FACT SHEET

Green technology

Key points

- ***Encouraging the diffusion of green technology requires a combination of voluntary approaches, government incentives and a comprehensive regulatory framework.***
- ***Policy signals stimulate private investments in R&D.***
- ***Least developed countries and small island developing states need special measures and support to promote green technologies.***

Green technology explained

There is no commonly accepted or internationally agreed definition of green technology. The term can be broadly defined as technology that has the potential to significantly improve environmental performance relative to other technology. It is related to the term "environmentally sound technology", which was adopted under the United Nations Conference on Environment and Development Agenda 21, although it is no longer widely used. Based on Agenda 21, environmentally sound technologies are geared to "protect the environment, are less polluting, use all resources in a more sustainable manner, recycle more of their wastes and products, and handle residual wastes in a more acceptable manner than the technologies for which they were substituted."[1] Other related terms for green technology include: climate-smart, climate-friendly and low-carbon technology.

How it works

In terms of pollution, green technology includes both process and product technologies that generate low or no waste and increase resource- and energy-efficiency. They also cover "end-of-the-pipe" technologies for treating pollution. Green technology does not only mean individual technologies but also systems, including know-how, procedures, goods and services and equipment, as well as organizational and managerial procedures.

Categories of green technology

Green technology covers a broad area of production and consumption technologies. The adoption and use of green technologies involves the use of environmental technologies for monitoring and assessment, pollution prevention and control, and remediation and restoration. Monitoring and assessment technologies are used to measure and track the condition of the environment, including the release of natural or anthropogenic materials of a harmful nature. Prevention technologies avoid the production of environmentally hazardous substances or alter human activities in ways that minimize damage to the environment; it encompasses product substitution or the redesign of an entire production process rather than using new pieces of equipment. Control technologies render hazardous substances harmless before they enter the environment. Remediation and restoration technologies embody methods designed to improve the condition of ecosystems, degraded through naturally induced or anthropogenic effects.[2]

[1] United Nations Department of Economic and Social Affairs, *Earth Summit Agenda 21: The United Nations Programme of Action from Rio* (Rio de Janeiro, 1992). Available from www.un.org/esa/dsd/agenda21 (accessed 31 January 2012).

[2] United Nations Environment Programme, *Environmentally Sound Technologies for Sustainable Development*, Revised Draft (Osaka, Division of Technology, Industry and Economics, 2003). Available from www.unep.or.jp/ietc/techtran/focus/sustdev_est_background.pdf (accessed 05 March 2012).

Sectors of green technology

- Agriculture
    - Organic agriculture
- Energy
    - Renewable energy technology
    - Efficiency technology
- Water and waste management
    - Recycling technology
    - Sewage treatment and solid waste management
    - Water purification
- Building
    - Sustainable building material
    - Building performance technology
- Transportation
    - Rail transport
    - Electric vehicle

Country experience: Green technology policy in Malaysia

In Malaysia, green technology has been recognized as a driver for future economic growth, energy security, climate change mitigation and adaptation. In April 2009, the Malaysian prime minister proclaimed his vision of a Green Malaysia and demonstrated his commitment to climate change mitigation and energy security by escalating the advancement of green technology through the creation of the Ministry of Energy, Green Technology and Water. The prime minister further enunciated his vision by developing Putrajaya and Cyberjava as pioneer townships in green technology that were to become a showcase for the development of other townships across the country.

The national green technology policy was developed in cooperation with all relevant parties to strengthen the institutional frameworks and policy coherence. The policy was designed to generate benefits in four areas: energy, environment, economy and social conditions. Progress will be monitored by a variety of indicators. Green technologies are to be developed in four core sectors: energy, buildings, water and waste management, and transport. Additionally, work is underway to develop a green technology roadmap for Malaysia.

Policies to strengthen institutional frameworks include: the formation of a Green Technology Council and a Cabinet Committee on Green Technology for high-level policy coordination among ministries, chaired by the prime minister; the establishment of a Malaysia Green Technology Agency to coordinate and oversee initiatives and programmes; a review of legal mechanisms and the creation of new legislation that is in line with national goals; and a revision of institutional clarity so that all agencies are aware of their roles and responsibilities.

Policies to encourage the growth of green technology sectors include: support for higher-learning and research institutions for R&D; increased foreign and domestic investment; establishment of a Green Technology Fund; feed-in tariffs legislation to support renewable energy in power generation; and the recognition of green products through standards, ratings and labelling programmes. Various industry programmes inform SMEs about new green technologies, strategic green technology hubs throughout the country, and funding mechanisms.

Other fiscal incentives for renewable energy include: "pioneer status", which provides exemptions from income tax (25 per cent from 2009 onwards) on 100 per cent of statutory incomes for ten years[3]; investment tax allowances on qualifying capital expenditure incurred within five years of the first expenditure; and import duty and sales tax exemptions for one year on imported machinery, equipment, materials, space parts and consumables that are used for renewable energy by both importers and third-party distributors.

[3] Kementerian Tenaga Teknologi Hijau Dan Air, *Incentive for Energy Efficiency and Renewable Energy in Malaysia* (Putrajaya, 2009). Available from http://seda.gov.my/pdf/PTM%20Incentives.pdf (accessed 31 January 2012).

Policies to improve human resource capacity include: several policies centre on training and education, such as financial and fiscal incentives for students pursuing studies in green technology disciplines at both the undergraduate and graduate levels; retraining and apprenticeship schemes for green jobs; a grading and certification mechanism for green technology-related skills; and brain gain programmes to strengthen local expertise.

Source: Kementerian Tenaga Teknologi Hijau Dan Air, "The national green technology policy", PowerPoint presentation (2010). Available from http://portal.ppj.gov.my/c/document_library/get_file?p_l_id=17335&folderId=27605&name=DLFE-4709.pdf (accessed 06 March 2012).

