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Letters

Reader Commentary

RE: "OPEN STANDARDS, OPEN SOURCE, AND OPEN INNOVATION,"
BY ELLIOT MAXWELL

At many conferences I have mumbled privately that the word "open" should be banned. Everyone agrees that "open" is good, but agreement ends there. Different speakers use the word for different purposes, referring to different processes or outcomes. While it would be Draconian to ban the word, it would force speakers to be clear about what they mean.

Of course, banning a single word would not be very practical. Fortunately, the next best thing is: defining terms carefully and employing their meaning in a consistent manner. That is what Elliot Maxwell does.

Elliot Maxwell distinguishes between various meanings of open: making decisions transparent; making outcomes accessible to others; making a process welcoming to input from a wide set of decision makers; and making a process capable of debating distinct points of view. It would be excessively blithe and inaccurate to say that he is in favor of them all. Rather, he finds merits in transparency and accessibility, because they nurture accountability in processes that welcome diverse viewpoints. In many contexts—both business and government decision making—that leads to more innovative outcomes.

Maxwell also recognizes that some types of transparency are not a slam dunk all the time: transparency can clash with other values, such as privacy and security. After all, nobody wants the records from their latest medical exam to end up on the Internet without their permission, but if a doctor makes an incompetent decision we also want the doctor to be accountable.

Finding the right balance has become more challenging in recent times. Two of Maxwell's arguments resonated with me. On the one hand, most of the time, an incremental movement towards more transparency and accountability results in an improvement. That is true in many parts of the developed world, including the U.S., as well as in the developing world. Second, we are entering an era when know-how in our society accumulates more easily and spreads more quickly than in the past. Most of us recognize this in its pieces: when we send email; when we read Wikipedia; when we find lost writing with Google; when we contribute to an open source project like Linux; when we read on-line journals. The act of acquiring, accumulating and generating knowledge is changing. That change demands a rethinking of core principles.

Clear language has a clear benefit: it identifies the hard problems. Maxwell's paper bring two such problems to the fore:

First, if we agree on the direction of movement, how do we get from here to there, even incrementally? It is not easy to operate processes in the way that Maxwell advocates. Accountability from transparent information has a benefit, but it also has costs that self-interested participants in society can and will seek to avoid. The details of such choices do not always lead to easy decisions about how to balance competing values. Why would a big private firm want its decisions to be transparent to others if they gain strategic advantages from cagey secrecy? Why would the stock-holders for a marketing company holding lists of names, addresses, and social security numbers want their firm to be held liable for a clerical error? Why would a big firm devote its valuable human resources to a national standardization effort, if it can just live off the efforts of others who do the coordinating in standards committees?

Second, there are unanticipated consequences from the movement towards more accessible information. It makes it possible for different facets of society to broadcast their behavior in new ways. As a parent, teacher, and participating member of civil society I find myself struggling to come to terms with the unwanted sides of these changes. For example, it is becoming tremendously distracting to watch vanity behavior increase—from teenagers, musicians, athletes, and self-aware politicians, not just porn stars. Most of us want the Internet to lead to a grocery with better produce, dairy, and meat sections, not a larger section devoted to the National Inquirer and other eye-catching tabloids. Yet, what comes across many of our computer screens every morning makes us confront what we happily and much more easily avoided in the past.

Shane Greenstein
Elinor and Wendell Hobbs Professor of Management and Strategy
Kellogg School of Management
Northwestern University

RE: "THE HONEY BEE NETWORK" BY ANIL K. GUPTA

Biodiversity faces historically unparalleled threats. Deforestation continues apace; fresh water sources are increasingly polluted; coral reefs are imperiled. The human footprint on planet earth expands in a way which seems to threaten almost everything, everywhere.

At the same time, biotechnology is finding evermore applications for natural products, semi-synthetic derivatives, and even synthetics based on, or inspired by, natural products. New technologies are being developed daily that can find, analyze, and manipulate molecules in ways once unimaginable. As a consequence, biotech has increased not only the present utility, but also the potential future utility, of species in all of their diversity.

How ironic, then, that we should be destroying something as it becomes evermore useful: new treatments for "incurable" diseases, new fibers for industry, new biodegradable pesticides, and maybe even new sources of energy that are literally going up in smoke.

Further complicating the ability to harness Mother Nature's genius is the issue of Intellectual Property Rights (also known by the acronym "IPR"), which addresses the key issues of who owns species and/or the knowledge of how best to use them. The history of the interaction between cultures—primarily western and indigenous cultures—has not been a mutually beneficial one. Indigenous peoples generally have received little or nothing in return for their familiarity with local flora and fauna, and their knowledge of how such natural resources can be used to the benefit of humans.

At a time when most discussions that surround IPR issues focus on the sorry history of these interactions or the difficulty (or even impossibility) of successful partnerships, Anil Gupta's article detailing the many successes of the Honey Bee Network in India comes as a distinct breath of fresh air. While not as well known to the western NGO and donor community as the now famous Grameen Bank which has so successfully developed the concept of microlending, the Honey Bee Network has innovated an approach that has potential to be at least as successful in helping poor and marginalized people help themselves. Their techniques have the advantage of being elegant, straightforward, and empowering the local partners to lead their own initiatives. Notably successful efforts to date have included bringing together representatives of rural communities to exchange organic farming techniques; organizing biodiversity contests in which children compete to show off their knowledge of local medicinal plants; organizing competitions among women where the challenge is to cook the most nutritious meal possible with available resources; and many other clever initiatives. Gupta delineates his concept of the "long tail for inventions" in which Honey Bee Network actually helps local inventors develop patent protection, including products as diverse as a motorcycle based tractor, and a novel type of cart used by local farmers which actually received patent protection from the U.S. Patent Office!

Many of the ideas developed by the Honey Bee Network seem directly applicable to IPR issues in countries other than India. Some of their approaches should be adaptable directly, others may prove applicable after certain modifications, while still others will inspire completely novel ideas. Gupta's article—concise, clearly-written and chock full of successful examples—should prove highly effective at helping spread the word about this powerful Indian initiative.

Mark Plotkin
President
The Amazon Conservation Team

RE: "THE ENERGY INNOVATION IMPERATIVE," BY JOHN P. HOLDREN

I strongly agree with, and share, John Holdren's intuition that accelerating the incentive for innovation is the most powerful and also politically feasible strategic avenue open [for addressing energy challenges].

That there is little investment in public research may not be altogether such a bad thing. The data I have seen about the efficacy of government research in either the environment or the energy area is quite discouraging—and not in the least bit surprising given the incentive structure prevailing in government laboratories.

You mentioned the leverage of emissions trading in a final sentence of your discussion of innovation. When we were working to create this system in the Carter years and before, in fact it was precisely this end that was my chief motivation and argument. If one can get every plant manager and engineer to have a powerful interest in innovation and in pollution abatement—especially in those elements where results are relatively low cost—one has achieved the best possible result. Once emissions trading is going full blast, every plant manager will have the same incentive (profit maximization) to innovate for the public environmental good as she or he does to increase the production of goods. (A July-August 1981 *Harvard Business Review* article I authored, titled "Thinking Ahead: Getting Smarter about Regulations," outlines what we had then built. As you'll see if you review the article, the basics today are what they were then!)

In contrast, the existing system gives managers a powerful incentive not to innovate lest that innovation becomes the new "best available technology." Equipment manufacturers, most notably, sell to customers who very definitely do not want them innovating to raise the bar.

Strong incentives to reduce emissions help energy conservation; but, I believe, we need incentive tools that are aimed directly at energy as well.

In this regard, I would draw to Holdren's attention a working paper [titled "Job Creation Tax Options"] that Get America Working [an organization of which I am the founder and chair] published several years ago. It outlines 20 natural resource taxes to demonstrate how easy it would be entirely to replace the country's enormously destructive payroll taxes. The energy inefficiency tax, in particular, is politically low cost and would give managers a most powerful incentive continuously to seek out new energy technology "S-curves."

Bill Drayton
Founder & CEO, Ashoka: Innovators for the Public
Founder & Chair, Get America Working

Editors' note: Drayton was Assistant Administrator at the U.S. Environmental Protection Agency from 1977-1981, during which time he led the implementation of the first emissions trading system and the introduction of other mechanisms to sharpen incentives to comply with environmental regulations. Drayton and Holdren are both members of the advisory board of Innovations.

Klaus Schwab and Pamela Hartigan

Social Innovators with a Business Case

Facing 21st Century Challenges One Market at a Time

If there is one thing about which public and corporate leaders around the world today can agree, it is the ever-growing importance of innovation. The search for innovative solutions to the world's myriad local, national and global challenges has become a clarion call rallying people across multiple borders defined by nation, industry, and academic discipline. Yet policy making reflects deep ambivalence about innovation. The cheerleading over innovation exists in contrast to the myriad institutional, legal, regulatory, and educational impediments to the work of innovators.

While not innovation experts, we have been privileged to interact over a span of decades with the some of the world's most recognized innovators—from those working at the grassroots to those at the helm of new industries. This has provided us with some perspective on the nature of innovation and the hurdles innovators face daily as they search for ways to disseminate their approaches and products.

Education is a good place to start. A society's capability to innovate arguably begins, or possibly ends, in school.[1] For the vast majority of primary schools, among the qualities of a "star" pupil are tidiness, adherence to rules and directions, and good behavior. In the later grades, outstanding achievement is measured in grades, standardized test scores and sometimes, the number of extracurricular activities undertaken. These constitute the ticket to acceptance to top schools producing the world's elite. But it is not clear that this is how to develop the talents of tomorrow's innovators.

The educational system is reinforced by employment policies in most government institutions and corporations. When reviewing candidates, recruiters invariably look for evidence of academic achievement and a steadiness that produces good exam pass rates and grades rather than for experiences that might suggest a candidate is innovative and inspired, perhaps even rebellious. This is because most organizations have a low tolerance for mistakes. Risk-averse societies and organi-

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zations keep people from failing. They also keep them from trying. And the key to successful innovation is initial failure and persistence.[2]

It is hardly surprising, then, that among the commonly shared experiences of successful innovators is the recollection of having been described at some point as crazy, not just by acquaintances, but by family, friends and close colleagues. Almost by definition, innovators are mavericks. Most organizational structures and their corresponding managers and civil servants deal with what is. Innovators do exactly the opposite. They focus on creating things the world has never seen. They systematically disregard boundaries—whether of nation, academic discipline, or social status—to the predictable annoyance of those who consider it their responsibility to keep boundaries in place. An irony results: While the world clamors for innovation, it tends to deprive innovators of the resources and recognition that would maximize their potential to transform societies for the better The challenge of innovation in the 21st century is therefore also about reshaping societies to be not only tolerant, but actually welcoming, of innovators.

While the world clamors for innovation, it tends to deprive innovators of the resources and recognition that would maximize their potential to transform societies for the better

In the case of the innovators using technology on which this journal focuses, past innovation heroes had their impact on business. From the individual brilliance of Thomas Edison came the global powerhouse that is GE; from the unique inspiration of Kiichiro Toyoda came the car company of today that continues to be a global standard setter. In the coming century, however, the greatest opportunities for innovation exist in domains of public service heretofore left to governments. Social innovators who have taken a business perspective today are pioneering new approaches and helping to map out future markets where most would only see looming problems and risk. In doing so, they are the harbingers of the biggest market opportunities of the century. And history suggests that they have at least as much chance of shaping the twenty-first century as many of today's great incumbent businesses. On current trends 75% of 2001's Standard & Poor's 500 will have disappeared from the S&P index by 2020. In their stead, companies unheard of today, using new business models, will be delivering products and services to new and existing markets, dislodging incumbents who have not been able to innovate fast enough to keep up with 21st century needs.[3]

Already today, there are hundreds of such innovators who are reaching new markets, serving unmet needs, and creating new supply chains. This journal recently profiled KickStart and its founders, Martin Fisher and Nick Moon.

Kickstart designs, produces and sells appropriate technologies to rural entrepreneurs in some of the world's poorest markets, allowing them to start small-scale businesses. In 2005, KickStart sold over 8,400 pieces of equipment that helped start 5,964 businesses generating an additional $5.3MM in annual profits and wages for new businesses. Martin and Nick have ventured into territory no mainstream company would dream of entering—and in doing so, they have paved the way for a new group of producers and consumers to emerge.

