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Analysis of Small Business Innovation in Green Technologies

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by

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I. Introduction and Key Findings

A. Overview

This report describes the key findings from an ambitious project designed to highlight differences between the patent activity of small and large innovative firms in so-called "green" technologies and industries. For this project, we created a detailed database of 1,279 small and large technology firms. The firms were selected because they have been granted at least 15 U.S. patents in the last five years. We refer to such firms as innovative firms, in order to highlight the fact that they are a special subset of U.S. firms that produce significant numbers of patents. In total, these firms have been granted more than one million patents.

This project extends previous studies of small business patenting activity conducted by the authors for the Office of Advocacy. We refer to the current project as SBA4. In SBA1[1] and SBA2[2] we established the existence of a cohort of independent, nonbankrupt, for-profit, small firms with 15 or more patents over a five-year period. Since small firms often find patenting too expensive and difficult, and thus make little use of the patent system,[3] few would even have guessed such firms exist. SBA1 and SBA2 were the first studies of small business patenting that were based on a large, rich, and well defined dataset that encompassed the universe of significant patenting companies, rather than being based on a sampling of a specialized patent set, or on the results of a survey.

In SBA3[4] the dataset again consisted of all companies with 15 or more patents in a five-year period (2002-2006). That study showed that small firms were more active in emerging technologies than expected, and also that small firms had a higher percentage of emerging technology patents in their portfolios than do large firms. Another finding examined patents per employee, where we extended an earlier result showing small innovative firms had 15 times as many patents per employee as large firms. This result was quantified in SBA3 to show that this is not a small-firm versus large-firm phenomenon, but is actually a firm size issue at all levels. In particular, even within the small innovative firm domain, companies with fewer than 25 employees were shown to have a higher patent-to-employee ratio on average than firms with 50 employees, which in turn have a higher patent-to-employee ratio than firms with 100 employees, and so on.

B. Green Technologies

Green technologies have become a hot topic. For example, a recent Google search for the words green technology returned 281 million web pages. Whether the primary driver is climate change, a dependence on foreign energy sources, the rising cost of energy, or a combination of all of the above, it is clear that the future of the U.S. economy will depend on moving away from fossil fuels, or using existing energy sources more efficiently.

[1] Diana Hicks et al., *Small Serial Innovators: The Small Firm Contribution To Technical Change*, Office of Advocacy, United States Small Business Administration, Contract No. SBAHQ-01-C-0149, February 2003.
[2] Anthony Breitzman et al., *Small Firms and Technology: Acquisitions, Inventor Movement, and Technology Transfer*, Office of Advocacy, United States Small Business Administration, Contract No. SBAHQ-02-M-0491, January 2004.
[3] J. Obermeyer, *The Role of Patents in the Commercialization of New Technology for Small Innovative Companies* final report for the U.S. Small Business Administration, Research & Planning Inc., Cambridge MA, August 1981.
[4] Anthony Breitzman et al., *An Analysis of Small Business Patents by Industry and Firm Size*, Office of Advocacy, United States Small Business Administration, Contract No. SBAHQ-07-Q-0010, November 2008.

It is important to note that there is a lot of debate about what exactly constitutes green technology. For example, some believe that nuclear energy is green, in the sense that it does not contribute to global warming. Meanwhile, others believe that nuclear energy is anything but green, because there is no easy way to dispose of spent nuclear fuel rods. For this project, we defined green technology as the set of categories found in Table I.1 below.

Table I.1 List of Green Technologies Covered in Study

Batteries
Clean Coal
Smart Grid/Smart Metering/Electric Grid Infrastructure
Fuel Cells
Geothermal Energy
Generic Green Technology
Hybrid Electric Vehicle Systems
Hydro Power
Solar Energy
Wind Energy

This is not necessarily an exhaustive list of green technologies, and there may be debate about whether categories like clean coal belong in such a list. Similarly, some may ask why technologies such as mass transit or rail systems are not included, since an increase in the use of these transportation systems could have a huge effect in reducing dependence on fossil fuels.

There are two reasons why the technologies in Table I.1 were selected. The first reason is that this study is technology based. It is designed to identify green technology developments, and to assess the role of small businesses in these developments. While mass transit is an important green energy implementation, the increased use of mass transit is unlikely to be driven primarily by technology developments, but rather by a change in attitudes among commuters, possibly as a result of broader government policies. This is in contrast to fuel cells or solar energy, in which technology developments can improve efficiency, lower costs, and increase usage. The second reason for selecting the technologies in Table I.1 is that we have used these technologies successfully in previous high-profile green energy projects, including the California Green Innovation Index[5] and the IEEE Spectrum Clean Tech 50.[6]

C. Hypotheses Explored

There is great academic and policy interest in identifying and tracking green technologies and industries. To our knowledge, however, nobody has previously studied the contributions of small firms versus large firms in green technologies. For example, it is not clear whether small firms would be more suited to creating green innovations because they are less bureaucratic and more nimble, or whether large firms would be more effective because they have greater resources for R&D and fewer barriers to entry within the energy business. Based on these ideas, along with others developed while producing SBA1 through SBA3, the

[5] Collaborative Economics, "The California Green Innovation Index 2009," Published by Next10, Palo Alto, CA. 2009. http://www.next10.org/pdf/GII/Next10_GII_2009.pdf
[6] Patrick Thomas and Anthony Breitzman, "The Clean Tech 50," IEEE Spectrum, Piscataway, NJ. 2010. http://spectrum.ieee.org/green-tech/fuel-cells/the-cleantech50

authors proposed testing three hypotheses in this project:

Hypothesis 1 – The number and percentage of small innovative firms active in green technologies patenting will exceed the number of large innovative firms active in green technologies patenting.

Hypothesis 2 – More than 50 percent of the small firms in the new study will be new entrants.

Hypothesis 3 – A large proportion of small firm inventors in green technologies will have strong inventive or entrepreneurial histories.

In this report, we explore each of these hypotheses in detail. We also explore a number of other results uncovered during the analysis phase of the project.

D. Key Findings

The major findings from the project are summarized below. Additional details of these findings, and a full discussion of each topic, can be found in the main body of the report.

Basic Statistics

1. We identified 1,279 U.S. firms that were granted 15 or more U.S. patents in the five-year period 2005-2009. Of these firms, 42 percent are small firms with 500 or fewer employees. This is a higher percentage of small firms than the 33 percent found in SBA1 (completed in 2003), and slightly higher than the 41 percent and 40 percent from the SBA2 (2005) and SBA3 (2008) projects.

2. We also found that 57 percent of all the firms, and 29 percent of the small firms, in the database are publicly listed on major U.S. exchanges (i.e. not including companies whose stock is traded over the counter). We estimate that fewer that 0.1 percent of all firms are publicly traded on major U.S. exchanges. The large share of publicly traded firms in the database for this project is therefore notable. It suggests that firms of all sizes with patented technology are more likely to become successful enough to go public than firms that do not produce patents.

3. In our earlier SBA studies, we showed that small innovative firms are much more productive than large innovative firms from a patents-per-employee perspective. Specifically, in SBA1 it was shown that small innovative firms outperform their large counterparts 13 to 1 in terms of patents per employee. In the updated database for the current project, we confirmed that small firms remain highly productive in terms of patents per employee. Indeed, in 2005-2009 the difference in patents per employee has now risen to 16 to 1 in favor of small innovative firms versus large innovative firms (27 patents per 100 employees, versus 1.6 patents per 100 employees).

4. Numerous validation studies have shown a relationship between patent performance metrics (such as citation impact) and positive outcomes such as inventor awards, licensing revenue, increases in sales and profits, etc. When we compare the small innovative firms in the database with their larger counterparts, we find that small firms outperform large firms on average in every case. Patents of small firms are cited 79 percent more by recent patents than is typical for patents of the same age and patent classification, while patents of large innovative firms are cited just slightly above average. We

also found that the small firms in the study outperformed large firms in patent generality, originality, and patent growth.

Differences between Current Database and 2002-2006 U.S. Innovative Firm Database

1. Of the 532 small innovative firms in the current analysis, 224 (42 percent) are new entrants and were not part of the previous analysis. That is, more than four in ten of the small firms in this study either did not exist or did not patent significantly in the five years ending in 2006.

2. In total, there are 28 more small firms in the current database than in the 2002-2006 database. With 224 new entrants, one might expect the increase in small firms to be greater. However, small firms are at greater risk than large firms of failing to satisfy various criteria for retaining their position in the database. For example, episodic patenting is characteristic of firms with low patent output, and one-third of small firms are very close to the 15 patent threshold, in that they have 20 or fewer patents (less than 10 percent of the large firms have 20 or fewer patents). Smaller firms are also more likely to increase employment and pass the 500 employee mark, or to be acquired by larger firms.

3. Perhaps surprisingly, 37 large firms from the previous SBA3 database dipped below 500 employees and are now in the current study (SBA4) as small innovative firms. This may be due to the effects of the 2008 recession. We also found that only 34 small firms from the 2008 study (SBA3 covering patent activity from 2002 to 2006) have been acquired since completion of that study. In SBA3, we noted 87 acquisitions of small firms from the earlier SBA2 study, so the recession may have had an effect on small firm acquisition as well.

4. In spite of the recession, the innovative firms in the database have performed very well on average. Small innovative U.S. firms have revenues averaging $46.5 million per year. This compares favorably to their cohort set from the 2008 study, which averaged $39.4 million per year. Large innovative firms have done even better, with average sales increasing from $7.4 billion to $8.4 billion over the same period.

Green Technology Patenting by Small and Large U.S. Firms and Foreign Organizations

1. U.S.-based organizations were responsible for 43 percent of U.S. patents in green technologies in 2005-2009, while Japanese organizations have 32 percent of these green patents. No other countries have more than 6 percent of the patents. While the United States owns more green patents than other countries, the lead is smaller than expected. In all technologies, the U.S. invents about 50 percent of granted patents, with Japanese inventors producing about 20 percent of granted patents. One interpretation of these percentages is that the United States has less emphasis on green technologies than it does on other technologies, while Japan has a greater emphasis on green technologies. Alternatively, one could argue that Japanese inventors are overachieving in green technologies, with the United States slightly underachieving.

2. Another key result concerns the extent to which green innovations are core technologies to small innovative firms. There are four times as many large innovative U.S. firms with at least one green patent as there are small innovative U.S. firms. However, green patents form a much lower

percentage of these large firms' portfolios than the small firms' portfolios (1.5 percent on average for large firms, versus 20 percent for small firms). There are also several small firms whose patent portfolios are almost entirely green, which is not the case for any of the large firms. It thus appears that many small firms are building their business around green technologies, while large firms are largely enhancing product lines with green technologies. For example, the business models of small firms like Bloom Energy, The Current Group, and Valence Technology are based solely on green technologies. This is in contrast to General Motors and Toyota, who are patenting in batteries, fuel cells, and hybrid systems, but whose green efforts are actually a small part of their overall business.

3. Small firms patent more often than expected in several green subcategories and in green technology in general. Overall, small firms account for approximately 8 percent of all patents in the U.S. innovative firm database. However in both smart grids and solar energy, small firms account for more than 32 percent of the patents. Small firms also account for more than 15 percent of the patents in batteries and fuel cells. In all green technologies combined, small firms account for 14 percent of the patents, almost twice as many as one would expect given the overall level of small firm patent output.

4. Small firms tend to have high citation scores in the green subcategories in which they are active. This is similar to the result we found for emerging technologies in SBA2. It suggests that small firms are inventing important green technologies, and also that these firms tend to only file patents on their significant green inventions. Specifically, on average, green patents from small firms are cited 2.5 times as frequently as green patents from large firms. It is worth noting that high citation rates such as these have been correlated with outcomes such as inventor awards, increases in sales and profits, stock price appreciation, and greater licensing revenues.[7]

5. Overall, the results with respect to green technologies reveal that small firms are particularly active in green technologies. Small firms with green patents also tend to have green technology as a core business more often than large firms. In addition, small firms tend to produce high-impact green patents, as reflected in their high citation rates. Small firms, or firms that recently passed 500 employees and thus graduated to large firm status,[8] may thus be an important source of future breakthroughs in green technology.

Prolific Inventors from Small Green Firms

1. We examined prolific inventors within small green technology firms. There are 32 individuals who had five or more recent green patents with a citation index of 1.0 or more. We discovered that these prolific individuals also tended to be high achievers in other aspects of their careers, and many of them have founded or run green energy firms after working at large firms in other industries.

2. Of these prolific inventors, 35 percent are now C-level (CEO, CTO, Chief Scientist) executives at small green firms and nearly 30 percent are cofounders of green firms.

[7] See Anthony Breitzman and Mary Mogee, "The Many Applications of Patent Analysis," *Journal of Information Science*, 28(3), 187-205, 2002, for a summary of various validation studies.

[8] It is quite possible that a small firm with a breakthrough will have "graduated" into a large firm at the time of the breakthrough. Several of the interesting firms highlighted in this report have close to 500 employees now and will likely become large firms in the next few years.

3. Approximately 80 percent of the prolific green inventors had previously worked at large companies or large government or university labs. Over 30 percent had five or more patents for previous employers in nongreen technologies. This illustrates the difficulty in training a person at a university to be a green entrepreneur. Most of these individuals were not recent college graduates, but instead were people who had successful careers prior to joining or founding green firms.

4. The policy relevance of this finding is that, although we do not fully understand the mechanisms through which individuals decide to leave jobs at large firms in order to launch startups, there is a need to cultivate such behavior and support it. As the results of this project show, small firms tend to be better incubators for the development of green technologies (and presumably other emerging technologies) than are large firms. Hence, one strength of the U.S. economic system that should be encouraged is the ability for creative people to leave the security of large firms in order to launch small green technology firms.