Box 1: Recent developments in eco-design in Europe

Eco-design, which is often referred to as cradle-to-cradle design (C2C), is a policy tool aimed at improving the environmental performance of products throughout their lifecycle by introducing specific requirements in their design stage. Eco-design can take a variety of forms, such as guidelines, checklists, indicators and life-cycle assessment. While eco-labelling helps to disclose information on the products in order to assist consumers in making informed decisions, eco-design, in contrast, directly influences the way the product is designed, manufactured, packaged, transported, used and disposed. Eco-design can play a critical role in greening markets by singling out inefficient products and pulling them out of the market.

In the European Union, concerted efforts are being made to establish and update eco-design through the Ecodesign Directive. The Ecodesign Directive sets minimum energy efficiency requirements and other environmental standards for 32 indicative product groups, including electronic appliances and office lighting, based on a life-cycle approach.[4] The implementing measures vary depending on the respective product groups. Nine new broad product groups may be added for the period 2012 to 2014, depending on their energy saving potential and market volume. These groups under consideration include windows, steam boilers (less than 50MW), power cables, enterprises servers, storage and ancillary equipment, and smart appliances/meters. According to the working plan, these priority product groups are estimated to achieve energy savings of 1,157 TWh per year by 2030.

Source: European Commission, *Communication from the Commission to the Council and the European Parliament: Establishment of the Working Plan for 2012-2014 under the Ecodesign Directive*, Draft (Brussels, 2012). Available from www.ebpg.bam.de/de/ebpg_medien/wp2_2011-12_wd_kom.pdf (accessed 06 March 2012).

Strengths from adopting green technology[5]

- **Ability to meet strict product specifications in foreign markets:** Manufacturers in developing countries typically need to meet stricter environmental requirements and specifications to export their products to industrialized countries than vice versa. The adoption of green technologies can help exporting companies to gain advantage and market share over competitors.

- **Reduction of input costs:** Green technology can improve production efficiency through the reduction of input costs, energy costs and operating and maintenance costs, which can improve a company's competitive position.

- **Environmental image:** Adopting green technology can improve a company's environmental reputation, which is crucial if other competitors and consumers are becoming more environmentally conscious.

[4] INFORSE-Europe website "ECO-Design for Energy Efficiency: Framework Directive with Implementation Measures" (July 2010). Available from www.inforse.dk/europe/eu_ecodesign.htm (accessed 16 January 2012).

[5] R. Luken and F. Van Rompaey, "Drivers for any barriers to environmentally sound technology adoption by manufacturing plants in nine developing countries", *Journal of Cleaner Production* (2008), vol.16, No.1, pp. 67-77.

- **Ability to meet stricter environmental regulations in the future:** Companies that invest in green technology are more likely to be better equipped and ready for stricter environmental regulations as well as product specifications that are expected to be imposed on them in the future.

Box 2: Transfer of green technologies

Technology transfer is not a passive, one-way process. To entice the transfer of green technologies from industrialized economies to the developing world, both supply and demand factors must be considered. On the supply side, investors and businesspeople who participate in the transfer of technology seek an enabling environment in recipient developing countries, specifically the capacity and infrastructure to support production and management and the regulations that encourage further development of green technology. On the demand side, there must be local demand (pull factors) in order for green technologies to be successfully absorbed.

If developing countries want to embrace sustainable strategies for green growth, they must nurture the transfer of green technologies by building technical capacity and by creating an institutional framework that enables them to absorb, adapt and improve the transferred components and systems.

Currently, most of the green technology transfer is happening in the biggest emerging economies, such as China, Brazil and India. But it is not entirely unidirectional. It also takes place between, within and across industrialized and developing countries in many ways. The most frequent transfer path is the straightforward buying and selling. Additionally, there are also in-licensing and out-licensing agreements regarding potential technologies and associated know-how and the creation of more sophisticated platforms aimed at developing, transferring and using technology, such as joint ventures, strategic alliances and R&D services. Another transfer path is the acquisition of knowledge of different technologies through specialized programmes, technical assistance, training and education.

Source: World Intellectual Property Organization, *World Intellectual Property Report 2011: The Changing Face of Innovation* (Geneva, 2011). Available from www.wipo.int/freepublications/en/intproperty/944/wipo_pub_944_2011.pdf (accessed 05 March 2012).

Challenges to green technology adoption

Generally, green technology is more expensive than the technology it aims to replace, because it accounts for the environmental costs that are externalized in many conventional production processes. Because it is relatively new, the associated development and training costs can make it even more costly in comparison with established technologies. The perceived benefits are also dependant on other factors such as supporting infrastructure, technology readiness, human resources capabilities and geographic elements. Hence, what could be a feasible green technology in one country or region may not be in another.

Adoption and circulation of these technologies can be constrained by a number of other barriers. Some may be institutional, such as the lack of an appropriate regulatory framework; others may be technological, financial, political, cultural or legal in nature.

From a company's perspective, the following are likely barriers to adopting green technologies:[6]

- High implementing costs
- Lack of information
- No known alternative chemical or raw material inputs
- No known alternative process technology
- Uncertainty about performance impacts
- Lack of human resources and skills.

[3] R. Luken and F. Van Rompaey, "Drivers for any barriers to environmentally sound technology adoption by manufacturing plants in nine developing countries", *Journal of Cleaner Production* (2008), vol.16, No.1, pp. 67-77.

Overcoming these barriers is a complex process because it can involve a large number of parties, ranging from government, private sector, and NGOs to financial, research and educational institutions. Promoting green growth requires identifying and removing these barriers that hinder the large-scale dissemination of clean technology to developing countries, especially to those countries with special needs, such as least developed countries and small island developing states.[7] Table 1 highlights motivating and influencing factors for adopting new technologies from the viewpoint of various parties.

