WEBSITE : www.chem.uoa.gr 1 March 2016

Ανανεώσιμες και Περιβαλλοντικά Αειφόρες Ενεργειακές Πηγές. Ο Ρόλος της Χημείας και οι Νέες Τεχνολογικές Εξελίξεις

Αθανάσιος Βαλαβανίδης
Τμήμα Χημείας, Πανεπιστήμιο Αθηνών, Πανεπιστημιούπολη Ζωγράφου, 15784 Αθήνα

Περίληψη. Η ιστορία της εξέλιξης του ανθρώπινου πολιτισμού περιγράφεται μέσα από τους αιώνες των πηγών ενέργειας που ήταν προσβάσιμες στον πλανήτη Γη και τις χρήσεις τους για τις μεγάλες ανθρωπολογικές αλλαγές, την επιβίωση και την παραγωγή υλικών από τον πρωτόγονο άνθρωπο. Η πρόσβαση σε διαθέσιμες και αξιόπιστες πηγές ενέργειας αποτελούσε πάντοτε ακρογωνιαίο παράγοντα οικονομικής ανάπτυξης και πλούτου για τις ανθρώπινες κοινωνίες από την εποχή της εξέλιξης της γεωργίας και της βιομηχανικής επανάστασης του 18^ου^ αιώνα.

Η στροφή στις ανανεώσιμες πηγές ενέργειας επιταχύνθηκε λόγω της ενεργειακής κρίσης του 1973, της αυξανόμενης κλιματικής αλλαγής και της περιβαλλοντικής ρύπανσης από ορυκτά καύσιμα. Η μείωση της εξάρτησης από τους συμβατικούς ενεργειακούς πόρους (κάρβουνο, πετρέλαιο, φυσικό αέριο) έγινε επιβεβλημένη με την προοπτική της μελλοντικής εξάντλησης ενεργειακών πόρων και την ενίσχυση της ενεργειακής ανεξαρτησίας σε εθνικό επίπεδο. Η συλλογή με παθητικά ηλιακά συστήματα και η φωτοβολταϊκή μετατροπή, η αιολική ενέργεια με ανεμογεννήτριες, οι υδατοπτώσεις, η γεωθερμία, η βιομάζα, η εκμετάλλευση των αστικών αποβλήτων, τα θαλάσσια ενεργειακά κύματα, η παλιρροϊκή ενέργεια μπορούν να αντικαταστήσουν τις συμβατικές ενεργειακές πηγές. Η ανασκόπηση περιλαμβάνει τις βασικές ανανεώσιμες ενεργειακές πηγές, τα προβλήματα έρευνας και τις τάσεις ανάπτυξης της τελευταίας δεκαετίας. Οι ανανεώσιμες πηγές ενέργειας το 2011 παρήγαγαν 1,360 GW. Το μεγαλύτερο τμήμα της ανασκόπησης επικεντρώνεται στο ρόλο της χημείας και των τεχνολογικών εξελίξεων στη βελτίωση της απόδοσης των ανανεώσιμων ενεργειακών πηγών. Περιγράφονται νέες τεχνολογίες, ανακαλύψεις νέων υλικών, δυνατότητες επιλογής προσαρμοσμένες στις ανάγκες του ενεργειακού χρήστη, χαμηλό λειτουργικό κόστος και συμβολή σε οικονομική και κοινωνική αναζωογόνηση υποβαθμισμένων περιοχών και προστασίας του περιβάλλοντος.

Πλήρες κείμενο της εργασίας στα αγγλικά [57 σελίδες]: αρχείο PDF, 7.7 MB

<**Επιστροφή στη λίστα επιστημονικών θεμάτων και ανακοινώσεων**>

Renewable and Environmentally Sustainable Energy Sources. The Role of Chemistry and New Technological Developments

Athanasios Valavanidis
Department of Chemistry, University of Athens, University Campus Zografou, 15784 Athens, Greece

Abstract

The historical context of human development was seeing through the ages of the available energy on the planet and its use for fundamental changes in survival and material production. Access to affordable and reliable energy has been a cornerstone of the world's increasing prosperity and economic growth since the beginning of the industrial revolution in the 18th century.

The oil crisis of 1973 was the turning point for changing direction in search for energy resources and the sustainable use of Earth's renewable energy sources. Climatic changes and CO_2 emissions became a very important problem that promoted the search for alternative renewable energy sources and reduction of dependence on conventional fossil fuels. For many decades technological and scientific research investigated the use and expansion of renewable energy sources. A vast array of renewable energy resources were established and many energy innovations were discovered in most developed industrial countries in last decades. Wind turbine power, thermal photovoltaic conversion, solar panels, hydro power, geothermal power, fuel cells, biofuels, biogas, biofuels from algal energy farms, hydrogen power, wireless power transmission from space panels, offshore wind, wave and tidal power, etc. Renewable energy grew at a rate faster than any other time in history by a large increase in international investment and by the end of 2011, total renewable power capacity worldwide exceeded 1,360 GW.The world expenditures on renewable energy totaled over 6 trillion $ USD (2004-2014).This review presents the most important renewable energy resources, their development, technological innovations, cost and expansion in industrial countries. Also, the review focused on the role of chemistry and chemical technologies in all aspects of renewable energy sources. From the large number of research literature the review used selective scientific research papers and reports covering patents, projects and technological developments in the field of renewable energy sources.

Introduction: Human Civilization and Energy Resources

Many environmental historians who studied the links between natural environment of planet Earth and human civilization, provided a new historical narrative of human society development as an integrated approach to the forms of energy use, flow, storage and conversion. The historical context of human development was seeing through the ages of the available energy on the planet and its use for fundamental changes in survival and material production. The mastery of controlled fire was a cornerstone in the relationship of humans with the Earth's biosphere and distinguished humans from other mammals. The ability of humans to manipulate fire permitted early humans to tap the solar energy that was stored in plants and wood (biomass) and to transform extensively the natural environment and the exploitation and use of natural resources. All archaeological evidences until now suggest that the discovery of controlled fire was the key factor that brought big changes in human development and human history.[1]

The student of human civilization finds that the use of energy defines the beginning and the most important stages of human civilization, when the human prehistoric human mastered the control of fire for domestic comfort and cooking. Throughout the centuries, the human society has evolved step by step by increasingly using new forms of energy that were necessary for the functioning of contemporary society, its prosperity and the survival of human civilization.[2]

The ages of human civilization can be subdivided into three distinct phases: The age of solar energy (fire, farming, agrarian age, late agrarian age), the age of fossil fuels (industrial revolution, coal-steam, petroleum oil, natural gas, biogas) and the age of renewable energy sources (solar, wind, wave, etc) and nuclear power.[3,4,5,6] Access to affordable and reliable energy has been a cornerstone of the world's increasing prosperity and economic growth since the beginning of the industrial revolution. The impact of the rapidly growing economies of the highly populated countries (China, India, Brazil, etc), the problems of availability, cost, sustainability of energy resources, as well as of the concern about global warming formulated the importance in the use of renewable energy sources. In the past, human civilization has relied heavily upon fossil fuels (coal, oil, and natural gas) to support its energy needs. Fossil fuel reserves are finite - it's only a matter of when they run out-not if. But there are various arguments in the scientific literature for the future energy needs and resources.[7]

Renewable and alternative energy sources hold key to the solution of twin problems, energy and climate change, with a high initial investment. Transition from fossil fuels to sustainable and renewable energy resources of requires major investment and innovatory technologies. Perhaps CO_2 and H_2O based fuel systems would facilitate climate change and grand energy transition. An energy mix consisting of fossil fuels, hydrogen, bio-fuels, and renewable energy sources seems to be a good initiative for the future energy needs of the planet. In a climate constrained future, hybrid energy-economy models and decarbonising the energy system are critical in mitigating climate change.[8,9]

Figure 1. Fossil fuels as energy sources will run inevitably out in the future. The world in the last decades strives to develop renewable energy resources to support future energy needs and growth and reverse the environmental problems of climate change.

Over the last 25 years, various predictions have been made about the supply of fossil fuel oil. According to these figures we should have run out of oil by now! But at the moment the world is finding as much oil as humans are using. As technology improves, new oil fields are discovered and small fields can be exploited more economically. People are also using energy more efficiently to conserve energy resources. Scientists and environmentalists agree that energy in the 21st century must be from sustainable sources. Solar and water–based energy generation, and engineering of microbes to produce biofuels are a few examples of the alternatives.[10,11,12,13]

The future of energy resources and environmental threats by the rapid and wasteful growth of world's economies became a debatable subject for many years in the 1970s. One of the most important publications predicting future exhaustion of energy resources and negative environmental changes on Earth was from the Club of Rome (a global think tank dealing for a variety of international environmental and political issues concerning the future of humanity, founded in 1968) and scientists from the MIT (Massachusetts Institute of Technology). Their book the *Limit to Growth* sold 30 million copies and raised the issue on numerous debates all over the world. In 1972 the Club of Rome and MIT forecasted a pessimistic view that world energy resources would be running out by the end of the 20th century. The computer models and the Report *Limits to Growth* failed to consider technological changes and new, renewable, energy resources. The Limits to Growth team published new developments in the Earth's capacity to deal with energy and environmental problems.[14,15,16]

World Energy Consumption and Energy Sources

World energy consumption refers to the total energy used by humans in all countries and for every sector of technological and domestic activities (industrial, domestic, transport, etc). After the industrial revolution (early 19th century), energy sources, use and storage, inevitably became the most important sectors of financial and technological developments. The energy industry significantly influences the vibrancy and sustainability of the entire global economy, from job creation, to technological progress, growth, resource efficiency and the environment. Most importantly, energy is an input to nearly every good and service in the economy and its availability and reasonable energy prices are important in economic growth and human prosperity.[17]

Until the last century the international economic and political scene was preoccupied by the developments in world energy production sources, energy prices, and world consumption. The fact is that energy production, prices and consumption have deep implications for humanity's social, economic and political spheres. In the past, fuel shortages, wars, disasters and export embargo brought energy crises to a global stage, and caused high prices of petrol. Typical example was the 1973 oil crisis that was caused by an OPEC (Arab oil-producing states) oil export embargo in response to Western countries' support of Israel during the Yom Kippur War. The 1979 oil crisis was the result of the Iranian Revolution. The 1990 oil price shock was caused by the Gulf War.[18]

The International Energy Agency (IEA, Paris) estimated that in 2012 the world energy consumption was 13,371 Mtoe [million of tone or ton of oil equivalent, 1 tone = 11.63 megawatt-hours (MWh)] or 5.6×10^{20} joules. In the period 2000–2012 the use of petroleum oil, coal and natural gas had considerable growth covering the 82% of energy consumption. Biofuel and waste increased substantially reaching 10% in 2012. Renewable energy sources, such as hydro power, solar, wind, geothermal, etc., increased to 3,5%. Renewable energy grew at a rate faster than any other time in history by a large increase in international investment. The world expenditures on energy totaled over 6 trillion $ USD (2004-2014), or about 10% of the world gross domestic product (GDP). Europe spends already close to 25% of the world energy expenditures, China with the rapid economic growth in the last decade came second with 20%, USA close to 20%, and Japan over 6%.[19,20]

Total World Energy Consumption by Power Source in 2013:

1. Petroleum oil 31.1%
2. Coal 28.9%
3. Natural gas 21.4%
4. Energy from biofuels and waste 10.2%
5. Nuclear energy 4.8%
6. Hydro energy 2.4%
7. 'Other' sources of energy (solar, wind, geothermal, etc.) 1.2%

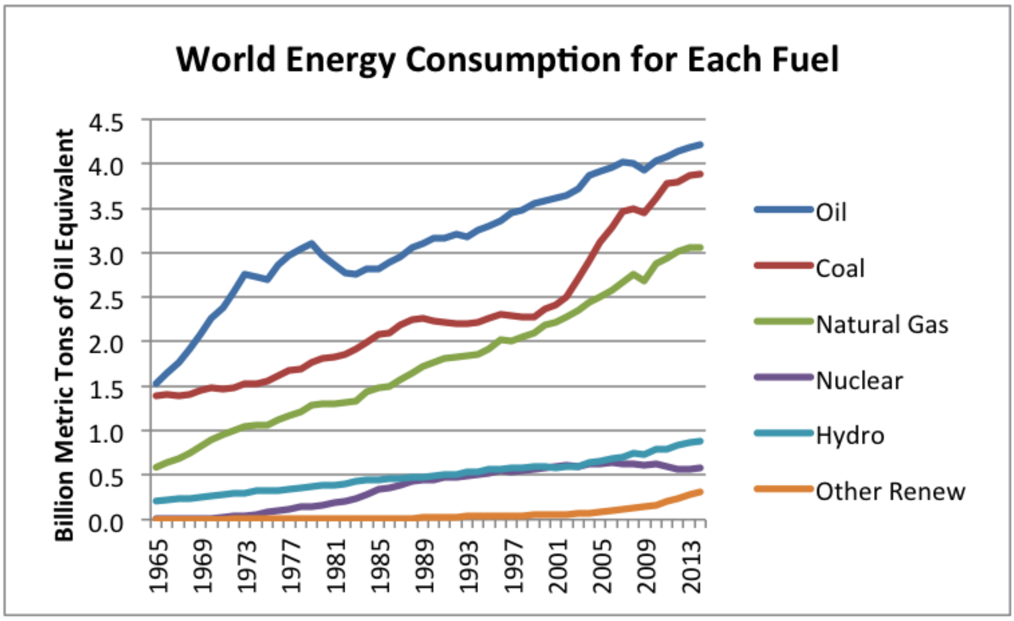


Figure 2. Petroleum, Coal and Natural Gas continue to be the main sources of energy production. [*British Petroleum..(*BP). *Statistical Review of World Energy*. For 2013. [http://bp.com/statisticalreview2013]. (BP, 2013)].

World Electricity Generation by Source in 2014.

