World Intellectual Property Organization

Patent-based Technology Analysis Report

-Alternative Energy Technology-

World Intellectual Property Organization

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EXECUTIVE SUMMARY

Since the oil crises of the 1970s, the world has increasingly paid attention to the development and diffusion of alternative energy sources in order to reduce dependency on fossil fuels. During the oil crises, the primary focus was on increasing self-sufficiency with respect to energy sources. By the 1990s, environmental concerns had taken the forefront, leading to a new phase in the development of alternative energies. This new phase coincided with an increase in the number of patent applications as well as the number of applicants involved in developing alternative energy technologies, particularly from 2000 onwards, when a rapid acceleration in patent activity took place. Among the major patent offices at which patent applications for alternative energy technologies were filed, namely those of the United States, Japan, and Germany, the distribution of applications among different areas of technology appears to be related strongly to the countries' geographic and resource situation as well as the distribution of research and development budgets and supporting policies.

Japan entered the field of alternative energy development early and has seen strong patenting activity from domestic applicants. Patent applications at the Japan Patent Office (JPO) have focused strongly on solar power and hydrogen and fuel cell technologies. Patent applications at other patent offices based on priority applications at the JPO appear to mirror this pattern. Patent applications at the United States Patent and Trademark Office (USPTO) have been relatively evenly distributed between domestic and foreign applicants. During the period from 2001 to 2005, the USPTO saw rapid growth both in the number of patent applications and the number of applicants. The focus of patent applications filed at the USPTO has been primarily on bio energy, geothermal energy, and hydrogen and fuel cell technologies. The European Patent Office (EPO) and major European national patent offices have experienced a relatively steady growth in both the number of patent applications and applicants since the 1990s. Patent applications at the EPO and European national offices have tended to focus on different areas of technology, depending on the office. Germany, the national office with the largest number of applications filed, received patent applications primarily for wind power and solar energy technologies. In Korea and China, most patent applications were

filed by domestic applicants. Though the initial number of applications filed at the patent offices of these countries was quite small, the growth rate has been very high. While patenting activity at the Korean Intellectual Property Office (KIPO) has focused on wind power and hydrogen and fuel cell technologies, the largest number of applications at the State Intellectual Property Office (SIPO) in China have been for solar energy and hydropower technologies.

Figure 1 Technological specialization for selected countries

1. INTRODUCTION

Industrial development has led to increased prosperity for many people around the world but has also led to a depletion of natural resources and environmental damage. The consumption of fossil fuels, on which industrial development has been largely based, has been recognized as a major cause of climate change. The impacts on the global ecosystem resulting from climate change are in turn expected to lead to substantial economic losses. As a result, it is clear that new means of fueling industrial development must be found in order to avoid compromising the gains in human welfare that have been achieved over the past decades. The continued dependence of most countries on fossil fuels – primarily oil and natural gas – from a small number of often politically unstable regions is also troubling from a political and security perspective. The potential for resource conflicts and other political and social problems will only increase as oil and natural gas resources become increasingly concentrated in these regions and global demand for fossil fuels rises.

People have turned increasingly to alternative energy sources as an answer to the environmental, political, and social problems linked to fossil fuel use. Alternative energy sources are broadly defined as energy sources that do not cause or limit net emissions of carbon dioxide and thus largely avoid the environmental impacts associated with the combustion of fossil fuels. Furthermore, they are generally defined as being renewable sources of energy not requiring the input of fossil fuels, which also speaks to their political and social advantages.

1.1. Background on the subject

The advantages of switching from fossil fuels to alternative energy sources are manifold:

1. Economic: Countries’ vulnerability to economic shocks resulting from changes in fossil fuel prices can be reduced. High fossil fuel prices can act as a significant damper on economic growth in countries reliant on external supply and can cause undesirable economic effects even in fossil fuel-producing countries, e.g., by reducing the

competitiveness of industries not involved in fossil fuel production. The rapid increase in energy demand from emerging economies such as China and India has magnified the competition for increasingly scarce fossil fuel resources and is thus likely to ensure rising prices over the medium and longer term. Industries linked to the production of alternative energy also are potentially significant sources of employment and income, particularly in high-wage technology sectors.

2. Environmental: Alternative energy sources can contribute significantly to a reduction in greenhouse gas emissions and thus to the mitigation of climate change. Nearly every all states have committed themselves to the goal of avoiding climate change caused by human activity under the United Nations Framework Convention on Climate Change (UNFCCC) and many states have further committed themselves to specific reductions in greenhouse gas emissions under the Kyoto Protocol, which calls for an average reduction by 5.2 percent of greenhouse gas emissions compared to 1990 levels.

3. Social: Resources used in the production of many forms of alternative energy – including sunlight, wind, biomass, and the Earth's warmth – are distributed relatively equally all over the world. Remote areas not served by centralized electricity networks can thus benefit from the exploitation of alternative energy sources, such as solar power, wind power, biomass-based energy production, and geothermal energy.

4. Political: The concentration of fossil fuel resources in a relatively small number of countries provides these countries with significant political leverage over other countries dependent on the fossil fuel they supply. Diversification of energy supplies and possibly greater self-sufficiency in energy production should help insulate countries from this type of political pressure and possibly improve the global security situation.

Nonetheless, the unit cost of alternative energy generally remains above that of conventional energy. In addition, high initial costs are involved in the development of alternative energy technologies and establishment of large-scale alternative energy production facilities. Governments can address these obstacles to wider adoption of alternative energies through supportive fiscal and regulatory measures designed to diminish costs or risks of investing in alternative energy production and lower the unit cost of alternative energy relative to conventional energy.

1.2. Purpose of this study

Governments will require in-depth analysis of their countries' particular needs and capacities and of trends in technological innovation in order to design appropriate policies for the promotion of alternative energies. The present study is designed to contribute to this discussion by providing an overview of recent trends in the development of alternative energy technologies, as reflected by patent applications filed at different patent offices around the world. Specifically, the study: (i) examines developments in the number and character of patent applications filed at several patent offices for different types of alternative energy technologies; (ii) identifies the major countries and companies involved developing alternative energy technologies and analyzes their respective technology portfolios; and (iii) puts these trends and factors in a wider policy context.

2. METHODOLOGY

2.1. Data

The data used in this report was extracted from the patent databases of the United States Patent and Trademark Office (USPTO), the Japan Patent Office (JPO), the European Patent Office (EPO), the Korean Intellectual Property Office (KIPO), the State Intellectual Property Office of the People's Republic of China (SIPO), and the International Bureau of the World Intellectual Property Office (WIPO) as well as the WIPS patent database.

International Patent Classification (IPC) symbols and simple keywords were used to identify relevant records in the databases. IPC symbols have the advantage of being language-independent and generally assigned to patent applications in a uniform manner across different countries. A complete summary of IPC symbols and keywords used for the analysis can be found in Annex A.

Table 1. Data sources

Database	Year of publication	Data coverage	Records
EPO	12/1978 – 04/2008	Full text	6,702
WIPO	10/1978 – 03/2008	Full text	5,632
USPTO	01/1976 – 04/2008	Full text	15,326
JPO	10/1976 – 12/2007	PAJ[1], full text	42,843
KIPO	07/1979 – 04/2008	Full text	5,103
SIPO	01/1991 – 11/2006	Full text	2,207

[1] Patent Abstracts of Japan

2.2. Definitions

Alternative energy broadly refers to sources of energy other than traditional fossil fuels. In common usage, it can refer to renewable energy but also energy obtained from fossil fuel sources whose production does not involve a net emission of carbon dioxide. For the purposes of this report, a definition based on that used by the European Commission is adopted. According to this definition, alternative energy technologies include: solar energy, wind power, bioenergy, geothermal energy, wave and tidal power, hydrogen and fuel cells, and carbon capture and storage (CCS) as well as hydropower and energy derived from solid and liquid waste (EC 2006).

2.2.1. Solar energy

Solar energy production can be divided into two types: solar thermal energy and photovoltaic power production. In the former case, heat captured from the sun is used for residential heating or industrial processes or for thermal power generation. Technologies involved in solar thermal energy production include solar heat collection, heat storage, systems control, and system design technologies. In the latter case, specially adapted semiconductor devices are used to convert solar radiation into electrical current. Related technologies include solar cell design, storage battery, and power conversion technologies.

Advantages

- Clean and unlimited source of energy
- Local energy production is possible
- Low regional variations in availability compared to fossil fuels
- Short construction and installation period
- Low maintenance costs (solar thermal)

Disadvantages

- Power generation capacity is dependent on local weather conditions
- Large installation areas are required because of low energy density
- Large initial investment required

2.2.2. Wind power

Wind currents can be used to generate electricity by using wing-shaped rotors to convert kinetic energy from the wind into mechanical energy and a generator to convert the resulting mechanical energy into electricity.

Advantages

- Low maintenance cost due to minimal fuel expenses and the possibility of unmanned remote control
- Unit cost of energy production is comparable to that of fossil fuels
- Short construction and installation period
- Land on which installations are constructed can also be used for farming due to high installation height
- Installations can also be developed into tourist attractions

Disadvantages

- Wind power can only be produced economically in areas where average wind speeds exceed 4 meters per second
- Installations are sensitive to changes in the natural environment including new obstacles to wind currents
- Significant noise generated by installations requires that these be placed away from residential areas

2.2.3. Bioenergy

Bioenergy generally refers to energy produced from biomass, that is to say organic matter including dedicated energy crops and trees, agricultural food and feed crops, agricultural crop wastes and residues, wood wastes and residues, aquatic plants, animal wastes, municipal wastes, and other waste materials. Biomass can be converted into solid, liquid or gas fuels or used to produce thermal energy through biochemical or physical conversion processes. In the former case, biomass is broken down using anaerobic decomposition and fermentation, while in the latter case, energy is produced through gasification, pyrolysis or direct combustion.

Advantages

- Raw material is abundant
- Production is carbon-neutral insofar as biomass absorbs and fixes carbon dioxide from the atmosphere during photosynthesis

Disadvantages

- Low energy density
- Unstable supply of raw materials

2.2.4. Hydropower

Electricity can be generated through the conversion of potential energy of water contained in a reservoir using a turbine and a generator.

Advantages

- Low maintenance cost
- Relatively short design and construction period
- High energy conversion efficiency

Disadvantages

- High initial investment cost
- Water supply can be unstable

2.2.5. Geothermal energy

Thermal energy derived from magma heat and stored in soil, underground water, or surface water can be used for heating or cooling buildings by means of a ground-coupled heat pump system. Such systems operate by having a heat exchange embedded in a borehole supply the energy for the evaporation and condensation of a refrigerant. Geothermal liquid can also be used to drive turbines and thus generate electricity.

Advantages

- Highly economical due to the combined use of heating and cooling
- Stable supply due to the absence of significant fluctuations in ground temperature
- Excellent space utilization

Disadvantages

- High initial investment cost (for exploration and surface development)
- Settling of ground may occur and is difficult to investigate

2.2.6. Wave and tidal power

The energy from incoming and outgoing tides and from waves can be harnessed to generate electricity using, for instance, turbines.

Advantages

- Large-scale power generation possible
- No storage facility is required

Disadvantages

- High initial construction cost
- Low energy density
- Impacts coastal ecosystems
- Distant from users

2.2.7. Hydrogen and fuel cells

Hydrogen gas can be produced from water through electrolysis or from hydrocarbons through steam reforming. Electrolysis of water requires a far greater energy input than steam reforming and is therefore less economical. The energy input may be lowered using improved catalysts. Hydrogen gas can then be used in combustion engines or to generate electricity in fuel cells.

Hydrogen fuel cells convert the chemical energy generated by the reaction between hydrogen and oxygen into electrical energy. Hydrogen fuel cells are commonly identified by the type of electrolyte used and include polymer electrolyte membrane fuel cells (PEMFC), solid oxide fuel cells (SOFC), molten carbonate fuel cells (MCFC) and phosphoric acid fuel cells (PAFC).

Advantages

- Water is a practically inexhaustible primary material
- Different primary materials can be used (water, natural gas, methanol, coal gas, etc.)
- No carbon emissions on combustion or reaction
- Hydrogen is easily storable and transportable as high-pressure gas, liquid or metallic compound
- No noise is produced (fuel cell)
- No coolant is required (fuel cell)
- Installation is simple and requires little space (fuel cell)

Disadvantages

- High cost of manufacturing hydrogen from non-hydrocarbon sources
- Lack of hydrogen fueling infrastructure (combustion engines)
- Low durability and dependability (fuel cell)

2.2.8 Carbon capture and storage

Carbon dioxide produced by power production and other industrial processes can be captured and stored in order to prevent it from entering the atmosphere. The cost of capturing the gas currently corresponds to around 70 to 80 percent of the total cost of carbon capture and storage (Wee 2008).

Advantages

- Abundant carbon dioxide sources amenable for capture (coal, oil, and natural gas based power production, bio energy, iron, cement, and pulp production, etc.)
- Integrated gasification combined cycle (IGCC) fueled using biomass can be combined with carbon capture and storage on a much smaller scale than coal-fueled IGCC
- Technology widely used in the chemical industry

Disadvantages

- Adds to costs of energy production
- Reduces energy efficiency
- Capturing carbon dioxide remains costly and difficult

2.2.9 Waste-to-energy

Household and other waste can be processed into liquid or solid fuels or burned directly to produce heat that can then be used for power generation ("mass burn"). Refuse derived fuel (RDF) is a solid fuel obtained by shredding or treating municipal waste in an autoclave, removing non-combustible elements, drying, and finally shaping the product. It has high energy content and can be used as fuel for power generation or for boilers.

Advantages

- Relative short time required for commercialization
- Low price of materials
- Eliminates waste and diminishes greenhouse gas emissions from landfills

Disadvantages

- Requires advanced technologies to prevent toxic emissions

Table 2. Classification of alternative energy technologies

Main class	Main class symbol	Subclass 1	Subclass 2	Subclass symbol
Solar energy	SOL	Photovoltaic	Cells and modules	PVT_cell
			System	PVT_sys
		Solar thermal	Collectors	THM_collector
			Heating	THM_heat
Wind power	WIN			
Bio energy	BIO	Thermo-chemical		thermochem
		Bio-chemical		biochem
Hydro power	HYD			
Geothermal energy	GEO	Geothermal system		geosys
		Ground-coupled heat pumps		geopump
Wave and tidal power	OCN	Wave		wave
		Tidal		tidal
Hydrogen and fuel cell	H&FC	Hydrogen	Production	h_pro
			Storage	h_str
		Fuel cells	PEMFC	PEMFC
			SOFC	SOFC
			MCFC	MCFC
			Others	OTFC
Carbon capture and storage	CCS			
Waste-to-energy	WST	RDF		RDF
		Mass burn		massburn

3. PATENT ANALYSIS

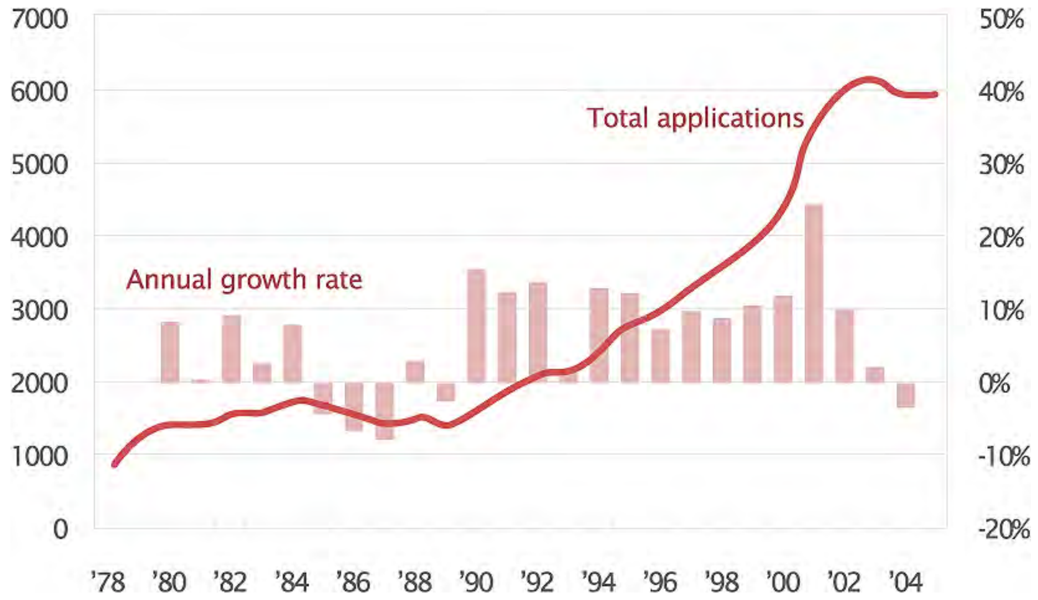
For the purposes of this analysis, alternative energy-related patents were classified according to application year, country, technology sub-class, and applicant. Number of applications, shares in total applications, and growth rates were then examined and compared to research and development expenditure and other factors. The objective is to uncover possibilities for technology cooperation and technology transfer and to highlight areas in which further research might be carried out.

3.1. Trends by country/region

Overall patenting activity in alternative energy technologies has risen from the 1970s to the present, as evidenced by applications filed at the USPTO, JPO, EPO, KIPO and SIPO and through the PCT system. Total patent filings have increased at a rate of 10 percent per year starting in the 1990s and at a rate of 25 percent from 2001.

Changes in the price of oil and increasing awareness of the issue of climate change can be considered significant factors in driving patenting activity during these periods. During the late 1970s, the price of oil increased dramatically, increasing the impetus for alternative energy technologies. This momentum subsided in the 1980s, when the oil price dropped down again to around 20 dollars a barrel. In the 1990s, worries over global warming led to the conclusion of international environmental agreements calling for the restriction of greenhouse gas emissions into the atmosphere. OECD countries in particular focused on alternative energy research as a means of reducing their greenhouse gas emissions. The late 1990s heralded the beginning of a new surge in oil prices, which a number of major countries addressed by establishing national energy strategies as part of which energy research and development budgets were strengthened.

Figure 2 Total applications and application growth rates



In most countries examined here, with the exception of Japan and China, few applications were filed until the beginning of the 1990s. The number of applications began rising during the mid-1990s and then rapidly increased after 2000. This trend was followed particularly in PCT filings and applications at USPTO and KIPO, which experienced dramatic increases during the last five years.

European patent applications have increased at a relatively steady rate since the beginning of the 1990s. The European Union has claimed a leadership role in climate policy since the emergence of climate change as a major international issue and has focused on the development of alternative energy technologies adapted to different resource endowments and geographical conditions of its member states. In 1997, the European Commission set a common goal for the European Union of achieving a 22 percent share of renewable energy in total power generation and 12 percent share in total energy consumption by 2010 (REN21 2005). Sweden announced that it would further completely eliminate its dependence on oil by 2020 by using alternative energy sources such as bio-ethane (West 2005). To meet these goals, the European Union has created an emissions trading scheme, launched awareness raising campaigns, strengthened community policy and fostered cooperation among member states (Kim and Oh 2006). Following the example of Germany, the majority of EU member states have introduced feed-in tariffs (FITs). These tariffs have been credited for increasing alternative energy production in Germany from 14 terawatt-hours to 37 terawatt-hours between 2000 and 2004, a dramatic increase also experienced in Denmark and Spain, which also had implemented FIT schemes (REN21 2005). Renewable Portfolio Standards (RPSs), which require that a certain share of power be generated using alternative energy sources, have also been established in several European countries, including Italy, Poland, Sweden and the United Kingdom.

The number of patent applications for alternative energy technologies at the USPTO remained at a low but constant level until the early 1990s, at which point a slow increase was experienced. The number increased nearly two-fold between 2000 and 2001, after which it declined again from 2003.

On the policy side, the United States began promoting the development and deployment of alternative energy technologies through the 1978 National Energy Act and the Public Utilities Regulatory Policies Act (PURPA), which were passed in response to the oil crises affecting the United States during that period. In general, federal policies for the promotion of alternative energy in the United States have not been as far-reaching or constant as policies in Europe or Japan. Instead the US government has controlled energy supply and demand primarily through policies aimed at increasing the efficiency of fossil fuel use and the promotion of nuclear energy. The reason for this appears to have been the low efficiency of alternative energy sources compared to conventional sources in spite of the higher setup costs generally associated with conventional energy production. Interest in alternative energy sources appears to have increased again since 2000 based on the level of patenting activity, led by bio energy and hydrogen and fuel cell technologies. Substantial state and federal government subsidies and other incentives have been introduced for bioethanol, in particular, while major automotive and energy companies have begun actively investing in the development of hydrogen and fuel cell technologies.

At the Japan Patent Office, nearly as many patent applications were filed in alternative energy technologies as at all the other offices examined here combined. The number of applications declined during the 1980s, however a positive growth rate has been evident again since the late 1980s.

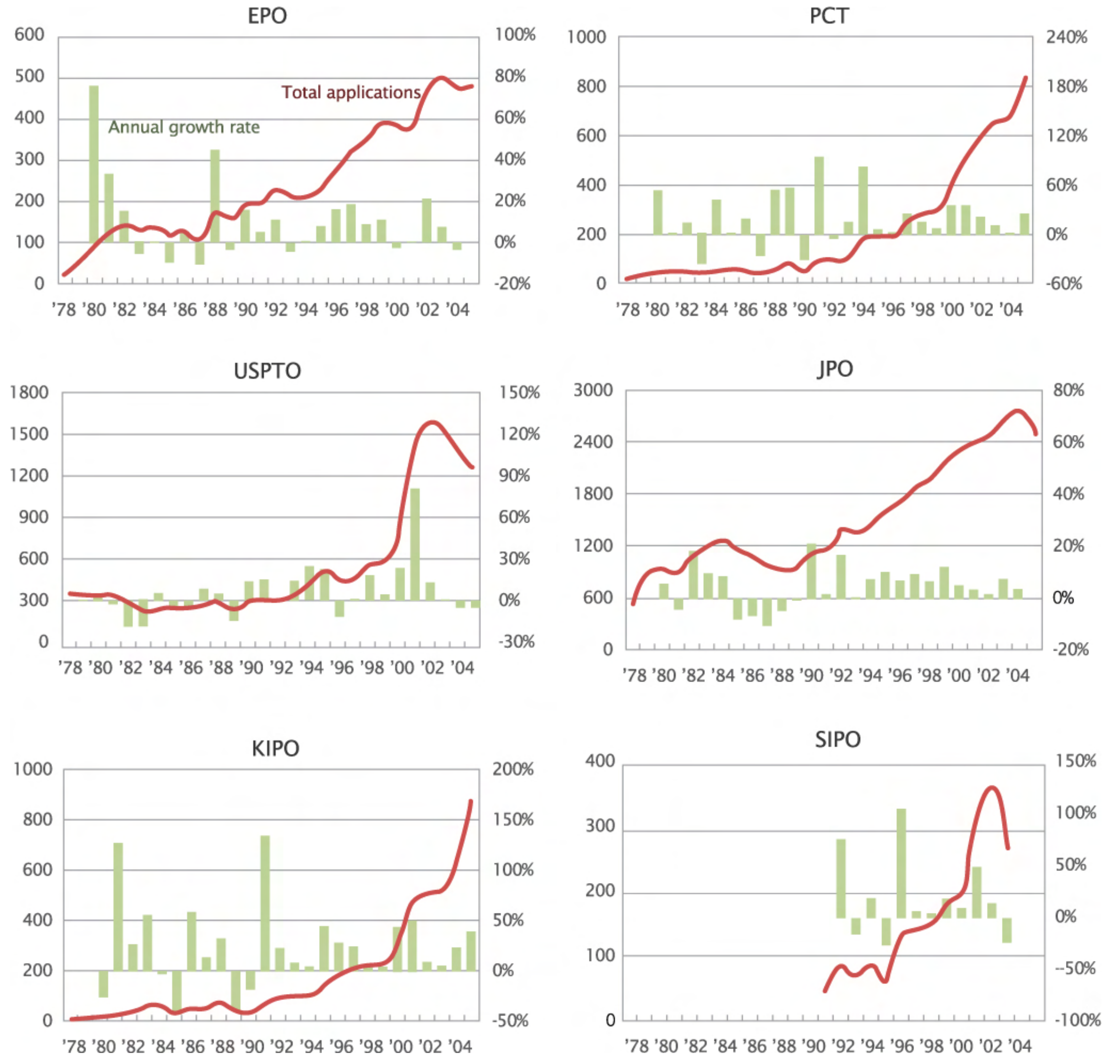
Limited domestic supplies of natural resources and a resulting dependence on foreign sources have motivated Japan to pass legislation for the promotion of alternative energy since the 1970s. The 1974 Sunshine Plan and 1978 Moonlight Plan emphasized the development of new energy sources and energy conservation, respectively. The New Sunshine Plan, launched in 1993, expanded investment into research and development of alternative energy technologies, with a particular focus on hydrogen production and photovoltaic power generation, which received 50 percent of total funding under this plan (IEA 2006d). These programs have made Japan a leader in photovoltaic power technologies as well as hydrogen and fuel cell technologies. The success of the Japanese government programs can also be attributed to the active cooperation between research institutes and private companies, allowing for a rapid deployment of new technologies onto the market.

The growth in alternative energy patent applications at KIPO was quite gradual prior to 2000, at which point an abrupt increase was experienced. The oil crises of the 1970s led to the creation of state-funded research organizations such as the Korea Institute of Science and Technology (KIST) and the Korea Institute of Energy Research (KIER). In 1997, the Korean government launched the ten-year National Plan for Energy Technology Development, which aimed to promote the development and deployment of alternative energy technologies and improve energy savings. In 2004, the 1987 Alternative Energy Development Promotion Act was revised to set higher standards for alternative energy use, promote the creation of international standards, and extend capacities for research into alternative energy technologies.

Since data on alternative energy patent filings is only available for SIPO from 1991 onwards, it is difficult to compare with the data from other offices. From the mid-1990s, alternative energy patent filings at SIPO increased sharply before dropping again after 2003, mirroring the pattern set by EPO, JPO and USPTO.

Responding to sharply increasing energy consumption (55 percent from 2001 to 2005) that came with rapid economic growth (CSP 2005), the Chinese government began establishing policies to promote greater energy efficiency. The Ministry of Science and Technology and the National Development and Reform Commission have also been tasked with providing the human and financial resources to reach the goal set by the central government of commercializing wind, solar and hydrogen and fuel cell technologies on a larger scale in China. Nonetheless, in spite of advantageous conditions for alternative energy production found in China – large land mass and abundant natural resources – alternative technologies examined in this report still appear to lack the credibility in China to attract greater investment and research and development spending.

Figure 3 Applications and application growth rates by patent office



3.1.1. Patterns in patenting activity

A general model for patterns in patenting activity can be established to understand the stages of development of a particular technology. On the introduction of a new technology, only a small number of applicants are involved in patenting in the field and only few applications are filed. Following this growth period, the technology enters a development period, during which the technology develops rapidly as a result of active competition between numerous applicants, who together file many applications. As research and development continues, the growth in the number of applications stagnates or declines as does the number of applicants. This period can be termed a "maturity period". As new technologies or even entirely new technology paradigms emerge, a period of decline begins for the original technology, at which point the number of applications and applicants in that field declines strongly. It is possible for a revival of interest to occur in the original technology, if a new application can be found for it, leading to resurgence in the number of applications and applicants (KIPI 2005).

Based on patenting activity at the patent offices examined here, the alternative energy technologies appear to be in a growth phase according to the model laid out above. At EPO and JPO, patent applications have been increasing at a steady pace, while the growth in patent applications has drastically increased under the PCT system and at USPTO and KIPO. The limited data available for SIPO also shows a relatively steady growth in the number of alternative energy patent filings.