II. Overview of the Small Business Patent Database

A. Introduction

One of the key tools used in this project is a carefully constructed database of small and large technology firms. Specifically, we identified all U.S. firms that were granted 15 or more U.S. patents in the five-year period from 2005 to 2009. We call these firms innovative firms to highlight the fact that they have significant numbers of patents.

The database is similar to the databases of patents through 2002 and 2006 that the authors built in previous projects for the SBA, which will be referred to in this report as SBA3[9] and SBA2[10] respectively. The current database is a unique resource, consisting of 1,279 firms and over a million patent records. In addition to patent information, the database contains information on number of employees, revenues, and industry classification where available.

In this section of the report, we describe how the database was constructed. We also highlight interesting results, such as the high percentage of small firms in the database that are publicly listed, and the extent to which the patents of small firms outperform those of large firms on a number of performance metrics.

B. Summary

In this chapter we look at basic statistics related to the U.S. innovative firm database constructed for this study. Some key findings are:

1. We identified 1,279 U.S. firms that were granted 15 or more U.S. patents in the five-year period 2005-2009. Of these firms, 42 percent are small firms with 500 or fewer employees. This is a higher percentage of small firms than the 33 percent found in SBA1 (completed in 2003), and slightly higher than the 41 percent and 40 percent from the SBA2 (2005) and SBA3 (2008) projects.

2. We also found that 57 percent of all the firms and 29 percent of the small firms in the database are publicly listed on major U.S. exchanges (i.e. not including companies whose stock is traded over the counter). We estimate that less that 0.1 percent of all firms are publicly traded on major U.S. exchanges. The large share of publicly traded firms in the database for this project is therefore notable. It suggests that firms of all sizes with patented technology are more likely to become successful enough to go public than firms that do not produce patents.

3. In our earlier SBA studies, we showed that small innovative firms are much more productive than large innovative firms from a patents per employee perspective. Specifically, in SBA1 it was shown that small innovative firms outperform their large counterparts 13 to 1 in terms of patents per employee. In the updated database for the current project, we confirmed that small firms remain highly productive in terms of patents per employee. Indeed, in 2005-2009 the difference in patents

[9] Anthony Breitzman et al., *An Analysis of Small Business Patents by Industry and Firm Size*, Office of Advocacy, United States Small Business Administration, Contract No. SBAHQ-07-Q-0010, November 2008.
[10] Anthony Breitzman et al., *Small Firms and Technology: Acquisitions, Inventor Movement, and Technology Transfer*, Office of Advocacy, United States Small Business Administration, Contract No. SBAHQ-02-M-0491, January 2004.

per employee has now risen to 16 to 1 in favor of small innovative firms versus large innovative firms (27 patents per 100 employees, versus 1.6 patents per 100 employees).

4. Numerous validation studies have shown a relationship between patent performance metrics (such as citation impact) and positive outcomes such as inventor awards, licensing revenue, increases in sales and profits, etc. When we compare the patent metrics of small and large innovative firms in the database, we find that small firms outperform large firms across all metrics. Patents of small firms are cited 79 percent more by recent patents than is typical for patents of the same age and patent classification, while patents of large innovative firms are cited just slightly above average. Small firms in the study also outperform large firms in terms of patent generality, originality, and growth rate.

C. Method

The database built for this project leverages the existing 1790 Analytics corporate thesaurus consisting of all organizations with 40 or more patents issued in the last five years. It is important to understand that the patent office records assignees and not necessarily companies. Patents owned by a company may be under different assignee names, including divisions, subsidiaries and acquisitions. As an example, large firms like General Motors and Procter & Gamble patent under more than 100 names. Extreme cases of firms that have a history of mergers, such as Glaxo-SmithKline, will have patents under more than 300 names.

The 1790 Analytics corporate thesaurus tracks over 4,000 organizations in three patent systems, including U.S. firms, foreign firms, nonprofits, universities, and government agencies. This thesaurus contains more than 60,000 individual subsidiary and variant assignee names, and is maintained by a data manager with more than 25 years experience with tracking and standardizing assignee names. The thesaurus is licensed to information companies such as Thomson Scientific.

The database used for this project uses a subset of the corporate thesaurus, since the project focuses on U.S.-based companies. The database also extends the thesaurus to include U.S. firms with 15 or more patents granted between 2005 and 2009 (rather than the 40 patents required for inclusion in the main thesaurus). It also includes the number of employees for each of the 1,279 firms, as well as revenues, line of business and SIC (Standard Industrial Classification) and NAICS (North American Industry Classification System) codes where available. These data were identified using multiple sources including Mergent/Moody's International, Lexis/Nexis, Annual Reports, and Dun & Bradstreet.

Assembling the database was by far the most time-consuming part of the project, and the authors and 1790 staff were scrupulous in this task. We are well aware of the hazards of firm identification, particularly when it comes to small businesses. The story of Tether's reanalysis of Pavitt's work is worth mentioning here. Pavitt analyzed 4,278 innovations commercialized in the United Kingdom since 1945, and reported statistically significant results showing that small firms were becoming more important to innovation.[11] Tether reanalyzed the Pavitt data in the 1990s and re-checked the classification of the firms as small or large

[11] Keith Pavitt, M. Robson and J. Townsend. 1987. "The Size Distribution of Innovating Firms in the UK: 1945-1983." *Journal of Industrial Economics 35*: 297-316.

at the time of the innovation.[12] He found that some of the subsidiaries of large firms had been misclassified as small firms. The net result was that Pavitt's findings regarding the increasing importance of small firms in innovation were no longer statistically significant. This cautionary tale points to the need to be very careful in assembling company data.

In this project, the cutoff date for the company structure is December 31, 2009. Any firms that merged after that date are as they were at the end of 2009. Similarly, while we removed companies that were bankrupt in general, any that have become troubled since December 31, 2009, have not been removed.

In general, all subsidiaries are combined with their parent companies. For example, the patents of Ethicon and Cordis are combined in the database with their ultimate parent company Johnson and Johnson. Similarly, the U.S. biotechnology company Genentech is removed completely because it is majority owned by the foreign firm Roche Holdings, and foreign firms are not part of this study.

Private equity firms are an exception to this parent-subsidiary rule in the database, because these investment firms may hold a variety of companies for a short period of time. In this project, if an equity firm holds a majority interest in one or more firms that run as independent companies, we treat those companies as independent companies within the database. For example, companies such as Johns Manville and Polaroid are treated as independent companies, even though they are majority owned by holding companies like Berkshire Hathaway, or private equity firms like Hilco Consumer Capital.

In summary, this project is built upon a database of more than one million patents from 1,279 U.S. firms with 15 or more U.S. patents granted between January 1, 2005, and December 31, 2009. These companies range from the small firm Hillcrest Labs, an interactive media firm with 60 employees and 15 patents in the period, to computer giant IBM with 399,409 employees and 18,949 U.S. patents in the period.

D. Results

Summary Statistics

This section of the report provides summary statistics from the database, in order to give the reader an overview of the contents of the database in general. Table II.1 reveals the breakdown of the 1,279 firms covered in the database. Of the firms, 728 are large, 532 are small, and no size information could be obtained for 19 firms. These latter firms are very likely to be small firms based on the dearth of information and the small number of patents. However, since they represent only 1 percent of the total, including or excluding them from any analysis would not change the results in a significant way.

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[12] Bruce S. Tether., I.J. Smith and A.T. Thwaites. 1997. "Smaller enterprises and innovation in the UK: the SPRU Innovations Database revisited." *Research Policy* 2: 19-32

Table II.1 – Summary Statistics for U.S. Company Patent Database

Company Size	# of Companies	% of Identifiable	% of Total	# Publicly Listed	% Publicly listed	Avg # Pats 2005-09
Large	728	58%	57%	558	77%	320
Small	532	42%	42%	156	29%	38
Unknown	19		1%			25
Total Known	1260			714	57%	
Grand Total	1279					

Table II.1 shows that 42 percent of the U.S. firms with 15 or more patents in the five-year period are small firms.[13] This is a higher percentage of small firms than the 33 percent found in the SBA1 project and slightly higher than the 41 percent and 40 percent from the SBA2 and SBA3 projects. A detailed discussion of the fate of firms entering and exiting the databases in these projects can be found later in the report in section III.

Table II.1 also reveals that 57 percent of all the firms, and 29 percent of the small firms, in the database are publicly traded. Here, publicly traded is defined as companies traded on the major U.S. exchanges, and not companies that are technically public, but not traded or only traded over the counter. Using this narrow definition of publicly traded, we estimate that fewer than 0.1 percent of all firms are publicly traded.[14] The large share of publicly traded firms in this dataset is therefore notable. It suggests that firms of all sizes with patented technology are more likely to become successful enough to go public than firms that do not patent.

Table II.2 – Additional Summary Statistics for U.S. Company Patent Database

Company Size	Avg Sales	Avg # Employees	Avg Sales Per Employee	Median Sales Per Employee	Avg # Pats 2005-09	2005-09 Pats Per Hundred Employees
Large	$8,385,038,016	19440	$431,335	$317,917	320	1.6
Small	$46,540,617	141	$330,075	$179,775	38	27.0

Table II.2 shows additional summary statistics from the database. For example, large innovative firms tend to exceed the 500 employee threshold by a wide margin, having an average of 19,440 employees and more than $8 billion in sales. Twenty-nine of these firms have over 100,000 employees, and 13 of them have sales exceeding $100 billion. Not surprisingly the large firms produce more patents than the small firms, but the small firms obtain more patents per employee than the large firms.

Patents per Employee

The finding from Table II.2 that small innovative firms obtain more patents per employee than larger firms is not a new result and was discussed extensively in SBA1 and SBA3. In fact, SBA3 further showed that the

[13] Throughout this project we consider a firm with 500 or fewer employees to be a small firm.
[14] This calculation comes from dividing the 3,162 U.S. publicly traded companies identified via Google Finance http://finance.google.com [accessed August 10, 2010] by the estimated 6,049,655 employer firms in 2007 obtained from the U.S. Small Business Profile, SBA Office of Advocacy, 2007, http://www.sba.gov/advo/research/us_07ss.pdf [Accessed August 10, 2010]. Even though the company counts are 3 years old, the estimate of less than 0.1% of firms being publicly traded remains reasonable, since it would remain valid even if the number of employer firms decreased by more than 2 million.

patents-per-employee rate decreases steadily as the firm gets larger. That is, innovative firms with 10 employees have more patents per employee than those with 50 employees, which in turn have more patents per employee than those with 100 employees and so on. While we do not repeat that analysis here, it is worth highlighting that the overall patents-per-employee relationship has improved slightly for small innovative firms. In SBA3, small innovative firms obtained patents at a rate of 26.5 per hundred employees in the five-year period ending in 2002-2006. The most recent statistic from this project is 27 patents per hundred employees. Meanwhile, in SBA3, large innovative firms patented at a rate of 1.7 patents per hundred employees, which has fallen to 1.6 patents per hundred employees in the most recent period. As a result, on average, small innovative firms patent at a rate 16 times higher than large innovative firms from a patents-per-employee perspective.

Patent Scorecard

Patent scorecards are used in this project to compare the patents of large firms versus small firms using a variety of quantitative metrics, which are described below.

Number of Patents. This is the number of U.S. patents granted to a company in a given time period.

Percent Growth. This is the growth in U.S. patents from one time period to another. In this case, we examine the percentage change in patent activity from the five-year period 2000-2004 to the period 2005-2009.

2009 Pipeline Impact **–** the basic idea behind patent citation analysis is that highly cited patents (those cited by many subsequent patents) tend to contain technological ideas of particular importance, since many others build upon them and reference them as prior art. Such patents are thus regarded as having a strong impact on subsequent technological developments. Numerous validation studies have shown an association between highly cited patents and various positive outcomes. For example, patents that have won inventor awards tend to be highly cited. Also, firms with highly cited patents have shown increases in sales, profits, and stock price. A review of validation studies related to patent citation analysis can be found in Breitzman and Mogee (2002).[15]

The pipeline impact is a citation metric designed to focus on the recent impact of a company's patent portfolio. More specifically, it measures the impact of a company's patents issued in the last five years upon patents issued in the most recent year (2009 in this case). The pipeline impact for each patent within a company's portfolio is calculated by first taking the number of times the patent has been cited by 2009 patents. This number is then divided by the mean number of citations received in 2009 by all patents from the same Patent Office classification and issue year as the subject patent.[16] The expected pipeline impact for any patent is 1.0.

The pipeline impact for a company's patent portfolio is then calculated as the mean of the pipeline impact values of each patent within it. The expected pipeline impact value for a patent portfolio is therefore also 1.0.

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[15] Anthony Breitzman and Mary Mogee, "The Many Applications of Patent Analysis," *Journal of Information Science*, 28(3), 187-205, 2002.

[16] All normalizations here are calculated against the full USPTO database, which includes unassigned, public sector and foreign patents (as well as patents from firms with fewer than 15 patents in the last 5 years). The patents in this study accounted for 32% of US issued patents in 2005-09.

A pipeline impact value above 1.0 shows that a patent portfolio has been cited more frequently than expected by recent patents. For example, a pipeline impact of 1.50 shows that an organization's patents have been cited 50 percent more frequently than expected. A value below 1.0 suggests that an organization's patents have been cited less frequently than expected. A pipeline impact of 0.80 shows that an organization's patents have been cited 20 percent less frequently than expected by recent patents.

2009 Pipeline Generality. Whereas pipeline impact measures the level of impact of a company's patent portfolio, pipeline generality measures the breadth of this impact. It is calculated based on the range of Patent Office Classifications (POCs) represented by the patents that cite a company's patent portfolio.