Table 1: Motivation and influence for technology adoption

Stakeholders	Motivations	Areas of influence
Governments • National/federal • Regional/state/provincial • Local/municipal	• Development goals • Environmental goals • Competitive advantage • Security	• Taxation • Import/export • Innovation policies • Education and capacity-building • Regulatory programmes • Institutional development • Credit and investment
Private sector business • Transnational • National • Local/micro-enterprise (including producers and users)	• Profits • Return on investment • Market share • Competitive advantage	• Capital investment • Technology R&D/commercializing • Marketing • Skills/capabilities development • Acquisition of information • Technology transfer • Technology transfer pathways • Lending/credit policies(producers, financiers) • Technology selection (distributors, users)
International development institutions • Multilateral banks • Bilateral aid agencies • Other agencies (Global Environment Facility, World Trade Organization, United Nations, OECD)	• Basic and applied knowledge • Research • Teaching • Knowledge transfer • Perceived credibility	• Research and development • Technology commercializing • Technology transfer • Technology transfer pathways
Media/public groups • TV, radio, newspapers • Schools • Community groups • NGOs	• Information dissemination • Education • Awareness • Informed decisions • Collective welfare	• Promotion and advertising • Educational programmes • Community programmes • Lobbying for resources • Information dissemination
Individual consumers • Urban • Rural	• Survival • Quality of life • Information • Affordable solutions	• Purchase decisions • Information selection • Learning pathways • Application of knowledge

[7] United Nations Economic and Social Commission for Asia and the Pacific, *Financing an Inclusive and Green Future: A Supportive Financial System and Green Growth for Achieving the Millennium Development Goals in Asia and the Pacific* (Bangkok, 2010). Available from www.unescap.org/publications/detail.asp?id=1393 (accessed 31 January 2012).

Source: United Nations Environment Programme, *Environmentally Sound Technologies for Sustainable Development* (Osaka, Division of Technology, Industry and Economics, 2003). Available from www.unep.or.jp/ietc/techtran/focus/sustdev_est_background.pdf (accessed 6 March 2012).

Until fossil energy resources and GHG emissions are priced appropriately, marked by the point when distorting subsidies are removed and externalities are internalized, government policies will need to support R&D and the adoption of certain green technologies. Four policy measures that have proven successful in the Asia-Pacific region are: i) renewable energy targets and portfolio standards; ii) renewable energy certificates; iii) feed-in tariffs; and iv) green public procurement.[8]

Green technology – agriculture

Agriculture accounts for about 13–15 per cent of global greenhouse gas emissions.[9] Having a share in global GDP of only about 4 per cent, it is very greenhouse-gas intensive. Under a business-as-usual scenario, agricultural greenhouse gas emissions are predicted to rise by almost 40 per cent by 2030. Climate change could reduce total agriculture production in many developing countries by up to 50 per cent in the next few decades. At the same time, the population of the world is projected to nearly double, potentially creating tensions between food supply and demand.[10]

Green growth in agriculture is achieved through a shift to practices that take into account the regional environmental capacity, by promoting low-carbon production and carbon sequestration capacities. What is needed is a low-carbon life cycle, not only in terms of production but also encompassing distribution, processing and consumption.

Agriculture that pursues green growth can be characterized as green agriculture – although the term is not widely used. There are several green concept terms more commonly used in reference to agriculture. Sustainable agriculture is one such term. It integrates the three goals of sustainable development: environmental protection, economic profitability and social equity. Sustainable agriculture covers organic farming, low external-input agriculture, agro-ecological and bio-dynamic production systems, integrated livestock and crop farming systems and conservation tillage.

Organic agriculture

Organic agriculture, according to the Codex Alimentarius Commission, is "a holistic production management system that avoids use of synthetic fertilizer, pesticides and genetically modified organisms, minimizes pollution of air, soil and water and optimizes the health and productivity of interdependent communities of plants, animals and people."[11]

Box 3: Codex Alimentarius Commission

The Codex Alimentarius Commission, working under the Joint FAO/WHO Food Standards Programme, develops food standards, guidelines and codes of practice since its foundation in 1963 by FAO and WHO. The programme aims to protect the consumer health, promote fair trade practices and facilitate the coordination of all food standards work undertaken by international government and non-government organizations.

Source: World Health Organization and Food and Agriculture Organization, *Understanding the Codex Alimentarius*, third edition (Rome, 2006). Available from ftp://ftp.fao.org/codex/Publications/understanding/Understanding_EN.pdf (accessed 06 March 2012).

[8] Jeffrey Crawford, *Promoting Trade and Investment in Climate-Smart Goods, Services and Technologies in Asia and the Pacific* (Bangkok, UNESCAP, 2011).

[9] Ulrich Hoffmann, *Assuring Food Security in Developing Countries under the Challenges of Climate Change: Key Trade and Development Issues of a Fundamental Transformation of Agriculture* (Geneva, United Nations Conference on Trade and Development, 2011). Available from www.unctad.org/en/docs/osgdp20111_en.pdf (accessed 31 January 2012).

[10] ibid.

[11] Nadia El-Hage Scialabba and Maria Müller-Lindenlauf, "Organic agriculture and climate change", *Renewable Agriculture and Food Systems* (2010), vol. 25, No. 2, pp. 158-169. Available from www.redagres.org/Organic-agric.pdf (accessed 05 March 2012).

Organic agriculture consists of practices that increase resource efficiency by optimizing nutrient and energy flow while minimizing human health risks and environmental impact includes:

- Crop rotations
- Crop diversity
- Integrated livestock production
- Organic fertilizer
- Biological pest control.

Organic and biodynamic farming systems possess soils of higher biological, physical and, in many cases, chemical quality than that of conventional practices. When social and environmental costs are accounted for, the organic alternative can also be economically competitive. The market for global organic food and beverage is currently estimated at around US$51 billion and expected to reach US$104.5 billion by 2015.[12] Governments can support organic and sustainable agriculture by consolidating organic standards and setting up certification and regulatory mechanisms, technology packages and market networks.

