

Winning the Green Innovation Economy: AN ANALYSIS OF WORLDWIDE PATENTING

GREENTECH INNOVATION SERIES

A RESEARCH BRIEFING FROM THE UNIVERSITY OF VIRGINIA'S DARDEN SCHOOL OF BUSINESS

IN BRIEF

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Today's critical environmental challenges and prolonged global recession have resulted in calls for a new "green" economy that could simultaneously promote sustainability, generate economic growth and create jobs. For politicians and policy makers, encouraging this green economy is a matter not only of global importance but of local and regional competitiveness, and a race is on among countries and localities to become the leader in green technology.^{1,2} To find out who's winning this race, we've analyzed patent activity around the world to discover who is innovating in "greentech." This Batten Briefing provides the first results from this analysis, which inform our initial insights about where green innovations are being developed, which types are most significant, and the connection between innovation and adoption of green technologies.

¹ Khan, M. 2009. "Think Again. The Green Economy." *Foreign Policy*. (172): 34-35.

² Gander, S., Hoey, A. 2012. "Clean State Energy Actions: 2011 Update." A Report from the National Governors Association.

Global Hotspots

CLUSTERS OF GREENTECH INNOVATION

DATA AND METHODOLOGY

Patents were classified as “greentech” using the World Intellectual Property Organization’s IPC (international patent classification) Green Inventory. The IPC Green Inventory classifies alternative energy production patents across thirteen broad technology subsectors: solar, wind, geothermal, biofuel, biomass, fuel cell, hydro, synthetic gas, integrated gasification combined cycle (IGCC), man-made waste, mechanical power from muscle energy, natural heat and waste heat. We assigned a country of origin to each greentech patent on the basis of the location of the primary inventor listed on the application. Patents filed in multiple jurisdictions were counted only once. A small portion of the registered patents have no identified inventor country, and for this analysis, such patents were excluded. Within our dataset, the vast majority of patents without an inventor country were filed at the JPO.

Spurred by mounting environmental concerns and the global recession, there has been substantial investment in green technology around the globe. In 2010 global investment in greentech³ topped \$211 billion, bringing renewable energy’s portion of worldwide electricity production to 19.4%.⁴ To understand the source of these technologies, we examined patents filed in the world’s three largest patent offices—the U.S. Patent and Trademark Office (USPTO), the European Patent Office (EPO⁵) and the Japanese Patent Office (JPO). (See the sidebar about our data and methodology.)

Analyzing the distribution of greentech patents across countries over time, we have identified clusters of innovation that correspond to the world’s most developed and fastest growing economies. The U.S. leads all countries, at 67,432 greentech patents granted since 1990, with Japan in second at 53,217 and Germany a somewhat distant third at 36,328. East Asia represents the strongest growth region for greentech patenting, with China, Taiwan and South Korea all averaging annual increases of 20% or more from 1990 to 2008. Despite its high growth in patenting, however, China remains far removed from the top countries for greentech innovation with a mere 0.5% of all patents filed at the three major patent authorities.⁶

Considering patent intensity (patents per capita), the smaller European countries stand out, perhaps indicating greater efficiency in greentech innovation. Denmark (third), Norway (eighth) and Sweden (ninth) all jump into the top ten in terms of patent intensity while the U.S. slips to sixth and the UK drops to twelfth.

Although the bulk of greentech innovation still takes place in the most developed countries of North America, Western Europe and East Asia, large developing economies have been quicker to adopt and implement the technologies. China, Brazil and India now rank first, fourth and fifth among all countries for total existing renewable power capacity.⁷ Within the smaller subset of geothermal power installations, the Philippines, Indonesia and Mexico all crack the top five globally.⁸

³ Green technology, or “greentech,” refers to products and services that reduce energy and material consumption, waste and pollution.

⁴ Sawin, J., et al. 2011. “Renewables 2011 Global Status Report.” A Report from Ren21.

⁵ Within the EPO patent data, we also included patents filed separately at local offices of the following EPO member countries: France, Germany, UK, Italy, Spain, Belgium, Netherlands, Denmark, Norway and Sweden.