Dr. Devi Prasad Shetty is meeting unmet needs of a different sort through an innovative business model in health. An Indian cardiologist, Shetty's organization, Narayana Hrudayalaya, strives to make sophisticated healthcare available to all in India. His network of hospitals is able to provide 60% of treatments below cost or for free, thanks to drastically reduced costs resulting from high volumes, innovative cost saving methods and donations. A network of 39 telemedicine centers reaches out to patients in remote rural areas. Two health insurance programs provide coverage for 2 million farmers at Rs 120 per year (USD 3). Again, innovators lead the way in coming up with business models to provide quality health care for the poorest who cannot afford it—while sustaining and growing the enterprise.

In Nigeria, Isaac Durojaiye has both created a new product and tapped into a new source of labor. His company, Dignified Mobile Toilets (DMT) is the first manufacturer of mobile toilets in West Africa. DMT makes, installs and maintains thousands of public toilets in Nigeria through a franchise system providing job opportunities to members of youth gangs that oversee the daily maintenance of the facilities and keep 60% of the profits. The toilets are placed in high traffic areas, such as bus stations and markets, where there is a high demand for sanitation facilities. Thus, DMT offers an alternative to current widespread and unhygienic practice of using the street as a toilet. It also aims to attack the unemployment situation, particularly among youth. More than half of the population of Nigeria is under 35 years of age, and many are unskilled. While Nigerian employment statistics are under debate, it is believed to be in the range of 17%, with an even higher rate among urban youth. Up to 55% of the unemployed are secondary school graduates, underlining the fact that education and skills do not guarantee employment.

Sub-Saharan Africa is not the only region where new solutions are needed to address emerging models of participation in the work force. Sara Horowitz is spearheading a form of portable unionism to promote the interests of the growing number of independent workers in the United States. Unlike traditional trade unions which are limited by law to employees of workplace-based organizations, Working Today, founded by Horowitz, provides flexible and portable benefits applicable to an increasingly mobile and decentralized workforce adjusting to the changing contours of the U.S. and global economy. It has built a membership of 16,000, including 10,000 independent workers who receive health insurance. Its model could be expanded to address the needs of the more than 30 million independent workers across the U.S.—and beyond.

The more acute the societal challenge, the greater need for an innovation-driven societal transformation. Global climate change is number one on the list in terms of the magnitude of the challenge and in terms of the scope of the required response. The climate challenge in this century will not be solved by changing power plants, designing new automobiles, or reformulating gasoline. It will be solved, and must be solved in this generation, by people changing their behaviors and their institutions. National policies, corporate programs, venture financing and consumer behavior will all contribute. But if they are counted upon to be the drivers of change, that change simply will not occur. To catalyze the shift, the general population must be spurred to action, in turn pressuring governments.

The more acute the societal challenge, the greater need for an innovation-driven societal transformation.

One such catalyst is Yann Arthus-Bertrand, a photographer who has demonstrated through creativity and perseverance that there is no real North-South divide when it comes to environmental threats. Bertrand produced a series of extraordinary books, exhibitions and films introducing us to our planet from the air. Like most innovators, he is unrelenting. He has taken over 100,000 images just to put together "Earth from the Air." As one of his colleagues put it, "With him, I learned that nothing is impossible. People will tell him 'No', and he hears 'Maybe'. And herein lies the strength of such innovators—and their common bond. The word "no" doesn't exist for them. As Barry Coleman, co-founder of Riders for Health,[4] has quipped, "There is nothing as motivating as when someone tells us 'It can't be done'. It is our call to action."

What set of incentives will lead to the deep diffusion across society of the capability to innovate and the inclination to respect and value innovators? The first place to start is to step beyond paying lip service to the importance of innovation in the public interest. Acknowledging the role innovation must play in addressing the challenges of inequity is a prerequisite. But to date, and except in a small number of wealthy countries, such as the U.S., U.K., and the Scandinavian countries, governments have played a modest role in financially supporting innovation, particularly when directed towards social transformation.

The vacuum has been only very partially filled by venture capitalists, private investment, and philanthropy—individual and corporate. Thus, among the examples of social innovators highlighted previously, not one of them secured national public sector support—other than international aid—when launching their initiatives. While one might argue it is better not to be financially supported by a government in the early phases of the venture in particular—because it can compromise the ability to be truly innovative—the existing financing vacuum evident as these social ventures scale up cannot be filled by wealthy individuals or enlightened business alone. Increasing recognition of the importance of social innovation and the concomitant growth of "philanthropreneurs" may spur more funding flows to support early stage innovative hybrids focusing on social transformation.

Many, if not most, of today's social innovators defy traditional legal pigeonholing as "not-for-profit" or "for-profit" organizations. Rather, they "intersect" across both—they are social innovators with a business case, so to speak, hybrids that straddle between a charity and a profit maximizing company. Consequently, many find themselves maneuvering through a tangled web of legal regulations to identify what benefits and obligations exist in relation to their enterprise. The fact is that to date, no country has developed a specific legal model recognizing the hybrid nature of such organizations and the social and economic functions they serve.

Our fascination with these pragmatic visionaries and their organizations lies much less in the goods and services they provide than in the catalytic role they play in triggering innovations in the social sector. Like the business innovators who come up with major innovations for the marketplace, social innovators are the mad scientists as it were—working away in their organizations that act like social innovation laboratories. They test and perfect different approaches, and when they come up with the most effective and efficient ones with the greatest impact, it should be government and the corporate sectors' respective roles to celebrate the innovation, take it up, learn from it, and help scale it so that all can benefit. Ultimately, the innovation lies in the models devised for service and product delivery all along the supply chain—not in the provision of the good itself. It is those models that others need to take up and replicate.

Innovators in the public interest are the flame that ignites the fire of social transformation. That flame must be fanned and nurtured by governments, publicly traded and private companies, academia, media and individuals working together to achieve its promised impact.

We invite reader comments. Email <editors@innovationsjournal.net>.

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1. We recognize that a vast number of children in poor communities must abandon their formal education after the primary school years. Yet patterns of learning are developed at the primary level.
2. Thomas Edison is oft-quoted as saying. "I have not failed. I have found 10,000 ways it won't work."
3. Richard Foster and Sarah Kaplan, 2001. *Creative Destruction: Why Companies That Are Built to Last Underperform the Market—And How to Successfully Transform Them* (New York: Random House).
4. Working with Ministries of Health and NGOs in African countries, Riders for Health builds local capacity to maintain and manage motorcycles and other vehicles, enabling health care workers to reliably service remote areas. As a result, RfH is able to operate fleets of vehicles in the harshest conditions with a zero breakdown rate for five years or longer. RfH has demonstrated that a properly managed vehicle under its system will save more than 50% of costs over a six-year period, compared to an unmanaged vehicle. RfH has been able to lower infant and maternal mortality in targeted communities. With each motorcycle it runs, 20,000 receive primary health care every year.

Richard Jefferson

Science as Social Enterprise

The CAMBIA BiOS Initiative

Nearly four billion people live on daily incomes lower than the price of a latté at Starbucks. Most of them make dramatically less than that—and from that income, they must acquire their food, their medicine, their shelter and clothing, their education, and their recreation, and they must build their future and their dreams. Their lives, and the quality of their lives, hinge on biological innovation.

Biological innovation is the ability to harness living systems for our social, environmental and economic well-being. It is the oldest and most fundamental form of human innovation, involving as it does the getting of food, the striving for health, the making of homes, and the building of communities. The wealth created over the millennia through the domestication and husbandry of plants and animals has powered human society.

Of all areas of biological innovation, agriculture is the most important, affecting our environment, our health, our economies, and the fabric of our societies. The world's poorest nations depend largely on agriculture for their economic survival as well as their food, fuel and fiber. The challenges of innovation to create and sustain productive and environmentally sound agriculture are even more pronounced in these societies. Any failure to do so has enormous implications for the global community, over and above the social, economic, and environmental impacts.

For thousands of years biological innovation has been informed and guided by keen observation and the accumulation and sharing of generations of empirical knowledge. Farmers selected better crop varieties and livestock breeds, and devel-

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oped management strategies to maximize their performance. Seeds were shared as a practical matter of survival and each improvement formed the basis for further innovation. Because seeds of most crop plants breed true, the ease of sharing, and the barriers to doing so were minimal. As with digital information, it is hard *not* to share, and hard to impose limits on sharing, so norms evolve to maximize value from this inevitability.

Extraordinary efficiencies occur when the tools of innovation are shared, are dynamically enhanced, have increased levels of confidence (legal and otherwise) associated with their use, and are low or no-cost.

But the post-Enlightenment explosion of possibility that began when the unprecedented power of science became focused on food, agriculture, health, medicine and environment seemed to dwarf all previous attainments. And indeed in the past hundred years, with the advent of genetics, the pace has been gathering; the last thirty years has seen an unprecedented dynamism in life sciences that is being hailed as a "biotechnology revolution." But in this revolution, biotechnology is rarely being applied to the critical issues of alleviating poverty, eliminating hunger, stewarding natural resources, and preventing or curing the diseases of the disadvantaged. The margins are small, the markets are modest, and the challenges are great. Are the paradigms and practices that have emerged to harness science for society sufficient to engage, and even solve, these seemingly intractable problems?

Today control over agricultural biotechnology is effectively limited to a few multinational corporations who integrate seeds, agrichemicals, and biotechnology. This disturbing consolidation of power is matched with a trend toward "me-too," big-ticket "innovations" of remarkable dullness. How many herbicide-tolerant big acreage crops are enough? Similar trends are surfacing among the large pharmaceutical companies, collectively known as "big-pharma": how many blockbuster lifestyle drugs does society need?

Within the value system they respect, and according to their own success metrics of profitability, big agriculture and big pharma are not abject failures, but they surely are not enough.

To address the myriad challenges of agriculture, environment and health that are local in nature and modest in market or profit margins will require vigorous, competitive, local-scale small to medium enterprises creating a business and innovation ecology. It will also require a biological innovation culture where the costs of innovation are low, and the power and relevance of technology are high. It will require leveraging the contributions of diverse people and institutions to create tools that better engage science into an integrated and economically sustainable social agenda.

The mission of CAMBIA, of which I am the founder, is to advance this set of required capabilities so that biological innovation can address the human challenges of the 21st century; the BiOS (Biological Open Source) Initiative is CAMBIA's mechanism for achieving its mission.

The term "open source" describes a paradigm for software development associated with a set of innovation practices. The concept evolved out of the "free software" movement, and is often merged into the expression "free and open source software." (See text box.) Several features together qualify a project as "open source."[1] These include full disclosure of enabling information including documented source code and the use of legal instruments such as copyright licenses to confer both permissive rights and responsibilities; they bind contributions into a commons that is accessible to all who agree to share alike. Typically, certain practices and cultural norms are associated with distributive innovation, although this is by no means required; some very successful free and open source software projects have only a few serious contributors, while others have thousands.

Extraordinary efficiencies occur when the tools of innovation are shared, are dynamically enhanced, have increased levels of confidence (legal and otherwise)

How Do you Make Money in Open Source?

Free and open source software has rapidly engendered highly productive and profitable business models that create value from the non-rivalrous[2] use of software components. Examples of such software include the famous Linux operating system, the Apache web server, databases such as MySQL, myriad programming languages such as Perl and Python, and the Firefox web browser. These types of open source projects, co-developed by thousands of programmers, and shared through creative licensing which demands covenants of behavior rather than financial consideration from the licit community of users, have transformed the information and communications technology (ICT) sector.

Most of the high-profile free and open source software projects that have affected both the sector and the public's imagination have been "tools" and platforms, rather than end-user applications. These allow users to build fully commercial web applications, with high functionality, on robust, dynamic platforms, with no reach-through financial obligations. The economic success stories of free and open source software thus are not Linux and Apache, but eBay and Google. The business models that are shaking the ICT world are not the modest ones selling support for open source products, such as Red Hat Linux. The signal successes are commercial enterprises that create wealth by providing new social value. Many ask, "How do you make money in open source?" The answer: you make money not by selling open source, but by *using* open source.

associated with their use, and are low or no-cost. Rent extraction from the process of innovation is reduced, transactions costs are minimized and developers focus their resources on creating revenue by providing products and services and enlarging markets.