Figure 4 A general model for patent filing activity

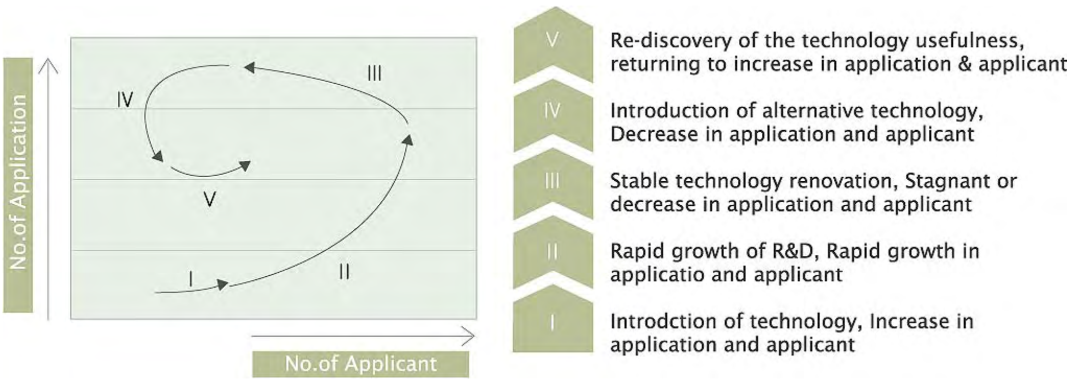
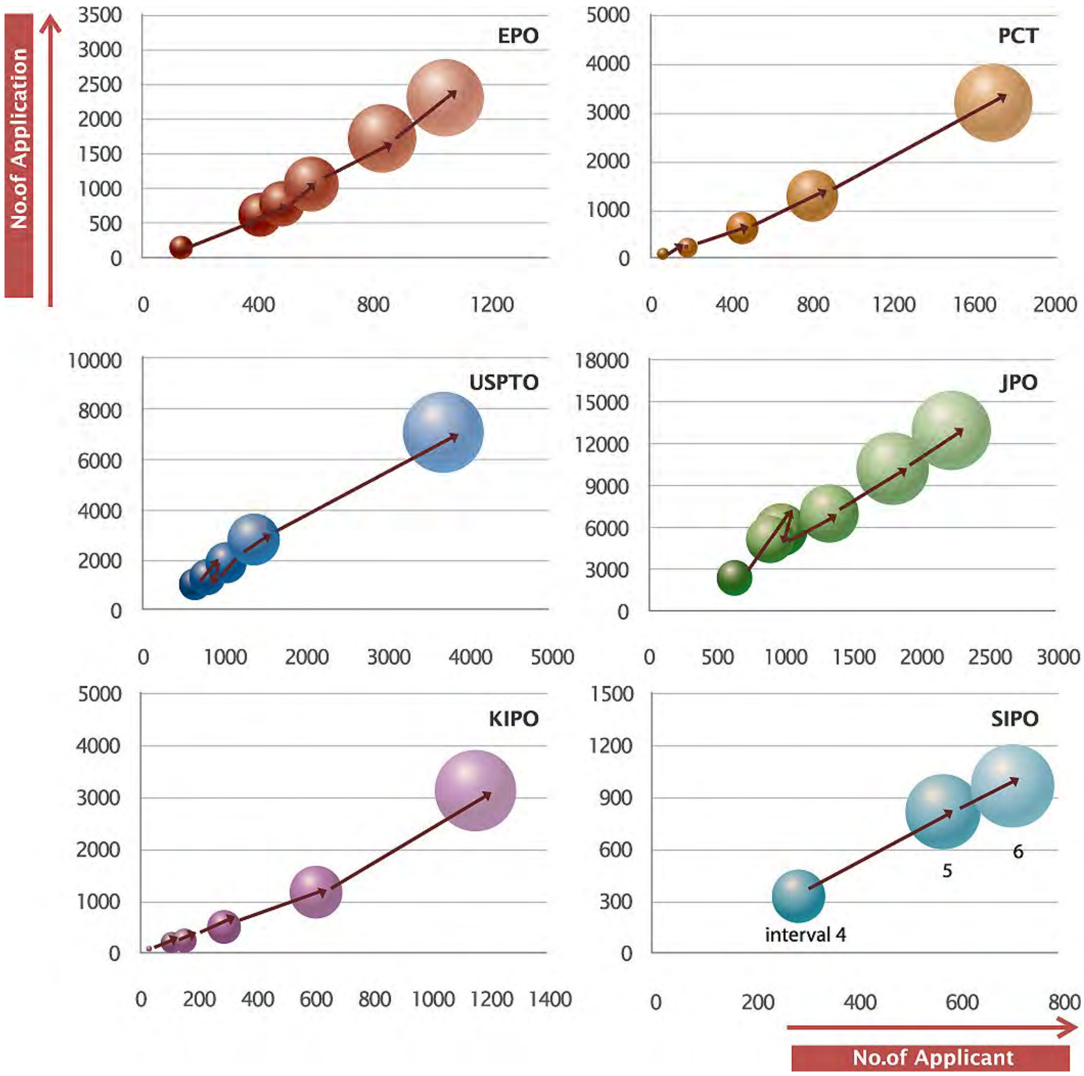


Figure 5 Applications vs. applicants by patent office



In the figure above, the bubble sizes represent the number of applications filed for each period. The periods for which numbers of applications are given are as follows:

- Interval 1: Before 1980
- Interval 2: 1981-1985
- Interval 3: 1986-1990
- Interval 4: 1991-1995
- Interval 5: 1996-2000
- Interval 6: 2001-2005

3.1.2. Correlation between government R&D budgets and patent applications

At this early stage in the development of alternative energy industries and their markets, the role of government is crucial, since the initial investments required and unit costs are higher than those for fossil fuels. As a case in point, the active support by the Japanese government for solar power technologies through significant R&D investment and the supports provided under the Advanced PV Generation (APVG) program are widely credited for having made Japan a leader in this field of technology (EC 2002). In the United States and Brazil, substantial subsidies for biofuels have played a major role in creating a large industry to bring these fuels to the market.

The role of government in countries leading in alternative energy technologies includes the creation of incentives through regulation and subsidies, direct research and development funding, and installation of infrastructure compatible with different types of power generation facilities. To study the correlation between these different types of government support and the development of alternative energy technologies, the numbers of patent applications in this field were compared to the government spending on alternative energy research and development during the period from 1996 to 2005. Figures for public spending on alternative energy research and development including for specific fields of technology were obtained from the International Energy Agency (IEA) R&D Statistics Access Database (2007 Edition).

Countries with large government research and development budgets such as Japan, the United States and Germany generally have a larger number of patent applications compared to countries with small budgets such as Australia, Norway and Austria. As a counterexample, Korea had a small R&D budget but accounted for a larger number of patent applications than Germany. In general, however, a close correlation between government budget and the number of applications could be discerned.

Government involvement in alternative energy research and development has been quite strong in Germany, Japan, and the United States since the 1990s. The total amount invested by these countries – over 100 million dollars since 1990 – was higher than the amount spent by all other countries combined. In the United States, the R&D budget for alternative energy accounted for 9-10 percent of total government energy spending since 1995 and was increased to around 14 percent from 2004. The primary focus of this spending has been on solar energy and bio energy, though the budget for hydrogen and fuel cell research has expanded drastically since 2000. As of 2004, spending on hydrogen and fuel cell technologies accounted for 40 percent of the government alternative energy research and development budget, while solar energy and bioenergy were allocated 20 percent of this budget each.

In Japan, around 3-4 percent of the total energy budget has been devoted to research and development. At the end of 2004, this proportion was increase to 7 percent. Before 2000, the majority of R&D resources were assigned to solar and geothermal power production technologies, while since 2005, hydrogen and fuel cell, solar and bio energy have been allocated 95 percent of the budget for alternative energy research and development. The budget for geothermal power research decreased significantly from a high level in 1991 until geothermal power was finally taken off the support list in 2003.

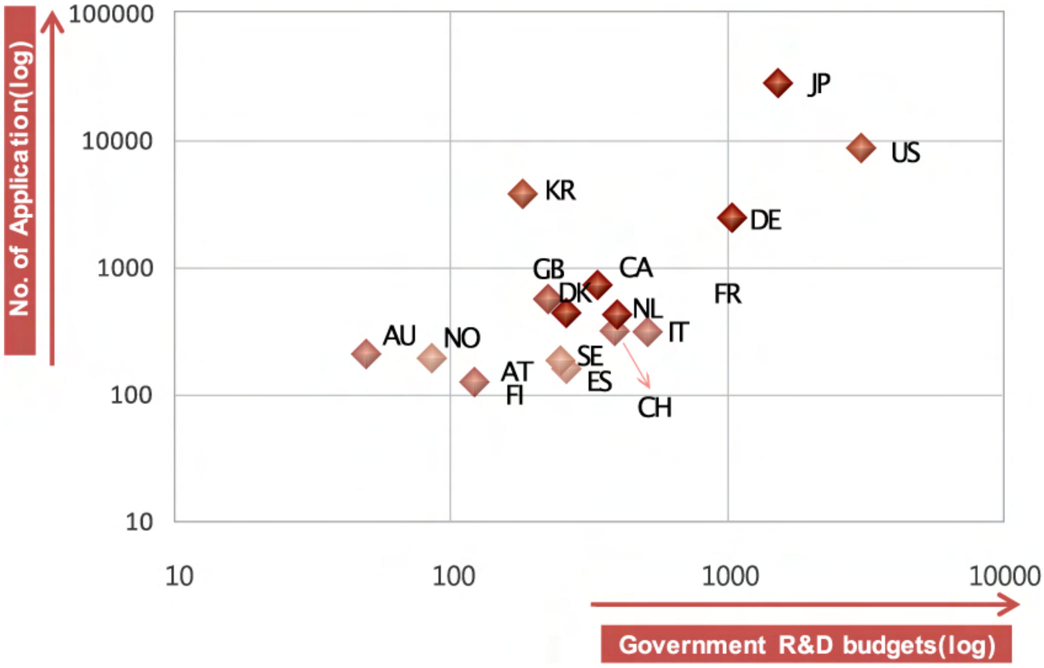
In Germany, a country in which alternative energy technologies have developed the most quickly among all European countries, the budget for research and development accounts for 25 percent of total government energy spending, a very high level indeed. This funding has been allocated primarily to research on solar and wind power. Solar energy receives over 45 percent of total research funding, while the proportion set aside for hydrogen and fuel cell research has increased gradually to 20 percent as of 2005. A number of regulatory policies and subsidies have also played a part in making Germany a market leader in the fields of solar and wind power, including the 2000 Renewable Energy Sources Act.

In Korea, government support for alternative energy technologies began quite late compared to other industrialized countries but by 2000 had reached a comparable level. The Korean government fully funds projects at universities and research institutes, while private companies receive support according to their size (Lee 2007). The level of government support provided is also determined based on the type of technology, the level of development of that technology, the probability of success of the project and the potential, economic and otherwise, of the project (Lee 2007). Hydrogen and fuel cell, photovoltaic and wind power have received particular attention under these programs.

Since alternative energy production must be adapted to national conditions, countries generally seem to focus their efforts on those technologies that best suit their conditions.

The support granted for research into a particular technology in turn generally translates into patent applications in that particular field.

Figure 6 Public R&D budgets vs. patent applications (1996-2005)



AT - Austria, AU - Australia, CA - Canada, CH - Switzerland, DE - Germany, DK - Denmark, ES - Spain, FI - Finland , FR - France, GB - United Kingdom, IT - Italy, JP - Japan, KR - South Korea, NL - Netherlands, NO - Norway, SE - Sweden, US - United States

Source: IEA, Energy Technology RD&D Statistics 2007 Edition

3.1.3. Foreign vs. domestic patent filings

For the purposes of determining the origin of patent applications, applications were classified according to the nationality of the first-named applicant. All applications filed by nationals of contracting parties of the European Patent Convention were considered as domestic patent applications for purposes of the European Patent Office. At EPO, domestic applications constituted 49.5 percent of total applications from 1978-2005. Over the time period examined here, the proportion of domestic filings has declined steadily, with increasing numbers of applications being filed by US and Japanese applicants.

At USPTO, the proportion of domestic applications has declined from the 1970s onward. Nonetheless, they have consistently outnumbered foreign applications, accounting for

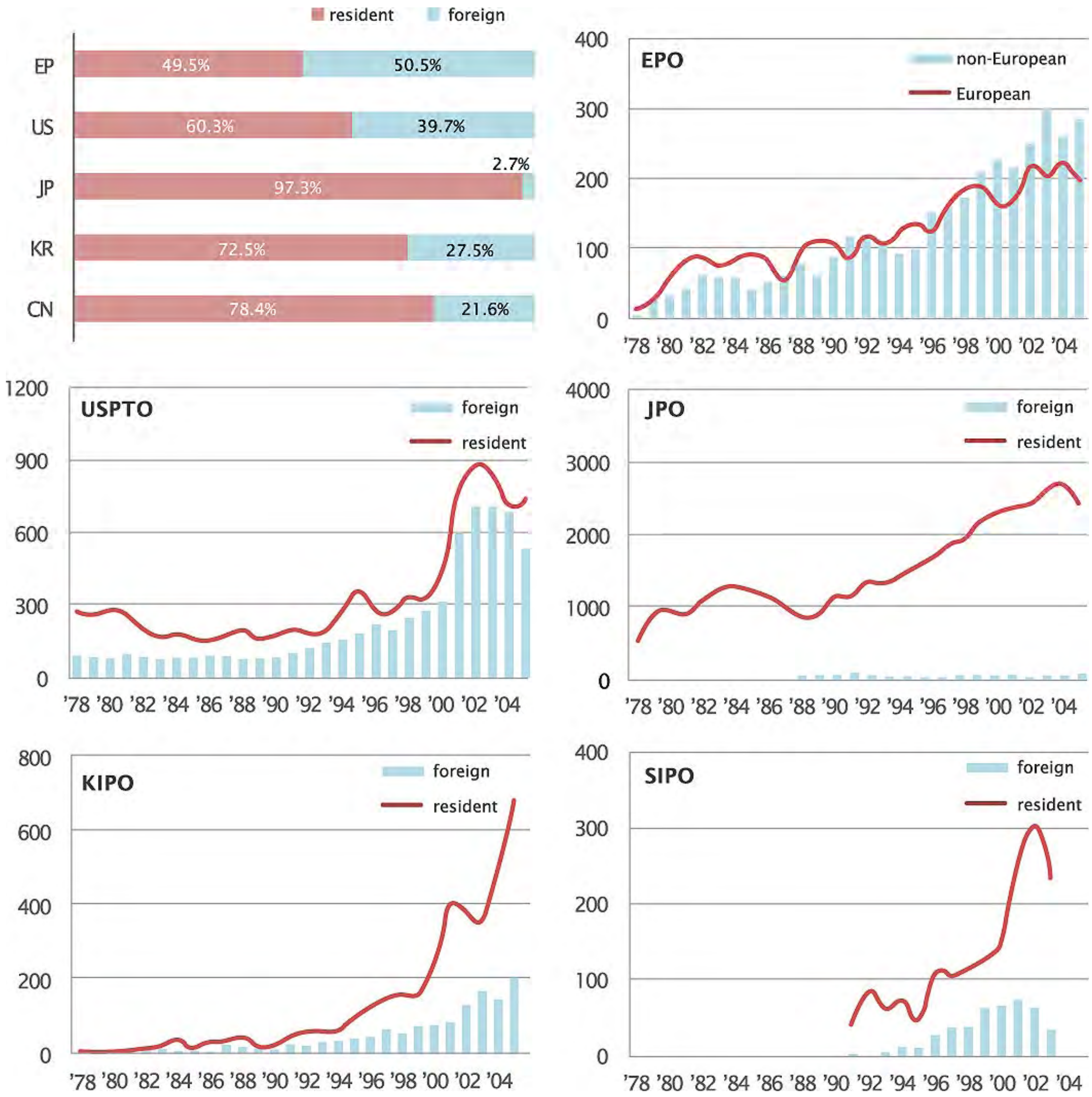
60 percent of total application from 1978-2005.

On average, domestic applications at JPO accounted for 97 percent of total applications. However, it should be noted that priority filings by foreign applicants at JPO were not included in the dataset used for this study. As a result, the actual proportion of domestic applications may be lower than indicated here.

Only few patent applications were filed at KIPO until the 1990s, with foreign applications outnumbering domestic applications. The number of domestic applications has increased rapidly, so that by 2005, 72.5 percent of applications were filed by domestic applicants.

At SIPO, the number of domestic applications exceeded the number of foreign applications from the beginning of the period examined here, with the gap between domestic and foreign applications increasing rapidly from 2001 onwards.

Figure 7 Resident filings vs. non-resident filings by patent office

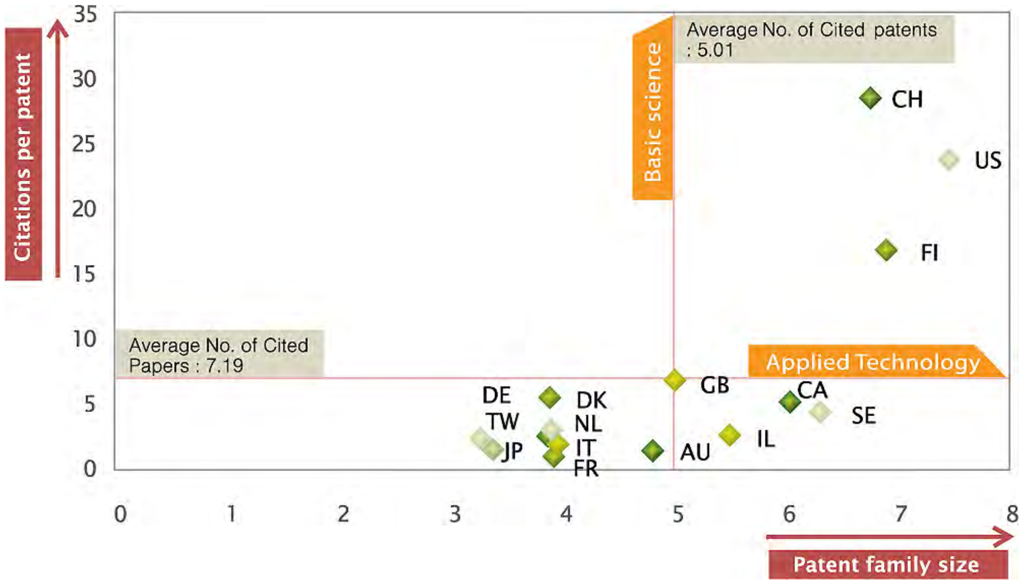


3.1.6. Sources for technological innovation

Citations provided in patent applications constitute a valuable source of information and can be used to determine the orientation of research and development efforts in a particular country. Patent applications deriving references primarily from non-patent scientific and technical literature could be said to focus on basic science, while those with reference obtained mainly from patent documentation could be said to focus on applied technology. US patent applications are a rich source of citation data, since under US patent law, applicants are required to disclose to USPTO in their applications any known prior art.

In terms of patent and non-patent citations, Switzerland, the United States and Finland appear to orient themselves mostly towards basic science, having a particularly high ratio of patent to non-patent citations. Basic science builds the foundations for technological innovation, and the research from universities and research institutes can be developed into commercial technologies, creating new markets and providing fuel for economic development.

Figure 8 Non-patent citations vs. patent citations



3.1.4. Technology focus

Based on the fact that the number of patent applications filed at each patent offices varies among different alternative energy technologies, with some offices having more applications in one field than others, it can be concluded that applicants pursue different strategies according to countries' local resource conditions and degree of technological and economic development.

At EPO, Japanese and US applicants account for the largest number of alternative energy patent filings. While Japanese applications focus primarily on hydrogen and fuel cell technologies, US applications are distributed relatively equally between CCS, wind power, hydrogen and fuel cell, bio energy and solar energy technologies. Among European countries, which trail Japan and the United States in terms of number of patent applications, Germany, France, the United Kingdom, Italy and Switzerland hold the top places. Applications from Germany concentrate particularly on CCS and those from Denmark and Spain on wind power. Canadian applications focus on hydrogen and fuel cell technologies.

The distribution of German applications at EPO among different technologies were as follows between 1978-2005: 35 percent were filed for CCS technologies, followed by solar energy (12 percent), bio energy (12 percent), wind power (11 percent) and waste-to-energy (11 percent). The share of alternative energy in total primary energy supplies has increased from 1.5 percent in 1990 to 3.2 percent in 2004, with bio energy accounting for 60 percent of that amount, wind for 18 percent, and hydropower for 15 percent (IEA 2006b). The largest portion of the alternative energy research and development budget was allocated to solar energy in 2005, followed by hydrogen and fuel cell technologies, wind power, bio energy, and geothermal energy (IEA 2007a). In terms of market share, the fastest growing fields of alternative energy are photovoltaic and wind power (Lee 2007). The subsidies and price supports as well as programs such as the “100 000 solar roofs” program have made Germany the world’s largest market for solar cells as of 2004 (Brown 2001). Wind power facilities in Germany account for one-third of all wind power produced worldwide (Lee 2007).

Among French alternative energy applications at the EPO from 1978-2005, hydrogen and fuel cell technologies held the first place with 20 percent of all such applications, followed by carbon capture and storage (17 percent), wind power (16 percent), hydropower (13 percent), wave and tidal power (11 percent) and bio energy (9 percent). The share of alternative energy in primary energy production in France is 6 percent, while its share in power generation is as high as 11.6 percent, with a substantial contribution from hydropower (IEA 2006a). Hydrogen and fuel cell research received the largest portion of the French government alternative energy research and development budget, trailed by solar energy and bio energy (IEA 2007a).

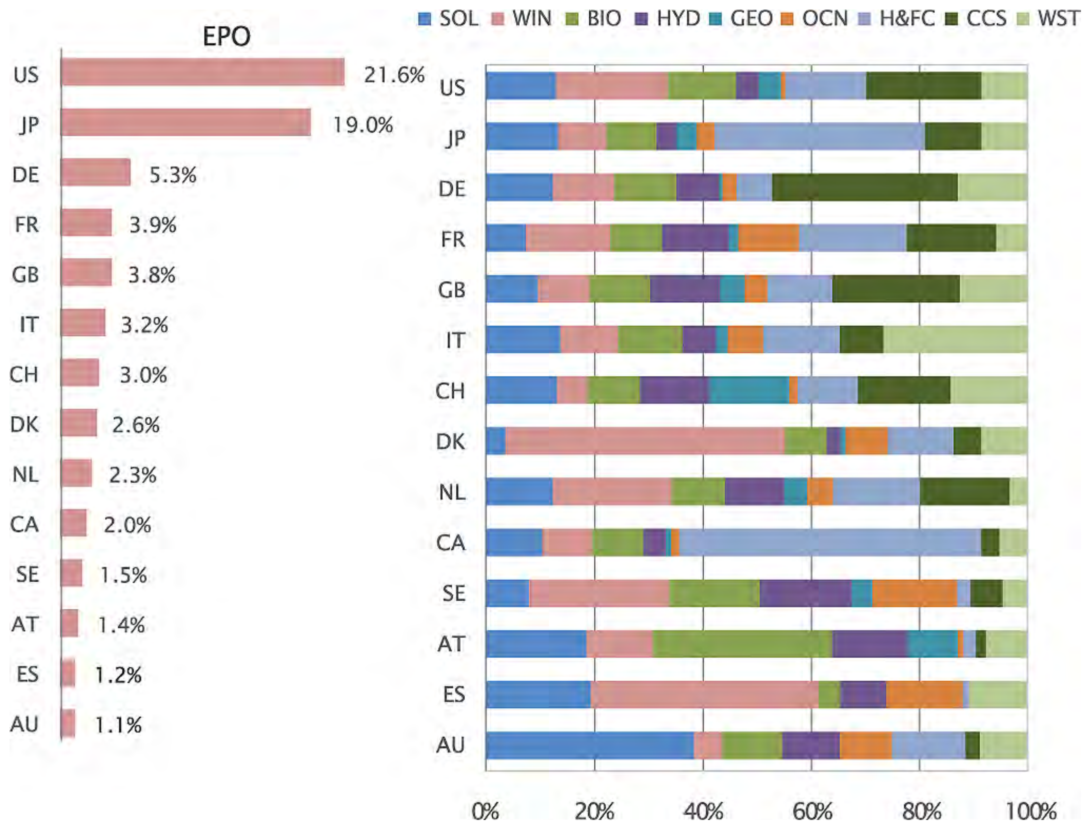
With 24 percent of total alternative energy filings, carbon capture and storage technologies account for the largest share of UK applications at EPO, followed by hydropower (13 percent), hydrogen and fuel cell (12 percent), waste-to-energy (12 percent), bio energy (11 percent), wind power (10 percent) and solar energy (9 percent).

The United Kingdom trails Germany and Denmark in terms of the share of alternative energy in primary energy production (1.5 percent) and total power generation (2.8 percent) (IEA 2006a). In 2005, the British government increased the budget for alternative energy research seven-fold with respect to the level in 2000, with solar and wind power receiving a particularly large share of this support (IEA 2004a; IEA 2007a)

The wind power industry in Denmark has grown rapidly during the past 20 years, so its share in the global wind turbine market had increased by over 40 percent with respect to its share in 2005. This growth has widely been credited for a decline in Denmark's dependence on oil (Lee 2007). A particularly successful project has been the wind power test station established by the Risø National Laboratory. Since 1979, wind turbines approved and certified by the test station have been eligible for substantial subsidies from the government (MKE 2005).

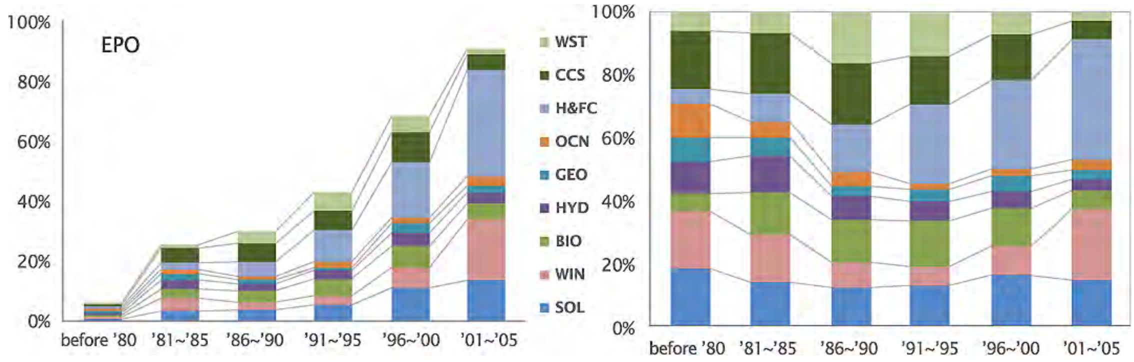
Overall, patent applications in the fields of solar and wind power and hydrogen and fuel cells have been increasing at EPO. Between 2001 and 2005, hydrogen and fuel cells accounted for 40 percent of total applications, followed by wind power (23 percent) and solar energy (16 percent). The development of hydrogen and fuel cell technologies can still be considered at its initial stage in the European Union. Research and development budgets allocated to hydrogen and fuel cell technologies increased 16-fold for the five-year period from 2002 to 2006 compared to the period from 1997 to 2001 (IEA 2007a). The commercialization of fuel cell technologies, establishing and merging of hydrogen supply infrastructure, and mass-production of fuel cells are main research themes (Jo 2005).

Figure 9 Applications at EPO by applicant nationality



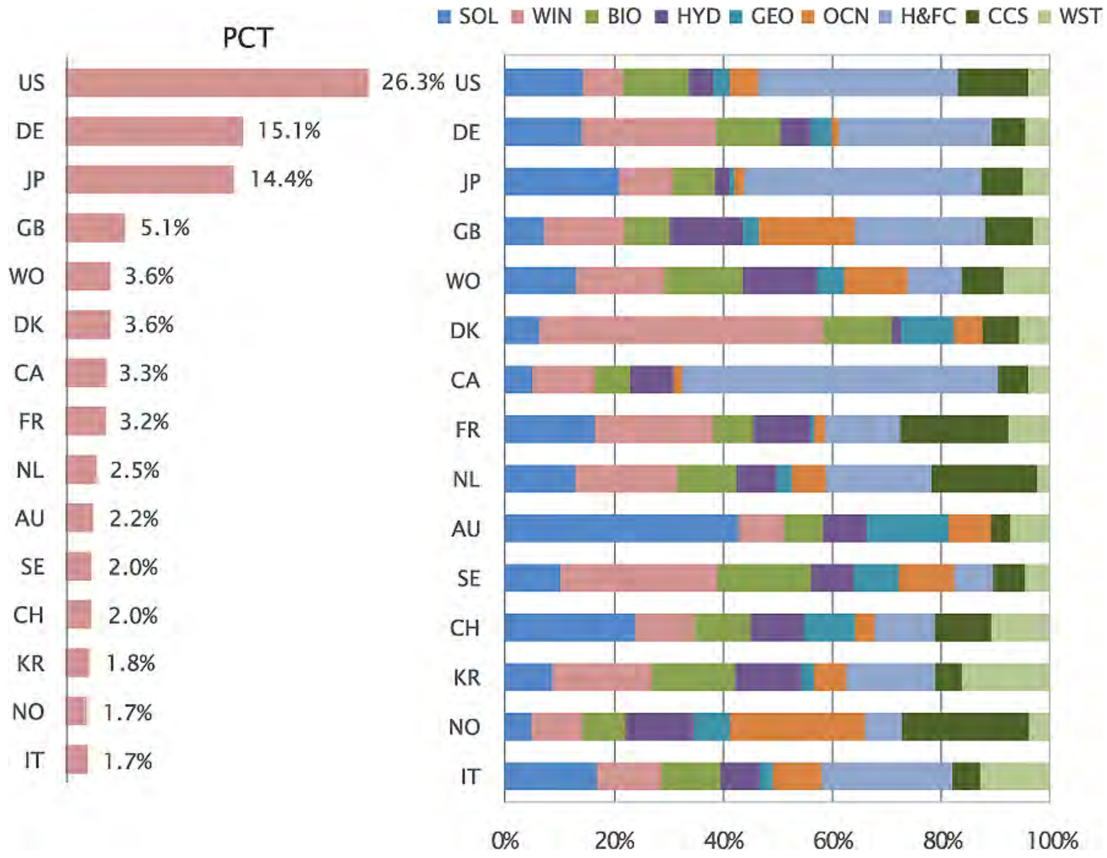
The European Union leads the world in terms of Wind power production, accounting for 74 percent of global wind power production and 90 percent of total power production facilities in 2005 (Lee 2007). Many countries' research efforts are performed under the leadership of the European Union. Under the International Energy Agency (IEA) Implementing Agreement for Co-operation in the Research, Development, and Deployment of Wind power Systems, or IEA Wind, a large-scale effort has been launched into sea and large wind power generation (IEA 2007b). Though only few patent applications were filed for wind power technologies prior to 2000, the number of applications have increased rapidly in more recent years.

Figure 10 Applications at EPO by technology



US applicants account for the largest proportion of alternative energy patent applications filed under the Patent Cooperation Treaty (PCT) at 26.3 percent of total applications and tend to focus primarily on hydrogen and fuel cell technologies. They are followed by German applicants (15 percent) and Japanese applicants (14 percent), who filed primarily in solar and wind power and hydrogen fuel cell technologies. In contrast, German applicants file primarily in CCS technologies at EPO. Danish applicants file mainly for wind power technologies, while Canada and Australia focus on hydrogen and fuel cell and solar energy technologies, respectively.

Figure 11 Applications through the PCT system by applicant nationality

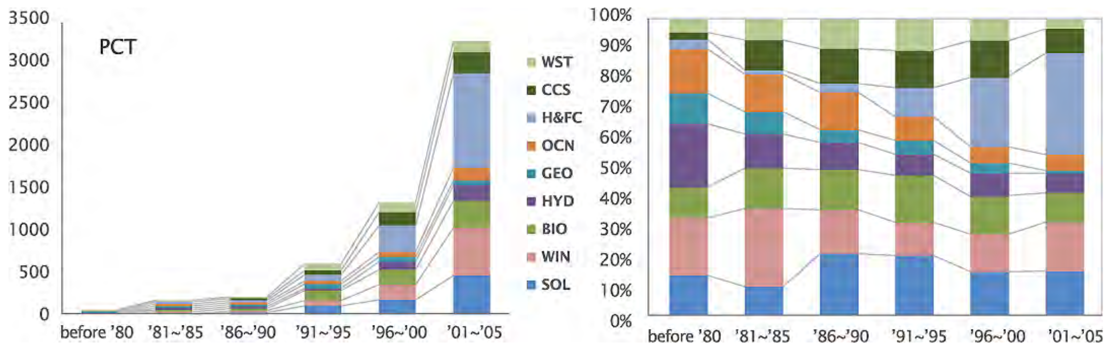


Canada is a net exporter of energy resources with abundant fossil fuel and uranium reserves (MKE 2005). Large-scale hydropower and bio energy energy production appear to be practical options for supplying Canada's alternative energy needs. Alternative energy production has increased rapidly in Canada and supplied more than 15 percent of primary energy produced in the country from the 1990s (MKE 2005). By 2006, alternative energy accounted for 53 percent of primary energy production (MKE 2005). As a result of its substantial alternative energy production and large conventional energy resources, Canada is in a very favorable situation with respect to its energy security.