Table 2: Environmental benefits and adaptation potential of organic agriculture

Objectives	Means	Impacts
• Alternative to industrial production inputs (mineral fertilizers and agro chemicals) to decrease pollution • *In situ* conservation and development of agro-biodiversity • Landscaping • Soil fertility	• Improvement of natural resources processes and environmental services (soil formation, predation) • Farm diversification (polycropping, agroforestry and integrated crop/livestock) and use of local varieties and breeds • Creation of micro-habitats (hedges), permanent vegetative cover and wildlife corridors • Nutrient management (rotations, corralling, cover crops and manuring)	• Reliance on local resources and independence from volatile prices of agriculture inputs (mineral fertilizers) that accompany fossil fuel hikes • Risk splitting (pests and diseases), enhanced use of nutrient and energy flows, resilience to climate variability and savings on capital-intensive seeds and breeds • Enhanced ecosystem balance (pest prevention), protection of wild biodiversity and better resistance to wind and heat waves • Increased yields, enhanced soil water retention/drainage (better response to droughts and floods), decreased irrigation needs and avoided land degradation

Source: Nadia El-Hage Scialabba and Maria Müller-Lindenlauf, "Organic agriculture and climate change", *Renewable Agriculture and Food Systems* (2010), vol. 25, No. 2, pp. 158-169. Available from www.redagres.org/Organic-agric.pdf (accessed 06 March 2012).

[12] *PRNewswire*, "MarketsandMarkets: Global Organic Food and Beverages Market Worth $104.50 Billion By 2015", February 24, 2011. Available from www.prnewswire.com/news-releases/marketsandmarkets-global-organic-food-and-beverages-market-worth--10450-billion-by-2015-116804058.html (accessed 31 January 2010).

Box 4: Climate-smart agriculture

FAO and the COP16 in 2010 have both recognized the future dilemma of feeding a climate-change ridden world whose population is ever-increasing. Thus, they emphasized the need to transform the agricultural sector from being part of the problem to being part of the solution, by making it 'climate smart'. Climate smart means agriculture that sustainably increases productivity and resilience against environmental pressures while at the same time reducing greenhouse gas emissions or removing them from the atmosphere. The FAO stresses that climate smart practices do not need to be newly invented in many cases, but that a variety of them already exists that could be widely instilled in developing countries, where food production is bound to change due to changing economic, environmental and social circumstances.[13]

Source: United Nations Economic and Social Commission for Asia and the Pacific, *The Role of Trade and Investment in the Context of Track 4 (Turning Green into a Business Opportunity) and Track 5 (Low Carbon Economics) of the LC GG Roadmap for the Asia-Pacific Region* (Bangkok, Trade and Investment Division, 2011).

Country experience: Roadmap for the agriculture sector in the Republic of Korea

The Korean Government has already started adapting its agriculture sector in the face of a changing climate. The adaptation strategy was charted in a roadmap for 2030 designed in three phases: short-term base build-up phase (2010–2013), mid-term take-off phase (2014–2019) and long-term settlement phase (2020–2030). Each phase covers seven categories, and a total of 19 adaptation measures listed below:

- **R&D** – breeding, production technology development, base technology development, resource management innovation and climate information system
- **Infrastructure management** – farmland management, agricultural water management and agricultural facility management
- **Economic means** – provision of grants
- **Legal and institutional improvement** – insurance system expansion, resource management system set-up and regional plans
- **Human resource training and education** – training, education and public relations
- **Monitoring** – assessment of adaptation and vulnerability
- **Technology and management applicable to farm households** – production technology management, soil management, water management and farm household finance management.

Not all the measures apply to all of the three phases, but many do. The three measures included in the infrastructure management category, constitute the main tasks in all phases. In the economic category, the low-carbon grant is critical in the base build-up phase but it should continue as well. In the legal and institutional improvement category, the agricultural disaster insurance system needs to be carried on continuously so that it can be established securely. Public relations and education should also be continued in order to establish a consensus on adaptation to climate change. In the monitoring category, the tasks for developing a model to make medium- and long-term forecasts of the world food demand and supply should also be kept up in each phase. And in the category of technology and management applicable to farm households, R&D programmes should be present in each phase to promote new, green technologies.

Source: Chang-Gil Kim, *The Impact of Climate Change on the Agricultural Sector: Implications of the Agro-Industry for Low Carbon, Green Growth Strategy and Roadmap for the East Asian Region*, Consultant Report (Bangkok, UNESCAP, 2011).

[13] The Food and Agriculture Organization of the UN (FAO, 2010) has a new report out on precisely this issue: "Climate-Smart" Agriculture: Policies, Practices and Financing for Food Security, Adaptation, and Mitigation.

Country experience: Countering climate change in the agriculture sector in China

The Chinese government's agricultural countermeasures against climate change are largely divided into greenhouse gas mitigation and adaptation.

The mitigation strategies entail:

- popularizing of low carbon-emitting, multi-harvesting rice varieties and half-drought type cultivation techniques;
- adopting efficient irrigation methods and soil-specific fertilization techniques;
- researching and developing high-quality ruminant breeding technology and stockbreeding management technologies;
- strengthening the management of animal excrement, wastewater and solid wastes;
- improving the efficiency of methane use; and controlling methane emissions.

Adaptation means entail:

- strengthening the measured forecast level for extreme meteorological disasters by supplementing the measured forecast emergency action mechanism, the multi-department decision-making mechanism and ensuring a comprehensive community-involvement mechanism in provisions against various disasters;
- establishing a meteorological disaster defence process (by 2010) that has an essential role in securing the society;
- improving the comprehensive measured forecast level, defence level and disaster-mitigation capacity to cope with extreme meteorological disasters;
- forming 24 million ha of new grassland and clearing 55 million ha of degraded, desertificated and/or alkali grasslands (by 2010) by strengthening farmland construction, cultivation system adjustments, resistant- variety selection and development, and biotechnology development.[14]

In terms of climate change adaptation policies, the Chinese Government has enacted the Agriculture Act, the Grassland Act, the Fisheries Act, the Land Management Act, an Ordinance on Emergency Measures Against Sudden Critical Animal Epidemic and an Ordinance on Pasture Fire Prevention. The Government has made efforts to supplement the political and regulatory system for the agricultural sector's adaptation to climate change. In addition, it has strengthened agricultural infrastructure, promoted the construction of farmland irrigation systems, expanded the irrigated agricultural area and improved irrigation efficiency. Additionally, the Government has popularized water-saving technology for hardy crops, enhanced the agricultural disaster prevention and reduction capacity, and developed crop varieties that can endure high temperature, blight and pests.