1. Coal/peat 40.4%,
2. Natural Gas 22.5%,
3. Hydro 16.2%,
4. Nuclear 10.9%,
5. Oil 5%,
6. Renewable sources of energy (solar, wind, etc) 5%

The U.S. Energy Information Administration (EIA) estimates that about 11% of world marketed energy consumption is from renewable energy sources (biofuels, biomass, geothermal, hydropower, solar, and wind) with a projection for 15% by 2040. Also, EIA estimated that about 21% of world electricity generation was from renewable energy in 2011, with a projection for nearly 25% in 2040.[21]

World Renewable Sources of Energy

Renewable sources of energy have been increased substantially in the last decade in all developed countries. Renewable sources of energy accounted for almost 50% of all new power plants that were build in 2014, representing a “clear sign that an energy transition is underway”, according to the International Energy Agency. Green energy is now the second-largest generator of electricity in the world, after coal, and is set to overtake the fossil fuel in the early 2030s. [22]

In 2014 the renewable sources of energy continued to grow, but not as rapidly as in the past. In 2014 it was 12.0%, (compared to 22.4% in 2011, 18.1% in 2012, 16.5% in 2013). Despite the increasing rate renewables amounted to only 2.5% of total world energy consumption in 2014.[23]

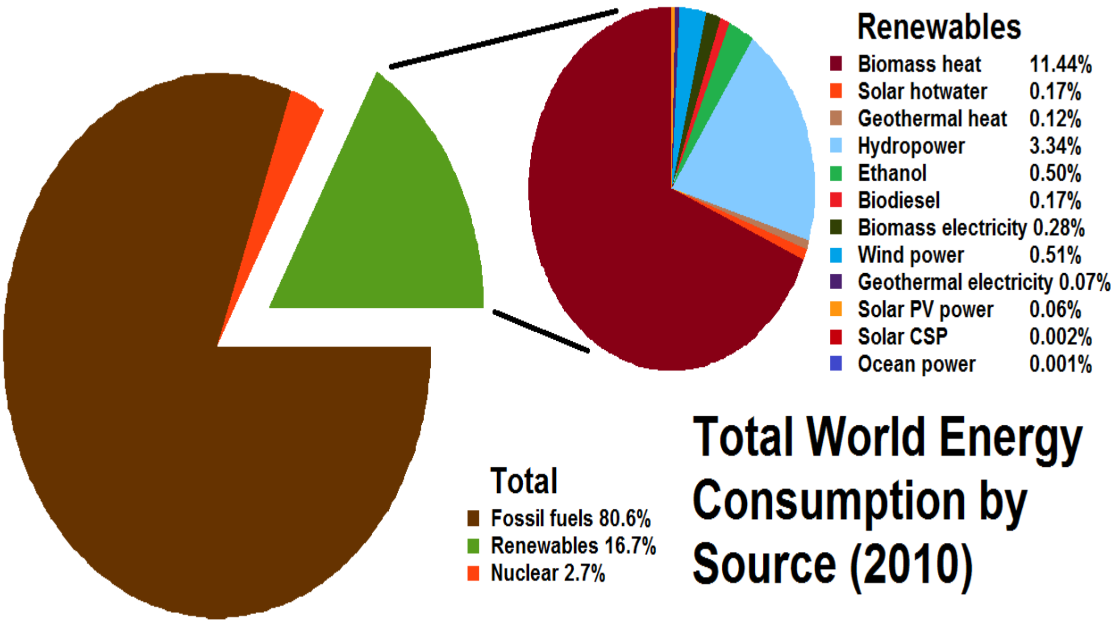


Figure 3. Renewable Energy Sources: Biomass heat, Solar hot water, Geothermal heat, hydropower, Ethanol, Biodiesel, Biomass–electricity, Wind power, Geothermal electricity, Solar PV (Photovoltaic systems) power, Solar CSP (Concentrating Solar Power), Ocean power.[23]

Renewable energy technologies (RET) represent a critical element of the low-carbon pillar of global energy strategy for avoiding CO_2 emissions and climatic changes in the future. Global subsidies for RET amounted to $120 billion in 2013. It is estimated, with rapid cost reductions, continued investment and creating new markets, that renewable energy sources will account for almost 50% of the increase in total electricity generation to 2040. The share of renewables in electricity power generation increases most in OECD countries (USA, Canada, Western Europe, Australia, Japan, etc), reaching 37%, and their growth is equivalent to the entire net increase in OECD electricity supply. Also, in China, India, Latin America and some

African countries renewable energy sources grow at a faster rate. Globally, wind power accounts for the largest share of growth in renewable-based generation (34%), followed by hydropower (30%) and solar technologies (18%). Wind power generation has reached 20% of total electricity generation in the European Union and solar PV accounting for 37% of summer peak demand in Japan. Particularly Germany, Denmark, the US and Spain are the countries that have led the way, developing innovative policies that have driven much of the change witnessed over the past decade. Today, Germany's commitment to the "Energiewende"—the transition to a sustainable economy based on renewable energy and energy efficiency—as well as Denmark's commitment to 100% renewable energy by 2050, are inspiring other countries.[24]

Renewable Energy Sources in the European Union

The use of renewable energy sources in the European Union is seen as a key element in energy policy, reducing the dependence on fuel imported from non-EU countries, reducing emissions from fossil fuel sources. Directive 2009/28/EC on promotion of the use of energy from renewable sources established accounting criteria for the 2020 targets on renewable energy sources in European Union countries.

Primary production of renewable energies in the EU is on a long-term increasing trend. Between 1990 and 2013 it increased by 170 % (an average annual growth rate of 4.4 %). Among renewable energies, the most important source in the EU-28 was biomass and renewable waste, accounting for just under two thirds (64.2 %) of primary renewables production in 2013. Hydropower was the other main contributor to the renewable energy mix (16.6 % of the total). There was a particularly rapid expansion in the output of wind and solar energy, which accounted for 10.5 % and 5.5 % respectively of the EU-28's renewable energy produced in 2013. The remaining shares were 3.1 % for geothermal energy and 0.02 % for tide, wave and ocean energy, the latter being found in only France and the United Kingdom.[25]

Gross electricity production in 2013 from renewables sources increased by 11 % compared with 2012. Between 1990 and 2012, total electricity generation from renewables increased by 177 %. In 2013, renewable electricity generation accounted for 26 % of total gross electricity generation.

Hydropower plants generate by far the largest share of electricity from renewable energy sources, increased by 28 % between 1990 and 2013. The countries with the highest hydropower production (in terawatt-hours. TWh) in 2013 were: China (905 TWh), Brazil (415), USA (269), Canada (388), Russia (175) an India (143).

Wind power generation more than triple over the period 2005-2013: since 2000, it has been the second largest contributor to renewable electricity, replacing wood and other solid biomass.

Solar power electricity generation has increased rapidly in recent years and in 2013 accounted for 10 % of all renewable electricity.

Biofuels and biogas, from negligible in 1990, reached 6.7 % of world electricity production in 2013.[25]

The largest producer of renewable energy within the EU-28 in 2013 was Germany, with a 17.5% share of the total; Italy (12%) and France (12 %), followed by Spain (9%) and Sweden (8.7 %). Solar energy produced more than 3/5 of renewable energy in Malta and Cyprus. Hydropower produced more than 1/3 of energy in Croatia, Austria, Slovenia, and Turkey. More than 1/5 of the renewable energy production in Italy was from geothermal energy sources (where active volcanic processes exist). The share of wind power was particularly high in Ireland (51%) and also accounted for more than 1/4 of renewable energy production in Denmark, the United Kingdom and Spain.[25]
In 2013, the share of energy from renewable sources (gross final consumption) reached 15 % in the European Union, compared with 8.3% in 2004, the first year for which the data was available.[26]

Renewable Energy Sources in Greece

National Action Plan for RES (2010-2020) Estimated installed capacity of the different technologies for electricity production Greece presented early last summer its National Action Plan for Renewable Energy Sources (time frame 2010-2020) It is an ambitious plan aiming to reform the county’s energy sector so that 20% of the primary energy use is coming from RES by 2020 (penetration level: 40% electricity, 20% heat and 10% transport) In the electricity sector, major RES players are going to be Wind and PV (7.5 and 2.2 GW target values for 2020) and, evidently, the existing large hydro. This does not exclude additional contributions from other RES e.g. biomass, geothermal energy and concentrated solar power. The Centre for Renewable Energy Sources and Saving (Κέντρο Ανανεώσιμων Πηγών Ενέργειας, CRES) is the Greek national entity for the promotion of renewable energy sources, rational use of energy and energy conservation. The overall investments needed for Greece in the energy sector are estimated to 22.2 billion euro for the 2010-2020 timeframe. From these 16.5 will go to new RES capacity, nearly 7 billion to wind, 5.5 billion to PV, 1.6 billion to pump storage for supporting the variable RES production, 1.1 billion to solar heating and cooling, 0.5 billion to biomass and biogas projects.[27]

The Most Important Renewable Energy Sources

Renewable energy sources has the potential to reduce pollution, slow global warming, create new industries and jobs, and move toward a cleaner global energy future with technological challenges and impacts.[28-31]

WIND ENERGY. Pollution free and inexhaustible energy. Engineers are creating new blade designs and more efficient turbines

SOLAR ENERGY. Inexhaustible and cheap, solar energy. Solar Thermal, Photovoltaic Conversion. Harnessing the sun's energy.

Figure 4. Photovoltaic solar panels transform directly sun's energy into electricity. The fastest growing renewable energy source. Onshore wind is an inexpensive source of electricity, cheaper than coal or gas plants.

HYDROPOWER. Energy from river and lake water is the largest source of renewable electricity. Water is a renewable resource, rivers are not.

GEOTHERMAL ENERGY. Reservoirs of steam and hot water beneath the earth's surface, a valuable renewable energy resource from volcanic activity.

Figure 5. Geothermal energy has been used for thousands of years in some countries for cooking and heating. It is simply power derived from the Earth's internal heat. Hydropower represents about 16% (International Energy Agency) of total world electricity production.

OFFSHORE WIND, WAVE, AND TIDAL ENERGY. Tidal turbines in coastal and estuarine areas. Ocean current turbines in areas of strong marine currents. Ocean thermal energy converters in deep tropical waters.

Underwater energy from currents, tidal and wave energies

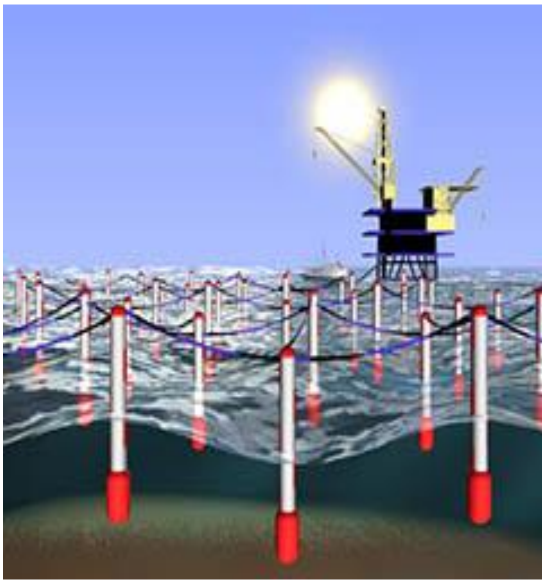


Figure 6. Wave, tidal and ocean energy technologies are just beginning to reach viability as potential commercial power sources.

BIOMASS ENERGY CONVERSION AND CELLULOSIC ETHANOL Plant materials, such as wood, corn, and soy, but are not always sustainable.

BIOGAS ENERGY. Farmers can reduce pollution and generate their own heat and electricity by converting animal waste into a clean-burning gas.

FUEL CELLS RENEWABLE ENERGY. Electrochemical device, like battery, converting the energy form from a chemical reaction directly into electricity and heat. Modern fuel cells produce electricity by combining hydrogen and oxygen without using combustion.

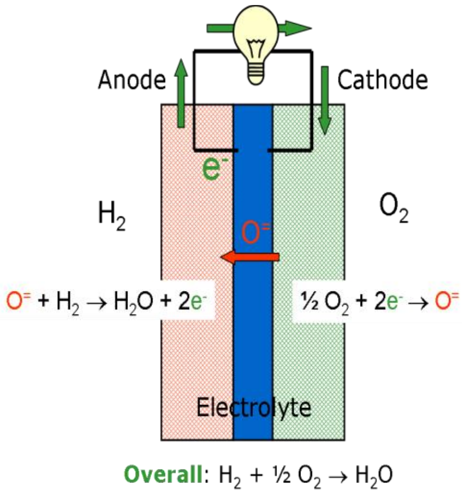


Figure 7. Fuel cells are renewable sources that transform chemical energy into electricity. The basics of fuel cell operation is the electrolyte component of the fuel cell can either be proton conducting or oxygen ion conducting. For the purposes of illustration, hydrogen is assumed to be the fuel.

HYDROGEN PRODUCTION. Hydrogen from water can serve as a means of delivering energy produced by various technologies. Over $1 billion of been spent on the research and development of hydrogen fuel in the USA. The National Renewable Energy Laboratory and Sandia National Laboratories have departments dedicated to hydrogen research.

WIRELESS POWER TRANSMISSION (WPT) FROM SPACE SOLAR PANELS. The Japanese Space Agency (JAXA) developed technologies to transmit electricity wirelessly from space solar panels.

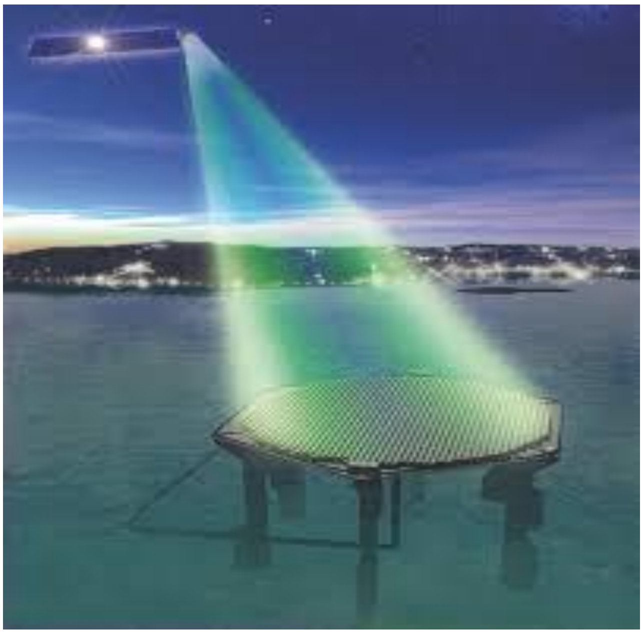


Figure 8. Wireless Power Transmission. There are different power transmission technologies that use time-varying electromagnetic fields. In wireless power transfer, a transmitter device connected to a power source, such as the mains power line, transmits power by electromagnetic fields.

ALGAE FUEL. Biofuel which is derived from algae (photosynthetic algae capture CO_2 and sunlight and convert it into oxygen and biomass). Three forms of energy fuel: heat, biofuel, and biomass. Algal fuel development is at an early stage – and wide open to innovation.

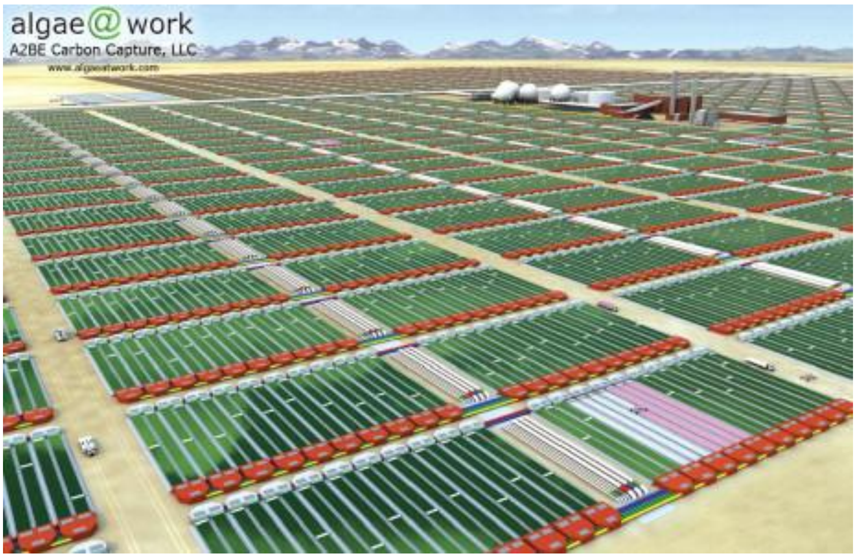


Figure 9. Farms of photosynthetic algae can be used to capture carbon dioxide from the air and with the sun's rays convert it into biomass and heat.

WIND TURBINE The MIT-based outfit (Altaeros Energies) created an airborne wind turbine designed to float 300 meters in the air, taking advantage of the frequent, powerful wind that occurs at such altitudes.

Figure 10. Buoyant Airborne Turbine, or BAT, the device can be transported and deployed without having to use cranes. BAT is ready-made for small, isolated towns that have little resources or access to electricity.

For every type of renewable energy source there is a variety of technologies that have been developed to take advantage of collecting and transmitting energy or converting into electricity. For the solar energy for example there are various technologies:[32]

Photovoltaic Systems, production of electricity directly from sunlight.