The 2009 pipeline generality for a single patent is calculated based on the dispersion across POCs of the patents granted in 2009 that cite it as prior art. If a patent is cited only by other patents in the same POC, its breadth of influence is regarded as relatively low. On the other hand, if a patent is cited by patents from across a range of POCs, it is regarded as having a more general influence.

Like the pipeline impact, the pipeline generality for a patent is divided by the expected value for a patent of the same POC and year, so the expected generality for any patent is 1.0. The pipeline generality for a patent portfolio is then calculated as the mean of the generality values of all patents within it. The expected value for the pipeline generality of a patent portfolio is therefore 1.0. Values above this denote a patent portfolio with a higher than expected breadth of influence, while values below 1.0 show a portfolio whose patents have a relatively narrow influence.

Pipeline Originality. This metric measures the breadth of technologies cited by an organization's patents. It is based on the idea that patents that cite a wide range of technologies are more likely to contain original ideas than patents that build upon a narrow range of similar technologies, which tend to be incremental improvements on existing technology.

Pipeline originality is calculated in a similar way to pipeline generality, except that it examines the POCs of patents referenced by a portfolio, rather than the POCs of later patents citing the portfolio. As is true of pipeline generality, the mean pipeline originality for any patent, or patent portfolio, is 1.0. Values above this show a portfolio that builds on a wide range of technologies, and thus has more likelihood of containing original ideas. A value below 1.0 shows a portfolio that builds on a narrow set of previous technologies, and so may contain many patents that represent incremental improvements on previous technologies.

Citation Index. This is a traditional citation measure used by analysts to measure the impact of papers and patents. It is similar to the pipeline impact, in that it is a normalized citation measure with an expected value of 1.0 for an average portfolio. The main distinction is that the citation index examines all citations to a patent portfolio, whereas the pipeline impact only examines citations from patents issued in the most recent time period. The shortcoming of the citation index is that, if a portfolio starts to age and lose impact over time, this will not be reflected in the citation index as clearly as it is in the pipeline impact.

Table II.4 – Patent Scorecard for 1,260 Firms in Patent Database

Firm Size	# Firms	2000-04 Patents	2005-09 Patents	% Growth	2009 Pipeline Impact	2009 Pipeline Generality	Pipeline Originality	Citation Index
Small Business	532	13926	20051	44%	1.79	2.02	1.06	1.64
Large Business	728	223607	232673	4%	1.16	1.24	1.01	1.09

Table II.4 is a patent scorecard that measures the previously defined metrics for the set of all U.S. patents produced by small and large innovative firms. This table reveals that, other than the overall number of patents, small firms outperform large firms on every metric. For example, the output of patents from small firms has increased 44 percent in the last five years compared with the previous five-year period. Much of this growth results from the number of new entrants into the database, as well as small firms that did not exist in the first time period. Even so, the growth rate remains impressive, and is much higher than the 4 percent growth in patenting for large firms.

The pipeline impact figure for both small and large firms is above average, but the patents of small firms are much more highly cited by 2009 patents than are the patents of large firms. The 1.79 pipeline impact figure suggests the patents of small firms are cited 79 percent more by recent patents than is typical for patents of the same age and patent classification. This is comparable to the results using the standard citation index, which shows that the patents of small firms are cited 64 percent more than expected for patents of their age and technology class. Patents of large firms are also cited more than expected, but not as often as the patents of small firms.

The small firms also outperform their larger counterparts in the generality and originality metrics. This suggests that, in general, patents from small firms tend to combine a wider range of technologies in order to create new inventions, and in turn they are built upon by a greater variety of subsequent technologies.

E. Conclusion

In this section, we described the methodology used to build the database of small and large firm patents. This database is the key building block for the remainder of this research project. We also derived some summary statistics from the database and described them in detail. Highlights include the fact that small firms outperform large firms across a range of patent performance metrics, and that small innovative firms generate patents at a rate 16 times higher than large innovative firms on a patents-per-employee basis.

III. Changes over Time in the Innovative Firm Database

A. Introduction

This project is built upon a carefully constructed database containing all U.S. firms that were granted 15 or more patents in the five-year period from 2005 to 2009. This is similar to the databases of patents through 2002 and 2006 that the authors built in previous projects for the SBA, which will be referred to in this report at SBA2[17] and SBA3.[18] The current database consists of 1,279 small and large firms and over a million patent records. In this chapter we discuss the fates of the firms in the last project and also highlight some differences between the new data and previous results.

B. Summary

In this chapter, we examine differences between the current database of U.S. innovative firms from 2005 to 2009, and the previous database of U.S. innovative firms covering 2002-2006. The key findings are:

1. Of the 532 small innovative firms in the current analysis, 224 (42 percent) are new entrants and were not part of the previous analysis. That is, more than four in ten of the small firms in this study either did not exist or did not patent significantly in the five years ending in 2006.

2. In total, there are 28 more small firms in the current database than in the database covering 2002-2006. With 224 new entrants, one might expect the increase in small firms to be greater. However, small firms are at greater risk than large firms of failing to satisfy various criteria for retaining their position in the database. For example, episodic patenting is characteristic of firms with low patent output, and one-third of small firms are very close to the 15 patent threshold, in that they have 20 or fewer patents (fewer than 10 percent of the large firms have 20 or fewer patents). Smaller firms are also more likely to increase employment and pass the 500 employee mark, or to be acquired by larger firms.

3. Perhaps surprisingly, 37 large firms from the previous SBA3 database dipped below 500 employees and are now in the current study as small innovative firms. This may be due in part to the effects of the 2008 recession. We also found that only 34 small firms from the 2008 study (SBA3) have been acquired since completion of that study. In SBA3, we noted 87 acquisitions of small firms from the earlier SBA2 study, so the recession may have had an effect on small firm acquisition as well.

4. In spite of the recession, the innovative firms in the database have performed very well on average. Small innovative U.S. firms have revenues averaging $46.5 million per year. This compares favorably to their cohort set from 2002-2006, which averaged $39.4 million per year. Large innovative firms have also performed well, with average sales increasing from $7.4 billion to $8.4 billion over the same period.

[17] Anthony Breitzman et al., *Small Firms and Technology: Acquisitions, Inventor Movement, and Technology Transfer*, Office of Advocacy, United States Small Business Administration, Contract No. SBAHQ-02-M-0491, January 2004.
[18] Anthony Breitzman et al., *An Analysis of Small Business Patents by Industry and Firm Size*, Office of Advocacy, United States Small Business Administration, Contract No. SBAHQ-07-Q-0010, November 2008.

C. Discussion

New Entrants and the Fates of Previously Studied Firms

A small firm enters the innovative firm database if it has 500 or fewer employees and at least 15 patents in the five-year period. We hypothesized that at least 50 percent of the small firms in the database for the current study would be different from the last project, which was completed in 2008. Table III.1 reveals that this hypothesis is incorrect, but not by much. A full 42 percent (224 of 532) of the small innovative firms in the study are new entrants. That is, they have 500 or fewer employees and have reached 15 U.S. granted patents for the first time in the five years. In comparison, only 17 percent of the large innovative firms are new entrants.

The reader may question why we would hypothesize that the number of small firm new entrants would be so high. The answer is that in past projects, the percentage of new entrants has exceeded 50 percent. For example, Table III.2 is from the 2008 study and is analogous to Table III.1 from the current study.

Table III.1 Overlap of Firms in Current Study (SBA4) and Previous Study (SBA3)

Firm Size	Firms in Database	Also in Previous Study (SBA3)	Percent in Previous	New Entrants	Percent New Entrants
Large	728	607	83%	121	17%
Small	532	308	58%	224	42%
Total	1260	915	73%	345	27%

Table III.2 Overlap of Firms in SBA3 (2008) and SBA2 (2003)

Firm Size	Firms in Database	Also in Previous Study (SBA2)	% in Previous	New Entrants	% New Entrants
Large	760	539	71%	221	29%
Small	504	198	39%	306	61%
Total	1264	737	58%	527	42%

Table III.2 reveals that, in the previous study, the percentage of new entrants among small firms was 61 percent, while the percentage of new entrants among large firms was 29 percent. Both percentages are significantly higher than in the current study. One possible reason for the lower percentage of new entrants in the current study is that less time has elapsed between this project and SBA3 than had elapsed between SBA3 and SBA2 (2 years versus 4 years).

Referring back to Table III.1, of the 532 small innovative firms in the current study, 224 are new entrants, and 308 are carried over from the previous study (SBA3). These 308 carryovers include 37 firms that were defined as large in SBA3, but are now defined as small. This means that 271 small firms from SBA3 remain in the database as small firms. Given that the total number of small firms in SBA3 was 504, 233 of these firms (504-271) are no longer in the database as small firms.

The fate of all 504 small innovative firms from SBA3 is shown in Table III.3. This table reveals that the main reason small firms dropped out was because they no longer reached the 15 patent threshold for 2005-2009. The small firms in SBA3 only averaged 38 patents in 2002-2006, and many had only 15-20, so it is not surprising that a number of these companies would fall below 15 patents in the 2005-2009 period.

Table III.3 Fate of Small Innovative Firms in Previous Study (SBA3)

Fate	Number of Firms	Percent of Firms
Acquired	34	7%
In New Study - Became Large	23	5%
In Both Studies (stayed small)	271	54%
Dropped below 15 Patents	165	33%
Moved Headquarters out of US	5	1%
Bankrupt/Out of Business	6	1%
Total	504	100%

Having said this, it should be noted that the number of patents was the first criterion we checked among firms from SBA3 to see if they should stay in the database. Those that did not make the 15 patent cutoff were dropped without any further research, so it could be that a number of those belong in the other categories. For example, a firm that became bankrupt would have a dropoff in patents and fall below the initial 15 patent threshold. Hence, the number of companies listed in Table III.3 under bankruptcy may be a lower bound.

Effects of the 2008 Recession on Small and Large Firms

There is evidence that the recession has affected the overall database in the current project, in that there are slightly fewer firms overall and many fewer large firms. Further, as revealed in Table III.4, 37 large firms from the last study have dropped below 500 employees and are now small firms in this study. This staffing reduction may be partly caused by the recession.

Table III.4 Fate of Large Innovative Firms in Previous Study (SBA3)

Fate	Number of Firms	Percent of Firms
Acquired	37	5%
In Both Studies (stayed large)	593	78%
In New Study - Became Small Firm	37	5%
Dropped below 15 Patents	88	12%
Moved Headquarters out of US	1	0%
Bankrupt/Out of Business	4	1%
Total	760	100%

It is also worth noting the sharp decline in acquisitions in the current study. In the SBA3 study, 87 of the small firms from the previous study (SBA2) had been acquired. In this round, only 34 of the small firms from the previous study were acquired. This lack of acquisitions may also be related to the recession.

There have been some positive notes despite the recession. As shown in Table III.5, the innovative firms in the current study have increased revenues compared with their counterparts from the previous SBA3 study. Specifically, large firms with 15+ patents in 2005-2009 had average revenues of $8.4 billion, compared with $7.4 billion for the set of large firms from the previous study (those with 15+ patents 2002-2006). The average revenues for small firms with 15+ patents also increased from $39.4 million to $46.5 million over the same period.

Table III.5 Database Statistics for SBA3 and SBA4 Studies

Data Set	Firm Size	Avg Sales	Avg # Employees	Avg Sales Per Employee	Median Sales Per Employee	Avg # Pats 2005-2009 and 2002-2006 Respectively	5-Year Patents Per Hundred Employees
SBA4 2010	Large	$8,385,038,016	19440	$431,335	$317,917	320	1.6
	Small	$46,540,617	141	$330,075	$179,775	38	27.0
SBA3 2008	Large	$7,405,416,093	18489	$400,532	$250,000	307	1.7
	Small	$39,420,941	143	$275,018	$105,971	38	26.5

Large innovative firms also saw an increase in average numbers of employees from 18,489 to 19,440, while average employment at small innovative firms dipped ever so slightly from 143 to 141. These numbers suggest that U.S. innovative firms—i.e., those with significant patent activity—have fared relatively well on average during the recent economic recession.

D. Conclusion

In this chapter, we examined differences between the firms in the previous SBA study (SBA3) conducted in 2007-08 and the current study. We found that 42 percent (224 of 532) of small innovative firms in the current analysis are new entrants and were not part of the previous analysis. That is, more than four in ten of the small firms in the current study either did not exist, or did not patent significantly, in the five years ending in 2006.

There are 28 more small firms in this study than in SBA3. With 224 new entrants, one might expect more small firms to be in the current analysis, but small firms are at greater risk than large firms of falling short of various criteria for entry into the database. For example, episodic patenting is characteristic of firms with low patent output, and 32 percent of the small firms are very close to the 15 patent threshold, in that they have 20 or fewer patents (fewer than 10 percent of the large firms have 20 or fewer patents). Smaller firms are also more likely to increase employment and pass the 500 employee mark, or to be acquired by larger firms.

Perhaps surprisingly, we found that 37 large firms from the last study dipped below 500 employees and are now in the current study as small innovative firms. This may be due in part to the effects of the 2008 recession. We also found only 34 small firms from the previous study have been acquired since then, compared with 87 acquisitions of small firms between SBA2 and SBA3. The recession may have therefore affected acquisition activity as well.

In spite of the recession, the set of small and large innovative firms have actually performed quite well on average. Small U.S. firms with 15+ recent patents have revenues averaging $46.5 million per year. This compares favorably to their cohort set from the previous project, which averaged $39.4 million per year. Meanwhile, the set of large innovative firms has seen average sales increase from $7.4 billion to $8.4 billion over the same period.