This concept is fully generalizable—although clearly the specifics are not—and a large part of CAMBIA's BiOS initiative explores and extends the software metaphor. BiOS strives to create new norms and practices for dynamically designing and creating the tools of biological innovation, with binding covenants to protect and preserve their usefulness, while allowing diverse business models for wealth creation, using these tools.

In the first part of this paper I discuss the simultaneous burst of knowledge in molecular biology and the precipitous decline of a commons of tools, using examples from plant biotechnology. I develop a practical model of innovation, highlighting how biological innovation is stymied or deflected to high margin applications if tools are not freely available, continuously improving and embodying the permission to deliver work product into markets. I explore parallels, divergences and resonance with open source paradigms in software engineering. The rest of the paper focuses on CAMBIA BiOS Initiative activities: the BiOS Framework, the PatentLens, and the BioForge, and the creation of a "commons of capability" through which new actors, including farmers and small-to-medium enterprise, can use science to create viable innovations relevant to their needs.

POWER, TOOLS, AND THE COMMONS OF CAPABILITY

Twenty-eight years ago, I began a project to develop a set of tools—of techniques—in molecular biology that could help researchers in that field visualize how genes and cells functioned. Like virtually all scientific work, and most technology development, it was inspired and informed by what came before. And like all tools and methods, it depends on the use of other tools and methods.

Some years earlier, Ethan Signer, Jonathan Beckwith, and others had made a remarkable contribution to our toolkit for understanding how genes worked in bacteria. They conceived of a single tool that would allow scientists to learn how genes turn on and off in a bacterium. The tool "hooked up" the beta-galactosidase gene (called lac) for which they had simple measurement tools and assays, to another gene (called trp) for which measurement was difficult, but whose behavior they were keen to understand. In so doing, they measured the trp gene by actually measuring lac. This *tour de force* of microbial genetics used publicly available technologies and methods—in fact it was then unthinkable that there would be any other kind. This occurred well before the advent of recombinant DNA, which now allows apparently sophisticated genetic experiments to be done very simply. And it occurred well before anyone had even contemplated patents on life sciences.

Years later, I thought, why not use the same concept to understand how cells in animals and plants work? Why not have the organisms talk to us about their environment, through their genes? I set out to develop a parallel system, using a different enzyme and gene that could function in these new organisms. The one I chose was prosaically called GUS.

As I worked, I became increasingly aware that the availability of tools, and their capabilities, completely dictated the science that was done, and who was doing it. As an undergraduate at the University of California and the University of Edinburgh, I worked in some of the key laboratories responsible for inventing recombinant DNA methodology. I watched, time and again, how an entire field of scientific endeavor would almost instantly change course when a new technique—tool—was provided.

I became increasingly aware that the availability of tools, and their capabilities, completely dictated the science that was done, and who was doing it.

When I first developed the GUS technology, the scientific community I was originally working within—which studied animal embryo development—was not very interested; the tool just wasn't needed much. My first paper on this topic was received with an ill-stifled yawn. But I moved my interests to plants and agriculture, during the heady dawn of plant molecular genetics.

Efforts to transfer beneficial genes into key crops such as cotton, soybean, maize, and rice were running into a brick wall. There was no way to visualize success, nor to measure and improve on first steps. The GUS reporter system made visualizing genes and their action in plants very easy and efficient—it was proving to be a very powerful tool at the right time.

In 1985 I arrived for my postdoctoral research at the Plant Breeding Institute (PBI) in Cambridge, England, a vigorous international group of colleagues who were at the cutting edge of technology development and exploration in molecular plant sciences. The Plant Breeding Institute was also one of the few sites in the world that combined the patient and disciplined craft of successful agricultural innovation, such as plant breeding and agronomy, with the impatient and fermenting world of molecular biology. As well, the Plant Breeding Institute was still at that time an entity focused on the public good, a non-profit institute that earned substantial income for the U.K. government through royalties on its own crop varieties.

At Plant Breeding Institute, my colleagues[3] and I designed and conducted the first field test of a transgenic food crop. It was also the first BioSentinel experiment: a gene we wished to study was fused to the GUS gene, to conduct a field trial asking a fundamental question about how genes act under field conditions. We used public money, in the public sector, to ask a fundamental question for the public. The field was planted on June 1, 1987—completely by chance one day before Monsanto's first field trial. The lessons of the field trial were fascinating. We found that gene activity in a field is extraordinarily variable, and our preconceived laboratory-based notions of how genes worked would turn out to be very inadequate when dealing with field populations. Our technology, though cutting-edge, was not up to the questions that real-world agriculture presents.

The Plant Breeding Institute was an international institute, with students and scientists from all over the world. The institute had a reputation for brilliant wheat breeding and genetics, so most of the countries whose agriculture depended on cereal production would send their scientists to us for training. Many of the students and postdoctoral fellows in the Molecular Genetics department came from India, Pakistan, Turkey, the Middle East, China, Africa, Latin America, and Eastern Europe. Most of them indicated that this period in Cambridge was their one shot at career establishment. If they published a paper or two in a good journal, they had a reasonable chance of employment back home. And some of them confessed that they likely would not be able to use the new biotechnologies to effect any change in their home agriculture or economy. Not only did they lack the finances and infrastructure to make use of these high-tech tools, but the tools were better for science than for problem solving.

These people were exemplary of perhaps the most crucial but neglected resource for social advancement through science: dedicated and capable people. I observed, however, that instead of using their own experience to inform the science that was being done and the technologies being developed, their own worldviews and self-images were rapidly aligning to the incentive and reward system of the prevailing and fashionable science trends. And their energy to change the options in their home countries was dissipating.

By early 1987, after intensive experimentation in-house, we had assembled hundreds of copies of a GUS kit of dozens of DNA molecules and a comprehensive "how-to" manual. I rewrote the big "GUS Manual" and sent it to a mass-mailed newsletter called *Plant Molecular Biology Reporter*, which was distributed free to thousands of scientists rather than initially publishing a peer-reviewed scientific paper, which I eventually did.[4] The grapevine is also a powerful communications tool in science; soon many people were hearing about this new technology that would let them see the cells and tissues where their gene was functioning. It would also allow let them optimize gene delivery experiments; this was an urgent priority for both industry and academia. At that time no important commercial crop had been genetically engineered, so requests started flooding in for the GUS system. And I started sending out hundreds, even thousands of samples, and the User's Manual, all with no licenses, to scientists in dozens of countries, in both the private and public sectors. I only included a letter saying that while I had filed for a patent on the system, I wanted everyone to use it, and royalties—if any resulted—would go back to creating the next generation of technology.

I sent the kit to scientists at Agracetus in Wisconsin who were working, with little success, on transferring genes to soybeans. They had no idea if the genes they were introducing with their new process were actually making it into the right cells. One of those scientists, Paul Christou, told me of their thrill when they were able to immediately visualize gene transfer with the blue color of the GUS test, and soon succeeded at introducing genes into soybeans for the first time. And they could only do it with GUS, which also had no apparent restrictions. They were delighted, of course, as was Monsanto, for whom they worked.[5]

That work with GUS turned out to be the single biggest money maker in plant biotechnology, possibly ever in agriculture. Monsanto developed its RoundUp Ready™ soybean line, which it ultimately used to breed most of the transgenic soybean plants now covering the world, using GUS to select plants.

Within a year after we began widely distributing the GUS technology, hundreds of new avenues of plant science were emerging. Within two years, breakthroughs in maize, soybean, cotton, and many other crops occurred.

Within a year after we began widely distributing the GUS technology, hundreds of new avenues of plant science were emerging. Within two years, breakthroughs in maize, soybean, cotton, and many other crops occurred. New technologies were invented that used the tool in its very creation and optimization, such as particle bombardment (the tool that Agracetus had been exploring) and critical improvements were made to core technologies such as gene transfer by *Agrobacterium*. GUS demonstrated that one powerful new tool, widely distributed, could rapidly change an entire field.

The idea of *intentionally* changing the directions of inquiry and the demographics and economics of problem-solving by designing and providing new tools would shape the next thirty years of my professional life. With increasing exposure to the realities of practical agriculture, intellectual property, policy and business, my definition of "tool" matured. It came to include not just the technologies needed for scientific investigation, but also the critical normative, economic, policy, legal and business instruments to convert investigation into socially and economically sound innovations. A business model really can be a tool.

Enclosing the Toolkit: The Case of *Agrobacterium*

But while this period hinted at the vast potential for new tools emerging from molecular biology to lead to rapid innovation, it also saw the rush to privatize the kinds of tools that had always been seen as a commons, as exemplified by the adventures of *Agrobacterium*. When I started to work at Plant Breeding Institute, plant molecular genetics was in its infancy, and only three or four major institutions had serious capability in this nascent field. All of them were using

Agrobacterium-mediated transformation as their fundamental tool for transferring genes to plants.

Several years earlier, several public research teams had discovered an astonishing biological phenomenon.[6] A soil bacterium long known to be the agent of a familiar plant disease called crown gall was found to cause these tumors on plants by a hitherto unforeseen mechanism. The bacterium—*Agrobacterium*—actually inserted into the plant, by "natural" genetic engineering, a component of its own genome, and in so doing reprogrammed the plant to produce a "gall" and new food for the bacterium. This phenomenon, a sort of biological Trojan horse, was thought to be unique in the biological realm. And everyone in plant biology saw that it was to be a critical tool in the development of new options of biotechnology.

> [T]he contents of many patents were breathtakingly obvious to all practitioners in the field, but for small- to medium-sized enterprises these patents still served as a real disincentive to innovate.

The groups that first made the discoveries were all in the public sector, funded largely by public monies; they could all see that *Agrobacterium* would be a fundamental tool of the field. In spite, or perhaps because of all this, the gold rush for patenting started. And not only did the pioneer groups in the field file patents; over the next twenty years over a thousand patents were filed—and granted in many nations—that covered various aspects of *Agrobacterium*-mediated gene transfer. Some were so minor and trite as to be laughable were they not presumed valid by law, but they still produced a thicket of rights, nearly impenetrable even to the specialist.

And of course the pioneering patents were fought over viciously. To monetize the patents, the rights were sold to the highest bidder. But the rights were not clear; bitter wrangling over primacy with the fundamental patents continued for almost twenty years before any legal clarity emerged. Of course the winning bidders ended up being large multinational companies, notably Monsanto (either directly or by acquisition); and in most cases the payments to universities and institutes were negligible or even negative. But the effect of increasingly consolidating these patents in a few hands was anything but negligible.

Soon, public and private sector scientists were patenting their developments as a matter of course. Some of these findings became powerful patent estates that potentially blocked most of the world's agricultural enterprises from using these tools without permission, often at any price. For example, Japan Tobacco discovered and patented a method to use *Agrobacterium* to transfer genes into rice and other cereal crops.

The case of *Agrobacterium* was repeated with many subsequent technologies, ranging from genetic selections, to the wholesale patenting of promoters and genes,[7] to gene inactivation technologies (such as RNAi and co-supression). Again, the contents of many patents were breathtakingly obvious to all practitioners in the field, but for small- to medium-sized enterprises these patents still served as a real disincentive to innovate. They also extracted huge rents from industry, and raised transaction costs to an unbearable level, mostly because the patent landscapes were so opaque and complex. This trend has accelerated markedly and now applies to medical as well as agricultural technologies. The consequences are clearly that only the biggest-ticket targets are getting attention. But blockbusters alone don't make for good agriculture, good environmental management or good public health.

In 1985 the sector was viewed as exhilarating, entrepreneurial and vibrant, with almost unlimited possibility for doing good in world agriculture; within a decade or so it had all but stalled into a corporate oligopoly, with vertical integration, ossified and oppressive business models, and massive patent portfolios tying up almost every key technology and platform used in the field. And though nearly all the pioneering discoveries were made in the public sector, they were not reserved for public use or for the small-to-medium enterprise sector that the public trusts. It is no surprise then that the public now views the entire agricultural biotechnology sector—as manifest in the outcry against GMOs—as being a tawdry exercise in failed promises, industry consolidation, public sector abandonment and simplistic agendas. Perhaps the greatest crisis that has emerged from this corporate control of problem-solving in agriculture is that the public now seems to have very little confidence in the use of *any* science in agriculture! This has indeed been a case of throwing the baby out with the bathwater.[8]

Biotech Bazaar: Tools for Sale

At the Plant Breeding Institute, I was working with colleagues from scientific cultures that had historically used the discoveries and technologies that came before to grapple with the next generation of scientific challenges, with the tacit understanding that this process would naturally yield real-world solutions, such as plant varieties and agronomic processes. After all, the Plant Breeding Institute paid its way in the world by doing just this.