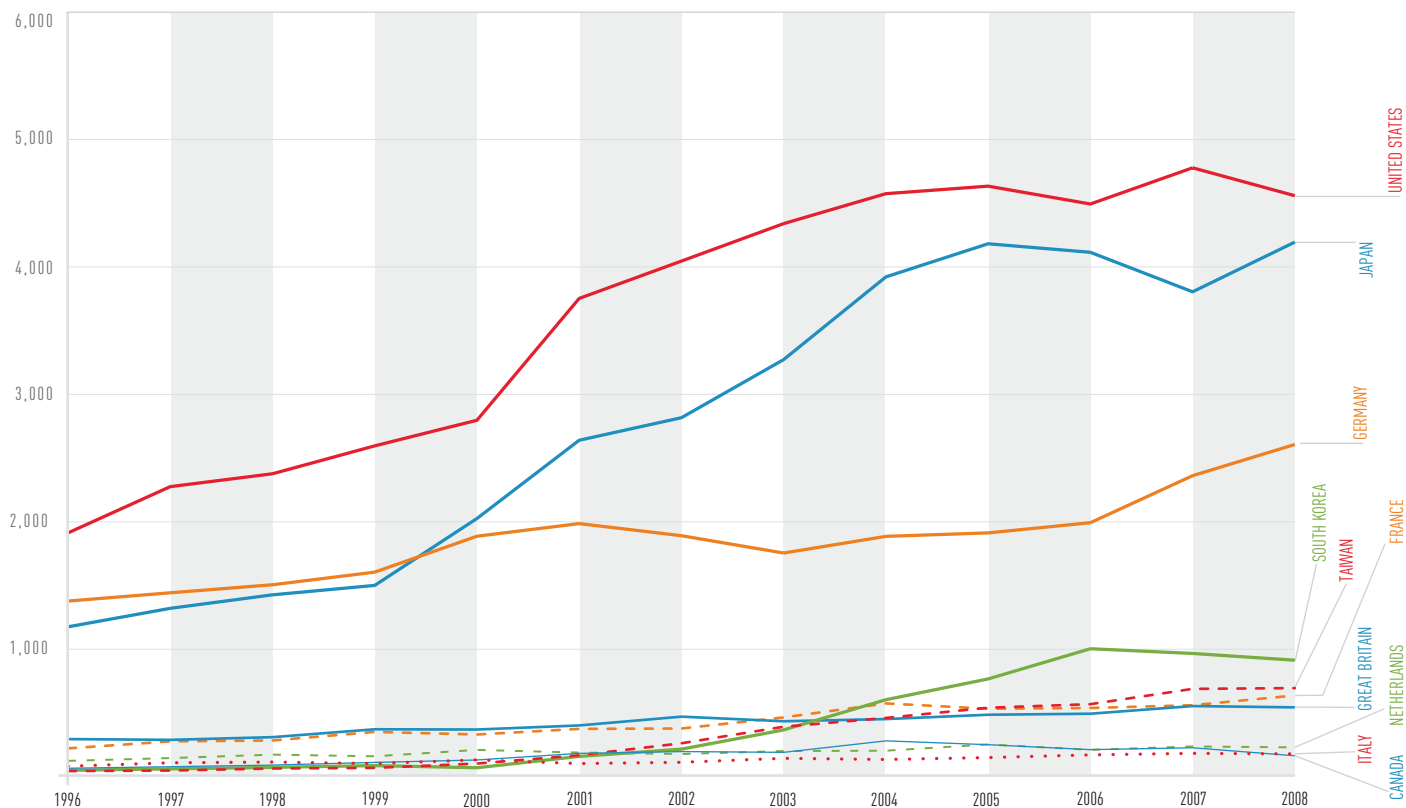
⁶ Patents filed with the Chinese Patent Authority, which has reported a significant increase in greentech patenting in recent years and accounts for approximately 24% of all greentech patents, have been excluded from this analysis. “The Curious Case of China” in this Briefing discusses the reasons for this exclusion in greater detail.

⁷ This ranking includes hydropower, which is all energy generated from flowing water. Excluding hydropower, China falls to second and Brazil drops out of the top five.

⁸ Sawin, J., et al. 2011.

GREENTECH PATENTING ACTIVITY BY COUNTRY

Number of patents granted by the world's three largest patent offices (US, EU, JP)⁹



GREENTECH PATENT INTENSITY

Top 10 cumulative patents per capita (1990-2010)

- | | |
|-----------------|-------------------|
| 1 GERMANY | 6 UNITED STATES |
| 2 JAPAN | 7 NETHERLANDS |
| 3 DENMARK | 8 NORWAY |
| 4 SWITZERLAND | 9 SWEDEN |
| 5 TAIWAN | 10 SOUTH KOREA |

⁹ Each patent is recorded according to the year of filing. Since patents can take three or more years to be granted after filing, only data through 2008 is used for time trend graphs. For cumulative patenting activity, data through 2010 is incorporated as we assume that delays for granting patents are distributed randomly across countries and inventors.

The Curious Case of China

GREENTECH PATENT FILING ANOMALIES

GREENTECH PATENT FILING, HOME COUNTRY COMPARISONS

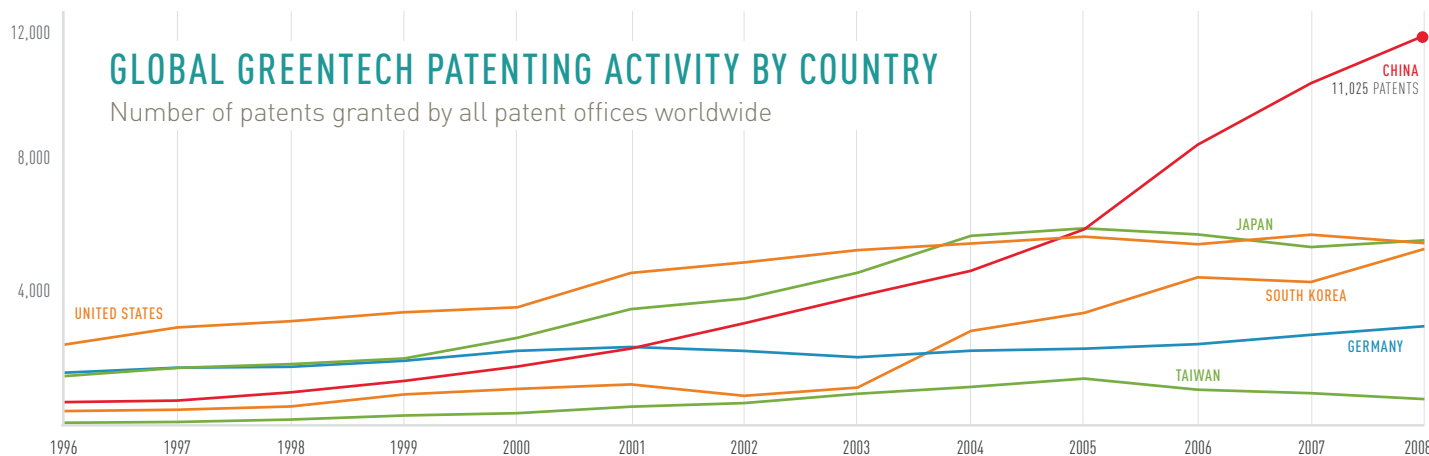
Patents filed across all patent authorities worldwide (1990-2008)

