 million. Thus it is profitable to operate the biodiesel plant as described in Taiwan.

Alcohols that can be used in the transesterification process include methanol, ethanol, propanol, butanol, amyl alcohol, etc. Due to its lower cost, methanol is used. The transesterification reactions can be alkaline or acidic or enzyme catalyzed. If the free fatty acid contents and water in the oil are less than 1 and 0.5 wt %, respectively, the alkaline catalyst is preferred. Should the free fatty acid content be higher than 1 wt% the acid catalyst has been found to be a better choice (Kulkarni and Dalai, 2006). Reaction rates have been found to be higher when alkali catalyst is used. Hence, this is selected for commercial applications. Often commercial application is at a reactor temperature as hot as the boiling temperature of alcohol at a molar alcohol/oil ratio of 3:1 (Noureddini and Zhu, 1997). This process is sensitive to the purity of the reactants. Moisture may cause saponification of ester under alkaline conditions. Dehydrated vegetable oil may be a better feedstock for biodiesel production. Waste cooking oil contains excess moisture and free fatty acids. Free fatty acids are formed during frying. Some triglycerides may polymerize during frying. These can affect the transesterification reactions and the properties of biodiesel. Biodiesel production from waste cooking oil is effected by two-step process of acid catalysis followed by alkali catalyzed. Acid catalysis can render the process free from sensitivity to free fatty acids. The reaction rates are slower in this route.

The cost of raw materials is crucial in the profitability of biodiesel plants. Bender (1999) and Weber (1993) reviewed 12 reports concerning the economic feasibility of biodiesel production using different feedstocks and scales of operation. The production costs for conversion to biodiesel from different feedstocks along with references to further information are given in Table 3.

Nelson *et al.* (1993) identified the significant factors that affect the cost of production of biodiesel. These include cost of raw materials in general and feedstock in particular, plant size and credit received for glycerine by product sales. Waste cooking oil is less expensive compared with pure vegetable oil. Restaurant waste oils costs less than the food-grade canola and soybean oils. The first factory that produces biodiesel at 3000 tons year^{-1} from waste cooking oil was established in Chiayi county of Taiwan in October 2004. In 2005 over 700 garbage trucks in 13 counties in Taiwan were fueled using biodiesel.

Bioethanol

Alcohol fuels such as methanol and ethanol can be blended with gasoline in different proportions. Gasohol or E10 is 10% ethanol and 90% gasoline. E85 is 15% ethanol and 85% gasoline.

Table 2. AW analysis of biodiesel plant in Taiwan

Description	Cost (US $)
Transesterification reactor	335,000
Neutralization reactor	25,000
Washing column	115,000
FAME distillation column	181,000
Heat exchangers	4,000
Pumps	53,000
Separator, vacuum systems	52,000
Materials	
Soybean oil feedstock	6,234,000
Methanol	196,000
Catalyst and solvent	368,000
Labor cost	564,000
Utilities	124,000
Overhead	431,000
Revenue from biodiesel	6,845,000
Glycerin credit	3,038,000
Capital cost	765,000
Materials cost	6,798,000*
Labor, utility and overhead	1,119,000
Total Revenue	9,883,000*
(A/P,3%,20)	0.067216
Capital recovery	51,420.24*
AW	1,914,579.76

* *per year.*

Mankind has known ethanol for 6 millennia. World production of fuel grade ethanol has increased from 4.6 billion gallons in 2000 to 7.5 billion gallons in 2006 at a rate of 22% per year. The ethanol production capacity by state in shown in Table 4 (Source: Renewable Fuels Act, 2007).

Bioethanol can be produced by the fermentation of sugars obtained from saccharine biomass such as sugar cane or sugar beets, starchy biomass such as corn, cellulosic biomass such as agricultural wastes. Bioethanol can be used as alternate fuel to fossil fuel resources such as coal and petroleum. It comes from renewable resources. Six different methods have been identified for recovering ethanol from fermentation broth. These methods are: (i) Steam Stripping and Distillation, (ii) Flash Fermentation and Distillation, (iii) Single Column Distillation, (iv) Two Column Distillation (v) Distillation with heat pump, and (vi) Flash and Vacuum Distillation.

The ethanol production rate was set at 100 million liters per year in the process simulation study (Haelssig and Thibault, 2008). The cost data for cases where the ethanol concentration in the fermenter was 40 g L^{-1} is shown in Table 5. At an ethanol price of 50 cents per gallon the IRR for the six methods were calculated.

The IRR in row 6 of Table 5 was calculated using MS Excel spreadsheet. The PW as a function of interest rate for the six methods of recovery of ethanol from bio feed stock is shown in Figure 5.

Other feed, apart from sugar, can be used for bioethanol production. These are; (i) corn, (ii) cellulosic crops, and (iii) waste biomass.

In 2007, President George W. Bush announced the goal of making cellulosic ethanol cost competitive compared with gasoline by the year 2012 and producing 35 billion gallons per year by 2017. In addition to this with increased automobile fuel economization the gasoline consumption can be reduced by 20% in 10 years. Congress codified this initiative in December 2007 and extended as a 35 billion gallon RFS by 2022. By 2005 Energy Policy Act the Department of Energy announced grants to build 6 cellulosic plants in 4 years. The $385 million grant will leverage private funds for a total investment of $1.2 billion. The companies selected are as follows:

(i) Abengoa Bioenergy Biomass of Kansas for a plant with 11.4 metric tons per year of ethanol plus net electricity from corn stover, wheat straw, switch grass.

(ii) ALICO, Inc. for a plant with 13.9 metric tons per year of ethanol from green and wood waste.

(iii) Broin Companies for a plant of 125 metric tons per year of ethanol: 25% from cellulosic corn fiber, cobs and stalks.

(iv) Iogen Biorefinery Partners, LLC for a plant with 18 metric tons per year of ethanol from agricultural residues including wheat straw, barley straw, corn stover and switch grass.

(v) Range Fuels for a plant with 40 metric tons per year of ethanol plus 9 metric tons per year of methanol from woody residues and crops.

Iogen also has a proprietary enzyme used in its ¼ million gallons per year wheat straw to ethanol plant in Ottawa, Canada. Shell Oil, Goldman Sachs and other investors have provided funds for its Idaho commercial scale facility. Some critics maintain that it takes more energy to make ethanol than you get out of it.

Table 3. Review of production costs of twelve different routes to biodiesel

Nature of feedstock	Per liter production cost	Reference
Soybean oil	$0.30	Weber, 1993
Animal fats	$0.32-$0.37	Nelson and Schrock, 1993
Canola oil, sunflower oil	$0.40, $0.63	Weber, 1993
Rapeseed oil	$0.69	Haelssig *et al.*, 2008

Geothermal

Population and societal growth has continued to put a heavy burden on energy needs. The same has resulted in a gradual depletion of fossil fuel based energy sources and aroused interest in developing new sources. At the same time, increasing awareness of the link between the use of present day fossil fuel sources and climate change is encouraging mankind to look for cleaner energy sources. If such sources could be renewable and plentiful, it should solve both the energy and the climate change problem simultaneously. Hence there is a great need for developing all possible renewable sources by improving the required technologies. However, the term "renewable" is a misnomer for most of the energy sources, as they are not always available and their renewability is coupled with uncertainty. Solar, wind, water are available only at certain locations and at certain times or seasons. Same thing applies to biomass, etc. Geothermal appears to fit the definition of renewability to the best extent in terms of temporal sense. Further in a spatial sense also, geothermal energy is available for every human being to make use of, anywhere on the earth.

Table 4. Ethanol production capacity

State	Capacity (million gallons per year)
Iowa	3,358
Nebraska	1,746
Illinois	1,172
South Dakota	985
Minnesota	1,102
Indiana	848
Wisconsin	498
Kansas	508
Michigan	264
Missouri	186
North Dakota	333
Ohio	529
Texas	355
New York	164
Other	826

One should note that earth is a storehouse for all the energy, which reaches it from the Sun, the planets and the universe, in various forms and mainly in the form of radiation. In addition, it stores all the energy dissipated in various forms near the earth in the form of heat. One should also note that the unused solar and wind energy is stored in the earth. Similarly, it gives out energy in various forms. Fossil fuel energy is derived from the earth in the form of chemical energy. Nuclear energy is a product of materials, also derived from earth. Hydropower is also derived from the potential energy of water stored on the surface of the earth at various locations. Biomass is created from the earth through various ecological processes and the chemical energy packed in some form of biomass can be converted into useable electric power. Hence it should be no surprise that the geothermal energy potential of the earth is huge. In addition, it is a clean source. Per DOE (Department of Energy) estimates, space heating and cooling consumes nearly one-third of the annual energy usage in the United States. Geothermal is the only energy source, which is in a readily usable form. Unlike energy conversion as in wind, biomass (even including fossil fuels), nuclear, water or energy capture and transport as in solar, geothermal energy need only be transported efficiently. This eliminates the efficiency loss during capture and conversion, and tends to keep the overall system simple and efficient geothermal systems. However, higher grade or high intensity geothermal energy is also available that can be used to generate electricity. The first use of geothermal energy for electricity generation was demonstrated in 1904. However, hot geothermal sources in the form of dry steam or hot water springs are not commonly available and until recently, electricity generation was confined to those places where geysers or hot springs or large hot water reservoirs were located. Recent research (see Tester *et al.*, 2006) has indicated that the heat available in the ground beneath 3-10 km depth can be mined by creating enhanced geothermal systems (EGS). These are large, single or multiple reservoirs created at large depths of

Table 5. Cost information for six methods (M - million)

Description	Steam stripping process	Flash fermentation	Single column distillation	Two column distillation	Distillation withheat pump	Flashand vacuum distillation
Capital equipment cost	\$6.0M	\$18.0M	\$14M	\$6M	\$10M	\$25M
Utility cost	\$5.5M/year	\$7.5M/year	\$6.5M/year	\$3.5M/year	\$3.6M/year	\$5.5M/year
Feedstockcost	\$10.6M	\$14M	\$39.1M	\$41.7M	\$7.9M	\$25.6M
Revenue	\$50M	\$50M	\$50M	\$50M	\$50M	\$50M
Plant life	10 years	10 years	10 years	10 years	10 years	10 years
IRR	565%	157%	28%	77%	385%	77%

3-10 km and interconnected by natural or artificial path or piping. The natural or artificially created cracks in the ground sustain the mass and energy transport to the reservoir/s. Research on decreasing the cost for creating such EGS's has picked up pace due to increased interest in developing this important renewable energy source with a huge potential. There is lot of scope for transplanting the technology developed for extracting oil and gas. In fact, water is normally found to co-exist with oil and gas and that too they are found in large proportions (about 10 times). Such hot water is another source, which is being exploited as a useful geothermal source in abandoned oil and gas fields. Geothermal energy is eternal, ubiquitous, available for direct use as well as conversion to useable electricity, clean and safe for extraction. The MIT panel assigned by DOE to assess the potential of geothermal energy envisioned at least 10% contribution from EGS to the future electricity needs of US. Hence in the authors' view, geothermal source appears to have a huge potential for helping solve the energy problem to a large extent and progress towards its exploitation will not stop due to its notable multiple attributes which none of the other energy sources possess.

