Globalization Alters Traditional R&D Rules

The international R&D community has more than new technologies to consider when evaluating how it structures itself, including how to interact with brand new high-tech players.

The examination of the changing dedication to R&D on a global scale is an essential component in understanding the R&D structure and practices now occurring within the U.S. and other technologically developed countries. Indeed, it has become well established that the expansion of R&D activities—especially in China, India, and other countries of Eastern and Southern Asia—cannot be viewed as isolated events.

Major changes in government attitudes and approaches in these countries have sparked a significant escalation in R&D activities. Direct government investments, for example, have been made in an effort to enhance the countries' economic and/or military strengths. General liberalization of the economies has led to an environment where private investment and expansion have been encouraged. In addition, regulations relative to economic development and foreign investment and ownership have been modified in several technologically developing nations to the point where foreign industry has begun to take advantage.

Superposed on all of these actions—and directly related to them—major emphasis has been directed toward development of a highly-educated, technology-oriented population that can provide an immense source of support in the pursuit of technology-based economic development.

The combination of all of these factors has made a major difference relative to the way in which industry from all over the globe has developed relationships with the R&D community of

Global R&D Spending

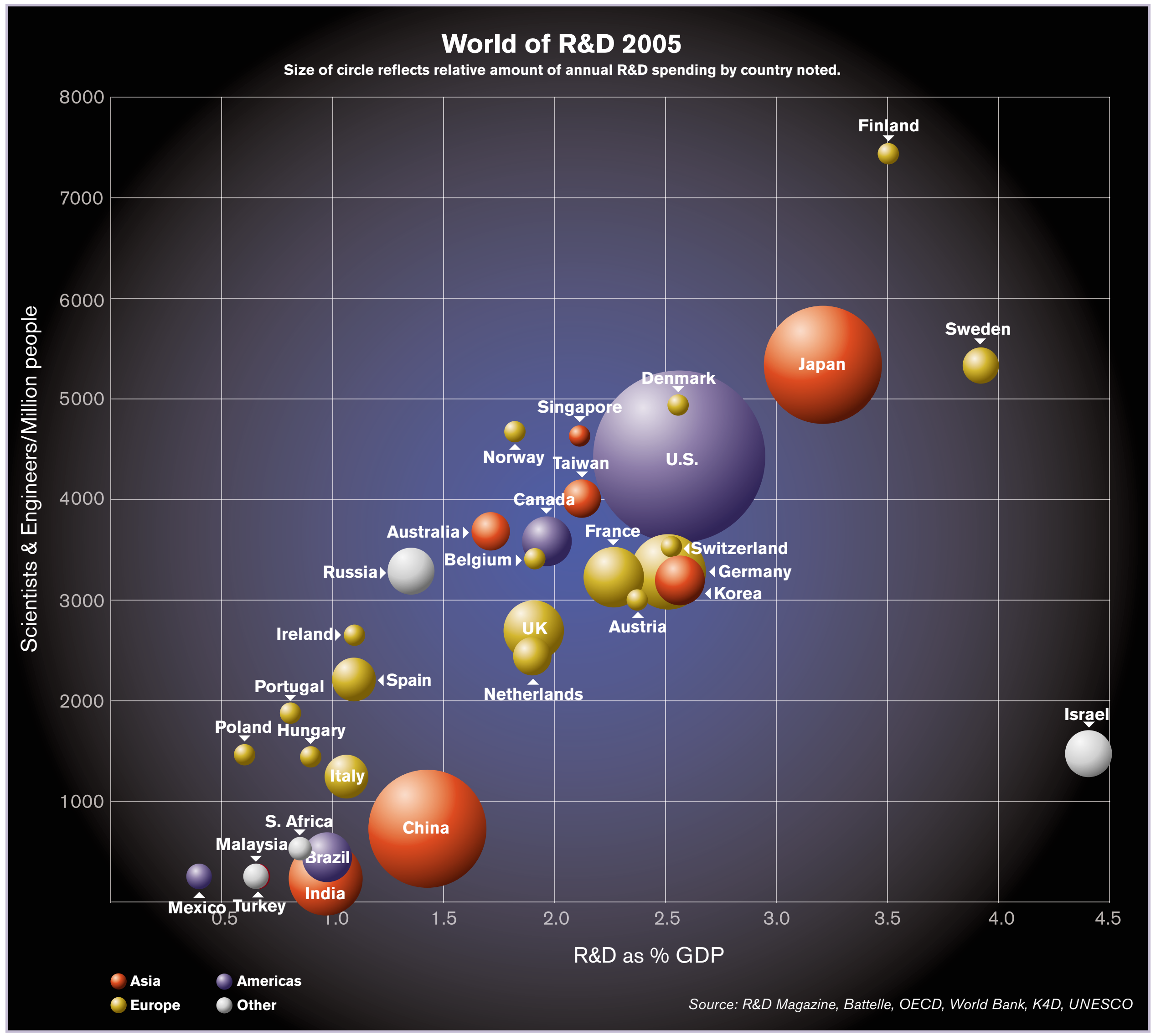
	GDP PPP 2005 billions, $	R&D % GDP 2005 percent	R&D PPP 2005 billions, $	R&D PPP 2006 billions, $	R&D PPP 2007 billions, $
Americas	15,874	2.3	369.07	379.69	387.64
U.S.	12,192	2.6	319.60	328.90	335.50
Asia	19,086	1.8	341.30	361.85	384.01
China (Mainland)	8,859	1.4	124.03	136.30	149.80
Japan	3,890	3.2	124.48	127.84	131.29
India	3,611	1.0	36.11	38.85	41.81
Europe	12,764	1.8	236.09	240.16	244.42
Germany	2,388	2.5	59.68	60.21	60.75
France	1,879	2.2	41.36	42.10	42.86
UK	1,933	1.9	36.72	37.39	38.06
Other	2,276	1.4	31.88	33.76	35.68
World	50,002	2.0	978.34	1,015.46	1,051.75

Share of Total Global Research and Development

	2005	2006	2007
Americas	37.7%	37.5%	36.8%
U.S.	32.7%	32.4%	31.9%
Asia	34.9%	35.6%	36.5%
China	12.7%	13.4%	14.8%
Japan	12.7%	12.6%	12.5%
India	3.7%	3.8%	4.0%
Europe	24.1%	23.6%	23.2%
Germany	6.1%	5.9%	5.8%
Other	3.3%	3.3%	3.5%
World	100.0%	100.0%	100.0%

Source: R&D Magazine, Battelle, OECD, World Bank these expanding countries. This interaction has grown from a casual "testing-the-waters" approach with preliminary contract research arrangements to, what have now become, major investments in institution building, the creation of new subsidiary operations, and the development of a wide range of joint ventures.

As a result of the changing opportunities for R&D activities in different countries, including the more "traditional" partnering arrangements in Western Europe and Japan, it is apparent that the modifications in the internal policies of East and South Asia, in particular, have had and will continue to have, an influence on the amounts



The changing and growing availability of talented and highly educated work forces has created a new and accelerating mode of international competition, one that will have an impact on both the developed and developing nations. In the period following World War II, major competition between countries was driven by arms races, which were fueled by having "reliable enemies." Later years witnessed efforts to enhance cooperative economic benefits through manufacturing and assembly operation, thus leading to a competitive hands race providing lower cost manual labor.
The third wave of this internationalization has evolved into a heads and brains race in the development and application of technology to the resolution of research problems and opportunities. It is tempting, and certainly most reasonable, to acknowledge the fact that each of these races has involved a reliable adversary, one which continues to present challenges that can be met and conquered or accommodated only by long-term strategic investment and will.

and patterns of R&D performance in the U.S. and other nations.

In spite of the fact that there are very significant changes that are influencing the patterns of spending on R&D, and that there are evolving trends in R&D support and performance, one must also look at the manner in which such trends are sustainable. Are we witnessing a massively changing paradigm or a temporary experiment? Will there be a significant long-term disruption or merely a spate and spurt, to be followed by an assessment and readjustment?

This report looks at these concerns and further outlines the global R&D landscape and the impact that actions taken by U.S. companies has had.

Offshore collaborations

Over the past few years, the practice of offshore collaborations has increased considerably. Although detailed statistics on the amount of this effort have not been published on a continuous basis, early studies by the Dept. of Commerce (DOC) highlighted the strong and growing tendency for U.S. companies to support R&D in their own subsidiaries in Western Europe and Japan.