Percent of patents filed in U.S., Europe, Japan	vs.	Percent of patents filed only in home country authority
CHINA	2%	98%
US	89%	67%
GERMANY	93%	73%
ISRAEL	19%	63%
CANADA	45%	50%
KOREA	20%	73%

Despite China's growing prowess as a leading *adopter* of greentech, this country is only number 20 on the list of patent *filers* with the three largest patent offices (U.S., Europe and Japan). A conflicting picture emerges, however, when considering all patents filed worldwide. From this latter perspective, China tops the list for annual greentech patents filed worldwide in 2008, with more than double the patents from U.S. inventors. In fact, since 2005 China has managed to double its annual greentech patent output.

Taking a closer look at the worldwide patent data, 98% of Chinese inventors filed patents in China alone and only 2% of them in the U.S., Europe and/or Japan (see table). Since patents issued by the Chinese patent authority carry no protection in foreign markets, the utility of these Chinese patents is debatable, especially given China's poor record of enforcing intellectual property rights at home.^{10,11,12} Over two-thirds of the patents filed worldwide are filed in either the U.S., EU, or Japan. Remove patents granted by the Chinese patent authority and the number of worldwide patents filed in either the U.S., EU, or Japan jumps to 82%. In each of these three authorities, we see significant numbers of foreign inventors apply for patent protection.

While ample variation exists across countries, the Chinese case is indeed an anomaly. Some observers point to a program of direct incentives created by the Chinese government for filing patents as a potential driver of the high percentage of patents filed solely in China. Rewards for individuals who file patents can include cash bonuses, tenure for professors and city residence permits for students and workers. Corporations may benefit from reduced income tax and higher preference for government contracts. Given the high incentives for simply filing a patent whether or not the underlying idea has value, skepticism has arisen as to the actual worth of many of the ideas protected by these Chinese patents. Perhaps further skewing activity, patent reviewers are said to receive higher pay for issuing more patents.¹³



Sector Standouts

TOP SECTORS OF GREENTECH PATENT ACTIVITY

Solar and biofuel technologies account for the majority of greentech innovation across sectors, with 71% of all patents since 1990. While innovation in biofuels has stagnated over the last decade, showing negligible growth in annual patents, solar technology patents jumped 177% since 1999. By 2008 solar represented 36% of all annual greentech patents while biofuels sank to just 10%, down from 24% in 1999. Fuel cell technology remains a distant third to solar and biofuels in patenting, but has surged since 1990 by 591% on the back of growing investment in electric vehicles. Due to centuries of utilization and development, wind power accounts for only 2.5% of all greentech patents since 1990. However, this technology still represents an important growth sector for annual new investments, ranking third behind solar and biofuel.

¹⁰ Leonhardt, D. 2011. "The Real Problem with China." *The New York Times*.