Solar Hot Water, heating water with solar energy.

Solar Electricity, using the sun's heat to produce electricity.

Passive Solar Heating and Daylighting, using solar energy to heat and light buildings.

Chemistry and chemical technology will play a key role in enabling renewable sources to have novel materials and achieve solutions for sustainable energy pathways for the future. In the last decade advances have been achieved: innovative Batteries, Supercapacitors, new Fuel cells, special Hydrogen storage, Photovoltaics and Solar cells, new catalysts for Hydrogen production, novel Biofuels, materials for Carbon dioxide sequestration and conversion, Thermoelectrics (energy saving materials), novel illumination sources, etc.[33]

The Role of Chemistry and Chemical Technologies in Innovative Renewable Energy Sources

The development of renewable energy sources in the future will require intensive research, innovative inventions, chemical technologies and solutions to highly challenging problems. The role of chemistry will be crucial If solar energy is going to be the major primary source of renewables, in order to promote chemical schemes to capture, convert, and store solar energy in the form of chemical bonds. Similarly, chemistry research and chemical technology must play a crucial role in producing cheaply hydrogen from water or other "green" biofuels to replace fossil fuels.[34]

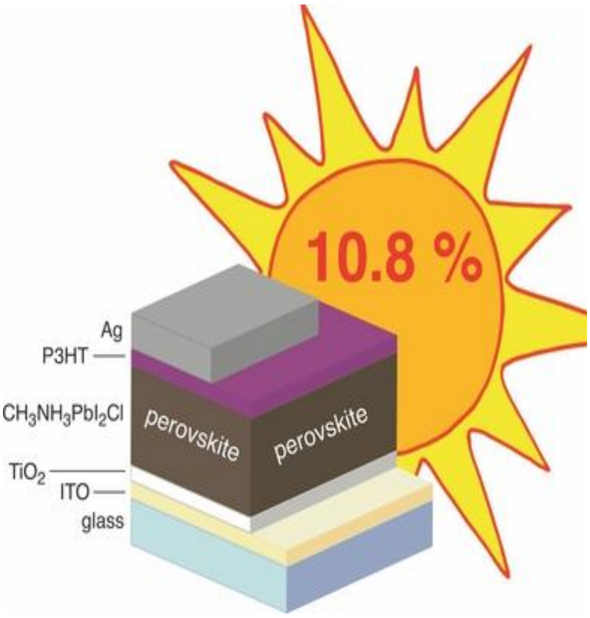
Biotechnology also can play an important role in renewable energy sources. It has been proposed that marine macroalgae (i.e., seaweed) have many advantages as an attractive renewable source for producing innovative fuels and chemicals. Recent research showed that diverse carbohydrates from seaweed biomass can be transformed into liquid biofuels (e.g., bioethanol) through metabolic engineering.[35]

Material scientists are researching another field which will play an important role in the future development of renewable energy sources. It is the large-scale electrical energy storage and transportation of intermittent renewable energy in electric grid. The challenges for material science and materials chemistry is very obvious. There is a need to develop efficient storage technologies, such as Li-ion batteries, sodium (sulfur and metal halide) batteries, Pb-acid battery, redox flow batteries, and supercapacitors. All these challenges need innovative and greener battery designs and new chemistry combinations to reduce the cost of energy storage devices.[36,37,38]

Solar Energy. Technological Developments

Selected scientific papers have been collected from the vast scientific field on solar energy technological developments. Solar energy is the most abundant, inexhaustible and clean of all the renewable energy resources. The power from sun intercepted by the earth is about 1.8×10^{11} MW, which is many times larger than the present rate of all the energy consumption. The development in solar **Photovoltaic panels** (PV) for electricity production technology is growing very fast in recent years due to technological improvements, cost reductions in materials and government subsidies worldwide.39 At present, the PV market is growing rapidly worldwide at an annual exponential rate of 35–40%, which makes photovoltaic as one of the fastest growing industries. The efficiency of solar cell is one of the important parameter and extensive research work is going for efficiency improvement of solar cells. The efficiency of monocrystalline silicon solar cell has showed very good improvement lately. It started with only 15% in 1950s and then increase to 17% in 1970s and continuously increase up to 28% nowadays.[40] In 2014, worldwide installed PV capacity increased to at least 177 gigawatts (GW), sufficient to supply 1% of global electricity demands. China, followed by Japan and the United States, is the fastest growing market, while Germany remains the world's largest producer, with solar contributing about 7% percent to its annual domestic electricity consumption.[41]

Perovskite solar cells (PSCs). Third-generation PVs are designed to combine the advantages of both the first and second generation devices and they do not have Shockley-Queisser efficiency (theoretical limit) for first and second generation PV cells. The thickness of a third generation device is less than 1 μm.[42] One emerging alternative and promising technology is based on an organic-inorganic hybrid solar cell made of methylammonium lead halide perovskites. Perovskite PV cells have progressed rapidly over the past few years and have become one of the most attractive areas for PV research.[43] Though perovskite solar cells are only 5 years old, their efficiency has skyrocketed from 3.8% to 19.3%. Ultimately, engineers may be able to layer perovskite solar cells (PCSs) atop conventional photovoltaics made from crystalline silicon, creating cells that are up to 32% efficient. That could make solar electricity as cheap as power produced from fossil fuels.[44,45] However, there has been very little study of the issue of stability, which restricts the outdoor application of PSCs. The issues of the degradation of perovskite and the stability of PSC devices should be urgently addressed to achieve good reproducibility and long lifetimes.[46]



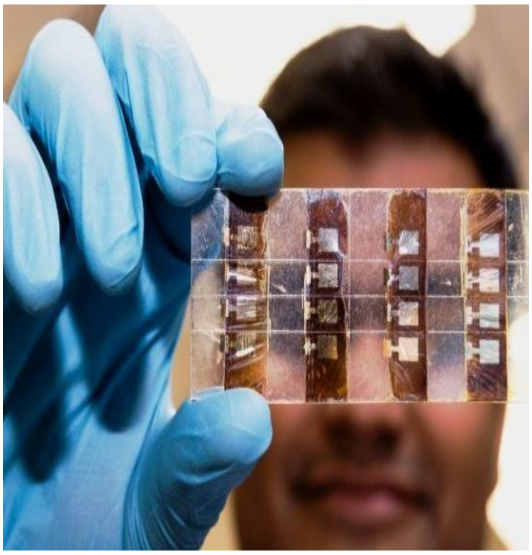


Figure 11. The unique material Perovskite is far cheaper to produce and generates almost as much power as today's thin-film solar cells. Organometal halide **Perovskites** (Calcium Titanium Oxide mineral composed of calcium titanate, with the chemical formula $CaTiO_3$). The mineral has tremendous potential as light absorbers for photovoltaic applications.

Two new promising **thin film technologies** are copper zinc tin sulfide (Cu_2ZnSnS_4 or CZTS) and zinc phosphide (Zn_3P_2). Both of these thin films are currently only produced in the lab but may be commercialized in the future.[47] Today's thin film photovoltaic technologies comprising $CuInS_2$ (CIS), $CuInGaSe_2$ (CIGS) and CdTe rely on elements that are costly and rare in the earth's crust (e.g. In, Ga, Te) and are toxic (e.g. Cd). Hence, in future cost reduction and increased production, using abundantly available non-toxic elements, seem to be the main issues. Cu_2ZnSnS_4 (CZTS), having the kesterite structure, is one of the most promising absorber layer candidates for low cost thin film solar cells, because of its suitable direct band gap between 1·4 and 1·5 eV and large absorption coefficient, over 10^4 cm^{-1}. Also it is composed of earth abundant and non-toxic elements, promising price reductions in future. Recently, research in this area has gained momentum due to the desirability of producing Ga, In and Cd free absorber layers and the potential to obtain new insights. Hence, a review of recent literature is urgently warranted. The CZTS progress and present status of CZTS thin film solar cells has been reviewed, with the hope of identifying new paths for productive research.[48]

Polymer semi-transparent thin film materials for photovoltaic panels is an active field in many scientific institutions. Organic and polymer photovoltaic (OPV) are a relatively new area of research. The tradition OPV cell structure layers consist of a semi-transparent electrode, electron blocking layer, tunnel junction, holes blocking layer, electrode, with the sun hitting the transparent electrode. OPV replaces silver with carbon as an electrode material lowering manufacturing cost and making them more environmentally friendly. OPV are flexible, low weight, and work well with roll-to roll manufacturing for mass production.[49] Recent progress in the development of polymer solar cells has improved power-conversion efficiencies from 3% to almost 9%. Based on semiconducting polymers, these solar cells are fabricated from solution-processing techniques and have unique prospects for achieving low-cost solar energy harvesting, owing to their material and manufacturing advantages.[50]

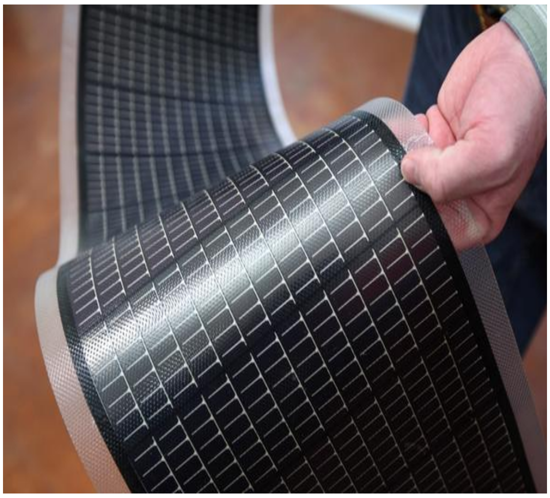


Figure 12. Thin film photovoltaic cells are made from materials that absorb sunlight very strongly. While a crystalline silicon solar cell is 0.1-0.2 mm thick, thin film cells are about 0.01 mm thick. That thinness means it can be manufactured with relatively inexpensive roll-to-roll fabrication techniques. It also means thin film solar materials are light and flexible.

Gallium arsenide (GaAs) is an important semiconductor material for high-cost, high-efficiency solar cells and is used for single-crystalline thin film solar cells and for multi-junction solar cells. In recent years a number of photovoltaic (PV) materials and devices achieved high conversion efficiencies. Silicon has the advantage that is a thousand times cheaper to make. As a result, gallium arsenide-based devices are only used in niche applications where their special capabilities justify their higher cost. Gallium arsenide achieved conversion efficiencies of 40% (nearly double of crystalline silicon, 18-24%), but high fabrication costs made GaAs-based solar cells prohibitively expensive for mass market. Ultrahigh-efficiency (>30%) PV cells have been fabricated from gallium arsenide (GaAs) and its ternary alloys of gallium indium phosphide (GaInP2).[51]

Dye-sensitized solar cell (DSSC) provides credible alternative concept for inorganic solid-state photovoltaic devices. The conversion efficiency of DSSC is mainly based on the dye coated on the porous semiconductor TiO_2 film. The use of natural dyes in solar cells is a promising development to this technology because it cuts down the high cost of noble metals and chemical synthesis. Therefore, this type of solar cell has attracted considerable attention from the academic and industrial communities. Numerous kinds of pigments, such as anthocyanin, carotenoid and chlorophyll, have been tested as sensitizers.[52]

Wind Power Technologies. New Developments

Wind power is the most cost-effective renewable energy source. It is the most advanced of the “new” renewable energy technologies and was the subject of one of the first roadmaps produced by the IEA, in 2009. Since then, the development and deployment of wind power has been a rare good news story in low-carbon technology deployment. A much greater number of countries in all regions of the world now have significant wind generating capacity. In a few countries, wind power already provides 15% to 30% of total electricity. The technology keeps rapidly improving, and costs of generation from land-based wind installations have continued to fall. Wind power is now being deployed in countries with good resources without special financial incentives. Modern wind turbines are increasingly cost-effective and more reliable, and have scaled up in size to multi-megawatt power ratings. Average turbine generating capacity has increased substantially through the development of longer, lighter rotor blades, taller towers, more reliable drivetrains, and performance-optimizing control systems. [53]

New materials for Wind Turbines. Wind turbines come in many sizes and configurations and are built from wide range of materials. Wind turbine consists of a rotor that has wing shaped blades attached to a hub; a nacelle that houses a drivetrain consisting of a gearbox, connecting shafts, support bearings, the generator, plus other machinery; a tower; and ground-mounted electrical equipment.

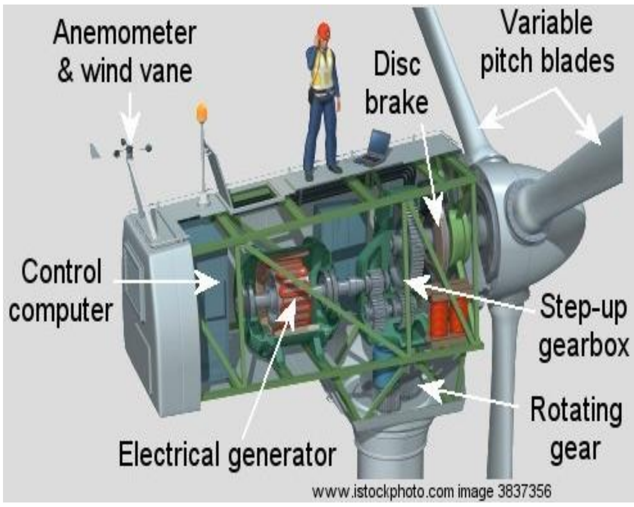


Figure 13. Technological improvements for wind turbines with new materials is the new challenge for material scientists. Light weight high-strength materials for blades and motors

The components of turbines are changing as the technology improves and evolves. There is a trend toward lighter weight systems. Light weight, low cost materials are especially important in blades and towers for several reasons. First the weight of the blades and rotor is multiplied through out the machine. The tower weight is key because it is typically 65% of the weight of the turbine above the foundation, due to the fact that sophisticated lightweight, high-strength materials are often too costly to justify their use.[54]

Most rotor blades in use today are built from glassfiber-reinforced-plastic. Other materials that have been tried include steel, various composites and carbon filament-reinforced-plastic. The gearbox used on large turbines today is expected to be replaced in future machines. Most small turbine designed for battery charging use a variable speed, permanent magnet, variable frequency generator connected to a rectifier. As high power solid state electronics are improved, larger and larger machines are likely to use AC-DC-AC cyclo-converters. The nacelle **(**is a cover housing all of the generating components in a wind turbine) contains an array of complex machinery including, yaw drives, blade pitch change mechanisms, drive brakes, shafts, bearings, oil pumps and coolers, controllers, etc). Low cost materials are especially important in towers, since towers represent as much as 65% of the weight of the turbine. Pre-stressed concrete is a material that is starting to be used in greater amounts in European turbines, especially in off-shore or near-shore applications. Concrete in towers has the potential to lower cost, but may involve nearly as much steel in the reinforcing bars as a conventional steel tower. Turbine material usage is and will continue to be dominated by steel, but opportunities exist for introducing aluminum or other light weight composites, provided strength and fatigue requirements can be met. Input materials in blade production have not evolved as rapidly. Resin technology has expanded somewhat to include both polyester and epoxy on a broad scale. Wood or foam cores are still used in many cases. Skins are comprised of multiaxial fabrics with some use of unidirectional materials. The root end section of the blade is comprised of rovings and/or multiaxial fabrics. Spars have been manufactured with fiberglass rovings and a combination of unidirectional and multiaxial fabrics.[55]

Rare Earth elements for generators are used for permanent-magnet generators and for more economically feasible wind turbine generators technology. The use of rare earths yields smaller, lighter generators by eliminating copper from the generator rotor. Wind turbines that use rare earth permanent magnets comprising neodymium, iron, and boron require about 216 kg of neodymium per megawatt of capacity, or about 251 kg of neodymium oxide (Nd_2O_3) per megawatt of capacity. World production for Nd_2O_3 in 2010 was estimated to be 27,000 tons, and world supply was estimated to be 24,400 tons leading to a reported supply deficit of about 10%. China produced about 96% of the world's rare earth elements in 2009.[56,57,58]

New chemical materials for recycling wind blades. At present outdated wind turbine blades and aircrafts made of expensive fibreglass are cut up into pieces and buried in the ground. In is hoped in the future, that new chemical substances could be added that separates the glass from the plastic fibres so they can be recycled. Researchers and companies in Innovation Fund Denmark's new project called DreamWind, are focusing their research on designing an agent for fiberglass that can be reused when it has been cleaned – for new fibreglass components for structures such as wind turbines, aircraft or cars (Aarhus University, Vestas and the company's material suppliers, the Danish Technological Institute and Innovation Fund Denmark).[59]

Figure 14. The global installed world wind power in 2015 has the capacity to provide electricity for 100 million houses. Technological problems and improvements are always big challenges for material scientists and technologists.