Geothermal energy source is more than 100 years old. However, the high initial capital cost (essentially for digging and piping installation) for harvesting it either for power generation or for heating has discouraged its development until now. In the US, it got some boost from the oil embargo during the 80's, which, however was not sustained. In this 21st century, it has received an additional boost both from the fear of oil depletion and the climate change issue. Following the assessment and visionary report by Tester *et al.*, 2006, DOE increased funding to GTP particularly since 2008. Figure 6 (taken from Collins *et al.*, 2001) shows the US as well as international investment in geothermal energy projects in 2007 in USA.

Geothermal source can be used to develop centralized power generation as well as distributed power generation. Although conventional hydrothermal power generation would normally require a hot water source >150°C, binary cycle power plants based on low boiling point fluids have been employed to produce power from low temperature sources with as low a temperature as 74°C (Cross and Freeman, 2009).

Figure 8 (taken from Blackwell, 2010) shows the US ground temperature map at 6 km depth. It indicates that almost the entire region has ground temperatures >75°C at a depth >6 km. Hence this binary cycle technology together with the latest advances in drilling technology transplanted from the oil and gas industry makes most of the United States amenable for power production. Such low heat application systems can be developed as, distributed systems serving individuals and communities of various sizes. Creation of such geothermal maps in India and other developing countries will pave the way for geothermal energy exploitation. As with any other system, smaller and distributed systems tend to be more expensive than large-scale systems. This is the reason why geothermal technology has not yet become popular. During this period of technology invigoration, GTP has also initiated R&D work on EGS (Enhanced Geothermal Systems). R&D in that area should help develop more geothermal, low as well as high temperature sources at much shallower depths for electric power generation.

Unlike other energy resources, geothermal source can be directly used for domestic purposes and water heating. Direct applications include buildings, aqua culture ponds, spas, snow melting on pavements and bridges, etc. In addition, an air source heat pump can be modified to use

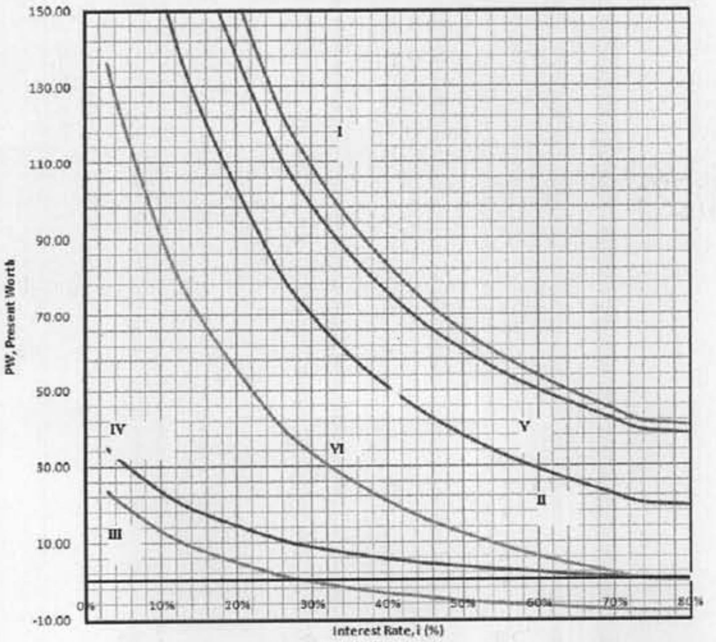

Fig. 5. IRR Analysis for six methods of recovery of ethanol from biomass.

ground water as a source for boosting the overall efficiency of the heat pump. For this purpose, as shown in Fig. 6, one could either use available ground water source from under the ground or from a pond, lake, etc. (water source heat pump) or circulate water (generally a mixture of water and anti freeze) through the ground (ground source heat pump), which acts as a heat exchanger. One should note that extraction of geothermal energy, whether for electric power generation or for heating/cooling, involves extensive digging and installation of pipes which is labor intensive thus resulting in high initial cost, particularly in countries like US, where the labor rates are high. Even developments in heat exchange technology for reduction in digging cost by the use of more complex and optimized pipe layout as in multiple pipes, helical pipes, etc., has not reduced the cost enough to make the pay back more attractive. Further R&D to increase the heat diffusivity inside the ground by increasing the effective thermal conductivity of the heat flow path should further contribute to cost reduction.

Wind

There is a great need for improving the established technology of harnessing wind energy by using wind turbines as it is estimated that it has a potential to meet 20% of the US energy needs by the year 2030. In addition, it is expected to cut down 7600 million metric tons of carbon dioxide emissions. To achieve these goals, technological advancement should also make it competitive with the cost of energy from currently established sources like fossil fuels, hydroelectric and nuclear energy. Table 6 shows a worldwide comparison of the annual wind power capacity development in 2009 as well as the cumulative capacity until 2009. Published estimates from DOE indicate that a 10% reduction in capital cost and 15% increase in capacity factor are required to reach the 2030 goal. Hence advances in technology leading to improvement of efficiency, reliability and capacity factor of wind turbines occupies a prominent place for harnessing the huge potential particularly from offshore wind farms.

In addition to quality or performance, reliability of any system determines its market value. This is particularly important for systems with a long life as in wind turbines, which are expected to last for 20-30 years. For a wind turbine manufacturer, to achieve even 90% reliability in his 30 year life model, it should last for a minimum of 27 years, which itself is a long period.

Reliability is especially important for wind power, which also faces the inherent disadvantage of being dubbed as an unreliable energy source due to its dependence on the highly unpredictable nature of wind speed and direction at any location. Reliability does not imply only functional dependability in terms of maintaining its design

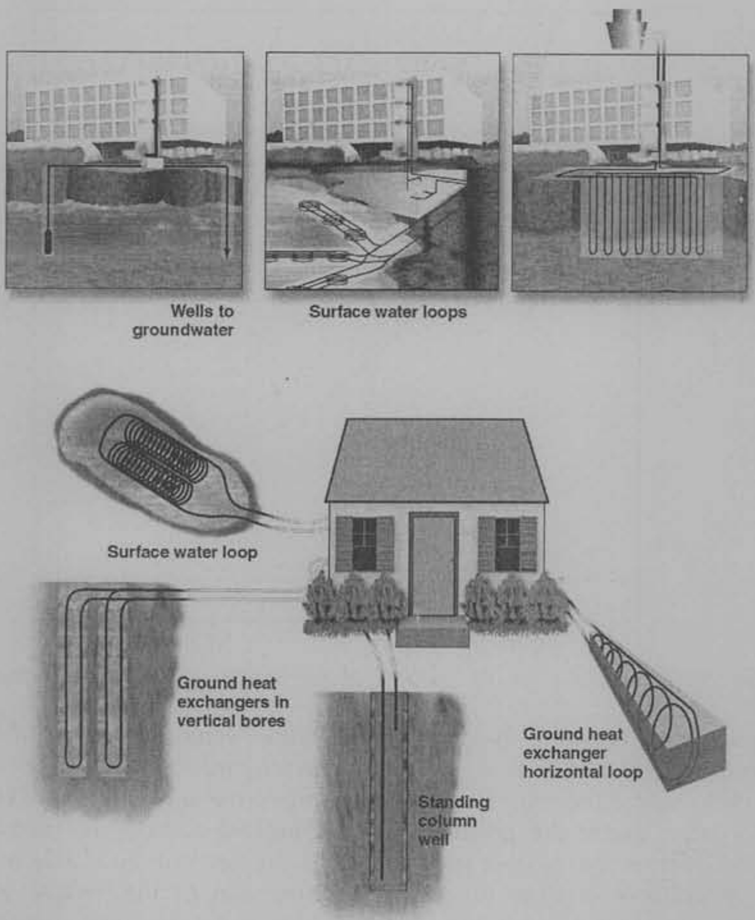

Fig. 6. Various geothermal source/sinks that can be applied to geothermal heat pump systems in commercial or residential applications (Collius et al., 2009).

performance or efficiency, but also structural reliability. Hence, condition monitoring is important for both performance and structural health monitoring (SHM).

Just like the other renewable energy technologies, wind energy harvesting from wind turbines is an ancient technique known to exist over more than a millennium. It was used as a source of mechanical power for pumping water from wells and for grinding corn and grains. Finally, after the invention of the electric generator, it became useful for generating electricity also. The science and art of designing better blades for capturing the maximum amount of energy from the wind got a boost from developments in aerospace technology as the blades are similar to airplane propellers and the cross section of the blades resemble the aerofoil cross section of an airplane wing. The wind turbines are basically classified into 2 main types depending on the orientation of its axis as horizontal or vertical type. In the vertical axis type however, there are 2 sub types, the savonius and the eggbeater type. The former is essentially a curved scoop, which scoops the air and the drag force provides the torque for its rotation. The egg beater type has its ends hinged to the axis to strengthen the blades. Both horizontal and vertical axes have their own merits and demerits. The horizontal axis is more common and has become bigger in size with blades of 250 ft diameter producing 5-10 MW of power. There have to be mounted on towers to clear the ground either upstream or downstream depending on its structural design and ability to withstand bending loads. An upstream tower will introduce the tower wake in to the blade flow field and reduce the blade efficiency for capturing energy from the wind. This design gives some structural design flexibility for the blade as it can bend without impacting the tower. On the other hand a downstream tower requires the blade to be stiff enough to limit its deflection for preventing impact. However this design will result in good aerodynamic efficiency. The wind speed is very

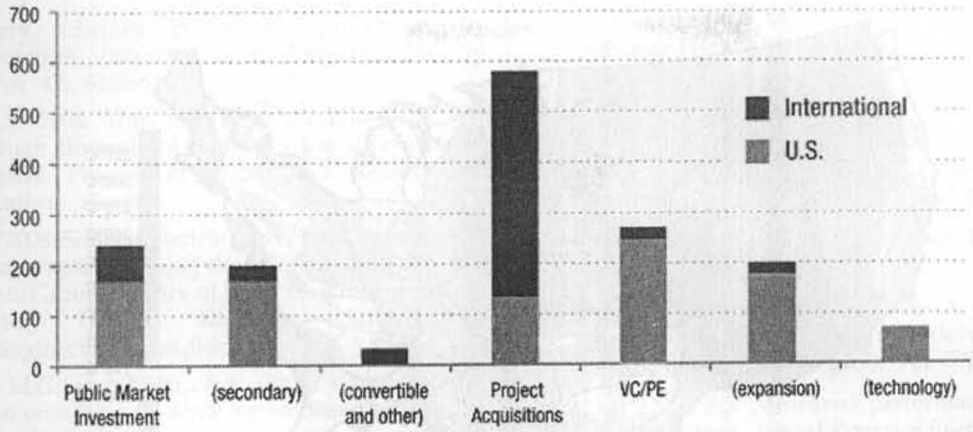

Fig. 7. US and international investments in 2008 in geothermal energy technology (taken from Cross and Freeman, 2009).

important as it determines the amount of energy, which is available at any location at any time. Wind speed varies both spatially as well as temporally. However, it increases with height above ground. Hence taller the tower, the greater is the power which can be generated. For this reason, vertical axis turbines, which do not need a tower are normally exposed to lower wind speeds and cannot generate as much electricity as horizontal axis turbines, mounted on tall towers. These design considerations are important during optimization stage as those big turbines can produce large power as well as large blade loads. At the time of this preparation of this overview, the biggest size turbine the authors' have come across is the Enercon 7.5/126 (Enercon News, 2011) which is a 7.5 MW turbine with a 126 m rotor diameter installed at Magdeburg, Germany, in Feb. 2011.