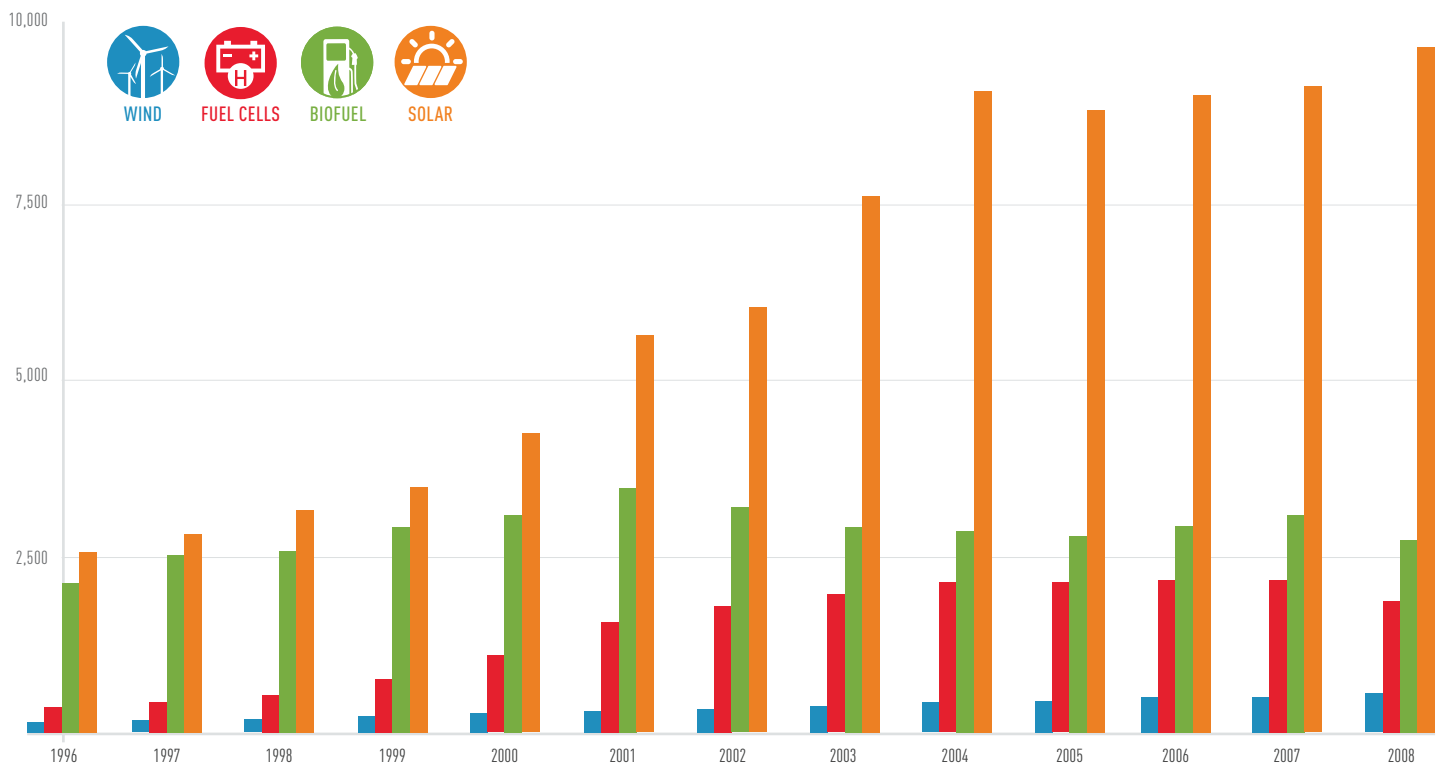
¹¹ Gupta, A., Wang, H. 2011. "Safeguarding your Intellectual Property in China." *Bloomberg Businessweek*.

¹² Martina, M., Younglai, R. 2011. "Geithner slams China's Intellectual Property Policies." *Reuters*. <http://www.reuters.com/article/2011/09/23/us-china-geithner-idUSTRE78M15G20110923> (Accessed 22 March 2012)

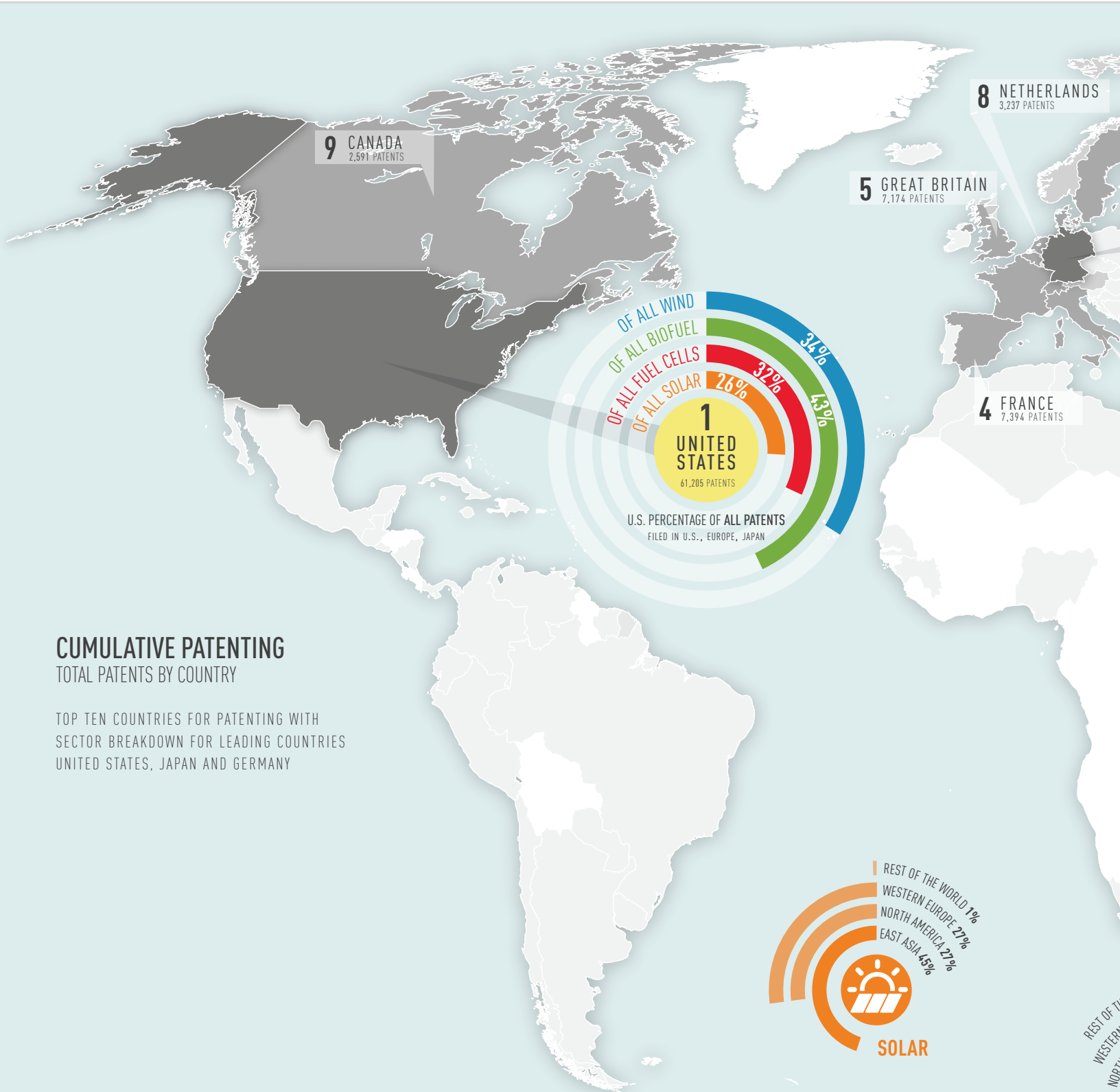
¹³ Anonymous. 2010. "Patents, yes; ideas, maybe." *Economist*. 397(8704): 78 (US).