To meet the growing demand, wind turbines are being scaled up both in size and power rating. However, as the size increases, the structural loads of the turbine become more dominant, causing increased fatigue stress on the turbine components which can lead to early failure. Intensive efforts and research is going on at an international focusing on new light and durable metal and plastic materials for wind turbine.[60,61,62]

China in 2015 was the World Leader in Wind Power

In 2015 China has become the world leader in wind power production after constructing nearly half of all the new turbines built around the globe. According to statistics by the Global Wind Energy Council (GWEC) China installed 30,500 megawatts of new wind power last year, compared to the world total of 63,000 MW. China now has 145,100 MW of wind power, out of the global total of 432,400 MW. Statistical data showed that there is now enough wind power installed around the world to generate electricity for about 100 million homes.[63]

The USA target for 2030 is to have at least 20% of the US energy supply by onshore and offshore wind farms. To meet these demands, wind energy costs have to be able to compete with traditional fossil fuel sources. Hence, it is essential and vital that wind turbine designers and manufactures search the optimal solution that fits the objectives under a set of design constraints. Common alternatives such as blade mass minimization and maximization of the rotor thrust and torque are the main research efforts.[64]

In the United Kingdom wind power is recognised as the main source of renewable energy to achieve the European Union 2020 renewable energy targets. Currently over 50% of renewable power is generated from onshore wind with a large number of offshore wind projects in development. The United Kingdom is the world's leading generator of offshore wind power, followed by Denmark. [65]

Denmark has been a consistent wind power leader (per capita) for years. 30% of electricity in Denmark is produced by wind power, and aims to get 50% of its electricity from wind power by 2020. There's no denying that Denmark's love affair with wind power is still going strong[Clean Technica. Top wind power countries per capita. http://cleantechnica.com/ 2013/06/20/ top-wind-power-countries-in-the-world-per-capita-per-gdp-in-total/].

Wind power is the most cost-effective renewable energy. It is one of the lowest-priced renewable energy technologies available today, costing between four and six cents per kilowatt-hour (kWh), depending upon the wind resource and the particular project's financing.

Hydroelectric Power the Most Cost-Efficient

Hydroelectric power comprises about 6.9% of total world energy production and at present it is the most important and widely-used renewable source of energy. According to the International Energy Agency the hydropower represents about 16,4% of total world electricity production. China is the largest producer of hydroelectricity, followed by Canada, Brazil, and the United States. Hydroelectric dams are very expensive. It is estimated that 65% of the economically feasible hydropower potential remains to be developed in the future. Untapped hydro resources are still abundant in Latin America, Central Africa, India and China. Supplying 16.4% of global electricity power supply in 2013, hydropower has experienced an upsurge in development activity over the past decade, reaching 1000 GW (Gigawatt = one billion watt) of total installed capacity, with 40 GW installed in 2013 alone. Hydropower can serve as a tool for climate mitigation. It can also provide climate change adaptation services through its ability to store water, contributing to flood control and drought alleviation in some countries.[66]

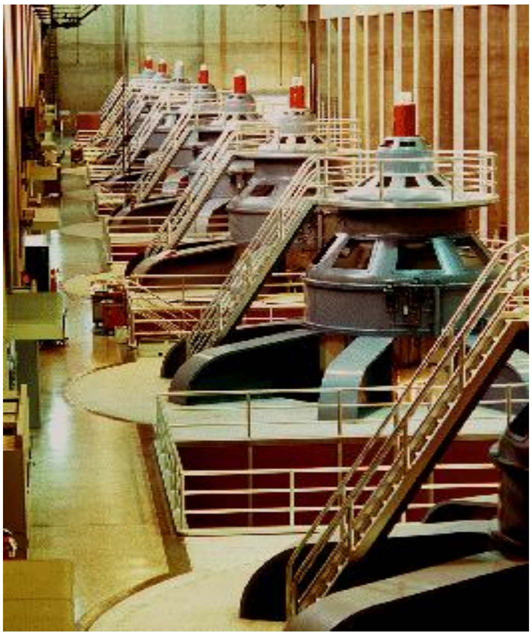


Figure 15. The 194-MW Kerr Dam in Montana of USA**.** The giant generators at Hoover Dam that produce on average, about 4 billion kilowatt-hours each year for use in Nevada, Arizona, and California - enough to serve electricity for 1.3 million people.

Types of hydropower generation

Electricity in hydropower plants is generated through the transformation of hydraulic energy into mechanical energy to activate a turbine connected to a generator. There are mainly three types of hydropower plants.[67]

Storage hydropower: uses a dam to impound river water, which is then stored in a reservoir for release when needed. Electricity is produced by releasing water from the reservoir through operable gates into a turbine, which in turn activates a generator.

Run-of-river hydropower: channels flowing water from a river through a canal or penstock to drive a turbine. Typically a run-of-river project will have little or no storage facility. Run-of-river provides a continuous supply of electricity.

Pumped-storage hydropower: generates peak-load supply, harnessing water which is cycled between a lower and upper reservoir by pumps, which use surplus energy from the system at times of low demand. When electricity demand is high, water is released back to the lower reservoir through turbines to produce electricity.

Both reservoir and pumped storage hydropower are flexible sources of electricity that can help system operators handle the variability of other renewable energy such as wind power and photovoltaic electricity.[67]

Key Recent Innovations in the Hydropower Industry

The 20th century saw huge advances in water turbine technology for flexible generation of electricity. Particularly, the invention of adjustable rotor blades and inlet guide vanes, providing greater operating range and efficiency. Variable speed pumps are now in operation at new hydropower stations, enabling flexible generation in both pumping and generating mode. New technological developments in this field aimed to enable retrofitting of existing stations and turbines with similar levels of pumping/generating flexibility, allowing hydropower to deliver more finely tuned ancillary services to the electrical grid. An electrical grid is an interconnected network for delivering electricity. It consists of generating stations, high-voltage transmission lines that carry power from distant sources to demand centers, and distribution lines for individual customers. Hydropower is very important for electricity supply security in the European continent as well as for the economy of regions (primarily peripheral) that possess water resources.[68]

Hydropower is the only large-scale and cost-efficient storage technology available today. Despite promising developments in other energy storage technologies, hydropower is still the only technology offering economically viable and efficient large-scale electricity storage.[69,70]

New materials for turbines: Turbines have benefitted from advances in materials science in the hydroelectric industry. Steel components in the early 1800s replaced wood. **Steel** retains its strength through high fatigue loading and resists cavitation erosion and corrosion. Its properties are well-understood and the processes for component manufacture are well-developed. For large turbines units, steel will still remain the material of choice for the near future.[71]

Figure 16. Modern hydropower turbines are constructed from steel, or new alloys of tungsten carbide, or fiber-reinforced composites to withstand high pressures and resist corrosion from sediments.

But in the last decades, technological improvements included new alloys, such as **tungsten carbide** (WC, containing equal parts of tungsten and carbon atoms). WC can be pressed into shapes for use in industrial machinery. Tungsten carbide is approximately two times stiffer than steel and turbines are more resistant to erosion and abrasion from sediments. Turbine parts can be subjected to higher pressure flows enabling operation in harsher environments and producing more power. Modern **fiber-reinforced composites** have stability and fatigue strength that can rival steel components. The components are constructed with a polymer matrix and synthetic or natural fiber reinforcement. They are chosen for their strength-to-weight ratio and economy of scale for complex shapes.[71]

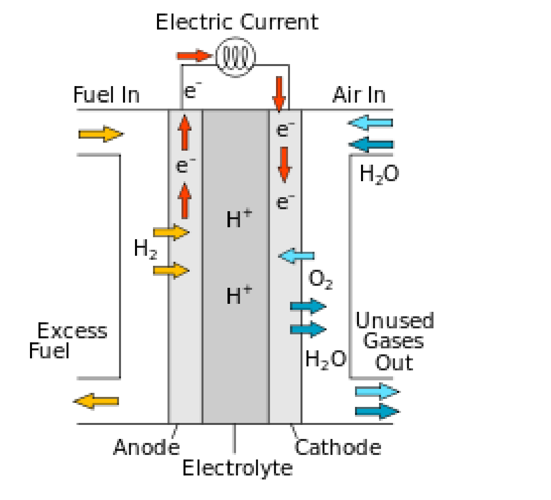
Innovative Changes for Environmental Protection in Hydropower Plants

The environmental consequences of hydropower are related to interventions in nature due to the construction of dams, changes in water flow of rivers, reduction of fish habitats, formation of sediments and the construction of roads and power lines that cause environmental damage. Additionally, hydroelectric power plants may affect the area's ecosystem complex interactions and physicochemical factors, such as dissolved oxygen concentration and sediment transport. Damming rivers may disrupt wildlife and reduce biodiversity. Some fish, like salmon, may be prevented from swimming upstream to spawn. Adverse environmental impacts, such as land flooded and evaporative water lost, smaller facilities might cause greater environmental disruptions per unit of energy produced than do larger facilities.[72,73]

Hydropower is very vital energy sector for many countries and hydropower companies strive to apply innovative changes and counteract on negative environmental issues. New hydroelectric plants apply new measures like fish-friendly turbines; fish lifts and more effective fish ladders specifically adapted to local species; turbines with limited impacts on dissolved oxygen; oil-free turbines and bio-degradable lubricants; and the addition of bottom outlet sluices and other sediment management techniques to flush damaging to the bottom of the rivers. [74,75] Other innovative and environmentally friendly measures are water management optimisation: Stored water to be utilised for energy generation when its value is high and stored when it is low. Mitigation of climate conditions in the dam areas, protection of wildlife and biodiversity. Better reservoir management to maximize efficiency and advances mathematical modeling for highly sophisticated optimization software and decision-support tools which help inform operational decision making.[76,77]

Fuel Cells Renewable Energy. New Technological Advances

Fuel cells are electrochemical devices, like batteries, converting the energy form by combining hydrogen and oxygen without using combustion into electricity. There are many types of fuel cells, but they all consist of an anode, a cathode, and an electrolyte that allows positively charged hydrogen ions (protons) to move between the two sides of the fuel cell. The anode and cathode contain catalysts that cause the fuel to undergo oxidation reactions that generate positively charged hydrogen ions and electrons. The hydrogen ions are drawn through the electrolyte after the reaction. At the same time, electrons are drawn from the anode to the cathode through an external circuit, producing direct current electricity. At the cathode, hydrogen ions, electrons, and oxygen react to form water. [Fuel Cell Basics, http://americanhistory.si.edu/fuelcells/basics.htm].[78,79]



Scheme of a proton-conducting fuel cell

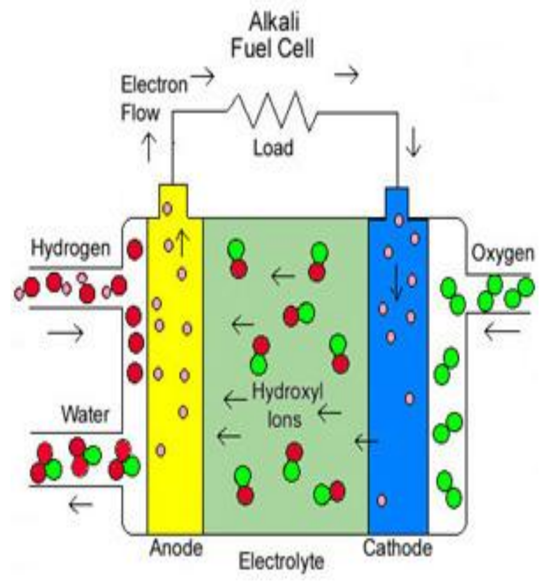


Figure 17. Schemes of Fuel Cells which come in many varieties but all work in same manner. Many of the choices facing fuel cell developers are constrained by the choice of electrolyte.

Types of Fuel Cells

Scientists of fuel cells have designed many different types in search for greater efficiency, but the main constrain is the choice of electrolyte. Today, the main types use as electrolyte: alkali, molten carbonate, phosphoric acid, proton exchange membranes (PEM) and solid oxide. Two chemical reactions occur at the interfaces of anode, cathode and electrolyte. The net result of the two reactions is that fuel is consumed, water or carbon dioxide is created, and an electric current is created, which can be used to power electrical devices. At the anode a catalyst oxidizes the fuel, usually hydrogen, turning the fuel into a positively charged ion and a negatively charged electron. The electrolyte is a substance specifically designed so ions can pass through it, but the electrons cannot.[80]

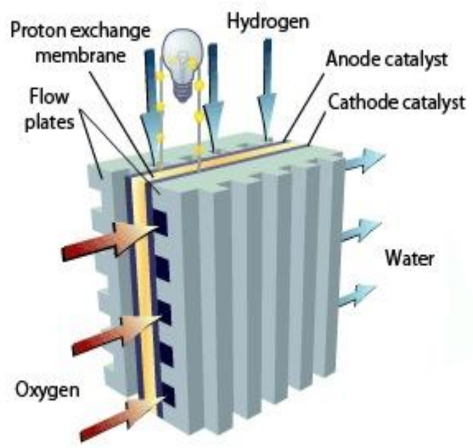
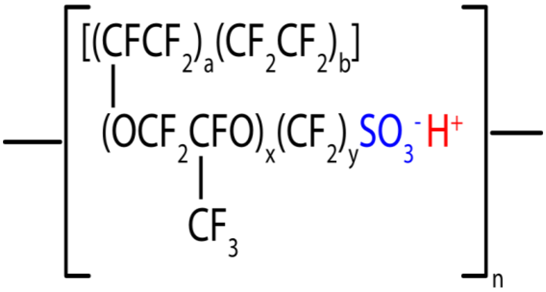


Figure 18. Fuel cell electric vehicle. High power fuel stacks for zero-emission vehicles of the future. Proton exchange membrane fuel cells (PEMFC) convert hydrogen and oxygen into electrical energy by a catalytic process requiring the use of platinum-based catalysts

Proton Exchange Membrane Fuel Cells (PEMFCs). Fuel cells PEMFCs operate by reacting O_2 from the air with electrons and H+ ions using catalysts, which typically contain rare and expensive materials such as platinum. The use of such expensive materials, however, drives up fuel cell costs and makes them harder to scale to high-volume production. In the archetypical hydrogen–oxide proton exchange membrane fuel cell design, a proton-conducting polymer membrane, perfluorinated, (typically Nafion) contains the electrolyte solution that separates the anode and cathode sides.[81]



Nafion, perfluorosulfonic acid membrane

Figure 19. Nafion polymer in PEMFCP and water electrolyzers. The thickness of Nafion is 183 micrometers. DuPont™ Nafion® 117 are films chemically stabilized by perfluorosulfonic acid/PTFE copolymer in the acid (H+) form.