These detailed studies were confined to the interactions within the individual corporate structures and did not get into what has now become one of the more visible forms of R&D performance—that with independent institutions. Furthermore, the DOC work could not take into account the extent to which the practice has become a significant part of corporate operations. In addition, the DOC examination did not venture deeply into ancillary issues related to the rationale behind the decision (of U.S. companies) to use this approach for acquiring technological assets or the extent to which the process met its goals.

As a part of the continuing study on R&D processes and the changing patterns of support and performance, the 2007 version of the *Battelle/R&D Magazine* series on Trends in Global R&D addresses selected aspects of

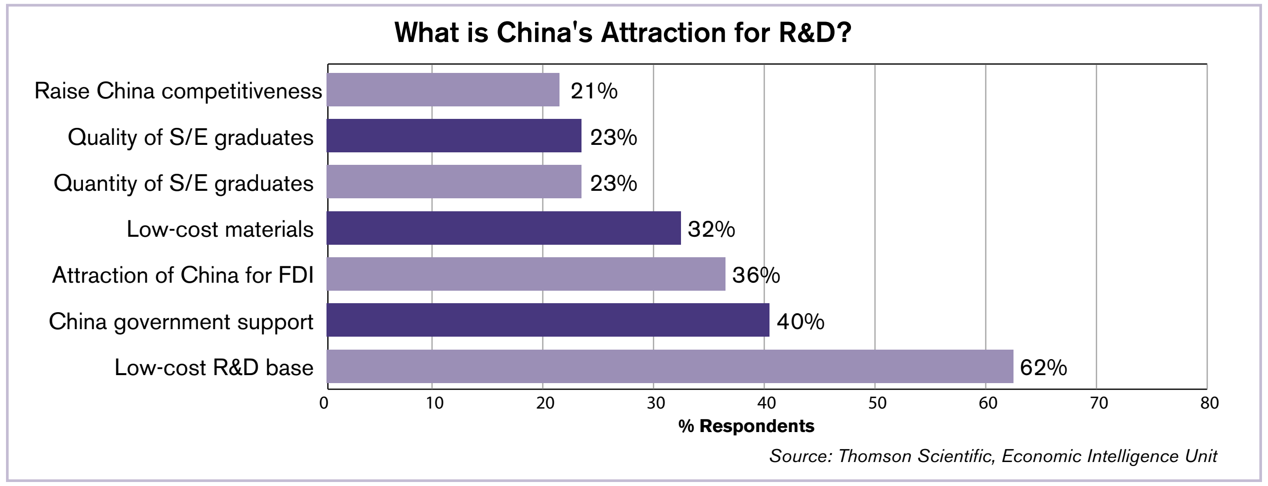
Global Research and Development Spending

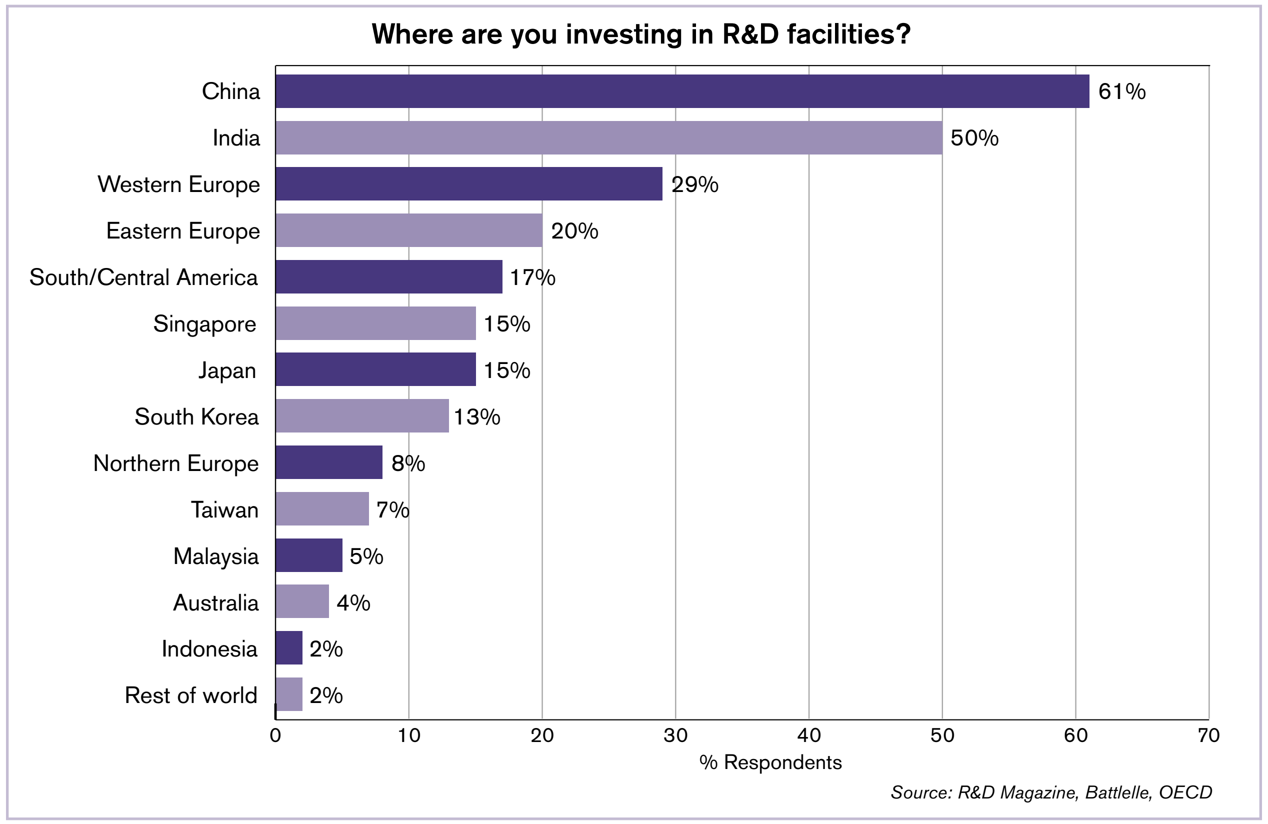
	GDP PPP 2005 billions, $	GDP Growth 2004-2005 percent	R&D % GDP 2005 percent	R&D PPP 2005 billions, $	R&D PPP 2006 billions, $	R&D PPP 2007 billions, $
Australia	629.1	2.5	1.7	10.70	11.00	11.29
Austria	265.2	1.9	2.3	6.10	6.22	6.34
Belgium	330.7	1.5	1.9	6.93	7.08	7.25
Brazil	1556.0	2.4	1.0	24.44	25.03	25.63
Canada	1033.9	2.9	2.0	20.66	21.26	21.88
China (Mainland)	8859.0	9.9	1.4	124.03	136.30	149.80
China (Taiwan)	631.5	3.0	2.2	13.89	14.42	14.97
Denmark	175.0	3.4	2.6	4.55	4.66	4.77
Finland	165.8	2.2	3.5	5.80	5.98	6.16
France	1879.9	1.4	2.2	41.36	42.10	42.86
Germany	2388.6	0.9	2.5	59.68	60.21	60.75
Hungary	168.0	4.1	0.9	1.51	1.57	1.64
India	3611.0	7.6	1.0	36.11	38.85	41.81
Ireland	152.3	4.7	1.1	1.68	1.75	1.84
Israel	154.5	5.2	4.5	6.95	7.31	7.69
Italy	1629.5	0.1	1.1	19.55	19.58	19.65
Japan	3890.0	2.7	3.2	124.48	127.84	131.29
Korea (South)	1051.5	3.9	2.6	27.33	28.39	29.50
Malaysia	290.2	5.3	0.7	2.03	2.14	2.25
Mexico	1092.1	3.0	0.4	4.37	4.50	4.63
Netherlands	514.7	1.1	1.9	9.78	9.89	10.00
Norway	182.9	3.9	1.8	3.29	3.42	3.56
Poland	508.4	3.2	0.6	3.05	3.15	3.25
Portugal	206.0	0.3	0.8	1.85	1.86	1.87
Russia	1589.0	6.4	1.3	20.66	21.98	23.30
Singapore	124.3	6.4	2.2	2.73	2.91	3.10
South Africa	533.2	4.9	0.8	4.27	4.47	4.69
Spain	1124.6	3.4	1.1	12.36	12.78	13.22
Sweden	283.5	2.7	3.9	11.04	11.33	11.64
Switzerland	255.5	1.8	2.6	6.63	6.75	6.87
Turkey	601.0	5.6	0.7	4.21	4.44	4.69
UK	1933.3	1.8	1.9	36.72	37.39	38.06
U.S.	12192.6	3.5	2.6	319.60	328.90	335.50

Source: R&D Magazine, Battelle, OECD, World Bank the practices of offshore outsourcing. Using a relatively straightforward survey instrument, selected questions were raised to the readership of *R&D Magazine* relative to the rationale for pursuing offshore collaborations, the extent to which this process had returned expected results, the various exceptions of areas of comparable technological strengths, and associated issues. Selected results of the random survey were drawn upon and will set the stage for more detailed formalized research and analysis papers.