But that world was collapsing. The distinction between discovery and invention was being blurred as patents were filed on each component; that process entirely altered the dynamic of translation into true innovation: delivering the products of science and technology to the marketplace. It was now possible to control the tools and platform discoveries themselves, not just the products that they created.

In the early 1980s with the passing of the Bayh-Dole Act, universities in the United States were actively encouraged to patent their work products. The Act's fundamental policy goal was to see publicly- funded science and technology better used by society, by encouraging industry to adopt it. The trend of public agencies using the patent system exploded internationally into a filing frenzy. No one foresaw then that the fragmentation of the platforms and tools would make it so complex, so expensive and so intractable to assemble the "freedom to operate and freedom to innovate." Nor did we see that the resulting innovations themselves would be so few, so stodgy, and so slow to reach the marketplace.

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At almost the same time, the advent of recombinant DNA and the ability to determine DNA and protein sequences massively increased scientists' ability to explore, understand, and manipulate living systems, or at least living organisms. So every new life sciences discovery could be, and often was, dressed up as an invention and subject to patent; as the patent claims were granted, they cast a huge net over the possible options. Public sector coalitions would frequently compete with private big-science, and who usually won the plum of patent monopoly? The privatized efforts. Was this right, or necessary?

I began my own foray into patents and their importance when I arrived in Cambridge in 1986. I discovered close relationships between some large companies and the public-sector institute where I was based, shaped by personal histories and friendships. I didn't view this as a bad thing. I shared all my ideas and technologies with them from the outset. In fact, I shared with pretty much anyone who was interested, thinking that—in economic terms—my ideas were non-rival; sharing didn't cost me the ability to use them myself.. How wrong I would later prove to be.[9] And how times were changing.

One company, ICI,[10] was keen to use GUS in its commercial development programs; like many companies it was mostly interested in having clear rights to do so. ICI suggested that I patent my technology so it could be sure it would have access to GUS in the future. I didn't understand the logic at the time, but I took the first steps and filed a patent in the United Kingdom and the United States, with a filing date in 1986. The University of Colorado, where the first stages of the work had been done, had waived its interest in patenting it.

Thus began a long and painful learning process of partnerships with powerful attorneys in which I watched patent-Craft by The Masters. It took almost seven years for my first patent to issue in the USA, and nine years for the one with most of the valuable claims. Even when it was issued, complex agendas and issues[11] kept me from licensing the patents or even having a clear title for quite some time. This delay wrought havoc with my ambitions to use patents to create and fund CAMBIA, and when revenue did come in, it was in sporadic bursts, and barely in time to make payroll.

As a technology, GUS has had a surprisingly long shelf-life, and is unusual in being a largely stand-alone technology. If one has the "right" to put a gene into a plant, GUS remained a useful and legally usable tool to monitor that gene and its activity. But it turned out that even that right, the legal permission to transfer a gene to a plant, proved to be a critical and contentious issue because patents are opaque and licensing rights even more so, and because advances in the life sciences are so interdependent.

Wheels and Spokes: The Interdependency of Technologies

The patent system is so complex it is almost awe-inspiring. Single patent documents can run to hundreds of pages, with arcane language that few understand, and rights that courts interpret and re-interpret on the fly. Thousands of these can exist in a single field of innovation, with many thousands more latent in the system. One or two—or none—may be, or may unexpectedly become, dominant. Fundamental biological processes, such as the ubiquitous gene-regulation mechanism, RNAi, have been patented. Most of the important genes of many important organisms—humans, rice, maize, mice- have been subject to patent applications and sometimes grants, many of them contestable by many separate claimants. The platforms on which we must build are privatized and enclosed, but the owners and their ambitions are completely unclear; the platform for future innovation is built on shifting sand.

But worse, while the ownership of the "patent" itself is usually a matter of public record, the ownership of the *rights*—the most important feature of a patent — is completely obscured. Nowhere, in most jurisdictions, is there recorded or available the patterns of power: who owns what rights. A university may own hundreds of patents, and may have sold off the rights to any of the useful ones, but who bought them? The answer is rarely clear.

When a small company licenses a patent, or develops its own patent portfolio, to whom has it licensed and on what terms? The patterns of power and ownership are as important—and in the aggregate perhaps more important—than any other feature of a patent grant. And yet we have no public information whatsoever, except in piecemeal and scattered disclosures. Some jurisdictions, including Brazil and France, do impose a responsibility on licensees to disclose—at least to the patent office. But most do not. And none make it easy to find this information. This makes it difficult, if not impossible, for a researcher in a small- or medium-scale enterprise to assemble all the licenses or capabilities needed to refine and adapt a tool and ultimately to create an innovation that will help meet basic needs.

And researchers need this information because few discoveries stand on their own, and even fewer inventions. Not only do they each depend on the pre-existing knowledge base; they almost always incorporate components of many other technologies in their execution. This is particularly true of "meta-technologies," tools and technologies with broad effects used by communities of innovators quite distant from the tool's original inventor.

Consider the wheel, perhaps a six-spoked wheel. In some ways, it is the most fundamental and important tool in society. It has countless uses unanticipated by its inventors; most were made by people who are not wheel-builders. The wheel is only useful when it is used for something, such as moving a cart; its economic value to society lies not in the price of the wheel, but in the wealth created through the use of the wheel.

Virtually all the practices of academic scientists promote the belief that "good science" can, almost by magic, transform itself into public or private goods. It can't.

If it takes all six spokes for this wheel to turn, and each of these spokes is potentially different in some way, we have a good metaphor for a modern biological technology. Increasingly, biological technologies are not self-contained; rather they are rather interdependent technologies that require multiple key methods and components to function. If one spoke is withheld, no wheel is built. If one spoke is broken the wheel will jam. And then the cart cannot move forward. By analogy, the most powerful technologies can be considered as "wheels," requiring a number of "spokes" to function. For instance, the ability to transfer a gene to a crop plant may require dozens of individually protected, discrete technologies. Denial of access to any one of these "spokes" obstructs not only the use of the technology, but its improvement. Only when the core technology is in place, with full functionality, can it be subject to iterative and cooperative shaping to meet diverse users' needs.

Unfortunately, even placing one or more key methods or components into the public domain allows no leverage to bring other components into a collective whole with broad access. Virtually all the practices of academic scientists promote the belief that "good science" can, almost by magic, transform itself into public or private goods. It can't. In fact, by failing to deliver such goods with broad and preserved access, the public sector science community is complicit by neglect, because the true stranglehold rests where much less public sector effort is expended: in the process of converting invention and discovery into innovation, by building and using wheels.

But we can change this landscape, if we provide one or more of the spokes to all the wheel-builders and users with covenants of behavior, rather than financial consideration (outlined later as BiOS licenses). If a user can access a spoke only by promising to share spokes, or improvements, then the whole logic can change.

This is where we find the leverage: change the logic of copyright licenses in software to allow free and open source software to exist, and do the same for patent licenses or Materials Transfer Agreements (MTAs) in BiOS. Then we can regain a full complement of spokes, and see the "wheels" of real innovation turn rapidly and deploy on many roads, creating wealth through their use.

How Fear, Uncertainty, and Doubt Can Deter Innovation

Uncertainties over intellectual property rights undermine the long-term and sustainable pursuit of innovation by making projects look more risky to potential partners and investors. This risk combines with others characteristic of early stage technology development: lack of a fully-specified business model, concerns over potential technology effectiveness, and the absence of a well-established delivery channel. Together they generate the fear, uncertainty and doubt (FUD, in the awkward but widely used acronym) that is the core impediment to technology development. Currently, every worldwide industry that depends intensively on science and technology experiences FUD. Sometimes a competitor is the focus; sometimes the bleak patent situation alone can lead an investor, client, customer and/or the public to lose confidence in the prospects of creating a viable technology-driven enterprise.

In the face of the uncertainties associated with the complex and opaque patent situation, multinational private-sector firms have responded by acquiring large IP portfolios and negotiating cross-licensing arrangements to obtain platforms of enabling technologies. Even so, these companies still often find themselves with constrained freedom to operate. Faced with the uncertainty of patent rights, they seem to be involved in a sort of mutually assured destruction.

In contrast, the public-good sector, and small-to-medium enterprises have only fragmentary portfolios, often made up of publicly-developed technology and modest non-fixed capital pools that they believe can be expanded by their eagerness to license them out, but they are at a grave disadvantage; they face a monopsony.

Unfortunately, this approach not only destroys public value and confidence; it is also ineffective in ensuring a sustainable private competitive advantage. As the expense of sequestering intellectual property outside the public domain in iterative patents has increased, some leading technology firms have decided that an open source model may yield higher private, as well as public, returns. A notable example is IBM Corporation; in a bold recent move it is stimulating a universally accessible "protected commons" of patents in a pool available for any open source development. As the world's largest patent holder, IBM could be viewed as a "rights maximalist;" over 500 of its key software patents have been made available to all—including competitors—who choose to use them under open source rules. Within days, Sun Microsystems followed suit with another 1600 patents, and a myriad of other companies are doing the same. The snowball effect continues, as companies realize that their sector makes progress when the standards and the toolkits are clear, open, of high quality and consistently available.

Clearly, true wealth creation will come not through extracting rent from a tool, but through *using* a continuously improving toolkit, with continuously decreasing costs of innovation and a continuously expanding group of tool users. Diverse and prosperous agriculture, robust public health and sustainable natural resource management are the publicly valuable goals we must keep in clear sight. The tools associated with their improvements must be plentiful, powerful and affordable.

As the ICT sector realized, we also need an open source movement in biological innovation that can empower public and private sector innovators with the tools, platforms and paradigms to allow rapid and efficient life-sciences innovations for neglected priorities and new opportunities.

CREATING CAMBIA, MAKING CHANGE

In the mid-1980s, when I first formulated the ideas that became CAMBIA, I did not intend to build an institution; I spent much time between 1987 and 1990 trying unsuccessfully to convince universities or later the United Nations or the CGIAR[12] system to take on and host CAMBIA's mission. But the complexity and edgy nature of the mission, the need to integrate diverse skills and strategies, and the entrepreneurial spirit, ultimately required an independent base.

In early 1992 I moved to Canberra, Australia, to begin a project on behalf of the Rockefeller Foundation, troubleshooting its rice biotechnology network in Asia. At this point CAMBIA was not a legally incorporated body, but had reams of letterhead and surprising credibility. Our job was to travel to virtually every laboratory in the developing world that had Rockefeller Foundation support—and over the next eight years this must have been hundreds—to help develop, improve, and apply their biotechnology capabilities, especially as they pertained to rice molecular biology. We developed and provided to many hundreds of labs—perhaps over a thousand—the most effective and widely used "vectors" in plant molecular biology, the pCAMBIA series, and provided courses and workshops in the science and increasingly over time, in intellectual property management. In hundreds of working visits to China, Indonesia, India, the Philippines, Thailand, Vietnam and many other countries of Asia, Africa and Latin America, we forged a sense of the possibilities if we had new types of technologies, and new communities to improve and share them.

During these years, as we became more sophisticated about licensing and understanding the patent systems, we also became more aware of the yawning gulf between biotechnology rhetoric and innovation realities in most of the world. On the one hand we saw a large, untapped population of dedicated and knowledgeable problem solvers, committed to solve problems of real substance to their countries and peers—but they lacked the usable technologies that would improve their situation. We also saw that the science itself was not up to the job: The research being conducted in the early days of plant molecular biology (and sadly still now) is intensely reductionist, whereas the problems of agriculture and society are integrated into complex systems. On the other hand, if we could design and provide tools that fit the problem and the hand of the tool-user, we could rapidly and effectively change the entire platform of problem solving, as long as the tools were dynamic and could embody the permissions to integrate into real-world innovation. CAMBIA was conceived to integrate and to address these issues.