Phosphoric Acid Fuel Cell (PAFC). Phosphoric acid fuel cells were first designed and introduced in 1961. Phosphoric acid is used as a non-conductive electrolyte to pass positive hydrogen ions from the anode to the cathode, able to work in temperatures of 150 to 200 degrees Celsius. At high temperatures heat and energy is produced. This heat can be used to produce steam for air conditioning systems or any other thermal energy consuming systems. Since the hydrogen ion production rate on the anode is small, platinum is used as catalyst to increase this ionization rate. The reactions in PAFC are: **Anode reaction**: $2H_2 \rightarrow 4H^+ + 4e^-$

Cathode reaction: $O_2\ (g) + 4H^+ + 4e^- \rightarrow 2H_2O$

Overall cell reaction: $2\ H_2 + O_2 \rightarrow 2H_2O$

A key disadvantage of these cells is the use of an acidic electrolyte, increasing the corrosion or oxidation of components. This type of fuel cell is used in stationary power generators with output in the 100 kW to 400 kW range to power many commercial premises around the world, and they are also finding application in large vehicles such as buses. Most fuel cell units sold before 2001 used PAFC technology.[82,83]

High-temperature Fuel Cells (SOFC). Solid oxide fuel cells (SOFCs) use a solid material, most commonly a ceramic material called yttria-stabilized zirconia (YSZ), as the electrolyte. Because SOFCs are made entirely of solid materials, they are not limited to the flat plane configuration of other types of fuel cells and are often designed as rolled tubes. They require high operating temperatures (800–1000^{o}C) and can be run on a variety of fuels including natural gas. SOFCs are fuel-flexible – they can reform CH_4 internally, use CO as a fuel, and tolerate some degree of common fossil fuel impurities, such as ammonia and chlorides. Sulfur-bearing contaminants, such as hydrogen sulfide, are tolerated less but can be dealt with using available commercial desulfurization methods. With internal reforming, this reaction is heat-absorbing and will tend to cool the cell and the module. This advantage can reduce the need for cooling air consequently reducing the parasitic power needed to supply that air.[84,85]

Alkaline Fuel Cell (AFC) or Hydrogen-Oxygen Fuel Cell. The hydrogen-oxygen fuel cell or alkaline fuel cell was used as a primary source of electrical energy in the Apollo space program. The cell consists of two porous carbon electrodes impregnated with a suitable catalyst such as Pt, Ag, CoO, etc. The space between the two electrodes is filled with a concentrated solution of KOH or NaOH which serves as an electrolyte. $2H_2$ gas and O_2 gas are bubbled into the electrolyte through the porous carbon electrodes. Thus the overall reaction involves the combination of hydrogen gas and oxygen gas to form water. The cell runs continuously until the reactant's supply is exhausted. Alkaline fuel cell although popular in the 1970s and 1980s, has fallen out of favour with the technical community in the light of the rapid development of Proton Exchange Membrane Fuel Cells (PEMFCs). AFCs have been shown to provide high power densities and achieve long lifetimes in certain applications.[86] Although fuel cell technologies have long been recognized as one of the most promising future energy solutions, major technological barriers hinder the potential realization of this clean energy source. At present there are major research trends, critical technological issues, and proposed resolutions to raise the effectiveness of investment of Research & Development (R&D) resources in fuel cell technology development.[87]

Molten Carbonate Fuel Cells (MCFC). Molten carbonate fuel cells (MCFCs) use a molten carbonate salt suspended in a porous ceramic matrix as the electrolyte. Salts commonly used include lithium carbonate, potassium carbonate and sodium carbonate. They operate at high temperature, around 650ºC that is improving dramatically reaction kinetics and thus it is not necessary to boost these with a noble metal catalyst. As a result, MCFC systems can operate on a variety of different fuels, including coal-derived fuel gas, methane or natural gas, eliminating the need for external reformers.

Anode Reaction: $CO_3^{2-} + H_2 \rightarrow H_2O + CO_2 + 2e^-$

Cathode Reaction: $CO_2 + \frac{1}{2}O_2 + 2e^- \rightarrow CO_3^{2-}$

Disadvantages associated with MCFC units arise from using a liquid electrolyte rather than a solid and the requirement to inject CO at the cathode as carbonate ions are consumed in reactions occurring at the anode. MCFCs are used in large stationary power generation. Most fuel cell power plants of megawatt capacity use MCFCs, as do large combined heat and power (CHP) and combined cooling and power (CCP) plants. These fuel cells can work at up to 60% efficiency for fuel to electricity conversion.[88,89]

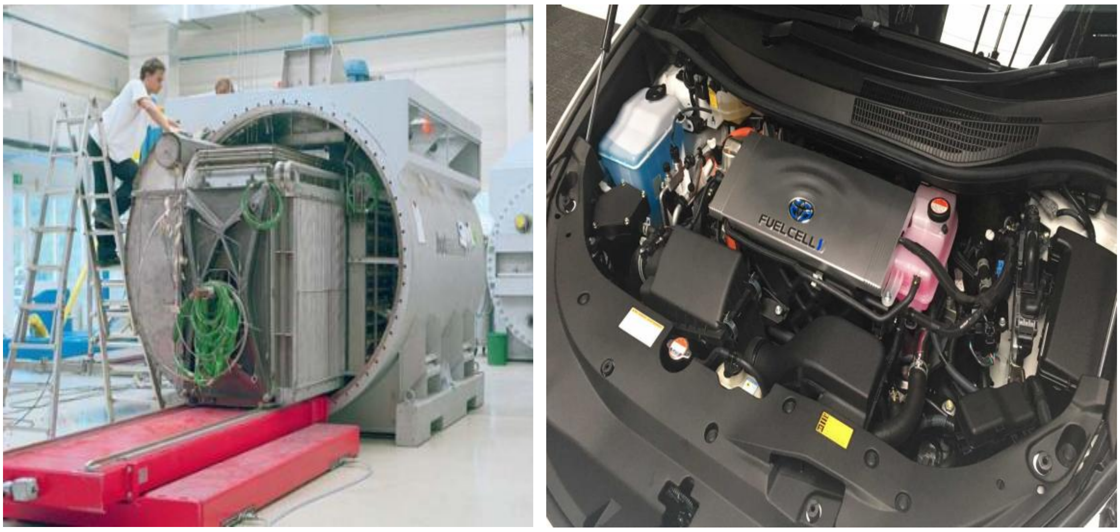


Figure 20. Molten Carbonate Fuel Cell in a T-Mobile Centre in Munich. The engine interior of the Toyota Mirai Fuel Cell hydrogen vehicle at the World Hydrogen Technologies Convention 2015 in Sydney, Australia.

Zinc–airBatteries (non-rechargeable) **and Zinc–air Fuel Cells** (mainly rechargeable). These are metal-air batteries powered by oxidizing Zinc with O_2 from air. They have high energy densities and are relatively inexpensive to produce. Sizes range from very small button cells for hearing aids, larger batteries used in film cameras that previously used mercury batteries, to very large batteries used for electric vehicle propulsion.[90] A zinc–air fuel cell (ZAFC) generates electricity by the reaction between oxygen and zinc pallets in a liquid alkaline electrolyte. ZAFC is a potential candidate for an alternative energy generator, efficient for completely renewable source of energy, and cheap in fabrication because precious metal catalysts are not necessary.[91]

Research and Development of Fuel Cell Technologies

Scientists claim that the various types of Fuel Cell are promising renewable technologies for use as sources of heat and electricity for buildings and machines, and as electrical power sources for electric motors propelling vehicles. Fuel cells operate best on pure hydrogen. But fuels like natural gas (CH_4), methanol (CH_3OH), or even gasoline (CxHz) can be reformed to produce the hydrogen required for fuel cells. As a technology, fuel cells help to bolster the electric grid, provide reliable and resilient power, reduce emissions, reach remote and rural parts, and utilize domestic sources of energy (e.g. natural gas). Recent nanotechnological structured cathodes have advanced in fuel cell applications.[92,93]

The fuel cell industry in the USA surpassed $2.2 billion in annual sales in 2014 and continues to grow. But in 2014, the U.S. was surpassed by Japan. In the last decade Japan is working on doing for the hydrogen fuel cell what it accomplished with computer chips and cars in the last century, slashing costs to make them more appealing to consumers. As fuel-cell technology finds its way into factories and commercial buildings, Japanese manufacturers including Panasonic Corp. are working to make them small and cheap enough for the home. With 100,000 already installed, residential fuel cells the country has set a goal of installing them in 5.3 million homes by 2030, about 10% of all households for combined heat and power generation. Fuel cell technological advances are taking place in recent years in USA, UK, Germany, Japan and Australia.[94,95]

By far the greatest research activity over the last 10-15 years on fuel cells has occurred in Japan, as the result of generous government funding (circa €200 m per year) for both research and demonstration projects to catalyse fuel cell micro-CHP (combined heat and power) development. A series of large demonstration programmes were carried out between 2002 and 2010, resulting in the installation of 3352 PEMFC (Proton Exchange Membrane Fuel Cells) and 233 SOFC (solid oxide fuel cells) units into private homes. Japan also lies at the forefront of SOFC development. The government roadmap aims for widespread commercialisation of SOFC from 2015 to 2020.[96]

Solid oxide fuel cells (SOFC) have emerged as energy conversion devices in achieving high efficiency of over 70% with regeneration. The critical components of SOFC are the anode, electrolyte, and cathode. Research in the last decade showed advances in material selection along with a detailed insight into the conceptual role of thermodynamics and kinetics of surface/cell reactions, effect of phases and microstructure on conductivity, and fuel flexibility. A recent comprehensive review analysed, chemical technology issues, design and selection of materials, underlying mechanisms, and performance of each SOFC components.[97]

Nanoporous carbon electrodes. Nanotechnological research is investigating the ideal catalyst support towards the development of high-performance electrodes for fuel cells with advantageous structural and chemical features. In order to satisfy these requirements scientists have use in the design of fuel cells nanoporous carbon electrodes and a great deal of efforts has been devoted to the functionalization of these electrodes. They focus on fine controls of pore size and graphitization degree, surface modification, heteroatom-doping, and encapsulation of nanoparticles.[98]

Microbial fuel cells (MFC) designs are promoted for novel biological fuel cells. These are bio-electrochemical systems drive a current by using natural bacteria which have electrochemically active redox proteins such as cytochromes on their outer membrane. In the last decade MFCs find a commercial use in the treatment of wastewater.[99] Scientists experimented with microbial fuel cell (MFC) anode that is fabricated by electrochemically reducing graphene oxide and coating polyaniline (PANI) nano-fibers on the surface of carbon cloth. Results showed high conductivity and large specific surface area improving the charge transfer efficiency and the bacterial biofilm loading.[100]

Hydrogen Production as Renewable Source of Energy

Hydrogen is an important energy carrier which could play a very significant role in the reduction of emissions of greenhouse gases. Hydrogen can be produced through methane reforming or through the electrolysis of water with the use of electricity or it can be produced directly by gasification from biomass.[101] Steam gasification is considered one of the most effective and efficient techniques of generating hydrogen from biomass. Of all the thermochemical processes, steam gasification offers the highest stoichiometric yield of hydrogen**.**[102] Researchers have recognized hydrogen (H_2) as an important renewable energy source. Hydrogen is considered as the alternative fuel as it could be generated from clean and green sources. Despite many advantages, storage of H_2 is a serious problem. Due to high inflammability, adequate safety measures should be taken during the production, storage, and use of H_2 fuel in refilling station, and in H_2 powered automobiles and subsequent acceptance as renewable fuel.[103]

Methods of H_2 Production

Hydrogen can be produced using a number of different physicochemical and biological processes presented below:[104]

a. Thermochemical Processes. Some thermal processes use the energy in various resources, such as natural gas, coal, or biomass, to release hydrogen from their molecular structure. The main types are:

Natural gas reforming (also called steam methane reforming or SMR),

coal gasification, biomass gasification, biomass-derived liquid reforming and solar thermochemical hydrogen (STCH).

b. Electrolytic Processes. Electrolyzers use electricity to split water into hydrogen and oxygen. This technology is well developed and available commercially, and systems that can efficiently use intermittent renewable power are being developed.

c. Direct solar water splitting processes, or photolytic, processes use light energy to split water into hydrogen and oxygen. These processes are currently in the very early stages of research but offer long-term potential for sustainable H_2 production with low environmental impact. There are two main types: Photoelectrochemical (PEC) and Photobiological.

d. Biological processes. Microbes such as bacteria and microalgae can produce hydrogen through biological reactions, using sunlight or organic matter. These technology pathways are at an early stage of research, but in the long term have the potential for sustainable, low-carbon hydrogen production. There are two types: Microbial biomass conversion and Photobiological.

Innovative Research for Hydrogen Production

Some of the most advanced research projects for future innovative methods on hydrogen production, economically and form sustainable resources, are taking place in the NERL, National Renewable Energy Laboratory of the USA. Recent advances are : Biological Water Splitting, Fermentation, Conversion of Biomass and Wastes, Photoelectrochemical Water Splitting, Solar Thermal Water Splitting, Renewable Electrolysis and Hydrogen Dispenser Hose Reliability.[105]

Researchers in the NERL (Chemistry and Nanoscience Center, as in other research laboratories, investigated the use of cheaper molecular catalysts instead of precious metals but these have encountered issues with stability, and were found to have a lifespan shorter than the metal-based catalysts. Instead researchers decided to examine molecular catalysts outside of the liquid solution and attached the catalyst directly onto the surface of the semiconductor. They were able to put a layer of titanium dioxide (TiO_2) on the surface of the semiconductor and bond the molecular catalyst to the TiO_2. The catalysts were highly active as the precious metal-based catalysts. This is an advance toward affordable photoelectrochemical production of hydrogen.[106]

A recent review examined how cost effective and environmentally attractive are the variety of methods for hydrogen production. The results showed that photonic energy based hydrogen production (photocatalysis, photoelectrochemical method, and artificial photosynthesis) is more environmentally benign than the other selected methods in terms of emissions. Thermochemical water splitting and hybrid thermochemical cycles also provide environmentally attractive results. Both photoelectrochemical method and PV electrolysis are found to be least attractive when production costs and efficiencies are considered.[107]

Hydrogen production by means of biological processes is considered the most environmental friendly and relatively easy to operate. The major bottlenecks in biological processes are the low hydrogen yield and production rates at a large scale. At present researches have various targets for improvements and devising paths and various innovative techniques, such as pretreatment, cell immobilization, sequential fermentation, combined fermentation that have been used in biological processes for enhancing hydrogen production.[108]

Numerous photocatalysts have been investigated in the last decade for water splitting techniques. For example, a graphitic carbon nitride (g-C_3N_4) doped with Zn has been investigated as a photocatalyst for water splitting and organic dye degradation. This hybrid material (Zn/g-C_3N_4) showed high photocatalytic activity and good stability for hydrogen evolution from an aqueous methanol solution under visible light irradiation ($\lambda \geq 420$ nm).[109]

Recent advances are reported by an international team on research and development of the copper chlorine (Cu–Cl) cycle for thermochemical hydrogen production. Experimental results for CuCl/HCl electrolysis and integration of unit operations in the Cu–Cl cycle show promising results. There is also recent progress on photo-electrochemical cell developments for enhanced electrolysis processes.[110]