Issues and observations

For the most part, it is difficult to "set in stone" conclusions regarding the outcomes or the satisfaction level of the outsourcing experiment. The responses are generally across the board in terms of the fields of businesses and the





Strength, Growth, and Stability in the Global Top Three

The U.S. has been the global leader in overall R&D spending, performance, and achievement for more than 25 years. Even with all of the globalization effects and R&D outsourcing currently taking place, that status is not likely to change in the foreseeable future. Japan has been a strong number two in R&D investments during this same period, closely tracking at about 41% to the 45% of the U.S.'s R&D spending.

Over the past several years, however, this "dynamic R&D duo" has been joined by China, whose R&D growth over the past several years has been nothing short of fantastic.

Current Statistics

Average annual increases in R&D investments over the past 12 years have roughly ranged between 4% and 5% for the U.S., Japan, and the EU-25 (25 European countries). This has contrasted sharply with the 17% annual growth in R&D spending for China, which has accelerated over the past five years; registering in excess of 20% average annual increases (real dollars).

In PPP (purchasing power parity) exchange rates, China's R&D investment actually equaled that of Japan in early-2006, and is expected to far surpass it in upcoming years. China's R&D investment over the past several years has similarly grown as a percent of its GDP (gross domestic product) from less than 1.0% to nearly 1.6% now. This, however, is a long way from the 2.6% of GDP that the U.S. invests and still further from the 3.2% of its GDP that Japan continues to invest.

China's rapid advance on the R&D investments of both the U.S. and Japan is unprecedented in recent history. These figures are underscored by the growth of China's industrial research workforce, which expanded from 16% of those in the U.S. in 1991 to 42% in 2002. The number of U.S. industrial researchers (1.1 million) is roughly equal to the number of industrial researchers in all of the other 29 OECD (Organization for Economic Cooperation and Development) countries.

Japan's Turnaround

During most of the 1990s and the early-2000s, the Japanese economy languished and actually saw negative growth. While its R&D investments continued to grow during this period, the growth rates were suppressed by its economic difficulties. During this period, the U.S., China, and other Asian economies shifted into high-technology manufacturing sectors more rapidly than either the EU-15 or Japan. As a result, Europe and Japan continue to lose market share in the high-tech manufacturing arena.

Japan's recent economic expansion began in 2002 and is expected to continue through at least 2007, underpinned by improving labor markets and accelerating exports. However, as Japan emerges from this period of economic stagnation, there are internal challenges to its R&D strategies to maintain its overall growth. Recommendations to Japan's Ministry of Economy, Trade and Industry by the OECD include:

- Focus on increasing efficiency in R&D spending rather than meeting a specific spending level
- Maintain flexibility in allocating public R&D funds
- Attach greater importance to non-manufacturing R&D
- Focus on support of R&D for new start-ups
- Strengthen international links

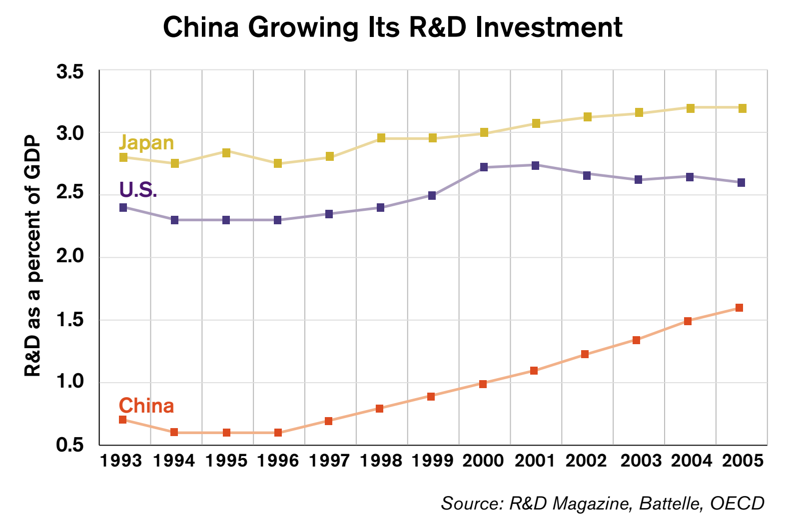
Outsourcing R&D; The China Connection

U.S. industry is looking heavily into outsourcing at least part of its R&D activity, according to recent surveys by *R&D Magazine* and others. Analyses are currently under way by many organizations to determine the appropriate amount of R&D that should be outsourced to maintain core technology capabilities in the U.S., while taking advantage of the benefits offered in offshore outsourcing (see attached survey charts for benefits of offshore outsourcing).

China is by far the primary choice for offshore R&D outsourcing. India is a prime source for computer and software R&D outsourcing, but even here China is making inroads to become more competitive. Gartner reports that both India and China will generate $27 billion in software outsourcing in 2006. All told, Chinese government incentives, infrastructure, academic relationships, and scientific capital investments continue to draw interest from the international R&D community.

China's government has a long-term goal to address all aspects of R&D across all technology sectors. They continue to support both internal growth and science and technology partnerships with all countries. Their overall strategy is to build their technological capabilities in whatever method they can, recognizing that they are starting from a lower point than most other countries. This strategy has worked quite well over the past several years, with substantial growth seen across the board in life and physical sciences, engineering, software development, materials sciences, and theoretical physics.

China's researchers are regularly recognized for their technological discoveries and achievements, their intellectual property (in terms of patents) continues to increase, and they continue to be a source of attraction for major science and engineering conferences. Their manned space program has gained professional credibility and their long-term dedication to meeting technical schedules in backed up by the financial growth and health of their economy.



Top 20 R&D Spending Global Companies

	Company	Location	Sales 2005 billions, $	R&D 2005 billions, $	R&D 2006 billions, $	R&D 2007 billions, $
1	Pfizer, Inc.	U.S.	51.4	9.09	9.82	10.61
2	Toyota Motor Corp	Japan	185.8	8.36	8.94	9.40
3	Ford Motor Co.	U.S.	177.2	8.00	7.80	7.60
4	Microsoft Corp.	U.S.	39.8	7.01	7.50	8.03
5	General Motors Corp.	U.S.	192.6	6.70	7.02	7.34
6	DaimlerChrysler AG	Germany	186.1	6.67	7.06	7.17
7	Johnson & Johnson	U.S.	50.5	6.67	7.34	8.00
8	Siemens AG	Germany	100.1	6.35	6.52	6.70
9	Sony Corp.	Japan	66.0	5.77	6.24	6.71
10	GlaxoSmithKline PLC	UK	39.4	5.39	5.84	6.13
11	IBM Corp.	U.S.	91.1	5.38	5.58	5.77
12	Intel Corp.	U.S.	38.8	5.14	5.00	5.00
13	Matsushita Electric Ind.	Japan	78.6	5.09	5.22	5.35
14	Novartis AG	Switzerland	32.2	4.85	5.39	5.96
15	Volkswagen AG	Germany	118.4	4.83	5.17	5.53
16	Sanofi-Aventis	France	35.4	4.79	5.25	5.85
17	Honda Motor Ltd.	Japan	87.5	4.57	4.75	4.94
18	Nokia Corp.	Finland	42.5	4.53	4.84	5.17
19	Roche Holdings Ltd	Switzerland	28.5	4.34	4.73	5.11
20	Hitachi Ltd.	Japan	83.6	4.02	4.23	4.45

Source: Schonfeld & Associates, Inc., R&D Magazine, Battelle

amount of time that the process has been in place. It would be expected that the responses, and thus the shape of the distributions, would be different were there to have been discrimination with respect to the period of time over which the period of performance was chosen. In addition, one would expect that there would be significant differences among the lines of business, the issue of captive or independent performers, and the nature of the R&D work being performed.

Random, and uncontrolled, surveys of selected clusters of the technical community are certainly not expected to provide the kinds of rigorous data that are best suited to detailed analyses, any more than the random "man on the street" surveys undertaken on any issue of public concern.

However, there are various perceptions that can be elicited from a voluntary survey of a selected group that can aid in shaving off the rough edges of opinions and provide a reasonable assessment of preferences, trends, reactions, and the like. So it is with the random survey conducted within the readership of *R&D Magazine*, where questions were raised relative to the comparative strengths and weaknesses of various national technology capabilities, and where various issues relative to the outsourcing experience were queried.