Outlined in the earliest CAMBIA prospectus was the premise of using patent revenues to create a sustainable funding base. We surmised that we would ask a fair, tiered licensing fee of each company that was using the technology, proportionate to their ability to pay. A big company pays a lot, mom-and-pop companies pay peanuts, developing countries pay nothing. Then we would use the resulting revenue stream to invent and distribute the next generation of technology. At the time it looked like a logical and efficient way to move the sector forward with fair and open competition, not for the capability to innovate, but for the innovations themselves.

This worked to some extent, in that CAMBIA exists and might not have done so without patent revenues. Companies that licensed the technology range from giants like Monsanto, Dupont, Pioneer, Bayer, BASF, and Syngenta down to entities as small as the Hawaiian Papaya Growers Cooperative. But we also realized we could not generalize or scale it as a business model in the current climate of fragmented rights and capabilities. The transaction costs of negotiating licenses, as more and more "spokes" were required to move forward, would simply be impossible to bear for any but the highest-margin applications.

CAMBIA addresses these challenges through three interdependent activities:

1. *The BiOS Framework* creates, validates and promulgates licensing tools, along with the norms and new business models to make use of strategies for "open source" creation, improvement, and sharing of enabling technology.
2. *The Patent Lens* is a platform to focus, understand, and investigate the patent rights and to inform practitioners and policy-makers.
3. *CAMBIA's own research* into creating and distributing key "pump-priming" enabling technologies is made available through our online interface, the BioForge.

The BiOS Framework

Biological Open Source is a nascent movement, evocative of the transformative changes in information and communications technologies (ICTs) wrought by free and open source software (FOSS). The two movements share some goals: seeing transformational effects on a sector, and increasing the democratic involvement in problem solving; we are learning many lessons from the software world, and will continue to. But it would be a mistake to push the comparison too far. BiOS concepts have emerged from twenty years within the life sciences and human development culture, to address the needs and challenges of biological innovation.

The idea of using patent licenses not to extract a financial return from a user of a technology, but rather to impose a covenant of behavior, is the single feature

Patent Lens: A Database for Understanding IP Landscapes

CAMBIA's Patent Lens includes one of the world's most comprehensive full-text searchable databases of patents; cost-free and available to anyone, it has a seven-year history of continued growth in features and power. It incorporates the full text of applications and granted patents from the U.S. Patent and Trademark Office, Patent Cooperation Treaty (PCV) database, European and Australian jurisdictions, and their status and family relationships in many dozens of countries. Its fast and user-friendly search engine has a nuanced interface and presents common and harmonized data structures so that these jurisdictions can be searched simultaneously.

The Patent Lens is becoming an increasingly important resource as the fee-requiring "value-added" patent data providers continue to consolidate. Because no national patent office has taken on the task of harmonizing collections over many jurisdictions, the role of the "patent clergy' remains central, and the gate-keeper functions of the information providers remain onerous. National and regional patent offices provide quite variable free patent searching; some are appallingly primitive while others, like the European Patent Office, are quite sophisticated. Patent offices, however, have complex relationships with commercial providers such as Thomson, which actually provide the patent offices with integrated searching functions for their own in-house use. To further complicate the situation, commercial providers have been calling for a reduction in the role of national patent offices as "value added" providers. The need for a public good provider has never been greater.

Patent Lens focuses on user-adaptability, integration, annotation capability and availability to the world community for free; these key features render it particularly helpful in efforts to restore public good and transparency as the *raison d'etre* of intellectual property systems.

Technology Intellectual Property (IP) Landscapes

IP Landscapes are analyses of key platform technologies, and the IP positions associated with their development and use. They build on and use the patent database, but include much more than a collection of relevant patents. Each landscape is a searching and analysis effort involving many person-months, by CAMBIA staff and soon others, who have particular knowledge of the science and technology and of patent claims. Typically, patent "professionals" within law firms accumulate billable hours by providing the same information over

of BiOS that is most resonant with Free and Open Source Software. We[13] worked with small companies, university offices of technology transfer, attorneys and large multinational corporations to understand their concerns and experiences, and then create a platform to share productive and sustainable technology.

and over for different customers, and charging full fees again to update them periodically. Increasingly we wish to do something no fee-requiring patent data provider will ever do: turn the landscapes into living repositories of constantly updated information, so no more updates will ever be required.

The goal is to use the harmonized datasets to create a facility where distributed and diverse users can generate, link, and dynamically annotate patent landscape analyses through web interfaces. The landscapes will ultimately become maps and decision support tools so users can distinguish greenfields from minefields in the long path from discovery to practical delivery of an innovation.

We have created a substantial number of such landscapes, in an early, hypertext-linked but basically flat structure. But we aim to enable the preparation of many more, by many people, by leveraging informatics to create ready frameworks and linkages between world patent literature and such resources as PubMed Central, and Google Scholar whose relevance engines can enrich the process. Ultimately we see the navigation of technology landscapes as being a critical feature in research and development decision making, but people will only use them when their costs, in both time and money, are negligible and the relevance and utility of the guided decisions are clear.

Patents, Policies & Practices

This component includes tutorials that guide users in reading and interpreting patents; the aim is to make novices more sophisticated about the nuanced realities of intellectual property, particularly patents. It also includes Policy & Practices papers that describe and advocate for informed and productive changes in international, regional and national forums and laws.

The goal is to forge a learning resource that participants in innovation systems at all levels—scientists and engineers, business and legal professionals, citizens and policy-makers—can use to learn of critical and timely issues relevant to improving the public good and social and economic value by engaging with the patent system.

The standards of modern patents are widely viewed as execrable; though many patents are presumed valid by law, they are at best frivolous and often egregious. We aspire to provide the public with tools to recognize and overturn such patents where they undermine progress or are being used without a long-term and well-articulated stake in industry or society.

The basic premise underlying that license is that we would not charge any fee for use of the "basket" of technologies with the patent estate being offered. By making the license cost-free, we hoped to induce the most valuable contribution to the license community: "freedom to innovate." In exchange for full, unfettered commercial rights to our technologies, licensees are required to comply with three conditions:

- They will share with all BiOS licensees any improvements to the core technologies as defined, for which they seek any IP protection.
- They agree not to assert over other BiOS licensees their own or third-party rights that might dominate the defined technologies.
- They agree to share with the public any and all information about the biosafety of the defined technologies.

Several further features of BiOS Certified licenses are very important:

- The definitions are critical. The core capabilities (enabling technologies, platforms) and their scope must be carefully defined to allow confidence in the development of viable business models that use these BiOS licensed technologies.
- The BiOS License structure must be scalable, and it should be generalizable, capable of development within these guidelines, and overseen by diverse institutions. We recognized that different technology sets have very different implications in the innovation chain, and that the agreement must accommodate different sectors (e.g., agricultural and medical) and different economic circumstances (industrialized and less-developed countries). Therefore we developed a suite of licenses around several different enabling technologies CAMBIA developed. We created them around our own technologies to have first-hand learning platforms from which we could generalize and help others create their own BiOS-Certified programs.

As we have gained experience with our first-generation licenses through the concerns and suggestions of many licensees and potential licensees, we have aimed to create a "brand" of Biological Open Source (BiOS) that is independent of institution. The BiOS certification program will help ensure that core BiOS characteristics are sculpted into forms that allow institutions to preserve their own cultures and priorities. They may do this through the medium of patent licensing or through materials transfer agreements (MTAs), a common form of bailment used to provide materials for life sciences research, such as bacterial strains, plant lines, cell cultures or DNA.

The certification approach has been particularly valuable in software development, through the activities of the Open Source Initiative (opensource.org) which overseas the branding of such licenses associated with copyright of free and open source software. However, life sciences are extremely sector-specific and technology-specific, and it is impossible to forecast or fully anticipate the emerging patent rights; these facts complicate BiOS certification and licensing. Of course these same challenges also render patent-based BiOS licensing and MTAs even more necessary.

Patent Lens: A Facility for Understanding IP Landscapes

With funding from the Rockefeller Foundation, in 1999 CAMBIA began to develop an integrated, full-text database of patents in the agricultural sciences. Under the initial guidance of Dr. Carol Nottenburg, then CAMBIA's Director of Intellectual Property, the CAMBIA IP Resource became a prominent web-based data tool to investigate patents in this field. Over the years, both the ambitions and the capabilities of the CAMBIA Patent Lens team grew,[14] and PatentLens has now become one of the world's foremost cost-free resources for full-text searching and understanding patents in many jurisdictions and in all classifications. Patent Lens (www.patentlens.net) harmonizes, parses and presents worldwide patent and technology data in a full-text searchable and highly integrated manner.

However, it is much more than a patent database. PatentLens is an integrated response to the massive complexity and opacity of the world of patents. It is intended as a public platform to enable many actors to investigate and share analysis of relevant IP issues, and to foster community involvement in overseeing and guiding the patent system.

The patent system has grown so rapidly and become so complex and opaque that even the most privileged and skilled clergy of patent law can only parse a tiny area of specialized knowledge, and that tiny area changes daily. This fragmentation has made it almost impossible to thoughtfully and factually assess the consequences of action and inaction: How can the consequences of policy be modeled or validated when patents are treated as fungibles? How can efficient progress in sectors critical to social progress, such as health, environment, and agriculture, be secured when the rights are tangled in a skein of patents?

The goal of the Patent Lens is to use the power of informatics and community to harmonize and make transparent the world of patents, so that thoughtful individuals, institutions and agencies can guide thoughtful and humane reform of the innovation system and to spur efficient and socially relevant innovation. This is an essential platform if we are to make use of the patent system itself to expand and protect a technology commons, and to collectively target breakthrough inventions, work-arounds and "work-beyonds"[15] and to make thoughtful and informed partnerships.

BioForge: Field of Dreams?

BioForge was initially launched as a web-based collaboration platform to take CAMBIA's pump-priming technologies—including Transbacter (described later), a new generation GUS called GUSPlus, and a novel genetic fingerprint technology called DArT—and throw open the gates to enlightened self-interest. We wanted scientists to try Transbacter in diverse bacteria and crops to create an open source and effective toolkit. The first version of the web facility was based on a very credible collaborative software development platform created by Brian Behlendorf[16] and his colleagues at Collabnet. We had hoped—in retrospect, perhaps naively—to see a surge of interest: scientists from around the world, initially from the public sector, would register, log on, and offer to collaborate to improve these tools, and to share their thoughts and actions.

BioForge: The Challenge of Aligning Incentives and Rewards

In initially designing BioForge, we had hoped that scientists in public sector institutions would come to see the value of working together to build powerful common toolkits to solve problems. Clearly most public entities endorse and even encourage *the notion* of pulling together to solve intractable social and economic problems: market failures. Indeed, this is the best justification for the very existence of a public sector. But if the toolkit does not encourage scientists to solve problems for their self interest, it will be irrelevant. And if such participation carries a cost—in real time and resources—that is yet another disincentive.

Furthermore, while discovery and occasionally invention are activities within the public purview in universities and government agencies, innovation—the delivery of new and tangible improvements to society—is not. Hence it is not part of academic science culture to be aware of the challenges to innovation. Nor does academia do much to reward sharing. The metrics for success are almost always being "first" in a field of endeavor that is widely hailed as being important and timely. The grind of innovation, with its need for long timelines and the building of confidence at many stages of product or process delivery, has little appeal and less relevance to academic advancement. In fact, the market increasingly rewards those who monetize or sequester the necessary components of innovation—a perverse set of incentives if there ever was one.

The initial response was mildly enthusiastic, but within a few months we realized that the actual engagement and contribution of scientific or personal resources was miniscule. While the BioForge has almost a thousand registered users, very few of them have substantially assisted the listed projects, technically or scientifically. However, many of the registered users are from India, China, and other countries widely viewed as out of the mainstream of cutting-edge biological research. This may reveal a latent need or desire for a better-crafted collaboration culture. We also believe it reflects CAMBIA's reputation as a provider of enabling technology. Thousands of our pCAMBIA DNA vectors toolkits are in use in almost every country, so this "market" knowledge and confidence could also be skewing the numbers. Still, at this stage BioForge has yet to create a vibrant web-connected community that actually does anything. We use it constantly, as a transparent and inclusive "lab notebook" for our own work at CAMBIA.

