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A GLOBAL VIEW OF RECENT DEVELOPMENT OF RENEWABLE ENERGY TECHNOLOGIES AND BARRIERS

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Abstract*- Rapid depletion of fossil fuels and stringent emission regulations strongly forced researchers to explore renewable sources of energy. The Intergovernmental Panel on Climate Change has recommended to reduce CO_2 emissions by 50 to 80 percent by 2050. By early 2010, more than 100 countries had some type of policy target and/or promotion policy related to renewable energy. The most relevant renewable energy technologies-wind, solar, biomass, hydro, wave, tidal and geothermal have been overviewed. Wind power and solar PV additions have been found to reach a record high during 2009, and in both Europe and the United States, renewable accounted for over half of newly installed power capacity in 2009. By 2010, renewable energy had reached a clear tipping point in the context of global energy supply. The recent development of "RET" and their shares in the global energy supply have been overviewed in the current study. All the relevant renewable energy technologies along with associated barriers are studied separately.*

Keywords: Fossil fuel, renewable energy, CO2 emissions, RET, barriers

1. INTRODUCTION

Since 1990s, the renewable energy sector has grown strongly and steadily. In 2009, governments stepped up efforts to steer their countries out of recession by transforming industries and creating jobs. By early 2010, more than 100 countries had some type of policy target and/or promotion policy related to renewable energy. For the second year in a row, more money was invested in new renewable energy capacity than in new fossil fuel capacity. Changes in renewable energy technologies and policies have been so rapid in recent years that perceptions of the status of renewable energy can lag years behind the reality. Renewables comprised fully one quarter of global power capacity from all sources and delivered 18 percent of global electricity supply in 2009. Existing renewable power capacity worldwide reached an estimated 1,230 (GW) in 2009, up 7 percent from 2008. When large-scale hydropower is not included, renewables reached a total of 305 GW, a 22-percent increase over 2008. So, advancement in renewable energy technologies is vivid in the recent years. The objective of this paper is to present the technological perspective of recent renewable energy technologies along with their barriers.

2. RECENT WIND TURBINE TECHNOLOGY

At the end of 2009, worldwide nameplate capacity of wind-powered generators was 159.2 gigawatts (GW)[1]. Energy production was 340 TWh, which is about 2% of worldwide electricity usage [1][2] and has doubled in the past three years. Several countries have achieved relatively high levels of wind power penetration (with large governmental subsidies), such as 20% of stationary electricity production in Denmark, 14% in Ireland[3] and Portugal, 11% in Spain, and 8% in Germany in 2009[4]. This technology has been advanced very past in recent years as depicted in Fig.1

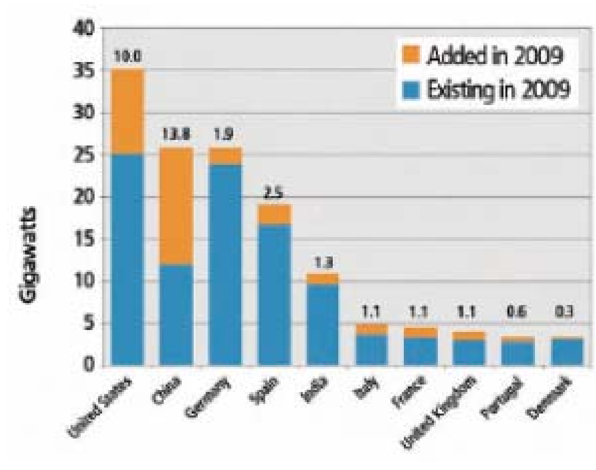

Fig.1 Wind Power capacity, top 10, 2009.