IV. Small Firm Participation in "Green" Technologies

A. Introduction

It has become clear in recent times that our long reliance on fossil fuels cannot continue unabated. Whether the driver is climate change, dependence on foreign oil, the rising cost of energy, or some combination, the need for energy efficiency has made green energy sources the subject of much debate, and a great deal of investment.

Within green technology, there is no clear consensus on the best way forward. For example, hybrid cars are viewed by some as a stepping stone technology at best, until fuel cell and battery-powered cars can be perfected. Others believe that electric cars are no better than gasoline-powered cars as long as most electricity comes from coal-fired generators. In another area of green technology, some believe that wind energy is the answer to energy needs, while others believe that enough wind farms could never be built to replace coal.

Since there is no clear winning green replacement technology, a number of companies are trying various strategies to develop green technologies. In this chapter, we use the patent system to identify small and large firms active in a number of green technologies.

B. Summary

In this chapter, we examine patenting of green technologies by small and large U.S. firms, as well as by foreign organizations. The key results are:

1. Organizations based in the United States were responsible for 43 percent of U.S. patents in green technologies in 2005-2009, while Japanese organizations have 32 percent of these green patents. No other countries have more than 6 percent of the patents. While the United States owns more green patents than other countries, the lead is smaller than expected. In the total U.S. patent system covering all technologies, the United States invents about 50 percent of granted patents, with Japanese inventors producing about 20 percent of granted U.S. patents. One interpretation of these percentages is that the United States has less emphasis on green technologies than it does on other technologies, while Japan has a greater emphasis on green technologies. Alternatively, one could argue that Japanese inventors are overachieving in green technologies, with the United States slightly underachieving.

2. Another key result concerns the extent to which green innovations are core technologies to small innovative firms. There are four times as many large innovative U.S. firms with at least one green patent as there are small innovative U.S. firms with at least one green patent. However, green patents form a much lower percentage of these large firms' portfolios than the small firms' portfolios (1.5 percent on average for large firms, versus 20 percent for small firms). Several small firms have patent portfolios that are almost entirely green, which is not the case for any of the large firms. It thus appears that many small firms are building their business around green technologies, while large firms are largely enhancing product lines with green technologies. For example, the business models of small firms like Bloom Energy, The Current Group, and Valence Technology are based solely on

green technologies. In contrast, General Motors and Toyota are patenting in batteries, fuel cells, and hybrid systems, but their green efforts are a small part of their overall business.

3. Small firms patent more often than expected in several green subcategories and in green technology in general. Overall, small firms account for approximately 8 percent of all patents in the U.S. innovative firm database. However in both smart grids and solar energy, small firms account for more than 32 percent of the patents. Small firms also account for more than 15 percent of the patents in batteries and fuel cells. In all green technologies combined, small firms account for 14 percent of the patents, almost twice as many as one would expect given the overall level of small firm patent output.

4. Small firms tend to have strong citation metrics in the green subcategories in which they are active. This is similar to the result we found for emerging technologies in SBA2. It suggests that small firms are inventing important green technologies, and that these small firms tend to file patents only on their significant green inventions. Specifically, on average, green patents from small firms are cited 2.5 times as frequently as green patents from large firms. It is worth noting that high citation rates such as these have been correlated with outcomes such as inventor awards, increases in sales and profits, stock price appreciation, and greater licensing revenues.[19]

Overall, the results in this chapter suggest that small firms are particularly active in green technologies. Also, small firms that patent in green technologies tend to do so as a core business more often than large firms. They also tend to patent their more important green technologies, resulting in a higher citation impact. Small firms, or firms that have recently graduated from small firm to large firm status,[20] may thus be a particularly important future source of innovations in green technologies.

C. Method

As part of several recent projects, 1790 Analytics has created a number of search strategies for identifying green technology patents. For example, 1790's Patrick Thomas has worked on a number of projects for the Department of Energy (DOE). As part of these projects, 1790 has developed patent searches for identifying patents related to batteries, hybrid electric vehicles, wind energy, and geothermal energy.[21] In addition, 1790 developed the patent searches and data for the *2009 California Green Innovation Index* authored by Collaborative Economics.[22] This index provides a deep analysis of key economic and environmental indicators to better understand the role of green innovations in reducing greenhouse gas emissions while strengthening the economy.

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[19] See Anthony Breitzman and Mary Mogee, "The Many Applications of Patent Analysis," *Journal of Information Science*, 28(3), 187-205, 2002, for a summary of various validation studies.

[20] It is quite possible that a small firm with a breakthrough will have "graduated" into a large firm at the time of the breakthrough. Several of the interesting firms highlighted in this report have close to 500 employees now and will likely become large firms in the next few years.

[21] Ruegg, R. and Thomas, P. Linkages from DOE's Energy Storage R&D to Batteries and Ultracapacitors for Hybrid, Plug-In Hybrid, and Electric Vehicles. U.S. Department of Energy, February 2008.
Also
Ruegg, R. and Thomas, P. Linkages from DOE's Wind Energy Program to Commercial Renewable Power Generation. U.S. Department of Energy, 2009, In Press.

[22] Collaborative Economics, "The California Green Innovation Index 2009," Published by Next10, Palo Alto, CA. 2009. http://www.next10.org/pdf/GII/Next10_GII_2009.pdf

More recently, 1790 produced the scorecard used in the IEEE Spectrum Clean Tech 50.[23] As part of this effort we developed a number of additional searches including strategies for identifying patents in clean coal technology and smart grid/smart metering technology. In this project, we were able to leverage all of this previous work in order to study small innovative firms that are active in green technologies.

Table IV.1 List of Green Technologies Covered in Study

Batteries
Clean Coal
Smart Grid/Smart Metering/Electric Grid Infrastructure
Fuel Cells
Geothermal Energy
Generic Green Technology
Hybrid Electric Vehicle Systems
Hydro Power
Solar Energy
Wind Energy
All Green Combined

Table IV.1 shows a list of green technologies included in the current study. In order to search for patents in these technologies, we used a combination of keywords that appear in the patents along with U.S. Patent Office Classification (POC) codes. Table IV.2 shows an example of a patent filter, designed to identify patents related to clean coal. Similar filters were used to identify relevant patents in each of the other green energy categories.

Most of the subcategories are readily identifiable from their titles, except perhaps the “generic green technology” category. This subcategory consists of patents that mention the phrases “green technology”, “green energy,” “clean technology,, or “clean energy” anywhere in their text. There is also a “roll-up” category “all green combined” which contains all of the patents in all ten categories with duplicates removed.[24]

D. Results

Worldwide Firms in Green Technologies

Before examining results that are specific to small innovative firms, it is worth analyzing some overall results that may have policy relevance. Figure IV.1 shows the companies with the most green patents in the last five years, where we define green patents as the union of the ten categories listed above in Table IV.1. What is surprising about this figure is the apparent dominance of Japanese firms. Japanese firms hold the top two positions, as well as three of the top five, and six of the top ten, positions on the chart. Panasonic leads all firms with 579 green patents granted in the 2005-2009 time period. General Motors is the top U.S. firm with 348 green patents. There are 13 U.S. firms among the top 30 firms in Figure IV.1 including three small firms (The Current Group, Plug Power Inc., and Quallion LLC).

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[23] Patrick Thomas and Anthony Breitzman, “The Clean Tech 50,” IEEE Spectrum, Piscataway, NJ. 2010. http://spectrum.ieee.org/green-tech/fuel-cells/the-cleantech50

[24] Duplicates can occur if, for example, a patent claims a use in both batteries and hybrid electric systems

Table IV.2 Clean Coal Patent Search Strategy

Filter is POC AND Title/Abstract = (Keyword Set 1 or 2 or 3 or 4 or 5)

POC=
44/620-627
48/71-73, 77, 98-101, 200-202, 210
60
95
96
110
264/37.14-37.17
422/168-183
423/210-248
431

Keyword Set 1:
(CO2 or carbon or emission* or NOX or sulfur* or SO2 or mercury) and (captur* or sequest* or stor* or scrub* or mitigat* or reduc* or lower* or cut) and (coal* or fossil*)

Keyword Set 2:
FGD or (flue* and (de?sulfur* or scrub*))

Keyword Set 3:
coal* and (gasif* or wash* or de?water*)

Keyword Set 4:
IGCC or “integrated?gasification?combined?cycle”

Keyword Set 5:
(oxy?fuel* or pre?combust* or post?combust* or “fluidized?bed?combustion” or FBC) and ((coal* or fossil*)

Table IV.3 shows the distribution of green patents across subcategories for the firms in Figure IV.1. This table reveals that the patent activity of these leading firms varies widely across the different subcategories of green technology. For example, electronic firms such as Panasonic, Samsung, and Sony concentrate their efforts mainly in batteries, while the automotive firms Toyota, Honda, GM, Ford, and Nissan have most of their patents in fuel cells and hybrid systems (Toyota also has more than 100 battery patents). General Electric has patents across almost all categories, but leads by a large margin in the wind energy category. A small firm (The Current Group) actually has the most patents in the smart grid category.

Figure IV.1: Companies with the Most U.S. "Green" Patents 2005-2009

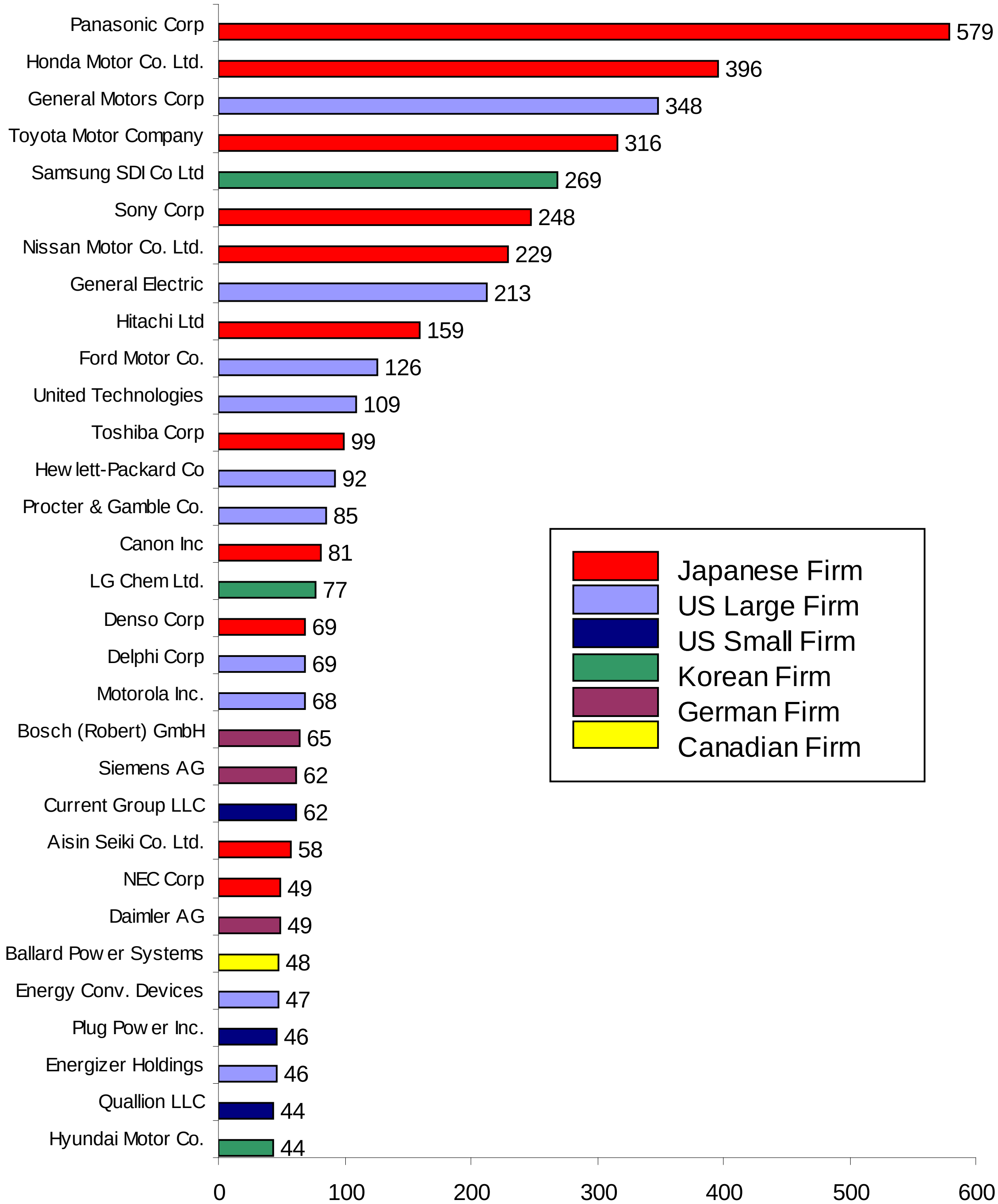

Table IV.3 Distribution of Top Green Firms by Sub-Category (2005-2009 U.S. Patents)