Australia is the world's largest coal exporter, accounts for 30 percent of global uranium production and is the world's third largest liquid natural gas (LNG) exporter. Nonetheless, alternative energy accounted for 5.6 percent of primary energy production in 2003. The Australian government has allocated 13 percent of its total energy budget to alternative energy research and development since 2000, with a primary focus on solar energy and bio energy (IEA 2007a). The hydrogen and fuel cell research budget has strongly increased since 2003, such that this field together with bio energy have since become the largest recipients of government funding (IEA 2007a). Australia is a signatory of the Kyoto Protocol and in 1997 launched the Renewable Energy Industry Development program, which provides incentives for installing solar heating systems and biomass combustion systems of high efficiency.

Overall, PCT patent applications have followed similar trends as European patent applications at EPO with respect to the distribution of applications among different technologies. Solar and wind power and hydrogen and fuel cell technologies, most notably, have seen substantial increases in patent applications, both in terms of numbers and shares in total alternative energy filings.

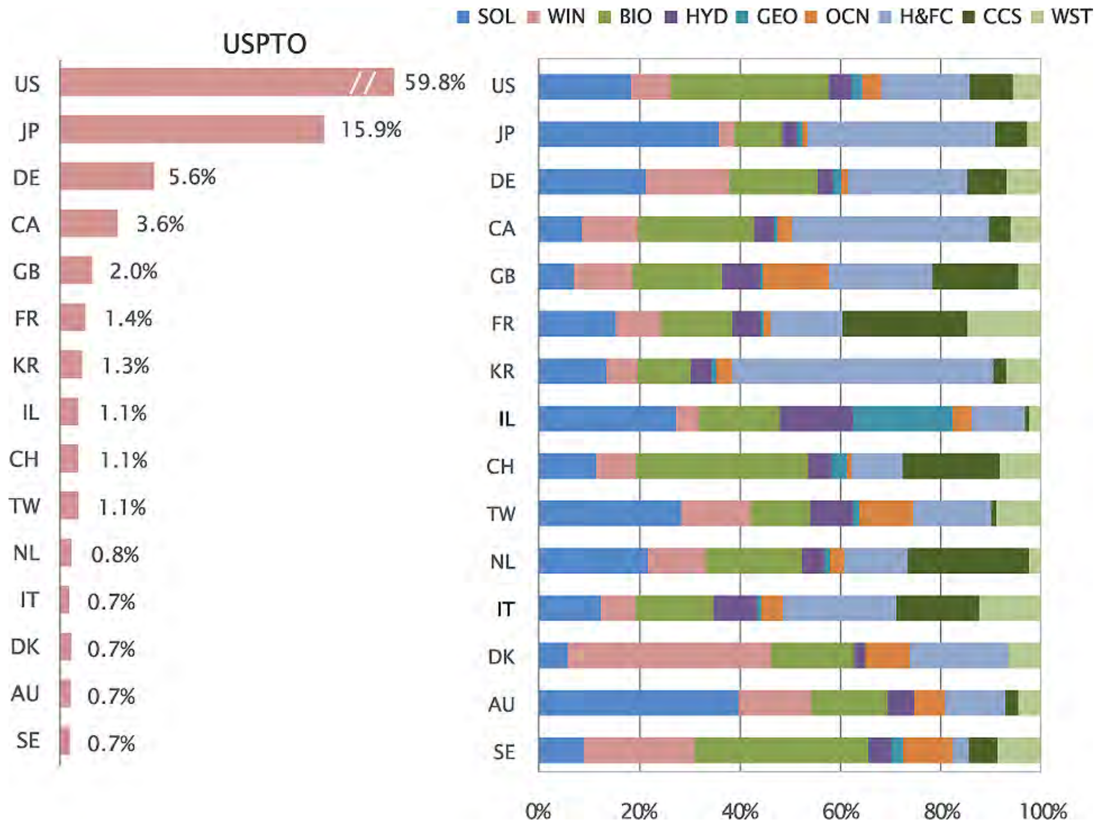
Figure 12 Applications through the PCT system by technology



At USPTO, US applicants accounted for 60 percent of alternative energy patent applications from 1978-2005, trailed by Japanese (15.9 percent), German (5.7 percent), and Canadian (3.6 percent) applicants. US applicants filed primarily in the fields of solar energy, bio energy, and hydrogen and fuel cell technologies, with bio energy holding the largest share of applications (32 percent). Japanese applications concentrated in solar energy and hydrogen and fuel cells, while German applications were filed primarily for solar, wind, bio energy and hydrogen and fuel cell technologies. Canadian and Korean applications were mostly filed for hydrogen and fuel cell technologies, Swiss and Swedish for bio energy and Danish for wind power technologies.

The amount of alternative energy produced in the United States is 7 percent of the amount produced using fossil fuels (IEA 2007d). Bio energy provides 48 percent of this amount, followed by hydropower (42 percent), geothermal (5 percent), wind power (4 percent) and solar energy (1 percent) (IEA 2006f). In the 1970s, the primary target of investment into alternative energy power production was geothermal energy. Since then, the share of investment received by bio energy and hydropower has increased substantially, with biogas production increasing fourfold between 1992 and 2001. Power generated from refuse-derived fuel (RDF) has increased by 6 percent between 1990 and 2001. The overarching goal of US energy policy is to reduce the country’s dependence on imported energy by increasing use of domestic energy sources and increasing energy efficiency (Lavigne 2007). The Energy Policy Act (EPACT), signed into law in 1992, is among the most important energy policies implemented by the United States government and provides for a 10-percent Production Tax Credit (PTC) for renewable energy production. The Renewable Portfolio Standard, introduced in 1997, requires that electric power supplier obtain a minimum share of their power from alternative energy sources – solar, wind, biomass or geothermal.

Figure 13 Applications at USPTO by applicant nationality

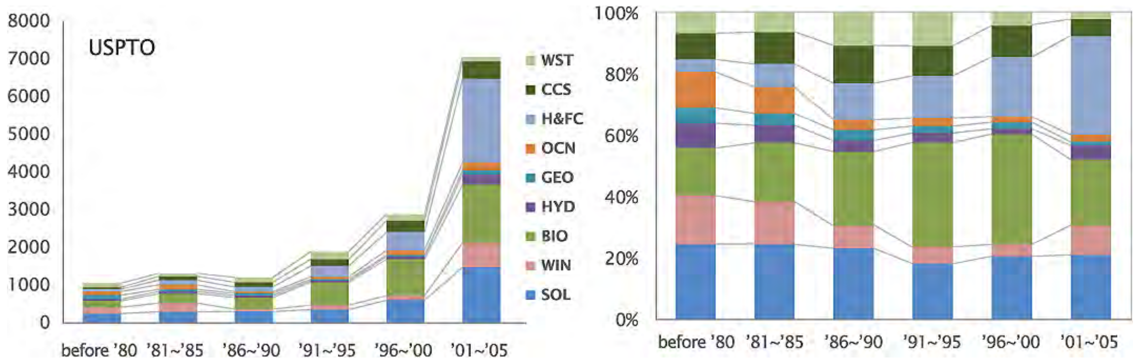


Applications at USPTO are filed primarily for solar, bio energy, and hydrogen and fuel cell technologies. Bio energy has received increasing attention since 1991, with applications rapidly increasing until 2000. Substantial support has been provided for the use of biomass in power generation and for biofuels, for example in the form of ethyl tert-butyl ether (ETBE), a common gasoline additive. Under energy tax regulation passed in 1998, domestic ethanol producers received a subsidy of 51 cents per gallon of ethanol tax exemptions. This tax exemption was transformed into an ethanol blender tax credit of 51 cents per gallon in 2004. At the same time, imports of biomass and biofuels are restricted through high tariffs, for example a 53 cents per gallon border tax on ethanol collected since 1980 (Dudley 2008; SEF 2008).

Hydrogen and fuel cell technologies have seen increasing numbers of applications at USPTO since the mid-1990s. Fuel cells were initially designed for use in spacecraft but in the 1990s, further civilian uses were identified. Recently, the US government, together with major automotive and refinery companies laid out a “National Hydrogen Energy Roadmap” to foster research and development of hydrogen-related technologies. Commercialization of hydrogen liquefaction systems and automotive fuel cells has also been a focus of industry in the United States (DOE 2006).

In the early 1970s, the primary focus of solar energy technologies was on heating uses. Since then, development has focused increasingly on photovoltaic technologies. All in all, the geographic situation of the United States is very favorable for solar power generation.

Figure 14 Applications at USPTO by technology

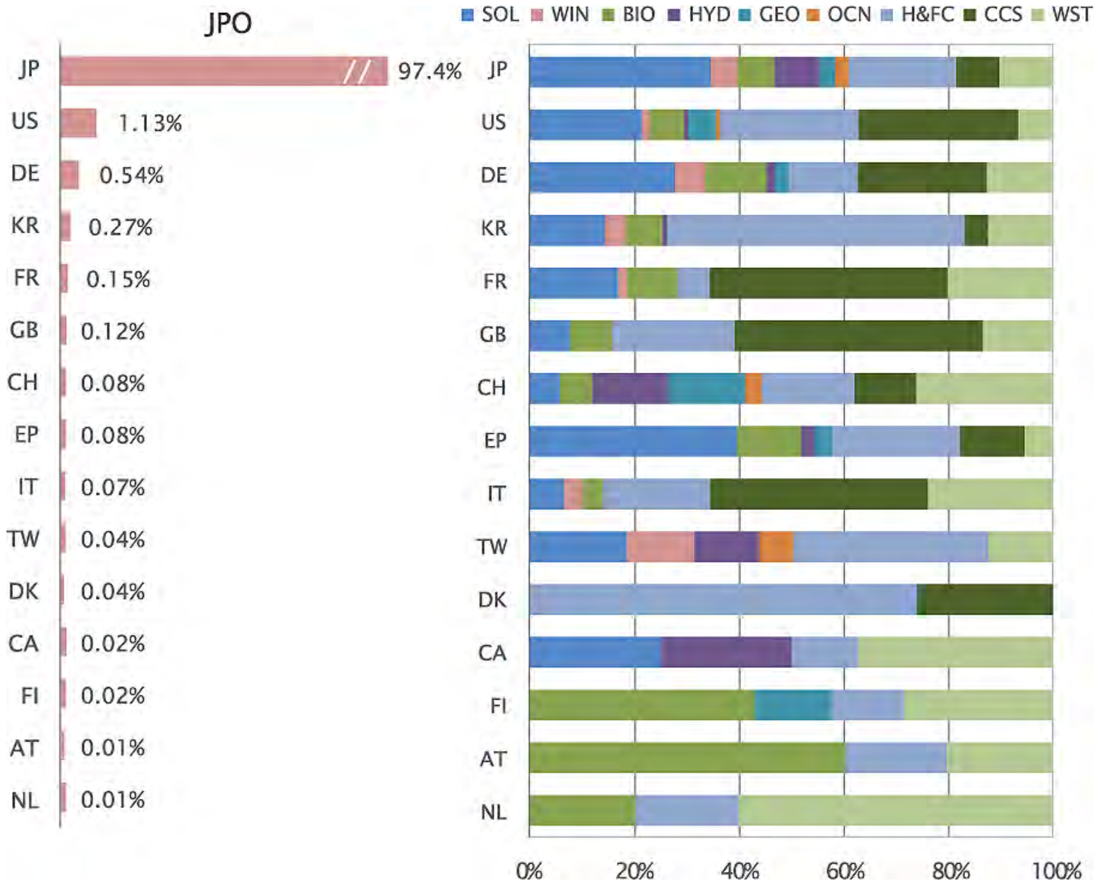


Most alternative energy patent applications at JPO were filed by Japanese applicants, who account for 97.8 percent of all applications in this field. Japanese applicants filed primarily for solar energy technologies (35 percent of total alternative energy applications), hydrogen and fuel cell (20 percent) and waste-to-energy (11 percent) technologies. In contrast, at other patent offices, Japanese applications focused more strongly on hydrogen and fuel cell technologies. Most foreign applications were filed for solar energy, hydrogen and fuel cells, CCS and waste-to-energy technologies. At JPO, applications from Denmark were filed primarily for hydrogen and fuel cell and CCS technologies, while at other offices, Danish applicants filed primarily in the field of wind power. Applicants from Finland and Australia distinguished themselves from the general trend of foreign filings at JPO, focusing mainly on bio energy technologies.

The number of patent applications for solar energy technologies has remained quite constant since 1980s, while applications for hydrogen and fuel cell technologies increased rapidly between 2001 and 2005, now outnumbering those for solar power.

Overall, most alternative energy patent applications are filed for solar power and hydrogen and fuel cell technologies, with the already small number of hydropower applications declining rapidly in recent years.

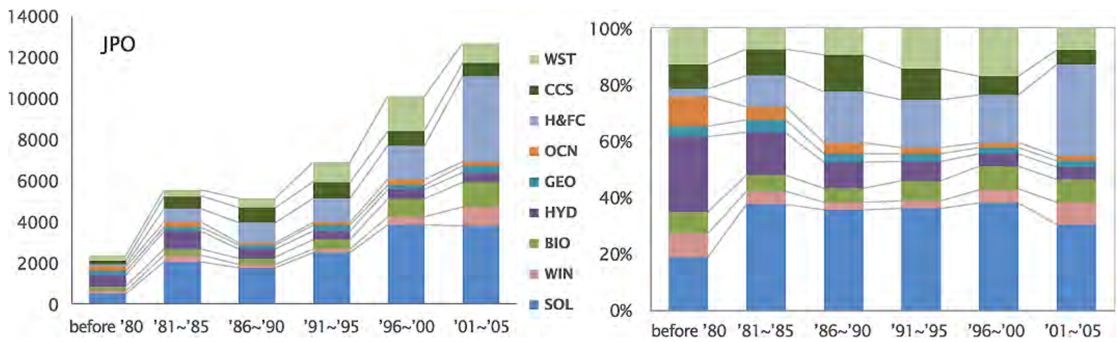
Figure 15 Applications at JPO by applicant nationality



The stated purpose of Japanese energy policy is to obtain high-efficiency energy technologies and diminish dependence on imported resources (Lee 2007). In spite of substantial government support and a large number of patent applications filed for alternative energy technologies, the share of alternative energy in total energy supplies remains low, at 3.5 percent in 2004 (IEA 2006c). The largest part of alternative energy production is accounted for by hydropower with 92.2 percent of production, followed by waste-to-energy (2.9 percent), solar (2.2 percent), wind (1.5 percent) and geothermal (1 percent) (IEA 2006e).

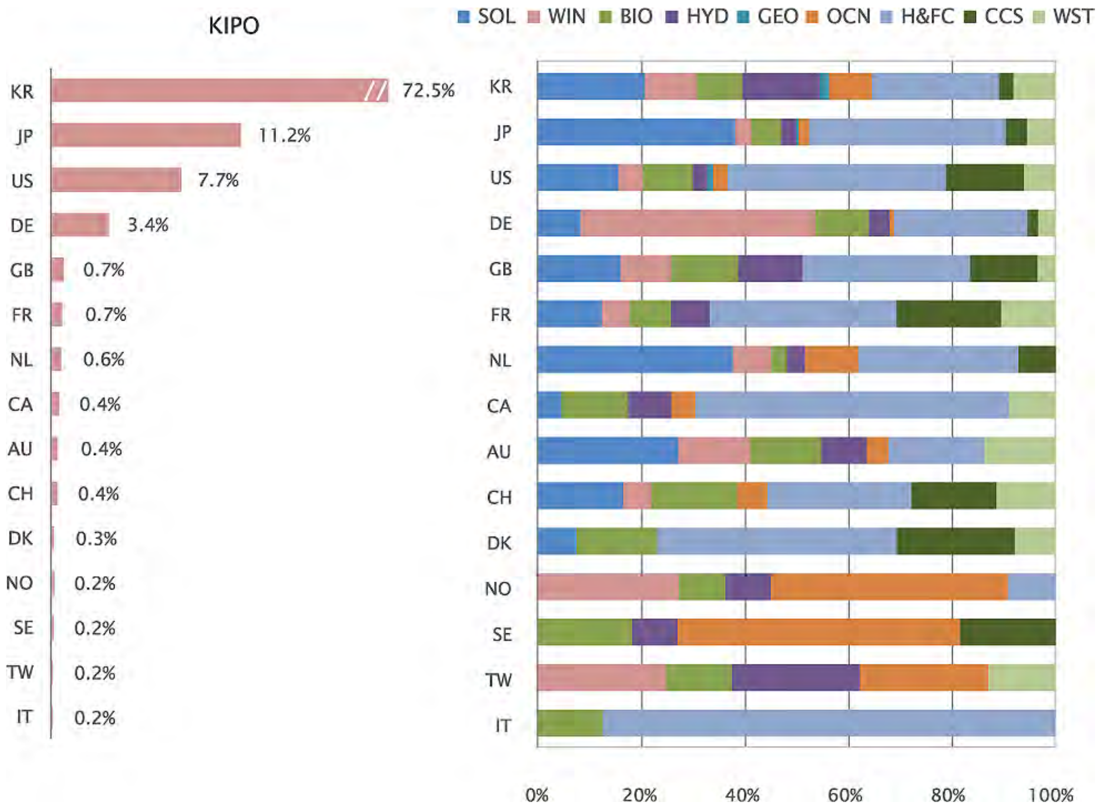
Solar energy and hydrogen and fuel cells have been identified as particularly promising technologies by the Japanese government and have consequently been the target of a major part of the government's support efforts. Renewable Portfolio Standards (RPS) were introduced to support photovoltaic power generation (MKE 2005), while the government provides subsidies for the installation of home solar power panels through the New Energy Foundation (NEF). Japan has caught up with the United States in terms of solar power capacity, market size, and technological development in no small part as a result of this support. Cooperation between the public and private sector on fuel cell technologies is facilitated through the Fuel Cell Commercialization Conference of Japan (FCCJ), whose members include companies such as Toyota and Honda, which have grown into world market leaders in automotive uses of fuel cell technology. Apart from promoting solar energy and hydrogen and fuel cells, the Japanese government also has set itself the target of increasing bio energy and waste-to-energy generation capacities to 330 megawatts and 4170 megawatts, respectively (IEA 2006c).

Figure 16 Applications at JPO by technology



The largest proportion of alternative energy patent applications filed at KIPO is accounted for by Korean applicants (72.5 percent), followed by Japanese (11.2 percent), US (7.7 percent) and German (3.4 percent) applicants. Overall, alternative energy patent applications are relatively even distributed between different technologies, though hydropower and CCS-related applications account for a larger than average proportion. Japanese and US applicants appear to focus primarily on solar energy and hydrogen and fuel cell technologies, while German applicants are particularly active in the fields of wind power and hydrogen and fuel cells. Norwegian, Swedish and Taiwanese applications are filed primarily for wave and tidal energy technologies.

Figure 17 Applications at KIPO by applicant nationality



Considering that Korea has been a late starter in terms of alternative energy development, progress in this field has been very rapid, largely as a result of active support from the Korean government. The share of alternative energy in primary energy production has increased rapidly in recent years, jumping from 0.4 percent in 1990 to 2.24 percent in 2006.

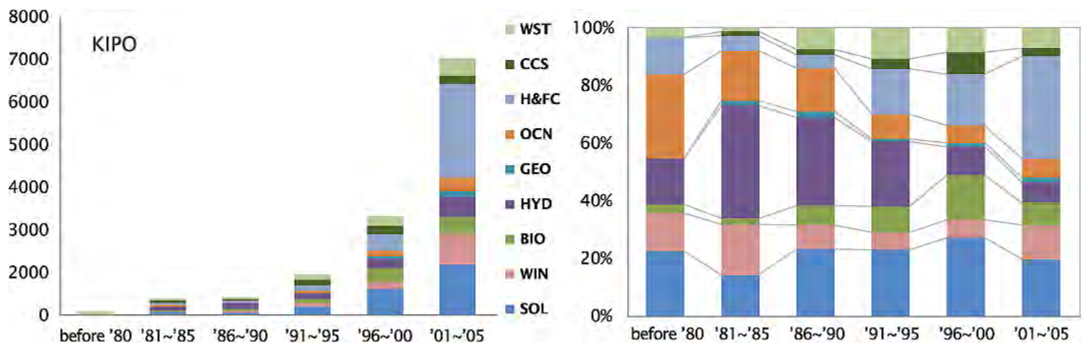
The Korean government has chosen to focus its support on four major energy technologies: hydrogen and fuel cell, photovoltaic, wind and coal integrated gasification combined cycle (IGCC). Specifically, the Korean government has supported the development of 300 kilowatts of molten carbonate fuel cell (MCFC) capacity as well as next-generation solar cells and mid-to-large wind power generation systems with 1 to 2 megawatt capacities (MKE 2007).

Since similar production facilities and resources are used for producing poly-crystalline solar cells and semiconductors, the large semiconductor production capacities available in Korea is expected to give the country a substantial advantage in producing solar cells.

A substantial effort is being invested in the commercialization of ultra-thin crystalline solar cells to allow mass production at low cost for home use (Kim 2006a). Fuel cell development has also been advancing rapidly, allowing greater possibilities for use in automobiles and the development of new technologies (Kim 2006a).

Prior to 1990, most alternative energy patent applications at KIPO were filed for hydropower and geothermal energy technologies. From the 1990s onward, their share in applications declined, while the share held by solar energy and hydrogen and fuel cell technologies increased. The share of applications accounted for by wind power, bio energy, wave and tidal power and waste-to-energy technologies has remained relatively constant and far smaller than the share from geothermal and CCS technologies.

Figure 18 Applications at KIPO by technology



The large majority of applications filed at SIPO are of Chinese origin (76.7 percent), while applications by Japanese, US and German applicants account for 9.5 percent, 3.7 percent, and 2.4 percent of applications, respectively. While the distribution of applications among different alternative energy technologies is fairly balanced, solar and geothermal technologies are predominant. Japanese applicants tend to file patent applications for solar and hydrogen and fuel cell technologies, while US applicants focused on hydrogen and fuel cell, solar, and CCS technologies, German and Danish on wind power technologies, and Swedish and Norwegian on geothermal technologies.

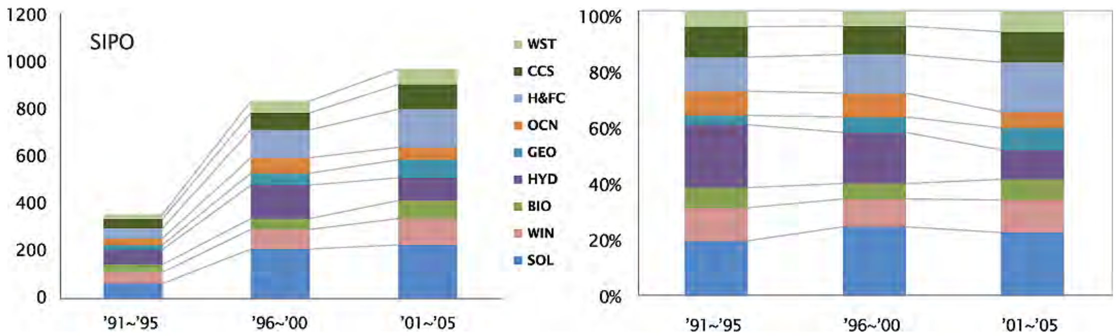
Figure 19 Applications at SIPO by applicant nationality

China's energy consumption has increased rapidly with economic growth, rising by 55 percent between 2001 and 2005, while GDP increased by 9.5 percent per year during that period (Kim 2006b). Concerned with the implications of this development on energy security, the Chinese government began launching policies aimed at increasing energy efficiency. As regulations governing renewable energy were approved, research and development into renewable energy also began to take off.

Within the framework of an effort by the Chinese government to achieve broad commercial use of wind, solar, and hydrogen and fuel cell technologies, the Ministry of Science and Technology and the National Development and Reform Commission have been charged with supplying human resources and coordinating the budget for research and development in these fields (Lee 2007). Most recently, the National Development and Reform Commission released the 2007 mid and long-term plan for alternative energy development in 2006. Under this plan, the Chinese government will invest a total of 1 trillion yuan into small hydropower, wind power, bio energy, and solar energy facilities until 2020. In order to raise the share of alternative energy in total energy production from 8 percent at present to 10 percent in 2010 and 15 percent in 2020, the Chinese government will provide price supports, tax deductions, and direct investment for alternative energy installations (IEA 2004b; Kim 2007b).

The distribution of patent applications at SIPO between different alternative energy technologies has been relatively equal and constant over time. The only exception has been hydropower-related applications, which have declined substantially during the period examined here.

Figure 20 Applications at SIPO by technology

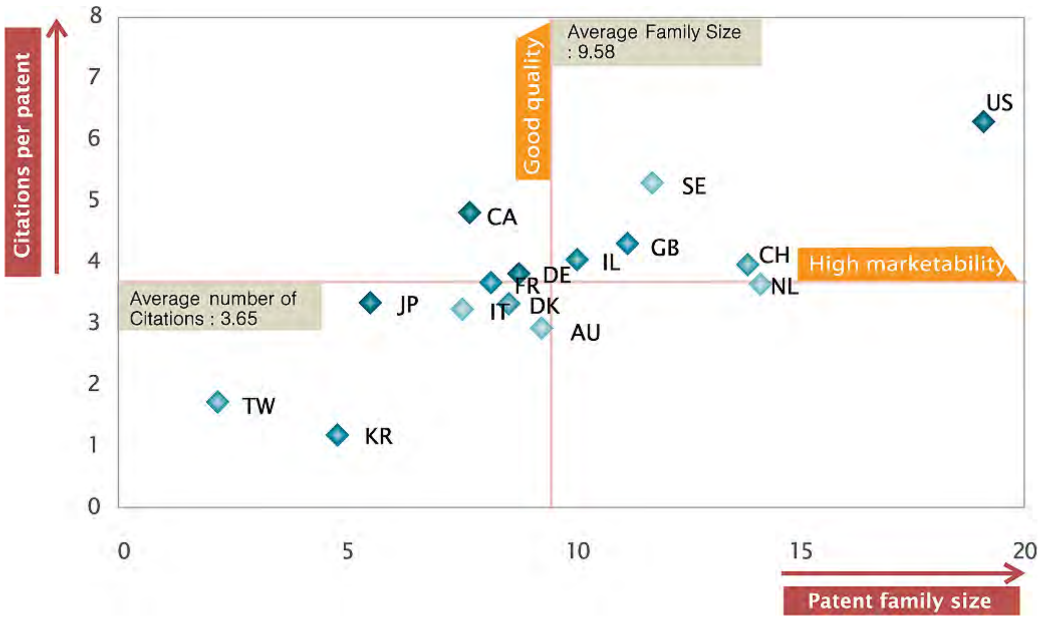


3.1.5. Perceived commercial value and technology influence

The perceived commercial value of a particular technology can be measured by evaluating the number of patent applications resulting from a specific patent application, or patent family size (PFS). How influential a patent application is within the patent system can be determined by examining the number of times that application is cited in subsequent patents, or citations per patent (CPP). In this study, the citation information contained in US patents was used for the purpose of determining CPP.

Using these measures, the United States, Sweden, the United Kingdom, Israel, and Switzerland were above the global average in terms of both perceived commercial value and technological influence, with the United States leading in both areas. In terms of perceived commercial value, the Netherlands ranked above the average PFS of 9.58, while in terms of technological influence, Canada and Germany led the average CPP of 3.65. Australia, Denmark, France, and Italy were slightly below the average for both PFS and CPP, while Taiwan and Korea rank significantly below the average for both. However, since the number of Taiwanese and Korean applications at USPTO and thus the sample size used here for those countries is small, the interpretation of the results for Korea and Taiwan is difficult.

Figure 21 Patent family size and citations per patent



3.1.7. Technology specialization

The distribution of patent application activity between different technologies can be measured using an Activity Index (AI), which compares the number of patents for a specific technology with the number of patents for all technologies.[2] An Activity Index greater than unity indicates a high level of concentration of patenting activity in a particular field of technology. For this study, the major applicants were sorted according to nationality for the patent offices of Japan, the United States, Germany, the United

[2] The formula used for the Activity Index (AI) is the following: where F is the number of patent filings in a given field of technology and for a specific applicant and a t are indexes for the applicant and the field of technology, respectively:

$$AI = \frac{F_{a,t} \Big/ \sum_{a} F_{a,t}}{\sum_{t} F_{a,t} \Big/ \sum_{a,t} F_{a,t}}$$

L. Soete. 1980. The Impact of Technological Innovation on International Trade Patterns: The Evidence Reconsidered. Paper presented to an OECD Science and Technology Indicators Conference, Paris.
L. Soete. 1981. A General Test of Technology Gap Trade Theory. Weltwirtschaftliches Archiv, 117.
L. Soete. 1987. The Impact of Technological Innovation on International Trade Patterns: The Evidence Reconsidered. Research Policy, 16: 101-130.

Kingdom, France and Canada and each field of technology was examined at the level of sub-technology (e.g., solar thermal as a sub-field of solar energy technologies).

In the field of solar energy, Japanese applicants showed an AI greater than unity at all patent offices except the USPTO, which indicates that Japanese applicants are particularly active in that field of technology. German applicants had an AI greater than unity at EPO, USPTO, and JPO but smaller than unity at SIPO and KIPO, suggesting that the concentration of filing activity for solar energy technologies is smaller at the latter offices than the former.

In the field of wind power, the concentration of German applications is notable, especially at KIPO. This finding can be linked to the fact that, generally speaking, most applications at KIPO are filed for solar energy, hydropower, and fuel cell technologies. Applicants from the United Kingdom and France also appear to concentrate strongly on wind power technologies at EPO and USPTO as well as in terms of applications filed through the PCT system.

For bio energy technologies, it appears that US applicants focus heavily on the Asian market, with a particularly significant concentration being found at KIPO and SIPO. Applicants from Germany, the United Kingdom, and France concentrated their filing activity for bio energy technologies at EPO and JPO.

With respect to geothermal energy, little patenting activity could be detected at any of the patent offices examined here. Applicants from the United Kingdom, France, and Canada filed no applications at JPO, KIPO, and SIPO, while only US applicants filed applications at KIPO and SIPO. Similarly, wave and tidal power technologies did not see much patenting activity, except by US and UK applicants. US applicants were active at KIPO and SIPO, whereas UK applicants concentrated their activity at EPO and USPTO and filed actively through the PCT system.