International research teams from many countries are cooperating to develop innovative photocatalysts for the dissociation of water and the production of hydrogen and other experimental methodologies. Also, innovative schemes are investigated for storage, hydrogen safety and distribution. Hydrogen and fuel cells for some scientists are the most promising renewable energy sources of the future. [111,112,]

Already, in the USA a hydrogen fueling infrastructure is design for the Northeastern section of the U.S for the period 2013-20125. This design gives priority to customer convenience with minimum additional investments for its implementation. Extensive research has been conducted on generating a hydrogen supply from factories and other potential sources that can satisfy demand in the region.[113]

Biofuels, Biomass and Renewable Energy Sources

Biofuels represent a significant potential for energy sustainability and can contribute to economic growth of industrialized countries because they can be generated from locally available renewable material. First-generation biofuels were directly related to biomass biofuels (grain, vegetable oils, sugarcane, maize, rapeseed) were defined as fuels produced from a wide array of different feedstock. The second-generation of biofuels are derived from biomass ranging from lignocellulosic feedstocks, forest cuttings, to municipal solid wastes. The third-generation biofuels are related today to algal biomass but in the future could to a certain extent be linked to utilization of CO_2 as feedstock.[114]

Based on current knowledge and technology projections, third-generation biofuels (low input-high yielding feedstock) specifically derived from microalgae are considered to be viable alternative energy resource for the future with many advantages. First-generation biofuels (from crops, such as sugarecane, sugar beet, maize and rapeseed) had major drawbacks and use crops which can be used for food and animal feed. Second-generation biofuels have certain advantages. They are derived mainly from lignocellulosic energy crops and agricultural (wheat straw) and forest biomass residues (woody biomass) and municipal solid waste. These feedstocks are transformed by thermochemical conversion processes, such as gasification and Fischer-Tropsch process. Key advantages are that much under use raw materials, especially waste, with lower cost of feedstock. The resulting fuel is of high quality. The third-generation microalgae-to-biofuels production systems are very promising because of high-value biomass fractions in a biorefinery concept. They offer sustainable resources by coupling microalgae propagation with CO_2 sequestration and use of plentiful solar light. Also, the method at the same time can be used for wastewater treatment.[115,116]

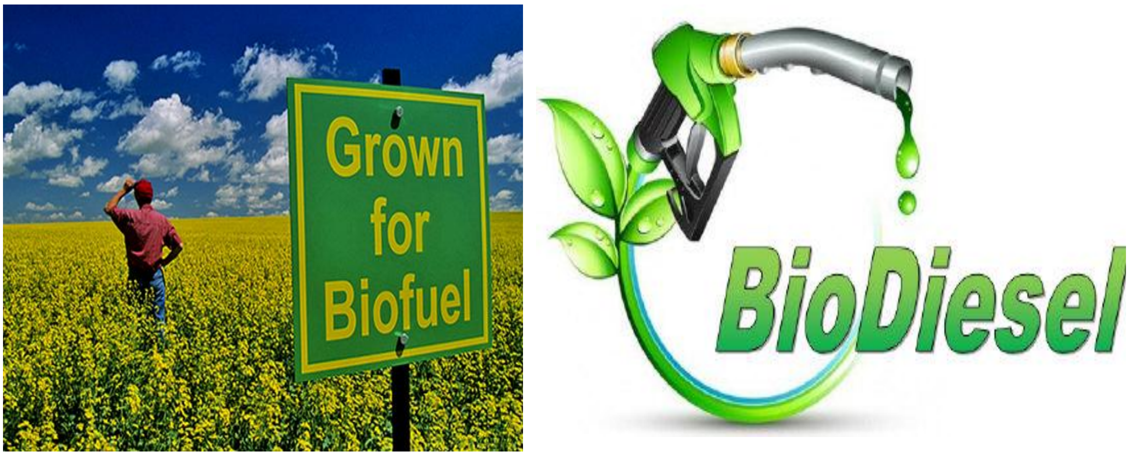


Figure 21. First-generation biofuels had major drawbacks. Biodiesel is considered a good quality fuel. Second-generation biofuels have certain advantages. Third-generation biofuels maximize biomass productivity, CO_2 sequestration and sustainability.

Algae can be converted into various types of fuel, depending on the technique and the part of the cells used. The lipid, or oily part of the algae biomass can be extracted and converted into biodiesel through a process similar to that used for any other vegetable oil, or converted in a refinery for petroleum-based fuels or algae can be fermented into bioethanol or butanol fuel. In the last decade the third-generation biofuels have been advancing on large size algal farms with various harvesting and extraction technologies to increase sustainability and viability of the methods. New research is focusing on comparing costs for three methods of harvesting and extraction in algae farms. The baseline harvesting centrifuge system can be improved by the electrocoagulation system. For extraction of oily algae biomass produced a wet solvent system is postulated as the baseline and is compared to the Hydrothermal Liquefaction–Catalytic Hydrothermal Gasification (HTL–CHG) and pyrolysis systems. Results indicate that each of the new technologies is an improvement over the baseline. The combination of the most promising harvesting and extraction systems shows a 64% improvement in net present value (NPV) and a 90% reduction in the cost.[117]

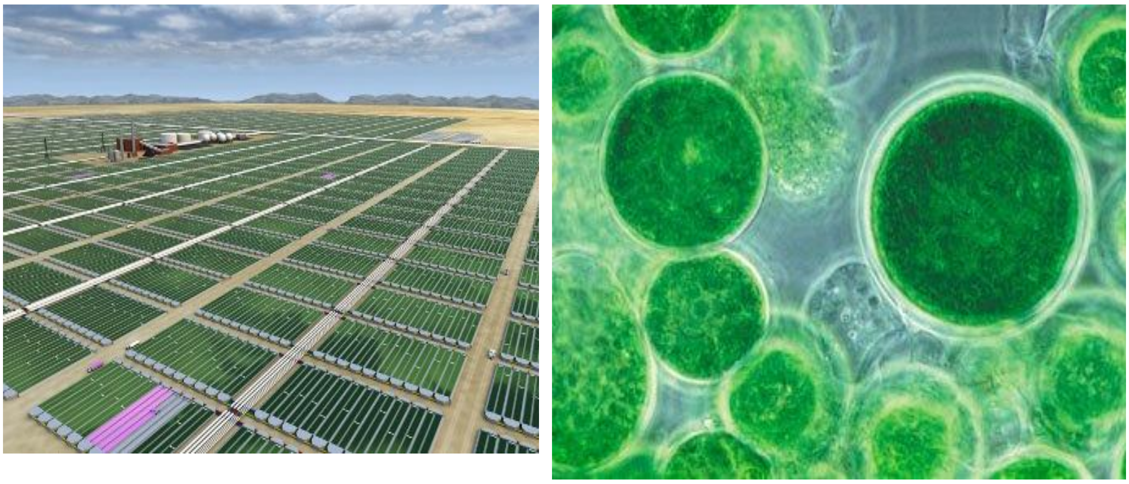


Figure 22. Algae cultivation methods for biofuels. Innovations and improvements were shown across the entire value chain, including technologies that maximised biomass productivity and improved algae cultivation methods.

Commercial Development, Cost efficiency of Algal Biofuel

There is clearly a demand for biofuels as renewable energy sources, but depends not only on sustainability but mainly on cost efficiency. Therefore, research is focusing on cutting the cost of algal biofuel production to compete with prices of conventional petroleum. The Algal Biomass Organization (an international organization in the USA, http://algaebiomass.org/) announced in February 2014 that "… algae can be part of the greatest economic opportunity of the 21st century…. and that algal fuel can reach price parity with oil in 2018 if granted production tax credits". These ambitious goals are not very easy to achieve in such a short time.

Although initially Exxon Mobil was committed to spend up to $600 million over 10 years on development of algal biofuel in a joint venture, finally Exxon pulled back after four years (and $100 million) when it realized that algae fuel is "probably further" than 25 years away from commercial viability. On the other hand, Solazyme and Sapphire Energy companies already began commercial sales of algal biofuel in 2012 and 2013, respectively, and Algenol hopes to produce biofuels commercially in 2014. **Solazyme company** (South San Francisco, California) has produced a fuel suitable for powering jet aircraft from algae and is supported by oil companies such as Chevron. **Sapphire Energy** (San Diego) has produced green crude from algae. **Algenol Biofuels** (Southwest Florida, USA, founded 2006) is a global, industrial biotechnology company commercializing its patented algae technology for production of ethanol and other fuels. **Blue Marble Production** (Seattle-based company, USA) is dedicated to removing algae from algae-infested water. This in turn cleans up the environment and allows this company to produce biofuel. The European Union has also responded to the challenge by quadrupling the credits for second-generation algae biofuels which was established as an amendment to the Biofuels and Fuel Quality Directives.[118,119,120]

Other Biofuels and Biodiesel

Biofuels use as energy sources have advanced in the last decade but as renewable resources have produced many scientific challenges. There are various social, economic, environmental and technical issues with biofuel production and use, which have been discussed in the scientific journals, books and conferences. These include: the effect of moderating oil prices, the "food vs fuel" debate, poverty reduction potential, CO_2 emissions levels, sustainable biofuel production, deforestation and soil erosion, loss of biodiversity, impact on water resources, the possible modifications necessary to run the engine on biofuel, as well as energy balance and efficiency.[121,122,123]

Bioethanols. Biologically produced alcohols, most commonly ethanol, and less commonly propanol and butanol, are produced by the action of microorganisms and enzymes through the fermentation of sugars or starches or cellulose.

Biodiesel is produced from oils or fats using transesterification. Chemically, it consists mostly of fatty acid methyl (or ethyl) esters. Feedstocks for biodiesel includeanimal fats, vegetable oils, soy, rapeseed, jatropha, flax, sunflower, palm oil and algae.

Green diesel is produced through hydrocracking biological oil feedstocks, such as vegetable oils and animal fats.

Biogas is methane produced by the process of anaerobic digestion of organic material by anaerobes. It can be produced either from biodegradable waste materials or by the use of energy crops fed into anaerobic digesters to supplement gas yields. The solid byproduct, digestate, can be used as a biofuel or a fertilizer.

Syngas, a mixture of carbon monoxide, hydrogen and other hydrocarbons, is produced by partial combustion of biomass. Before partial combustion, the biomass is dried, and sometimes pyrolysed.

Geothermal Power Clean and Sustainable

Geothermal power plants have much in common with traditional power-generating stations. They use many of the same components, including turbines, generators, transformers, and other standard power (electricity) generating equipment. The geothermal energy of the Earth's crust originates from the original formation of the planet and from radioactive decay of materials. Earth’s internal temperatures at the core–mantle boundary may reach over 4000^{o}C. Worldwide, 11,700 megawatts (MW) of geothermal power was produced in 2013. An additional 28 GW (gigawatts) of direct geothermal heating capacity is installed for district heating, space heating, spas, industrial processes, desalination and agricultural applications in 2010. [124,125]

Figure 23. In Greece there are many geothermal areas. Especially in Milos and Nisiros (above 150^{o}C, Celcius), Kamena Vourla, and in Chios, Lesvos, Delta Evros (90-150^{o}C)

Many technologies have been developed to take advantage of geothermal energy which as heat can be drawn from several sources: hot water or steam reservoirs deep in the earth that are accessed by drilling;

geothermal reservoirs located near the earth's surface. The geothermal plant can use the hot water and steam from reservoirs to drive generators and produce electricity for its customers. Other applications apply the heat produced from geothermal directly to various uses in buildings, roads, agriculture, and industrial plants. Research on geothermal power and new technological developments are concerned with innovative heat pumps, more efficient electricity production and useful ways of direct use of hot water for heating.[126]

Wave, Tidal and Ocean Energy Technologies

In the last decade wave, tidal and ocean energy technologies are beginning to reach viability as potential commercial renewable power sources. Tidal energy is produced through the use of tidal energy generators. These large underwater turbines are placed in areas with high tidal movements, and are designed to capture the kinetic motion of the ebbing and surging of ocean tides in order to produce electricity. Tidal power has great potential for future power and electricity generation because of the massive size of the oceans.

Figure 24. The MeyGen project off the coast of Scotland is well on track to start producing clean energy by early-2016. Photo courtesy of Atlantis Resources.

In the Orkney Islands, Northern Scotland, strong tidal currents have challenged sailors for centuries. But some of that marine energy is now being captured through a project known as **MeyGen.** The Atlantis group began construction on a submerged tidal turbine array consisting of four, three-bladed, seabed-mounted turbines, enough to deliver 6 megawatts to the grid by 2016 and power approximately 3,000 Scottish homes. By the early 2020s, Atlantis is planning to build 269 turbines capable of generating 398 megawatts of electricity, enough to power roughly 200,000 homes.[127]

The UK has positioned wave and tidal stream energy as key to the transition to deriving energy from renewable sources. It's estimated that the 50% of Europe's tidal energy resources are located in UK waters. The UK's Department of Energy & Climate Change believes that wave and tidal energy combined could deliver around 20% of the UK's current electricity needs. It would also establish the country as the world leaders in a global market worth £50 billion by 2050.[128]

Ocean energy has attracted increasing interest, particularly in the European Union countries, which are currently at the forefront of ocean energy development. Over 50% of global RD&D investments in ocean energy are taking place within the EU. The aim is for EU to reach 100 GW of combine wave and tidal capacity by 2050. The EU has implemented support mechanisms to aid the development of ocean energy. The first tidal energy demonstration is expected by 2016, and by 2018 it is expected that 66 MW of ocean energy projects will become operational. In order to achieve these targets the sector needs to overcome a series of challenges and barriers with regards to technology readiness, financing and market establishment, administrative and environmental issues and the availability of grid connections especially in remote areas.[129]

The ocean energy industry has made significant progress in recent years but is still at very early stage with some advanced prototypes that are currently being tested. Existing challenges include further development of the technology to prove reliability and robustness and to reduce costs but also deployment and risk reduction.[130]

Wireless Power Transmission from Space Solar Satellite Photovoltaic Panels

Space solar power is another interesting renewable energy source which needs to be explored. It can provide large quantities of energy to Earth with very little environmental impact. Space solar panels can gather energy from sunlight in space and transmits it wirelessly to Earth. The solar energy available in space is literally billions of times greater than we use today. Space-based solar power on a commercially viable scale will be an enormous undertaking. The idea has been re-evaluated from time to time by the U.S. Department of Energy, NASA, major aerospace companies and countries such as Japan and India. Their studies generally concluded that there is no technical barrier to implementing Space-based solar power; rather, the principal impediment has been economics -- the ability to provide SBSP at a cost that is competitive with other energy sources. Solar power satellites are large arrays of photovoltaic panels assembled in orbit, which use very low power radio waves to transmit solar power to large receiving antennas on Earth. Several of the technologies required to build a working SBSP satellite have, in principle, already been developed---and some of the component technology is already in use across a variety of sectors. The main disadvantages is high development cost. Space solar power development costs will be very large, although much smaller than American military spending in the last decade, or the costs of global warming, climate change, or carbon sequestration.[131]

The main disadvantages of Space Solar Power has high development cost. Space solar power development costs will be very large, although much smaller than American military spending in the last decade, or the costs of global warming, climate change, or carbon sequestration. Space-based solar power has been a dream since April 1941, when the idea was proposed by Isaac Asimov in a short story called “Reason.”