It is instructive, in the context of this report, to isolate and discuss a few of the pertinent points of this survey, for they provide a baseline from which to develop a more precise survey instrument and a setting within which one can analyze the outsourcing mode of operations.

Issues and insights

The open literature is replete with accounts of new relationships that are developing between U.S. companies and their counterparts or collaborators or subsidiaries in many different countries. Internet searches on topics related to R&D outsourcing to a number of different countries reveals that this single topic has been dominant over the past few years.

Greater numbers of deals have been struck between U.S. multinationals and their partners or subsidiaries throughout the world, with emphasis on China and India. In addition, a smaller—yet potentially quite significant—amount of attention is being given to Europe and Latin America as sites for future collaboration. In no small measure, the R&D investment is, or will become, a significant portion of the total R&D expenditures in facilities that are located in these so-called "partnering" countries, and is expected to be a major force that affects R&D patterns in both the donor and recipient countries.

That such should be the case can be understood in terms of a number of different driving forces, not the least of which include the growing availability of talent, the costs of doing business, and the changing internal policies of the host countries. The emergence of offshore outsourcing (a practice which has been a part of R&D performance and management for many years) has been accompanied by a variety of expectations.

Although viewed as a relatively recent phenomenon, the support of offshore R&D has been part of standard business practices for more than 20 years. If one were to confine this review to just the past two decades, it would be quickly noted that relations between U.S. companies and their collaborating institutions in India, for example, predate the present, highly visible efforts by at least 20 years. Case in point, U.S. software and chemical companies were obtaining research services in the late 1980s, in many cases using the opportunity to either supplement traditional work or to merely "test the waters" in terms of learning how the process could work.

The recent *R&D Magazine* survey addressed the question of expectations related to the decision to engage in offshore outsourcing. (Note that no distinction is made here among the three types of approaches: (1) support of R&D in pre-existing manufacturing or marketing facilities; (2) the establishment of facilities that are specifically developed for the purpose of conducting R&D on behalf of the parent corporation; and (3) the contracting with independent sources of R&D support, including academia and private laboratories that may serve a broad spectrum of clients.)

The establishment or utilization of an R&D capacity in connection with foreign markets had long been seen as a means to overcome a variety of [real or potential] barriers. Anecdotal discussions with a variety of participants in the activity reveal that the decision to expand the R&D role was based on various factors:

(1) localized technical support provided a means for quickly addressing problems or opportunities associated with the existing or planned manufacturing and marketing operations;
(2) it was necessary for local practices and activities to be cognizant of, and adapted to, local regulations, cultures, habits, and tastes;
(3) local operations may be influenced by local differences in resources, infrastructure and materials; and
(4) the establishment of "ancillary" R&D facilities may have been one of the conditions imposed in the local licensing and permit-granting process

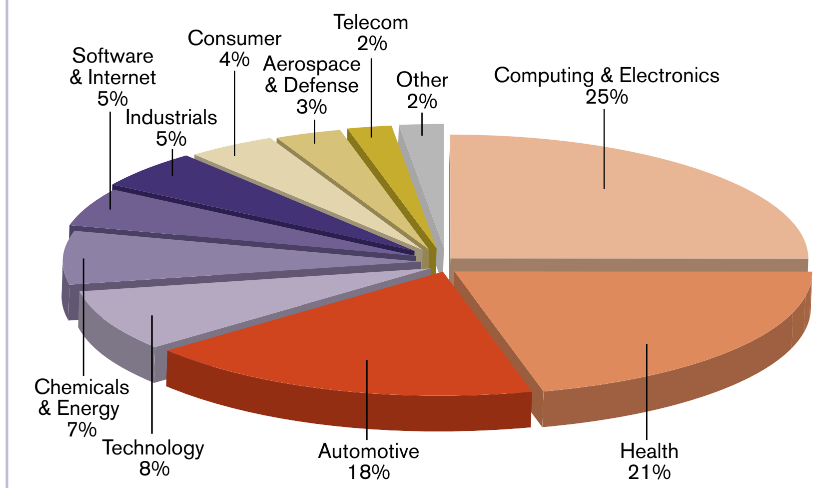
Superposed on these, and other, generalized descriptions of the rationale for establishing offshore R&D are the results of the *R&D Magazine* survey. When addressing the question of the values that were expected from outsourcing, the respondents, sometimes providing multiple answers, noted raw responses in order:

Percent of respondents

Improved R&D cost effectiveness	38.8
Increased competitiveness	31.4
Global R&D infrastructure	28.9
Increased overall R&D capabilities	26.4
Building new markets	26.4
Global R&D teamwork	23.1
Offshore manufacturing support	20.7
Increased R&D productivity	20.7
Faster response times	19.8
24/7 R&D capabilities	19.8
Customer support	14.0
Increased innovativeness	14.0
More overall flexibility	9.9

It's apparent that one of the more important features of offshore outsourcing is directly or indirectly related to the basic cost of doing business. The improved cost effectiveness is a direct reference to the lower costs that apply in most areas, especially the emerging countries of China and India. Furthermore, lowered direct costs enhance the competitive position vis-à-vis other (usually domestic) resources and, hence, lead to measures of higher productivity.

Global Industrial R&D Distribution



Source: Booz Allen Hamilton

It is further apparent that there has been an expectation of enhanced overall R&D capabilities, especially in those cases where new technologies—those that may lead to the development of platforms for innovation and new product lines—are more readily available without the direct investment in physical and human capital. Outsourcing is expected to provide a more rapid entry into new markets, processes, or products.

At first glance, it would appear that the relatively lower score given to the customer support aspect of offshore outsourcing is a bit counterintuitive. However, this score is apparently more reflective of the view that offshore R&D is directed more toward supporting the company's own offshore operations, such as in manufacturing and distribution, rather than as direct support to the external consumers of the company's output.

Satisfaction results

In regards to the expected value from an offshore R&D operation, the greatest expectations came in the areas of improved R&D cost effectiveness, an enhanced global R&D infrastructure and competitiveness, and support to other global operations. In many respects, these expectations have been met, although not without ancillary costs. It is not surprising that two of the interrelated changes most often noted with respect to the effect on domestic operations are (1) a reduction in staff levels in domestic facilities, and (2) a reduction in domestic funding of R&D. These changes will be discussed in greater detail in the forthcoming *Battelle/R&D Magazine Annual R&D Funding Forecast & Analysis* (January, 2007), but a few comments are appropriate here.

First, much of the offshore outsourcing of R&D has been in the area of pharmaceuticals, software, and specialized electronic systems and devices. In each of these areas, a considerable amount of funding has gone into both the support of R&D activities and the construction or acquisition of physical facilities.

Second, the subsequent impact on total R&D expenditures by a given

Global Change in the Infotech Rules

Information and communications technologies consume more global R&D spending than any other single industrial application, including the large health and life science sector. Not only is the overall market for products and services in this technology sector large and pervasive, but the products targeted for this sector are extremely volatile with an effective life cycle of less than a year, and sometimes even less than six months. This sector is truly global with large industrial organizations representing most countries and with no one truly global industrial leader.

Large industrial players in these sectors are also not immune to wide economic cycle swings; witness the current loss of market share by former industry leader Intel to the aggressive R&D-based product offerings from AMD. The free-for-all in the telecommunications sector as well, with its mergers and acquisitions, has placed continuing pressure on participants to aggressively support their R&D efforts, however the cut-throat marketplace and its overbuilt capital infrastructure continue to work in the opposite direction—forcing reductions in overall R&D spending.

Driving some of these changes are similarly dramatic technological changes in the baseline technologies that this sector was founded on. For more than 30 years, research organizations followed the guidelines of Moore's Law to drive their marketing and operational plans, R&D investments, and product growth. Feature sizes continued to shrink as circuit densities and overall performance increased, along with reductions in the cost per computational operation. Over the past few years, these "rules" have changed due to the unacceptable high cost of new manufacturing tools and processes, the unacceptable high rate of heat generated in the smaller circuits, and mostly unforeseen materials limitations that arose at the smaller feature sizes.

The net result is that researchers have changed their design "rules" to now include multi-core microprocessors, new computer architectures, clusters of computer workstations, and enhanced networking systems, all the while working with the current shrinking Moore's Law lithography design rules. This altered "systems design" approach (integrated with Moore's Law)," rather than the traditional evolutionary design approach, will likely result in a reshaping of the industry and its R&D programs. To the consumer, however, these changes are likely to be invisible and overall performance improvements will continue as before.