Hydrogen and fuel cell technologies saw significant activity by Japanese, US, and Canadian applicants. Japanese and Canadian applicants had an AI greater than unity for all patent offices except USPTO and JPO, respectively. US applicants were particularly active at JPO, KIPO, and SIPO. French applicants lagged behind applicants from other countries, with a low AI for hydrogen and fuel cell technologies.

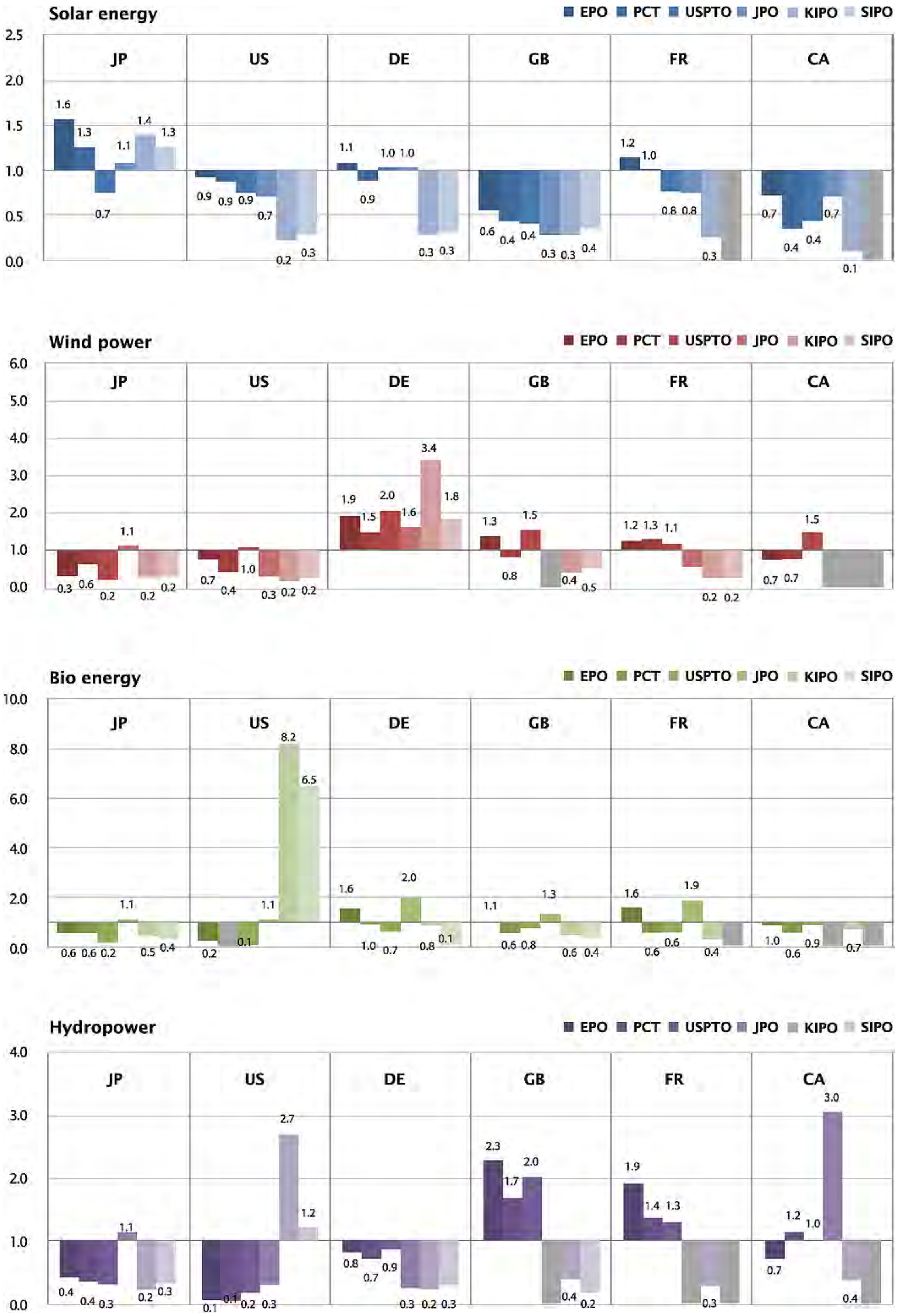
In the field of carbon capture and storage, only a small amount of patenting activity could be detected, as exemplified by Canadian applicants with an AI of nearly zero. Only US applicants showed any significant level of activity, at KIPO and SIPO.

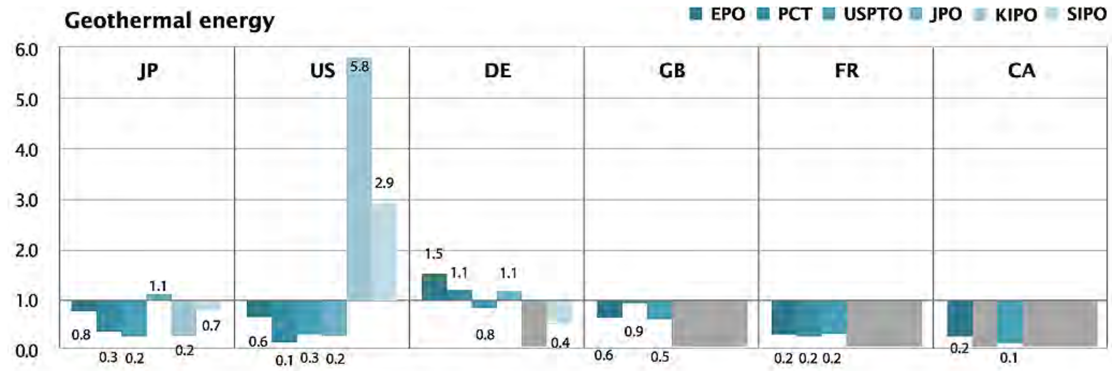
In terms of waste-to-energy technologies, French and German applicants were particularly active generally, while US applicants showed high levels of patenting activity at KIPO and SIPO. French applicants were negligible in terms of patenting activity in this field at SIPO but were highly active at EPO, USPTO, and JPO and in terms of filing through the PCT system.

On a country basis, Japanese applicants were particularly active in filing patent applications for solar energy technologies across all patent offices, while US applicants concentrated in filing applications at KIPO and SIPO for bio energy, hydropower, geothermal, wave and tidal power, hydrogen and fuel cell, carbon capture and storage, and waste-to-energy technologies. German applicants concentrated primarily on wind and waste-to-energy technologies, with a particularly high AI for wind power technologies across all patent offices. At EPO and USPTO and through the PCT system, UK applicants were particularly active in the fields of hydropower and wave and tidal power. French applicants concentrated especially on hydropower and waste-to-energy technologies, while Canadian applicants focused on hydropower and fuel cell technologies.

Among other countries, applicants from Denmark were particularly active in filing patents for wind power technologies, with an average AI of 4.9 across the different patent offices, a high level of patent activity concentration. Italian applicants focused on hydrogen and fuel cell technologies, with an average AI of 1.8, Australian applicants on bio energy, with an average AI of 3.1, and China on solar and hydropower, with an AI of 1.3 and 1.2, respectively.

Figure 22 Patent Activity Index (AI) by country




Geothermal energy
EPO
PCT
USPTO
JPO
KIPO
SIPO
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0.0
0.8 0.3 0.2 1.1 0.2 0.7
0.6 0.1 0.3 0.2 5.8 2.9
1.5 1.1 0.8 1.1 0.4
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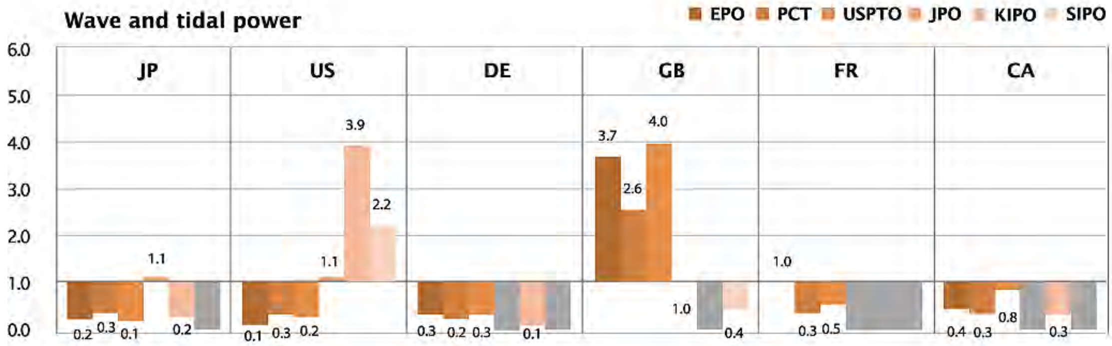
Wave and tidal power
EPO
PCT
USPTO
JPO
KIPO
SIPO
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6.0
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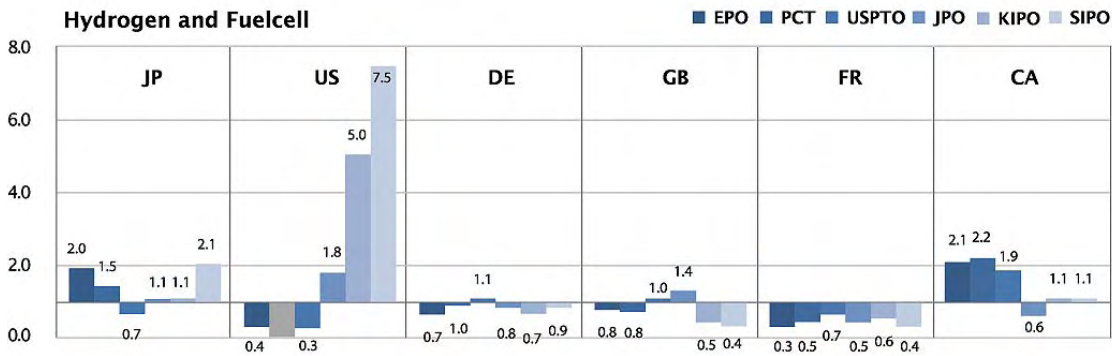
Hydrogen and Fuelcell
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PCT
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0.7 1.0 1.1 0.8 0.7 0.9
0.8 0.8 1.0 1.4 0.5 0.4
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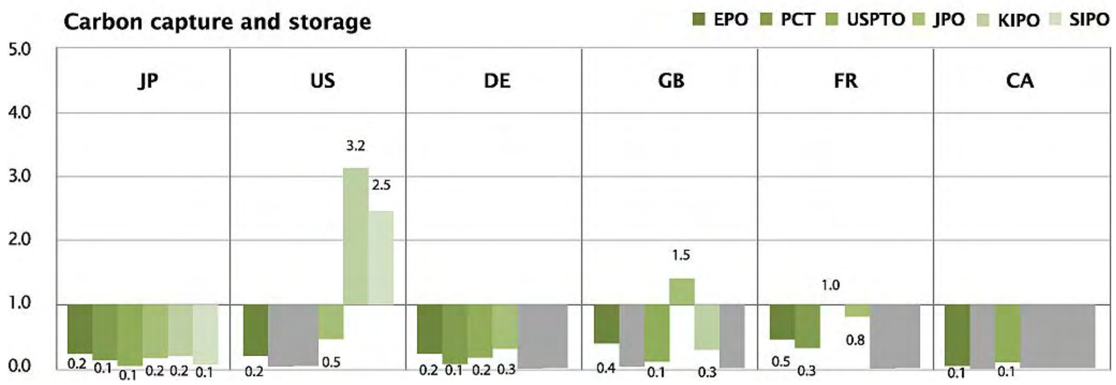
Carbon capture and storage
EPO
PCT
USPTO
JPO
KIPO
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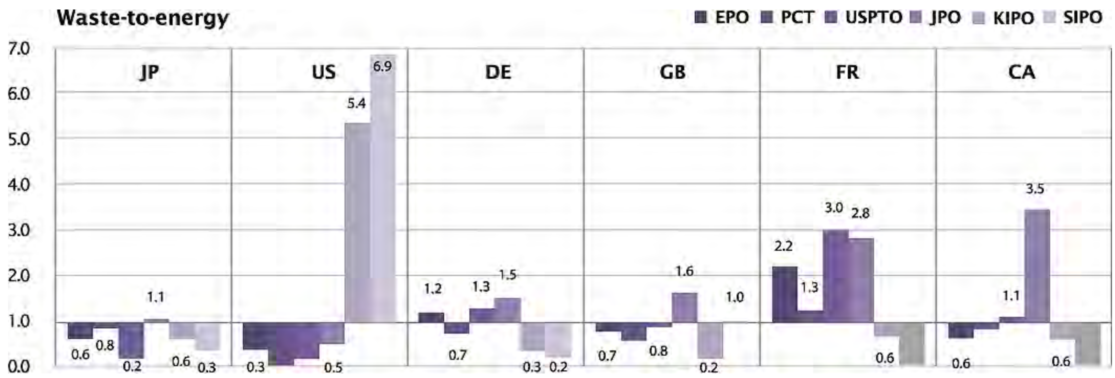
0.5 0.3 1.0 0.8
0.1 0.1

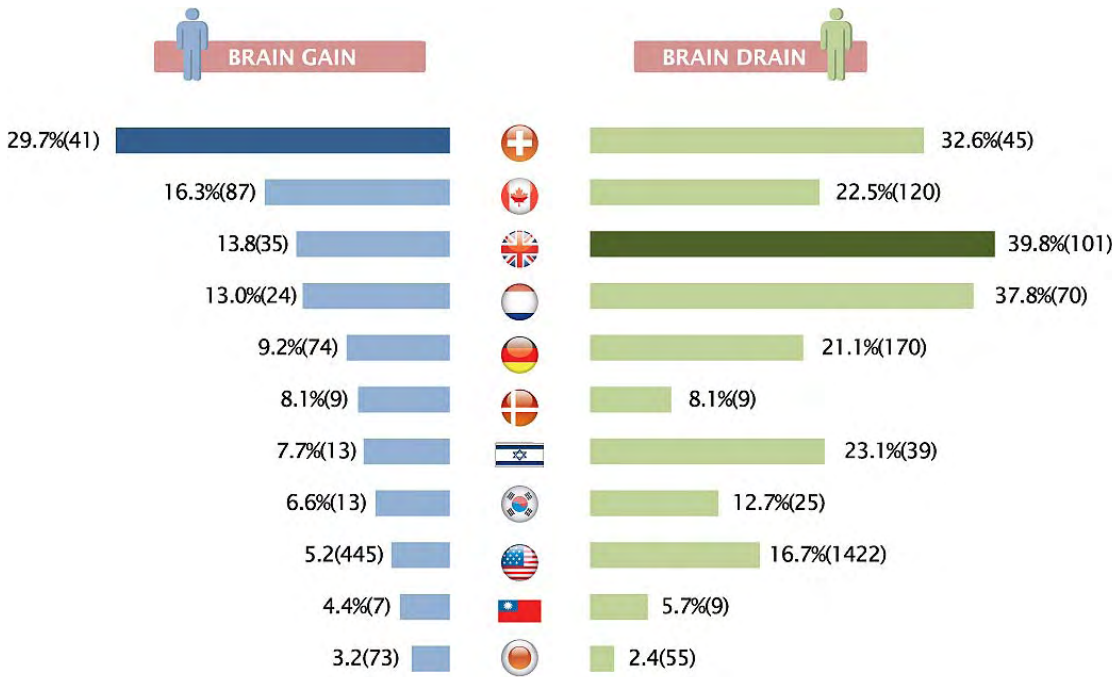


3.1.8. Flows of human resources

Residence data for applicants and inventors derived from patent applications and cited literature can provide information on the use of domestic human resources and the leakage thereof. The ratio of domestically owned applications including foreign inventors can be understood as the degree of influx of research capacity into a country, or brain gain. Likewise, the ratio of foreign owned applications including domestic inventors can be seen as a measure of outflux of research capacity, or brain drain. For the purpose of this measurement, the contribution of individual inventors to an application can be considered irrelevant.

In terms of brain gain, Switzerland ranks first among the countries studied here, followed by Canada, the United Kingdom, France, Germany, and Denmark. In terms of brain drain, the United Kingdom takes first place, followed by France, Switzerland, Israel, Canada, and Germany. Overall, European countries have high levels of both brain gain and brain drain, which would suggest that technology developed by European inventors is exported internationally to a large extent. While brain gain and brain gain are balanced for Switzerland and Denmark, most countries including France, Germany, Israel, and the United States have a higher level of brain drain than brain gain. This fact indicates that domestic technologies tend to be used overseas. Japan demonstrated low levels of both brain drain and brain gain, which indicates that technology developed by Japanese researchers is generally used domestically rather than internationally.

Figure 23 Brain drain and brain gain



International flows of technology can be tracked by examining the nationality of applicants whose patent applications are cited in subsequent patent applications. For the purposes of this study, citation information from the USPTO was used to determine flows of technology information. The results of this analysis show that most countries cite US patent applications. The countries that cite the highest proportion of domestic applications compared to foreign applications are the United States, the United Kingdom, Israel, Switzerland, and the Netherlands, all with over 50 percent of citations being of domestic origin. By contrast, Danish applicants primarily rely on prior French and German patent applications. The degree to which applications from a particular country's applicants are cited in subsequent applications indicates the degree of influence that that country's technology exercises worldwide. US patent applications are particularly influential with respect to other countries' patent applications. The United States and Japan have the highest proportion of domestic citations, which indicates a high degree of technology independence.

Table 3. International technology flows

Assignee's Nationality																						
Citing Patent References												Cited Patent References										
US	SE	NL	JP	IL	GB	FR	DK	DE	CH	CA		CA	CH	DE	DK	FR	GB	IL	JP	NL	SE	US
62.7	0.5	0.7	13.2	0.6	3.4	1.9	0.4	6.0	1.1	8.8	CA	17.1	0.3	4.2	0.3	0.8	0.8	0.5	10.8	0.4	0.2	64.0
66.5	1.1	1.0	8.2	0.9	3.9	2.8	0.2	6.0	6.4	2.7	CH	3.4	20.5	8.7	0.2	1.1	1.1	1.4	8.7	0.5	0.5	53.1
58.1	0.6	1.4	12.8	0.8	2.3	1.7	0.8	17.0	2.4	1.6	DE	3.5	1.4	11.9	0.6	1.2	1.5	0.8	11.9	1.5	0.8	64.7
0.0	0.0	0.0	0.0	0.0	0.0	29.6	0.0	59.3	0.0	11.1	DK	2.5	0.0	7.9	11.6	0.4	1.4	0.0	9.0	1.1	0.7	65.0
58.9	1.1	0.9	15.1	0.0	2.4	8.8	0.4	10.8	0.4	0.6	FR	2.4	1.3	4.8	0.7	8.9	2.6	0.7	10.9	1.5	0.7	65.1
67.8	0.2	1.2	9.8	0.2	7.7	3.2	0.3	6.0	1.6	1.4	GB	5.6	0.8	4.0	2.0	0.9	5.1	0.9	7.5	0.5	1.4	70.8
66.7	0.0	0.1	8.5	11.9	1.4	2.5	0.3	4.0	1.9	2.0	IL	1.0	0.4	2.0	0.0	0.6	1.0	18.4	2.6	0.0	0.2	73.8
58.5	0.3	0.2	32.4	0.1	1.0	1.1	0.2	4.3	0.8	1.1	JP	2.8	0.5	3.4	0.5	0.9	0.9	0.2	42.0	0.4	0.3	47.8
63.6	1.8	3.4	13.0	0.0	3.4	1.3	0.5	9.1	1.6	1.3	NL	2.8	0.8	4.5	2.0	2.0	0.8	0.8	9.3	4.5	1.2	70.7
53.1	9.3	0.2	15.3	0.2	2.9	2.0	0.9	10.2	3.6	2.0	SE	2.1	0.5	4.5	0.8	1.6	2.1	0.3	8.5	1.1	7.1	70.9
80.8	0.5	0.7	6.3	0.5	2.1	1.6	0.3	3.3	0.8	2.8	US	3.0	0.6	2.8	0.4	1.1	1.4	0.6	7.6	0.4	0.7	81.1

: Technological independence

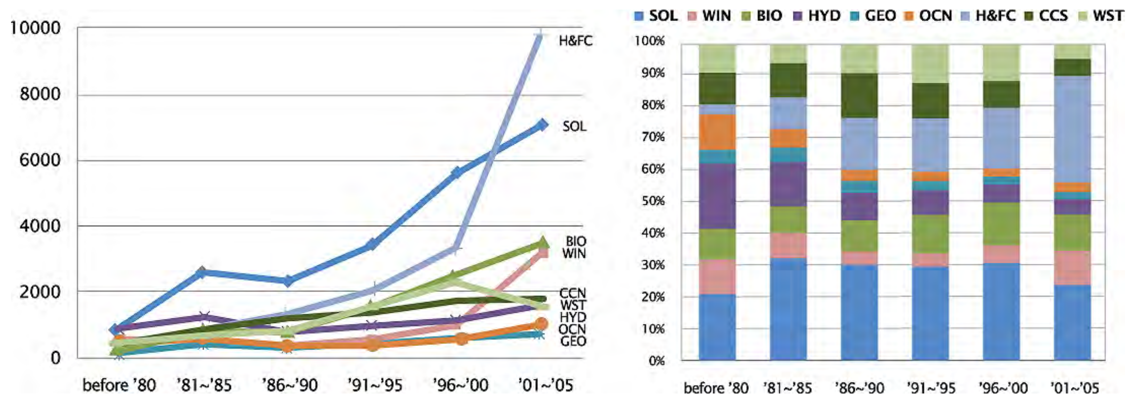
3.2. Trends by technology

In general, the number of patent applications for alternative energy technologies has increased across the board. Though the total number of applications filed for solar energy technologies were higher during the period examined here than for all other alternative energy technologies, the largest growth was seen for hydrogen and fuel cell technologies. Since 2000, applications for hydrogen and fuel cell but also for wind power technologies have increased dramatically, particularly in more recent years. Only applications for waste-to-energy technologies have declined since the beginning of the period examined here.

The share of total applications accounted for by hydrogen and fuel cell technologies has grown most dramatically during the entire period examined here, while the share held by solar energy technologies has declined gradually. While wind power applications lost shares between 1980 and 2000, its share in total applications has begun increasing again in more recent years.

During the period from 2001 and 2005, the shares in total applications for different alternative energy technologies was as follows: hydrogen and fuel cell (45 percent), solar energy (33 percent), bio energy (16 percent), wind power (14 percent), CCS (8 percent), hydropower (7 percent), waste-to-energy (7 percent), wave and tidal power (3 percent), and geothermal (3 percent).

Figure 24 Applications by technology



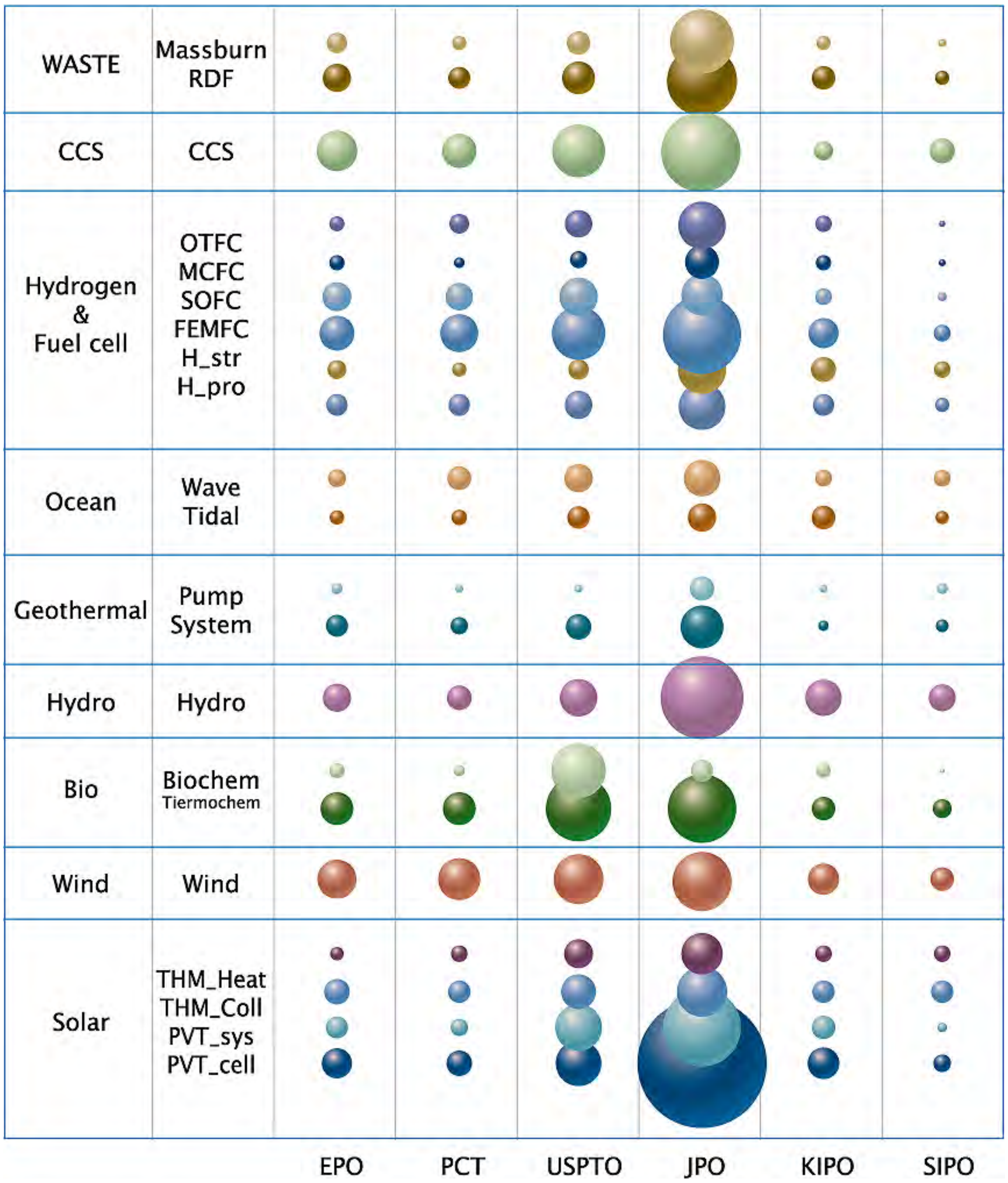
The periods for which numbers of applications are given are as follows:

- Interval 1: Before 1980
- Interval 2: 1981-1985
- Interval 3: 1986-1990
- Interval 4: 1991-1995
- Interval 5: 1996-2000
- Interval 6: 2001-2005

Patent applications for solar energy technologies were concentrated particularly at USPTO and JPO, while applications for wind power technologies were distributed relatively equally between the EPO, USPTO, and JPO and the PCT system. Among bio energy-related applications, most applications for thermochemical conversion technologies were filed at USPTO and JPO, while most applications for biochemical conversion technologies were filed at USPTO. JPO accounts for the most applications for hydropower and geothermal energy technologies. Wave and tidal power-related applications were few and filed in approximately the same number across all patent offices. JPO accounts for the largest share of applications for hydrogen and fuel cell and waste-to-energy technologies. For carbon capture and storage, JPO, USPTO, and EPO received the largest number of applications.

The largest number of applications at EPO and filed through the PCT system were for thermochemical conversion bio energy technologies, PEMFC and SOFC fuel cell technologies, and carbon capture and storage technologies. At USPTO, the most applications were filed for solar energy and wind, bio energy, and PEMFC fuel cell technologies, while at JPO, applications for photovoltaic cell and module technologies, thermochemical bio energy technologies, hydropower, PEMFC fuel cell technologies, and waste-to-energy technologies were predominant. Most applications at KIPO were filed for photovoltaic cell and module, wind power, hydropower, and PEMFC fuel cell technologies. SIPO received most applications for wind and hydropower and CCS technologies.

Figure 25 Applications by technology for selected patent offices



3.2.1. Solar energy

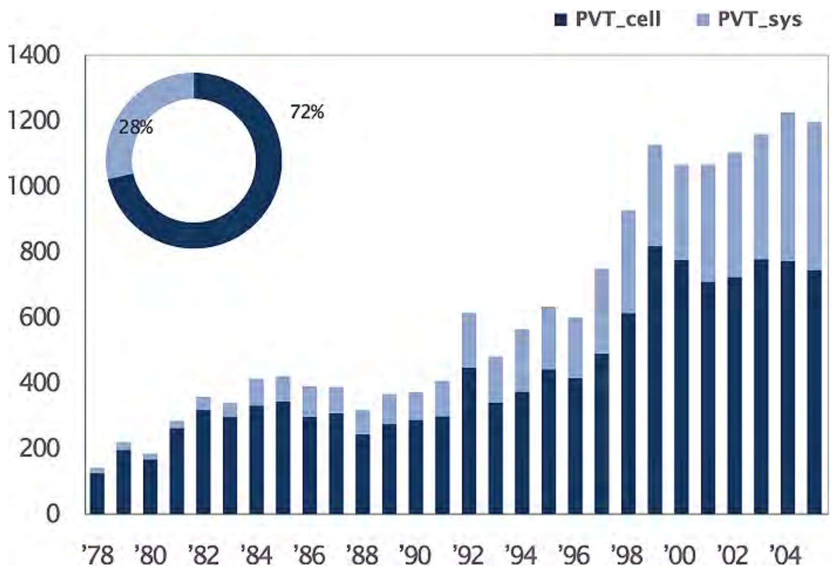
Photovoltaic power has developed rapidly with active government support policies, reductions in costs, and improvements in technology. The size of the world market for photovoltaic technology has increased strongly, at an average rate of over 30 percent, led by countries such as Japan, Germany, and the United States. Worldwide solar power capacity has increased from 110MW in 1992 to 1809MW in 2003, out of which Japan, Germany, and the United States accounted for 85 percent of the total (IEA 2006e).

The ratio of patent applications filed for photovoltaic cells and modules relative to photovoltaic systems is high. Applications for cells and modules account for 72 percent of applications for photovoltaic technologies.