To address the issue of enhancing contributors' reputations (see BioForge text box), CAMBIA has started a software development project called Karmeleon to create open source, modular, software-mediated reputation metric tools. We hope that people in many collaborative and distributive projects can use these tools, and tune them to their diverse needs, ranging from online review of scientific publications through to research collaboration and product development. Our premise is

Discoveries are routinely patented; while they are only part of the complex web of capabilities that must be aggregated to create wealth, owners can game them for short-term financial gain at the expense of sectoral progress.

Success with a BioForge project—or any cooperative project with long timelines and complex feedback loops—requires aligning incentives and rewards. The most prominent metric for academic advance is reputation, but the tools for recognizing and enhancing reputation are still very primitive, including publication in high-impact peer-reviewed journals and serving on committees and review panels to cement relationships.

BioForge lacks any mechanism to demonstrate its contributors' influence and success to the community at large, or to those entities and individuals that have power over professional advancement. It takes an exceptional scientist to work toward improving a technology if she or he has no personal stake in its success.

The long timelines of agricultural and medical research and product development all but forbid direct feedback when an innovation enters the marketplace. This is a key justification for vertically integrated companies: to ensure that managerial oversight creates these links. If we wish to see alternative, distributive innovation in sectors with such challenges, we must create intermediate, interconnected and valuable feedback that enhances contributors' reputations, as well as new incentive pulls to participate.

that individuals should be rated on their contributions by accredited (rated) peers in a transparent manner, but using sophisticated, multivariate metrics to reflect the complex and diverse nature of the value of their contributions. Beyond their professional value, these contributions can and often do have important community and utility implications.

If we make valid, less "game-able" metrics available, users can develop confidence in the value of one another's contributions, and provide rewards as their community norms dictate: career advancement, peer reputation, funding and so on. But the reputation metrics must be adaptable to the culture where the contributor is working and being evaluated. Our initial drafts of Karmeleon use three metrics: Community value, Utility value, and Professional value. Scores in each category in turn impact the "gravitas" of a user; we hope this will encourage more sensible ratings to emerge.

The first generation of BioForge taught us something fairly obvious: that the cultures of software engineering and the life sciences overlap very little. Software developers live online. Their tool—the computer - is their window to the Internet. Their product, software code, can be tested almost instantly and can be evaluated, rejected or accepted almost as quickly. The engineer can build on tested code, and be fairly confident of a secure base. In the life sciences, experiments can take

An "Apollo Project" for Biological Innovation?

Several months after we published our TransBacter paper in *Nature*, *Nature Biotechnology*—the most prominent scientific journal in the commercial biotechnology sector—published an editorial expressing skepticism that a true open source movement could happen in biotechnology, given the extent of entrenched norms and interests.[19] The title of the editorial, "Open Sesame," implied that a vision as clearly utopian and impractical as that of open source for biotechnology would need a magic incantation in order to become reality.[20] The article did conclude, however, that an open source movement in biotechnology might just take root if, in an "Apollo Project" of some type could be used to forge a common ground to develop new collaboration norms, tools, business models and science around some mutually agreeable and highly desirable goal.[21]

While we at CAMBIA do not agree with the editors of *Nature Biotechnology* that the only way forward for open source in biotechnology is a grand-scale "Apollo project" of the type they suggested, we do agree that it may be an attractive option

What would a 21st century Apollo project to spur biological innovation look like? If the BiOS Initiative and the movement need such a platform from which to explore, create and coordinate new modes of problem solving using life sciences, what will that platform be? First, the project would require a socially and economically highly desired goal for which a technological intervention of great promise can be articulated. The project would need to focus on catalyzing new opportunities for problem solving, not just on creating an

months or years; validation, scaling and quality assurance take even longer. And the process can be so expensive or so specific to circumstances that it may never be replicated by another entity.

We are cautiously optimistic that as we introduce new, recognized and respected "reputational" tools, if we nurture high profile and energetic champions for particular projects, and if we create new incentive and reward systems, we will be able to move the BioForge from a field of dreams into a productive and focused mechanism for distributive innovation.

Beyond the Thicket: Transbacter

By about 2000, my colleagues at CAMBIA and I had seen so much "me-too" science going on around the world and the vast increases in patenting and vertical industry integration. We also saw public support eroding for genetic modification and then for all scientific interventions in agriculture. So we decided it was time to act more aggressively.

imposed "solution." It would not have a linear impact, nor would it merely improve the cost effectiveness of conventional paradigms.

To engage both the scientific and the business community, such a coordinated effort would offer an intellectually exciting proving ground for new collaborative approaches and new science and must require interdisciplinary skills. The imagination and creative energy of science would be harnessed, but much of science is intensely self-absorbed. An interesting problem will attract much more attention than a mundane one.

The platform activities would afford opportunities for "spin off" value for other initiatives and activities, and would have impacts beyond its target goals. A broad constituency must see some merit in various components of the project—so that diverse, even divergent interests would build coalitions.

The project would also have a credible promise, or proof of principle.[22] It would not be too risky—or too safe. While it may be somewhat encumbered by intellectual property, it would not yet be completely constrained. If the target has a suite of challenging IP thickets, that would be a platform for new strategies—of decision support, collaboration and invention—to emerge, allowing us to hone these capabilities. It would be in a field with few entrenched interests, or those interests must be diffuse or distracted. If major economic interests push back too early, they could slow or stall the effort.

Finally—and critically—it would also be in an arena where civil society, industry and academia can engage constructively towards a détente, and where they can explore and validate new models of social enterprise and business, as well as new economic and innovation strategies.

We decided to attack the first and most prominent thicket of patent rights—that around *Agrobacterium*— which represented the beginning of the patent rush in agricultural biotechnology. We chose this technology not because we believe that it presents a unique or critical bottleneck to many new entrants into the sector, or because anyone has called for these patents to be revoked or broadly licensed. In fact, these tools have little market pull now. The "scorched earth" policy in the agricultural biotechnology sector has left virtually no inventive entities queuing up to develop products, and no public desire for such products.

Rather, we wanted to show the potential for a new combination: what if we combined patent informatics and transparency with creative, targeted scientific research, and new normative and licensing tools? What if we used it to build a true public commons of technology—or rather "rebuild" a public commons of capability. We sought not a silver bullet, but rather a platform to test and explore our hypothesis that in alternate universes of innovation, tools and foundational discoveries could be constantly improving common goods, and that prosperous industries and business could be built on them.

Assessing the Patent Landscape

In about 2000, we began a comprehensive analysis of the patent situation surrounding *Agrobacterium*-mediated gene-transfer (AMGT), the process I discussed earlier. We intended to publish a simple white paper describing this key thicket of rights. But the task proved much more complex. Ultimately we published the first analysis online; almost 400 pages, and covering the top few hundred patents,[17] it has since seen two major updates. Over 1000 users downloaded it. But as we began to realize the extent of the problem, we also realized that it could not be attacked piece by piece. As we analyzed the "patent landscape," we noted that all of the patents used a common language and set of definitions that dated to the original filings: that the inter-kingdom gene transfer was achieved as a unique event mediated by a particular bacterial species, *Agrobacterium tumefaciens*.

Definitions are the key to a patent; they are critical in a patent prosecution to establish the metes and bounds of the claimed invention, and to guide courts in the event of a dispute. And the pioneering inventions typically establish precedent that persists. In the case of *Agrobacterium*-mediated gene transfer, it was widely believed and promoted that *Agrobacterium* was a one-off; a unique situation in biology. To this day most scientific papers baldly state that it is the only such situation.

The Strategy

My logic, and that of most biologists trained in evolution, is that if something happens once in life, it probably happens many times—maybe ubiquitously. We think of a "one-off" because we can rarely see other instances. So I began looking for hints in the literature that other bacterial species could transfer genes to plants, either natively or with a bit of convincing. And I found hints aplenty. So we set out—again with support from the Rockefeller Foundation—to find or generate the capacity for benign plant-associated bacteria to conduct gene transfer, and thus to develop a system that would be competent to transfer genes to plants, which was not infringing any *Agrobacterium* patents. If we could do this, the toolkit would clearly fall outside all the patents over AMGT, rendering hundreds, even thousands of patents irrelevant as blocking tools, but useful as "background science and technology."

We further speculated that we would be able to develop a system that was not only free and clear of the onerous *Agrobacterium* thicket, but would ultimately be superior to *Agrobacterium* as a technology. *Agrobacterium* is a plant pathogen, which normally causes disease in susceptible plants. Plants—even non-susceptible ones—seem to know this, and become stressed. We reasoned that by using totally benign symbionts, we'd eliminate the stress on the plant, and open new opportunities for genetic enhancement. If we could make the technology more efficient and wide-acting than *Agrobacterium*, a wholesale migration to the use would occur, even by academics. This would infiltrate the new open source norms into that most conservative of communities.

The R&D

The process turned out to be more straightforward than most anyone expected, and we published our results, which described a new system called "Transbacter," in *Nature*[18] on February 10, 2005. After nearly two years of hard work by a skilled laboratory staff, we described in that paper how we had induced three different genera of benign plant bacteria to transfer genes to three different genera of plants. These plants included the world's most important crop, rice, over which Japan Tobacco held dominant rights, and broadleaf plants, over which Monsanto held dominant rights.

The capability of *Agrobacterium* to transfer genes to plants is virtually identical at a molecular level to the ubiquitous system by which virtually all bacteria exchange genetic material, and even by which proteins and other molecules are secreted. This similarity allowed us to excise and move this capability on a fairly well-defined DNA construct into the benign symbionts. We were able to test the system with the most sensitive tools in the sector: the open-sourced GUSPlus reporter system.

The paper received exceptional coverage in the press, ranging from the *New York Times* and *Science* to *Nature Biotechnology* and the *Economist*, but not just for its scientific contributions.

The BiOS Licensing Framework

To share this technology, perhaps counter-intuitively, we filed patents on it. At first glance, this is anathema to open sharing. But we were learning the lessons of positive selection and the ugliness of patent gaming and trolling (for an example, see appendix). As we developed the new technology we also developed, in parallel, draft licensing templates for a prototype "BiOS" license, as I described earlier. Two years later, we have over fifty licensees, including large multinational corporations, small companies, and diverse public sector institutions. We have recently streamlined this technology to be more universal and easily disseminated, and have distributed over 300 kits of the new materials. Traction is building as the technology is improving.

But this is not really transformative, merely illustrative and instructive. Real transformation occurs when completely new actors are brought into innovation systems, and when radically new options for problem solving emerge.

This is our next ambition.

BIOSENTINELS: A 3D VISION FOR EQUITABLE INNOVATION

The most powerful impact of the scientific method has been to help us understand what had been incomprehensible; it has also helped us visualize and measure the parameters of the natural world. The importance of measurement cannot be overstated. Without the ability to measure—to see the consequences of an experiment or intervention—we cannot understand it, or improve or build upon it. The future

The Role of Measurement in the Next Green Revolution

It is often said—and it is true—that the Green Revolution, which so transformed the agricultural and economic fabric of Asia and much of the rest of the world, passed Africa by. The Green Revolution is not largely about plant breeding, although the short-stature varieties garner great attention. Rather the great advances were in the availability and management of inputs in agriculture. Water, nitrogen, phosphorus, potassium, acidity and countless micro-nutrient and abiotic stresses can each separately and together constitute major production constraints, as well as input costs, to an agricultural system. Combine this complexity with the countless impacts of biotic challenges such as pests and diseases, especially cryptic or latent soil-borne diseases, and creating any kind of profitable and ecologically sustainable farming becomes horrifically complex in the best of circumstances. Little wonder that industrial agriculture's greatest successes—with their concomitant problems—come from homogenizing these environments with massive inputs and then breeding and managing these artificial and unstable conditions to get maximum yields.

These options are not available for transforming low-input, low-output agriculture into a prosperous enterprise. When capital, infrastructure and communications are precarious, it becomes even more crucial to accurately and judiciously source and apply suitable nutrition, and to guide management decisions well.