The global industrial community is already changing (with some effects due to normal economic cycles) with R&D spending in SIC 3674 (Semiconductor, related devices) expected to increase 7.5% in 2007, down from an 8.6% increase in 2006. Electronic computers (SIC 3571) will see flat R&D growth of 2.1% in 2007, the same as in 2006. Computer communication equipment (SIC 3576) is expected to increase 8.5% in 2007, down slightly from 8.7% in 2006. And radio and TV communication equipment (SIC 3663) R&D spending will drop to 6.3% in 2007 from 7.8% in 2006. Finally, R&D spending in telephone and telegraph apparatus (SIC 3661) will stay its depressed course and only see a 1% increase in 2007 (negative growth when adjusted for inflation), the same as in 2006.

organization is apparently one in which one would expect a decrease (or a slowdown in the rate of increase) of spending on domestic operations and a corresponding change in the domestic R&D personnel makeup. To date, no specific data have shown the extent to which these consequences have been realized. However, it would be expected that there would certainly be a shift in either the amounts of total funding of R&D (taking advantage of the differences in labor rates) or a shift in the nature of R&D that is supported.

Lastly, it is not unreasonable to postulate that the savings that accrue from the outsourcing of applied research and development programs could be applied toward in-house basic research that is necessary or desired for the establishment of more long-term platform building.

The extent to which this approach is employed will certainly be influenced by the recognition that the growth of relatively short-term offshore research activities presents an opportunity for investments that will enhance the long-term technology development.

The *R&D Magazine* survey included consideration of questions regarding experiences on several aspects of the offshore outsourcing of R&D, these cover both content (performance) and operational or environmental factors. Rated on a scale that went from "Better than expected" to "Worse than expected", the preliminary results suggest that the practice of using offshore R&D has been facilitated by the availability of improved communications technologies, calibration and the standardization of practices relative to performance, and similar technical issues, all of which point to the fact that host countries have come well down the road in terms of providing a technology-friendly environment.

Not quite as rosy a picture is painted relative to the non-technical issues, including government regulations, social issues, and the response of home country staff. As would be expected, initial performance response has not been as good as hoped, with this probably the result of high expectations associated with a high-risk venture.

It must be emphasized that none of these results are surprising, especially given the fact that the entire concept of offshore outsourcing of R&D is still relatively new: those that have been in the business for 20 years have generally worked out the difficulties of transition and integration, but the vast majority of efforts have been started in only the past few years.

Brakes Applied to Rapid Biotech R&D Run-up

A series of events over the past five years have resulted in a resurgence in biotechnology R&D. Of course, the primary event noted has been the sequencing of the human genome. However, the culmination of this more than 10-yr international research effort, not only resulted in the data collected on the human genome, but also the technologies that were created to collect this information. Microarray sampling, automation systems, and informatics systems have all made great leaps in development over the past five years, such that many entry barriers have been lowered.

The U.S. remains the overwhelming leader in R&D investments by biotechnology-active firms, with more than 10 times the investment (more than $16 billion 2004) of the second largest country (Gemany with about $1.4 billion), according to the Organization for Economic Cooperation and Development (OECD). The U.S. also has the largest number of R&D employees working in biotech (73,500), with nearly 50% more researchers than all other global countries combined. The UK (9,600), Germany (8,000), Korea (6,600), Canada (6,400), Denmark (4,800), France (4,200), and Switzerland (4,100) all have substantial numbers of researchers working in biotechnology areas.

The U.S. again accounts for the bulk of the sales generated by biotech firms with more than $60 billion in 2004 (a 25% increase from 2003). However, the still early period of the biotech development cycle has resulted in $4 to $11 billion losses in each of the past five years.

A small number of events have slowed the overall growth of biotech over the past two years—the withdrawal of the Cox-2 inhibitors by Merck (Vioxx), Pfizer (Celebrex) and others, and the fraudulent research performed by Korean stem cell researcher Hwang Woo Suk. The results of these two events have cut the amount of funds available for biotech research, along with an overall slowing of active research as other research administrators evaluate their own work to determine their potential future liabilities. Regulatory measures have also been implemented as a result of these events to ensure that future similar events do not occur.

Most global organizations involved in biotech are active in health areas (51%), followed by agro-food (19%), and industry-environmental (15%)—the remaining 16% are active in the "other" categories. Germany and the U.S. have the highest activity rate for health applications (65%), followed by China (63%) and Denmark (58%). Industry-environmental activity is highest in Korea (41%), while the activity rate for firms is less than 10% in the U.S., Canada, Switzerland, Norway, and Denmark.

A continuing decline in the number of new drug approvals by large pharmaceutical companies has also applied pressure on biotech firms to invest in health related applications of biotechnology. Partnerships and acquisitions between large pharma and biotech companies have also seen continuing increases (albeit slow) over the past several years to support the new drug revenue demands.

Innovation trends in biotech were also reflected in the rapidly increasing number of patents in the late-1990s (reflecting the human genome project research) and a slight drop-off, although still elevated number of global patent applications since then. The U.S. accounts for about 40% of the total number of biotech patents filed at the European Patent Office, while the European Union has a 35% share, Japan a 14% share, and all other countries account for the remaining 12%.

Ratings of Technology Strengths

The extent to which companies will seek to become involved in offshore alliances will be influenced by perceptions relative to the technological strengths in selected areas. While the EU analysis referred to elsewhere provides what is purportedly based upon agreed-upon measures, the R&D Magazine survey is based largely upon perceptions.

It is expected that decisions related to the pursuit of offshore R&D opportunities are based upon a variety of factors, including those which are perceived to provide direct support to the technology in question, as well as those that relate to which might better be termed the "R&D milieu." This latter characterization is likely based upon measures or observations of factors such as general educational levels; public understanding, support, and participation in technology; public and private financial support of and commitment to science and technology; and technology-specific educational initiatives. (These same criteria, and others, are just as important in site selection for domestic investment and development.)

Perceived Technology Capabilities and Resources

The comparative assessments were based upon a 1 to 5 scale ranking the state of technology from "Weak" to "Strong." By assigning weighting factors to the responses, an approximate overall ranking could be assigned to the status of the 12 science or technology areas in the four candidate countries. By weighing the responses, the semi-quantitative results indicate that the relative technological strengths range from a highest value for Aerospace Technology (when compared with the "second place" entry–which is almost always Japan), in decreasing order of dominance, the technological strength values decrease in the order shown above, through the fields from pharmaceutical discovery / development down to Academic Basic Research. Continuing the list, the analysis suggests that the technological strengths of the U.S., when compared with those of the other countries in the sample, decreases, being the "weakest" in the area of Automotive Development.

Perceived Technology Capabilities

Field D/Ranking 5	1st	2nd	3rd	4th
Aerospace Technology	USA	Japan	China	India
Pharma Discovery and Development	USA	Japan	India	China
Biotechnology	USA	Japan	India	China
Nanotechnology	USA	Japan	India	China
Information Technology	USA	Japan	India	China
Photonics	USA	Japan	China	India
Academic Basic Research	USA	Japan	India	China
Automation / Robotics	Japan	USA	China	India
Telecommunications	Japan	India	USA	China
Energy Research	Japan	USA	India	China
Electronics Research	Japan	USA	India	China
Automotive Development	Japan	USA	China	India

Technical Strengths in Europe

Over the most recent few years, major attention has been given to the development and utilization of R&D resources in China and India, and these have certainly received the greater amount of media attention. However, there are several other areas that merit special attention, including Latin America, other East and South Asia countries, and Europe. As will be noted below, the R&D Magazine surveys show, for example, that China and India dominate in terms of the numbers of respondents whose companies are involved in those countries' total R&D efforts. But there are also significant numbers of companies who look for technology assets in Japan, South Korea, Singapore, Taiwan, and Indonesia. Not surprising is the observation that almost 20% of the respondents report investment in R&D facilities in Latin America (with emphasis on Mexico and Brazil).

As we look at R&D outsourcing to facilities in Europe, it is interesting to note that there are some disconnects between the practice as observed by survey respondents and the individual country assessments of the technology climate that have been researched within the European Union. In looking at the European R&D scene, a central source of critical data can be found at the EU site: http://cordis.europa.eu/en/home.html.

Partner Country Drivers

The internationalization of R&D performance has been argued to be influenced by a number of different factors, many of which relate to internal policy changes in what might be called the "host country"—i.e., the country in which the R&D effort is performed—and the individual business decisions of the sponsoring organization in what might best be called the "investor country"—

the country of origin of the R&D support.