Solar cells are relatively inefficient economically relative to conventional thermal power generation, at a price of 3-4 dollars per watt (Smestad 2008). Given that wafer-type crystalline silicon is the most widely used material for producing solar cells and that the supply of high-purity silicon is expected to become increasingly tight, reducing the price of solar power will be a significant challenge. Consequently, the development of thin-film solar cells will be necessary to reach the aim of low cost, high efficiency solar cells. At present, such solar cells are produced using amorphous silicon, polycrystalline silicon, copper-indium-gallium diselenide (CIGS), and cadmium telluride. Nanotechnologies are increasingly gaining ground in solar cell research, for instance, to produce dye-sensitized solar cells or multi-junction thin-film solar cells.

Companies in the United States, Japan, and Europe have succeeded in making significant advances towards high efficiency solar cells and low cost inverters. Based on power conditioning systems (PCS) for distributed power supply launched in the early 1990s, technologies have been developed for maintaining power conversion efficiencies of greater than 90 percent, for preventing direct current (DC) drain, and for making the PCS transformerless to achieve small size and weight and improved reliability.

Figure 26 Applications for solar power technologies



Patent applications for solar thermal technologies remained relatively constant between 1978 and 1990, with the exception of a major spike in patenting activity in 1983 and 1984. From 1990 onwards, patent applications began growing again at a relatively steady rate until the present. The majority (62 percent) of applications filed for solar thermal technologies related to the collection of thermal energy, one of two major components of solar thermal power generation along with energy storage. A major contribution to the growth in patent applications for solar thermal technologies was made by Japanese applicants, including Matsushita Electric, which filed 130 patents for solar thermal power collection. Japan has been highly active in the production and marketing of solar thermal heating systems since the 1980s, due to concerns about high energy costs, particularly in light of the oil shocks of the late 1970s.

In terms of the number of applications filed, solar thermal heating technology has lagged behind solar thermal collector technologies. However, this gap has diminished with the number of applications for solar thermal collector technologies increasing since the mid-1990s. Solar thermal heating technology has been widely adopted and has contributed to a reduction in energy consumption in China, the European Union, Israel, Turkey, and Japan. China accounts for 60 percent of the total worldwide solar thermal heating market, followed by the European Union (11 percent), Turkey (9 percent), and Japan (7 percent) (MKE 2005). Solar thermal collector capacity is expect to reach 250 million square meters by 2010 and grow by another 160 million square meters by 2020, given a growth rate ranging from 17 percent to 20 percent per years (Fawer 2004).

A major barrier to the development of solar thermal technologies is the high initial investment required for their installation, which exceed the costs for other power generation technologies by a significant margin. Currently, research and development efforts into solar thermal technologies are focusing on solar thermochemical systems and low temperature solar thermal technologies (as opposed to high temperature solar thermal technologies, which concentrate solar radiation using reflective surfaces).

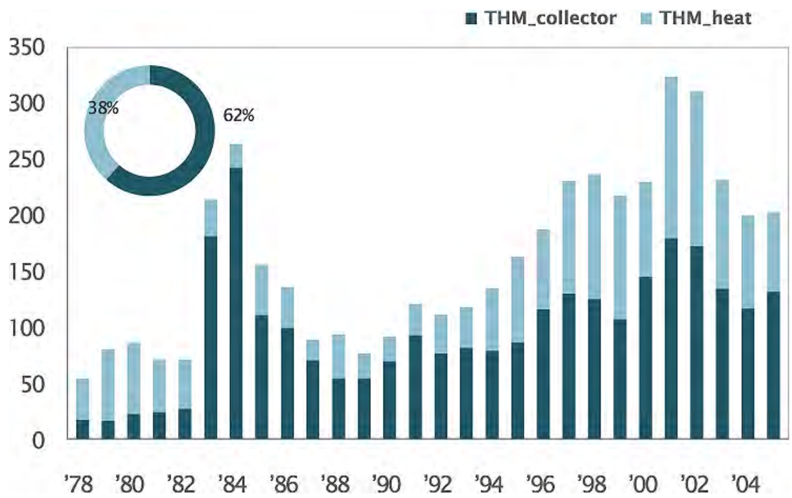
The European Union regards solar heat as an important source of energy for the future and expects to reach a total installed solar thermal power generation capacity of one billion square meters by 2010, the equivalent of 260 meters per person (MKE 2005).

The European Commission's JOULE-THERMIE program is intended to make a significant contribution to reaching this goal, combining research and development activities with demonstration and promotion elements. Among the main areas under development are air conditioning techniques and design types and large scale heating, ventilation and drying systems. Special window systems are also being developed through this program (MKE 2005).

Since 1977, the United States has also been engaged in a large-scale effort to promote uptake of solar thermal and air conditioning technologies under the International Energy Agency's Solar Heating and Cooling (SHC) program (Weiss, Bergmann and Faninger 2004). The United States have also promoted research into solar photovoltaic technologies, solar-related industrial systems and solar thermo-chemical technologies under the International Energy Agency's SolarPACES program for international research cooperation (IEA-SHC 2007).

In terms of solar thermal power technologies, Japan has focused its research and development efforts mainly on solar air conditioning and solar water heating systems under the New Sunshine Plan, launched in 1993. Methods for rooftop installation of solar thermal systems, construction materials, and hybrid solar-thermal heating systems have received particular attention under these efforts (KEMCO 2007).

Figure 27 Applications for solar thermal technologies



3.2.2. Wind power

Patent applications for wind power technologies remained at a relatively low level of around 100 applications per year until 1999, at which point the number increased rapidly, reaching a level of around 650 patent applications per year in 2006. With a sudden rise in demand for wind power and, as a result, increasing use of this source of energy, it has become more competitive relative to fossil fuels and thus more attractive as a target for research and investment (Lee 2008). The entry into force of the Kyoto Protocol in 2005 has only intensified this interest in wind power.

Wind power now costs a mere one to two cents per megawatt, which is half of what solar heat or photovoltaic power costs (Yoon 2004). Mass production of wind power can also take place on a far smaller installation area than many other types of alternative energy and can take place onshore or offshore. Certain challenges to the use of wind power remain, including rotor noise and visual impact and the risk of collisions between rotor blades and flying objects such as birds.

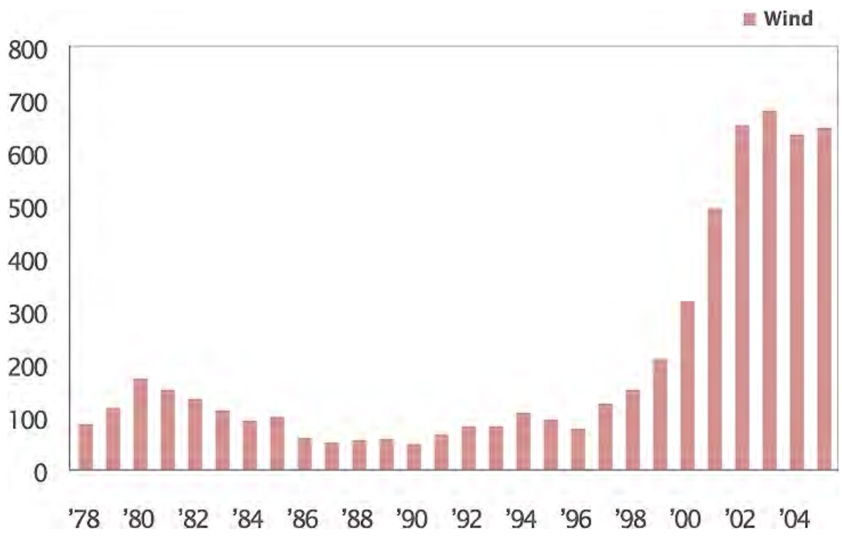
The United States and several European countries hold leading positions in terms of wind power technology development (GWEC 2006). Most countries are pursuing research into a diverse range of wind power technologies, including technologies for improving the efficiency of generators, enhancing blade pitch control, and diminishing generator noise, and methods for modeling and verifying the efficiency of generators at low or middle wind velocity and air current changes around generator parts. Other areas of research include novel turbine, generator, and systems designs aimed at reducing unit costs and intelligent control systems to optimize the operation of turbines.

The International Energy Agency has coordinated research for a number of offshore and large-scale wind power projects under the so-called “Wind Task”. The United States is involved in major offshore and onshore wind power generation projects, led by the National Renewable Energy Laboratory (NREL) and Sandia National Laboratory.

Denmark intends to install wind power facilities with a capacity of 5500 megawatts (4000 megawatts offshore) by 2030 under Energy 21, the Danish government’s primary plan for new energy development (DWIA 2003). In China and India, the wind power industry has also developed quickly as a result of these countries' strong economic growth and their burgeoning energy needs. India now ranks fourth in the world with a total wind power generation capacity of 7845 megawatts, surpassing Denmark with a growth in capacity of 1575 megawatts in 2007 (GWEC 2007; IEA 2007b). China's position as the fifth-ranking country in terms of wind power capacity has been cemented by a growth in capacity of 3307 megawatts in 2007 (GWEC 2007). Countries in the Asia-Pacific region have mainly focused on improving energy efficiency by increasing the scale of onshore wind power generation facilities rather than to engage in research into offshore wind power generators or into the reduction of per-unit construction and equipment costs (KEMCO 2007).

Research into offshore wind power generation has been driven primarily by the shortcomings of onshore wind power production. Compared to onshore wind power, offshore wind power benefits from higher wind velocities and smaller variations in wind direction as a result of which larger scale installations can be established and spatial limitations are less of an issue. Denmark, the Netherlands, Germany, and the United Kingdom are developing offshore wind power generation facilities with turbines installed at a depth of between 5 and 20 meters and at a distance of several kilometers from the shore. The high installation cost represents a significant barrier to the practical implementation of such facilities but the large scale of the facilities ensures that the unit cost of producing power is low (KEMCO 2007).

Figure 28 Applications for wind power technologies



3.2.3. Bio energy

Since the mid-1990s, patent activity with respect to bio energy technologies has begun gathering speed and has experienced a continuous increase until the present. Patent applications for thermochemical conversion processes dominate overall bio energy filings, accounting for about 76 percent of applications in 2006. By contrast, applications for biochemical conversion processes have at times fallen to as low as one third of the number of applications filed for thermochemical conversion processes.

Since the oil crises of the 1970s, technologies for utilizing biomass to create energy have developed beyond the simple combustion of fuels such as firewood and now include technologies for the production of biofuels, cogeneration technologies, and methane fermentation of organic wastes. In advanced countries such as the United States and member states of the European Union, the use of bio energy has become wide-spread and has contributed significantly to the reduction of greenhouse gas emissions.

The most common forms of biofuels are biodiesel and bioethanol. Biodiesel is usually produced from oil crops, while bioethanol is mainly derived from the fermenting of saccharides (sugars and starch) from grains such as corn, from sugar cane and sugar beet, or from grapes. Biodiesel can be used in conventional diesel engines if mixed with conventional diesel fuel and has become widely used over a short space of time.

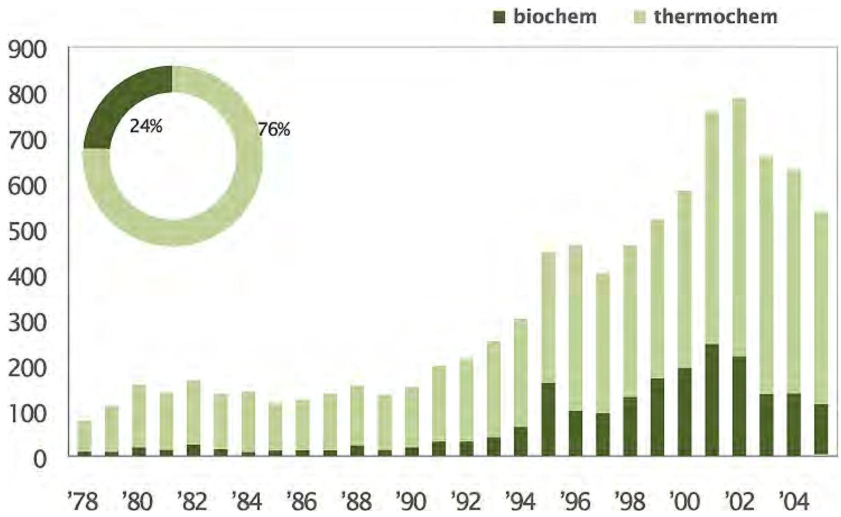
Research on biodiesel technologies has focused primarily on reducing the manufacturing cost of this fuel. For example, in the United States, Iowa State University researchers have demonstrated an increase in biodiesel production yields of 72 to 90 percent relative to conventional production processes using a sequential extraction process (Lee, Kang and Park 2002). Researchers from Texas A&M University have developed means of converting cholesterol, saturated fat, and other by-products of meat processing (produced at a quantity of around 13.5 billion gallons per year in the United States) into biofuels (Lee, Kang and Park 2002). In Canada, the SRC Research Foundation has improved productivity of biodiesel production by converting extracted plant oil directly into normal-paraffin (n-paraffin) prior to the necessary esterification step (NRC 2000). In Austria, the University of Graz is pursuing research into technologies for converting cottonseed oil from kitchen waste (produced at a quantity of around 60 thousand tons per year) into biodiesel (Lee, Kang and Park 2002). Vogel & Noot GmbH, based in Germany and Austria, has filed for patents for processes to improve biodiesel manufacturing yield by substituting the potassium hydroxide usually used in the process of manufacturing biodiesel with a catalyst, which should limit the generation of glycerol, an unwanted by-product of biodiesel production (Lee, Kang and Park 2002).

Bioethanol is generally produced from crops with large saccharide contents through fermentation processes using microbes such as yeast (saccaromyces, etc.) or bacteria (Zymomomnas, etc.) and acid or starch-digesting enzymes. The primary goals of current research are to improve the efficiency of fermentation processes, to determine optimal temperatures for enzymatic saccharification, to obtain microorganisms for fermentation capable of functioning even at high saccharide concentrations, heat-resistant microorganisms capable of ethanol conversion at temperatures between 40 and 50 degrees Celsius, or even microorganisms able to break down starch and produce ethanol simultaneously (Lee, Kang and Park 2002).

Large-scale power plants for power generation based on biomass gasification have been erected by countries around the world. In Finland, these power plants account for a total output of 167 megawatts of electricity and 240 megawatts of thermal energy for use in district heating. Most power plants of this type are based on fluidized-bed integrated gasification combined cycle (IGCC) technology (KEMCO 2007).

Large scale and high efficiency are currently necessary to achieve economic efficiency in energy production using biomass gasification. However, the quantity and stability of supply of biomass are limited, thus putting a significant damper on the adoption of this type of energy production. To overcome this problem, significant research is being invested into achieving higher efficiency in small-scale gasification power generation, to developing facilities able to use different types of biomass (with varying characteristics), and into producing crops with high energy content (KEMCO 2007).

Figure 29 Applications for bio energy technologies



3.2.4. Hydropower

From a peak in 1980, patent applications for hydropower technologies experienced a gradual decline until 1990. From 1991 onward, the number of patent applications started increasing again. Until 1989, these trends could be attributed primarily to patenting activity in Japan, which accounted for the largest share of applications in this field of technology. Later, the number of patent applications in Japan remained relatively constant, while applications from other countries began increasing, particularly after 2000.

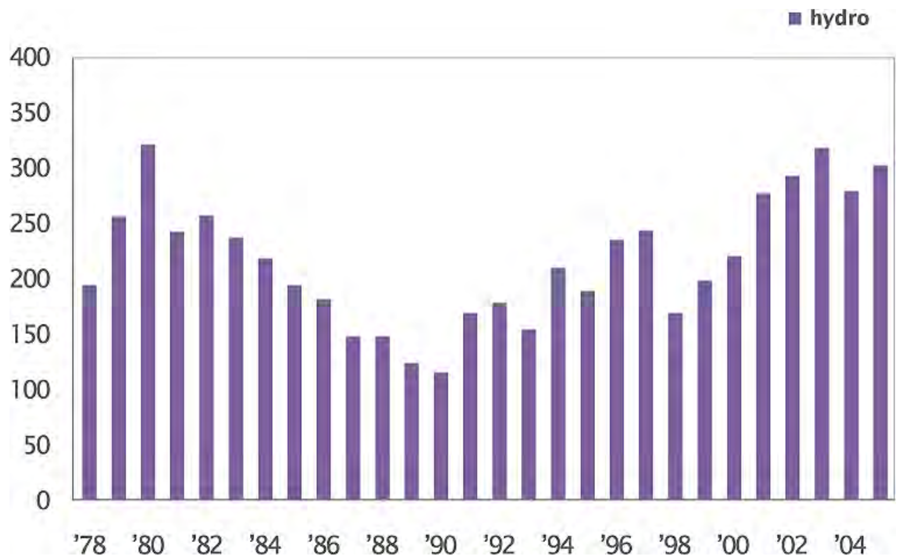
At present, only about 10 percent of total water resources usable for hydropower production have been developed for this use (KEMCO 2007). Both developed and developing countries have demonstrated an interest in further developing their hydropower capacities, both through large and small-scale production. Developing countries can be expected to have a particular interest in this source of energy due to the opportunities available for them to participate in projects under the Clean Development Mechanism established by the Kyoto Protocol.

The trend in hydropower development has been towards smaller scale production. Variable-speed generators have also been actively developed to better account for changes in hydraulic head and flux. Hydropower is commonly generated by several power stations under centralized supervision and control. The automated systems used for monitoring and controlling equipment such as generators, water mills, transformers, and protection relays have also been the object of extensive research.

The technologies involved in hydropower generation are closely related to those used in other industrial applications, including those related to generators, gearboxes, electronic control systems, and oil hydraulic equipment. Most products can therefore be standardized to achieve mass production.

Europe has taken a lead in worldwide hydropower generation and has become highly influential in terms of setting standards and conditions with respect to productivity and environmental impact (KEMCO 2007; Kwon and Kim 2006).

Figure 30 Applications for hydropower technologies



3.2.5. Geothermal energy

Geothermal energy was traditionally regarded as being usable only in places where hot water or steam is generated. However, the development of heat pumps has made geothermal energy accessible practically anywhere, with the heat pump using the ground as a heat sink or heat store. Patent applications for technologies related to geothermal energy production have increased steadily since the late 1970s, with most applications being filed for power generation technologies.

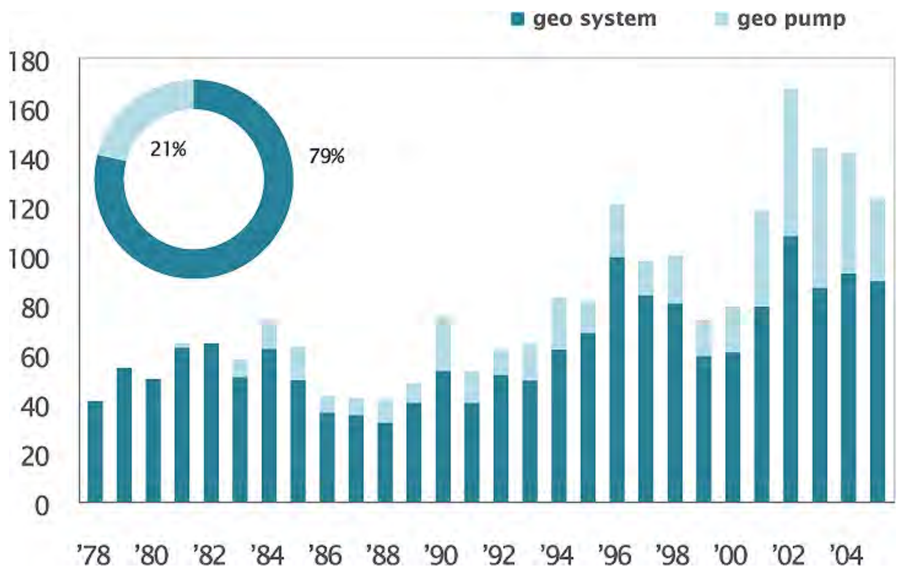
As of 2005, the largest consumers of geothermal power were the United States, with a geothermal power generation capacity of 7817 megawatts and Sweden with a capacity of 3840 megawatts (KEMCO 2007). Certain countries located around hot spots in the

Earth's crust, including the Philippines, Indonesia, Italy, Japan, and Mexico, have increasingly been taking advantage of their special geological conditions to expand their geothermal power production capacity (KEMCO 2007).

Power generation using geothermal heat has increased in annual use by 9 percent from 1975 through 1995 and its direct utilization has increased in annual use by 6 percent during the same period. In 1998, worldwide power generation using geothermal heat reached 45 terawatt hours and production of thermal heat reached 40 terawatt hours. Assuming a continued growth of 9 percent, geothermal power production will reach 130 terawatt hours by 2010 and 310 terawatt hours by 2020. Equipment capacity amounted to 8239 megawatts in 1998 and, given continued growth of 9 percent, will reach 25 000 megawatts by 2010 and 58 000 megawatts by 2020 (Encyber 2007).

An increasing proportion of patent applications related to geothermal energy utilization are related to heat pump systems. Currently they account for 21 percent of total applications for geothermal power technologies. In comparison with conventional heat pumps using air as a heat source and heat sink, geothermal heat pumps have greater efficiency and are therefore a very attractive source of renewable energy.

Figure 31 Applications for geothermal energy technologies



3.2.6. Wave and tidal power

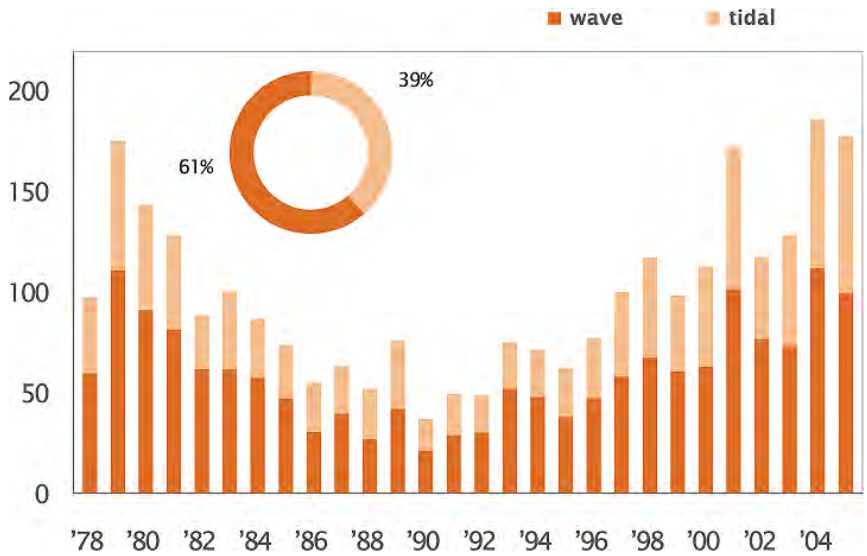
Wave and tidal power has been the object of major research and development efforts since the 1970s, though interest in this source of power appears to have decreased since the end of the 1980s as the viability of widespread industrial use began to be considered. These concerns have been addressed to some degree through the development of improved means of constructing generators since the 1990s, while at the same time interest in developing new water turbine designs began increasing. These developments are reflected in patent filing trends, which show a distinct decline in the number of filings from the early 1980s to 1990, after which filings began to increase again. The number of patent applications nonetheless remains low compared to other alternative energy technologies. Patent applications for wave power technologies are larger in number than applications for tidal power, accounting for 61 percent of the combined total.

Tidal power plants currently in operation include installations in Rance in France (completed in 1967 with a capacity of 400 kilowatts), Kislaya Guba in the Russian Federation (completed in 1968 with a capacity of 800 kilowatts), Annapolis in the United States (completed in 1986 with a capacity of 20 000 kilowatts), and Jiang Xia in China (completed in 1980 with a capacity of 3000 kilowatts) (KEMCO 2007). In order to establish effective tidal power facilities, a significant tidal change is required as well as high capacity reservoirs. As a result, the locations in which such facilities can be established are limited.

Japan, Great Britain, Norway, and other countries are pursuing research on technologies for generating power using energy from ocean waves. Wave power generation is subject to major changes in output, and offshore mooring presents a number of technical challenges. Nonetheless, the introduction of wave power generation facilities is expected to begin in the near future. Japan currently operates fixed offshore wave power facilities in Kaimei with a capacity of 250 kilowatts and has planned to build a floating power station with a capacity of 540 kilowatts under the supervision of the Japan Agency for Marine Earth Science and Technology (KEMCO 2007). In Great Britain, Queen’s University has installed a wave power station with a power generation capacity of 75 kilowatts (KEMCO 2007). Denmark is running an experimental wave power station with a capacity of 34 kilowatts (KEMCO 2007). Norway has constructed a wave power generation plant with a capacity of 500 kilowatts (KEMCO 2007).

Total worldwide installed wave and tidal power generation capacity is expected to grow by 47 megawatts between 2005 and 2009, reaching a total capacity of 227 megawatts by 2009. The major portion of this capacity will be located in the open ocean, while only a small fraction (24 percent) will be located on the seashore (KEMCO 2007).

Figure 32 Applications for wave and tidal power technologies



3.2.7. Hydrogen and fuel cells

The number of patent applications related to hydrogen energy increased dramatically between 1998 and 2002 but have leveled off more recently. Overall, these applications have been distributed relatively equally between hydrogen production and hydrogen storage technologies, at 47 percent and 53 percent, respectively. However, patent applications for hydrogen production were filed primarily before 2000, while applications for hydrogen storage have become predominant since then.

The main challenge faced in producing hydrogen lies in the need to find means of production that do not produce pollution and do not require excessive amounts of space. A number of research institutes as well as companies in the energy and automotive industries have launched research and development programs to meet this challenge, generally with the support of national governments. Among the means for producing hydrogen that are being investigated are water electrolysis using electricity generated from solar heat, wind power, geothermal heat, or other types of alternative energy and natural gas reforming methods that can be integrated into conventional hydrogen production methods.

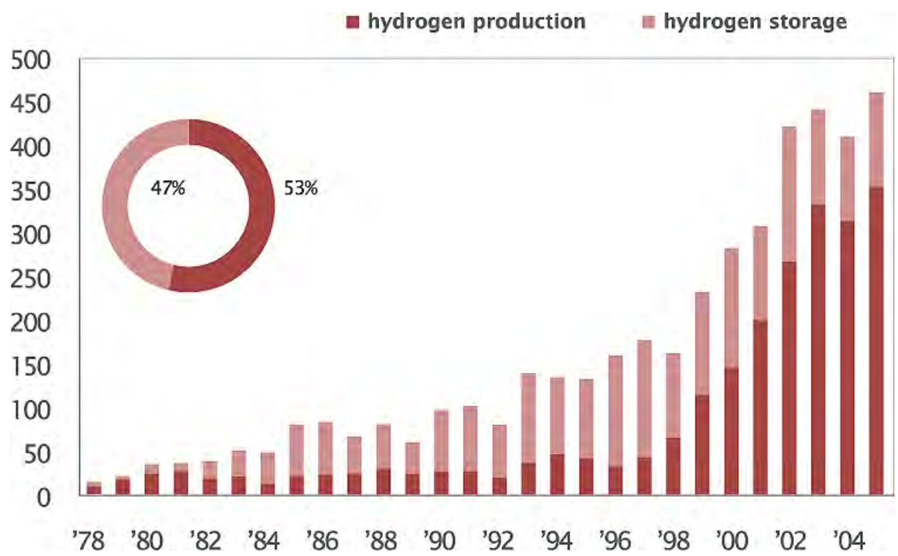
Among the technologies being researched for hydrogen storage are methods involving low-temperature liquid hydrogen, metal hydrides, and carbon nanotubes. Metal-organic frameworks and clathrate hydrates are also being investigated as storage materials to improve safety and storage efficiency. Thus far, however, the goal of producing a truly stable and economical hydrogen storage system has not yet been achieved. High-pressure gaseous hydrogen storage methods have reached an advanced stage of technological development and are nearing a level of sophistication needed for commercial introduction. However, before this type of hydrogen storage can be fully viable on the market, additional research is still needed to produce storage tanks able to withstand high pressures, to reduce manufacturing costs, and to find means of charging tanks with high-pressure gas at high speeds. Low-temperature liquid hydrogen storage holds great promise but requires a great deal of power input and currently suffers from problems with hydrogen evaporation. Thus, new insulation technologies and means for recovering hydrogen must be developed. Compared to gaseous and liquid hydrogen storage methods, storage methods based on metal hydrides, carbon nanotubes and metal-organic frameworks demonstrate superior storage capacity and safety, making them particularly interesting for future research.

Most private sector research into hydrogen storage technologies is being conducted by automobile companies. The German government has initiated a clean energy partnership with BMW, DaimlerChrysler, and other automobile manufacturers to demonstrate hydrogen-fueled cars and hydrogen fueling stations, with an initial investment of 33 million euros (Popular Science 2006). In addition, 30 hydrogen fueling stations were installed in 2007, as called for under the German transportation energy strategy. Through 2010, the German government intends to increase this number to 300 stations and establish a hydrogen pipeline infrastructure between 2010 and 2015 (Popular Science 2006).

Iceland launched the world’s first industrial-scale hydrogen fueling station in Reykjavik in 2003 and has introduced hydrogen-operated buses for its citizens. By 2030, the government of Iceland expects to completely substitute transportation use of fossil fuel with hydrogen (Popular Science 2006).

The state government of California in the United States has initiated a project to construct 200 hydrogen fueling stations along major highways by 2010 in order to encourage the spread of hydrogen-fueled cars and improve users' convenience. Together with the US Department of Energy, the National Aeronautics and Space Administration (NASA), and domestic and foreign companies, the California government also supports hydrogen technology research (Popular Science 2006)

Figure 33 Applications for hydrogen technologies



Patent applications for fuel cell technologies gradually increased until 2000, after which growth in applications rapidly accelerated. In 2005, the number of applications reached 1750 across the offices examined here. Most of this growth can be attributed to filings for polymer electrolyte membrane fuel cell (PEMFC) and solid oxide fuel cell (SOFC) technologies. Applications for PEMFC technologies began increasing greatly from 2000, increasing ten-fold in 10 years to 1130 applications in 2005. Applications for SOFC technologies began gaining momentum from 2001, reaching a peak in 2003.

In overall patent applications filed between 1978 and 2005, PEMFC technologies accounted for 54 percent the total, followed by SOFC technologies (22 percent), molten carbonate fuel cell (MCFC) technologies (8 percent), and other fuel cell technologies (16 percent). However, the distribution of applications has changed over time: Prior to 2000, phosphoric acid fuel cells (PAFC) and MCFCs, accounting for 24 and 21 percent of total applications, while PEMFCs and SOFCs held shares of 36 percent and 21 percent, respectively. Since 2000, PEMFCs have captured a 63 percent share in total fuel cell applications, while applications for SOFCs have declined to 2 percent. The share held by SOFCs grew slightly to 23 percent of total fuel cell patent applications, while other fuel cell technologies accounted for the remaining 12 percent. Overall, patenting activity has concentrated largely on PEMFCs, at the expense of patent applications for SOFCs.