2.1 Larger Diameters Turbines

Figure 2 shows trends by year of the typical largest turbine sizes. The Enercon E-126 is the largest turbine model built to date, manufactured by the German wind turbine producer Enercon with a hub height of 135 m (443 ft), rotor diameter of 126 m (413 ft) a total height of

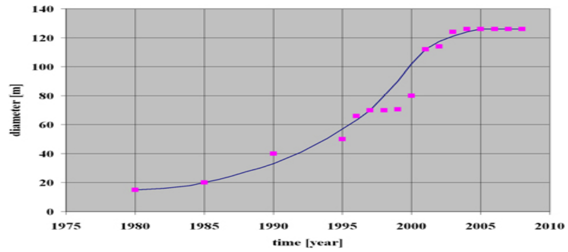

Fig. 2: Largest turbine sizes by year

198 m(650 ft). The nameplate capacity was changed from 6 MW to 7 MW after technical revisions were performed in 2009[5]. Enercon now aims to further increase this capacity to 7.5 MW, according to the *Enercon Magazine* [6]. The first turbine of this model was installed in Emden, Germany in 2007[7]. The biggest wind farm using this model of turbines has been constructed in Estinnes, Belgium [8][9].

2.2 Pitch Control replaces Stall Control

Pitch control unlike stall control involves turning the wind turbine blades about their long axis (pitching the blades) to regulate the power extracted by the rotor. In contrast to stall regulation, pitch regulation requires changes of rotor geometry by pitching the blades. There are now about four times as many pitch-regulated turbine designs on the market as stall-regulated versions. Overall costs are quite similar for each design type, but pitch regulation offers potentially better output power quality.

2. 3 Variable Speed Takes Up Fixed Speed

Recently variable speed operation of the wind turbine is being introduced. This allows the rotor and wind speed to be matched, and the rotor could thereby maintain the best flow geometry for maximum efficiency. Several observations show that operation at variable speed offers the possibility of increased ‘grid friendliness,’ load reduction and some minor energy benefits. Wind turbines of more than 1 MW scale have been found mostly to use variable speed system.

2.4 Direct Drive Overtakes Gearbox System

The motivation for direct drive is to simplify the nacelle systems, increase reliability, increase efficiency and avoid gearbox issues. E-126 is a burning example of direct drive wind turbine recently installed. In July 2008, Siemens installed the first of two new 3.6 MW direct drive turbines to assess whether direct drive technology is competitive with geared machines for large turbines. The two turbines, which have rotor diameters of 107m, use a synchronous generator and permanent magnets.

2.5 Innovative system concepts

An airborne wind turbine has been found as a design conception for a wind turbine that is supported in the air without a tower. Airborne wind turbines may operate in low or high altitudes as shown in Fig.2. Airborne turbine systems would have the advantage of tapping an almost constant wind, without requirements for slip rings or yaw mechanism, and without the expense of tower construction. As of 2008, no commercial airborne wind turbine has been found in regular operation.

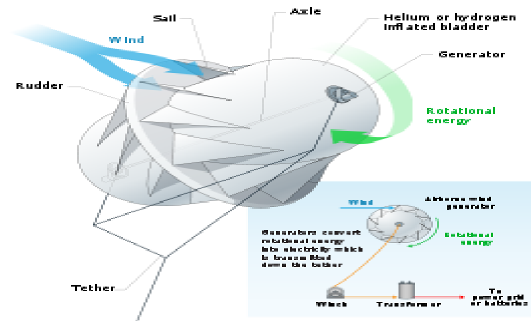

Fig.3. Airborne wind generator

Another innovative and attractive wind turbine concept is Maglev wind turbine. It is an innovative vertical axis turbine concept. Construction began on a large production site for Maglev wind turbines in central China, in November 2007[10]. According to a press release, Zhongke Hengyuan Energy Technology has invested 400 million Yuan in building this facility, which will produce Maglev wind turbines with capacities ranging from 400 to 5,000 kW. Using magnetic levitation, the blades of the turbine are suspended on an air cushion, and the energy extracted by linear generators with minimal friction losses. The major advantage of Maglev has been claimed to be that it reduces maintenance costs, and increases the lifespan of the generator.

2. SOLAR TECHNOLOGIES

Solar industry has been responding to price declines and rapidly changing market conditions by consolidating, scaling up, and moving into project development in the recent years. Thin-film PV has also experienced a rapidly growing market share in recent years. A growing of number of solar PV plants are so-called “utility scale” plants 200-kW and larger, which now account for one-quarter of total grid-connected solar PV capacity. Figure 2 depicts the cumulative PV installation by locations.