In the future, the Chinese Government will further popularize high-quality crop varieties and increase their coverage. Also, it will strengthen the prevention of critical animal epidemics.

Source: Chang-Gil Kim, *The Impact of Climate Change on the Agricultural Sector: Implications of the Agro-Industry for Low Carbon, Green Growth Strategy and Roadmap for the East Asian Region*, Consultant report (Bangkok, UNESCAP, 2011).

Green technology – energy

It is not just efficiency alone that advocates the use of green technology in the energy sector. Reduced costs, decreased environmental impacts, grid security and reliability are further benefits. Thus, new technologies should be carefully integrated into the system to complement existing infrastructure.

Solar

Currently, there are two main technologies for generating electricity using solar energy: photovoltaic (PV) and concentrated solar power (CSP). PV technology directly converts sunlight into electricity. CSP technology

[14] Chang-Gil Kim, *The Impact of Climate Change on the Agricultural Sector: Implications of the Agro-Industry for Low Carbon, Green Growth Strategy and Roadmap for the East Asian Region*, Consultant report (Bangkok, UNESCAP, 2011).

collects solar thermal energy by using mirrors to reflect and concentrate sunlight to produce heat or steam and convert it into electricity via a power generator.

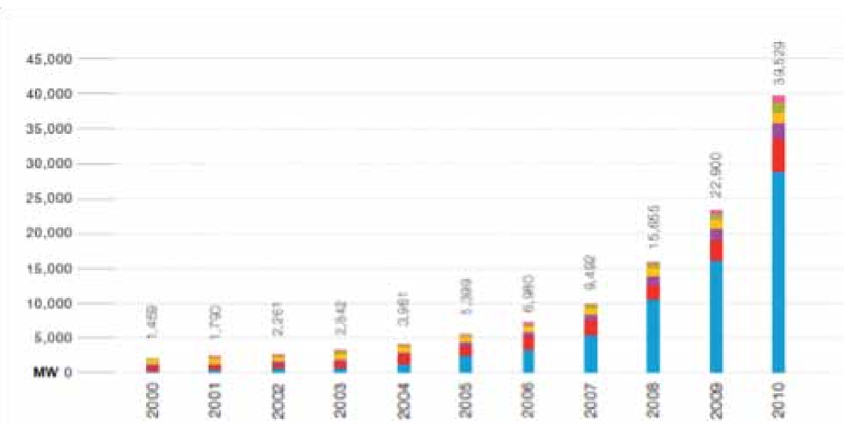
PV technology can be further divided into two categories: crystalline silicon and thin-film module. Crystalline silicon was the first PV technology to be commercialized and still accounts for most of the global production.[15] Thin-film technology is generally less efficient than crystalline silicon but is also less expensive to manufacture. Due to the low-cost advantage, thin-film technology has been adopted in emerging economies and developing countries.

The PV industry's power plants are relatively easy to operate because the PV panels have no moving parts, thus requiring less maintenance than CSP power plants. But due to the low conversion efficiency of the photovoltaic cells, a large land area is needed for a high volume of electricity generation. On the plus side, the scalability of the PV module enables rooftop-mounted applications, which represents a big potential application area as well as a viable source for distributed electricity generation.

There are four types of CSP systems: linear concentrator, dish/engine, power tower and thermal storage. The concept for producing electricity is basically the same for all of them. They differ in their solar concentration configuration, tracking system, heat storage and efficiency. Smaller CSP systems can be used in distributed-generation applications to produce power on-site. But unlike the PV technology, the CSP systems are not easily scalable and are generally used in utility-scale applications. The heat generated from the CSP can be stored, so the produced electricity does not fluctuate as widely as with the PV system, thus it possesses an advantage in providing reliable power to utilities. Because CSP power plants commonly use steam to generate electricity and are water cooled, the availability of water resources can pose a constriction for their application.

The high cost and low-conversion efficiency are the main barriers to the wide use of solar power systems. Costs per unit of electricity generated from solar elements have remained relatively high in comparison to other renewable energy sources.[16] Fortunately, the manufacturing costs for the PV system decrease as the market for the technology expands. Moreover, the current research on increasing the efficiencies of both PV and CSP technologies aims to make the generating of solar power even more cost competitive.

Figure 1: Global cumulative installed solar power capacity, 2000–2010



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
China	19	30	45	55	64	68	80	100	145	373	893
APEC	38	43	49	57	66	80	112	170	466	718	1,191
Rest of the world	758	814	894	971	1,000	1,010	1,128	1,190	1,303	1,427	1,944
North America	146	177	222	287	379	496	645	856	1,205	1,744	2,727
Japan	318	452	637	860	1,132	1,422	1,708	1,919	2,149	2,632	3,622
EU	181	275	414	613	1,319	2,324	3,307	5,257	10,387	16,006	29,252
Total	1,459	1,790	2,261	2,842	3,961	5,399	6,980	9,492	15,655	22,900	39,529

Source: European Photovoltaic Industry Association, *Global Market Outlook for Photovoltaic until 2015* (Brussels, 2011). Available from www.epia.org/publications/photovoltaic-publications-global-market-outlook/global-market-outlook-for-photovoltaics-until-2015.html (accessed 06 March 2012).

[15] Andrew David, *U.S. Solar Photovoltaic (PV) Cell and Module Trade Overview* (Washington, D.C, United States International Trade Commission, 2011).