Fuel cells are widely regarded as being the most reliable next-generation alternative energy technology, based on their level of technological maturity, lack of limitations with regard to environmental considerations and location, and supply of primary energy sources. In countries such as the United States and Japan, fuel cells have entered the stage of verification research and commercialization. Still, improvements in terms of commercial viability can be made by reducing equipment cost. To this end, research is being conducted into lower cost materials and means for standardizing equipment and reducing maintenance and operation costs as well as fuel cells' size and weight.

PEMFCs is a particularly flexible type of technology, being amenable for use in vehicles and aircraft, portable and fixed power supplies, and military applications based on their low operating temperature as well as high efficiency and output under different physical conditions. At present, this type of fuel cell is primarily being developed for use in automobiles and housing.

Proton exchange membrane technology is currently based on the use of fluorine-containing ion-exchange membranes. These membranes are relatively expensive and have low thermal resistance. To address these issues, research is being conducted by different organizations around the world, including the Japan Atomic Energy Research Institute (JAERI), which has developed a membrane manufactured through an irradiation process that improves current density threefold with respect to current ion-exchange membranes. Sophia University in Japan is also researching carbonate polymer membrane technologies by introducing sulfonic acid groups to heat-resistant engineering plastic. Some progress has also been made in developing heat-resistant and highly ion-permeable electrolytes using hybrids of inorganic materials or porous membranes. Progress in research on hydrocarbon ion-exchange membranes with improved heat resistance and performance has also been mirrored in patent filing trends (KISTI 2004).

SOFCs are considered as being particularly promising for use in the electrical power industry. SOFCs can be scaled to different applications, including portable 500 kilowatt portable power generators, a 5 kilowatt auxiliary power units, a 1-3 kilowatt residential power generators, and large-scale power-dispersed 250 kilowatt module systems. A small scale residential power generator system has also been developed capable of producing several kilowatts of power as well as heat. Such technologies should rapidly find their way onto the market as mass production decreases unit costs (You et al. 2004).

SOFCs must be operated at high temperatures of around 1000 degrees Celsius but do not require the use of high-costs metals such as platinum and avoid the risk of leakage by using a solid electrode. SOFCs are also useful for urban distributed power generation due to the fact that they use fuel such as methane and do not require pure hydrogen. However, their high operating temperature results in rapid degradation of materials. Research is being conducted on means to reduce operating temperatures without affecting efficiency, so as to increase the durability of materials and reduce operating costs. A number of different oxides have been researched for use in electrodes including cesium oxide, scandium oxide, zirconium oxide and lanthanum-germanium oxide, which demonstrate a higher ion conductivity than yttria stabilized zirconia traditionally used as an electrode material. To reduce manufacturing costs, Siemens Westinghouse Power Company has developed a plasma process to produce electrodes instead of the more expensive electro-vapor deposition process typically used. Hybrid MCFC or SOFC systems combined with gas turbines, demonstrated in the United States, show energy efficiency of 80 percent and have a stack cost of around 100 dollars per kilowatt and a total system cost of around 400 dollars per kilowatt. In Europe, research is being conducted to improve the durability of fuel cell systems to 40 000 hours for a 1000 kilowatt system and to develop a vehicle fuel cell lasting 10 000 hours at a cost of 100 dollars per kilowatt (KISTI 2004; Ni 2005).

MCFCs are a high-efficiency, high-temperature type of fuel cell with an energy efficiency of around 60 percent or as high as 85 percent when integrated into a combined system (Ni 2005). This type of fuel cell is under development in particular for high-capacity power generation purposes. Model units have been produced with outputs ranging from 2 to 100 megawatts (Ni 2005). In the United States, 280 kilowatt modular systems and 2 megawatt power generations have reached the stage of commercialization after testing was completed in 1999 (Kim 2006a). In Japan, testing has been completed on a 1 megawatt power generation system, while Italy has invested in the development of a 500 kilowatt stack (Kim 2006a).

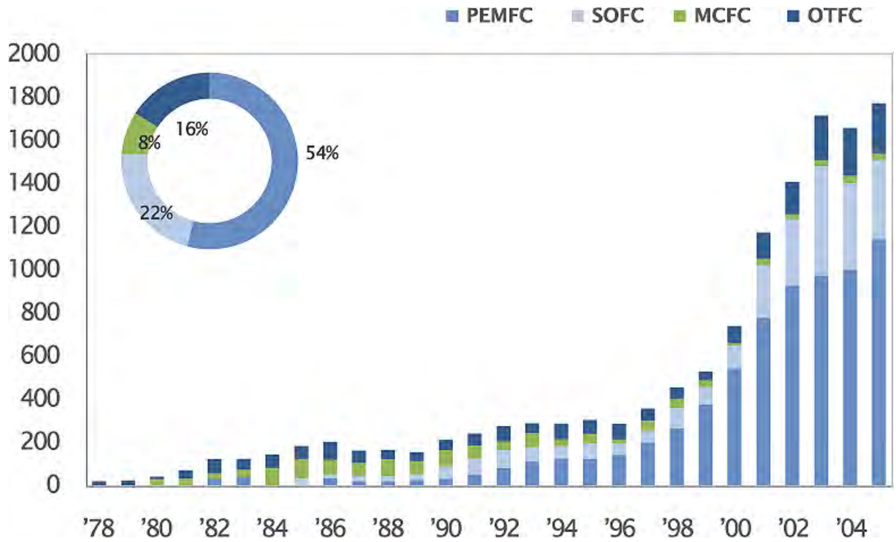
The addition of MCFC to a convention large-scale power station has been shown to reduce carbon dioxide emissions by around 15 percent, where the MCFC is fed emissions generated from the combustion of fossil fuels in the power station (Hayase 2005).

Since MCFCs must be operated at temperatures of 600 to 700 degrees Celsius, the corrosive electrolyte rapidly degrades the components of the fuel cell and thus reduces cell durability. Research is therefore being performed into means of increasing cell durability using corrosion resistant materials. In particular, researchers are focusing on adding rare earth metals to electrolytes containing lithium-aluminium oxide (Son and Kang 2006).

PAFCs are the most widely commercialized type of fuel cell over the past decades. PAFCs allow power generation using methane and biogas as well as natural gas and liquid propane gas. They are highly durable, lasting between 40 000 and 60 000 hours. PAFCs are mainly being developed for use in electrical power stations (KEMCO 2007).

Direct methanol fuel cells (DMFC) are being developed as a power supply for transportation and portable power supplies. The primary challenge in using DMFCs is to increase the activity of the electro-catalyst used in the methanol oxidation reaction. To this end, research is being conducted on reaction paths, adsorption/desorption, surface structures, and other related areas (Arico, Srinivasan and Antonucci 2001).

Figure 34 Applications for fuel cell technologies



3.2.8. Carbon capture and storage

Carbon capture and storage (CCS) is a means for reducing greenhouse gas emissions into the atmosphere that does not require a reduction in the use of fossil fuels. In order to achieve this effect, technologies must be used to separate and capture carbon dioxide from emissions and to either convert the carbon dioxide into resources such as methanol or store the carbon dioxide in a geological deposit. Since the conclusion of the Kyoto Protocol, interest in CCS has increased vastly, as reflected in patent filing trends.

The cost for processing carbon dioxides, including capture, separation, concentration, transportation, and storage, ranges between 6 and 196 dollars per ton of carbon dioxide (Jeong 2007). Capturing carbon dioxide accounts for 70 percent of the total cost of processing carbon dioxide (Jeong 2007). Thus, improving the efficiency of carbon dioxide capture is clearly a critical aspect in improving the overall efficiency of CCS technologies and reducing the cost of these technologies.

Among the technologies used for separating and capturing carbon dioxide are methods based on absorption of carbon dioxide using amine-based absorbents, methods based on adsorption, and membrane separation methods. The ultimate objective of research into the latter method is to develop technologies with no moving parts and low processing costs. Hybrid technologies also exist that integrate carbonate or amine-based absorbents to membrane separation systems. Other variants include biological systems using enzymes and carbon dioxide capture systems using ionic liquids (Illis et al. 2006; Ge et al. 2002; Kazarian et al. 2000; Cadena et al. 2004).

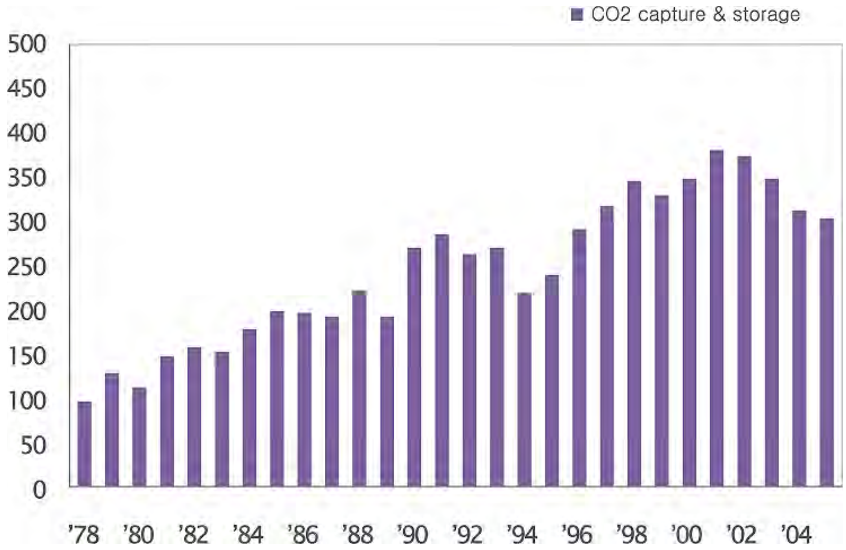
The US Department of Energy has set the target of commercializing carbon dioxide separation technologies with an emission level of zero by 2018 as part of a plan to achieve a 45-percent reduction of greenhouse gas emissions by 2050 (CDRS 2008). A number of technologies are being researched in this context including the use of dry-type regenerative absorbents (CDRS 2008).

Carbon dioxide storage involves depositing carbon dioxide under the ocean, underground or above ground after the carbon dioxide has been separated, pressurized, and concentrated. Ocean storage, which takes place at 2700 meters below the surface of the water, is the most economical variant but can unbalance the marine ecosystem. Accordingly, monitoring the influence of ocean storage on the marine ecosystem necessarily linked to the use of this type of carbon dioxide storage (Jeong 2007).

Underground storage takes place in depleted oil and gas reservoirs and has a long tradition of use by oil companies as part of the process of enhanced oil recovery, deep saline formation, and coal bed development. Testing of deep saline formation technologies has taken place at various locations around the world including Frio (United States), Sleipner (Norway), Insalah (Algeria), and Nagaoka (Japan). Norway holds a storage capacity of one megaton of carbon dioxide in the aquifer in the Sleipner field. Countries such as Canada, China, Japan, Poland, and the Netherlands have launched programs on coal bed storage, which involves injecting carbon dioxide into coal beds. Western Canada alone has a storage capacity of 300 gigatons in its coal beds, while the Netherlands has a capacity of 54 megatons of carbon dioxide (Kim 2007a).

Chemical, photochemical, and electrochemical methods of preparing storage reservoirs have also been under development and could be used to enhance submarine sedimentary layers, abandoned mines or oil fields and for otherwise fixing and recycling captured carbon dioxide (Jeong 2007; Kim 2007a).

Figure 35 Applications for carbon capture and storage technologies



3.2.9. Waste-to-energy

Patent applications for technologies for obtaining energy from waste increased rapidly from 1990 to 1996, after which they declined until the present. Refuse-derived fuel (RDF) technologies accounted for 56 percent of total waste-to-energy applications, with waste incineration technologies accounting for the remaining 44 percent.

Refuse-derived fuel is a low-pollution solid fuel manufactured by processing combustible solid waste with a heating value greater than 5000 kilocalories per kilogram. The use of RDF has become widespread since its development as an auxiliary fuel for power plants in the 1970s (KEMCO 2007). Most patent activity has taken place with respect to RDF combustion technologies, trailed by RDF manufacturing technologies. Technologies designed to improve the heat recovery ratio, using special coatings to increase the corrosion resistance of metal equipment or improved-efficiency combustion devices, have also received a great deal of attention. New areas of research have emerged in recent years, including technologies for the combustion of RDF mixed organic wastes such as water-bearing sludge, for the reduction of oxidized pollutants resulting from low air ratio in combustion, and for the recycling of carbide obtained from thermal cracking as an absorbent (KEMCO 2007).

The first commercial RDF manufacturing equipment was introduced in Europe, where the reclamation of organic waste was prohibited in 1999. All countries in Europe have since then developed and commercialized mechanical biological treatment (MBT) technologies along with organic waste treatment processes and RDF manufacturing processes. Accordingly, more than 90 RDF production sites were in operation in 2005, and RDF has found use in cement plants, power plants, brick kilns, and co-generation processes (KEMCO 2007).

RDF technologies developed in the United States have found widespread application in Europe. Power plants based entirely on the incineration of RDF, incorporating means for processing emissions, have been developed. Through the development of precise automated systems for the selection of waste, a much higher recycling ratio has been achieved in the manufacturing of RDF.

Significant advancements have been achieved in the construction of boilers used in the combustion of RDF, for example in cement kilns, as well as in post-processing technologies, for instance for the processing of emissions. In Japan, for example, patent applications have been filed for producing RDF adding slaked lime after drying and shaping (Kim et al. 2003). As of 2003, 57 installations fuelled with RDF and five RDF-only power plants were in operation in Japan (KEMCO 2007). Recently, technologies have begun to be developed for producing carbide through partial thermal cracking of RDF, which can then be used as an absorbent for environmental cleanup and other purposes. Technologies related to the production of RDF have been available for quite some time; however they have yet to reach the highest possible efficiency. As a result, technical developments for improving processing efficiency, aimed at reducing waste caused by each element in a production assembly, are necessary.

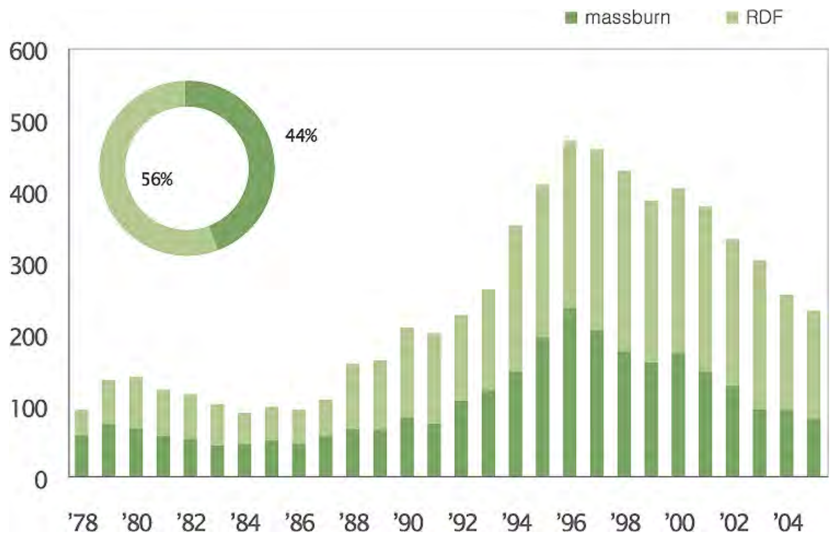
Means for capturing energy from waste incineration include traditional incineration systems such as stockers, incineration systems using circulation fluidized beds, incineration systems involving co-generation of heat and electrical power, and dual-fuel systems that mix RDF with other fuels such as coal. (Choi 2007; KEMCO 2007; Choi and No 2006). Traditional incinerations systems based on water processing have the advantage of reliability and the many years of experience that have been gathered in their use.

However, such systems suffer from low energy recovery ratios, particularly compared to modern circulation fluidized bed combustion systems, which are now available for use in large-scale production environments such as waste disposal plants. Cogeneration and dual-fuel systems also have high energy recovery ratios but are still not very reliable. As a resulting, progress must be made in the development of waste fuel use, process control technologies, and particulate matter and nitrogen oxide reduction (KEMCO 2007).

Europe has had waste incineration technologies on the market since the 1870s and is highly advanced in this field of technology. More recently, though, Japan has overtaken Europe as the leading force on the waste-to-energy market, after having launched cooperation programs with Europe in the field in the 1970s (Park 2002). The focus of Japan's research and development efforts into waste-to-energy technologies has been to improve corrosion resistance, to exploit the fossil fuel vapors generated at low and high temperatures in the incinerator to drive a turbine, and to raise energy conversion efficiency in the gasification of waste and production of RDF.

The current generation of waste incinerators has been built around stockers or inner and outer circulation fluidized beds. The next generation will likely be of a gasification melting type. Future development in this field will take aim at technologies for using incineration heat and molten incineration products, materials for use in melting furnaces, means of processing molten materials, and uses for recovery sludge and metals as well as technologies for using waste combined with coal in dual-fuel power stations.

Figure 36 Applications for waste-to-energy technologies



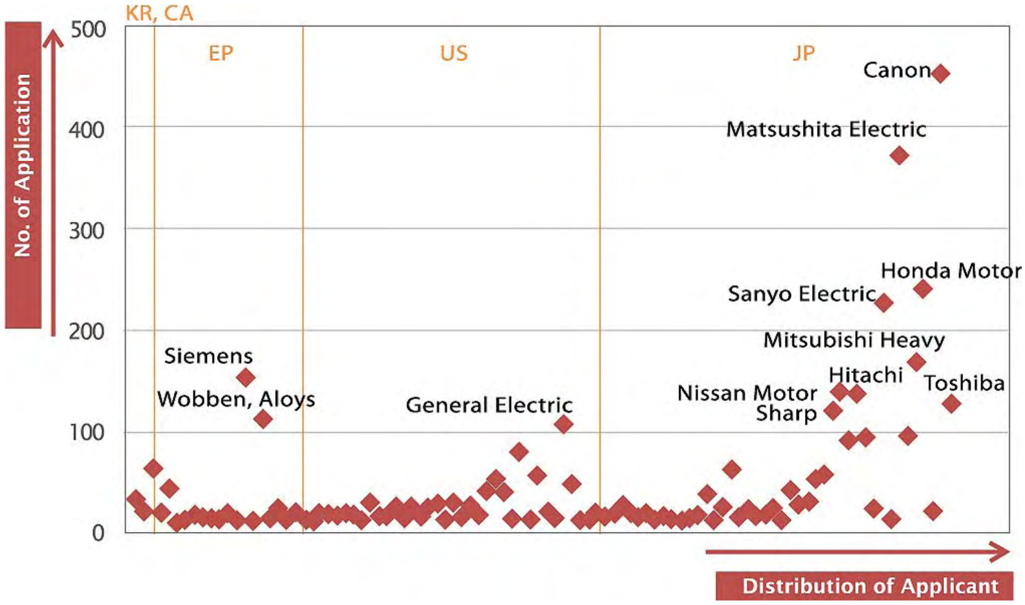
3.4. Trends by applicant

3.4.1. Top 100 applicants in terms of triadic patent families

Triadic patent families are sets of patent applications that are filed at the European Patent Office, the Japan Patent Office, and the United States Patent and Trademark Office based on a single priority filing. Among the top 100 applicants in terms of triadic patent families in alternative energy technologies, 45 were Japanese, 34 American, 18 European, 2 Korean and one Canadian. Nine out of the top 10 applicants were also Japanese. This fact suggests that Japanese applicants place a strong emphasis on the commercialization of their technologies not only in their domestic market but also in the largest international markets.

The top ranking applicants overall in terms of the number of triadic patent families filed were Canon, Matsushita Electric, Honda Motor, and Sanyo Electric. The largest numbers of triadic patent families were filed by these companies during the late 1990s to the early 2000s. The top ranking US applicants are General Electric and Westinghouse Electric. Among European applicants, two German applicants were particularly noteworthy, namely Siemens and Aloys Wobben (as owner of Enercon). Samsung Electric and Samsung SDI from Korea and Ballard Power Systems from Canada were also among the top ranking applicants in terms of triadic patent families filed.

Figure 37 Top 100 applicants in terms of triadic patent families

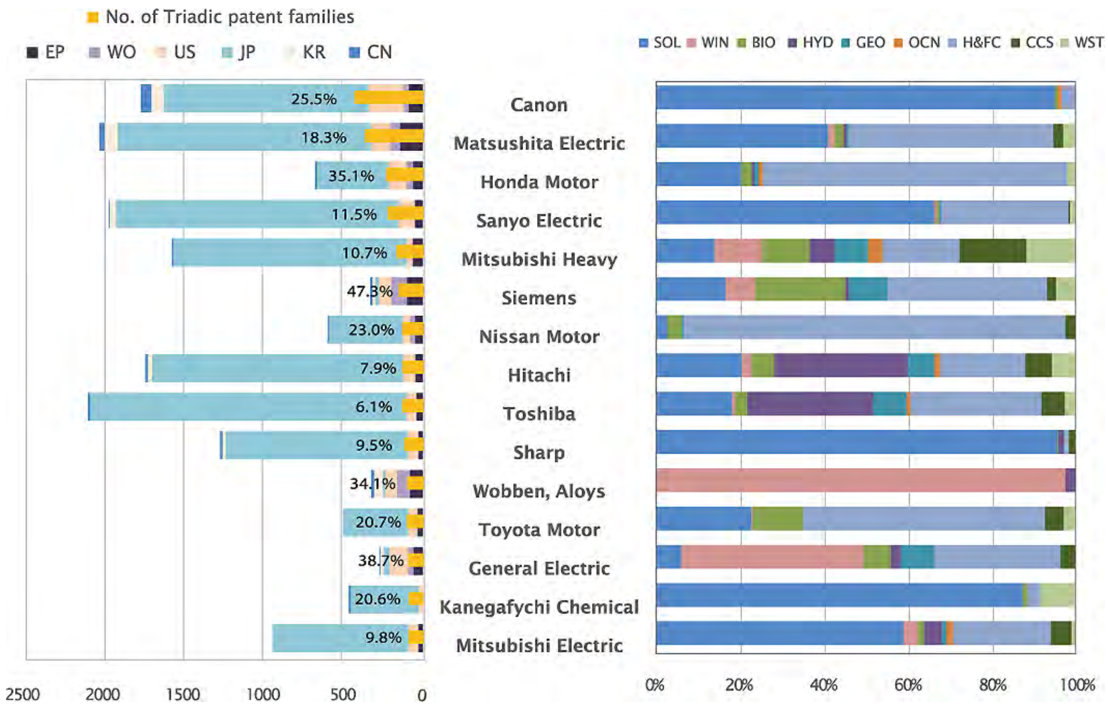


3.4.2. Patent portfolios of top applicants

Graph 36 shows the top 15 applicants in terms of triadic patent families, together with their total number of patent filings across several major patent offices. It is interesting to note that little correlation exists between rank in terms of triadic patent families and total patent filings. Though Toshiba is the largest single applicant for alternative energy technologies, only 6.1 percent of its applications belong to triadic patent families, putting the company in ninth place in the ranking according to the number of such patent families. Canon, the top applicant in terms of triadic patent families, comes in at fourth place after Toshiba, Matsushita Electric, and Sanyo Electric in terms of total patent applications for alternative energy technologies. Siemens has the highest proportion of triadic patent families among its applications (47.3 percent), followed by General Electric (38.7 percent), Honda Motor (35.1 percent) and Aloys Wobben (34.1 percent). In terms of total patent applications, Japanese applicants were outstanding, with many applications being filed at JPO.

Canon and Sharp focused their patenting activity primarily on solar energy, while Honda Motor, Nissan Motor, and Toyota Motor concentrated almost exclusively on hydrogen and fuel cell technologies. Toshiba, the largest single patent applicant, focused on solar, hydropower, and hydrogen fuel cells. Hitachi demonstrated a similar orientation in its patenting activity. Siemens, with the highest proportion of triadic patent families in its portfolio, filed most of its applications for hydropower, fuel cell, bio energy, and solar energy technologies. Almost all applications (97 percent) filed by Aloys Wobben were for wind power technologies.

Figure 38 Number and distribution of applications for selected applicants by office and technology

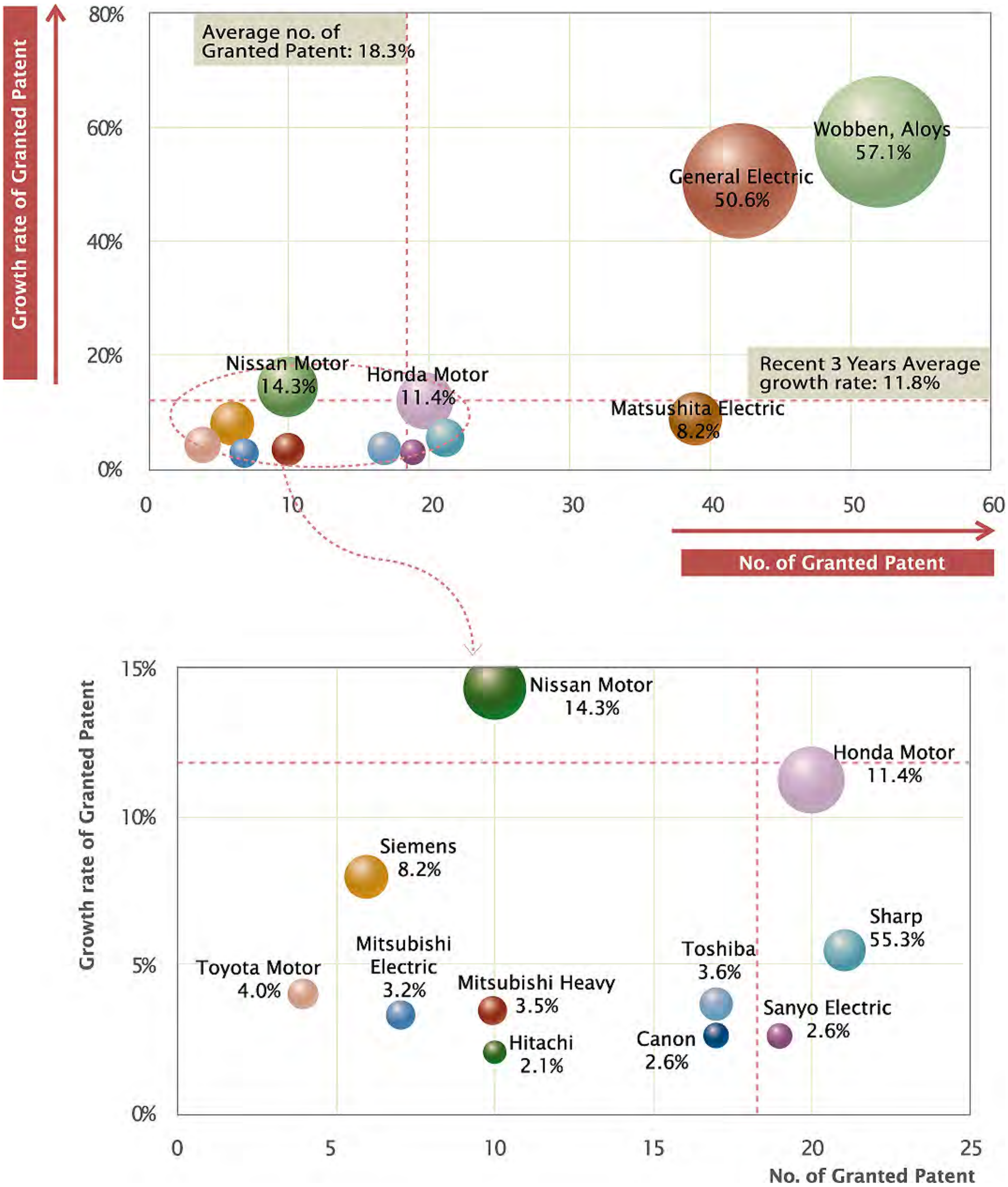


Among the top 15 applicants, the growth rate in number of applications has increased during the three-year period from 2003 to 2005.[3] The growth rate for Aloys Wobben and General Electric has been strong during this period, indicating that not only filing of patent applications but also maintenance of patents has a high priority for these applicants. Matsushita Electric has filed many patent applications during the three-year period given above, however their growth rate has been low, which can be explained by the particularly large number of applications filed between 1998 and 2002 relative to those filed between 2003 and 2005. In general, Japanese applicants among the top 15 demonstrate a below-average number of applications or growth rate, suggesting that their efforts to maintain patent protection have been relatively weak compared to their

[3] Growth rate is given as the number of patents granted during a specific period (in this case, three years) over the total number of patents granted.

efforts to file patent applications.