Firm Name	Country	All Green Combined	Batteries	Clean Coal	Smart Grid/Smart Metering/Grid Infrastructure	Fuel Cells	Geothermal Energy	Generic Green	Hybrid Systems	Hydro Power	Solar Energy	Wind Energy
Panasonic Corporation	JP	579	414		13	131		1	5		15	
Honda Motor Co. Ltd.	JP	396	26			272			91		3	4
General Motors Corp	US	348	24		1	205			116		1	2
Toyota Motor Company	JP	316	112			90			114		2	
Samsung SDI Co Ltd	KR	269	205		2	58					4	
Sony Corp	JP	248	194		4	42			1		6	1
Nissan Motor Co. Ltd.	JP	229	65			101			62			1
General Electric Co	US	213	13	14	14	34	6		16	2	11	104
Hitachi Ltd	JP	159	83		7	29			22		1	17
Ford Motor Co.	US	126	16			12			97		1	
United Technologies	US	109	1	1	2	94			1		8	3
Toshiba Corp	JP	99	49		3	44			1		2	
Hewlett-Packard Co	US	92	19		3	69					1	
Procter & Gamble Co.	US	85	62			23						
Canon Inc	JP	81	44			12		1			24	
LG Chem Ltd.	KR	77	70			7						
Delphi Corp	US	69	8			55			6			
Denso Corp	JP	69	29		3	19			16			5
Motorola Inc.	US	68	48		3	15					2	
Bosch (Robert) GmbH	DE	65	29		1	13			20		1	1
Current Group LLC	US	62			62							
Siemens AG	DE	62	8	6	12	26			1		2	7
Aisin Seiki Co. Ltd.	JP	58	3			21			34			
Daimler AG	DE	49	11			18			20			
NEC Corp	JP	49	44		2	3						
Ballard Power Systems	CA	48				48						
Energy Conversion Dev.	US	47	12			21		4	3		7	
Energizer Holdings Inc.	US	46	40			6						
Plug Power Inc.	US	46	1			45						
Hyundai Motor Co.	KR	44	4			14			26			
Quallion LLC	US	44	44									

Table IV.4 Distribution of Green Patents by Country of Ownership (US Patents 2005-2009)

Country of Ownership	Number of Patents 2005-2009	Percent Patents	Number of Organizations
US	4593	42.7%	901
Japan	3480	32.3%	291
Germany	621	5.8%	106
S.Korea	515	4.8%	51
Taiwan	305	2.8%	105
Canada	297	2.8%	78
France	208	1.9%	45
UK	132	1.2%	67
Switzerland	68	0.6%	20
Netherlands	59	0.5%	14
Hong Kong	55	0.5%	10
Italy	54	0.5%	22
China	50	0.5%	26
Australia	43	0.4%	22
Sweden	42	0.4%	16
Israel	38	0.4%	17
Belgium	28	0.3%	10
Denmark	22	0.2%	13
Spain	22	0.2%	9
Finland	15	0.1%	13
Austria	14	0.1%	7
Russia	11	0.1%	7
Norway	11	0.1%	7
Panama	9	0.1%	1
All Others	67	0.6%	45

The prominence of Japanese firms at the head of Figure IV.1 might give the impression that Japanese organizations own the largest number of green patents overall. However, this is not the case. Table IV.4 reveals that, while Japan has several of the leading patenting firms in green technologies, overall the United States has far more participants and more patents. Specifically, there are 291 Japanese firms that own 3,480 U.S. green technology patents issued in the period 2005-2009. In the same period, there were 4,593 patents granted to 901 U.S. firms in green technology. Overall, U.S. firms own 42.7 percent of the U.S. patents and Japanese firms own 32.3 percent of the U.S. patents in these technologies. None of the other countries' firms own more than 6 percent of the patents.

The broad range of U.S. participants in green technology may be a reflection of the large number of small firms that exist in America. It may also reflect the nature of filing patents at the U.S. patent office. Small foreign firms are less likely to file patents in both their home system and the U.S. system due to the expense involved in filing patents in multiple systems. Meanwhile, small U.S. firms may also only file in their home country, but their patents will still be included in this analysis.

The statistics above are based on patent assignees, the owners of the patent rights. It is also interesting to examine statistics based on patent inventors. These statistics provide a different picture of where green innovation is occurring. For example, it may be that large U.S. firms have green patents invented by foreign subsidiaries, which would count as U.S. owned in the statistics based on assignees. Similarly, large foreign firms may have U.S. labs with U.S. inventors.

Table IV.5 Distribution of Green Patents by Country of Inventor (Fractional Counts, U.S. Patents 2005-2009)

Inventor Country	# Patents	% Patents
US	4583	44.0%
Japan	3193	30.7%
Germany	662	6.4%
S.Korea	498	4.8%
Canada	317	3.0%
Taiwan	271	2.6%
UK	148	1.4%
France	118	1.1%
China	72	0.7%
Italy	64	0.6%
Sweden	49	0.5%
Denmark	46	0.4%
Israel	44	0.4%
Australia	43	0.4%
Netherlands	37	0.4%
Switzerland	37	0.4%
Spain	26	0.2%
Austria	24	0.2%
Belgium	22	0.2%
Finland	21	0.2%
Norway	17	0.2%
Russia	15	0.1%
Hong Kong	14	0.1%
India	13	0.1%
All Others	74	0.7%

Table IV.5 shows the green patent distribution by country of inventor.[25] This table reveals that there is only a slight disagreement between the statistics by assignee and inventor. The percentage of U.S.-invented green patents (44 percent) is slightly higher than the percentage of U.S.-owned patents (42.7 percent). Conversely, the percentage of Japanese invented green patents (30.7 percent) is slightly lower than the percentage of Japanese owned green patents (32.3 percent). This suggests that Japanese firms may have a slightly greater reliance on green innovations developed outside Japan, but the difference is not considerable.

From a policy perspective, it is important to note that, while the United States is leading in green technology patenting, its lead is small compared with other technologies. The U.S. patent system contains patents filed

[25] Note that the inventor counts are based on fractional counting. For example most patents have multiple inventors, and coinventors may be from different countries. To produce this table without increasing the number of patents in the set we fractionated the ownership of each patent. For example if a patent has two Japanese inventors and one US inventor we attribute 2/3 of the patent to Japan and 1/3 to the US.

by inventors from all over the world. In recent years, approximately 50 percent of all U.S.-granted patents were from U.S. inventors, and 50 percent were from inventors based outside the United States, including 20 percent from Japanese inventors. From this perspective, it appears that Japanese inventors and companies are over-represented in green technologies, while U.S. inventors and firms are under-represented. Specifically, Japanese inventors account for about 20 percent of all U.S. patents, but they account for 31 percent of U.S. patents in green technologies.[26]

U.S. Organizations Active in Green Technologies

This section of the report focuses on the green patents of U.S. organizations, in order to compare and contrast how U.S. small and large firms innovate in green technologies. Figure IV.2 is analogous to Figure IV.1, except all foreign firms have been removed. It thus contains the leading U.S. patenting organizations in green technology. Large U.S. firms dominate this figure, but it does also include nine small U.S. firms. There are also organizations that we exclude from the analysis of small and large firms, such as universities, government agencies, and bankrupt firms.

In total, we identified 197 large innovative U.S. firms, and 48 small innovative firms, with at least one green patent in 2005-2009. Table IV.6 provides summary statistics for these 245 innovative U.S. firms. This table reveals that, while there are many more large innovative companies with at least one green patent, green technology is much more central to small firms' patent portfolios. Overall, green patents make up almost 20 percent of the small firm patent portfolios, compared with less than 2 percent of the large firm patent portfolios. In fact, for many of the small firms in the set, their entire business is related to green technology.

The central role of green technologies to many small firms is also highlighted in Table IV.7. This table lists all of the innovative firms for which green technologies make up at least 10 percent of their patents issued in 2005-2009. There are 22 small innovative firms in this figure. For ten of these firms, green patents make up at least 75 percent of their patents issued in 2005-2009. None of the large firms meet this 75 percent threshold, and only eleven have a green patent share above 10 percent. This suggests that green technologies are the single focus for many small firms, while for most large firms, green technologies are a small part of their product line or an enhancement to their product line. Below we highlight a number of these innovative small firms with a single focus on green technology.

Plug Power Inc. is a development stage small firm that is developing fuel cell technology. Of its 48 recent patents, 46 are in green technologies. Plug Power develops and sells a range of fuel cell products and services for motive and stationary power, and a high-temperature fuel cell system for residential and light commercial cogeneration. Its primary product line includes GenDrive, a hydrogen fuel cell system to provide power to industrial vehicles; and GenSys, a liquid petroleum gas (LPG) fueled continuous prime power system that supports remote prime power applications, principally for the telecommunications sector.[27]

[26] A trend plot is omitted here because it is not very revealing. Such a plot would show that, while green patenting is growing for the US and Japan, the percentage of US invented patents has fallen from a peak of 47% in 2007 to 41% in 2009. Over the same period, the percentage of Japanese invented patents has grown slightly and the percentage of Korean invented green patents has quadrupled.

[27] Yahoo Finance, Plug Power Inc. Business Profile, http://finance.yahoo.com/q/pr?s=PLUG+Profile, Retrieved August, 2, 2010.

Figure IV.2: U.S. Organizations with the Most U.S. "Green" Patents 2005-2009

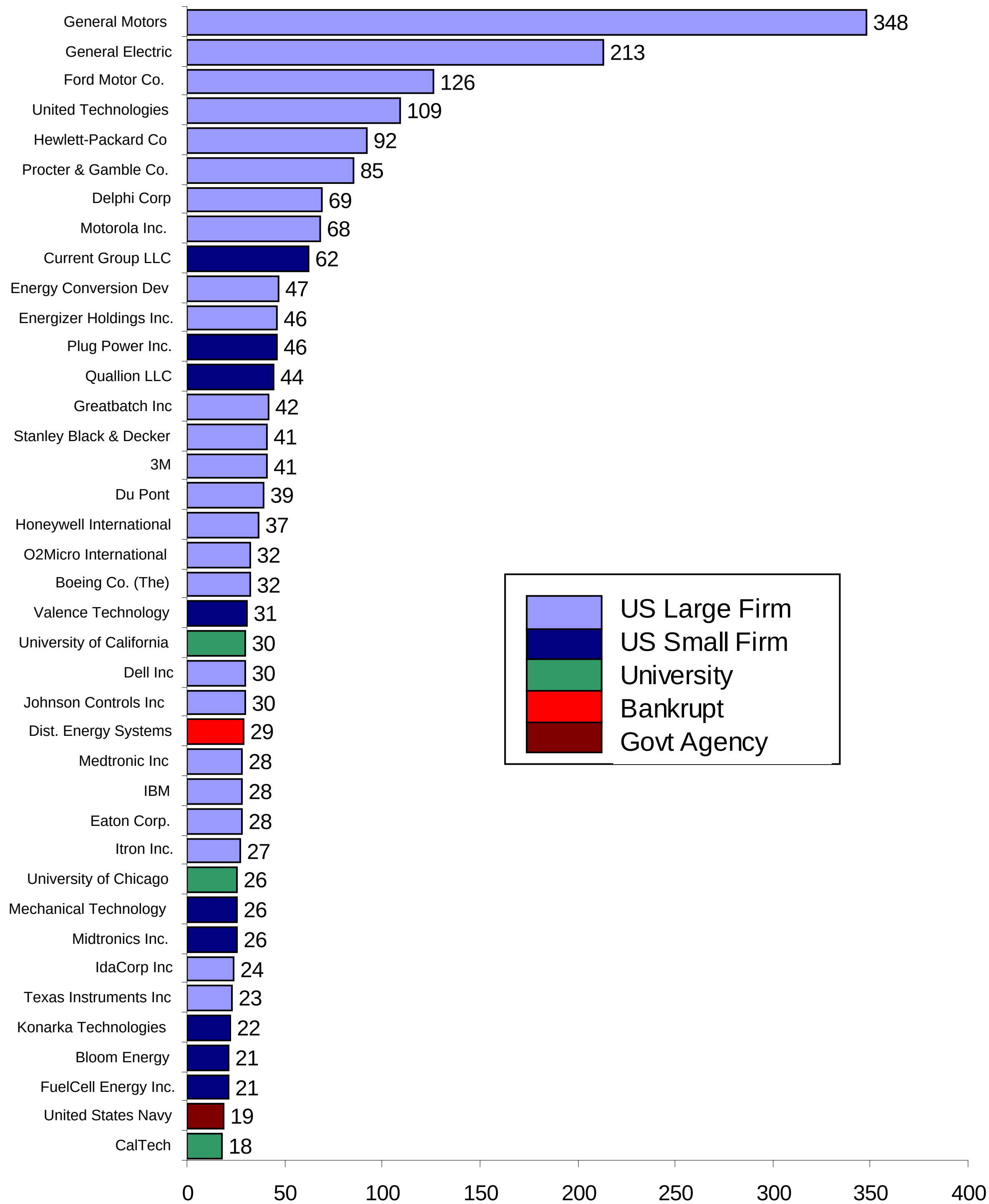

Table IV.6 Summary Statistics for U.S. Innovative Firms with Green Patents 2005-2009

US Innovative Firms in Database	# Firms with at least 1 Green Patent 2005-2009	# Green Patents 2005-2009	Total #US Patents 2005-2009	Share Green
Large Firms	197	2327	167967	1.4%
Small Firms	48	429	2225	19.3%

Bloom Energy is another small fuel cell firm, but its focus is different from that of Plug Power. All but one of Bloom's 22 recent patents are in green technologies. Bloom sells its "Bloom Boxes" to companies (and soon households) to generate on-site electricity via fuel cells. Derived from a common sand-like powder and leveraging breakthrough advances in material science, the Bloom technology is able to produce clean reliable electrical power practically anywhere from a wide range of renewable or traditional fuels. The Bloom energy servers are among the most efficient energy generators on the planet and produce dramatically lower greenhouse gas emissions and reduced electricity costs. Bloom has sold its energy servers to many high-profile companies including EBay, Google, Coca-Cola, Staples and Bank of America.[28] Bloom Energy was recently featured on CBS in a *60 Minutes* segment and has also been featured in *Business Week*, *CNN Money*, and *Fortune* Magazine.