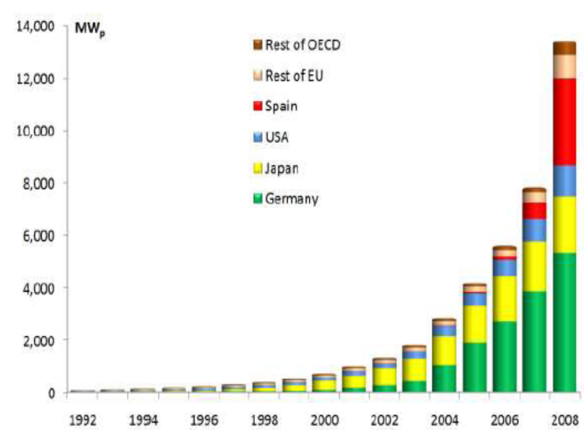

Fig.4: Cumulative PV installation by location (source: IEA-PVPS, 2009)

2.1 Organic Polymer Photovoltaic Solar Cell

Organic solar cell research has attracted scientific and economic interest triggered by a rapid increase in power conversion efficiencies in the last decade. Though efficiencies of these thin-film organic devices have not yet reached those of their inorganic counterparts (≈10–20%); the perspective of cheap production (employing, e.g., roll-to-roll processes) drives the development of organic photovoltaic devices further in a dynamic way. Low cost, environmentally friendly production methods; light weight, flexible substrates will allow the organic polymer photovoltaic solar cell a marked change in how and where energy can be generated.

2.2 Multi-junction PV cell

Multi-junction (MJ) solar cells are the most efficient photovoltaic devices with 32% conversion efficiencies at 1-sun and above 37% under concentrated sunlight [11].When combined with high concentration, MJ cell modules have the potential of producing the lowest $/watt amongst solar technologies [12].

2.3 Concentrating PV System:

Concentrating photovoltaic systems use lenses or mirrors to concentrate sunlight onto high-efficiency solar cells. The concentration decreases the required cell area while also increasing the cell efficiency. “High Concentration Photovoltaic," represents the highest efficiencies available in solar PV technologies. While many of today solar PV panels are considered "efficient" at 15%, HCPV technology is already at 40% efficiency.

2.4 Dye-Sensitized Solar Cell Technology

A dye-sensitized solar cell (DSSC, DSC or DYSC) is a class of low-cost solar cell belonging to the group of thin film solar cells. It is based on a semiconductor formed between a photo-sensitized anode and an electrolyte; a photo electrochemical system. These effects produce an upper limit on the efficiency of silicon solar cells, currently around 12 to 15% for common examples and up to 25% for the best laboratory modules. Overall peak power production efficiency for current DSSCs is about 11%.[13][14] DSSCs are currently the most efficient third-generation[15]. Other thin-film technologies are typically between 5% and 13%, and traditional low-cost commercial silicon panels operate between 12% and 15%. This makes DSSCs attractive as a replacement for existing technologies.

2.5 Spectral Beam Splitting Technology

A recent study shows solar concentrating systems that employ one or more quantum receivers may realize improved energy utilization and higher electric conversion efficiency by incorporating spectral beam splitting technology [16]. Such techniques were investigated in thermo- photovoltaic conversion, and in concentrating PV devices using cells of different band-gap materials. One major application was found in systems combining quantum and thermal receivers.

2.6 Solar Power Tower

In a solar tower, as shown in Fig.5, thousands of computer monitored mirrors direct the sun’s energy to a boiler mounted on top of tower. The concentrated sunlight converts water in the boiler into steam of around 1000^{o}F. The steam is then used to power a generator to produce electricity.

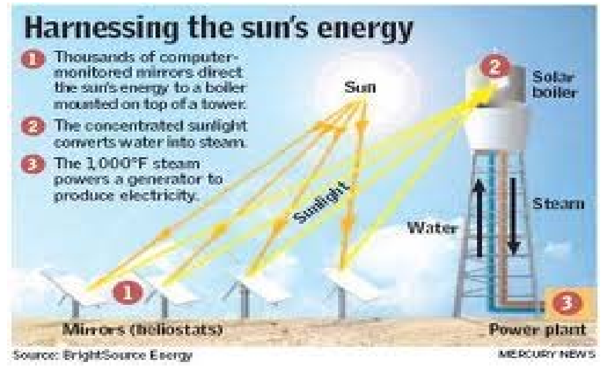

Fig.5 Solar Tower

3. BIOMASS TECHNOLOGY

Biomass power plants exist in over 50 countries around the world and supply a growing share of electricity. Several European countries are expanding their total share of power from biomass, including Austria (7 percent), Finland (20 percent), and Germany (5 percent). Biogas for power generation is also a growing trend in several countries.