Figure 39 Number and growth rate of patent grants for selected applicants



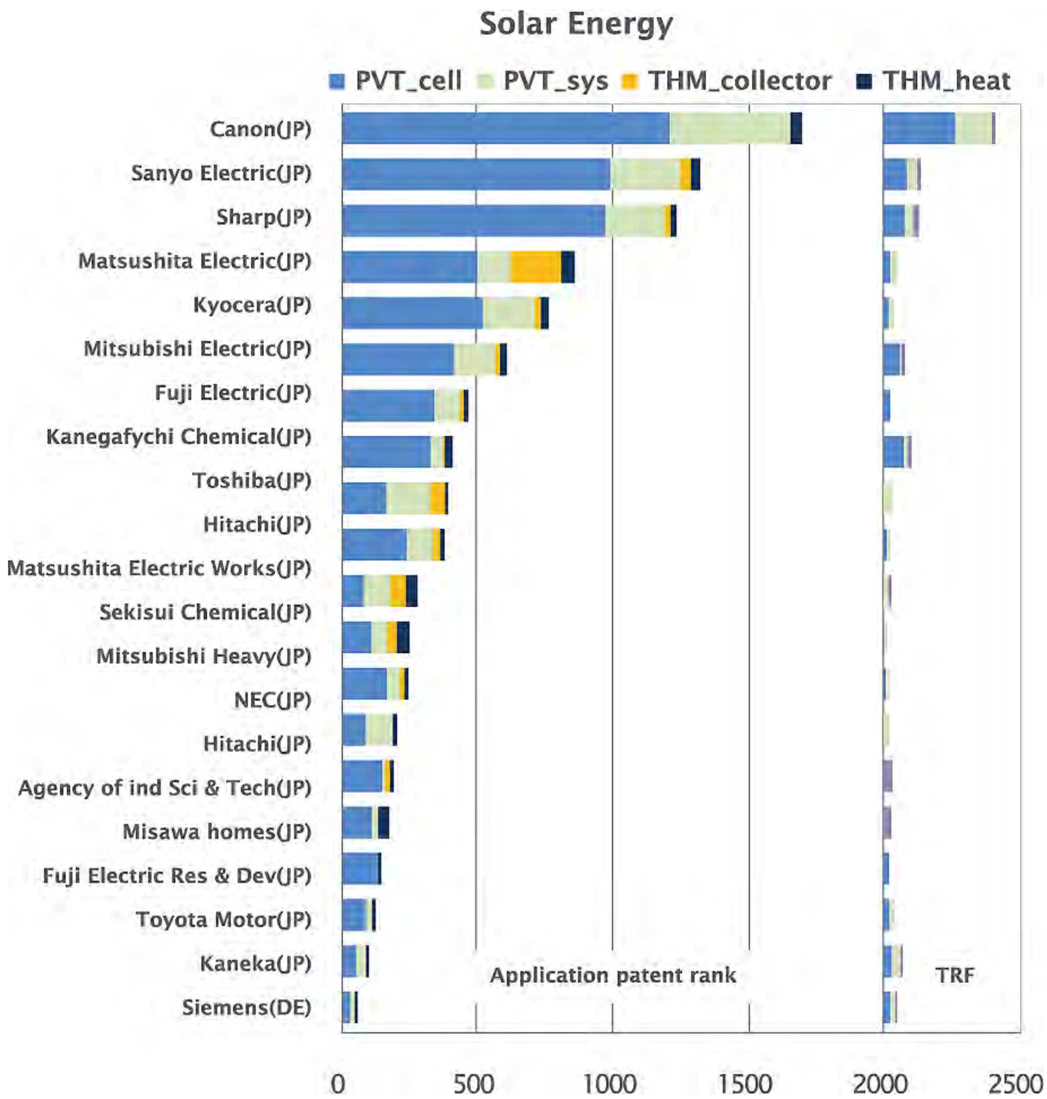
3.4.3. Technology trends in patenting activity of top applicants

- Solar energy

Japanese companies led the field in terms of applications for solar energy technologies, with Canon, Sanyo Electric, Sharp, Matsushita Electric, and Kyocera holding top positions. Canon is also exceptional in the high number of triadic patent families filed by the company. The applications filed by Canon were primarily for solar cell and module technologies, while Matsushita Electric also filed a significant number of applications for solar thermal collector technologies. Overall, Canon filed around 1700 patent applications for solar energy technologies, out of which 26 percent belonged to triadic patent families. Solar cells accounted for 71 percent of applications filed by Canon, while solar power systems accounted for another 26 percent of applications. Specifically, Canon focused on single crystal silicon and compound semiconductor solar cell technologies but also filed a number of applications for dye-sensitized solar cells, demonstrating a rather broad research focus. The problems to be solved by the technologies for which Canon filed applications included low energy conversion efficiency and high cost, indicating that these fields are a particular concern in the company’s research and development processes. Hardly any applications were filed by Canon for solar thermal technologies.

Sanyo filed only 10 percent of its applications for solar energy technologies as part of triadic patent families. Solar cells accounted for 76 percent of solar energy-related patent applications filed by the company, while solar power systems claimed a further 18 percent. In the 1990s, Sanyo began research into solar cells based on hetero-junction with intrinsic thin layer (HIT) structures, building on earlier developments in the production of amorphous silicon solar cells for small-scale electronics achieved in the 1980s. Towards the end of 2002, Sanyo Energy established HIT module manufacturing capacities totaling 12 megawatts per year in Monterry, Mexico (SPR 2005; Ikki 2006). The company has also been actively expanding its operations abroad, for example launching cooperative activities with Kyocera to set up module manufacturing plants in Hungary. Production capacity for 2005 was 50 megawatts with plans to grow to 100 megawatts in 2006 (SPR 2005; Ikki 2006). Sanyo holds a number of patents related to its activities in this area, focusing primarily on solar cells and solar cell modules, including for enhancements to element technologies related to semiconductor junctions and improvements to conversion efficiency by way of novel insulation layer and conductive layer technologies.

Figure 40 Top applicants for solar energy technologies



- Wind power

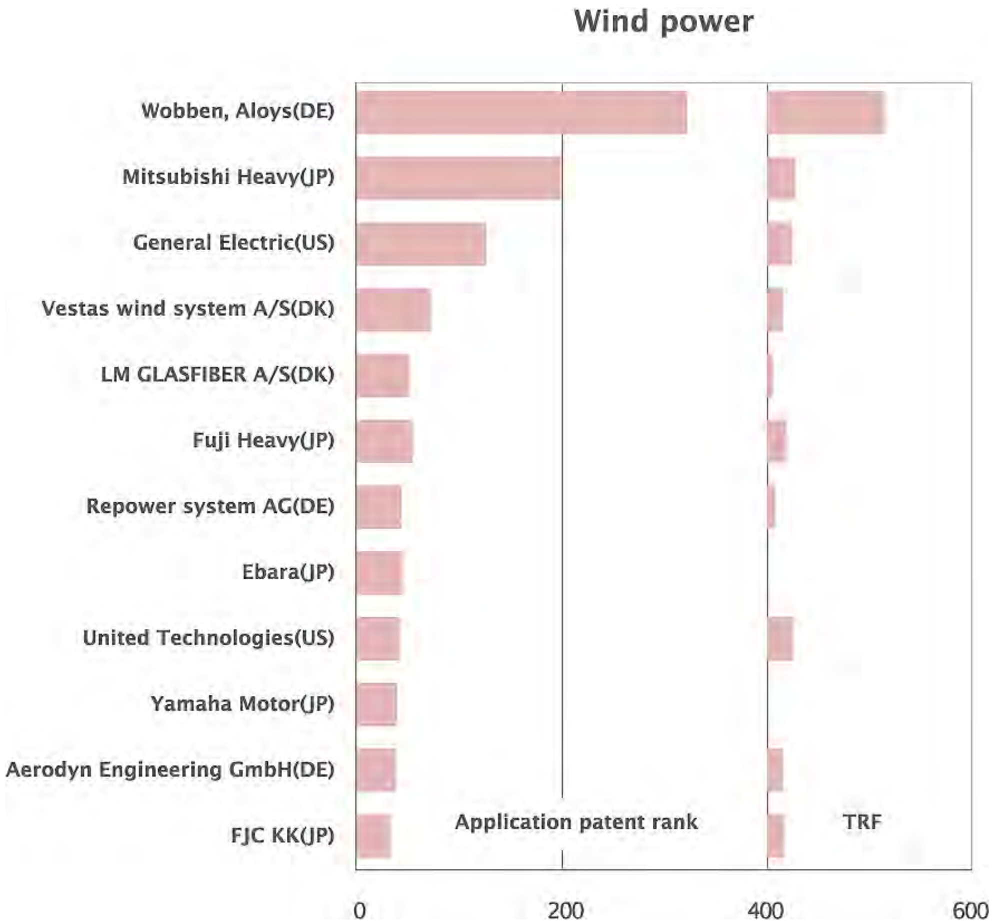
Aloys Wobben (owner of Enercon) is the leading applicant for wind power technologies, ahead of Mitsubishi Heavy Industries, General Electric (GE Wind), and Vestas Wind Systems. Five major companies based in countries with highly developed wind power industries control 86 percent of the total market in the field as measured by production capacity (including production of components, installation, and construction but excluding power generation services). These companies – Enercon and Siemens (Germany), Vestas (Denmark), GE Wind (United States), and Gamesa (Spain) – have established themselves as leaders, often by strengthening their competitiveness through mergers and acquisitions. For example, Vestas extended its market share through its merger with NEG Micon in 2003, making it the top company in the field worldwide (New Energy 2003). In 2001, GE Wind overtook Enercon to become the second largest company in the field (KEMCO 2007).

Enercon of Germany, established by Aloys Wobben in 1984, is a leading company in the field of wind power installations. The company has filed 320 patents related to wind power at the offices examined in this study, out of which 34 percent belong to triadic patent families. Enercon controls around 40 percent of the German market for wind power, basing its operations on a strategy of self-supply in terms of components and filing patent applications for technologies covering all aspects of wind power generation (Enercon 2007). A particular focus of Enercon’s patenting activity is on blade and system control as well as equipment technologies such as generation tower installation and monitoring technologies.

Mitsubishi Heavy Industries of Japan leads the field of wind power turbine manufacturing, in particular with respect to medium and large-scale wind power turbines. It has recently expanded its business operations to include offshore wind power generation facilities and announced a plan to establish new factories for manufacturing turbine blades and other components outside of Japan by 2011 (Lee 2007). The company intends to supply these components to countries in Europe and North America in which demand is particularly strong (MPAC 2006). In terms of patenting activity, Mitsubishi Heavy Industries has emphasized blade and turbine control technologies.

To a large extent, the operations of GE Wind and Vestas Wind are vertically integrated, allowing them to cover whole sections of power generation equipment. At GE Electric, wind power is the fastest growing among the different fields of alternative energy production, with an annual growth rate of 25 percent (Lee 2008). GE Wind has filed patent applications mainly in the field of power generation control. Vestas Wind Systems controlled around 33 percent of the worldwide market for wind power generation equipment and held the top position in the market for wind power generation systems (Lee 2008). The main focus of Vestas Wind Systems’ patenting activity has been on systems elements such as rotors, gear boxes, and power converters.

Figure 41 Top applicants for wind power technologies

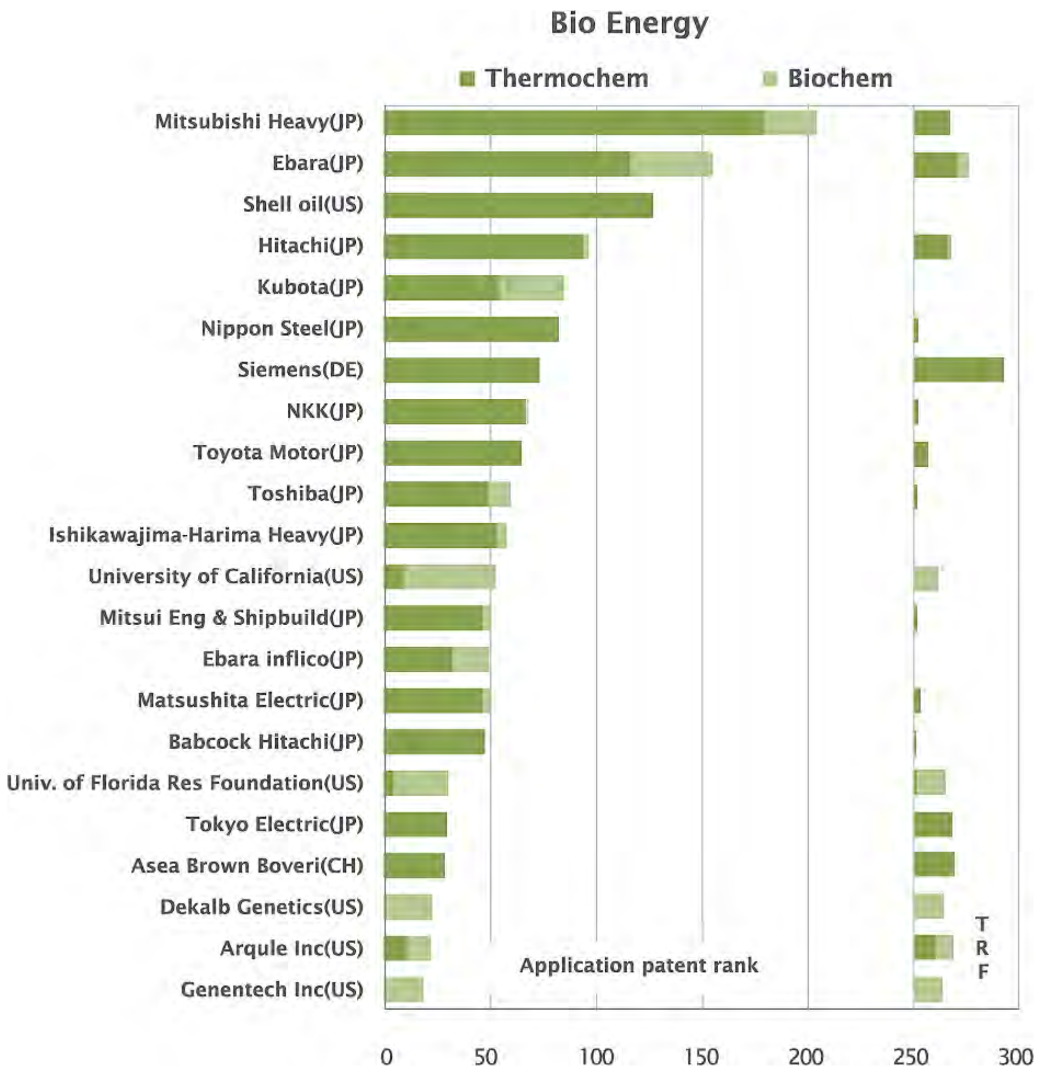


- Bio energy

Patenting activity in the field of bio energy has been led by applicants with US and Japanese nationality. Mitsubishi Heavy Industries, Ebara, and Shell Oil hold the top three places in terms of number of applications, while Siemens (Germany) accounts for the highest number of triadic patent families, of which Japanese companies typically have few. Furthermore, patenting activity is highly concentrated on thermochemical conversion processes, with far fewer applications being filed for biochemical conversion methods. Mitsubishi Heavy Industries, Shell Oil, Nippon Steel, the NKK Corporation and Toyota Motors are particular active in this particular field of technology.

Mitsubishi Heavy Industries, the top applicant for bio energy patents, filed 88 percent of its applications in this field for thermochemical conversion technologies, including several patent applications for producing synthetic gas (syngas) through gasification of biomass. Ebara of Japan filed a number of patent applications for ethanol manufacturing equipment with a special focus on power generation systems for thermochemical conversion processes. Nonetheless, a number of US universities including the University of California and the University of Florida as well as companies such as DeKalb Genetics and Genentech have been very active in filing patent applications for biochemical conversion processes.

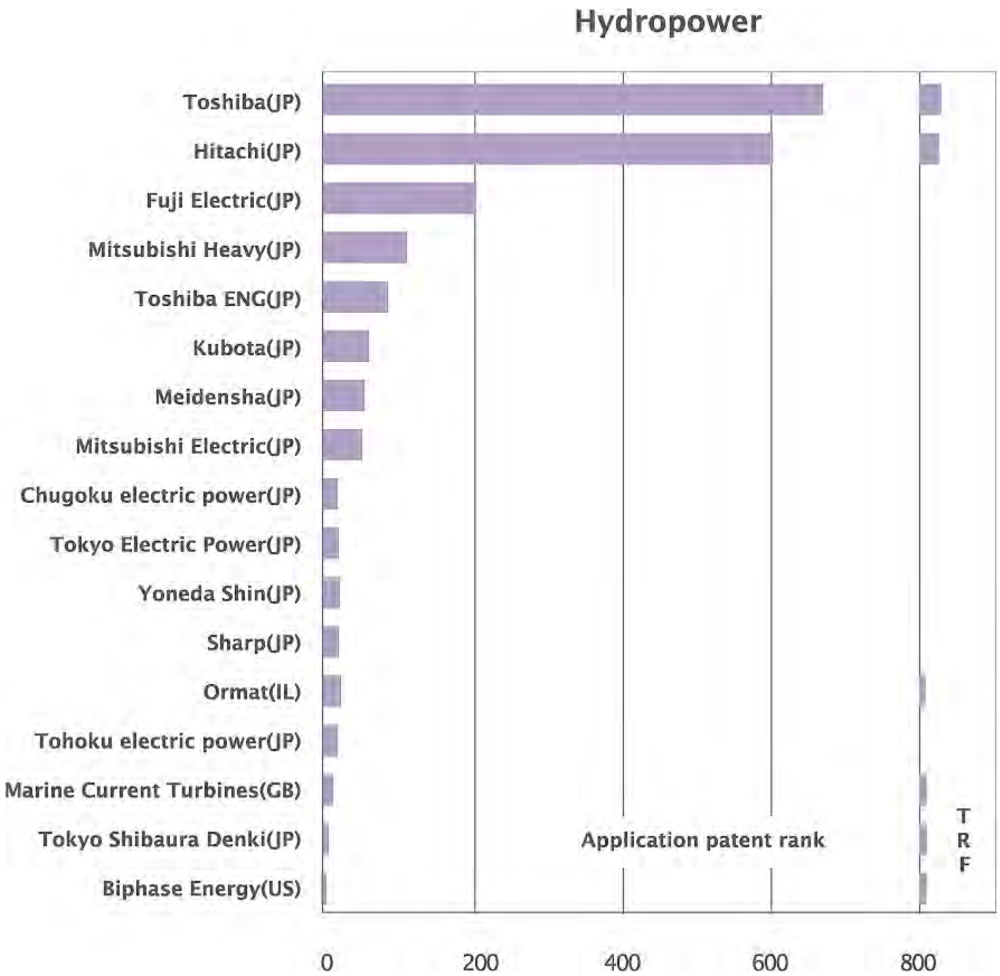
Figure 42 Top applicants for bio energy technologies



- Hydropower

Toshiba, Hitachi, and other Japanese companies dominate the ranking of applicants in the field of hydropower. Notably, however, Japanese companies hold very few triadic patent families in comparison with the number of applications. This fact seems to indicate that these companies orient themselves towards the domestic market or specific countries. Hitachi, the second-ranked applicant for hydropower technologies, has filed patents for methods of designing and manufacturing water mills and generally for power generation, automation, systems control, and performance estimation technologies. Toshiba, the first-ranked applicant, has filed patent applications mainly for technologies related to design and automation of watermills. Overall, these two companies mostly hold Japanese patents, indicating that their focus is on the Japanese market.

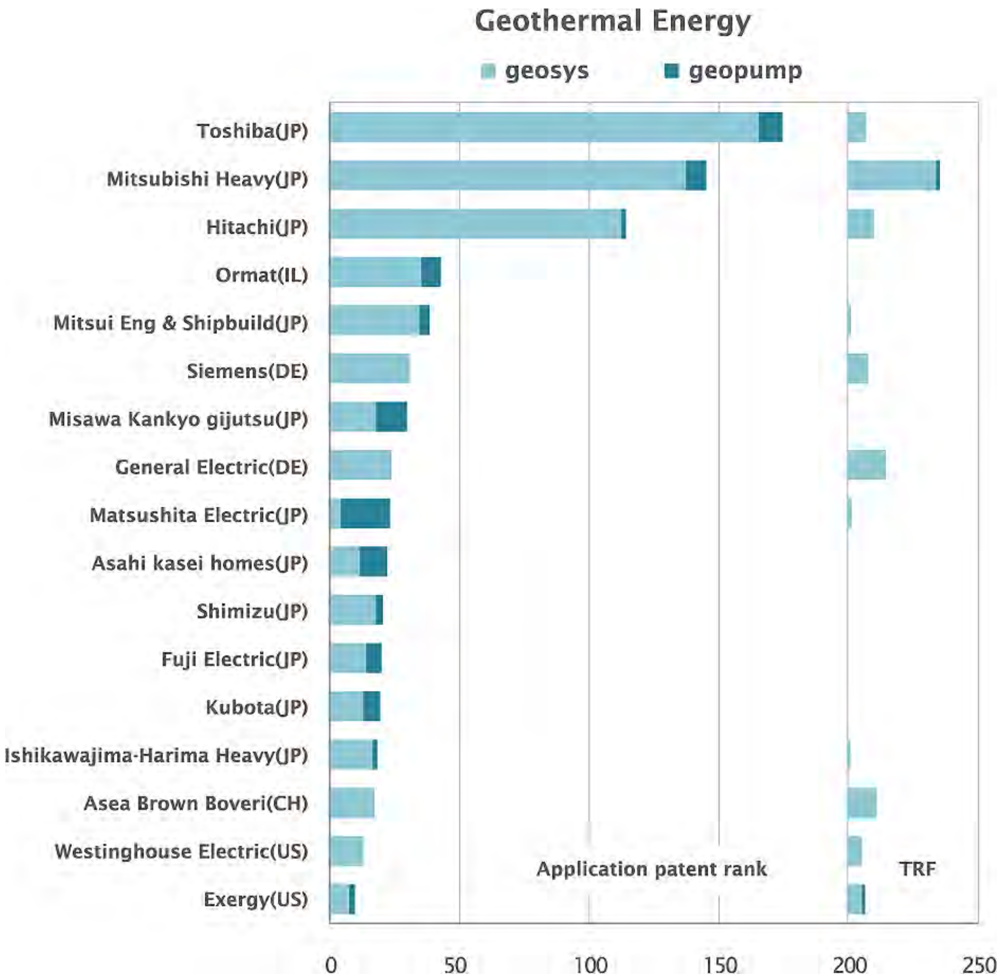
Figure 43 Top applicants for hydropower technologies



- Geothermal energy

In the field of geothermal energy, Toshiba, Mitsubishi Heavy Industries, and Hitachi alone account for the large majority of patent applications filed. Among these three companies, Toshiba holds the largest number of applications and Mitsubishi Heavy Industries the largest number of triadic patent families, which make up 28.5 percent of its patent applications. Most applications filed by the top applicants are for geothermal systems technologies, as opposed to geothermal pump technologies, though for example, Matsushita Electric has filed the majority of its applications for pump technologies. A number of patents have also been filed for geological exploration methods and equipment. Ormat Technologies, the fourth-ranked applicant, is a market leader in terms of the development of geothermal resources and the construction, acquisition, and operation of geothermal equipment (KEMCO 2007).

Figure 44 Top applicants for geothermal energy technologies



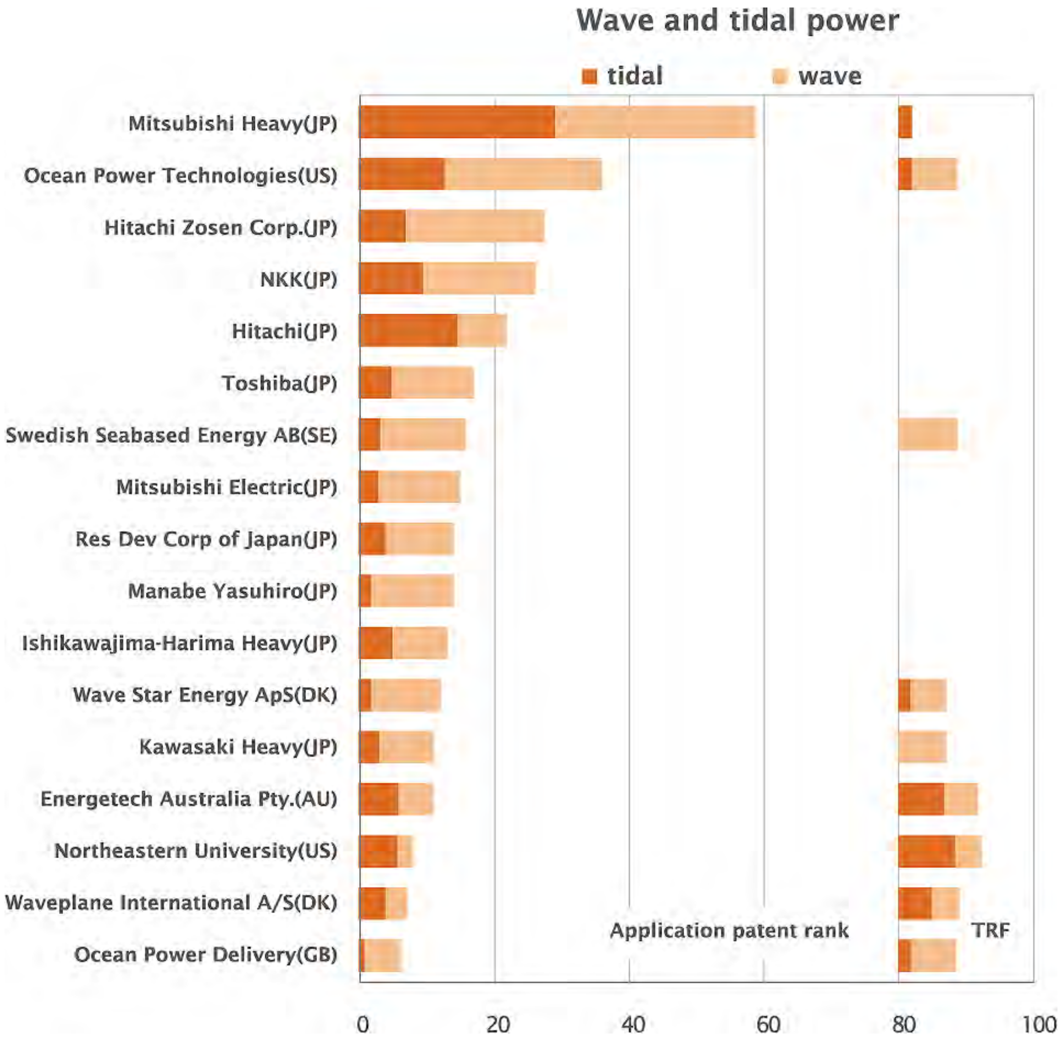
- Wave and tidal power

In the field of wave and tidal power, Mitsubishi Heavy Industries is the top applicant, followed by Ocean Power Technologies, the Hitachi Zosen Corporation, and the NKK Corporation. Mitsubishi Heavy Industries has filed nearly the same number of patent applications for tidal power and wave power, which account for 49 percent and 51 percent of its applications, respectively. Many of the patent applications filed by

Mitsubishi Heavy Industries have been for tidal current power generation devices. Ocean Power Technologies, Hitachi Zosen Corporation and Mitsui Engineering & Shipbuilding all tended to file predominantly in the field of wave power. Hitachi Zosen Corporation filed a significant number of its applications for wave-activated turbine technologies based on pole change induction generators. Ocean Power Technologies has assumed a leadership position in field of wave-activated turbine power generation, having developed a device for converting wave energy into electric power while submerged one meter below the ocean surface. Patent applications related to this device have been filed in many countries worldwide, and the company is seeking to extend its business into Australia and Spain with the assistance of the US Navy (OPT 2008).

The largest number of triadic patent families in the field of wave and tidal power are held by Northeastern University in the United States and Energetech Australia, mainly in the field of tidal power. Among the technologies developed at Northeastern University are a helical turbine pioneered by Alexander Gorlov, whose development has already entered into the field testing stage. Energetech Australia has designed a new type of Denniss-Auld turbine with a 350 kilowatt power generation capacity, for which the company has filed several related patents, and has also begun field testing of this device.

Figure 45 Top applicants for wave and tidal power technologies



- Hydrogen and fuel cells

Major applicants in the field of hydrogen and fuel cell technologies include mainly Japanese applicants but also Korean, Canadian, US, and German applicants. Matsushita Electric hold the top position in terms of applications in this field with around 1000 applications filed as well as the largest number of triadic patent families. Matsushita Electric and Sanyo Electric have filed the largest number of applications related to hydrogen technologies, while Matsushita Electric, Toshiba, Nissan Motor, Fuji Electric, Honda Motor, and Hitachi are the top applicants for fuel cell technologies.

Hydrogen product technologies accounted for 45 percent of Matsushita Electric's patent applications for hydrogen technologies, while hydrogen storage technologies accounted for the remaining 55 percent. Among fuel cell technologies, Matsushita Electric filed patent applications primarily for proton exchange membrane fuel cell (PEMFC) technologies, which accounted for 89 percent of its patent applications. In the field of hydrogen production, most of the patents filed by Matsushita Electric have aimed to increase modification efficiency and produce hydrogen more cleanly and efficiently. In the field of hydrogen storage, the company has focused its patenting activity on alloy electrodes used in manufacturing nickel-hydrogen storage batteries with high efficiency discharge characteristics. PEMFCs have been the object of many of the patent applications filed by Matsushita Electric, with most other these applications being filed for polyelectrolyte-type fuel cells and methods of operating such fuel cell. Specifically, the technologies have been designed to improve diffusion of gases, maintain high cell voltage for long periods of time and to prevent power-downs caused by temperature differences in the cells.

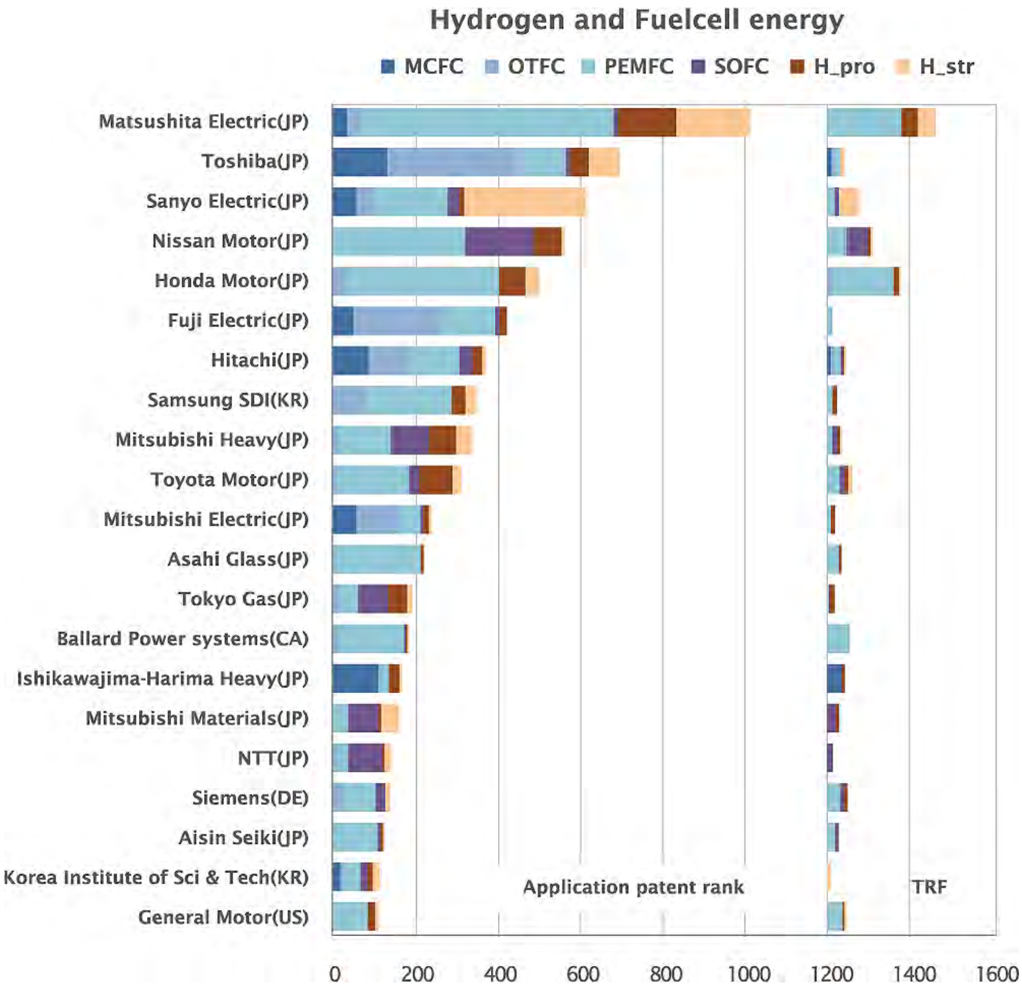
Like Matsushita Electric, Toshiba has filed patent applications in the hydrogen field primarily for hydrogen storage technologies (59 percent), with hydrogen production technologies accounting for the remaining 41 percent. In the field of fuel cell technologies, “other” types of fuel cells account for 54 percent of the company’s patent applications, followed by molten carbonate fuel cells (MCFCs, 23 percent) and PEMFCs (21 percent). The remaining patent applications were filed for direct methanol fuel cells (DMFCs), which Toshiba has used to power notebook personal computer and MP3 players. For this purpose, the company has developed miniaturized DMFCs, including a 0.1 watt micro fuel cell, launched in 2004, which Toshiba claims can power an MP3 player for up to 20 hours (DPreview 2004). In fact, many of the patent applications filed for “other” types of fuel cells are related to DMFCs, while a significant number of applications relate to phosphoric acid type fuel cells.