[16] Barry Rabe, *Race to the Top: the Expanding Role of U.S. State Renewable Portfolio Standards* (Michigan, Pew Center, 2006).

Country experience: Renewable energy in Thailand

In 2009, the Government of Thailand set the goal of generating 20 per cent of the country's energy from renewable sources by 2020. To achieve this, the Thailand's Ministry of Energy directed the Department of Alternative Energy Development and Efficiency to include a policy on alternative energy in the national agenda. The subsequently designed Alternative Energy Development Plan aims to generate 40,000 new jobs, reduce migration from rural to urban areas, decrease greenhouse gas emissions, save 460 billion baht per year in foreign currency reserves (value), currently spent to import fossil fuels, and generate up to 14 billion baht annual revenue from international carbon markets.[17]

The Alternative Energy Development Plan features provisions for the production and utilization of alternative energy in order to improve energy security. The Government will use a mix of market-based instruments as well as an oil fund to maintain energy prices at stable and affordable levels. Related policies included in the plan promote R&D of renewable energy from biofuels and co-generation from biomass and biogas, energy efficiency standards for electrical appliances and buildings, revision of existing obstructive legislation and updating of feed-in tariffs. The 8 baht added cost per kWh for solar energy, for example, may be reduced to 6.5 baht per kWh due to the reduction in the cost of solar technology.[18] Additionally, import duties on equipment for renewable energy will be waived and exemptions from corporate income tax for new investments and start-ups will be granted. Funding for new commercial alternative energy technologies will be encouraged by tax incentives and investments from a revolving fund.

In the long run, the alternative energy policy aims to expand the use of new green technologies, such as hydrogen and bio-hydrogenated diesel from palm oil, extend green city models to the communities in the country and encourage the export of biofuels and indigenous green technologies to the ASEAN region.

Table 3: Renewable energy potential for electricity generation in Thailand

Renewable energy type	Potential (MW)	Source
Solar	50,000	Urban areas; solar homes; majestic projects
Hydro	700	Micro-hydro; mini-hydro
Wind	1,600	Wind farms in southern Thailand
Biomass	4,400	Sugarcane and palm industries; biomass power plants; community power plants
Biogas	190	Livestock farms; Agro-industries

Source: Thailand, Thailand in the 2010's: *Thailand's Renewable Energy and its Energy Future: Opportunities & Challenges*, Final draft (Bangkok, Ministry of Energy, 2009). Available from www.nstda.or.th/attachments/7918_CASAVA-2.pdf (accessed 06 March 2012).

Wind

Wind power technology is one of the most mature renewable energy approaches. In 2010, for the first time ever, more new wind power capacity was installed in developing countries than in the traditional markets of the OECD.[19] The main barriers to wind power production are the intermittency of wind, location constraints and public resistance. Due to the irregularity of wind, a high penetration of wind power requires energy storage technology. Additionally, producing electricity from wind turbines requires non-turbulent wind (strong wind blowing

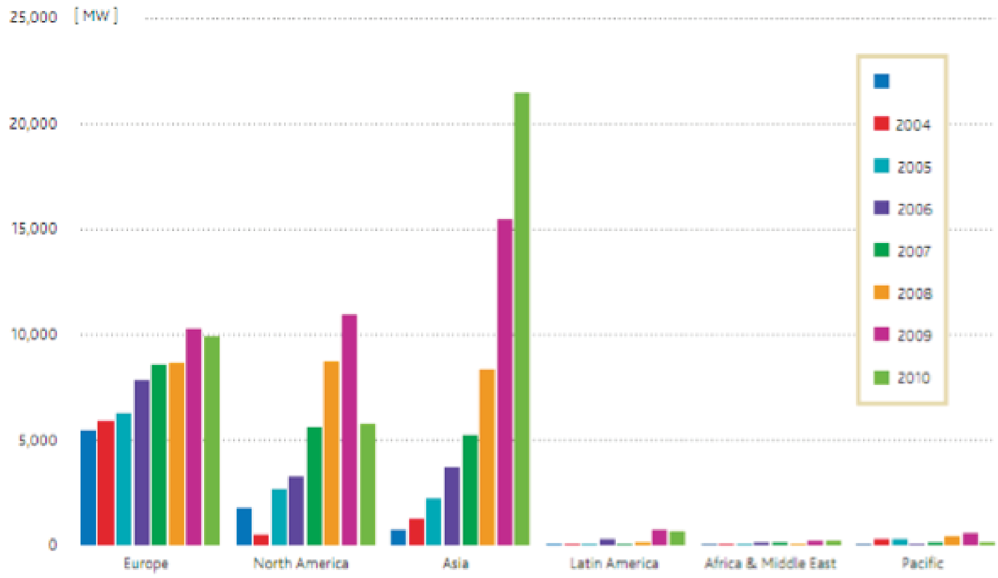
[18] *Bangkok Post*, "Subsidy Changes Leave Green Energy Future in Doubt", December 27, 2011.

[19] Global Wind Energy Council, *Global Wind Report: Annual Market Update 2010* (Brussels, 2011). Available from www.gwec.net/fileadmin/images/Publications/GWEC_annual_market_update_2010_-_2nd_edition_April_2011.pdf (accessed 06 March 2012).

with consistent force). Thus, available wind resources need to be the main consideration for the site selection of wind farms. However, some communities may be resistant to having a wind farm nearby due to aesthetic issues and the low-frequency noise of the windmills.