3.1 Fischer–Tropsch process

The Fischer–Tropsch process (or Fischer–Tropsch Synthesis) is a set of chemical reactions that convert a mixture of carbon monoxide and hydrogen into liquid hydrocarbons. Ongoing research aims to combine biomass gasification (BG) and Fischer-Tropsch (FT) synthesis to produce renewable transportation fuels (bio-fuels).[17]. Production of ethanol from lignocelluloses has been found to be quite advantageous in the recent years. According to U.S. Department of Energy studies[18] conducted by Argonne National Laboratory of the University of Chicago, one of the benefits of cellulosic ethanol is that it reduces greenhouse gas emissions (GHG) by 85% over reformulated gasoline.

3.2 Steam Injected Gas Turbine (SIGT)

A thermodynamic analysis, in a recent study, considering both the first and the second laws of thermodynamics has been made on a 53 MW (net) biogas-fired integrated gasification steam injected gas turbine (BIG/STIG) plant. The energy utilization diagrams (EUDs) for the plant and for the reaction subsystems have also been considered, revealing both problems and potentials for improvement. The analysis indicates a thermal efficiency of about 41% (power based) and 45% (power and recovered heat based) but that the energy loss in the combustion chamber is largest at about 79% of the total system energy loss [19].

3.3 Biomass Fuel Cell

Renewable biomass resources include starch, cellulose, sucrose, and lactose. These complex sugar molecules can be readily converted to the much simpler glucose molecule with little energy cost through fermentation processes. The glucose could then be used to release hydrogen using enzymes. Hydrogen can be burned either to provide heat, or to drive turbines, or in internal combustion engines for motive and electrical power. Many of these technologies need improvements in materials and processes to improve efficiency and durability.

4. GEOTHERMAL TECHNOLOGY

The International Geothermal Association (IGA) has reported that 10,715 megawatts (MW) of geothermal power in 24 countries is online, which is expected to generate 67,246 GWh of electricity in 2010[20]. This represents a 20% increase in geothermal power online capacity since 2005. In 2010, the United States led the world in geothermal electricity production with 3,086 MW of installed capacity from 77 power plants;[21] the largest group of geothermal power plants in the world is located at The Geysers, a geothermal field in California.[21]. The Philippines follows the US as the second highest producer of geothermal power in the world, with 1,904 MW of capacity online. The development of binary cycle power plants and improvements in drilling and extraction technology may enable enhanced geothermal systems over a much greater geographical range. A 3-Megawatt industrial project has been completed in 2007 in Landau-Pfalz, [22] Germany, and a demonstration project in Soultz-sous-Forêts,[23] France. An earlier effort in Basel, Switzerland was shut down after it triggered earthquakes. Other demonstration projects are under construction in Australia, (Cooper Basin,) the United Kingdom, and the United States of America.[24].

4.1 Binary Cycle Power Plants

Binary cycle power plants are the most recent development, and can accept fluid temperatures as low as 57°C [25]. The moderately hot geothermal water is passed by a secondary fluid with a much lower boiling point than water. This causes the secondary fluid to flash to vapor, which then drives the turbines. This is the most common type of geothermal electricity plant being built today. [26]

4.2 Enhanced Geothermal System

An approach to capturing the heat in dry areas beneath the earth surface is known as enhanced geothermal systems (EGS) or "hot dry rock" as shown in Fig.6. The Department of Energy, several universities, the geothermal industry, and venture capital firms are collaborating on research and demonstration projects to harness the potential of hot dry rock. Australia, France, Germany, and Japan also have R&D programs to make EGS commercially viable. The DOE hopes to have EGS ready for commercial development by 2015 and is currently funding several demonstration projects.