Large turbines of the above dimensions have reached the size of small power plants and can supply electricity to 10,000-15,000 residents. A few of them installed in wind farms could supply electricity to a city. However, the cost of wind power has still not become competitive with the conventional sources. This is due to the huge investment in wind turbines, in addition to the transmission cost. Hence even though wind energy appears to be free, it is not so and is currently more expensive than the conventional sources. In addition, the reliability of wind energy is so bad as to bring the capacity factor of wind turbines to about 20% to 30% depending on the location. Smaller distribution systems producing a few KW of energy and serving individual customers also has similar cost disadvantages even though the transmission cost does not exist. Instead, one will need a backup system with an ability to replace 100% of its power at short notice.

Currently in US, there is a big push for offshore wind farms. These have a potential to produce large power with a slightly higher capacity factor,

Table 6. Status of worldwide wind power development as of 2009 (taken from Wiser et al., 2009)

Annual Capacity (2009, MW):		Cumulative Capacity (end of 2009, MW):	
China	13,750	US	35,155
US	9,994	China	25,853
Spain	2,331	Germany	25,813
Germany	1,917	Spain	18,784
India	1,172	India	10,827
Italy	1,114	Italy	4,845
France	1,104	France	4,775
U.K.	1,077	U.K.	4,340
Canada	950	Portugal	3,474
Portugal	645	Denmark	3,408
Rest of World	4,121	Rest of World	22,806

industries, as well as the organic part of industrial and municipal waste. This includes, for example, wood, straw, energy crops, agricultural waste, agro-industrial waste, plants and animal waste.

Agriculture contributes to various extents to provide food, fibre, fodder and fuel (the 4Fs), and also provides feedstock for green chemistry, or bio-based materials. If the production of biofuel or biogas by agriculture is often presented as a new option valid for the future, it should be mentioned that in the 19th century in Europe, about 20% of agricultural land was used for non-food purposes. The assessment of the present or future availability of biomass is important at global level due to various factors such as:

- Increase of population at global level,
- change in diet, especially in Asia with an increase in meat consumption, and
- competition between biomass uses with the development of new uses of biomass, for example green chemistry and bio-materials.

The discussion of the agro-environmental impact of biofuels from tropical countries is essential in this period since:

- Criticism has often been expressed regarding biofuels sustainability in tropical ecosystems,
- most of the imports of biofuels or bioenergy feedstock to the European Union will originate from tropical countries or Russia, and
- ambitious targets have been set for the development of renewables including bioenergy, for example in Europe or the USA.

Part of the extra biomass needed in the future to satisfy all human needs could come from the use of extra land or from an increase in the yields of arable crops due to improved technology in plant breeding, crop nutrition and crop protection (Jaggard *et al.*, 2010). Nevertheless, the competition for biomass, including in tropical countries, will intensity.

In the European Union, the EU Member States have submitted in mid 2010 their Renewable Energy Action Plans (NREAP). Based on the analysis of 23 NREAPs, it appears that bioenergy (biofuels, biomass and bioliquids) accounts for almost 54.5% of the overall 2020 renewable energy target, with an estimated increase in absolute values and remains the main contributor to the renewable energy sector. Several Member States foresee a high import dependency of biofuels from outside Europe, for example Denmark (100%) Luxemburg, Cyprus, United Kingdom (87.7%), Ireland (70%), Greece (67%), the Netherlands (61.8%) and Germany (58.7%) (Atanasiu, 2010).

At global level, the IEA Energy Technology Perspectives 2010, Scenarios and Strategies to 2050, considers a contribution of 17% from renewables under the Blue Map Scenarioin in order to half global energy related CO_2 emissions by 2050, compared to 2005. For many countries or regions, the largest input from renewables will be provided by bioenergy, despite the progress in Solar PV and wind energy. This scenario corresponds to a rise in primary energy use of 32%, with a decrease of carbon intensity of energy by 64%, a decrease of liquid fuel demand by 4% (biofuels share of 20% and renewables providing almost 40% of primary energy supply).

Production, Use of Liquid Biofuels for Transport in the European Union and Imports

The Directive on the Promotion of the Use of Energy from Renewable Sources (2009/28/EC) had been approved on 23 April 2009. The objective of this Directive is to establish a framework for the promotion of energy from renewable sources, with a view to achieving the European Union (EU) target of a 20% share of renewable energies by 2020, indicated in the Renewable Energy Road Map. This includes a 10% share of energy from renewable sources in transport by 2020.

Unlike the other biofuel key players, the EU produces more biodiesel than bioethanol. 54.6% of transport fuels consumed in the EU are diesel versus 45.4% for gasoline. This proportion is not reflected in the production of biofuels: biodiesel accounts for more than 80% of EU total biofuels production. In 2007, the EU major producers of biodiesel were Germany (50.6%), France (15.3%), and Italy (6.35%) (EBB, 2008). The main feedstock for the production of biodiesel is rapeseed oil which corresponds approximately to 90% of the EU biodiesel production. In the EU the expansion of biodiesel production has put pressure on the rapeseed market. The areas under cultivation of rapeseed and sunflower seeds for energy use have increased from 780,000 ha in 2004 to 1,634,000 ha in 2006, corresponding to 22.5% of the total area dedicated to both crops. This expansion is taking place in areas traditionally dedicated to food crops. Currently, the EU is using about 40% of its rapeseed production and about 62% of its rapeseed oil production for the manufacturing of biodiesel. The pressure on rapeseed area is mainly due to the relatively low productivity of this feedstock in terms of litres of biodiesel per hectare. As a consequence, between 2002-2003 and 2006-2007 rapeseed oil prices have increased by 63%.

In Brazil, sugar cane, and more recently soybean, are the main crops used for energy purposes. Although in 2007 the EU was the world's third largest producer of ethanol (2.1 Billion litres), it is far behind the United States (24.6 BL) and Brazil (19 BL). EU ethanol production increased only by 11% compared to 2006 (in 2006 the increase was 71% compared to 2005, with 1.5 BL). The main producers of ethanol in the EU in 2007 were France (32.6%), Germany (22.2%), Spain (19.6%) and Poland (8%) (eBio, 2008). Contrary to the situation in Brazil with the development of biofuels so far mainly based on a single crop, i.e. sugar cane, ethanol in the EU is produced from a large variety of grain feedstock (wheat, barley, and rye), which account for the major part of the production, followed by sugar beet. Sugar beet is the most efficient crop for bioethanol in Europe, with production estimates around 7,250 litres of ethanol per hectare (3,125 for cereals). Since EU ethanol production is much smaller than biodiesel production, and since it is based on the utilization of various types of feedstock, of which the EU is a net exporter of some, ethanol has so far had no significant impact on agricultural land availability and commodity prices. On the contrary, it provides a new option to sugar beet producers, after the reform of the sugar Common Market Organisation adopted in February 2006 that reduced the sugar beet price by almost 40% and limited the sugar export opportunities to the World Trade Organization (WTO) quota.

Production and Use of Liquid Biofuels for Transport: A Controversial Issue

In order to reach European targets, there is a consensus on the possible need for Europe to complement at short- and mid-term biofuels produced from European feedstock with imports of biofuels from other countries. The amount of biofuel imports needed by the EU depends on the scenarios chosen and the sustainability benefits expected or taken into account by various groups.

Biofuels for transport are often considered as a tool to mitigate greenhouse gas emissions, reduce climate change, increase energy supply, increase diversity and security of energy supply, as well as new opportunities for agriculture and rural development. On the other hand, first-generation biofuels are also often criticised at various levels, for reports on their low environmental performance, their negative consequences on tropical deforestation and the diversion of land use (fuel against food). Biofuel policies, especially in Europe and the United States, are not a field of consensus, with very different scientific conclusions presented by different research groups as technical support for decision-making. The criticism towards biofuel development comes to a large extent from the scientific community (Crutzen *et al.*, 2007; Searchinger *et al.*, 2008), from some international organisations (OECD, 2007) and to a large extent from part of the media. Some NGOs are calling for a moratorium on biofuels. Another aggravating factor is the lack of consensus on Life Cycle Assessment results in relation to biofuels see for example Farrell *et al.* (2006) on the issue of US corn ethanol and Connor *et al.* (2006).

Biofuels in Brazil, Malaysia, India and Associated Agro-environmental Impact

Bioethanol: Brazil

The Pro Alcool Programme was started in Brazil in 1975, after the first oil crisis, mainly for security of supply concerns. Initially benefiting from public-support mechanisms, the activities were liberalised at the end of the 1990s, even if there are still some differential taxation schemes at State level. Information on the use of biomass for bioenergy in Brazil can be found in Focus on Brazil (IEA, 2006). From 1983 to 1988, 90% of the 800,000 new cars sold each year, on average were using ethanol. Due to the sharp increase in consumption, a severe shortage of ethanoloccured by the end of 1989, provoking a loss of consumer trust in the security of ethanol supply and Pro Alcool Programme. Due to these problems, by the end of the 1990s, the sales of ethanol-fuelled cars amounted to less than 15% of the total car sales. In 2003, car manufacturers introduced "flex-fuel" vehicles and it is estimated that "flex-fuel" vehicles correspond now to more than 3 quarters of new car sales in Brazil. Flex-fuel sales represented 88.2% in 2009. From 2003 until June 2010, more than 11 million flex-fuel vehicles were commercialised and the share in total light vehicles fleet is estimated to be 37%. Pure gasoline is no longer sold. The share of biofuels in road-transport fuel was estimated to be 14% in 2004 and has been growing since. The share of biofuels, considering diesel, gasoline and jet fuel reached 26% in 2008 against 74% of fossil fuels (MME).