Sanyo Electric has filed patent applications almost exclusively for hydrogen storage technologies (96 percent of all hydrogen-related applications). These patent applications relate to electrode alloys used for hydrogen storage as well as nickel-hydrogen and alkaline storage batteries. Most patent applications for fuel cell technologies filed by Sanyo Electric have been for PEMFC-related technologies (57 percent), with MCFCs and solid oxide fuel cells (SOFCs) accounting for 17.6 percent and 10.5 percent of patent applications, respectively. Specifically, a large number of applications have been filed by the company for polymer-type fuel cells and MCFCs. Among other things, Sanyo Electric has developed 1 kilowatt electrolyte fuel cells for household use and supplied fuel cell products to a wide range of large-scale commercial clients (NKJ 2005).

Nissan Motor and Honda Motor are two Japanese motor vehicle manufacturers with significant patent activity in the fields of hydrogen and fuel cells technologies. Notably, Honda Motors has filed applications mostly for hydrogen production and not for hydrogen storage technologies. In the field of fuel cell technologies, Nissan Motors has focused primarily on PEMFCs, for which 65 percent of its applications in the field were filed, while SOFCs claimed a further 34.3 percent. Specifically, Nissan Motors has sought patent protection not for cell stack technologies but for systems and operation technologies related to PEMFCs. Honda has concentrated even more strongly on PEMFCs, which accounted for 90 percent of its patent applications. Though both companies initially introduced cell stacks developed by other companies to the market, they quickly moved to develop their own cell stack technologies. Nissan Motors had first relied on cell stacks designed by UTC Power Company, while Honda Motors at the beginning marketed the MK902 cell stack from Ballard Power Systems but later is developing and installing its own cell stacks, using metallic bipolar plates and hydrocarbon membranes for which Honda Motors has filed patent applications (Kalhammer 2007).

Ballard Power Systems (BPS), a Canadian company, remains a leader in the market for fuel cell stacks and has filed numerous patent applications for hydrogen supply and water removal technologies necessary for the efficient functioning of hydrogen fuel cells as well as for gas flow path designs and separator technologies. Among other things, BPS has filed patent applications for an electrochemical fuel cell stack with compression bands, a lightweight fuel cell membrane electrode assembly with integrated reactant flow passages, and a continuous method for manufacturing a laminated electrolyte and electrode assembly.

Figure 46 Top applicants for hydrogen and fuel cell technologies



- Carbon capture and storage

In the field of carbon capture and storage, Mitsubishi Heavy Industries, Air Products and Chemicals, the BOC Group, Toshiba, and Hitachi rank among the top patent applicants in order by number of applications. The BOC Group holds the largest number of triadic patent families in this set of companies. The top 20 applicants in this field are mostly Japanese companies, though certain companies from Great Britain, the United States, and Germany also feature among the top applicants. Among the technologies developed by Mitsubishi Heavy Industries, the top applicant, is a liquid amine-based absorbent that the company claims costs only 103 US dollars per ton of carbon captured from power generation based on natural gas combustion, a 54 percent reduction in cost compared to convention liquid amine absorbents. This technology was finally completed in 2000 after a 10-year research and development period (CDRS 2005).

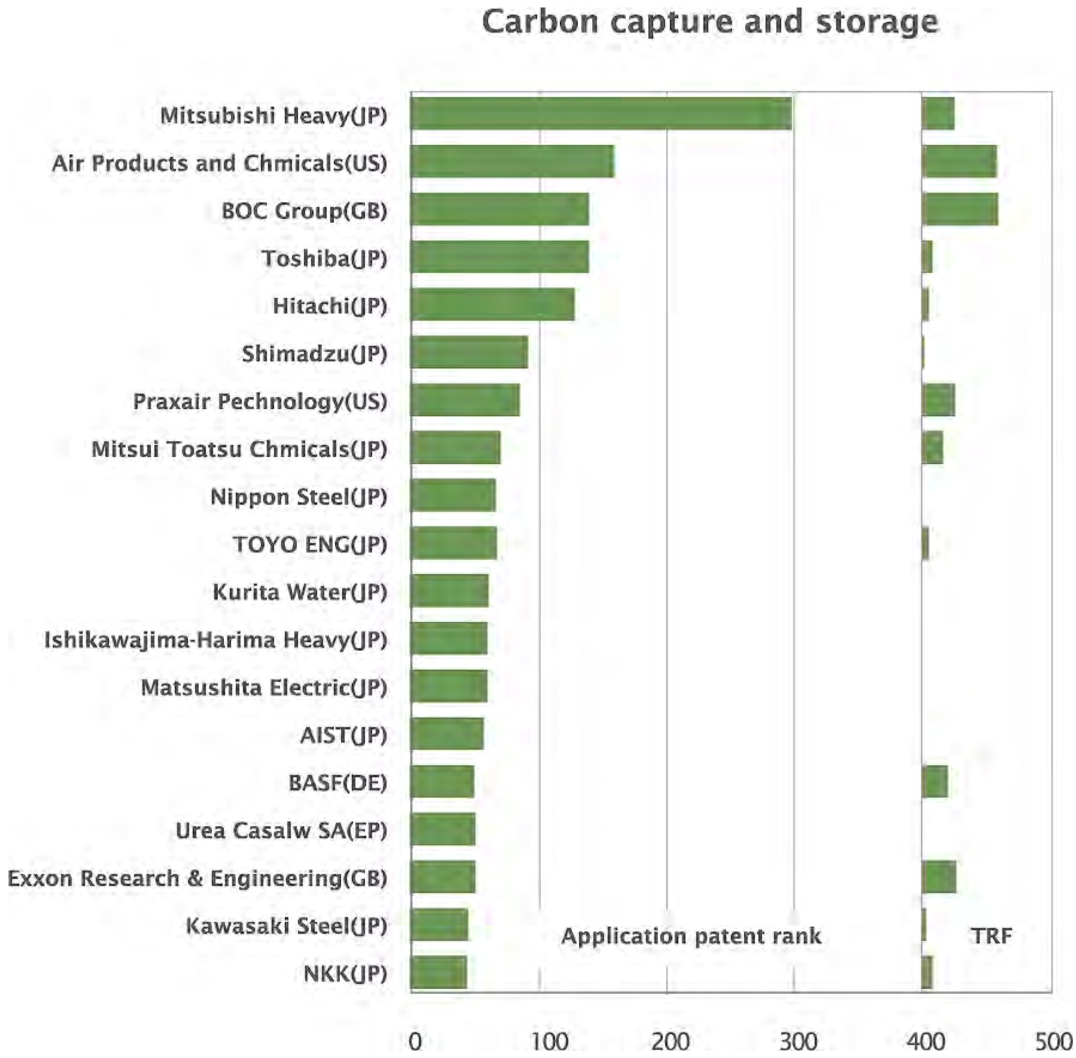
Overall, most of the patent applications filed by Mitsubishi Heavy Industries have been for amine absorbent and capture devices such as absorption towers. With respect to carbon storage, the company has filed a significant number of applications for a method in which a pressurized fluid mixture consisting mainly of carbon dioxide together with methanol is forced into an oil field. Several patent applications have been filed for methods and systems for injecting carbon dioxide into deep ocean waters.

Air Products and Chemicals began filing a significant number of patent applications for carbon capture and storage in the late 1990s. These applications relate to such technologies as a method for absorbing carbon dioxide from gas using solid absorbents containing zeolite and magnesia as well as a device used in implementing this method. A large portion of the company's patent applications are also devoted to methods for hydrogen separation, capture, and removal.

The patent applications filed by the BOC Group for carbon capture and storage-related technologies have increased since the mid-1990s and have focused primarily on capture technologies, in particular absorbents and methods of separating components from a gas mixture. For example, the BOC Group pioneered absorbent composite materials made of zeolite and inert binder materials to separate nitrogen and carbon dioxide from air.

In the field of waste-to-energy technologies, the largest number of applications has been filed by Mitsubishi Heavy Industries, the Ebara Corporation, Kubota, and the NKK Corporation. The greatest number of triadic patent families is held by the Ebara Corporation, Mitsubishi Heavy Industries, Von Roll Umwelttechnik, and Kinsei Sanyo.

Figure 47 Top applicants for carbon capture and storage technologies

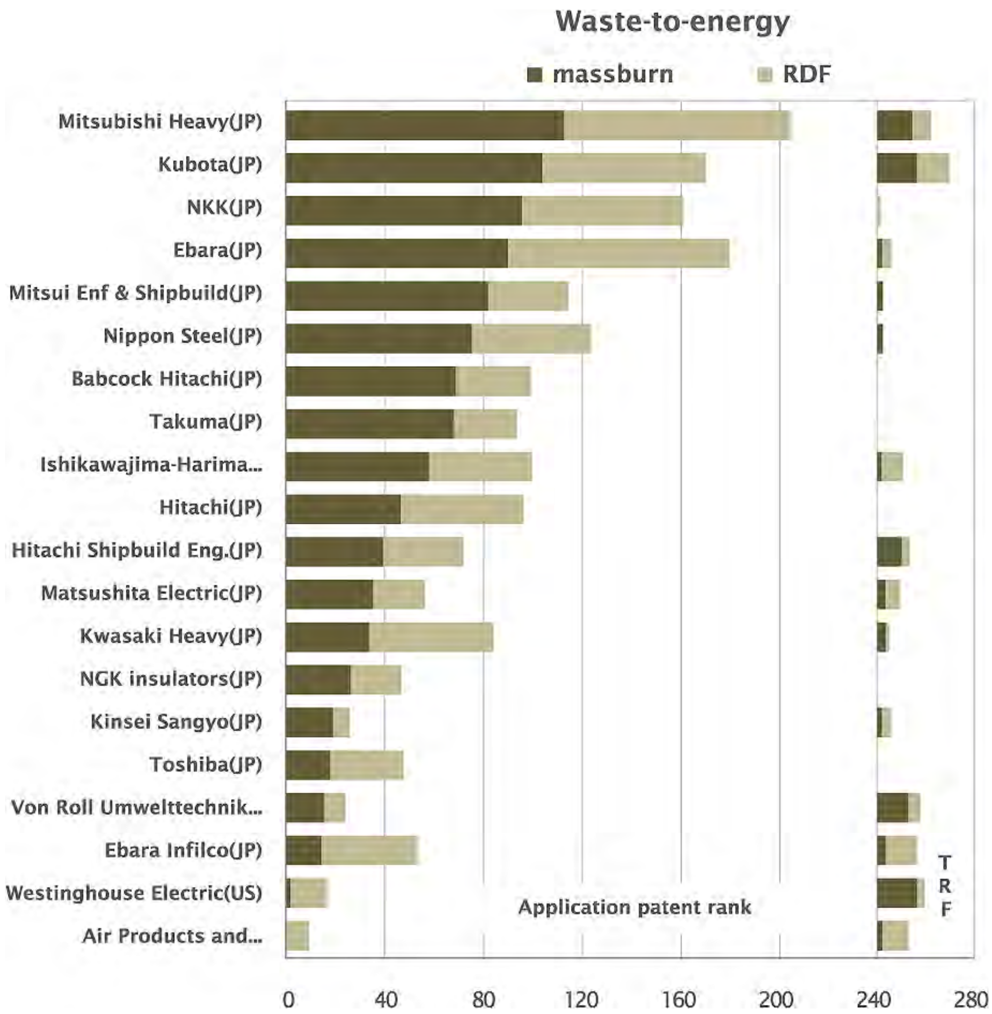


- Waste-to-energy

Mitsubishi Heavy Industries has filed the majority of its waste-to-energy patent applications for “mass burn” technologies (56 percent), while refuse-derived fuel technologies account for the remaining 44 percent of its applications. The filing patterns are similar for the Ebara Corporation. Kubota, the NKK Corporation, and Mitsui Engineering & Shipbuilding have concentrated even more heavily on “mass burn” technologies. By contrast, Kawasaki Heavy Industries, Ebara Inflico, Air Products and Chemicals, and Westinghouse have all focused their patenting activity primarily on refuse-derived fuel technologies. The top applicants for refuse-derived fuel technologies are the Ebara Corporation, Mitsubishi Heavy Industries, the NKK Corporation, Kubota, Kawasaki Heavy Industries, and Hitachi.

Specifically, Mitsubishi Heavy Industries has filed patent applications for innovations in the field of thermal cracking and kilns, mainly in Japan and Europe, and has started manufacturing a pyrolysis kiln integrated with a melting furnace, for which a large number of patent applications have been filed for combustion control devices and methods of thermal decomposition gasification. Toshiba has succeeded in producing light and heavy oil through a process for thermal decomposition of mixed waste plastic containing PVC and a catalyst in a continuous stirred-tank reactor (CSTR). Kubota has also succeeded in producing light and heavy oil using a process combining a CSTR and a fixed catalyst tower and has been working on a process for decomposing non-PET waste plastics. Ebara has filed a number of patent applications in the field of waste gasification, including for a system for gasifying and combusting solid waste using a combined melting furnace and fluidized bed incinerator.

Figure 48 Top applicants for waste-to-energy technologies



4. RECOMMENDATIONS

In light of the environmental, social, and security concerns linked with the use of fossil fuels, alternative energies must represent an important element in all countries' planning for the future. At present, alternative energies have relatively low efficiency compared to conventional energy sources. However, they have the potential to contribute to reducing greenhouse gas emissions, providing a clean and reliable source of energy for developing countries, and increasing security of energy supply. Accordingly, it is advisable for governments to take an active role in promoting the development and use of alternative energies, taking into account the particular national situations of their country rather than focusing solely on the competitors on the alternative energy market. Longer term policy stability is important in this context: The examples of the Netherland and United States have shown that frequent changes in the policy environment are detrimental to the investor confidence in the alternative energy market and thus can undermine the objectives of laws and regulations designed to promote the development and diffusion of related technologies.

Given an appropriate policy framework, alternative energy industries can be a potent source of wealth and employment. The private sector has the potential to active large streams of capital, as has been the case for "green" industries in Silicon Valley. Major companies with a global reach have an important role to play in this respect, however small and medium-sized enterprises can act as pioneers into certain areas of research and development and help sound out the depth and character of the alternative energy market.

As demonstrated by patent filing patterns, developing countries have been latecomers on the alternative energy market, which is still largely dominated by industrialized countries. Developing countries with their rapidly expanding, energy-hungry industrial sectors may not have the same affinity for alternative energies as developed countries, due to the relatively low efficiency of alternative energies. However, the adoption of alternative energies into earlier stages of the development process can be an effective way of creating major growth industries for the future.

To increase their share in the alternative energy market, developing countries must take certain steps.

Firstly, developing countries must raise awareness among their citizens on the benefits of alternative energies.

Secondly, long-term strategies on technology development should be devised based on a careful analysis of the countries' needs and capabilities as well as trends in patent filing and the state of the art, domestically and internationally. Technology transfer agreements should be sought to fill gaps in developing countries' technology portfolios. Developing countries can also foster the development of new technologies by building on existing patents from industrialized countries, while avoiding patent infringement by designing around the claimed innovations.

Thirdly, developing countries should seek cooperation with industrialized countries. The abundant resources (human and natural) available in many developing countries can act as a strong incentive to investment from industrialized countries, while industrialized countries can import advanced technologies into developing countries and help invigorate nascent industries emerging in developing countries and stimulate employment.

ANNEX A: DATA EXTRACTION METHOD

Operators

Operators are used to join two or more search terms.

Boolean operators – AND, OR and NOT – do not take into account the position or order of given search terms and only operate on the basis of whether these terms exist or not in the data.

A AND B
Search for data with both A and B, regardless of the position or the order of the keywords e.g. printer AND head
A OR B
Search for data with either A or B, regardless of the position or the order of the keywords. e.g. PV OR sun
A NOT B
Search for data with A but not B, regardless of the position or the order of the keywords. e.g. green NOT blue

Unlike Boolean operators, proximity operators – ADJ and NEAR – limit distance within which given search terms may be found in the data.

A ADJ[n] B
Search for data with A and B within certain number of words of each other in the given order. Here, n refers to the numbers over 0 and the default number is 1. (Maximum 40,000) Example: digital ADJ camera → Search for the keywords “digital” and “camera” in the given order (e.g. “digital camera with histogram zoom”) mobile ADJ2 camera → Search for the keywords “mobile” and “camera” in the given order, within distance of 2 words (e.g. “mobile camera telephone” or “mobile phone with camera”)
A NEAR[n] B
Search for data with A and B within certain number of words of each other regardless of their order. Here, n refers to the numbers over 0 and the default number is 1. (Maximum 40,000) Example: display NEAR panel → Search for the keywords “display” and “camera” regardless of the order in which they are given (e.g. “Glasses for flat panel displays” or “Flexible display panel device”) (input AND output) NEAR2 signal → Search for the keywords “input” and “output” in any order where either of these keywords must be within a distance of two words from the keyword “signal” (e.g. “approximately the same output value for a given dynamic input signal”)

The wildcard operator “*” is used to truncate search terms.

A*
Search for data with A and any terms that begin with A. Example: photo* → Search for the keyword “photo” and any variations that begin with photo (e.g. “photovoltaic”, “photo-voltaic”, “photosensitive”, “photonic”)
A*B
Search for data with AB and any terms that begin with A and end with B. Example: colo*r → Search for the keyword “color” and any variations that begin with “colo” and end with “r” (e.g. “colour”)

Parentheses are used to resolve potentially ambiguous combinations of operators.

(A ADJ B) OR C
Search for data with A and B, in the given order, or with C. Example: (tennis ADJ racket) OR ball → Search for the keywords “tennis” and “racket” in the given order or the keyword “ball” (e.g. “tennis racket adjuster”, “golf ball having arrangement structure of dimple”)
A ADJ (B OR C)
Search for data with A and either B or C, in the given order. Example: tennis ADJ (racket OR ball) → Search for the keyword “tennis” and either the keyword “racket” or the keyword “ball” in the given order (e.g. “tennis racket adjuster”, “novel tennis ball”)

General notes

IPC symbols are derived from the Seventh and Eighth Editions of the IPC.

IPC symbols are combined with keywords using the AND operator. Keywords are combined with keywords and IPC symbols with IPC symbols using the OR operator.

For example, if the search criteria are given as:

Materials, cells and modules	
IPC symbols	E04D 13/18, H01L 25/00, H01L 31/04, H01L 31/042, H01L 31/052 H01L 31/18, H02N 6/00
Keywords	(solarcell solar-cell photovoltaic* ((solar photo* PV sun) adj (light cell battery panel module*)))

The full search is:

(E04D 13/18 OR H01L 25/00 OR H01L 31/04 OR H01L 31/042 OR H01L 31/052 or H01L 31/18 OR H02N 6/00) AND ((solarcell OR solar-cell OR photovoltaic* OR ((solar OR photo* OR PV OR sun) ADJ (light OR cell OR battery OR panel OR module*)))

A1. Solar Energy

A1.1. Solar power

Materials, cells and modules	
IPC symbols	E04D 13/18, H01L 25/00, H01L 31/04, H01L 31/042, H01L 31/052 H01L 31/18, H02N 6/00
Keywords	(solarcell solar-cell photovoltaic* ((solar photo* PV sun) adj (light cell batter* panel module*)))
Systems	
IPC symbols	E04D 1/30, G02F 1/136, G05F 1/67, G01L 25/00, H01L 31/00, H01L 31/042, H01L 31/048, H01L 33/00, H02J 7/35, H02N 6/00
Keywords	(solarcell solar-cell photovoltaic* solar photo* PV sun) and (control* invert* convert* conversion system mount* instal*)

A1.2. Solar thermal

Collectors	
IPC symbols	F24J 2/00-46, F03G 6/06, G02B 5/10, H01L 31/052
Keywords	CSP concentrat* collect* trough dish tower sterling stirling
Heating	
IPC symbols	C02F 1/14, E04D 13/18, F02C 1/05, F03G 6/00, F03G 6/06, F22B 1/00, F24C 9/00, F24H 1/00, F24J 2/02, F24J 3/00, F25B 27/00 F26B 3/28, H01L 31/058, H02N 6/00
Keywords	((solar* sun*) and (heat* thermal accumulate* power generat* warm* boiler* building system house hot boiling))

A2. Wind power

General	
IPC symbols	F03D, B60L 8/00
Keywords	wind* turbin*

A3. Bio energy

Thermochemical processes	
Keywords	(biomass bio-mass Bio-recycling Biological* biorefinery ((bio* organic* wood (sugar adj (cane beet)) corn pulp rape palm waste* ((organic bio living bio) adj2 (waste substance* material resource* source* sludge*)) ((Vegitable mineral used wast*) adj (Oil fuel))) adj3 (mass recycl* energy fuel power oil generat* regenerat* refin*))) and (thermochemical* BDF biofuel* biodiesel* (Bio adj diesel) bio-disel bioethanol* biomethanol bioalcohol (bio* adj (fuel energy alcohol methanol ethanol butanol diesel

	gasolin*)) liquefact* liquidation pyrolysis (direct adj liquefaction) biorefin* gasifying gasification (gas adj turbin*) combustion (coal near (fir* burn* combust*)) co-firing (co adj fir*) incinerat* gasification gasifying (methane adj emission) (methane adj (gas emission)))
Biological processes	
Keywords	(biomass bio-mass Bio-recycling Biological* biorefinery ((bio* organic* wood (sugar adj (cane beet)) corn pulp rape palm waste* ((organic bio living bio) adj2 (waste substance* material resource* source* sludge*)) ((Vegetable mineral used wast*) adj (Oil fuel))) adj3 (mass recycl* energy fuel power oil generat* renerat* refin*))) and, ((biochemical (anaerobic adj digestion) ((Anaerobic Aerobic organic alcohol* methane ethanol lignin*) adj (digest* saccharif* fermentation)) micro-organisms SSF saccharification (methane adj digestion)) and (energy ethanol methane fuel recycl* reprocess*))

A4. Hydropower

General	
IPC symbols	E02B 9/00-06, F03B 1/00, F03B 3/00-18, F03B 7/00, F03B 13/00-08,22, F03B 15/00-22, F03B 17/00-06, F03G 7/00,10, F16H 41/00, H02K 57/00
Keywords	hydropower hydroelectric hydro-electr* hydro-power water-power* waterpower* flow fluid fluidpressure (fluid adj pressure) dam hydro* water* river drainag* float* hydraulic* buoyancy hydro* water * dam river tunnel pump ((pelton turgo ossberger fransis kaplan tubular bulb rim) adj (turbine))

A5. Geothermal Energy

Systems	
IPC symbols	F24J 3/00-08, F03G 4/00-06, F03G 7/00, F03G 7/04, F25B 30/06, F01K 23/10, F01K 25/00-14, F01K 27/00
Keywords	geothermal hydrothermal ((geo* earth* magma ground underground terrestrial lake pond water (hot adj water) hydro rock brine* steam) adj3 (heat source resource power thermal electric* resource energy system))
Ground-coupled heat pumps	
IPC symbols	F25B 30/00-04, F25B 1/08, F24J 3/08, F03G 4/00
Keywords	(GHP geoexchang* geo-exchang* (geo adj exchang*) earthcoupled earth-coupled (earth adj coupled) geothermal hydrothermal ((geo* earth* magma ground underground terrestrial lake pond water (hot adj water) hydro rock brine* steam) adj3 (heat source resource power thermal electric* resource energy system)))

A6. Wave and tidal power

Tidal power	
IPC symbols	E02B 9/00-08, F03B 13/00-26, F03B 15/00-20, F03B 17/02, F03G 7/00, F03G 7/05
Keywords	tidal* tide* seawater (sea adj water) ocean*
Wave power	
IPC symbols	E02B 9/00-08, F03B 13/00-26, F03B 15/00-20, F03B 17/02, F03G 7/00 F03G 7/05
Keywords	wave* bollow* offshore* onshore* duck* float*

A7. Hydrogen and fuel cells

A7.1. Hydrogen

Production	
IPC symbols	C01B 3 C25B 1/02 C25B 1/04 C07C 4/20
Keywords	(hydrogen adj2 (produc* generat* obtain* reform* preparat* manufactur*))
Storage	
IPC symbols	B01D 53/02 C01B 3/00-58 C22C 19/03 C22C 22/00 C22C 33/00 F25B 17/12 H01M 4/38 H01M 8/06
Keywords	(hydrogen adj2 (storag* reservoir* alloy* adsorb*))

A7.2. Fuel cells

Proton-exchange membrane fuel cells

General	
IPC symbols	H01M 4/00,86,88,90 H01M 8/00-24
Keywords	(fuel-cell* fuel-batter* (fuel adj (cell* batter*))) and (PEM PEMFC polymer* (((proton ion) adj (exchang*)) near membrane))

Solid oxide fuel cells

General	
IPC symbols	H01M 4/00,86,88,90 H01M 8/00-24
Keywords	(fuel-cell* fuel-batter* (fuel adj (cell* batter*))) and (SOFC* solidoxide* (solid adj oxid*) zirconium ZrO*)

Molten carbonate fuel cells

General	
IPC symbols	H01M 4/00,86,88,90, H01M 8/00-24
Keywords	(fuel-cell* fuel-batter* (fuel adj (cell* batter*))) and (MCFC ((molten melt*) adj (carbonat*)))

Other types of fuel cells

General	
IPC symbols	H01M 4/00,86,88,90 H01M 8/00-24
Keywords	(fuel-cell* fuel-batter* (fuel adj (cell* batter*))) and ((potassium adj hydroxide) phosphoric* (phosphoric adj acid) (liquid adj phosphoric*) ((direct) adj (methanol oxidation)) alkaline DMFC AFC PAFC)

A8. Carbon capture and storage

General	
IPC symbol	B63B 35 C01B 3 C01B 31/20 C01B 31/22 C02F 1 C07C 7/10 F01N 3/10 F25J 3/02 B01J 20 B01D 53 B01D 11
Keyword	(carbon-dioxide* (carbon adj dioxide*) (carbon* adj (gas dioxide*)) co2*) and (storage* captur* recover* deliver* regenerat*)

A9. Waste-to-energy

A9.1. Refuse-derived fuel

General	
IPC symbol	B09B 1/00 B09B 3/00 B09B 5/00 B29B 17/00 C02F 3/30 C04B 33/132 C10B 53/07 C10G 1/10 C10L 5/46 C10L 5/48 C11B 3/00 F23G 7/00-14 F23G 5/00-50 F25B 27/02 F02G 5/00-04 F012K 25/14 C10J 3/86
RDF	((RDF (refuse adj derived*) (solid* adj recover*) solid*) and (wast* used refus* garbage trash))

A9.2. Mass burn

General	
IPC symbol	B09B 1/00 B09B 3/00 B09B 5/00 B29B 17/00 C02F 3/30 C04B 33/132 C10B 53/07 C10G 1/10 C10L 5/46 C10L 5/48 C11B 3/00 F23G 7/00-14 F23G 5/00-50 F25B 27/02 F02G 5/00-04 F012K 25/14 C10J 3/86
Mass burn	((Burn* combust* incinerat*) and (energy heat)) and (wast* used refus* garbage trash)

ANNEX B. DATA SUMMARY

Table B1. Number of applications by technology and patent office

Technology		EP	WO	US	JP	KR	CN	Total
Solar energy	photovoltaic/cell	414	341	1,177	9,627	518	113	21,525
	photovoltaic/system	228	170	1,115	3,036	253	41	
	thermal/collector	275	264	542	1,218	251	218	
	thermal/heating	83	93	444	864	94	146	
Wind power		902	881	1,263	1,942	496	242	5,726
Bio energy	thermochemical	84	73	1,532	339	122	9	8,988
	biochemical	603	555	2,355	2,849	333	134	
Hydropower		424	403	665	3,546	614	340	5,992
Geothermal energy	systems	43	29	16	298	29	55	2,218
	ground-coupled heat pumps	203	132	288	993	52	80	
Wave and tidal power	tidal	64	98	195	416	250	42	2,753
	wave	173	240	345	704	112	114	
Hydrogen and fuel cells	hydrogen/production	239	186	364	1,257	207	55	17,009
	hydrogen/storage	187	77	208	1,187	266	92	
	fuel cell/PEMFC	637	668	1,496	3,381	566	122	
	fuel cell/SOFC	496	359	725	1,022	120	32	
	fuel cell/MCFC	119	52	159	604	83	6	
	fuel cell/others	131	150	357	1,235	150	14	
Carbon capture and storage		855	541	1,344	3,671	214	233	6,858
Waste-to-energy	RDF	329	196	482	2,436	275	71	6,744
	mass burn	213	124	254	2,218	98	48	
Total		77,813						

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