5. TIDAL TECHNOLOGY

A relatively new technology, tidal stream generators draw energy from currents in much the same way as wind turbines. SeaGen is the world's first large scale commercial tidal stream generator [27][28][29]

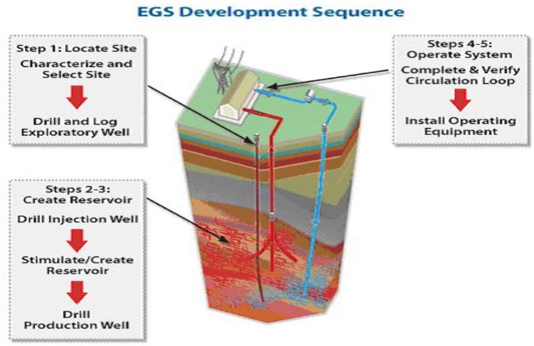

Fig.6: Enhanced geothermal system

It is four times more powerful than any other tidal stream generator in the world [30]. The first SeaGen generator was installed in Strangford Narrows between Strangford and Portaferry in Northern Ireland in April 2008 and was connected to the grid in July 2008[31]. It generates 1.2 MW for between 18 and 20 hours a day while the tides are forced in and out of Strangford Lough through the Narrows [32].

6. WAVE TECHNOLOGY

Wave power generation is not currently a widely employed commercial technology although there have been attempts at using it since at least 1890[33]. In 2008, the first commercial wave farm was opened in Portugal, at the Aguçadoura Wave Park [34]. Several technologies are being come into operations in the recent time to harness the wave energy. These include: point absorber, attenuator, terminator, oscillating water column (OWC) etc. Among these, point absorber and attenuator have been found to be utilized most widely. Point absorbers aren't oriented a particular way toward the waves, but rather can "absorb" the energy from waves that come from every which way. Attenuator devices are oriented parallel to the direction of the wave. One of the most well-known examples of this is the Pelamis Wave Energy Converter which is a semi-submerged, articulated structure composed of cylindrical sections linked by hinged joints. The wave-induced motion of these joints is resisted by hydraulic rams, which pump high-pressure fluid through hydraulic motors via smoothing accumulators. The hydraulic motors drive electrical generators to produce electricity.

7. SUMMARY

The global renewable energy development can be summarized by the following diagrams:

• Global renewable electricity installations (excluding hydropower) have more than tripled from 2000–2009 as evidenced from Fig.8

Including hydropower, renewable energy accounts for 21% of all global electricity generation; without hydropower, renewable energy accounts for 3.8% of global generation. (Table 1)

•Wind is the fastest growing renewable energy technologies worldwide. (Fig.7)

• In 2009, Germany led the world in cumulative solar PV installed capacity. The United States leads the world in wind, geothermal, biomass, and CSP installed capacity.

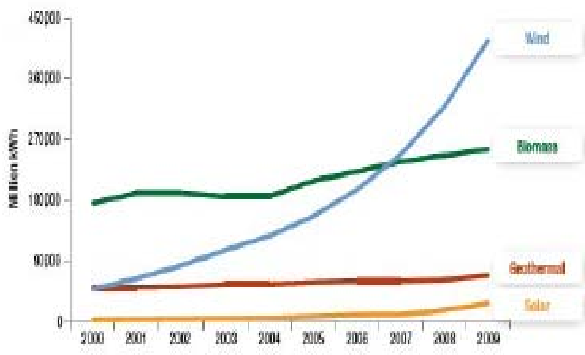

Fig.7 Global renewable electricity generation (source: REN21, GWEC, GEA, SEIA, EIA)

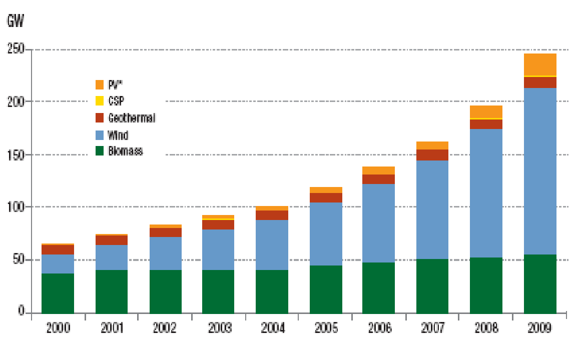

Fig.8 Global Renewable (excluding hydropoer) Electricity Generating Capacity(sources: REN21, GWEC, GEA, SEIA, EIA)