Most of the reduction in the cost of production of ethanol in recent years came from the agricultural part of ethanol production. It is estimated that around 60% to 70% of the final cost of ethanol corresponds to the cost of the sugar cane production. Agricultural yield has therefore a strong impact on the final cost of ethanol. Average productivity in Brazil is around 65 t ha^{-1}, but it can reach 100 to 110 t ha^{-1} in Sao Paulo State, which is the main ethanol producing region. Since the beginning of the Pro Alcool Programme, yields have improved by 33% in Sao Paulo, thanks to the introduction of new varieties and the improvement of agricultural practices. There has also been a development of improved mechanisation. In the period 2001-2006, in the mid-west, southeast and southern regions, about 35% of the sugar cane planted has been harvested mechanically and the mechanised harvesting rate can reach 90% in some regions.

It should also be noted that there has been an historical evolution of Pro Alcool, with a progressive change of technological priorities. This is especially to be taken into consideration when comparing respective advantages/disadvantages of EU local production or imports. Initially the main focus of the Pro Alcool was put on the increase of equipment productivity. The size of Brazilian mills also increased. The focus then shifted to the improvement of conversion efficiencies. Over the past 15 years, special attention has been paid to a better management of the processing units. As a consequence, presently almost all sugar cane distilleries in Brazil use bagasse-fired steam turbine systems for providing steam and electricity to cover their site needs. For example, most biomass cogeneration takes place in Sao Paulo State with 40 sugar mills selling 1.3 GW of surplus power to the electrical grid. Bagasse-based co-generation is developed in order to reduce the country's traditional reliance on hydropower and in addition this improves the competitiveness of Brazilian ethanol.

Regarding processing conditions, on average 5 m^3 of water are used for each tonne of sugar cane processed, even if values range from 0.7 m^3 t^{-1} to 20 m^3 t^{-1}. According to Macedo (2005) the levels of water withdrawal and release for industrial use have substantially decreased over the past few years from around 5 m^3 t^{-1} sugar cane harvested in 1990 and 1997 to 1.83 m^3 t^{-1} sugar cane in 2004 (sampling in Sao Paulo State). In the conversion to ethanol, the reduction of water consumption was mainly due to reuses and recycling, process improvements and substitution of wet cane washing with dry-cane washing; in the higher values of water use (5 m^3 t^{-1}) sugar cane washing, evaporation and cooling in condensers and fermentation cooling accounted for 87% of the water use. It seems possible to decrease water collection and use to 1 m^3 t^{-1} with no release, by optimising both the reuse and use of waste water for irrigation (Moreira, 2007).

In the past, direct discharge of vinasse (liquid residue from the distillation of ethanol, rich in potassium and organic matter) to water streams was a cause of significant environmental damage. For each litre of ethanol, 10 to 15 L of vinasse are produced. Vinasse began to be recycled to the cane fields in 1978 when the first legislation governing the disposal of vinasse was passed. The current practice is full recycling of vinasse and industrial waste-waters. The application of vinasse is optimised for specific topographic, soil, and environmental conditions. Filter cake, another waste stream is also recycled as a fertiliser. Nutrient recycling in turn has reduced application of fertilisers. The highly intensive production systems for ethanol have been in the past a cause of environmental degradation mainly due to the use of fertilisers and pesticides. Sugar cane cropping is also a source of air pollution due to burning prior to manual harvesting. The phase-out of burning is taking place in Brazil with a deadline for complete phase out in 2022.

Average annual ethanol production has grown from 3,900 L ha^{-1} in the early 1980s to 5,600 L ha^{-1} in the late 1990s. In the most efficient units, annual yields are as high as 8,000 to 10,000 L ha^{-1}. Sugar cane crops are virtually non-irrigated in Brazil, except for some small areas (supplementary irrigation). The annual rainfall in Sao Paulo State is roughly 1,000-2,500 mm.

In 2007 about 11.6% of the cultivated area was used for sugar cane, compared to 23.8% for corn and nearly 35% for soybeans (IBGE, 2008) (out of presently about 59 Mha of arable land (IBGE, 2008) and about 172 Mha of pasture land (IBGE, 2006)). It has been estimated (Earth Policy Institute) that expanding the sugar cane area, from about 6.7 Mha in 2007 to some 8 Mha, would allow Brazil to become self sufficient in automotive fuel within a few years while conserving its sugar production and exports. According to projections from the sugar/ethanol sector in Brazil, increasing internal and export market demands for sugar and ethanol can easily be met. It is assumed that the industry should be able to produce 33.7 Million ton (Mt) of sugar (12.8 Mt for internal consumption and 20.9 Mt for export) and 26.4 Million m^3 of ethanol (of which 4.4 Million m^3 for export) by the year 2015. This would mean an increase of about 230 Mt of sugarcane in ten years – a doubling in the ethanol production and an increase of 44% in sugar production (WWI, 2007). Presently, sugar cane corresponds to 4.2 Mha or 1% of arable land and the ten year plan (2010/2019) of the Brazilian Ministry of Mines and Energy considers a target of 64 Billion liters of ethanol in 2019 against 33 Billion liters in 2010 (Marlon Arraes, MAPA/Embrapa 2010 data). The suitable areas identified for sugar cane expansion through agro-ecologic zoning have been estimated at 64 Mha, i.e. 7.5% of the territory.

Biodiesel: Malaysia

The Malaysia National Biofuels Policy (Malaysia Energy Centre, 2005) was launched in August 2005. The Government is promoting, among other, the use of biodiesel in public fleets. The blend is not compulsory yet, but it will be in the next phase of the implementation plan.

For oil palm, the oil extraction rate is 20% with annual palm-oil yield of about 4 t ha^{-1}. It should be noted that the best fields can produce 7-8 tonnes annually. The planting density ranges from 136-160 palms per hectare. The economic life span is 20-30 years. An oil palm usually bears fruits from 30 months after planting. Malaysia, humid tropical climate with a temperature range of 24°C to 32°C throughout the year, an evenly distributed annual rainfall of about 2000 mm, is very adapted to the cultivation of oil palm. According to Oil Worlds 2007, annual average oil yield is 3.74 t ha^{-1} for oil palm (mesocarp) against 0.38 for soybean, 0.48 for sunflower and 0.67 for rapeseed. The average annual oil yield from rape-seed in Europe is 1.3 t ha^{-1}.

Malaysia produced 200 Million litres of biodiesel in 2006, consuming 1% of the 15.88 Mt of palm oil produced. In 2007, the production remained almost unchanged and has already totalled 5.3 Mt in January-April 2008 (of the 17 Mt expected for this year) (Department of Statistics Malaysia, 2008). In 2006 less than 13%, or 4.17 Mha (from 54,000 ha in 1960) (Basiron, 2007) of Malaysia's land is planted with oil palm (the bulk of oil palm estates was previously planted with rubber, coconut and cocoa) (with 7.9 Mha of land used for agriculture (FAOSTAT, 2005).

Malaysia is the world's largest exporter of palm oil selling around 13.5 Mt with a relatively low domestic consumption. Malaysia's share of global oils and fats trade was 27.9% in 2006 (Oil World). According to MPOB 2008, the EU was, after China, the second destination for Malaysian palm oil in 2007 with 2 Mt (about 18% against less than 1% to the USA), almost half of the total palm oil imported in EU in 2007.

For the future, improved planting materials and better management techniques are foreseen. Domestic consumption is relatively low and Malaysia exports most of its palm oil and kernel oil.

MPOB is reporting costs of oil production (US $ per tonne), to be 228 for Malaysia, 400 for soybean (USA), 648 for rapeseed (Canada), 900 for rapeseed (Europe). The palm sector in Malaysia corresponds to the employment of 860,000 persons with 100,000 small-holders with 650.000 ha.

In 2006, the palm oil plantations had the following distribution in Malaysia: 2.34 Mha (56%) in Peninsular Malaysia, 0.59 Mha (14%) in Sarawak and 1.24 Mha (30%) in Sabah. If there are clear advantages of oil palm in relation to other options, concern has been expressed especially by NGOs about the impact of oil palm plantation development on tropical deforestation. According to FAO (2007) based on country report, the total forest area in Malaysia (in thousands of ha) was 20,890, i.e. 63.6% of the land and the forest plantation area 1,573. The annual change (in thousands of ha) for 1990-2000 was -78 (-0.4%) and -140 (-0.7%) for the period 2000-2005.

Concerning the use of peatlands in South East Asia, an assessment of CO_2 emissions from drained peatlands in SE Asia has been performed in the PEAT-CO_2 project (Hooijer *et al.* 2006). In this study, present and future emissions from drained peatlands were quantified using available data on peat extent and depth, present and projected land use and water management practices, decomposition rates and fire emissions. This study estimated that the current likely annual CO_2 emissions due to decomposition of drained peatlands amount to 632 Mt (between 355 and 874 Mt). For comparison, the agricultural sector for EU27 is estimated to emit about 430 Mt $CO2_{eq}$

sources of uncertainty (see e.g., Adler *et al.*, 2007; Porder *et al.*, 2009; Scharlemann and Laurance, 2008; Smeets *et al.*, 2009). If only the direct land-use effects are considered, it is fair to say that most of this uncertainty derives from the difficulty to accurately estimate the emissions of N_2O that go ahead with all soil cultivations. The reason is that nitrogen, once it enters the system as 'reactive' nitrogen (all forms of N with the exception of the inert molecular nitrogen, N_2), undergoes several steps of transformations until it is eventually transformed back as N_2 (this is referred to as the 'nitrogen cascade', Galloway *et al.*, 2003). The processes of nitrification (converting ammonia to nitrate) and denitrification (converting nitrate back to molecular nitrogen), which both release traces of N_2O in varying quantities, have particular importance.

The resulting high variability of N_2O fluxes in space and in time, and the equally high variability in indirect emission pathways is one of the largest sources of uncertainty for estimating N_2O emissions from agricultural soils. In field studies for direct N_2O fluxes, coefficients of variation up to 200% have been observed and the part of the variability in fluxes can be explained with the major soil parameters, such as soil organic carbon, pH, and soil drainage texture determining soil moisture and redox-potential (e.g., Dobbie and Smith, 2001; Granli and Bøckman, 1994; Yanai *et al.*, 2003). Further soil compaction influencing (e.g. Sitaula *et al.*, 2000; van Groenigen *et al.*, 2005), and tillage methods (Skiba and Smith, 2000) are both influencing water and oxygen status in the soil and thus determine whether the aerobic process of nitrification or the anaerobic process of denitrification, both potential sources for N_2O, can take place.