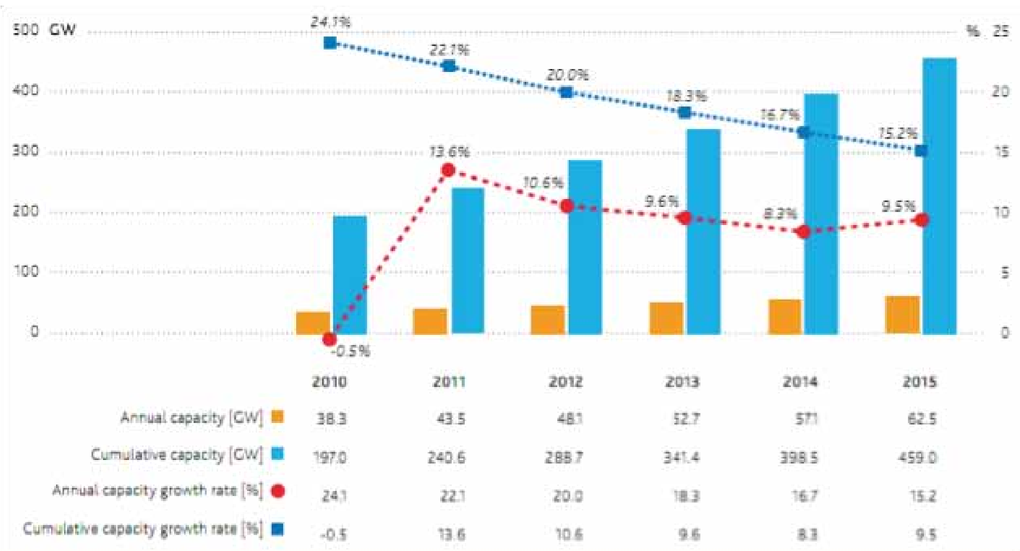
Offshore wind farms may attract less public resistance, but the entailed construction and operating costs are higher. The technological limitations of an offshore location, namely the need for submarine transmission lines, are additional obstacles. Offshore-wind generation has great potential due to better wind resources (stronger and more predictable) and easily available construction space, especially once the best sites for on-shore wind power generation are no longer available. Grid parity of wind-generated energy with natural gas and coal is predicted for 2025, if a carbon price of US$30 per tonne CO_2 emissions is introduced.[20]

Figure 2: Annual installed wind power capacity, by region, 2003–2010



Source: Global Wind Energy Council, *Global Wind Report: Annual Market Update 2010* (Brussels, 2011). Available from www.gwec.net/fileadmin/images/Publications/GWEC_annual_market_update_2010_-_2nd_edition_April_2011.pdf (accessed 06 March 2012).

Figure 3: Forecast for global wind market development, 2011–2015



Source: Global Wind Energy Council, *Global Wind Report: Annual Market Update 2010* (Brussels, 2011). Available from www.gwec.net/fileadmin/images/Publications/GWEC_annual_market_update_2010_-_2nd_edition_April_2011.pdf (accessed 06 March 2012).

[20] Exxon Mobil Corporation, The Outlook for Energy: A View to 2030 (Irving, Texas, 2009). Available from www.exxonmobil.com/Corporate/files/news_pub_eo_2009.pdf (accessed 18 January 2012).

Geothermal

Geothermal technology uses energy from the earth's crust to generate heat or electricity. The energy can be accessed by drilling wells into underground reservoirs to bring the hot geothermal fluid to the surface. The heat can then be converted into electricity or used directly in heating applications.

In the geothermal field, the term "energy conversion" refers to power-plant technology that converts the heat of geothermal fluids into electricity. There are three types of geothermal power plants currently in operation: dry (or direct) steam, flash steam and binary-cycle plant. The plant type depends on the specific location of the geothermal resource. Due to the variation in resources, such as composition, pressure and temperature of the geothermal fluid, geothermal power plants must be designed according to an assessment of the site-specific conditions in order to optimize the power generation efficiency. Unlike wind and solar power, electricity generated from geothermal sources is not intermittent, which means that it can provide reliable base-load power.

Box 5: Potential growth in geothermal power generation

The current global capacity of geothermal power is around 10.7 GW across 26 countries. Pike Research, a market research and consulting firm, has projected that the total worldwide geothermal power capacity could grow to 25.1 GW by 2020. The firm also estimated that there is a minimum of 190 GW of conventional geothermal resources around the globe that can be exploited using currently available technologies.

Source: Ecoseed website "Global Geothermal Capacity Can Hit 25.1 GW by 2020: Research" (30 September 2011). Available from www.ecoseed.org/geothermal/article/14-geothermal/11357-global-geothermal-capacity-can-hit-25-1-gw-by-2020-%E2%80%93-research (accessed 06 March 2012).

Table 4: Countries generating geothermal power in 2010

Country	Installed Capacity (MW)	Rank
United States	3,086	1
Philippines	1,904	2
Indonesia	1,197	3
Mexico	958	4
Italy	843	5
New Zealand	628	6
Iceland	575	7
Japan	536	8
El Salvador	204	9
Kenya	167	10
Costa Rica	166	11
Nicaragua	88	12
Russia	82	13
Turkey	82	14
Papua New Guinea	56	15
Guatemala	52	16
Portugal	29	17
China	24	18
France	16	19
Ethiopia	7.3	20
Germany	6.6	21
Austria	1.4	22
Australia	1.1	23
Thailand	0.3	24

Source: Alison Holm and others, *Geothermal Energy: International Market Update* (Geothermal Energy Association, 2010). Available from www.geo-energy.org/pdf/reports/gea_international_market_report_final_may_2010.pdf (accessed 06 March 2012).

The locations of geothermal power plants are mainly limited to areas with a hydrothermal resource and highly permeable rocks. Geothermal resources that are relatively dry, featuring rocks with low permeability and thereby insufficient water content, are undevelopable with current commercial geothermal technologies. However, enhanced geothermal system (EGS) (also hot dry rock, hot wet rock or hot fractured rock technology) is a technology being developed to use the resources that traditional geothermal technologies cannot exploit. EGS technology is under demonstration trials in several countries in the European Union.[21]

"Geothermal direct use" refers to the use of heat that comes directly from the geothermal source. In cold climates, water from a hydrothermal source is used for heating, such as in buildings, greenhouses and district heating. In warmer climates, geothermal heat has agricultural and industrial applications.