The management of natural resources, whether endogenous or enhanced by inputs, is the most critical and challenging bottleneck in agriculture. It will be the lynchpin of the next Green Revolution. It is also the component most amenable to measurement. But here is the conundrum: to have a sustainable and scalable impact, such management decisions must be made by local problem solvers, and many such people are extraordinarily poor. They cannot afford to measure, and they cannot afford not to.

of biological innovation will similarly hinge on turning the unseen into the seen, and to sensibly report on the world around us so we can better respond.

Most critically, we must *democratize* these abilities, both to measure and to respond, in order to *diversify* agro-ecosystems and environments and *decentralize* the problem-solving capability. We will achieve this by fostering scientific method and harnessing local knowledge and commitment in communities that have previously been ignored or treated as passive recipients of help. This is our 3D vision, and the BioSentinel project will be the platform for exploring and realizing this vision.

In many vineyards around the world, rosebushes are attractively located at the end of each row. This curious planting regime does not reflect some shared aesthetic among winemakers or grape-growers. Rosebushes are sensitive to certain fungal diseases that affect grapevines more than the grapes themselves. If they plant and observe roses, growers can easily see the early stages of fungal infection on the roses, and can take measures to prevent disease in the grapes. The rose is a natural BioSentinel.

For the last 15 years CAMBIA has been working on the components necessary to generalize this phenomenon.[23] Now, with the advent of new scientific understanding, new proofs of principle, and the BiOS Framework, this work can now be brought to scale. With initial support from the Lemelson Foundation, we are beginning to create an open source platform to use plants as versatile living BioSentinels to measure and report on the status of their environment.

[W]e are beginning to create an open source platform to use plants as versatile living BioSentinels to measure and report on the status of their environment.

Imagine a plant—not necessarily a food plant—that has been engineered as an instrument to produce a colour, a smell, or a shape that indicates the level of nitrogen or another essential nutrient in the soil. This plant will be developed in a collaborative, open sourced environment with components that are BiOS licensed and held in public trust. It will be a cost-free instrument that allows any farmer to better judge the condition of her cropping system, and to create wealth by making careful decisions, informed by measurements of the unseen parameters that influence her crop and its environment.

But the BioSentinel project involves much more than engineering one plant to make one color in a glasshouse. It is no mere academic curiosity. We intend to develop the platform to create a modular toolkit for the public and private sectors alike. We envision mixing and matching components to sense virtually any parameter (nutrient, water, pathogen), transmission of this signal via open standards, and reporting on this parameter with any of several different detection systems (color, fluorescence, smell, form). We also intend to consider all the quality assurance, regulatory and other parameters necessary for diverse collaborators to create practical and deliverable innovations. The BioSentinels will cost nothing to manufacture, once developed. They will cost nothing to use. But they will add value through the information they make available.

This platform will be built using technologies developed under BiOS license, guided by sophisticated patent informatics to ensure permissive use, and will pioneer new collaborative research methods that enshrine and perpetuate permissive use by all parties. The platform need not create GMO foods, but will create new communities of informed decision makers who are empowered to evaluate and improve their own ecologies and economies.

CONCLUSION

At the start of the twenty-first century, science is at a critical juncture. Four centuries of inquiry, discovery, and invention have created a base of knowledge that has the potential to provide people everywhere, in all circumstances, with nourishment, improved health, and longer life. But the institutional mechanisms that ostensibly exist to encourage the application of science to practical problems are today hindering that very process. The norms that have evolved around gate-keeping have created new clergy, new impediments and new inefficiencies. Without a systemic change, science's promise will not be available for those who most need it, and the promise of a truly diverse, robust and fair innovation culture may elude us.

Patents are at the heart of the system of institutions that convert basic scientific knowledge into practical applications. The modern patent system was intended to advance the public good by balancing the disclosure of ideas and the transparent definition of limited property rights. Today, it has degenerated into an instrument that is often misused to obstruct the public good through enclosure of ideas and obscure assertion of property rights that have no concomitant social benefit. To the shared dismay of both scientists and thoughtful citizens, patent systems and the myriad gaming practices they have spawned today are impeding innovation as a social enterprise, and continuing to deprive most of the world's population of such fundamentals as adequate nutrition, access to health care services, and clean water. This does not have to be. It is up to us to reclaim the beauty of science as a democratized tool for social advancement and wealth creation. It is up to us to write the terms of the compact. It is up to us to move beyond rhetoric and into constructive engagement in reforming our innovation systems for economic robustness and social justice.

We invite reader comments. Email <editors@innovationsjournal.net>.

APPENDIX. CO-OPTING THE COMMONS: A NEGATIVE EXPERIENCE OF POSITIVE SELECTION

For nearly seven years, with expenditures of over $100,000, CAMBIA has battled Syngenta, the large Swiss agribusiness, in European Patent Office opposition proceedings and appeals over the validity and scope of Syngenta's patents on "Positive Selection." These broad patents (e.g. EP 601092, but with counterparts in the USA) were granted with sweeping claims that conferred on Syngenta an absolute monopoly on "positive selection" in plants.

Positive selection is the provision of a benign compound—such as a sugar—that an organism cannot use without the action of a new gene; thus it "selects" for those organisms that have acquired that gene. Positive Selection is one of the most basic tools in genetics, used since the beginning of microbial genetics; all the bacterial genetics in the 1950's and 60's was based on one bacterial strain gaining the ability to grow on new sources of carbon and energy. When I started working with plants, it was thus immediately obvious to me (and presumably to anyone not employed at the patent office) that we could easily adapt this concept to plant genetics, to determine when a new gene had been added to a crop plant, and that a good first use would be my GUS gene.

So I began adapting GUS for this purpose, around the time I started sending out GUS kits and information, and giving hundreds of lectures on its use. While this mode of distribution was to dramatically change the field, it also allowed some aspects of the system to be co-opted. Our ideas and hard work were basically turned from "non-rival" goods that were available for all as we intended, into a private monopoly that could, and did, suppress innovation by competitors.

Scientists at a Danish sugar company, DANISCO, filed a patent well after I had given them the GUS gene, and after I had given public lectures on the use of GUS for such purposes. In this patent, they were granted broad claims to all uses of positive selection, with any compound and any gene in any plant. This breathtaking scope of claims was based solely on experiments described in the applications that used the GUS gene to activate a biological compound that would allow plant cultures that had GUS to stay green and be "selected." This was fundamentally what I had already reported at international meetings, with data showing that it worked. Like many scientists, when I reported it at international congresses, I intended to see it shared with everyone. DANISCO's intention clearly was not.

The potential value of this patent estate caught the eye of Heinz Imhof, then chairman of Novartis, who intervened personally to buy the patent applications from DANISCO outright. These patents then served as powerful ammunition in the patent war chest of Novartis, which went on to merge with other companies in the vertical integration frenzy of agricultural biotech, to become Syngenta. The evolving strategy of Mutually Assured Destruction by Patent Estate between the large multinationals required just such weapons.

The breadth of the claims as granted in Europe—together with their counterparts in the USA—ensures that any entity using the approach of conferring a growth advantage on a cell or plant to obtain transgenic plants would be infringing. This left only the use of antibiotic resistance and herbicide resistance as the means of selecting transformed plants. The adverse public response to such antibiotic gene use is well documented.

Thus the environmentally attractive and benign technology of cleaving a sugar and growing preferentially, with no antibiotics, was denied to the world's agriculture community by one group of patents, whose entire rationale was derived from work that I had intended to make public. But with the patent, it was "enclosed."

I had several meetings with Imhof and others at Syngenta; I attempted to make the case that using GUS to garner such a powerful and oppressive patent position was unjust and inappropriate and would ultimately be a pyrrhic victory for the sector. The discussions went nowhere.

So we made use of one of the few remedies afforded in the patent system to small players: the opposition process. Once patents are granted in Europe, they can immediately be challenged if one submits to the European Patent Office (EPO) prior art that had not been considered. Our contention in the EPO was that much public work, as well as my own work, including my public disclosure of the basic idea, pre-dated the filings and would thus invalidate the novelty requirement for the patent. We also argued that the patent was obvious in light of the pervasive use of positive selection in every other biological system for many years. We also asserted that the patent did not sufficiently enable one to practice the invention, and in particular, did not merit the breadth of claims granted.

The opposition process is widely touted as much more affordable than litigation. No doubt this is true. Instead of paying several million dollars to lawyers so we could be screwed by a multinational corporation in front of a judge, we only had to pay a hundred thousand or so for the same privilege, but in front of a panel of patent professionals. Of course reconsiderations of patent validity are conducted by the very same entity—the administrative machine of the patent office - that made the initial patent grant. So even in the face of what we felt to be compelling prior art, and convincing case law, the deck was stacked in favor of the status quo.

Watching the process, and the craft and gaming skills involved, was an eye-opener for me. Until one has actually endured the multi-year posturing, arguing, heartache and expense, there can be no clear way to convey the dysfunction of the system, or its debilitating effect on inventors. We achieved only modest inroads in restricting the breadth of their claims. But we did consume years of time and huge amounts of money, in a failed bid to restore for public use a key application of a technology that I had developed and had inadvertently let a multinational pull into its private fiefdom. The opposition process is not available in the United States, so the opportunity to lose extravagant sums of money there was denied to us.

What did Syngenta do with this technology? With the example they claimed using GUS, nothing. They never made a single product using that tool, nor did they develop it further. But they used the broad claims, granted by both the European and U.S. patent offices, to ensure that no other player—large or small—attempted positive selection without becoming beholden to them. Later, from DANISCO, they acquired other examples of positive selection protocols which worked pretty well and were protected under the umbrella of the broad claims, they made them "available" under a research license to unsuspecting scientists in the public sector. This "research license" strategy is one of the most pernicious co-opting approaches used by large private-sector companies. Once a tool is used under such a license, the only way to then release a product is through after-the-fact negotiations for a "commercial license." Several friends have gone through this process and reported a bare-knuckled strategy that gives the licensee almost no share in the benefit of the product they developed. Few takers, of course.

What are the lessons. Don't share? This is not a lesson I cleave to, nor a recipe for social progress. Could it have happened otherwise? Absolutely. This example was a case study of how "open source' licenses could be crafted and protect the public commons, yet allow the private sector to build prosperous businesses using that commons of technology. Perhaps I should have only sent the GUS gene and disclosed the information to those who agreed to terms by which they would share improvements that specifically used GUS; then the entire broad positive selection concept would likely have stayed available to all entities—public and private, large and small—that wished to explore its use. As would the many modifications on which others had filed patents. Just imagine: what would happen if the public sector technology transfer professionals had access to such a leverage tool to further the power of the commons toolkit and advance their mission?

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1. For example <www.opensource.org>.
2. In economics, a good is considered either rivalrous (rival) or nonrival. Rival goods are goods whose consumption by one consumer prevents simultaneous consumption by other consumers. In contrast, nonrival goods may be consumed by one consumer without preventing simultaneous consumption by others. Most examples of nonrival goods are intangible goods. (from Wikipedia, 2007).
3. Mike Bevan, my principal collaborator, went on to play a key role in coordinating the public sector sequencing of the Arabidopsis genome . Arabidopsis is the workhorse model plant of biotechnology, and was the first plant to have its entire DNA sequence described in the literature. The public efforts to create a public good, like some of mine, were likely co-opted by the secretive wholesale filing of patents on the Arabidopsis genome by Mendel Biotechnology, an affiliate of Monsanto. These patents have only recently surfaced (<www.patentlens.net>) but pre-dated the public effort by as much as two years, thus potentially capturing or hijacking much publicly-funded work, through a legal, though unpalatable practice called 'after-claiming'.
4. R.A. Jefferson, T. A. Kavanagh, and M. W. Bevan (1987), "GUS fusions: beta-glucuronidase as a sensitive and versatile gene fusion marker in higher plants." *European Molecular Biology Organization Journal,* December 20; 6(13): 3901–3907. Apparently it has been read often, as it has been cited in the scientific literature thousands of times. To our delight, however, the user's manual in Plant Molecular Biology Reporter has been similarly cited, and likely more influential, in the precursor to the Open Access publishing movement.
5. Monsanto later engaged Agracetus in a heated patent battle for the right to do genetic manipulations in soybeans, and ultimately purchased Agracetus and its patents. At this point the patents owned by Agracetus ceased being seen as reprehensible and unfair, and were defended as pillars of rectitude.
6. These scientists included groups led by Mary Dell Chilton, Marc van Montagu, Eugene Nester, Jeff Schell, Pat Zambryski and others, at the University of Washington, the University of Ghent, the Max Planck Institute, and elsewhere.