As is the case with decisions related to all types of R&D performance, the choice of the performing institution will be influenced by a number of characteristics, including inherent capabilities and the other driving forces that have been mentioned in this report. In addition, consideration is often given to the factors that influence the R&D enterprise and environment, including those that describe the manner in which the science and technology community interacts with the remainder of the host country.

In arriving at decisions relative to where investor countries commit to the establishment and/or use of R&D facilities in host countries, these decisions are generally based upon a number of different goals. In part, it appears reasonable for investor country institutions to look at the total environment and its technology-related components. Such inspection can be facilitated by research on the development of indexes that describe this environment.

One of the more comprehensive comparability reports is published by the European Union, and provides a framework within which an investor country institution may look at broad host country capabilities, government actions that enhance attractiveness as a source for R&D performance, and similar descriptors. For a deeper inspection of the output of these country-by-country analyses, it is suggested that attention be given to the discussions found at http://trendchart.cordis.lu/scoreboards/scoreboard2005/index.cfm.

The analysis of the "technological strength and sensitivity" is based upon a large number of factors that characterize the status in the individual countries. Without going into detail on the definitions and interpretation of these factors, it is important to highlight a few that may impact upon decisions related to cooperative research and development programs. As one looks at the potential for individual country growth, receptivity, and responsiveness to technology-based initiatives and opportunities, the authors of the cited report note the following factors that were used in their "national assessments":

- New S&E graduates per 1,000 population
- Population with tertiary education and youth education attainment level
- Public and private R&D expenditures (% of GDP)
- Medium-high-tech and high-tech R&D (% of manufacturing R&D expenditures)
- Share of enterprises receiving public funding for innovation
- University R&D expenditures financed by business sector
- Industry innovation expenditures
- Employment in high-tech services (% of total workforce)
- Sales and exports of high technology products
- Employment in medium-high and high-tech manufacturing (% of total workforce)
- Patents per million population

The overall report has a massive amount of data that have been analyzed and put into an order that permits some broad assessments relative to innovation in 25 European countries. Given certain broad characteristics, we use as a starting point what the report refers to in four broad categories, with the corresponding countries falling into each set:

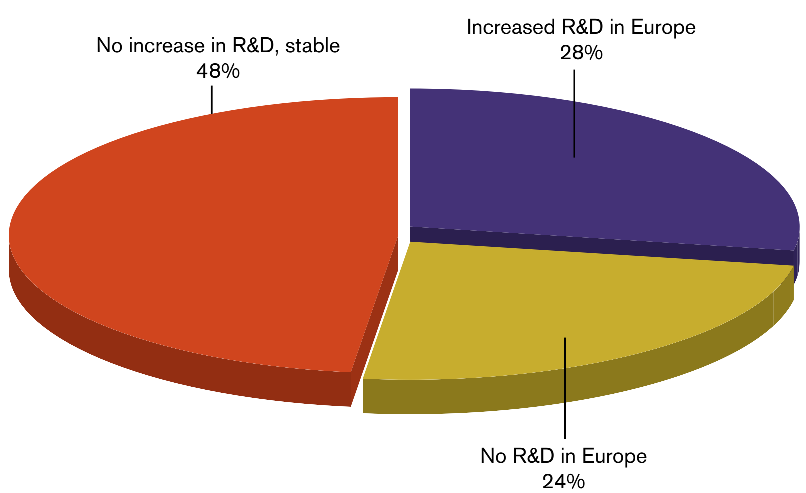
Leading Countries
- Finland
- Germany
- Switzerland
- Denmark

Average Performance
- Norway
- Ireland
- Iceland
- United Kingdom
- Netherlands
- Belgium
- France
- Italy

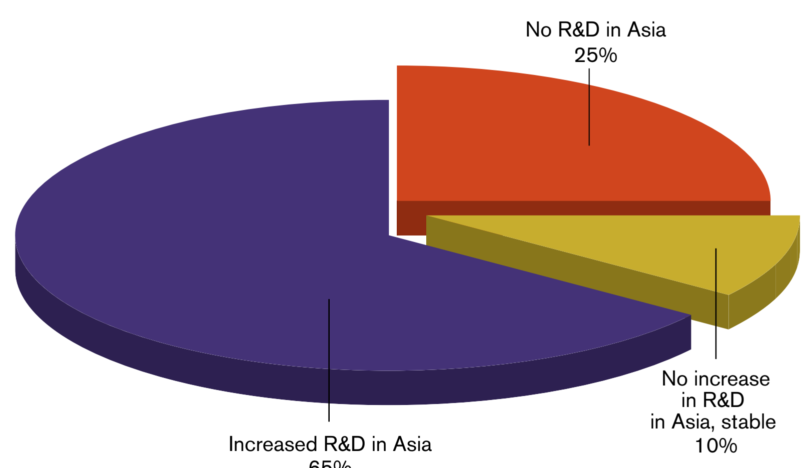
Catching Up
- Latvia
- Lithuania
- Czech Republic
- Hungary
- Slovenia
- Greece
- Portugal
- Malta
- Cyprus

Losing Ground
- Estonia
- Poland
- Slovakia
- Romania
- Bulgaria
- Spain
- Turkey

Are you increasing R&D operations in Europe?



Are you increasing R&D operations in Asia?



Source: R&D Magazine, Battelle

The Largest R&D Activity Focuses on the Very Small

Nanotechnology is the hottest topic in research and development labs around the world right now. Worldwide, governments are funding research in this area to ensure that future emerging technologies based on these materials are competitive with those from other regions. The U.S. Government Nanotechnology R&D Act of 2004, for example, provides for about $1 billion/yr through 2008. Corporate R&D funding is estimated to be about twice that this year with overall global funding at several times that as well. If you include electronics, life science, and coatings applications research, the overall R&D spending on nanotechnology in the U.S. is about $26 billion. More than 4,000 companies around the world are working on nanotechnology. The National Science Foundation has stated that the overall market for nanotechnology applications will exceed $1 trillion in less than 10 years, by 2015.

Nanotechnology is more than just the development of a new class of materials, in many cases it is an enabling technology allowing the creation of entirely new applications. In other cases, such as in drug reformulations, it allows companies to reapply existing materials (drugs) so that they can be used in entirely different ways (new drug delivery systems).

While there has been as substantial amount of R&D on nanotechnology, there are relatively few nano-enabled technologies in commercial use. From 1976 to 2002, there were nearly 90,000 patents involving nanotechnologies. The vast majority of these were dominated by the electronics, chemical/catalysis, and pharmaceutical industries. While the overall number of potential applications for nanotechnology is large, some platform technologies will serve more industries in improved manufacturing and product performance enhancements than others.

Nanotech Markets Billions, $

	2006	2010	2015
Materials	108	179	279
Electronics	129	160	246
Life Sciences	18	84	172
Chemicals	14	43	82
Aerospace	12	22	58
Modeling Tools	7	9	16
Sustainability	12	20	37
Americas	180	258	460
Europe	75	156	300
Asia	33	78	190
ROW	12	26	50

Source: Helmut Kaiser Consultancy

The leading countries working in this area are the U.S., Japan, China, and Germany. China is actually now one of the world leaders in terms of the number of newly registered nanotechnology firms. Over the past three years, more than 600 companies have been started in China, with an emphasis on nanotechnology. That said, warnings have also been issued that the rapid growth in this technology could supplant the current market and technology leaders with a new set of countries and organizations that happen to very successfully address a particularly important application.

Current nano-applications being heavily researched include life science, pharmaceuticals, medical diagnostics, food, environmental technologies, water, energy, electronics, and mechanical engineering. The global growth rates for these and other areas, amount to about 8% to 21%/yr over the next 15 years. Nanotechnology, biotechnology, information technology, and neural technologies have been converging for several years and over the next 10 years will create a revolution of innovations, new markets, and new applications.

Even medical and safety concerns over the impact that nanoparticles might have on the environment have failed to dampen any development of nanotechnologies. This is partially due of course to the relatively "newness" of the technology and its lack of pervasiveness, and also due to the lack of any findings of substance that reveal any environmental or health and safety problems or issues.

Regardless, a number of regulatory and standards programs are being investigated which will have a relatively minor impact on the overall development growth of this technology.