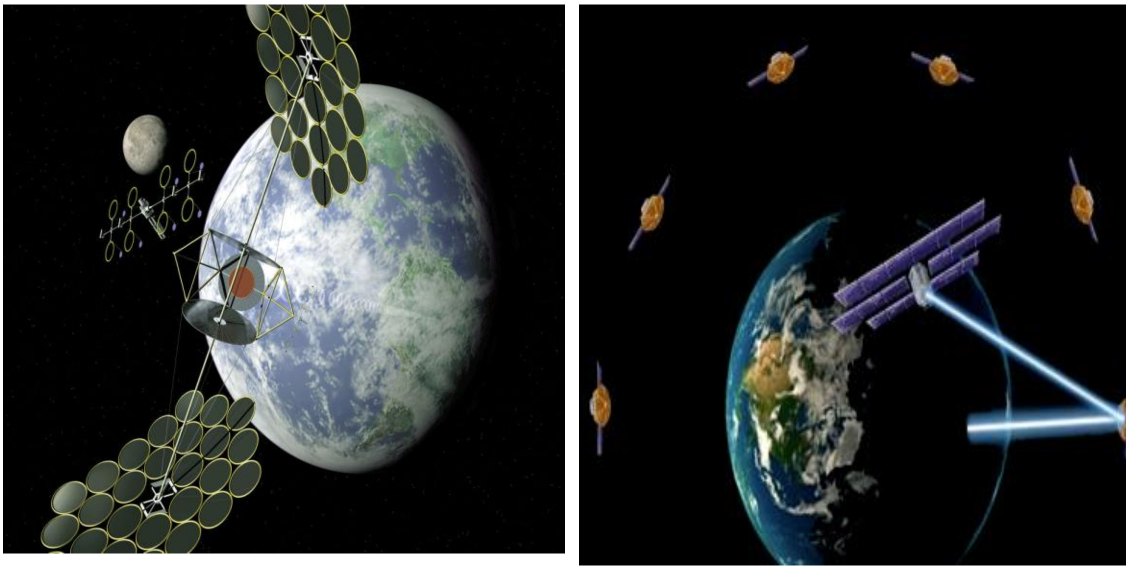


Figure 25. Space solar power and wireless energy transmission has many advantages but very high cost and difficult technological challenges.

Japan is in the leading among developed countries for this ambitious technological undertaking. For an output of 1 GW (gigawatt), Japan is planning on deploying a solar collector weighing over 10,000 metric tons and measuring several kilometers across. It would live in geosynchronous orbit, some 36,000 kilometers from Earth. A successful ground test (March 2015) of a system designed to ultimately collect solar power from orbit and beam it back down to Earth was announced in Japan this week by Mitsubishi Heavy Industries. The wireless power demonstration saw 10 kilowatts sent over microwaves from a transmitting unit to a receiver 500 meters away. Mitsubishi says the reception of the power sent through the air was confirmed through the illumination of lights using part of the power transmitted. The company did not confirm what percentage of the power sent actually made it to the receiver, however, which is a key question as the ultimate goal is to relay power from orbit thousands of miles above Earth. Previous tests of the technology yielded only a tiny fraction of the power sent from one Hawaiian island to another.[132]

The science of space solar power is sound. It can obviously generate solar power here on Earth using panels, that can transmit energy wirelessly via microwaves or lasers. The solar panels can be launched into space with usual technology for launching satellites.

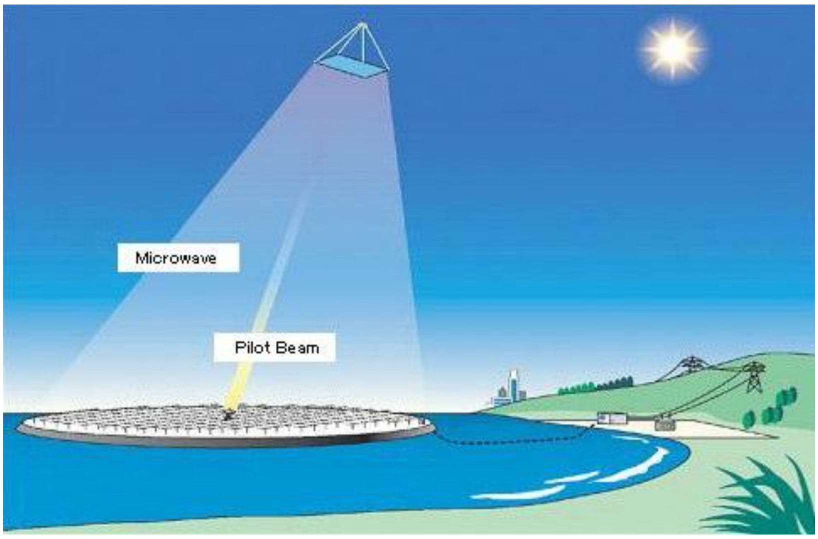


Figure 26. Schematic presentation of Japan's project to wireless power transmission from space-based solar satellite. Japan's Space Agency has been studying Space Solar Power System (SSPS) as an alternative future energy resource supported by the Ministry of Economy, Trade and Industry.

The US government spent $to million researching the idea between 1978-1981, during the height of the 1970s oil crisis. Since then, it has cut funding drastically, but researchers at the US Naval Research Laboratory continue to work on the underlying technology, necessary to put solar panels in space. There are two ways to send the power back to Earth: microwaves and lasers. Microwaves can, generally, go through clouds, which is a major drawback of lasers. But microwaves are less accurate and could generate radio interference with cell phones and other communications devices. Lasers, on the other hand, have pinpoint accuracy—a receiver station can be much smaller, potentially even portable. Laser-based power is potentially more flexible in deployment, and at a price point that may be cheaper because of the smaller form factor required. The biggest holdup, at this point, is getting a huge solar farm into space. A single large power station would seem like the easiest solution to manage in orbit, but then there's another issue: you have to assemble it in space.[133]

Conclusions

The use of renewable energy sources is considered by many scientists and energy specialists as the most important sustainable solution of human civilization on Earth for the 21st century. Climate warming and CO_2 emissions are already threatening to change the ambient environment and affect the sensitive balance after millions of years of the Earth's ecosystems. This is the most challenging problem of human civilization and is connected to future its survival on Earth. Renewable energy resources are "clean" and environmentally friendly sources of energy. The optimal use of renewable resources can be used to minimize environmental impacts and produce minimum secondary wastes. Renewables are sustainable based on current and future economic and social societal needs. Sun is the source of all energies. Sunlight and heat are transformed and absorbed by the environment in a multitude of ways. Some of these transformations result in renewable energy flows such as biomass, wind and solar energy. The present renewable energy technologies and future developments can provide an excellent opportunity to humanity for mitigation of greenhouse gas emission and reducing global warming through substituting conventional fossil energy sources that were developed after the industrial revolution of the 18th century.

Large-scale renewable energy implementation plans must include strategies for integrating renewable sources in coherent energy systems influenced by energy savings and efficiency measures. The necessary renewable energy sources (wind, solar, hydrothermal power, geothermal, biofuels, etc) are present, and if further technological improvements of the energy system are achieved the renewable energy system can replace to a large extent the conventional fossil energy sources in the near future. Especially technologies of converting the transportation sector and the introduction of flexible energy system technologies are crucial.

.

References

1. Vlachogianni Th, Valavanidis A. Energy and environmental impact on the biosphere. Energy flow, storage, and conversion in human civilization. *Am J Edu Res* 1(3):68-78, 2013.
2. Michaelides EE. *Alternative Energy Sources.* Green Energy and Technology Series. Springer-Verlag, Berlin, Heidelberg, 2012.
3. Burke E III. The Big Story. Human History, energy regimes and the environment. In : Burke E II, Pomeranz K (Eds). *The Environment and World History.* University of California Press, Berkeley, London, pp. 33-53, 2009.
4. Pyne SJ. *World Fire. The Culture of Fire on Earth*. Holt publishing, New York, 1995.
5. Smil V. *General Energetics. Energy in the Biosphere and Civilization*. John WEiley & Sons, New York, 1991.
6. Goudsblom J. *Fire and Civilization*. Penguin, London, 1992.
7. World Energy Council. World Energy Resources: 2013 Survey. WEC, London, 2013 [https://www.worldenergy.org/publications/2013/world-energy-resources-2013-survey/].
8. Abas N, Kalair A, Khan N. Review of fossil fuels and future energy technologies. *Futures* 69:31-45, 2015.
9. Glynn J, Fortes P, Krook-Riekkola A, Labriet M, et al. Economic impacts of future changes in the energy system—National perspectives. In: Giannakidis G, et al (Eds). *Informing Energy and Climate Policies Using Energy System Models*. Lecture Notes in Energy. Vol.30:359-387, 2015. Springer International Publishing, Switzerland, 2015.
10. Lior N. Energy resources and use: The present situation and possible paths to the future. *Energy* 33:842-857, 2008.
11. Chu S, Majumdar A. Opportunities and challenges for sustainable energy future. *Nature* 488:294-303, 2012.
12. Twidell J, Weir T. Renewable Energy Resources. 3rd ed, Routledge, London, New York, 2015 (1st 1986)
13. World Economic Forum. Report. *Energy for Economic Growth*. *Energy Vision Update 2012*. World Economic Forum. 2012 … [http://reports.weforum.org/energy-for-economic-growth-energy-vision-update-2012/].
14. Meadows DH, Meadows DL, Randers J, Behrens WW, III, and the Club of Role. *The Limits to Growth.* Universe Books, New York, and Pan Books, London, 1972.
15. Meadows DH, Meadows DL, Randers J. *Beyond the Limits*. *Confronting Global Collapse, Envisioning a Sustainable Future.* Chelsea Green Publishing Co, Hartford, VT, and Earthscan. London, 1992.
16. Meadows DH, Randers J. *Limits to Growth: The 30-Year Update.* Chelsea Green Publishing Co, Hartford, VT, 2004.
17. Hillebrand E, Closson S. *Energy, Economic Growth, and Geopolitical Futures. Eight Long-range Scenarios*. MIT Press, Cambridge, MA, 2015.
18. Oil Crisis. World oil crisis: driving forces, impact and effects........ [http://www.world-crisis.net/oil-crisis.html] (accessed Jan 2016).

19. International Energy Agency. 2014 Key World Energy Statistics, IEA publication, 2014. [PDF. *http://www.iea.org/publications/freepublications/* IEA. 2014].
20. British Petroleum (BP): Statistical Review of World Energy, Workbook (xlsx), London, 2013. *BP Statistical Review of World Energy*. [http://bp.com/statisticalreview2013].
21. U.S. EIA, Frequently asked questions. How much of world energy consumption and electricity generation is from renewable energy?, 2012 [http://www.eia.gov/tools/faqs/faq.cfm?id=527&t=4]
22. International Energy Agency (IEA). IEA's World Energy Outlook 2015 report. [https://www.iea.org/publications/freepublications/publication/WEO_2015_ES_English_WEB.pdf] (accessed January 2016).
23. REN21. Renewable Energy Policy Network for the 21st Century, *Renewables 2015. Global Status Report*. Available at : [http://www.ren21.net/status-of-renewables/global-status-report/] (accessed January 2016).
24. REN21. Renewable Energy Policy Network for the 21st Century. *The First Decade,2004-2014*. [http://www.ren21.net/Portals/0/documents/activities/Topical%20Reports/REN21_10yr.pdf]. (accessed January 2016).
25. EUrostat Statistics Explained. Renewable Energy Statistics (1990-2013). [Energy balance sheets - 2013 data - 2015 edition]. Available at [http://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_from_renewable_sources] (accessed January 2016).
26. Eurostat. News release. Share of renewables in energy consumption up to 15% in the EU in 2013. [http://ec.europa.eu/eurostat/en/web/products-press-releases/-/8-10032015-AP]. (accessed January 2016).
27. Chaviaropoulos PK (Head of RES Office, Ministry of Environment, Energy and Climate Change.) Renewable Energy Programs of Greece [http://www.academyofathens.gr/Documents/solar_energy_concentrating_solar_power/renewable_energy_program_of_greece.pdf] (accessed January 2016).
28. Boyle G. *Renewable Energy: Power for a Sustainable Future*. 3rd edition, Oxford University Press, Oxford, 2012.
29. Shere J. *Renewable. The World-Changing Power of Alternative Energy*. St Martins Press, London, 2013.
30. Ehrlich R. *Renewable Energy. A First Course*. CRC Press, Boca Raton, FL, 2013.
31. Wengenmayr R, Bunrke T (Eds). *Renewable Energy. Sustainable Energy Concepts for the Future*. 2nd edition, Wiley-VCH, New York, 20-12.
32. Tyagi VV, Rahim NAA, Selvaraj JAL. Progress in solar PV technology: Research and achievement. *Renew Sustain Energy Rev* 20:443-461, 2013.
33. Lewis NS, Nocera DG. Powering the planet: Chemical challenges in solar energy utilization. *Proc Natl Acad Sci USA* 103(43):15729-15735, 2006.
34. Journal open access. Springer publisher. Materials for Renewable and Sustainable Energy. Open access. [journal number 40243, http://www.springer.com/materials/journal/40243].

35. Wei N, Quarterman J, Jin Y-S. Marine macroalgae: an untapped resource for producing fuels and chemicals. *Trends Biotechnol* 31(2):70-77, 2013.
36. Liu J, Zhang J-G, Yang Z, Lemmon JP, Imho C, et al. Materials science and materials chemistry for large scale electrochemical energy storage: from transportation to electrical grid. *Advanc Function Mater* 23(8):929-946, 2013.
37. Alotto P, Guarnieri M, Moro F. Redox flow batteries for the storage of renewable energy: A review. *Renew Sustain Energy Revs* 29:325-335, 2014.
38. Larcher D, Tarascon J-M. Towards greener and more sustainable batteries for electrical energy storage. Review. *Nature Chemistry* 7:19-29, 2015.
39. Parida B, Inivan S, Goic R. A review of solar photovoltaic technologies. *Renew Sustain Energy Rev* 15(3):1625-1536, 2011.
40. Tyagi VV, Rahime NAA, Rahime NA, Selvarai JAL. Progress in solar PV technology: Research and achievement. *Renew Sustain Energy Revs* 20:443-461, 2013.
41. International Energy Agency. Photovoltaic Power Systems Programme. 30 March 2015. [https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapSolarPhotovoltaicEnergy_2014edition.pdf].
42. Brown GF, Wu J. Third generation photovoltaics. Laser Photon Revs 3(4): 394–405, 2009.
43. Gong J, Darling SB, You F. Perovskite photovoltaics: life-cycle assessment of energy and environmental impacts. *Energy Environ Sci* 8(7): 1953–1968, 2015.
44. Service RF. Perovskite solar cells keep on surging. *Science* 344:458–458, 2014.
45. Snaith HJ. Perovskites: The emergence of a new era for low-cost, high-efficiency solar cells. *J. Phys. Chem. Lett. 4*(21): 3623–3630, 2013.
46. Niu G, Guo X, Wang L. Review of recent progress in chemical stability of perovskite solar cells. *J Mater Chem A* 3:8970-8980, 2015.
47. Collier J, Wu S, Apul D. Life cycle environmental impacts from CZTS (copper zinc tin sulfide) and Zn_3P_2 (zinc phosphide) thin film PV (photovoltaic) cells. *Energy* 74: 314–321, 2014.
48. Suryawanshi MP, Agawance GL, Vhosale SM, et al. CZTS based thin film solar cells: a status review. *Ener Mater Mater Sci Engin Ener System* 8(1):98-109, 2013.
49. Krebs FC.; Jørgensen M. Polymer and organic solar cells viewed as thin film technologies: What it will take for them to become a success outside academia. *Solar Ener Mater Solar Cells* 119: 73–76, 2013.
50. Li G, Zhu R, Yang Y, et al. Polymer solar cells. *Nature Photonics* 6:153-161, 2012.
51. Wang, X; Khan MR, Gray JL, Alam MA et al. Design of GaAs solar cells operating close to the Shockley–Queisser Limit. *IEEE J Photovoltaics* 3(2): 737-744, 2013.