Table 1: RE Generation as a Percent of Total Generation (sources: REN21, GWEC, GEA, SEIA, EIA)

	Hydro	Solar PV	Biomass	Wind	Geothermal	All Renewables	Renewables without Hydropower	Renewable Generation without Hydropower (million kWh)
2000	16.8%	0.0%	1.2%	0.3%	0.3%	18.7%	1.9%	274,019
2001	17.3%	0.0%	1.3%	0.4%	0.3%	19.3%	2.1%	304,469
2002	17.1%	0.0%	1.2%	0.5%	0.3%	19.2%	2.1%	324,827
2003	18.0%	0.0%	1.2%	0.7%	0.3%	20.2%	2.2%	348,777
2004	17.3%	0.0%	1.1%	0.8%	0.3%	19.5%	2.2%	371,028
2005	16.9%	0.0%	1.2%	0.9%	0.3%	19.4%	2.5%	427,880
2006	16.7%	0.1%	1.2%	1.1%	0.3%	19.4%	2.7%	485,477
2007	17.4%	0.1%	1.3%	1.3%	0.3%	20.4%	2.9%	552,703
2008	17.4%	0.1%	1.3%	1.6%	0.3%	20.7%	3.3%	642,327
2009	17.4%	0.1%	1.3%	2.1%	0.3%	21.2%	3.8%	766,333

Table 2: Top Countries with Installed RE (2009) (Source: REN21, GWEC, GEA, SEIA)

Country ↓	Source →			
Geothermal	Wind	Solar PV	CSP	Biomass
U.S.	U.S	Germany	U.S	U.S.
Philippines	Germany	Spain	Italy	Brazil
Indonesia	Italy	Japan		Germany
Mexico	Spain	U.S.		Chaina
Italy	India	Italy		Sweden

7. BARRIERS AND CHALLENGES

Wind: The intermittency of wind creates problems when using wind power to supply a high proportion of total demand, such as increased costs, the need to upgrade the grid, and a lowered ability to supplant conventional production. Besides, variable speed wind turbine has some attractions, but also brings cost and reliability concerns. Wind speed and energy prediction are still a critical part of the development of a wind farm.

Solar: Despite solar energy technology is one of the fast growing renewable energy technologies; its cost and efficiency are still in question. One disadvantage of solar power is consistency and reliability. Storage technology, such as batteries, or an alternative source of energy is always required to ensure uninterrupted power flow. The major disadvantage to the DSSC design is the use of the liquid electrolyte, which has temperature stability problems. At low temperatures the electrolyte can freeze, ending power production and potentially leading to physical damage. Higher temperatures cause the liquid to expand, making sealing the panels a serious problem.

Biomass: Research and development work is leading to reduced production costs, higher energy conversion efficiency and greater cost-effectiveness of bio-energy. Electrochemical energy conversion like in fuel cell involves complex developments of materials due to the close link between electricity flow and corrosion processes, morphological changes.

Geothermal: The capital costs of geothermal technology tend to be high. Drilling accounts for over half the costs, and exploration of deep resources entails significant risks. A typical well doublet in Nevada can support 4.5 megawatt (MW) of electricity generation and costs about \$10 million to drill, with a 20% failure rate. Enhanced geothermal systems tend to be on the high side of these ranges, with capital costs above \$4 million per MW and levelized costs above \$0.054 per kW·h in 2007.

Tidal: Tidal stream generator technology is still an immature technology. Dynamic tidal power severely suffers from the demonstration point of view. A major challenge is that a demonstration project would yield almost no power, even at a dam length of 1 km or so.

Wave: Despite various techniques are being deployed to harness the wave energy but still no single method achieves high-efficiency energy conversion. One of the design dilemmas with wave energy is that wave frequency is too low to run turbines very effectively. On the other hand, sometimes waves and weather are by far harsh for wave energy devices to withstand.

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9. NOMENCLATURE

Symbol	Meaning	Unit
GW	Unit of poewer	(Watt)
TWh	Pressure	(Pa)
MW	Unit of power	(Watt)
PMG	Permanent Magnet Generator	-
GHG	Green House Gas	-
DSSC	Die-sensitized Solar cell	-
EGS	Enhanced Geothermal system	-