The Current Group is a small innovative firm that is working on making the electric grid smarter. It develops smart meters as well as grid management tools, and has also developed technology for using electric lines as communications lines. Sixty-two of Current's 66 recent patents are in green technologies. According to a recent company press release:

> CURRENT Group, LLC announced that it has been selected by Iberdrola to provide smart metering communications advanced sensing and network management solutions as part of their first phase deployment of Smart Grid solutions in Castellon, Spain. The Iberdrola deployment represents the first and largest deployment of smart metering technologies that demonstrate comprehensive end-to-end interoperability using the open PRIME metering standard, for which over twenty companies are now members or have applied for membership. Iberdrola plans to deploy an initial 100,000 meters and respective transformers incorporating two-way medium voltage and cellular communications, grid supervision and control, and meter collection infrastructure before expanding immediately to territory wide deployments of smart meters in early 2011. In support of Iberdrola's efforts, CURRENT will provide components of its industry-leading Smart Transformer Station platform comprised of infrastructure solutions for meter data concentration and collection, transformer sensing and supervision, and communications with network management. Combined, these solutions provide comprehensive support for smart metering, distribution management and provide the platform for secure communications. The Smart Transformer Station platform is a comprehensive Smart Grid solution specifically designed for the European Asian, and Australian markets and represents CURRENT's extensive experience in providing distribution grid communications and distribution management solutions with the utility industry's first open and interoperable smart metering data concentrator solution.[29]

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[28] Bloom Energy Website, http://www.bloomenergy.com, Accessed August 2, 2010.

[29] Bloomberg Businessweek Press Release on Current Group. http://investing.businessweek.com/research/stocks/private/snapshot.asp?privcapId=22104897, Retrieved August 2, 2010.

Table IV.7 Firms where Green Technologies make up at least 10 Percent of their Patents Issued 2005-2009

Firm Name	Firm Size	Green U.S. Patents 2005-2009	Total U.S. Patents 2005-2009	Green Share of Patent Portfolio 2005-2009
Plug Power Inc.	small	46	48	95.8%
Bloom Energy	small	21	22	95.5%
Current Group LLC	small	62	66	93.9%
Valence Technology Inc.	small	31	33	93.9%
Mechanical Technology Inc	small	26	28	92.9%
Quallion LLC	small	44	50	88.0%
Cymbet Corp	small	14	16	87.5%
Konarka Technologies Inc	small	22	28	78.6%
Nanosolar Inc	small	16	21	76.2%
FuelCell Energy Inc.	small	21	28	75.0%
IdaCorp Inc	large	24	33	72.7%
Polypore Inc	large	11	16	68.8%
Energy Conversion Devices Inc.	large	47	86	54.7%
Itron Inc.	large	27	51	52.9%
Midtronics Inc.	small	26	50	52.0%
Aerovironment Inc	large	11	22	50.0%
Ambient Corp	small	8	18	44.4%
Greatbatch Inc	large	42	125	33.6%
Ise Corp	small	6	18	33.3%
Spectrum Brands Inc	large	10	36	27.8%
Energizer Holdings Inc.	large	46	172	26.7%
Basic Resources Inc	small	4	17	23.5%
O2Micro International Ltd.	large	32	155	20.6%
Lynntech Inc.	small	6	31	19.4%
Ingrid Inc	small	3	16	18.8%
Nanosys Inc.	small	9	58	15.5%
Maxwell Technologies Inc.	small	7	52	13.5%
General Motors Corp	large	348	2608	13.3%
Reveo Inc	small	8	60	13.3%
NanoGram Corporation	small	2	16	12.5%
Intematix Corp	small	3	25	12.0%
Johnson Controls Inc	large	30	254	11.8%
Pelican Products Inc	small	2	17	11.8%
Wahl Clipper Corporation	large	3	26	11.5%
Schweitzer Engineering Laboratories Inc.	large	6	53	11.3%
W L Gore & Associates	large	11	102	10.8%
Streamlight Inc.	small	2	20	10.0%

Valence Technology is a small innovative firm with 31 of its 33 recent patents in battery technology. Valence develops, manufactures, and sells high-energy power systems both in the United States and internationally. Its products include the U-Charge energy system, which is a suite of products based on lithium iron magnesium phosphate technology. Its products have applications in the hybrid and full electric vehicle sectors, as well as in traditional battery applications such as wheelchairs, scooters, backup, robotics, and other devices.[30]

A number of large innovative firms also have a high percentage of green patents, and thus appear near the head of Table IV.7. For example, 24 of Idacorp's 33 recent patents are related to fuel cells. However, Idacorp differs from the small innovative firms like Bloom and Plug Power in that it is a holding company that owns a number of electric plants. It owns and operates 17 hydroelectric generating plants located in southern Idaho and eastern Oregon, as well as two natural gas-fired plants situated in southern Idaho. It also owns interests in three coal-fired steam electric generating plants located in Wyoming, Nevada, and Oregon.[31]

Polypore Inc. is one of the few large innovative firms whose core business is in the green technology space. Eleven of its sixteen recent patents are in green technologies. Polypore makes membrane separators that are critical components in lithium and lead-acid batteries, performing the core function of regulating ion exchange and thus allowing the charge and discharge process to occur.[32]

Energy Conversion Devices Inc. (ECD) is another large innovative firm whose core business is in green technology. The company designs, manufactures, and sells photovoltaic products, and more than 50 percent of its recent patents are in green technologies. ECD operates in two segments, United Solar Ovonic and Ovonic Materials. The United Solar Ovonic segment provides PV laminates that generate clean and renewable energy by converting sunlight into electricity. It also engages in the design, development, and installation of rooftop and BIPV systems and applications. The Ovonic Materials segment invents, designs, develops, and licenses materials and products. This segment also commercializes NiMH materials and consumer battery technology.[33]

These company snapshots show that both small and large innovative firms are doing interesting things within green technology. However, the importance of green technology is generally much greater for the small companies. Take for example a scenario in which fuel cell technology fails to deliver adequate results. This will not cripple large firms with many fuel cell patents, such as GM, United Technologies or Idacorp, since these companies have other technologies and product lines. On the other hand, the future of small innovative fuel cell firms like Plug Power or Bloom Energy would be in serious question if fuel cell technology is not a success.

At the outset of the project, we hypothesized that small firms would have more green technology patents than large firms. This hypothesis was based on the results of past projects, where small firms were found to have a higher percentage of their patent portfolios in emerging technologies than large firms.[34] The hypothesis turned out to be wrong. In our database of U.S. innovative firms with 15 or more patents, there are more large firms with green patents than small firms (197 vs. 48) and more large firm green patents than small firm green patents (2327 vs. 429). However, small firms have a much higher share of their patent portfolios in green technologies than large firms (19.3 percent vs. 1.4 percent). Moreover, there are many

[30] Yahoo Finance, Valence Technology Inc. Business Profile, http://finance.yahoo.com/q/pr?s=VLNC+Profile, Retrieved August 2, 2010.
[31] Yahoo Finance, Idacorp Inc. Business Profile, http://finance.yahoo.com/q/pr?s=IDA+Profile, Retrieved August 2, 2010.
[32] Polypore Website, http://www.polypore.net/ Retrieved August 2, 2010.
[33] Yahoo Finance, Energy Conversion Devices Business Profile, http://finance.yahoo.com/q/pr?s=ENER+Profile, Retrieved August 2, 2010.
[34] Anthony Breitzman et al., *An Analysis of Small Business Patents by Industry and Firm Size*, Office of Advocacy, United States Small Business Administration, Contract No. SBAHQ-07-Q-0010, November 2008.

more small firms whose core business is in green technology than there are large firms with a similar focus on green technology.

Green Technology Subcategories

The results above are based on all green technologies combined. In this section, we analyze the individual subcategories within green technology. Table IV.8 shows the numbers of patents by small and large innovative firms across green technology subcategories. The table also contains the total number of green technology patents by small and large innovative firms from Table II.4 in chapter II.

Table IV.8 Green Patents by Sub-Category of U.S. Innovative Firms 2005-2009

Technology & Sub-Category	#Large Firm Patents	#Small Firm Patents	% Large Firm	% Small Firm	Expected #Small Firm Patents	Small Firm Excess	Significance (P<)
Batteries	850	157	84%	15.6%	80	7.7%	0.0001
Clean Coal	28	0	100%	0.0%	2	-7.9%	NS
Fuel Cells	740	134	85%	15.3%	70	7.4%	0.0001
Generic Green	9	2	82%	18.2%	1	10.2%	NS
Geothermal Energy	12	0	100%	0.0%	1	-7.9%	NS
Hybrid Vehicle Systems	300	11	96%	3.5%	25	-4.4%	0.01
Hydro Power	4	0	100%	0.0%	0	-7.9%	NS
Smart Grid/Smart Metering/ Grid Infrastructure	168	81	67%	32.5%	20	24.6%	0.0001
Solar Energy	86	41	68%	32.3%	10	24.3%	0.0001
Wind Energy	134	4	97%	2.9%	11	-5.0%	NS
Green Energy Combined	2230	370	86%	14.2%	208	6.3%	0.0001
Non-Green Energy Patents	230443	19681	92%	7.9%		-0.1%	
All Patents Combined	232673	20051	92%	7.9%		0.0%	

As discussed in chapter II, and shown at the bottom of Table IV.8, small firms account for 8 percent of the patents in the overall database. Subcategories where small firm patenting exceeds 8 percent are thus said to have a small firm excess. The value of that excess (consisting of the percentage of small firm patents in the subcategory minus 8 percent) can be found in the second to last column in Table IV.8. All subcategories with a positive small firm excess are highlighted in green, and those with a negative small firm excess are highlighted in yellow.

For example, in batteries, fuel cells, and green energy combined, small innovative firms have almost twice as many patents as one would expect, given the overall patenting rate of 8 percent by small firms in the database. In the smart grid and solar subcategories, the excess is even greater, and small firms have almost four times as many patents as one would expect. On the other hand, small firms have fewer patents than expected in hybrid systems, a subcategory dominated by large automotive firms. Small firms also have few patents in clean coal, geothermal energy, and wind energy. A list showing the top patenting small and large firms for each subcategory can be found in Appendix A.

The final column in Table IV.8 contains the results of a chi-square test on the distribution of patents between small firms and large firms in each green technology subcategory. Specifically, this tests whether the differences between small firm patenting and expected small firm patenting are due to random variance. In subcategories where the numbers of patents are relatively small, or the small firm excesses are low, the results are not statistically significant and are highlighted in red. In other subcategories, the results are significant with P values less than .0001, suggesting that the probability that the difference is random is less than 0.01 percent.

The last part of the analysis that we report in this chapter is a citation analysis. As noted in Chapter II, the number of citations to a patent set is often used as a proxy for technological impact. Numerous studies have shown the correlation between citation impact and positive outcomes such as licensing revenue, stock price appreciation, inventor awards etc.[35]

Table IV.9 Citation Index for U.S. Innovative Firms with Green Technology Patents

	Large Firms		Small Firms	
Green Subcategory	#Patents 2005-09	Citation Index	#Patents 2005-09	Citation Index
Batteries	850	0.99	157	1.83
Clean Coal	28	0.84		
Smart Grid/Smart Metering/Infrastructure	168	0.78	81	3.78
Fuel Cells	740	0.89	134	0.81
Geothermal Energy	12	3.36		
Generic Green	9	1.95	2	0.24
Hybrid Systems	300	1.35	11	1.75
Hydro Power	4	0.41		
Solar Energy	86	0.40	41	3.20
Wind Energy	134	1.58	4	3.05
All Green Combined	2327	1.05	429	2.53

Table IV.9 shows the citation index for small and large innovative firms in each green subcategory. As described in Chapter II, the citation index is derived by dividing the number of citations received by a set of patents by the average number of citations received by peer patents of the same age and technology. The citation index is normalized so that a set of patents receiving an average number of citations would have a citation index of 1.0.

In Table IV.9, citation indexes above 1.5 (i.e. citations are 50 percent higher than expected) are highlighted in green. The highest citation index in the table is for the 81 small firm smart grid patents. The 3.81 value shows that these patents have been cited almost four times as often as expected given their age and technology. Small firms also have high citation indexes in batteries and solar energy, but their patents have been cited less than expected in fuel cells. Overall, for all green subcategories combined, the large firms have a citation index of 1.05, which is just slightly above average. Meanwhile, the small firms have a citation index of 2.53, showing that their green patents have been cited two and a half times as often as expected. A list of specific highly cited green patents from both small and large firms is provided in Appendix B.

[35] Anthony Breitzman and Mary Mogee, "The Many Applications of Patent Analysis," *Journal of Information Science*, 28(3), 187-205, 2002.

E. Conclusion

In this chapter, we examined patenting in green technologies by small and large U.S. firms, and by foreign organizations. We found that small firms are particularly active in green technologies, and these technologies are often core to their business. Small firms also tend to patent their more important green innovations, which results in a higher citation impact for their green patents. A more detailed version of the key results can be found in the summary at the beginning of this chapter.

V. Prolific Inventors from Small Green Firms

A. Introduction

In prior studies, we have shown the importance of prolific inventors to their organizations.[36] Such inventors not only have the largest number of patents, they are also often responsible for the most important patents within a firm. Further, we showed that prolific inventors are often three to five times as productive as average inventors, and are thus the driving forces behind technological developments within a firm. These findings were based on key inventors within large firms, but the same results are likely to carry through, and may even be more pronounced, within small firms.

In this chapter, we research the key inventors within small green firms in an attempt to gain an understanding of how green inventors and green entrepreneurs develop. Since this subject is not widely studied, it is not clear whether prolific inventors within green technologies are more likely to come from large firms or straight out of universities. It is also unclear whether the inventors will have always worked in green areas or have evolved from other disciplines into becoming green inventors.