Also year-to-year variation is very high and is mainly driven by the weather (e.g., Baggs *et al.*, 2003). Within a year, high N_2O emissions are frequently observed following the application of fertilizer nitrogen, but can also be related to springtime freezing/thawing events (e.g. Flessa *et al.*, 1995; Maljanen *et al.*, 2004). These emissions are typically very large and can represent about half of the annual total emissions (Regina *et al.*, 2004). They are mainly explained by the increased availability of organic material due to the death of microorganisms combined with anaerobic conditions. A similar effect is given for cycles of wetting and drying (e.g. Davidson, 1991; Zheng *et al.*, 2004).

The resulting variability is overlaid with effects that are active at a larger scale, such as climatic differences, management systems, variations in soil type and landscape morphology at a medium to large scale. So far, however, it was not possible to explain large-scale variations by large-scale drivers and most assessments rely on the up-scaling of small-scale estimates. The difficulty here is to assure that these are effectively representing the larger scale (see e.g., Leip, 2009).

Approaches to estimate N_2O fluxes varying from very simple to very complex

There are various options to estimate N_2O fluxes associated with the cultivation of crops. These methodologies are differing by the complexity, of the calculation method and number of variables that are taken into account – from single-input global values (Crutzen *et al.*, 2008) to data-hungry methods that are applicable at a high resolution (Leip *et al.*, 2008).

Even though there is little doubt about the high degree of variability in measured data, the most widely used method is the IPCC emission factor of 1.25% of N-input (IPCC, 2001) or the – recently updated – factor of 1.0% (IPCC, 2006). Both factors have thus as their only parameter the input of nitrogen (as fertilizer, organic nitrogen, or crop residue). Next to the factor to estimate direct N_2O emissions occurring on the field, the IPCC provides also a method to estimate the so-called indirect N_2O emissions, which occur further down in the "Nitrogen cascade". Even though many experts are aware that the average N_2O emissions in their country might be different from the IPCC estimates, the default factors are nevertheless used in most national GHG inventories because robust data to estimate country-specific factors are not available (Leip *et al.*, 2005).

A compilation of all studies giving annual estimates of N_2O fluxes and sufficient ancillary information is provided by Stehfest and Bouwman, (2006), improving on earlier work of (Bouwman *et al.*, 2002). The authors developed a statistical method on the basis of data including N application rate and type, crop type, soil and climate information and the length of the experiment in the analysis. Applying this model globally, (Stehfest and Bouwman, 2006) find an average fertilizer-induced emission factor of 0.9% of the N-input, but regional differences are high. However, using this method to assess the contribution of N_2O to the GHG balance of first-generation biofuels, (Smeets *et al.*, 2009) conclude that the statistical model remains to be among the largest contributors of uncertainty changing the overall GHG saving by potentially more than 100% points. More detailed statistical analyses become possible for smaller regions. Particularly in Europe, the density of N_2O measurements is relatively high so that the application of a method based on ecosystemic stratification might become possible (Jungkunst and Freibauer, 2005), which can be seen as a further development of regression-approach developed by (Freibauer, 2003). Still, even in Europe, the number of measurements is scarce and process-based models are seen as the only possibility to extrapolate into "unexplored" conditions and thus give a truly complete picture of larger regions (see for example, Adler *et al.*, 2007; Leip *et al.*, 2008; Werner *et al.*, 2007).

Example one; global approach by Crutzen et al. (2008): Crutzen *et al.* (2008) propose a global emission factor for N_2O emissions of 3-5% of nitrogen needed to grow (biofuel) crops. This emission factor stems from a global analysis of the increase of atmospheric N_2O concentration and the anthropogenic generation of "new" nitrogen. This approach is very attractive as it comprehensively includes both direct and indirect emissions of N_2O, without the need to "track the fate of nitrogen" as this is done in the IPCC methodology. Accordingly, the Crutzen-emission factor can be regarded as much more robust than any of the emission factors contained in the IPCC guidelines. On the other hand, there is the risk of double counting in the case that a significant part of the nitrogen taken up by the crops is not 'new' (i.e. obtained through the input of synthetic fertilizer, biological nitrogen fixation or also by draining the nitrogen pool in soils), but stems from the application of manure or from atmospheric deposition (Leip, 2007). Being robust at the global level, however, implies also that the emission factor cannot be used to estimate local or even regional N_2O fluxes. As soon as a 'subsample' of global N generation is evaluated, the Crutzen emission factor becomes much more uncertain and should be corroborated (or substituted) by a more flexible approach.

Example two; detailed approach by Leip et al. (2008): Through the combination of an economic model, a downscaling procedure of the most important anthropogenic drivers (geo-referencing of land use activities and quantification of farm input) and a mechanistic biogeochemistry model Leip *et al.* (2008) established a framework that allows the evaluation of GHG fluxes from agricultural soils using a state-of-the art mechanistic model (Li, 2000). This is embedded into a realistic setting, including the most likely environmental conditions of cultivation of crops and regionally estimated farm input consistent with the economic environment (for example livestock number, feed and fertilizer import, etc.). The possibility to simulate a large number of spatial units allows the assessment of the spatial variability. A disadvantage of this methodology is that it has been set-up for Europe and can not easily be implemented in other parts of the world. Where the validity of the mechanistic model can be shown on the basis of experimental data, which are scarce in large areas of the world (see Stehfest and Bouwman, 2006), appropriate environmental datasets, in combination with estimates of farm management, might become a significant hurdle. A first application of the method to rapeseed cultivation in Europe, combining simulated emission fluxes by the biogeochemistry model with literature data (including also CO_2 fluxes occurring during farming-energy consumption), for example, that this occurs on soils characterised by relatively high N_2O flux rates offsetting a large part of the GHG savings when using the crops as feedstock for biofuels (Erisman *et al.*, 2009). Using sugar beet leads to a better overall GHG balance due to the lower N-input requirement.

The evaluation of the best method is not only a scientific problem, but must be seen in the framework of the policy formulation. For example, if thresholds for minimum GHG savings are set, then the decision to use a global approach excludes N_2O emissions from distinctions of biofuel feedstock with respect to their origin, however the selection of the emission factor could well influence the "ranking" of biofuel crops.

In the case that GHG certificates are issued for crops cultivated for the production of biofuels only, and not for those that enter the feed, food or fibre industry, the use of a detailed methodology might lead to a shift between land used for biofuel production or other uses, without any real impact on total GHG fluxes.

Consequently, detailed methodologies can only pay off if thresholds for GHG emissions from the field are applied to the whole production of a crop in a country. This could be the average CO_{2eq} emissions over the country, or to assure environmental integrity, the demand that a minimum share of the production be sustainable with regard to the threshold. Only in this case, the application of detailed models, which take into consideration the local environmental conditions (soil, climate, etc.) in combination with a realistic estimate of the spatial distribution of the cultivated areas would be important. In case such a model could be properly set up, which requires high quality environmental datasets and realistic estimates for farm-input, the use of aggregated emission indicators would also lead to a minimum uncertainty in the estimate of the GHG balance of the biofuel.

It is of utmost importance to improve our knowledge of these indirect land use emissions and our capabilities to accurately predict the GHG impact of biofuel (targets) comprehensively (Porder *et al.,* 2009).

Life Cycle Assessment of Biofuels

Biofuels for transport are generally considered to be environment-friendly since they save non-renewable energy resources, and – at least at first glance – CO_2 neutral. The latter is only true for the direct combustion of biofuels which releases the same amount of CO_2 into the atmosphere that earlier has been taken up by the biomass. However, when looking at the entire life cycle of biofuels – from biomass cultivation (including the input of fertilizers, pesticides etc.) through conversion into biofuels and their energetic use – substantial amounts of (non-renewable) energy resources are used which in turn cause greenhouse gas (GHG) emissions. Thus, biofuels are not CO_2 neutral from a life-cycle point of view. In the 1990s, a method was developed which addresses the environmental aspects and potential environmental impacts throughout a product's life cycle: Life Cycle Assessment (LCA). The method is internationally standardised (ISO standards 14040 and 14044) and considers the input and output flows (raw and other materials, energy and wastes, waste-water, emissions, etc.) and potential environmental impacts (e.g. greenhouse effect, acidification, etc.) of the considered product system (product or service) along its entire life cycle (cradle-to-grave", from raw material acquisition through production and final disposal). Life cycle assessments usually address a number of environmental impact categories, such as use of resources, global warming, acidification, eutrophication, (stratospheric) ozone depletion, summer smog (photo-oxidant creation), human toxicity and ecotoxicity. In recent years, however, the scope of many studies was restricted to two of them: the use of non-renewable energy resources and global warming. In this case, the LCA method is used to obtain so-called energy and greenhouse gas balances.

Greenhouse Gas Balances of Biofuels

Throughout the past 20 years, many energy and greenhouse gas (GHG) balances of biofuels have been published. Most commonly cited studies are perhaps the JEC well-to-wheels study (JEC, 2007) and EMPA (2007). In addition, there are a number of review studies such as IFEU (2004), VIEWLS (2005), Larson (2006) and Gnansounou *et al.* (2009).

According to the Worldwatch Institute (2007), "the vast majority of studies have found that, even when all fossil fuels throughout the life cycle are accounted for, producing and using biofuels made from current feedstocks result in substantial reductions in GHG emissions relative to petrol fuels". Despite all standardisation, the results of GHG balances may vary quite substantially. Among others, this is due to the fact that most of the above-mentioned studies do not take into account GHG emissions from land-cover and/or land-use changes. In literature, both processes are often grouped under the term land-use change (LUC). A distinction is made between direct and indirect land-use change.

Direct land-use changes (dLUC) occur, if (semi) natural ecosystems (e.g. forest land) are converted into agricultural land (e.g. an oil palm plantation). Indirect land-use changes (iLUC) or 'leakages' arise if agricultural land so far used for food or feed production is now used for energy crop cultivation. Provided that the demand for food and feed is constant, food and feed production is displaced to another area where again unfavourable land-use changes might occur. Both direct and indirect land-use changes ultimately lead to changes in carbon stock of above-ground and below-ground biomass, soil organic carbon, litter and dead wood.

Mainly depending on the previous land use (i.e. carbon stock of vegetation and soil), these changes can be neutral, positive or negative. In the 1990s, for example, set-aside land (fallow) was readily available for energy crop cultivation in the EU, so there was no need to use the basic agricultural land (i.e. where food and feed crops were taken) nor to convert (semi-)natural ecosystems such as forests into agricultural land.