ANNUAL GREENTECH PATENTING BY SECTOR

Patents filed annually in the world's three largest patent offices (US, EU, JP)



LOCUS OF GREENTECH INNOVATION*

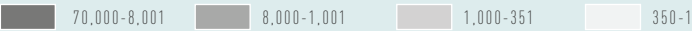


CUMULATIVE PATENTING

TOTAL PATENTS BY COUNTRY

TOP TEN COUNTRIES FOR PATENTING WITH
SECTOR BREAKDOWN FOR LEADING COUNTRIES
UNITED STATES, JAPAN AND GERMANY

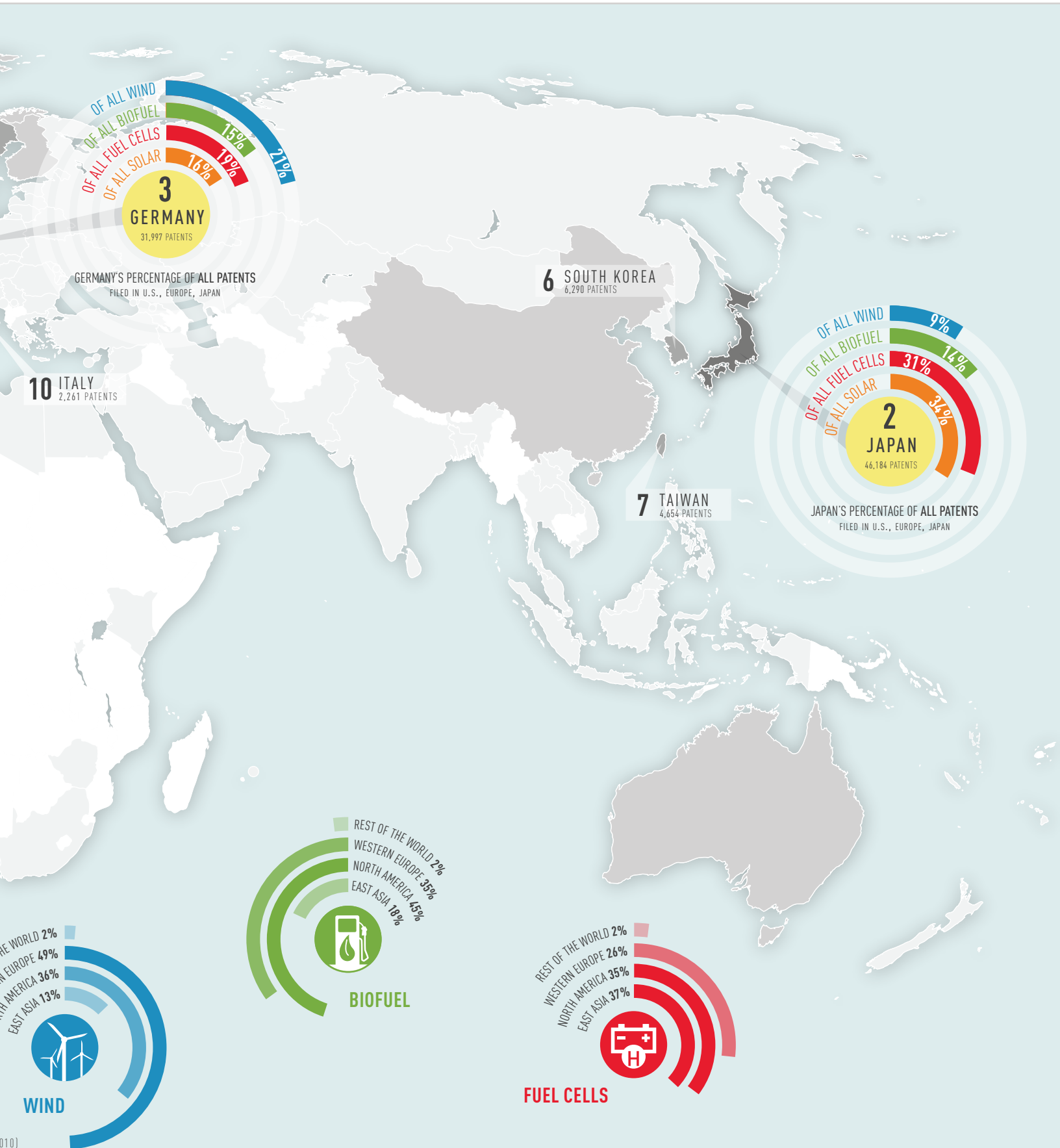
TOTAL PATENTS ALL GREENTECH



BY SECTOR

CUMULATIVE PATENTS ACROSS REGIONS

*INCLUDES GREENTECH PATENTS FILED IN U.S., EUROPE, JAPAN (1990-2010)