B. Summary

In this chapter we examine inventors from small firms who have invented five or more green patents granted in the period 2005-2009. Some key findings are:

1. There are 32 individuals who invented five or more recent green patents with a citation index of 1.0 or greater. We found that these prolific individuals also tended to be high achievers in other aspects of their careers, and many of them have founded or run green energy firms after working at large firms in other industries.

2. Of these prolific inventors, 35 percent are now C-level (CEO, CTO, Chief Scientist) executives at small green firms and nearly 30 percent are cofounders of green firms.

3. Approximately 80 percent of the prolific green inventors had previously worked at large companies or large government or university labs. More than 30 percent had five or more patents for previous employers in nongreen technologies. This illustrates the difficulty in training a person at a university to be a green entrepreneur. Most of these individuals were not recent college graduates, but instead were people who had successful careers prior to joining or founding green firms.

4. The policy relevance of this finding is that, although we do not fully understand the mechanisms through which individuals decide to leave jobs at large firms in order to launch startups, there is a need to cultivate such behavior and support it. As the results of this project show, small firms tend to be particularly effective incubators of emerging technologies such as green technology. Hence, one strength of the U.S. economic system that should be encouraged is the ability for creative people to leave the security of large firms in order to launch small green technology firms.

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[36] Narin F. and Breitzman A., "Inventive Productivity," *Research Policy*, (24), 1995, pp. 507-519.

C. Method

From the database of small firm green patents discussed in Chapter IV, we assembled a list of prolific inventors. An inventor is considered prolific if he or she has at least 5 green patents granted in 2005-2009 with a citation index of 1.0 or higher (i.e. the patents have been cited more frequently by subsequent patents than expected given their age and technology). The citation index threshold is used because we do not want to identify inventors as being some way "special" if they have numerous patents, but all are relatively unimportant.

D. Results

In this section, we test the hypothesis that prolific inventors in small green firms will have a strong history of invention or entrepreneurialism. The idea behind this hypothesis is that it seems unlikely that a recent college graduate would be capable of creating five or more patents related to a green technology such as wind turbines, batteries or fuel cells.

Table V.1 shows the 32 inventors from small green firms that have at least five green patents in 2005-2009 with citation indexes above one. Table V.1 also lists various attributes of these inventors, including past employers, total number of patents, and one or two interesting facts that we were able to obtain by looking at bios on their firm websites or via Google or business networking sites like LinkedIn or Spoke.com.

In several cases, the citation indexes of the inventors in Table V.1 exceed two, and in a small number of cases, they exceed five (i.e. the patents of these inventors are cited more than five times as frequently as expected). For example, Brian Sager's 14 nanosolar patents have been cited over five times as often as patents of the same age and technology class. One of his key patents from 2005 (U.S. #6,946,597) titled "Photovoltaic devices fabricated by growth from porous template" has received 33 citations. These citations come from the patents of large companies including 3M, Canon, HP, Intel and Sharp, as well as patents from universities such as Rice, Boston College, and the University of California. What makes the 33 citations so unusual is that the average 2005 peer patent has received fewer than three citations from later patents. Such wide interest from a large variety of companies and universities suggests that the photovoltaic device that Sager has created contains a technological achievement or teaching that others are building upon or building around.

The prolific green inventors from Table V.1 have an impressive list of achievements. For example, there are many cofounders of firms, CEOs, and CTOs on the list. However, in order to test the hypothesis that prolific inventors in small green firms will have a strong background as entrepreneurs or inventors, we need to better quantify these achievements. Table V.2 thus quantifies the achievements of each inventor in Table V.1 in a uniform way, based on six categories of achievements.

Table V.1 Prolific Inventors from U.S. Small Green Firms (2005-2009)

2005-09 US Green Patents	Inventor	Green Firm(s)	Green Citation Index	Previous Firms	Total Patents	Notes
33	Tsukamoto; Hisashi	Quallion LLC	1.92	Japan Storage Battery/GS Yuasa	76	Co-Founder, CEO, CTO of Quallion; Spent 19 years with Japan Storage Battery before co-founding Quallion
24	McElroy; James Frederick	Plug Power Inc.; Bloom Energy	2.39	United Technologies; Plug Power	41	17 patents for United Technologies; Co-Founder and Chief Scientist of Bloom Energy
23	Ballantine; Arne W.	Plug Power Inc.; Bloom Energy	1.53	IBM	78	41 IBM Patents
23	Mollenkopf; James Douglas	Current Group LLC	4.65	CIA, Orbital Sciences Corp	23	CTO Current Group
23	Ren; Xiaoming	Mechanical Technology Inc	1.85	US DOE/LANL; P&G	23	Director of Fuel Cell Technology - Mechanical Technology
22	Kline; Paul A.	Current Group LLC	5.87	Triquint Semiconductors; PC-Tel	33	
19	Berkman; William H.	Current Group LLC	3.35	The Associated Group, Inc., Mobilcom/Nextel	20	Co-Founder Current Group; Co-Founded Mobilcom which was acquired by Nextel; Co-Founder of Teligent; Currently General Partner, Liberty Associated Partners
19	Bertness; Kevin I.	Midtronics Inc.	3.45	TRW	83	Currently CTO; 60 other Midtronics patents (not necessarily green)
17	Cern; Yehuda	Ambient Corp	2.18	Jolt Ltd	23	Currently CEO Sarah Dave Systems
17	Kishiyama; Clay	Quallion LLC	1.60	No Information	17	Currently Senior Battery Engineer at Tesla Motors
17	Nagata; Mikito	Quallion LLC	2.88	Japan Storage Battery/GS Yuasa	17	
15	Gaudiana; Russell	Konarka Technologies Inc	3.23	Polaroid	55	40 patents for Polaroid
15	Gorer; Alexander	Symyx Technologies Inc	1.47	Graduate Student	17	5 pats co-assigned with Honda; Principal Scientist at Intermolecular (a spinoff from Symyx); Founder of Reel-Solar
15	Roscheisen; Martin R.	Nanosolar Inc	5.86	Serial Entrepenuer (Founded E-Groups; Trading Dynamics; FindLaw)	15	Recently Departed as CEO of Nanosolar; Co-Founder
14	Jenson; Mark Lynn	Cymbet Corp	3.95	Honeywell	19	Co-Founded Cymbet after 9 Years at Honeywell; Currently Solumen Corp. Co-Founder & CEO
14	Sager; Brian M.	Nanosolar Inc	5.31	Ernst & Young	14	VP Corporate Development of Nanosolar; Co-Founder
13	Parks; John W.	Plug Power Inc.	1.04	Bechtel: Sr. Engineer	13	Plug Power: Director, Electrical Engineering
11	Gottesfeld; Shimshon	Mechanical Technology Inc	1.08	US DOE/LANL	27	Current CTO at Mechanical Tech.; Led the Fuel Cell Research Program at LANL for 15 years
10	Li; Lian	Konarka Technologies Inc	2.00	U. Mass	10	Konarka created as Spinoff from U. Mass
10	Sridhar; K. R.	Bloom Energy	1.51	U. Arizona	10	CEO and Principal Co-Founder of Bloom Energy; Previously at U. Arizona's Space Technologies Laboratory; Named one of Fortune's Top 5 Futurists
9	Chittibabu; Kethinni	Konarka Technologies Inc	2.20	U. Mass; Sr. Scientist at Molecular Technologies Inc.	9	Co-Founder of Konarka
9	Gottmann; Matthias	Bloom Energy	4.08	U. Arizona	9	Bloom Energy, Chief Engineer; Spent 9 years at U. Arizona Space Technologies Laboratory
8	Nakahara; Hiroshi	Quallion LLC	3.74	GS Yuasa	10	
7	Montello; Alan	Konarka Technologies Inc	2.02	Polaroid; G24i	7	All but one patent co-invented with Edmund Montello
7	Montello; Edmund	Konarka Technologies Inc	1.73	No Information	7	All but one patent co-invented with Alan Montello
7	Radtke; William O.	Current Group LLC	1.57	Broadwing Corp./Level 3 Communications	8	Principal Architect - Current Group
7	White; Melvin Joseph	Current Group LLC	5.62	No Information	7	
7	Yaney; David Stanley	Current Group LLC	5.79	AT&T, Motorola, GM, Allied Signal, Others	9	Current Group CTO, VP of Advanced Development
6	Mitlitsky; Fred	Bloom Energy	5.92	US DOE, Distributed Energy Systems Corp.	13	Principal Engineer - Bloom Energy
6	Pichler; Karl	Nanosolar Inc	4.18	Osram Opto Semiconductors/Siemens AG	18	Current Founder and Owner of Karl Pichler Consulting; 12 Patents for Siemens prior to joining Nanosolar
6	Vonderhaar; J. David	Midtronics Inc.	3.18	Case New Holland	12	Currently with Hendrickson International Corp.

Table V.2 Selected Properties of Prolific Green Inventors

2005-09 US Green Patents	Name	Last Known Firm (Title)	At Least One Prior Job	Prior Job with Large Firm/Govt Agency/ University Lab	Co-Founded Green Firm	Co-Founded Other Firms	Current or Former CEO/CTO/ Chief Engineer/ Scientist of Green Firm	5+ Pats Prior to Green Firm
33	Tsukamoto; Hisashi	Quallion (Co-Founder, CEO, CTO)	✓	✓	✓		✓	✓
24	McElroy; James Frederick	Bloom Energy (Co-Founder, Chief Scientist)	✓	✓	✓		✓	✓
23	Ballantine; Arne W.	Bloom Energy	✓	✓				✓
23	Mollenkopf; James Douglas	CTO Current Group	✓	✓			✓	
23	Ren; Xiaoming	Mechanical Technology (Director Fuel Cell Tech)	✓	✓				✓
22	Kline; Paul A.	Current Group	✓	✓				✓
19	Berkman; William H.	Liberty Associated Partners (General Partner)	✓		✓	✓		
19	Bertness; Kevin I.	Midtronics	✓	✓			✓	
17	Cern; Yehuda	Sarah Dave Systems	✓				✓	
17	Kishiyama; Clay	Tesla Motors						
17	Nagata; Mikito	Quallion	✓	✓				
15	Gaudiana; Russell	Konarka Technologies (VP Research)	✓	✓				✓
15	Gorer; Alexander	Intermoleculary Inc.			✓			
15	Roscheisen; Martin R.	Nanosolar (Co-Founder, CEO)	✓		✓	✓	✓	
14	Jenson; Mark Lynn	Solumen Corp. (Co-Founder & CEO)	✓	✓	✓	✓	✓	✓
14	Sager; Brian M.	Nanosolar (Co-Founder, VP Development)	✓	✓	✓			
13	Parks; John W.	Plug Power (Director Electrical Engineering)	✓	✓				
11	Gottesfeld; Shimshon	Mechanical Technology	✓	✓			✓	✓
10	Li; Lian	Konarka Technologies	✓	✓				
10	Sridhar; K. R.	Bloom Energy (CEO, Principal Co-Founder)	✓	✓	✓		✓	
9	Chittibabu; Kethinni	Konarka Technologies (Co-Founder)	✓	✓	✓			
9	Gottmann; Matthias	Bloom Energy, Chief Engineer	✓	✓			✓	
8	Nakahara; Hiroshi	Quallion	✓	✓				
7	Montello; Alan	Konarka Technologies	✓	✓				
7	Montello; Edmund	Konarka Technologies						
7	Radtke; William O.	Current Group (Principal Architect)	✓	✓				
7	White; Melvin Joseph	Current Group						
7	Yaney; David Stanley	Current Group	✓	✓			✓	
6	Mitlitsky; Fred	Bloom Energy	✓	✓				✓
6	Pichler; Karl	Karl Pichler Consulting, Owner	✓	✓		✓		✓
6	Vonderhaar; J. David	Hendrickson International Corp.	✓	✓				
	Percent of Total		87%	81%	29%	13%	35%	32%

Table V.2 suggests that the hypothesis that prolific small green inventors will have a strong history as inventors or entrepreneurs is supported in terms of invention, but less so in terms of entrepreneurship. Specifically, 32 percent of the inventors with five or more green patents for small firms had five or more previous patents at other firms (and 40 percent of the inventors with 10 or more green patents for small firms had 5+ previous patents). We estimate the probability of a working age adult inventing five or more patents in a lifetime to be 1 percent.[37] Hence, the fact that 32 percent of the inventors in Table V.2 have done so before joining a green firm, and then done so again during their tenure at a green firm, suggests that these individuals form a select group in terms of invention history.

The other half of the hypothesis—strong entrepreneurial histories—is not supported based on the number of other firms cofounded. Four individuals in Table V.2 have founded firms other than their green technology firm. Of these four, only Martin Roscheisen seems to be a true serial entrepreneur. William Berkman cofounded a series of companies prior to the green energy company, but it appears that this may have been as a private equity investor. The others who have cofounded firms have done so after founding a green firm, so they did not have a history of founding firms before founding their first green company.

Hence, while the hypothesis that prolific green inventors would have a strong history of invention and entrepreneurialism is not fully supported, the idea behind it appears sound. This idea is that college training alone would be unlikely to be sufficient for an individual to make an extensive impact within green technology. Table V.2 illustrates that the select group of 32 individuals with at least five patents for small green firms have tended to have very impressive and varied careers. Specifically, 87 percent had a prior technical job before joining or cofounding the small green firm, and 80 percent worked for large firms such as IBM or United Technologies, or large labs like the Los Alamos National Laboratory or the University of Arizona's Space Technologies Lab. Many of these inventors have subsequently cofounded a green firm or act as a C-level (CEO, CTO, Chief Scientist) executive at a small green firm. To further illustrate the impressive and varied careers that led to individuals founding or joining small green firms, it is worth sketching out brief biographies for some of these individuals.