Since set-aside land (fallow) still remained agricultural land (not subject to natural succession), its carbon stock did not change significantly compared to cropland. Thus, the re-conversion of set-aside land (fallow) into cropland did not induce any GHG emissions. This situation changed in the 21st century with biofuel mandates increasing the pressure on both agricultural land in Europe and (semi-)natural ecosystems elsewhere in the world. If ecosystems such as grassland, forest land or wetland are converted into cropland, high GHG emissions can occur. In contrast, the use of degraded land may even lead to carbon sequestration.

Both dLUC and iLUC can be dealt with in life cycle assessments, as Reinhardt (1993) and Jungk *et al.* (2002) have shown for dLUC and iLUC, respectively, although referring to it as the 'agricultural reference system' at the time. The first GHG balance studies to account for GHG emissions due to (direct) land-use change from natural forest to oil palm plantation were published by WWF (2007) and Reinhardt *et al.* (2007) using IPCC (2006) data for the calculation of dLUC. The results show that GHG balances of palm oil biodiesel could even turn out negative, i.e. use of palm-oil biodiesel could cause higher life cycle GHG emissions than the use of conventional diesel fuel.

Indirect land-use change effects are difficult to verify empirically: they occur at global level and in contrast to direct land-use changes there is no causal link between the cultivation of energy crops (e.g. in Europe) and land-use changes elsewhere in the world. The topic of indirect land-use changes caused by biofuels was brought to widespread attention by Searchinger *et al.* (2008) who estimated the indirect or 'leakage' land-use impacts of US corn ethanol to double the greenhouse gas emissions per fuel mile compared to conventional gasoline over 30 years. The paper marked the starting point of a controversial debate. Despite all efforts to date, there is no commonly accepted method on how to quantify iLUC effects (Banse *et al.*, 2008; Kim *et al.*, 2009; Fehrenbach *et al.*, 2009), let alone how to integrate iLUC in life cycle assessments (Kløverpris *et al.*, 2008; Liska and Perrin, 2009).

Irrespective of all criticism it faced, the iLUC concept has recently been implemented in legal documents such as California's Low-Carbon Fuel Standard (LCFS) and U.S. EPA's Renewable Fuel Standard (RFS2). In the case of LCFS, GHG emissions due to iLUC are quantified by the GTAP (Global Trade Analysis Project) model, a general equilibrium model. On the contrary, RFS2 prefers a combination of two partial equilibrium models, the FASOM (Forest and Agriculture Sector Optimisation Model) and the FAPRI (Food and Agricultural Policy Research Institute) model. Both approaches have been peer reviewed by several experts (ICF International, 2009) who conclude that none of them is superior to the other and that the science on indirect land-use change is in its infancy (Sheehan, 2009). Work on iLUC is also performed in the EU in relation with the Renewable Energy Directive (2009/28/EC) implementation.

Example - Greenhouse gas balance of palm oil biodiesel: Quite a number of greenhouse gas balances for palm oil and downstream products, such as palm oil biodiesel (palm oil methyl ester, PME) can be found in literature, e.g. Germer and Sauerborn (2008); Reijnders and Huijbregts, (2008); Reinhardt *et al.*, (2007); Schmidt, (2007); Wicke *et al.* (2007; 2008), WWF (2007) and Yusoff and Hansen (2007). The results of these greenhouse-gas (GHG) balances vary quite substantially, mainly depending on whether and how direct land-use changes are considered, both in terms of methodology and basic data. Secondly, the way co-products obtained in palm oil production are accounted for, plays a crucial role. When applying the so-called substitution method (system expansion), great optimisation potentials can be identified.

Palm oil biodiesel and GHG emissions related to direct land-use change: Direct land-use changes (dLUC), i.e. the conversion of (semi-) natural ecosystems (e.g. forest land) into agricultural land (e.g. an oil palm plantation), induce changes in above-ground and below-ground carbon stock which can lead to high GHG emissions. These have to be included in GHG balances.

GHG emissions from land-use changes can either result from singular events (e.g. clear-cutting and/or slash-and-burn) – which require an annualisation – or from continuous processes (e.g. peat subsidence) that prevail for many years after land conversion. If fire is used to clear the site (slash-and-burn), emissions of methane and nitrous oxide have to be considered in the GHG balance too. A detailed analysis by Reinhardt *et al.* (2007) has shown that the two factors are most important.

Magnitude of carbon stock change: Depending on the previous land use, the amount of carbon stored in both the above-ground and below-ground vegetation, as well as in the soil differs considerably. Most authors use IPCC (2006) data for carbon stocks of vegetation and mineral soils. Data on the carbon stock of organic soils, however, is rare and depends heavily on soil density, organic matter content and peat thickness. GHG emissions from vegetation fires are only included in Germer and Sauerborn (2008) and Rettenmaier *et al.* (2007), the latter also covering peat fires.

Annualisation: GHG emissions resulting from single event, such as clear-cutting of natural forests, have to be evenly divided over a certain period of time (i.e. annualised). As the length of this period is not specified by LCA standards, it is up to the user to define an adequate time span. Many opt for 100 years, others for 25 years which equals one plantation cycle (economic life span of oil palms), whereas IPCC (2006) and the EU Renewable Energy Directive (2009/28/EC) stipulate an annualisation over 20 years.

Regarding basic data for continuous processes such as CO_2 emissions due to peat subsidence and N_2O volatilisation due to fertilization of organic soils, IPCC (2006) unfortunately does not give clear guidance. For example, if drained peat soils are classified as 'drained organic soils in managed forests', annual CO_2 emissions are as low as 1.36 t C ha^{-1}. However, if they are classified as 'cultivated organic soils' the figure is considerably higher: 20 t C ha^{-1}. IPCC suggests basing the classification on drainage depth, but gives no threshold values. In the above-mentioned GHG studies, values from 8.6 t C per ha per annuam (Germer and Sauerborn, 2008) to 25 t C per ha per annum (Reinhardt *et al.*, 2007) are used, the latter based on an equation by Hooijer *et al.* (2007) and a drainage depth of 1 metre. Melling *et al.* (2005a) criticize Hooijer's figures, but derive their own ones from disturbed ecosystems (Verwer *et al.*, 2008).

In order to obtain more accurate results for the GHG balances, further research is needed, especially regarding GHG emissions from tropical organic soils.

GHG emissions related to palm oil production

Next to land-use change, cultivation and processing are two critical stages along the life cycle of palm oil biodiesel, which can be optimised considerably (Helms *et al.*, 2006; Reinhardt *et al.*, 2008). Great optimisation potentials emerge from (a) yield increase due to the use of improved planting material, tailored fertilization and just-in-time harvesting, (b) the use of entire amount of co-products such as fibres, shells and EFB (empty fruit bunches) for energy purposes, and (c) the retention and utilisation of the biogas from POME (palm oil mill effluent) treatment.

These three elements considerably improve the GHG balance of palm oil biodiesel: the disadvantage (i.e. net GHG emission) accounts for 'as little as' 5.9 t CO_{2eq} per ha instead of 9.7 t CO_{2eq} per annum without optimisation.

A comparison of basic data for palm-oil production (Rettenmaier *et al.* 2007) showed much less variability as compared to the basic data for land-use changes. All of them point at a significant potential to optimise both oil-palm cultivation and palm-oil extraction.

Conclusion: Life cycle assessment is a very suitable tool to assess the environmental impacts of biofuels. Despite all standardisation, it could be shown that the results may vary substantially. This is due to differences in methodologies differences regarding system boundaries (e.g. exclusion of land-use changes) or the method used to account for co-products (substitution versus allocation method) as well as differences in basic data (e.g. crop yields, carbon stocks, N_2O emission factors).

As far as GHG balances are concerned, the largest influencing factor is GHG emissions from land-use changes. If LUC – as it is common scientific consensus – are included in the balance, the qualitative results (positive or negative) are rather similar. The quantitative results, however, are differing due to varying basic data. Here, more efforts are needed to harmonize the underlying basic data. Moreover, research concerning indirect land-use changes is still in its infancy. A harmonised approach to account for indirect effects in life cycle assessments urgently needs to be developed.

Water and biofuels

The extent of land under irrigation in the world was 277 Mha in 2002, corresponding to about 20% of all cropland and about 40% of agricultural production. In terms of freshwater withdrawals from rivers, lakes and aquifers, defined as 'blue water', agriculture accounts for 70%, up to more than 90% in some developing countries. Rainfed agriculture covers the remaining 80% of arable land (Faurès *et al.*, 2007 and UN Water Statistics). In 1995, 38% of cereals grown in developing countries were on irrigated land, accounting for just under 60% of cereal production. A significant difference in productivity between irrigated and rainfed agriculture has been observed, averaging 1.5 and 3.3 t ha^{-1} for rainfed and irrigated cereal yields, respectively (Rosegrant *et al.*, 2002).

Semi-arid areas where many of the world's farmlands are cultivated are expected to become drier due to climate change. Another effect of climate change is expected at regional level, where mountain snow pack, glaciers and small ice caps play a crucial role in freshwater availability. Widespread mass losses from glaciers and reductions in snow cover over recent decades are projected to accelerate throughout the 21st century, reducing water availability, hydropower potential, and changing seasonality of flows in regions supplied by meltwater from major mountain ranges (e.g. Hindu-Kush, Himalaya, Andes), where more than one-sixth of the world population currently lives (Climate change, 2007). Furthermore the intensive human-induced stresses on the aquifers have already reduced groundwater tables and river levels in many parts of the world. Water has been withdrawn at rates far faster than natural renewal and in some area level receded more than 30 meters e.g. in three US States as Texas, Oklahoma and Kansas (Brown *et al.*, 2006). Thus, even if the percentage of water presently used for a specific purpose (e.g. for biofuels) is very low, it is fundamental to evaluate if the withdrawal is sustainable.

At national level, the water impacts of French biofuel development at the 2030 time horizon have been studied by Lorne and Bonnet (2009). In 2006, French biofuel production occupied nearly 800,000 ha, amounting to around 2.8% of agricultural land supplying 1.8% of the country's total fuel supply. Protecting water resources is a main concern for the French authorities, especially when it comes to formulating agricultural strategy for a given territory. Four scenarios were elaborated:

- S1A: 5 Mtoe of first-generation liquid biofuels
- S1B: 5 Mtoe of first-generation liquid and gaseous biofuels
- S2: 20 Mtoe of second-generation biofuels
- S3: 14 Mtoe of second-generation biofuels, with water resource protection

Each scenario was defined by the crop needs and agricultural area dedicated to attaining the required levels of biofuel production. The change in land use was first defined at national level, and then at the level of two main hydrographic basins, Adour-Garonne and Seine-Normandy. An assessment methodology at the level of the main basins was developed. The water stress assessments measure the effects of land conversion in 2030, compared to a 2006 baseline. The assessments involve quantitative aspects (water consumption, impacts on water balance in the Basins)—as well as qualitative aspects (nitrate and pesticide pollution)—of mobilizing water resources. The scenarios reflect agricultural production choices at the 2030 time horizon, based on hypotheses and constraints regarding the rollout of the different biofuel industries. Each scenario is based on biofuel production from agricultural products or co-products produced on current useable farmland.