Greentech Clusters

COMPARING INNOVATION AND ADOPTION



WIND

A wind energy system transforms the kinetic energy of the wind into mechanical or electrical energy that can be harnessed for practical use. Wind electric turbines generate electricity for homes and businesses and for sale to utilities, while mechanical energy is commonly used for pumping water as well as grinding grain, sawing and even pushing a sailboat. Horizontal-axis wind turbines are most common today, constituting nearly all of the “utility-scale” (100 kilowatts, capacity and larger) turbines in the global market. As of 2011, over 197 GW of wind-power-generating capacity was installed globally.¹⁴ The wind power market (new installation capital costs) is projected by Clean Edge to expand from \$71.5 billion in 2011 to \$116.3 billion in 2021.¹⁵

When considering individual greentech sectors, innovation hotspots do not necessarily translate to regions with the highest levels of adoption of these technologies. The surge of renewable technology deployment by the large developing economies, in particular, does not align with these countries’ relatively meager contributions to patenting. Similarly, in the case of solar photovoltaics, Western Europe claims the majority of installed capacity while East Asia¹⁶ leads all patenting activity. To highlight the evolving trends in greentech deployment and patenting, the below analysis compares clusters of innovation and adoption of wind, solar, biofuel and fuel cell technology.

Wind

Western Europe is the largest hub for wind innovation, accounting for 49% of all patents. Led by Germany, other major patent contributors include the UK, Norway and the Netherlands. Looking outside of Europe, the U.S. is an active innovator for wind power as well, securing the most patents by any single country.

Western Europe still claims the largest existing capacity of installed wind energy, but its dominance as a wind power adopter is not expected to last.¹⁷ Large developing economies¹⁸ now account for the majority of new installations, and China has carried this trend with 19 Giga Watts (GW) of new wind power installations in 2010, or almost 50% of total wind power production (39 GW) added that year. Similarly India is fifth in wind power capacity at 13 GW, although it has yet to crack the top 20 in wind patenting.

TOP INNOVATOR WESTERN EUROPE

TOP ADOPTER WESTERN EUROPE + LARGE DEVELOPING ECONOMIES

LEADING INNOVATORS in percent of cumulative wind patents filed in U.S., Europe, Japan (1990-2010)

United States	34%	Norway	4%
Germany	21%	Netherlands	4%
Japan	9%	Spain	3%
Great Britain	7%	France	3%

LEADING ADOPTERS in percent of installed global wind power capacity

China	22%	France	3%
United States	20%	Great Britain	3%
Germany	14%	Italy	3%
Spain	10%	Canada	2%
India	7%	Denmark	2%

¹⁴ Anonymous. 2011. “World Wind Energy Report 2010.”

¹⁵ Perneck, R., Wilder, C., Winnie, T. 2012. “Clean Energy Trends 2012.” A Report from Clean Edge.

¹⁶ In this analysis East Asia includes Japan, South Korea and Taiwan.

¹⁷ Anonymous. 2011. “World Wind Energy Report 2010.” A Report from the World Wind Energy Association.

¹⁸ In this analysis Large Developing Economies include China, India and Brazil.

Solar (Photovoltaics)*

*Since solar photovoltaics have seen the vast majority of R&D investment in recent years, this section deals only with this subsector of solar technology. See the sidebar on solar for further details.

In the last five years rapid innovation in solar photovoltaic (PV) technology has brought system costs down by more than half, from \$7.20 to \$3.47 per watt.¹⁹ Alongside this trend, solar PV has surpassed all other renewable energy technologies in annual growth, having tripled global capacity from 13 GW to 40 GW.²⁰

Perhaps due to its historic strength in semiconductors and microelectronics, East Asia is the innovation hub for solar PV technology, with 50% of all patenting, with 45% of all patenting. Conversely, Western Europe has led adoption, claiming almost 70% of global capacity in solar PV with Germany the biggest adopter by far at 17.6 GW installed or 44% of the total. Spain and Italy, both minimal solar patent producers, rank second and third for total installed solar PV capacity.^{21,22}

TOP INNOVATOR EAST ASIA				TOP ADOPTER WESTERN EUROPE			
LEADING INNOVATORS in percent of cumulative solar PV patents filed in U.S., Europe, Japan (1990-2010)				LEADING ADOPTERS in percent of installed global solar PV power capacity			
Japan	39%	France	2%	Germany	44%	France	3%
United States	27%	Great Britain	2%	Spain	10%	Great Britain	3%
Germany	12%	Netherlands	1%	Japan	9%	Belgium	2%
South Korea	6%	Italy	1%	Italy	6%	China	2%
Taiwan	4%	Canada	1%	Czech Republic	5%	South Korea	2%