Source of R&D Funds				
	Industry	Government	Other	Funds from Abroad
Australia	46.4%	44.4%	9.2%	0.0%
Austria	43.9%	34.7%	0.4%	21.0%
Belgium	64.3%	21.4%	2.5%	11.8%
Brazil	38.2%	60.2%	1.6%	0.0%
Canada	47.5%	34.5%	9.9%	8.1%
China	57.6%	33.4%	6.3%	2.7%
Denmark	61.4%	28.2%	2.6%	7.8%
Finland	70.0%	25.7%	1.1%	3.1%
France	54.2%	36.9%	1.7%	7.2%
Germany	66.1%	31.1%	0.4%	2.3%
Hungary	30.7%	58.0%	0.4%	10.7%
India	23.0%	74.7%	2.3%	0.0%
Ireland	66.8%	25.5%	1.7%	6.0%
Israel	69.6%	24.7%	2.9%	2.8%
Italy	41.7%	53.0%	0.0%	5.3%
Japan	74.5%	17.7%	7.5%	0.3%
Korea	74.0%	23.9%	1.7%	0.4%
Malaysia	51.5%	32.1%	4.9%	11.5%
Mexico	29.8%	59.1%	9.8%	1.3%
Netherlands	51.9%	35.8%	1.3%	11.0%
Norway	49.2%	41.9%	1.5%	7.4%
Poland	30.3%	62.7%	2.4%	4.6%
Portugal	31.5%	61.0%	2.4%	5.1%
Russia	30.8%	59.6%	0.6%	9.0%
Singapore	49.9%	41.8%	1.1%	7.2%
South Africa	49.4%	33.0%	10.0%	7.0%
Spain	48.4%	40.1%	5.8%	5.7%
Sweden	65.0%	23.5%	4.3%	7.3%
Switzerland	69.1%	23.2%	3.4%	4.3%
Turkey	44.9%	48.0%	6.3%	0.8%
UK	43.9%	31.3%	5.4%	19.4%
U.S.	63.1%	31.2%	5.7%	0.0%

Source: R&D Magazine, Battelle, OECD, UNESCO

Inspection of the data and rankings provides a rationale for making decisions relative to the potential for developing technology-based partnerships, and indications of the extent to which these countries offer comparative potential for collaborative efforts. (We note, of course, that the indices used in these analyses are applicable to the country in general, and do not speak to the capabilities of individual institutions.

Furthermore, they do not address the non-technological factors that will—and certainly must—influence the business decisions relative to the initiation and implementation of technology development plans. The indices do not, for example, take into account government regulations, national cultures, disposable incomes, and the viability of local markets. Nor do they address, either directly or indirectly, any issues that may relate to business decisions in connection with the establishment of technology relationships.)

The researchers go into detail relative to the extent to which the countries involved can approach the U.S. and Japan in its innovative indices. The EU report concludes that narrowing of the gap will not occur in the foreseeable future (the next 40 years or so). However, one must be cautious in using these data, for they are based largely upon semi-linear extrapolations of change in all of the countries involved.

Thus, they make the assumption that U.S. and Japanese practices, habits, and capabilities will continue to grow at some established rate. However, it does not seem to take into account the question as to the impact of changing government and industrial funding of the U.S. R&D performance enterprise. In the event that the funding levels are not maintained within a certain growth rate, the period of catch-up could be significantly shortened.

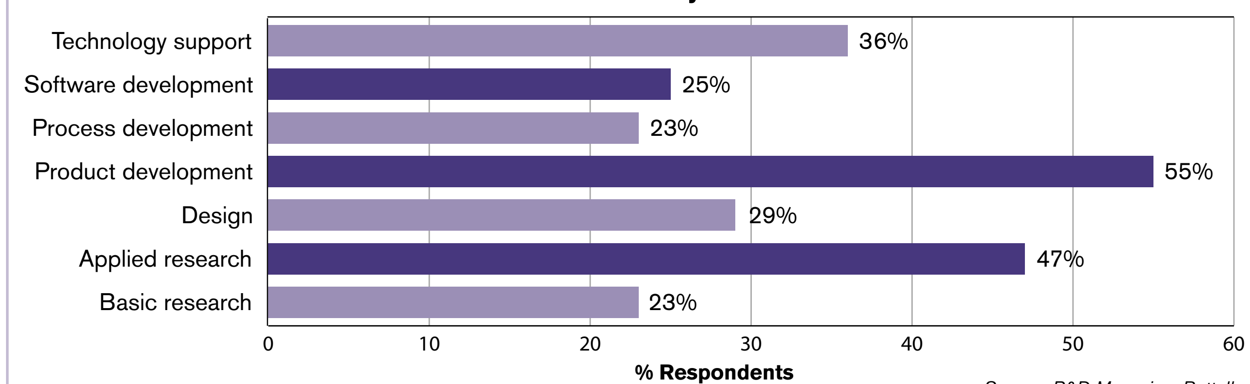
Is this important? We seem to think that it is, because the relative technological position has been one that has been a driving force behind the U.S.'s abilities to grow economically and maintain self-reliance relative to defense. Furthermore, it is important because the technological profile of other countries will have an impact on the manner in which any country's multinational firms analyze the climate in areas where they operate, and distribute their R&D funds in accordance with a number of different criteria.

The recent *R&D Magazine* survey on where U.S. organizations are investing in R&D offshore facilities shows results that are counter-intuitive when compared with the "technology strength" ratings of the EU countries. The results, again without specific reference to the areas of research or the types of companies, indicate that surveyed companies had a higher rate of participation in offshore R&D facilities in Western Europe (29% of respondents), Eastern Europe (20%), and Northern Europe (8%), quite at odds with the EU assessment of technological strength and the environment for technology.

One might tentatively conclude that the apparent greater interest and investment in the European countries has been driven by factors other than the inherent technological profiles of the site. As has been hypothesized from the earliest days of considering the rationale for offshore outsourcing, it appears that the disconnect may have been the result of primary decisions made relative to the need for local support of manufacturing or marketing activities. Alternatively, it may also be the result of special arrangements that were negotiated in order to obtain manufacturing or marketing rights.

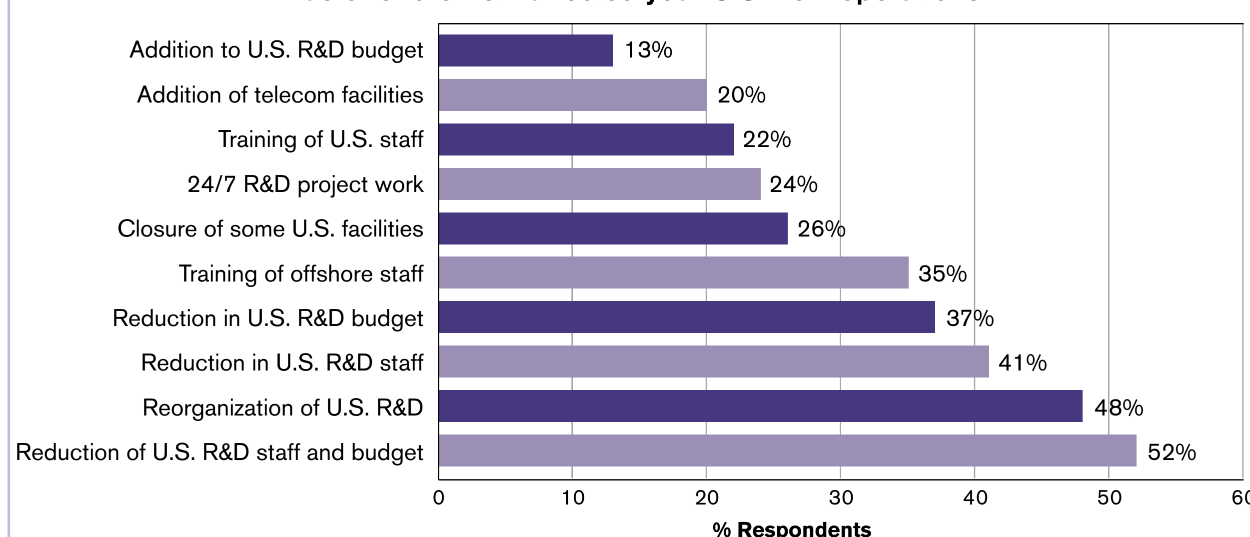
Overall, as might be expected, the *R&D Magazine* survey also shows that

What R&D activities do you outsource?



Source: R&D Magazine, Battelle

Has offshore R&D affected your U.S. R&D operations?



Source: R&D Magazine, Battelle

Globalization Linked to Outsourcing

The increasing globalization efforts of multinational companies continues to drive the outsourcing of R&D operations from established North American and European locations to primarily Asian countries, although some of this outsourcing can also be seen in East European countries, such as in Hungary and the Czech Republic. Surprisingly, research growth in many of the non-OECD (Organization for Economic Cooperation and Development) countries now seems to be one of the strongest drivers of global innovation.