The cultivations for the year 2030 are either field crops used for first-generation biofuels (e.g., from grains and oleaginous plants), or for second-generation biofuels (lignocellulosic biomass and whole plants). The agricultural land in 2006 that is subsequently converted includes the following main types of land destined for non-food use in Europe: agricultural land set aside as specified by the Common Agricultural Policy, cropland for energy use, non-cultivated agricultural land, cropland for export outside of the European Union, a fraction of permanent grasslands, and poplar plantations. Conversion matrices for agricultural land subject to the evaluation in the period 2006-2030 are established for the two water basins, consistent with the conversions in the northern and southern zones.

In the Seine-Normandy Basin, the agricultural area dedicated to biofuels is likely to increase from 343 thousand ha in 2006 to 848, 624, 1 487, and 1 465 thousand hectares in the four scenarios for the year 2030. 10-25% of the useable farmland of the Seine-Normandy Basin is thus mobilized.

In the Adour-Garonne Basin, the dedicated area may rise from 63 thousand ha in 2006 to 442, 300, 1 163, and 1 083 thousand hectares in the four scenarios by the year 2030. These areas represent 6-25% of the useable farmland of the Adour-Garonne Basin.

Three main groups of results were prepared: (1) Quantitative stresses based on crop water balance. For each scenario, the different terms of the balance (e.g., evapotranspiration, consumption, water deficit, drainage) determine the pressure indicators, which are evaluated at the level of the basins using the assessments of land conversion between 2006 and 2030. (2) Qualitative nitrate stress based on the evaluation of nitrogen leaks and nitrate concentrations in sub-root draining. (3) Qualitative phytosanitary stress based on the study and on the adjustment of existing indicators such as treatment frequency index (TFI) and contamination of surface and subsurface water (SIRIS-Pesticides ranking).

Scenarios 1A and 1B refer to first-generation fuels and are based on conventional food agriculture. The choice of agricultural areas on which biofuel crops are planted avoids direct competition with staple food production. Scenarios 1A and 1B lead to an intensification of the stress, with clear and relatively coherent trends. Scenario 1A in particular leads to a clear intensification of stress on all indicators with respect to 2006: intensification of water consumption, more nitrogen leaching, and no improvement in phytosanitary stress. Scenario 1B, which keeps the same predominant agricultural panorama as that of Scenario 1A, reduces the stress thanks to the reduced area made possible by biogas production. This biogas is produced from harvest co-products (in both basins) and from dedicated perennial production (in Seine-Normandy). This moderates the growth in the stresses that are present in Scenario 1A, although there is still no improvement compared to the 2006 situation: The improvement is only relative. The influence of this biogas industry tempers the negative impacts due to cultivation of land that was initially fallow or grassland.

Scenario 2, which describes significant development of intensive energy cultivation for second-generation biofuels increases certain quantitative stresses, while reduces others (nitrogen stress). The phytosanitary stresses evolve differently in each basin. In Adour-Garonne, an intensification of practices and exposure risk is observed; in Seine-Normandy, there is diminished intensity of practices without any change in risk. These differences between the two basins are due to the characteristics of the crops planted and the substances involved.

Scenario 3, whose objective is to improve the water resource situation on the same area as in Scenario 2, proves that it can provide effective protection. The water balance is clearly improved. There is an improvement in nitrogen stress, though dramatic because of the perennial cultures that are generally favourable on this point. The phytosanitary practices, which are less intensive by definition (with adapted technical paths), result in a clear reduction of exposure risk with respect to 2006, and Scenario 2. The overall results for the different quantitative criteria, and for nitrate and pesticide quality, corroborate one another for Scenario 3 in both Adour-Garonne and Seine-Normandy. The trends are thus opposite to those of Scenario 1A.

In Scenario 2, there is significant degradation of the quantitative performance (a very clear increase in water consumption), while the nitrate and phytosanitary indicators improve.

Scenario 3 thus distinguishes itself from others through its proposition of a policy option: On a dedicated area that is significant but realistic, combine the environmental "energy" goal with that of water resource conservation, by fully taking advantage of environmental opportunities presented by energy crops. This role of water resource protection appears particularly interesting for the zones in which solutions for reducing agricultural stress are sought.

At global level, the water footprint of biofuel-based transport has been studied by Gerbens-Leenes and Hoekstra (2010). This study calculated the water footprint of different transport modes using bio-ethanol, biodiesel or bio-electricity and of European transport if 10% of transport fuel is replaced by bioethanol. The results for Europe were compared with similar goals for other regions (Africa, Asia, Latin America, the former USSR, Australia and North America). The results were compared with the water footprint of food and cotton.

It appears that, in general, it is more efficient to use bio-electricity and bio-ethanol than biodiesel. Transport per train or electric car using bio-electricity (8-19 and 11-13 litres per passenger km) is more water efficient than transport by car driven by bio-ethanol (36-212) or by airplane using bio-ethanol (65-136 litres per passenger km).

In case of a European goal to have 10% biofuel in transport in 2020, it is estimated that this would result in a water footprint of 62Gm^3 per year. This corresponds to about 10% of the present European water footprint of food and cotton consumption. Differences in per capita energy use for transport between European countries, together with differences in production systems, result in a wide range of transport-related water footprints, e.g; from 60 m^3 per capita per year in Bulgaria to 500 m^3 per capita per year in Finland.

If the same 10% biofuel target was applied in other parts of the world, the additional water footprint of China would be equivalent to 5% of the water footprint related to food and cotton consumption. This figure would be 3% in the rest of Asia, 4% in Africa, 10% in Latin America, 22% in former USSR and 52% in North America and Australia. It is estimated in this study that the global water consumption related to biofuel-based transport in this scenario would correspond to 9% of the current global water consumption for feed and cotton. These results thus show that a trend towards the increased application of biofuels in transport will increase the competition for fresh water resources.

The issue of biofuels sustainability and the impact of the future water use for bioenergy feedstock production has to be assessed in a wide framework, considering not only water use for agriculture. Kummu *et al.* (2010) have analyzed water shortages around the world over the past two millennia. Population growth has been a significant pressure on supplies and will continue to increase in the future.

Long-term trends in water shortages from the year 0 AD to 2005 AD have been analyzed using climate and hydrological modelling of water balance in river basins. The results provided a picture of water shortages over 12 regions across the world in relation to population growth. According to this study, water shortages developed around 1800, when about 5% of the world population (about 40 million people) lived under moderate water shortage, i.e. there were 1000-1700 cubic metres of water available for each person every year (m^3/capita/yr).

From 1900 onwards, the number of people living under water shortage conditions increased sharply: by 1960, 280 million people, or 9% of the global population were living under chronic water shortage (less than 1000 m^3 $capita^{-1}$ yr^{-1}). In 2005 about half the world's population, or about 3 billion people, were living with some form of water shortage, of which 2.3 billion (or 35%) were living under chronic water shortage.

Some regions have particularly serious problem of water shortage problems. By 2005, South Asia was the region with the highest percentage (95%) of people living under some form of water shortage (less than 1700 m^3/capita/yr). In North Africa this figure was 81% and 76% in the Middle East. The annual population growth in these regions is over 2% and will probably lead to further water shortages. The most severe water shortages occur in North Africa and the Middle East, where more than half of the population live under extreme water shortage (less than 500 m^3 $capita^{-1}$ yr^{-1}).

Historically, a number of adaptative measures have been used in response to water shortages. During the 20th century, three most common strategies were to construct dams and reservoirs to store water, to irrigate crops in low rainfall areas, and to withdraw groundwater in areas where there is little fresh water. In addition, global trade in agricultural products can help alleviate water shortages, as areas with inadequate water resources import crops grown in regions with sufficient water.

Nevertheless, structural adaptation measures alone are not enough to combat physical water scarcity in the future. 'Soft' adaptation measures (non-structural) are increasingly an essential component of water management, and include increasing the efficiency of water use, reducing the intensity of water use, the pricing of water services, recycling water, improving water distribution networks and improving water irrigation technologies. For these strategies to contribute to water security, water governance, management and policies must be fully integrated into a society's political, social and economic development.

Biomass and Competition of Uses

Regarding the assessment of the future sustainability of bioenergy and biofuels for transport, an increasing attention is now paid to the issue of competition of land uses for the biomass feedstock. To a certain extent, the same categories of biomass feedstock (and thus the same land acreage) can be used for traditional food, feed, fuel crops, as well as for new uses especially in bio-materials and green chemistry. These last two categories are now growing with the development of biotechnologies. The issue of competition of uses of biomass is influenced by several factors, especially by the choice of public support mechanisms. It has to be addressed at international, national, regional or local level, but there is often a lack of quantitative data and a lack of awareness about the potential of the industrial use. For Germany, the nova-Institut (See Carus *et al.*, 2010) has performed a study of all industrial material uses of renewable raw materials in Germany: domestically produced agricultural materials, wood and imported materials.

Data from all sectors have been systematically collected and analyzed to identify the characteristics of these materials from a public policy perspective. It appeared that there is a lack of data relating to material uses compared to the data available for the bioenergy area. For this study, renewable raw materials were defined as the totality of plant, animal and microbial biomass, including biomass delivered through food chains, whose primary production is based on photosynthesis and which are provided for material and energy uses of all kinds outside food and feed. With material use, the biomass serves as raw material for the (industrial) production of all types of goods.

For Germany 2007, it was estimated an available amount of 90.6 Mt of renewable raw materials. The study shows that a total of 47.9 Mt of renewable raw materials were used for their material properties by German manufacturing industry in 2007. Of this, 3.6 Mt were provided by agricultural crops (excluding straw) while wood accounted for 44.3 Mt. In addition, 6 Mt of cereal straw were used, particularly in agriculture. In contrast, a total of 10.1 Mt of agricultural materials and 32.6 Mt of wood, that is a total of 42.7 Mt, were used for energy purposes. Overall, a total of 90.6 Mt of renewable raw materials were used for non-food purposes in Germany in 2007, of which 53% were used for industrial purposes and 47% were used for energy. When only the agricultural sector is considered, 26% of non-food output is used for industrial use and 74% is for energy. The proportion used for energy has risen continuously over the last 10 years.