SOLAR

Photovoltaic (PV) cells, made of semi-conductors such as crystalline silicon or various thin-film materials, can convert sunlight directly into electricity. Photovoltaics can provide tiny amounts of power for small electronics such as watches, large amounts for the electric grid, and everything in between. As of 2010 more than 40 GW of solar PV capacity had been installed globally, with the industry expected to grow from \$91.6 billion in 2011 to \$130.5 billion by 2021. Although the majority of R&D in recent years has been invested in PV, solar thermal systems, including solar water heating and concentrated solar power (CSP) technologies, have high utilization rates, particularly in China. These systems use reflective materials to concentrate the sun's heat energy, which can be used simply for heating as well as for driving a generator to produce electricity. For solar thermal technology, China reached 118 gigawatts-thermal (GWth) in existing capacity, or 64% of the global total, deploying primarily small-scale units used for household water heating.

¹⁹ Perneck, R., et al. 2012.

²⁰ Pernick, R., Sosnovce, S., Wilder, C. Winnie, T. 2011. "Clean Energy Trends 2011." A Report from Clean Edge.

²¹ Sawin, J., et al. 2011.

²² Separate from photovoltaics, solar thermal systems including solar water heating and concentrated solar power (CSP) have seen notable investments in installations.



BIOFUELS

The two most common types of biofuels are ethanol and biodiesel. Ethanol—an alcohol—is most commonly used as an additive for petroleum-based fuels to reduce toxic air emissions and increase octane. Around half of the gasoline sold in the United States includes 5% to 10% ethanol, and more than 200 ethanol-mix fueling stations exist in 30 states. Biodiesel, made primarily from soybean oil, has relatively limited use, but its benefits to air quality can be dramatic. Biodiesel is typically blended at 20% with petroleum diesel. This fuel blend is used chiefly by vehicle fleets and is also available to individual consumers with diesel vehicles. There are roughly 180 fueling stations in about two-thirds of U.S. states.²³ As of 2010, almost 39 billion gallons of biofuel production capacity had been installed globally. Biofuels (global production and wholesale pricing of ethanol and biodiesel) reached \$83 billion in 2011, and some estimates project the market to grow to \$139 billion by 2021.²⁴

²³ United States Department of Energy. http://www.energysavers.gov/renewable_energy/biomass/index.cfm/mytopic=50002 (Accessed 14 March 2012)

²⁴ Perneck, R., et al. 2012.

²⁵ Anonymous. 2011. "BP Statistical Review of World Energy June 2011 Workbook." A Database from BP. www.bp.com/statisticalreview (Accessed 20 March 2012)

²⁶ Anonymous. "Top 25—Global Ethanol and Biodiesel Production Capacity." A Ranking from the Global Biofuels Center. http://globalbiofuelscenter.com/NM_Top5.aspx (Accessed 14 March 2012)

²⁷ Sawin, J., et al. 2011.

Biofuels

Liquid biofuels provided 2.7% of global road transport fuels in 2010, with the majority of this product in the form of corn- and sugar-based ethanol rather than biodiesel. Although biofuel production capacity is fairly evenly split at 62% ethanol to 38% biodiesel,^{25,26} actual production numbers give ethanol 89% of the market in 2010. Biodiesel plants operated at only 40% capacity in this year due to rising input costs and cheaper alternatives.

North America, the world's largest producer of corn, dominates both adoption and innovation of this sector with 45% of all patents since 1990 and 50% of global production in 2010. At the country level, the U.S. and Brazil top all biofuel producers in 2010, combining for 77% of global supply with only 4% of their output in biodiesel. Western Europe, led by Germany and Spain, has focused primarily on biodiesel, accounting for nearly half of global production. Argentina rose to third globally among biodiesel producers, up 57% in output from 2009, making it one of the fastest growing suppliers. A number of developing Asian economies including Indonesia, Malaysia and Thailand emerge alongside China as prominent biofuel producers with a mix of both ethanol and biodiesel.²⁷

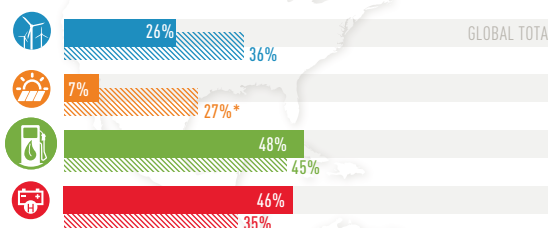
TOP INNOVATOR NORTH AMERICA

TOP ADOPTER NORTH AMERICA

ADOPTION VS. INNOVATION

Percentage of Global Total ^{31, 32, 33, 34, 35}

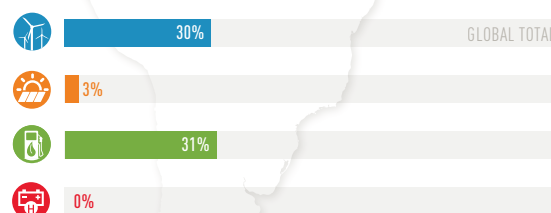
NORTH AMERICA



* Figure includes only solar PV patenting.