52. Ludin NA, Al-Alwabi Mahmoud AM, Mohamad AB, et al. Review on the development of natural dye photosensitizer for dye-sensitized solar cells. *Renew Sustain Energy Revs* 31:386-396, 2014.
53. International Energy Agency. Technology Roadmap. Wind Energy. EnergyTechnology Perspectives. Paris, 2013 edit. [https://www.iea.org/publications/freepublications/publication/Wind_2013_Roadmap.pdf].
54. Ancona D, McVeigh J. Wind Turbine - Materials and manufacturing fact sheet. Office of Industrial Technologies, US Department of Energy, 2001. [available at http://www.perihq.com/documents/WindTurbine-MaterialsandManufacturing_FactSheet.pdf].
55. Watson JC, Serrano JC. Wind Systems. Composite materials for wind blades. PPG Industries, Inc. US Fiber Glass Science and Technology, [available http://www.windsystemsmag.com/article/detail/149/composite-materials-for-wind-blades].
56. Wilburn DR. USGS. Wind Energy in the United States and Materials Required for the Land-Based Wind Turbine Industry for 2010 through 2030. US Dpt of Interior, U.S. Geological Survey. Report 211-5036, U.S. Geology, Reston, Virginia, 2011 [http://pubs.usgs.gov/sir/2011/5036/sir2011-5036.pdf].
57. Lowder, Sally, 2010, Jack Lifton—North America doesn't need China's rare earths: The Gold Report, June 21, 6 p., accessed June 23, 2010, at http://www.theaureport.com/pub/na/6584].
58. Hedrick, J.B., 2010, Rare earths: U.S. Geological Survey Mineral Commodity Summaries 2010, p. 128–129. [available at http://minerals.er.usgs.gov/minerals/pubs/commodity/rare_earths/mcs-2010-raree.pdf.].
59. Recycling Portal: Wanted: Chemical substance to separate wind turbine plastic fibres from composites [http://recyclingportal.eu/Archive/21083].
60. Njiri JG, Soffker D. State-of-the-art in wind turbine control: Trends and challenges. *Renew Sustain Energy Revs* 60:377-393, 2016.
61. Brondsted P, Nijssen RPL. *Advances in Wind Turbine Blade Design and Materials*. Woodhead Publishing, Cambridge, 2013.
62. Lacal-Arantequi R. Materials use in electricity generators in wind turbines – state-of-the-art and future specifications. *J Cleaner Prod* 87:275-283, 2015.
63. Global Wind Energy Council. China breezes past WU as top wind power. gwec-in-press-11.2.2016. [http://www.gwec.net/].
64. Chehouri A, Younes R, Llincar A, Perron J. Review of performance optimization techniques applied to wind turbines. *Applied Energy* 142: 361-388, 2015.
65. Higgins P, Foley A. The evolution of offshore wind power in the United Kingdom. *Renew Sustain Energy Revs* 37:599-612, 2014.
65. World Energy Council (Conseil Mondial de l'Energie). *Charting the Upsurge in Hydropower Development, 2015*. WEC publication, London, Paris, 2015. [https://www.worldenergy.org].
66. Hydro Equipment Association, "Pump Storage power plants," December 2013. [Available at : http://www.thehea.org/hydropower/special-focus/pump-storage-power-plants/].

67. Gaudard L, Romeno F. The future of hydropower in Europe: Interconnecting climate, markets and policies. *Environ Sci Policy* 37: 172-181, 2014.
68. IRENA. International Renewable Energy Agency. Renewable Energy Technologies. Cost Analysis Series. Vol.1. Power Sector, Issue 3/5, Hydropower. IRENA Publs, Bonn, Germany, June 2012.
69. Europe Tomorrow. Energy. Energy Innovations. [[http://europetomorrow.org/social-environmental-innovation/energy/]
70. Spicher T. Hydro Review. Choosing the right material for turbine runners. [http://www.hydroworld.com/articles/hr/print/volume-32/issue-6/articles/choosing-the-right-material-for-turbine-runners.html].
72. Gleick PH. Environmental consequences of hydroelectric development: The role of facility size and type. *Energy* 17(8):735-747, 1992.
73. Bakken TH, Aase AG, Hahen D, et al. Demonstrating a new framework for the comparison of environmental impacts from small- and large-scale hydropower and wind power projects. *J Environ Manage* 140:93-101, 2014.
74. International Commission on Large Dams (ICOLD). Position paper on dams and the environment http://genepi.louis-jean.com/cigb/chartean.html. Paris, 1997. (http://www.icold-cigb.org/GB/contact.asp).
75. International Energy Agency (IEA) 2000. Survey of the environmental and social impacts and the effectiveness of mitigation measures in hydropower development. IEA 92 pp., 2000.
76. World Commission on Dams (WCD). *Dams and Development: a New Framework for Decision-making*. Earthscan Publications Ltd., London., 2000.
77. U.S. Energy Information Administration. Hydropower generators produce clean energy, but hydropower does have environmental impacts. [http://www.eia.gov/Energyexplained/index.cfm?page=hydropower_environment].
78. O'Hayre R, Cha S-W, Colella W, Prinz FB. *Fuel Cell Fundamentals*. Wiley & Sons, New York, 2006.
79. Revankar ST, Majumdar P. *Fuel Celle: Principles, Design, and Analysis*. CRC Press, Boca Ration, Fl, 2014.
80. Stolten D, Emonts B. Fuel Cell Science and Engineering: Materials, Processes. Systems and Technology. Wiley-VCH-Verlag, Berlin, 2012.
81. Barbir F. *PEM Fuel Cells. Theory and Practice*, 2nd edition. Elsevier, Academic Press. Amsterdam, 2013.
82. FuelCellToday. The phosphoric acid Fuel Cells PAFC……….. [http://www.fuelcelltoday.com/technologies/pafc].
83. Sotouchi H, Hagiwara A. Phosphoric Acid Fuel Cells.Vol.11. Energy Carriers & Conversion Systems. Encyclopedia of Life Support Systems(EOLSS).[http://www.eolss.net/sample-chapters/c08/e3-13-10-05.pdf].
84. U.S. Department of Energy. Energy.gov. Office of Fossil Energy. Why SOFC Technology? [available at http://energy.gov/fe/why-sofc-technology]. (accessed Febr 2016).
85. Singhai SC. Advances in solid oxide fuel cell technology. *Solid State Ionics* 135(1-4): 305-313, 2000.

86. McLean GF, Niet T, Prince-Richard S, Djilali N. An assessment of alkaline fuel cell technology. *Int J Hydroge Ener* 27(5):507-526, 2002.
87. Ho JC, Saw E-C, Lu LYY, Liu JS. Technological barriers and research trends in fuel cell technologies: A citation network analysis. *Technol Forecasting Soc Change* 82:66-79, 2014.
88. Dicks AL. Molten carbonate fuel cells. *Curr Opin Solid Sate Mater Sci* 8:379-383, 2004.
89. McPhail S, Moreno A, Bove R. *International Status of Molten Carbonate Fuel Cell (MCGC) Technology.* ENEA. Ente per le Nuovo Technologie, l' Energia e l'Ambiente. Report RSE/2009/181, (www.enea.it).
90. Li Y, Dai H. Recent advances in zinc–air batteries. *Chem Soc Revs* 43:5257-5275, 2014.
91. Sapkota P, Kim H. Zinc–air fuel cell, a potential candidate for alternative energy. *J Industr Engin Chem* 15(4):445-450, 2009.
92. Jiang SP. Nanoscale and nano-structured electrodes of solid oxide fuel cells by infiltration: Advances and challenges. Int J Hydrogen Energy 37(1):449-470, 2012.
93. Zhang X, Chan SH, Ho HK, et al. Towards a smart energy network: The roles of fuel/electrolysis cells and technological perspectives. *Int J Hydrogen Energy* 40(21):6866-6919, 2015.
94. U.S. Department of Energy. *State of the States: Fuel Cells in America*, 2015. 6th edition, Fuel Cell Technologies Office, Dec. 2015. [http://energy.gov/sites/prod/files].
95. Elmer T, Worall M, Wu S, Riffat SB. Fuel cell technology for domestic built environment applications: State of-the-art review. *Renew Sustain Energy* Revs 42:913-931, 2015.
96. Dodds PE, Staffell I, Hawkes AD, et al. Hydrogen and fuel cell technologies for heating: A review. *Int J Hydrogen Ener*gy 40(5):2065-2083, 2015.
97. Mahato N, Baneriee A, Gupta A, et al. Progress in material selection for solid oxide fuel cell technology: A review. *Progr Mater Sci* 72:141-337, 2014.
98. Tang J, Liu J, Torad NL, et al. Tailored design of functional nanoporous carbon materials toward fuel cell applications. *NanoToday* 9(3):305-323, 2014.
99. Oliveira VB, Simoes M, Melo LF, Pinto AMFR. Overview on the developments of microbial fuel cells. *Biochem Engin J* 73:53-64, 2013.
100. Hou J, Liu Z, Zhang P. A new method for fabrication of graphene/ polyaniline nanocomplex modified microbial fuel cell anodes. *J Power Sources* 224:139-144, 2013.
101. Koroneos C, Rovas D. A review on energy comparison of hydrogen production methods from renewable energy sources. *Energy Environ Sci* 5:6640-6651, 2012.
102. Parthasarathy P, Narayanan KS. Hydrogen production from steam gasification of biomass: Influence of process parameters on hydrogen yield – A review. *Renew Energy* 66:570-579, 2014.
103. Dutta S. A review on production, storage of hydrogen and its utilization as an energy resource. *J Industr Engin Chem* 20(4):1148-1156, 2014.

104. U.S. Energy.gov. Office of Energy Efficiency and Renewable Energy. Hydrogen Production Processes [http://energy.gov/eere/fuelcells/hydrogen-production-processes]. (accessed Febr. 2016).
105. National Renewable Energy Laboratory, USA. Hydrogen Production Research [http://www.nrel.gov/hydrogen/proj_production_delivery.html].
106. Gu J, Yan G, Young J, Steirer, et al. Water reduction by a p-GaInP$_2$ photoelectrode stabilized by an amorphous TiO_2 coating and a molecular cobalt catalyst. *Nature Materials* 2015, DOI:10.1038/nmat4511.
107. Dincer I, Acar C. Review and evaluation of hydrogen production methods for better sustainability. *Int J Hydrogen Energy* 34:11094-11111, 2015.
108. Singh L, Wahid ZA. Methods for enhancing bio-hydrogen production from biological process: A review. *J Ind Engin Chem* 21:70-80, 2015.
109. Ye B, Li Q, Iwai H, et al. Hydrogen production using zinc-doped carbon nitride catalyst irradiated with visible light. *Sci Technol Advanc Mater* 12(3), 2011 (online 2016).
110. Naterer GF, Suppiah S, Stolberg L, et al. Progress in thermochemical hydrogen production with the copper–chlorine cycle. *Int J Hydrogen Energy* 40(19):6283-6295, 2015.
111. Garland NL, Papageorgopoulos DC, Stanford JM. Hydrogen and fuel cell technology: Progress, challenges, and future directions. *Energy Procedia* 28:2-11, 2012.
112. Hoffmann P. *Tomorrow's Energy Hydrogen, Fuel Cells, and the Prospects for a Cleaner Planet.* (revised and expanded edition). The MIT Press, Cambridge MA, London, 2012.
113. Hamad YM, Hamad TA, Amer A. A design for hydrogen production and dispensing for northeastern United States, along with its infrastructural development timeline. Review. *Int J Hydrogen Energy* 39(119):9943-9961, 2014.
114. Lee RA, Lavoie J-M. From first- to third-generation biofuels: Challenges of producing a commodity from a biomass of increasing complexity. *Animal Frontiers* 3(2):6-11, 2013.
115. Brennan L, Owende P. Biofuels from Microalgae: Towards Meeting Advanced Fuel Standards. In: Lee JW (Ed). *Advanced Biofuels and Bioproducts.* Springer Science, New York, pp. 553-599, 2013.
116. Mohr A, Raman S. Lessons from first generation biofuels and implications for the sustainability appraisal of second generation biofuels. *Energy Policy* 63:114-122, 2013.
117. Richardson JW, Johnson MD, Lacey R, et al. Harvesting and extraction technology contributions to algae biofuels economic viability. *Algal Res* 5:70-78, 2014.
118. Oilgae. Comprenhensive Oilgae Report. *Energy from Algae: Products, Market, Processes & Strategies*, Jan. 2013, Clixoo, India, www.oilgae.com.
119. Darzins A, Pienkos P, Edye L. *Current Status and Potential for Algal Biofuels Production.* International Energy Agency Bioenergy Task 39. IEA, National Research Energy Laboratory (NREL), August 2010.
120. Biofuels from Algae and other Renewable sources. Biol Fuel Digest. [http://www.genstrom.net/public/biology/trends/biofuels.html].
121. Mousdale DM. *Biofuels: Biotechnology, Chemistry, and Sustainable Development.* CRC Press, Boca Raton, FL, 2008.

122. Lee S, Shah YT. Biofuels and Bioenergy: Processes and Technology. CRC Press, Boca Raton, FL, 2012.
123. Jose S, Bhaskar T. *Biomass and Biofuels: Advanced Biorefineries for Sustainable Production and Distribution*. CRC Press, Boca Raton, FL, 2015.
124. Glassley WE. *Geothermal Energy: Renewable Energy and the Environment*, CRC Press, Boca Raton, FL, 2010.
125. MIT. *The Future of Geothermal Energy. Impacts of Enhanced Geothermal Systems on the US in the 21st Century*. Massachusetts Institute of Technology, Cambridge, MA, 2006 This report on geothermal energy is available on the Internet at: http://geothermal.inel.gov and http://www1.eere.energy.gov/ geothermal/egs_technology.html].
126. U.S. Department of Energy (DOE) Geothermal Technologies Office (GTO). [http://energy.gov/eere/geothermal/about].
127. Environment 360. Will tidal and wave energy ever live up to their potential? 15.10.2015. Report., available at the internet site: [http://e360.yale.edu/feature/will_tidal_and_wave_energy_ever_live_up_to_their_potential/2920/].
128. Renewable UK. The Voice of Wind and Marine Energy. Wave and tidal energy in the UK. Capitalizing on capability. 25/2/2015. Available at . [http://www.renewableuk.com/en/publications/reports.cfm/Wave-and-Tidal-Energy-UK-Capitalising-on-Capability].
129. Magagna D, Uihlein A. Ocean energy development in Europe: Current status and future perspectives. *Int J Marine Energy* 11:84-104, 2015.
130. Uihlein A, Magagna D. Wave and tidal current energy – A review of the current state of research beyond technology. *Renew Sustain Energy Revs* 58:1070-1081, 2016.
131. Space Energy.com. Space-based solar power. From concept to reality… [http://www.spaceenergy.com/SBSP/SBSP_Overview.htm].
132. Acherman E. Institute of Electrical & Electronics Engineers, IEEE Spectrum. Japan demoes wireless power transmission for space-based solar farms. 16.3.2015, [http://spectrum.ieee.org/].
133. Koebler JK. Everything we know about beaming solar power to Earth from Space. Motherboard.vice.com, 17.3.2015. Available at [http://motherboard.vice.com/read/everything-we-know-about-beaming-solar-power-to-earth-from-space].