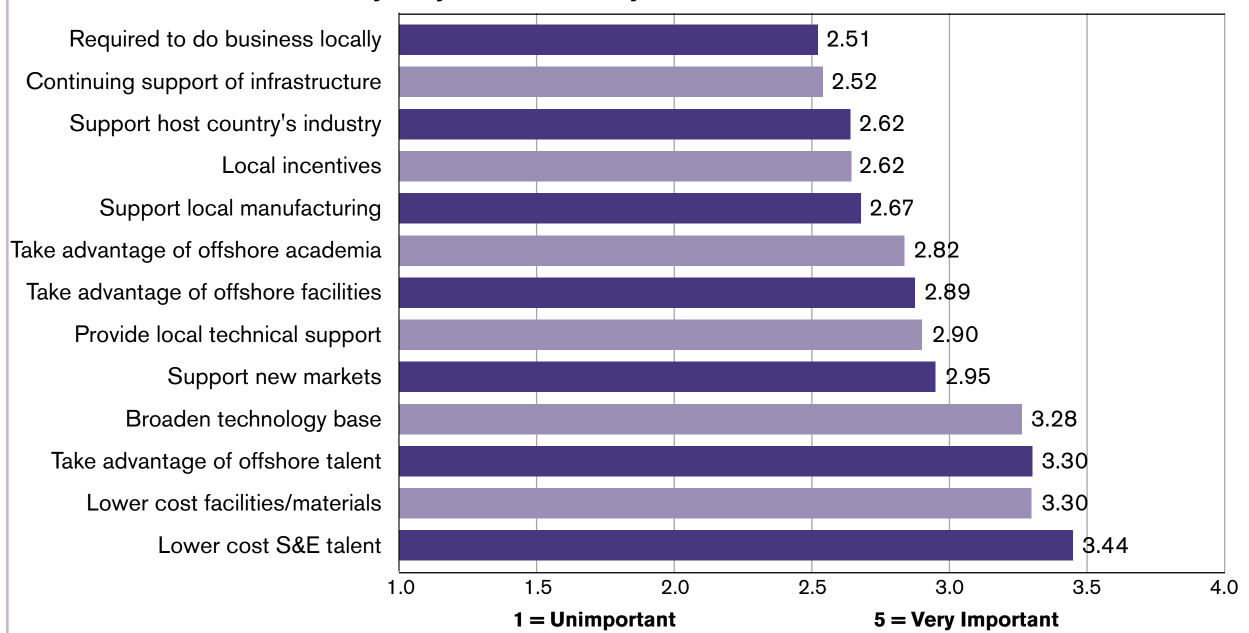
The holdout in this outsourcing appears to be Japan. Less than 5% of the R&D in Japan is performed by multinationals. Japan is also the least active OECD country in international cooperation in patenting. Less than 4% of the domestic inventions in Japan are owned by foreigners, compared with more than 12% in the U.S. and 38% in the UK. Japan is also the least involved in international collaboration, with less than 3% of its patents being the result of such collaboration, compared with almost 12% for the U.S. and more than 21% for the UK.

Offshore outsourcing of R&D operations is likely to have a short-term effect on U.S. R&D operations as companies restructure their R&D organizations to reflect upon a global enterprise, rather than a purely domestic operation. Some loss of jobs, budgets, and even facilities within the U.S. and Europe will occur during this transition, but the long-term effect will be a financially stronger multinational company with growth that is reflected in a stronger overall R&D infrastructure with U.S. and non-U.S. operations. The implementation of the offshore R&D operations is also very likely to support economic growth of the multinational in that offshore country, which would likely have been less if that facility was not there. Overall, the multinational becomes a true multinational in all aspects of its operations and continues to grow by reason of economy of scale, even faster than those organizations in those offshore countries.

Indeed, according to a recent report by A.T. Kearney, the U.S. continues to rank highly in globalization—No. 4 behind Singapore, Ireland, and Switzerland. This ranking system, which takes into account economic integration, technological connectivity, political engagement, and personal contacts, identifies the U.S. as a continuing strong player in the international marketplace and a country with a strong economy and long-term economic growth capability. The Kearney report goes on to state that highly globalized countries are often less corrupt and freer.

It should be noted that a significant portion of the overall U.S. R&D annual expenditures are focused on military and defense spending. Due to political and security pressures, little of these R&D operations will ever be outsourced to offshore organizations, not even captive organizations.

Why do you outsource your R&D?



Source: R&D Magazine, Battelle

the percentage of respondents whose companies are investing in China and India are 61% and 50%, respectively, with smaller numbers being involved in Singapore, Japan, South Korea, Taiwan, Malaysia and Indonesia. Somewhat surprisingly, investment in Latin American countries appears to be preferred over all of the second-tier Asian locales, and twice as high as for Northern Europe (which includes the leading Scandinavian countries).

Finally, we take a brief look at the Latin American scene. The *R&D Magazine* survey indicates a strong preference for R&D investment in Central and South America, with nearly 20% of the respondents pointing to this area as one in which they are involved. Several U.S. and Indian companies have established activities in software development as well as in R&D and engineering; while many others have taken the first steps for using Brazilian talents in call centers and back-office operational support. Recent reports on Brazil note its R&D is largely funded (70%) by public sources, that regulations have been put in place to encourage greater R&D and innovation investment by small and medium-sized businesses, and that the country has achieved relatively high degrees of "technology infrastructure"–using broadband connections as a surrogate measure of increasing sophistication.

In addition to promoting advanced technology capabilities, Brazilian commitment to alternate fuels is expected to create a greater cost-avoidance component in the emerging patterns of growth.

–Jules Duga and Tim Studt

The Authors

Dr. Jules Duga is a Senior Analyst at Battelle in Columbus, Ohio. Battelle has been creating R&D forecasts for more than 35 years.

Tim Studt is the Editor in Chief of R&D Magazine, a publication of Advantage Business Media.

References and Resources

The following web sites are particularly good sources for information relative to the R&D enterprises in selected countries that are included in this report. The listing is representative, and certainly not inclusive.

American Association for the Advancement of Science
www.aaas.org

Battelle
www.battelle.org

Booz Allen Hamilton Global Innovation 1000
www.boozallen.com/publications/article/981406?lpid=386277

China Ministry of Science and Technology
www.most.gov.cn

Chinese Academy of Sciences
http://english.cas.cn/Eng2003/page/home.asp

Economic Intelligence Unit
www.eiu.com

European Commission Research
http://ec.europa.eu/research/index_en.cfm

European Industrial Research Management Association (EIRMA)
www.eirma.org

European Union Community R&D Information Service (CORDIS)
http://cordis.europa/eu/en/home.html

Industrial Research Institute
www.iriinc.org

Japan Ministry of Education, Culture, Sports, Science and Technology
www.mext.go.jp

Japan Science and Technology Agency
www.jst.go.jp/EN/

KPMG Competitive Alternatives
www.competitivealternatives.com

McKinsey Global Institute
www.mckinsey.com

Organization for Economic Cooperation and Development (OECD)
www.oecd.org

RAND National Security Research Division
www.rand.org

Shonfeld & Associates, Inc.
www.saibooks.com

Thomson Scientific
www.thomsonscientific.com

U.S. National Science Foundation
\www.nsf.gov

World Bank Economic Indicators
http://devdata.worldbank.org/wdi2006/contents/cover/htm

World Economic Forum
www.weforum.org/en/index.htm

R&D Performance

	Industry	Government	Other
Australia	48.8%	20.3%	30.9%
Austria	66.8%	5.7%	27.5%
Belgium	74.1%	6.4%	19.5%
Canada	53.0%	11.0%	36.0%
China	61.2%	28.7%	10.1%
Denmark	68.6%	11.9%	19.5%
Finland	70.5%	9.7%	19.8%
France	62.3%	17.1%	20.7%
Germany	69.8%	13.4%	16.8%
Hungary	36.7%	31.3%	26.7%
Ireland	70.1%	8.1%	21.8%
Israel	73.0%	5.8%	21.2%
Italy	49.1%	18.4%	32.6%
Japan	75.0%	9.3%	15.8%
Korea	76.1%	12.6%	11.3%
Mexico	30.3%	39.1%	30.6%
Netherlands	58.4%	13.8%	27.8%
Norway	57.5%	15.1%	27.5%
Poland	27.4%	40.7%	31.9%
Portugal	31.8%	20.8%	47.5%
Russia	69.9%	24.5%	5.6%
Spain	54.1%	15.4%	30.5%
Sweden	74.1%	3.5%	22.4%
Switzerland	73.9%	1.3%	24.8%
Turkey	33.7%	7.4%	58.9%
UK	65.7%	9.6%	24.6%
U.S.	68.9%	9.1%	22.1%