** Calculated from total installed GW for solar PV and wind, annual production in billions of liters for biofuels, and total power capacity in MW of annual deployments for fuel cells.

LARGE DEVELOPING COUNTRIES



INCLUDES CHINA, BRAZIL AND INDIA

Fuel Cells

East Asia and North America lead both innovation and adoption of fuel cell technology, together accounting for 72% of all patents and over 90% of annual new capacity (measured in MW). Western Europe represents an emerging player in this market amassing, 26% of patents and surpassing both East Asia and North America in units purchased in 2010. However, Western Europe's emphasis on portable unit sales with comparatively tiny energy capacity gives the region only a small portion of annual new utilization in terms of megawatts. As of 2010, the global market for annual fuel cell deployment reached 90 MW, up 143% from 2007. While fuel cells have enjoyed steady growth in recent years, the sector's total power capacity remains orders of magnitude smaller than the other major renewable energy sectors.^{28,29}

TOP INNOVATOR NORTH AMERICA & EAST ASIA

TOP ADOPTER NORTH AMERICA & EAST ASIA



FUEL CELLS

Fuel cells convert the chemical energy of a fuel, such as hydrogen, into electricity through a chemical reaction with oxygen or some other oxidizing agent. They differ from batteries in that they require a constant source of fuel and oxygen to function but operate continually as long as these inputs are supplied. The technology has three primary applications: 1) stationary, the largest with up to 400 kW providing electricity to systems that are not designed to be moved; 2) transportation, up to 100 kW offering propulsive power or range extension to vehicles; 3) portable, up to 20 kW built into movable systems. As of 2010, the global market for annual fuel cell deployment reached 90 MW. According to Fuel Cell Today, a fuel cell research firm, the market is projected to have dipped down to 86 MW in 2011 due to a shift in utilization levels favoring portable units of smaller capacity.³⁰

²⁸ Anonymous. 2011. "2010 Fuel Cell Technologies Market Report." A Report from the United States Department of Energy.

²⁹ Anonymous. 2011. "Fuel Cell Today Industry Review 2011." A Report from Fuel Cell Today.

³⁰ Anonymous. 2011. "Fuel Cell Today Industry Review 2011."

³¹ Anonymous. 2011. "BP Statistical Review of World Energy June 2011 Workbook."

³² Sawin, J., et al. 2011.

³³ Anonymous. 2011. "World Wind Energy Report 2010."

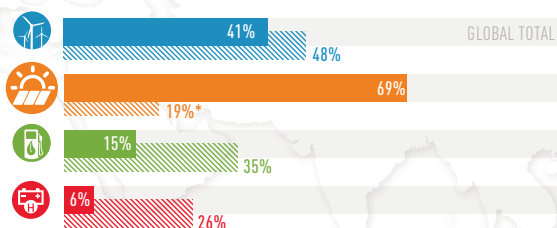
³⁴ Anonymous. 2011. "Fuel Cell Today Industry Review 2011."

³⁵ Anonymous. "Top 25-Global Ethanol and Biodiesel Production Capacity."

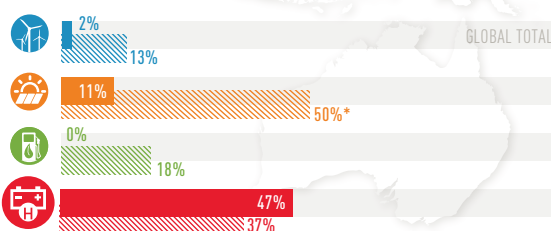
Adoption as percent of global total**

Innovation as percent of cumulative patents filed in U.S., Europe, Japan (1990-2010)

WESTERN EUROPE



EAST ASIA



INCLUDES JAPAN, TAIWAN AND SOUTH KOREA

Greentech Innovation Highlights

>> LEADERS

Since 1990, the U.S., Japan and Germany have dominated greentech innovation, accounting for 75% of all patents granted in the U.S., Europe and Japan. Between 1990 and 2008 the U.S. generated 32% of greentech patents, followed by Japan (24%) and Germany (17%).

>> LAGGARDS

The largest developing economies, including India and Brazil, have negligible rates of greentech innovation, despite being fast adopters of green technology.

>> CHINA

China's inventors have been patenting green technology at increasingly higher rates, but only through the China State Intellectual Property Office.

>> SECTORS

Solar technology has been the focus of most greentech patents (47%) since 1990, followed by biofuels (24%) and fuel cells (10%). Wind technology has seen relatively little patenting (3%), although it remains a prominent sector for annual new installations.

>> CLUSTERS

Regional specialization in green technology innovation is occurring in East Asia (solar & fuel cells), Europe (wind power) and North America (biofuels & fuel cells).

Next in the Greentech Innovation Series

GREENTECH PATENT ANALYSIS IN THE U.S.

The U.S.—whose inventors claim the most patents filed in the world's three major patent offices—sits at the heart of greentech innovation. Yet even *within* the U.S., there are a number of hotbeds for greentech innovation. In the next briefing in this series, we will explore clusters of greentech innovation inside the U.S., using patent data once again to investigate where the centers for innovation have formed and what forces appear strongest for creating them. Are incentive programs and other government policies responsible? Or are these trends determined more by regional strengths in human capital and natural resources? Or are there other factors driving this activity?

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