A geothermal heat pump (GHP) (also referred to as GeoExchange, earth-coupled, water-source and ground source heat pump) uses the moderate temperature of the ground to raise the efficiency of heating and cooling of buildings. The GHP application of geothermal energy is widespread in colder climates. However, the technology is fundamentally different from what is used for geothermal power generation and the market segment and applications are also different.

Fuel cells

Fuel cells convert the chemical energy contained in hydrogen to electricity and heat using an electrochemical process. Inside a fuel cell, hydrogen electrochemically merges with oxygen to create electricity, resulting in water and potentially useful heat as by-products. There are many types of fuel cells, though in general, they all share the same basic configuration, featuring two electrodes sandwiched around an electrolyte. The types of fuel cells are categorized by the electrolyte substance.

Power produced by a fuel cell depends on the fuel cell type, size, operating temperature and the gas supplied. Hydrogen is the most optimal fuel for use in fuel cells. However, other hydrogen-rich fuel sources, such as biogas from waste treatment and natural gas, which are rich in methane, can also be used as fuel. Fuel cells can be used for backup power, power for remote locations, distributed power generation and combined heat and power applications. To sustain electricity generation, though, the fuel needs to be supplied continuously; thus a reliable supply of gas or a bulk storage system is needed.

Because fuel cells do not use combustion, emissions are much lower, and conversion efficiency is higher than with conventional thermal power generation. A typical conventional combustion-based power plant has around 33–35 per cent efficiency, while fuel cell systems can generate electricity at efficiencies up to 60 per cent.[22]

Unfortunately, fuel cell technology has not advanced to the point where it can compete with conventional power generation. The two main barriers to the commercializing of fuel cells are cost and durability. Material and manufacturing costs for fuel cells are high compared to traditional combustion systems, and fuel cells have not demonstrated the needed system reliability and durability to compete with existing technologies.

Energy storage

Energy can be used more efficiently through the addition of short- and long-term energy storage, both on and off the grid. Thermal and electrical energy storage systems enable more efficient power generation by balancing fluctuating energy supply and demand. Thermal energy storage can also be used to reduce electricity consumption by increasing the efficiency of heating and cooling systems, while an electrical storage system can supply excess electricity, which is generated during periods of low consumption, to meet peak power demand.

Depending on the technology, energy can be stored as electrical, chemical, thermal or mechanical energy. Not all technologies are suitable for every application, however, mainly due to power output and storage capacity limitations. Identifying a suitable storage technology depends on several factors, such as storage capacity, charging and discharging power, efficiency, storage period, storage cycle and cost.

[21] International Energy Agency, *Technology Roadmap Geothermal Heat and Power* (Paris, 2011). Available from www.iea.org/papers/2011/Geothermal_Roadmap.pdf (accessed 10 January 2012).

[22] United States of America, *Hydrogen & Our Energy Future* (Washington, D.C., Department of Energy, 2009). Available from http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/hydrogenenergyfuture_web.pdf (accessed 10 January 2012).

"Grid energy storage" (also large-scale or utility-scale storage) refers to a grid-connected energy storage system. A high penetration of renewable energy sources will require major alterations to a power system's operation. Electricity from renewable energy sources (specifically wind and solar) are intermittent, which can lead to system instability and a mismatch in supply and demand. Thus, energy storage is essential to increase the penetration of renewable energy power generation as well as for the overall energy efficiency in the power generation sector.

The commercial readiness of energy storage varies according to the technology and application. Pumped storage is the most widespread system in use on power networks, representing about 3 per cent of the global generating capacity. Other storage technologies include compressed air energy storage (CAES), flywheels, lead-acid batteries, sodium sulphur batteries and capacitor systems.[23] Battery storage methods are suitable for small-scale applications, such as battery-backup systems for solar panel homes.

Smart grids

Smart grid technology consists of multiple components and systems. A smart grid basically describes the existing grid enriched by new networks of sensing, communication and control technologies. These networks are linked by universal standards and protocols that are constantly added and updated. The grid becomes "smarter" through the deployment of communication and control devices and through the integration of complex optimizing software enabled by advances in information technology. In simpler terms, a smart grid is made up of a series of smart devices connected over a network to computers that use the data provided by the devices to optimize the system.

Box 6: Potential growth in the smart meter market

The global number of smart meters installed is expected to reach 535 million units by 2015 and 963 million units by 2020.[24] The Asia-Pacific region is expected to be a major contributor to the growth in use, with China's state grid smart meter market alone valued at US$7.7 billion and a potential market of 300 million smart meter units. Currently, China has a smart meter base of around 70 million. The state grid is expected to install smart meters at a rate of 50 million to 60 million units per year through 2014.[25]

Source: *Metering International Magazine*, "Efficiency from metering to service solutions", Issue 3, 2011.

On the supply side, smart grids enable a high penetration of renewable energy sources through enhanced control of the fluctuations in the power supply. The supply of many renewable resources is intermittent, so utility services normally have a hard time integrating them into the system. What smart grid technology offers, is a system that can virtually go out and see what resources are available and dispatch them to the consumers. On the demand side, the deployment of a smart meter and smart appliances lets system operators as well as consumers know when demand for electricity is outstripping supply and thus curtails the use of electricity.

Smart grid technology is not yet commercially viable because the standards and protocols for the system integration are still under development. There are several smart grid pilot projects around the world. The biggest barrier to smart grid application may be the costs, as it will be expensive to implement smart grid technologies because old equipment and transmission infrastructure will need to be replaced and upgraded.

[23] Susan M. Schoenung and William V. Hassenzahl, *Long- vs. Short-Term Energy Storage Technologies Analysis* (Livermore, California, Sandia National Laboratories, 2003). Available from http://prod.sandia.gov/techlib/access-control.cgi/2003/032783.pdf (accessed 20 January 2012).

[24] *Metering International Magazine*, "Smart meter base to near 1 billion units globally by 2020", Issue 3, 2011.

[25] *Metering International Magazine*, "China's state grid smart meter market valued at $7.7 Billion", Issue 3, 2011.

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