K.R. Sridhar is the Principal Co-Founder and CEO of Bloom Energy, a fuel cell firm that hopes to power homes and businesses with its "Bloom Boxes." Bloom has been featured in *Newsweek*, *Forbes*, and *Business Week* and was profiled recently in the CBS *60 Minutes* program. Prior to founding Bloom, for nine years Dr. Sridhar was director of the Space Technologies Lab (STL) at the University of Arizona. He was also a professor of aerospace and mechanical engineering at the university. Under his leadership, STL won several nationally competitive contracts. His work for the NASA Mars program involving conversion of Martian atmospheric gases to oxygen for use in propulsion and life support was recognized by *Fortune*, where he was cited as one of the top five futurists who are inventing tomorrow, today. He has nine patents for Bloom Energy, and his Bloom Boxes have been purchased for electricity generation by Google, EBay, Coca-Cola, Wal-Mart, FedEx, and many other large well-known firms.[38]

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[37] The 1% figure is based on the following estimates. Approximately 260,000 U.S. named inventors were granted patents in 2009. Over a 40-year period that gives us an upper bound of at most 11 million U.S. inventors with 1+ patent (the actual number is probably well below that). By Lotka's power law (see Narin F. and Breitzman A., "Inventive Productivity," *Research Policy*, (24), 1995, pp. 507-519) we can expect approximately 1/25 as many inventors with 5+ patents in the 40 years, giving us an upper bound of 440,000 U.S. individuals with 5+ patents. There were approximately 165 million working age adults in 2000 and an additional 162 million will reach working age in the next 40 years, but even if we use a much smaller figure like 200 million as a lower bound, the probability that a person picked at random will create 5+ patents is only about 0.2%.

[38] Retrieved from http://www.bloomenergy.com/about/ August 19, 2010.

Martin Roscheisen is a serial entrepreneur. He makes it into our study because he cofounded and became CEO and Chairman of Nanosolar, the first Silicon Valley energy firm focused on making solar power broadly affordable. Prior to Nanosolar, Mr. Roscheisen had founded a variety of successful firms. In 1995, he cofounded FindLaw. This became the most widely used Internet legal site, making U.S. legal decisions easily accessible to the public. FindLaw was sold to Thomson's West Group. In 1997, Mr. Roscheisen cofounded TradingDynamics, an enterprise software company, which was acquired by Ariba for $740 million. In 1998, Mr. Roscheisen became CEO of eGroups, an email messaging company, which was financed by Sequoia Capital and ultimately acquired by Yahoo in a transaction valued at $450 million. In 2003, *Fortune* named Mr. Roscheisen as one of the United States' Top Ten entrepreneurs under the age of 40.[39]

James Mollenkopf was, until September 2010, the CTO of the Current Group, a smart-grid firm for which he had 23 granted patents. Most of his patents are for methods of communicating over power lines, which is necessary for smart metering technology. His 2006 patent, U.S. #6,998,962 entitled "Power line communication apparatus and method of using the same" has 42 citations in a technology where the average patent of a similar age has less than four. Prior to joining Current, Mr. Mollenkopf worked at Orbital Sciences where he led the communications system design team for the Orbcomm space segment. Before joining Orbital, he served for 11 years with the Central Intelligence Agency in a variety of technology development positions.[40]

Table V.2 thus contains a number of high achievers who are working in green energy within small firms. The common denominator for these individuals tends to be a strong technical background, but not necessarily an entrepreneurial background. Most of these individuals come from large organizations, and are likely to have had successful careers if they stayed at those large organizations. For some reason they moved to (or cofounded) small firms, and were then responsible for a series of green innovations within these firms. This is in line with the creative destruction that the economist Joseph Schumpeter spoke of in 1942.[41] in which individuals leave good jobs at large organizations in order to found small firms built around a key idea. This is one of the supposed strengths of the U.S. economy.

This raises two interesting questions. The first is whether these individuals would have been able to develop their high-impact green technologies with their former firms, or whether the small business model was an important component. The second question is whether this pattern of leaving large organizations to found small firms would happen extensively in economies outside the United States, or whether the culture of the entrepreneur is a particular feature of the U.S. system. Both of these questions are beyond the scope of this study, but it is clear that the U.S. economy depends on the ability of creative people to launch small high-tech firms based on a good idea. This is particularly true given the results from Chapter IV, which showed that small firms are particularly effective as incubators of emerging technologies such as green energy.

[39] Retrieved from http://en.wikipedia.org/wiki/Martin_Roscheisen August, 19, 2010.
[40] Retrieved from http://www.currentgroup.com/management.php August 19, 2010.
[41] Joseph Schumpeter, *Capitalism, Socialism and Democracy* (New York: Harper, 1975) [orig. pub. 1942].

E. Conclusion

In this chapter we examined prolific inventors within small green technology firms. We identified individuals who had five or more recent green patents with a citation index of at least one. These individuals were found not only to be prolific inventors, but also high achievers in other aspects of their careers. Many have founded or run green energy firms after having careers at large firms in other industries. The policy relevance of this finding is that, although we do not fully understand the mechanisms through which individuals decide to leave good jobs at large firms to launch startup companies, such behavior should be encouraged. This is especially true since small firms have been shown to be good incubators for emerging and green technologies.

VI. Closing Summary

Overall, the findings of this report reinforce those from our earlier reports (SBA 1-3), namely that small firms participate extensively in the patent system, they produce large numbers of patents relative to their size, and these patents tend to have very strong quality metrics.

The main body of this report consists of four somewhat self-contained sections. The first section describes the construction and content of a database of innovative firms. The second section then analyzes how the content of this database compares with the content of similar databases constructed for earlier projects in this series. The other two sections are focused specifically on green technologies. They examine the role of small firms in the development of these technologies, and highlight the importance of key inventors within this development.

The key resource developed for this project is a database of innovative firms described in Chapter II. The database contains all firms with 15+ patents issued between 2005 and 2009. There are 1,279 firms in the database, which are referred to as ‘innovative firms’ because of their high level of patent activity. These firms were researched further in order to identify small firms (those with 500 or fewer employees) and large firms (those with more than 500 employees). In total, we identified 532 small firms and 728 large firms, plus 19 firms where no employee information could be identified (these latter firms are very likely to be additional small firms).

Given the difficulty and expense of filing patents, it is somewhat surprising that a full 42 percent of U.S. innovative firms (that is, those with 15+ patents in the last 5 years) are small firms with 500 or fewer employees. Perhaps even more surprising is that 57 percent of all the firms, and 29 percent of the small firms, in the database are publicly listed on major U.S. exchanges (i.e. not including companies whose stock is traded over the counter). We estimate that fewer than 0.1 percent of all firms are publicly traded on major U.S. exchanges. The large share of publicly traded firms in the database for this project is therefore notable. It suggests that firms of all sizes with patented technology are more likely to become successful enough to go public than firms that do not produce patents.

In Chapter II, we also reconfirmed a result from one of our earlier SBA studies, where we showed that small innovative firms are much more productive than large innovative firms from a patents-per-employee perspective. Specifically, in SBA1 it was shown that small innovative firms outperform their large counterparts 13 to 1 in terms of patents per employee. In the updated database for the current project, the difference in patents per employee has now risen to 16 to 1 in favor of small innovative firms versus large innovative firms (27 patents per 100 employees, versus 1.6 patents per 100 employees).

Small innovative firms in the database also outperformed their larger counterparts on a variety of patent quality metrics. Patents of small firms are cited 79 percent more frequently by recent patents than is typical for patents of the same age and patent classification. Meanwhile, patents of large innovative firms are cited just slightly above average. Small firms in the study also outperformed large firms in patent generality, originality, and patent growth. Numerous validation studies have shown a relationship between patent metrics and positive outcomes such as inventor awards, licensing revenue, increases in sales and profits, etc.

As mentioned previously, much of this study is based on a carefully constructed database of U.S. firms with 15+ granted U.S. patents in 2005-2009. We constructed a similar database for an SBA project completed in 2008 (SBA3). That database was based on U.S. patents granted in 2002-2006. Chapter III is devoted to discussing similarities and differences between the databases from these two periods. One of the key findings is that 42 percent (224 of 532) of the small innovative firms in the current analysis are new entrants and were not part of the earlier analysis. That is, more than four in ten of the small firms in this study either did not exist, or did not patent significantly, in the five years ending in 2006.

In total, there are 28 more small firms in this study than there were in the previous study. With 224 new small firm entrants, one might expect more small firms to be in the current analysis. However, small firms are at greater risk than large firms of falling short of various criteria for retention in the database. For example, episodic patenting is characteristic of firms with low patent output, and 32 percent of the small firms are very close to the 15 patent threshold, in that they have 20 or fewer patents (fewer than 10 percent of the large firms have 20 or fewer patents). Smaller firms are also more likely to increase employment and pass the 500 employee mark, or to be acquired by larger firms.

Perhaps surprisingly, 37 large firms from the previous SBA3 database dipped below 500 employees and became small innovative firms in the current study. This may be due in part to the effects of the 2008 recession. Also, only 34 small firms from the SBA3 study have been acquired since completion of that study, compared with 87 acquisitions between SBA2 (the previous study in this series) and SBA3. The recession may thus have had an effect on small firm acquisition as well.

In spite of the recession, the innovative firms in the database have actually performed well on average. The small firms in the current study have revenues averaging \$46.5 million per year. This compares favorably with their cohort set from SBA3, which averaged \$39.4 million per year. Large innovative firms have also performed well, with average sales increasing from \$7.4 billion to \$8.4 billion in the same period.

Chapter IV of the report examines patenting of green technologies by small and large U.S. firms, and by foreign organizations. This analysis reveals that U.S. organizations were responsible for 43 percent of U.S. patents in green technologies in 2005-2009, while Japanese organizations had 32 percent of these green U.S. patents. No other countries had more than 6 percent of the patents. While the United States owns more green patents than other countries, the lead is smaller than expected. In all technologies, U.S. inventors are responsible for approximately 50 percent of granted U.S. patents, followed by Japanese inventors with 20 percent, and all other countries combined with the remaining 30 percent. The lower than expected percentage of U.S. invented patents in green technologies could mean that the United States has less emphasis on green technologies than it does on other technologies, while the opposite is true for Japan. Alternatively, one could argue that Japanese inventors are overachieving in green technologies, with the U.S. underachieving to some degree.

Chapter IV also reveals the importance of green innovations to small innovative firms. There are four times as many large innovative U.S. firms with at least one green patent as there are small innovative U.S. firms with at least one green patent. However, green patents form a much lower percentage of these large firms' portfolios than the small firms' portfolios (1.5 percent on average for large firms, versus 20 percent for small firms). There are also several small firms whose patent portfolios are almost entirely green, which is not the case for any of the large firms. It thus appears that many small firms are building their business around green technologies, while large firms are largely enhancing product lines with green technologies. For example, the business models of small firms like Bloom Energy, The Current Group, and Valence Technology are based solely on green technologies. This is in contrast to General Motors and Toyota, who are patenting in batteries, fuel cells, and hybrid systems, but whose green efforts are only one element of their overall business.

Small firms also patent more frequently than expected in several green subcategories, and in green technology in general. Overall, small firms account for approximately 8 percent of all patents in the U.S. innovative firm database. However, in both smart grids and solar energy, small firms account for more than 32 percent of the patents. Small firms also account for more than 15 percent of the patents in batteries and fuel cells. In all green technologies combined, small firms account for 14 percent of the patents, almost twice as many as one would expect given the overall level of small firm patent output.

In addition, small firms tend to have strong patent metrics in the green subcategories in which they are active. Specifically, on average, green patents from small firms are cited 2.5 times as frequently as green patents from large firms. This suggests that small firms are inventing important green technologies, and also that these firms tend to only file patents on their significant green inventions.

The results in Chapter IV thus suggest that small firms are particularly active in green technologies, that these technologies are often core to their business, and that they tend to patent their most important green innovations. Small firms, or firms that have recently graduated from small to large status, may thus be a particularly likely source of future breakthroughs in green technology.

Chapter V contains an analysis of prolific inventors within small green technology firms. We identified 32 individuals who had five or more green patents for a small firm between 2005 and 2009 with a citation index of 1.0 or more. These individuals were not only prolific inventors, but they also tended to be high achievers in other aspects of their careers. For example, 35 percent of these prolific inventors are now C-level (CEO, CTO, Chief Scientist) executives at small green firms, and nearly 30 percent are cofounders of green firms. Also, about 80 percent of the prolific green inventors had previously worked for large firms, and 30 percent of them had at least five patents for those firms prior to joining a small green firm.

This finding suggests that it is difficult to train a person at a university to be a green entrepreneur, since most of these individuals had successful careers prior to joining or founding green firms. The policy relevance of this finding is that, although we do not fully understand the mechanisms through which individuals decide to leave good jobs at large firms to launch startups, there is a need to cultivate such behavior and support it. As the results of this project show, small firms tend to be particularly good incubators for emerging technologies such as green energy. Hence, one strength of the U.S. economic system that should be encouraged is the ability for creative people to leave the security of large firms in order to launch small green technology firms.

As noted, the findings of this report reinforce those from our earlier reports (SBA 1-3). This project also extends those earlier reports to reveal the prominence of small firms in the development of green technologies. Small firm patents tend to have stronger performance metrics in green technologies than large firm patents, and there are a number of small firms whose entire business is built around green technology, which is not true for any of the large firms in this analysis.