Major industrial users of agricultural raw materials include the chemical industry (various feedstock chemicals, structural chemicals, pharmaceuticals, bio-based plastics) (47%), the oleochemical industry (surfactants, paints and inks, lubricants, polymers, etc.) (28%), the paper and pulp industry (paper starch) (18%), the textile industry (textiles, insulation materials, non-wovens and composites) (4%) and the pharmaceuticals and cosmetics industry (2%). Wood is used for the sawn timber and other wood-based industries (construction, furniture, packaging) and for the pulp and paper industry. Smaller quantities of cellulose derivatives and regenerated celluloses are produced for a variety of applications (textiles, thickeners, adhesive paste, cigarette filters and processed polymers).

Of the 3.6 Mt of agricultural raw materials used in industry, 2.3 Mt (64%) are imported and 1.3 Mt (36%) are grown in Germany on a total area of 280,000 ha. Imports are dominated by vegetable oils (palm, coconut, soy), natural rubber, chemical cellulose, natural fibres (mainly cotton), corn starch and medicinal plants. Until 2008, there were little or no imports of proteins or sugar-based raw materials.

In the wood sector, the proportion of imports is about 10% and this level of imports is evenly distributed through the processing chain. When wood and agricultural raw materials are considered together, the net import is only 14% of the total supplies of renewable industrial raw materials. Germany is thus 86% self-sufficient in renewable raw materials used for non-food purposes in industrial manufacturing.

This study raises concerns about unbalanced policy, with high levels of support for bioenergy while material uses are neglected. In the past decade, the German Renewable Energy Resources Act (EEG), the Energy Tax Act, the Biofuel Quota Act, reduced VAT for firewood and wood pellets, a market incentive programme for wood pellet heating, and many other measures have provided a comprehensive set of incentives that support the use of biomass for energy. In German while the agricultural area used for energy production has increased 10-fold to 1.8 Mha, the area under crops for material uses stagnated at around 300.000 ha. The authors of the Nova study retain that the various support measures account for 50% to 80% of revenues of many bioenergy products and options. On a production area basis, these equate to 300 to 3,600 ha^{-1} with biodiesel and other vegetable oil fuels (by now) at the lower end of this scale and small-scale biogas, bioethanol and BTL at the upper end.

According to this analysis, there are 2 to 3 Mha available for non-food crop production purposes in Germany. This estimate takes into consideration the reduced availability of land for non-food crop production in times of high prices for food crops (with production of wheat for export). Under favourable conditions (e.g. adequate public support, high oil prices) it is considered that material uses could account over 1.8 Mha of arable land by 2020 in Germany, which is equivalent to the area now used for energy. The main sources would be rapeseed (905.000 ha), wheat (670.000 ha) and sugar beet (175.000 ha). The most important sectors would include the chemical industry in general, bio-based materials and products as well as the oleochemical industry (surfactants, lubricants) in particular. In addition, niche crops such as hemp, Miscanthus, short rotation coppice (e.g. willow) and medicinal plants could amount to up to 90.000 ha. They would be mainly used as bio-based materials and products (wood-based materials, natural fibre reinforced plastics, insulation materials, textiles) and in pharmaceuticals. Based on the analysis of macro-economic studies and surveys, it is considered by the authors that the material use of renewable raw materials supports more employment and results in more value-added compared with the use of the same resource for bioenergy. When considered on the basis of the quantity of biomass used or the area used for production, material uses result in 5 to 10 times more people directly employed and 4 to 9 times more value added. The reason for this is the more complex and longer supply chains for material use.

The study involved reviewing a total of 160 life-cycle assessments. Most show clear advantages for renewable materials compared with materials based on fossil oil. The material use of biomass generally delivers area-related climate protection benefit at least equal to that of first generation biofuels (each based on the same area). Most deliver higher benefits and the best are significantly higher than the benefits of the second-generation biofuels. On average across all product lines, material uses can be expected to deliver a saving of 5 to 10 t CO_2-eq. ha^{-1} per year. When cascade use is considered, which involves repeated material uses followed by recovery of energy, the saving can be increased significantly. There is a lack of robust data on these additional benefits of cascading.

Scientific Challenges in the Field of Biomass Conversion and Biorefineries

The efficiency of the entire chain of biofuel production depends on the biomass cultivation but also on the biomass conversion. Biomass feedstocks for use in bioenergy processes vary widely in their composition and properties. Work within the European standards organisation, CEN, has almost completed a set of technical specifications for methodologies to determine a wide range of properties of biomass for use as solid biofuels, and these technical specifications are being converted to standards for market implementation (CEN/TC335). The properties of biomass have a large impact on what the biomass can be used for and also strongly influence the selection of method of conversion to biofuel, heat or electricity. For example, animal slurries and manure have high water content and can only be used as a feedstock in anaerobic digestion (AD) providing a biogas that can be used after simple cleaning to produce heat and electricity, or can be upgraded to biomethane for use as a transport fuel or injected into natural gas grids (Wellinger *et al*, 2005). The challenges for more effective and more efficient use of wet agricultural residues include improved methods for accelerating the methanation process using co-digestants containing easily released forms of carbon, overcoming inhibiting effects and maintaining optimum process control. Biogas technology is developed to the stage where a few thousand plants already exist in Europe, but economic viability is not easily achieved without the application of renewable energy subsidies and feed-in tariffs (Weiland, 2008).

Many types of biomass, including agricultural residues and energy crops such as maize and sugar beet can be used to produce liquid biofuels (e.g. bioethanol) with existing first generation commercial biofuel technologies which make use of simple, easily released sugars from carbohydrates contained in the biomass. The main challenge facing the biofuel industry is to convert non-food biomass containing ligno-cellulose to biofuel, using so-called second generation biofuel processes. Two main approaches are being addressed. One, a biochemical process, involves pre-treatment of ligno-cellulosic biomass by mechanical grinding to increase surface area, followed by steam explosion, sometimes called cavitation, and enzyme treatments and fractionation to isolate sugars and other useful residues. These processes are under intensive development (Kamm *et al.*, 2008). Separation of individual components of the biomass after pre-treatment offers the possibility to obtain additional products by bio-refining. Biorefineries to produce chemical pre-cursors are the subject of intense research in many countries. The focus of developments devoted to both pre-treatments and synthesis/refinement of chemical products (e.g BIOSYNERGY European Project, 2009). The biorefinery processes under development are in direct competition with hydrocarbon-based production of chemicals and one of the ways to address the high cost element of biorefineries could be to integrate with fossil refineries. The other approach is to treat the biomass thermally at high temperature using gasification or pyrolysis to produce an intermediate fuel essentially in one process step. This avoids many steps in the process, but also involves destroying a number of possible useful co-products available in biochemical processes (e.g. lignin), however providing a very versatile precursor (syngas or bio-oil) that can be readily converted to one of many hydrocarbon products, or even hydrogen. Fischer-Tropsch diesel is the best known product of gasification of biomass to produce a second-generation biofuel. While the F-T diesel process has been proved on pilot scale, the big challenge is to ensure high catalyst performance over long periods of production in large-scale facilities and to prove high energy conversion efficiency. New catalysts are also sought, while pre-treatment of the woody biomass, mainly to facilitate trouble-free feeding to the thermal process, needs to be made less energy consuming.

Direct combustion of biomass or co-firing of biomass in fossil power plants for heat and electricity generation is the most widely used technology for producing bioenergy in most European countries. Early trials by the power generators resulted in numerous problems, either during feeding of the biomass into boilers or due to fouling and corrosion after combustion (Tillman, 2000). Pre-treatment by drying and grinding has led to a number of successes, but there remain safety challenges due to the production of biomass dust (fires/explosions) and minimising energy consumption during drying, chipping and pelleting operations. Torrefaction of woody biomass, which involves removal of moisture and light volatile species, has been tested on a small-scale and needs evaluation at a large scale to establish the costs in terms of energy consumption on the one side, and energy conversion efficiency and reduced corrosion on the other. For direct co-firing of solid biomass with coal, energy efficiency and reliability of a plant using 100% coal are reduced.

Conclusions and Recommendations

Even if modern bioenergy (for transport, but also for heat and electricity) is now operational and not anymore a possible option for a distant future, it is a developing technological field and some scientific challenges need to be addressed. The activities of technology development and agro-environmental assessment are relevant for both tropical and non-tropical countries. To reduce uncertainties related to the sustainability assessment of biofuels and provide options to lower the controversy, especially in Europe and the United States, about the advantages/disadvantages of biofuels and bioenergy, the following points can be stated:

- The success of the Brazilian experience with ethanol from sugar cane is based on the achievements of a programme started more than 30 years ago, initially with public support, then progressively liberalised. Even if the complex issue of indirect land use change is not quantified accurately (neither for bioenergy nor for other uses of biomass), the environmental record of the Brazilian Programme has been improving. In our view, the economic or environmental comparisons between oil-derived fuels on one hand, European, US and tropical biofuels on the other hand are only valid if they take into account externalities, financial fluxes and the difference in maturity among several technology options.
- Biofuels certification is an opportunity both for exporters from tropical countries and for importers, for example from the European Union. Extreme care must be taken to make sure that biofuel certification will provide a fair treatment both to European and tropical biofuel feedstock productions, and will be acceptable for WTO standards. The implementation of sustainability certification systems and the corresponding verification mechanisms, for example through remote sensing, will allow to reduce some uncertainties.
- More research is needed to quantify GHG emission in relation to biofuels and bioenergy, especially considering N_2O emissions, the contribution of peat soils to emissions in case of land-use change, indirect effects on tropical deforestation, the price interactions between food/feed and biofuel prices. Life cycle assessment of biofuels is a useful tool of analysis only if it is transparent, but the results are associated to a high level of uncertainty, often due to different methodological choices. The indirect effect (displacement, leakage) of EU and US policies on land-use/land-cover in tropical countries is a complex issue which requires more research using among others global macro-economic models, land use/land cover models and emission models.
- In addition to the production of liquid biofuels for export, there is also a need to strengthen international cooperation around initiatives such as the Indian Biodiesel Programme aiming specifically the development of bioenergy for social and rural development programs.

- Crops must be grown in a sustainable way irrespective of their final use. All crops have advantages/disadvantages and it is our responsibility that the biofuels development based on tropical and other feedstock takes into account 'how' (i.e. farming practices including water needs) and not 'what' (i.e. this crop is "good" and this one is "bad"). In addition to the work on the quantification of GHG emissions of biofuels, it is essential to improve the quantification of the water footprint of bioenergy options for different ecosystems.
- The final decision for a country or group of countries to implement biofuel or bioenergy programmes should be based on the combination of policies such as: transport, environment, energy, climate change, agriculture, rural development, employment, security of supply, development and aid. In addition to traditional uses, the use of biomass for new bio-materials and green chemistry should also to be taken into account. Part of the confusion presently observed in the biofuels and bioenergy debate is in our view linked to scientific uncertainty mixed with policy-driver confusion and market evolution.

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