7 See forthcoming "Patent Landscape on Plant Genomes."

8. Jefferson, R.A. (2001). "Transcending Transgenics: Is there a baby in that bathwater, or is it a dorsal fin?," in *The Future of Food*," edited by Phil Pardey (International Food Policy Research Institute with Johns Hopkins Press), pp75-91.
9. See Appendix on positive selection.
10. Imperial Chemical Industries; its plant work was later absorbed into Zeneca and then into Syngenta.
11. More details on the complexities of this period can be found in Richard Poynder's online interview of me: The Basement Interview: Biological Open Source, <http://poynder.blogspot.com/2006/09/interview-with-richard-jefferson.html>
12. The Consultative Group on International Agricultural Research, <www.cigar.org>, a consortium of 15 agricultural research institutes and many governments, is the principal non-profit entity engaged in agricultural development through science for poverty reduction.

13. Dr Marie Connett, CAMBIA's Deputy CEO, a scientist, patent agent, and IP Manager, jumped into the deep end when she joined in 2005, and found herself working round the clock on creating the license, consulting with dozens of technology transfer professionals, lawyers, industry colleagues and scientists.
14. The Patent Lens was featured in an editorial in *Nature Biotechnology* (2006, 24:474), called "Patently Transparent" which was disarmingly positive about our PatentLens activity providing a critical breath of transparent fresh air to the patent frenzy that is creating a crisis in biotechnology. The PatentLens team, led for the last two years by Dr. Marie Connett, still has its original three software informatics specialists, Greg Quinn, Doug Ashton and Nick Dos Remedios, and has been strengthened by additional talent, including Paul Freeland, Neil Bacon and Josh Cole.
15. A work-beyond refers to a created technology which both bypasses and transcends the proprietary technology it seeks to replace. Transbacter, described later, is an example of a 'work around', which will become a work-beyond when its efficacy and uptake increases.
16. Brian Behlendorf is the Chairman of the Apache Software Foundation, and a driving force in the creation of the Apache Web server, one of the most widely used open source software tools in the world, with nearly 70% of the world wide web making use of it.
17. See <www.patentlens.net>. The first version was mostly a tour de force by Carolina Roa Rodiguez with guidance from Carol Nottenburg. -
18. *Nature,* 2005, 433:629-633. "Gene Transfer to Plants by Diverse Species of Bacteria."

19 An outstanding article by Kenneth Cukier appeared about a year later: "Navigating the Future(s) of Biotech Intellectual Property," *Nature Biotechnology* (2006) 24:249-251. It articulately described the increasing impasse in biotechnology caused by misuse of the IP system, and featured CAMBIA's BiOS Initiative very prominently and favorably. The metaphor Kenn used in this paper-that of maritime navigation and commerce - is extremely apt and informative. His paper is strongly recommended.

20. "Open Sesame," *Nature Biotechnology* (2005), 23:633. Clearly the authors did not have a young child to remind them that "Open Sesame" was the incantation that would open the cave in which thieves had already sequestered stolen riches, a suitable parable for the misuse of the patent system.
21. The Apollo project was the concerted effort by the United States government to reach the moon before the Soviet Union did. The long-term focus may have been to reach the moon, but the project's real purpose was to coordinate massive scientific, engineering and technological progress with industrial development, while building and preserving a societal and political confidence associated with success. It wasn't really about reaching the moon, it was about being able to reach the moon.

22 In the absence of jet aircraft, rocket propulsion and supersonic flight, the idea of space flight would have seemed ludicrous to many.

23. This work has benefited particularly from early contributions of Kate Wilson and Steve Hughes, both Members of CAMBIA, now with CSIRO and Exeter University, respectively. Summarized in, e.g. R. A. Jefferson (1993), "Beyond Model Systems: New Strategies, Methods, and Mechanisms for Agricultural Research," *Biotechnology R & D Trends*, Volume 700 of the Annals of the New York Academy of Sciences, December 21, 1993. pp 53-73; Wilson, K. J, A. Sessitsch, J. C. Corbo, K. E. Giller, A. D. L. Akkermans, and R. A. Jefferson (1995), "□-Glucuronidase (GUS) transposons for ecological and genetic studies of rhizobia and other Gram-negative bacteria." *Microbiology* 141: 1691-1705.

Sara Boettiger and Brian D. Wright

Open Source in Biotechnology: Open Questions

Innovations Case Discussion: CAMBIA-BiOS

The case narrative by Richard Jefferson in this issue of *Innovations* shows how the rate and direction of progress in biology is constrained by available tools; a novel tool can set the field on a new and more productive course, but only if creative scientists are free to use it. The history of β-glucuronidase (GUS) reporter genes illustrates the great impact a technology can have when it is novel, useful, and globally available on reasonable terms. Now Jefferson's energy is directed at restoring biotechnologists' global freedom to innovate, by "inventing around" essential, but proprietarily owned, research tools, and trying to ensure that the new alternatives remain freely available for use and improvement.

A key part of his program is the development of BiOS, an institutional innovation that applies aspects of the open source software model to biotechnology. Although the jury is still out on the effectiveness and sustainability of BiOS, Jefferson's detailed account provides a good foundation for initial analysis. Perhaps more important than his discussion of the BiOS model itself, however, is Jefferson's articulation of the intellectual property problems faced by innovators in biotechnology who want to see their efforts make a difference to end-users globally. What he has to say demands the attention of the many lawyers and economists who see no problems with intellectual property protection in biotechnology

Open source is currently one among several approaches designed to encourage broad based participation in research in biotechnology in the face of the restrictions imposed by intellectual property rights on key enabling technologies.[1] Open source in biology is a work in progress, highly experimental and controversial. This essay seeks to reach beyond the rhetoric of openness and transparency, to consider some of the challenges that confront the BiOS project, and some of the oppor-

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tunities that might be created in biotechnology in general, and agricultural biotechnology in particular, by open source innovation.

A DIFFERENT PATH

The GUS reporter gene and subsequent innovations, (and especially Jefferson's publication with almost 4,000 citations) are achievements for which many a professor would contemplate homicide. This narrative has a familiar ring to those who like to read the lives of the academic super-heroes. Outstanding student meets creative mentors on the cutting edge, encounters the right research problem in the wrong field, and ports the solution to the right application just when it is needed. The accomplishment is widely celebrated and the just patent reward is claimed.

While most lawyers and economists were still debating whether access to technology and freedom-to-operate problems even existed, Jefferson designed CAMBIA and, in turn, BiOS to tackle those problems.

But at this point Jefferson begins to steer his career away from the conventional, exhibiting reckless disregard of academic disciplinary boundaries and fiscal prudence. Many of those GUS citations, some might have noticed, were generated by his own efforts to disseminate the reporter gene technology far and wide in useful kits which enabled disenfranchised scientists in obscure corners of the world to do more effective plant breeding. Eschewing the single-minded pursuit of further publications and attainment of tenure, Jefferson turned to champion an international community of scientists, entrepreneurs, and farmers and their capacity to embrace the emerging scientific opportunities offered by biotechnology. Against the backdrop of such auspicious scientific potential, the constraints imposed by lack of resources and encroaching patent claims caught his attention. Had he followed Adam Smith's recognition of the key role of specialization in innovation and the social merits of selfish pursuing profit maximization, Richard Jefferson's career would have taken a very different, and less interesting, path.

Because he has played on both sides of the patent game in a rapidly evolving commercial field, he has had the opportunity to observe how patents can restrict, or even kill, promising technologies, and stifle the formation of startup firms that generate the flow of innovations to the end users. While most lawyers and economists were still debating whether access to technology and freedom-to-operate problems even existed, Jefferson designed CAMBIA and, in turn, BiOS to tackle those problems. His experience has earned him notable credibility in this debate.

OPEN SOURCE: FROM SOFTWARE TO BIOLOGY

The merits of open source (OS) in software, though still debated, are widely acknowledged. Some advocates of OS software, from its beginnings, have promoted its development with mystical zeal. But, over time, its success as a production model has garnered the respect of hard-headed lawyers and businessmen. OS has proved to be an efficient, thus far sustainable, and competitive system for development of some software applications, delivering high quality products, with faster development time, at a fraction of the cost of firm-based production models.

In OS, self-selected volunteers develop ideas that might make their own lives a little easier. For example, they remove bugs encountered in their idiosyncratic work environments (Bessen 2005), some of which could only be detected by a centralized research authority with great difficulty and expense. This activity is known as user innovation Von Hippel (2005). Often, they share their results with others, and enjoy the resulting peer acknowledgement of their contributions. But none of this started with software. Not by a long shot.

The first modern economist, Adam Smith, described the phenomenon in 1776.

> A great part of the machines … in those manufactures in which labor is most subdivided, were originally the inventions of common workmen, who, … employed in some very simple operation, naturally turned their thoughts towards finding out easier and readier methods of performing it. Whoever has been much accustomed to visit such manufactures must frequently have been shown very pretty machines, which were the inventions of such workmen in order to facilitate and quicken their particular part of the work.

Note the lack of any hint of monetary awards for the inventions, and the assumed willingness of the employers to share them with all comers. Long before Smith, farmers were solving biological problems without thought of monetary award, and sharing their inventions with their peers. Open source agriculture is more a restoration than a revolution.

To agricultural scientists, OS offers a promise of a return to the scientific environment of decades past, where materials and ideas were exchanged with greater fluidity, and today's preoccupation with intellectual property rights that was absent. But BiOS' wet lab plant biotechnology constitutes a young field very different from that of software production, or traditional plant breeding before the twin revolutions in biotechnology and intellectual property rights. Jefferson's initiative accordingly provides an interesting lens through which to examine the prospects for the open source model in novel terrain.[2]

The shift from copyright to patent law, and the complex and expensive regulatory regime, profoundly affect the prospects for open, distributed innovation and the creation of protected commons of easily accessible technology in plant biotechnology. The appropriate architecture for an OS model in biotechnology, like the appropriate design of any innovation, is hard to predict *ex ante*. The fate of BiOS, as a practical implementation of the model, will be highly instructive.

Patent vs. Copyright Law

Free access to technologies in the OS model fundamentally depends on the protection of those technologies from encroaching IP claims. This is accomplished through an open source license in which the right to use the technology is exchanged for the promise not to privately appropriate it. In software, the strategy designed to create a protected commons of accessible technologies involves the dominant IP form, copyright, as the key legal instrument in the open source. In biology, the dominant form of intellectual property protection is not copyright but patents. Several characteristics of patent law pose serious challenges to the translation of the OS software model to biotechnology.[3]

The shift from copyright to patent law, and the complex and expensive regulatory regime, profoundly affect the prospects for open [source]...in plant biotechnology.

Whereas copyright attaches instantaneously and with zero cost to new software code, obtaining patent protection ("patent prosecution") for an innovation in biotechnology costs tens of thousands of dollars, and entails months if not years of back and forth between the applicant and the patent office. The traditional OS model depends on the collaborative contributions of programmers who engage in the project for any number of well-researched motives (reputation, fun, improved skills, connection to community, etc.), but if their innovations were to be protected by patents, and the cost of patenting were shared by all research collaborators, the community of contributors would likely collapse.

Given that the cost of the patent system discourages the patenting of every iterative improvement to open sourced biotechnologies, it would be necessary to make informed bets as to what *ought* to be patented in order to achieve a cost-effective degree of protection for the growing commons of the project. Remaining technologies might be defensively published. The Single Nucleotide Polymorphism (SNP) consortium[4] provides an example of effectively combining defensive publishing and defensive patenting to reach a similar goal of sustained open access, but without the complication of maintaining access to "improvements" of key enabling technologies.

A priori decisions must also be made regarding *where* to patent. One strength of the OS model in software is its ability to cross national boundaries, gaining from the talents of a truly international set of developers.[5] While copyright lends itself to virtually costless international coverage,[6] patents are national in scope. Applying for patent protection worldwide can be prohibitively expensive; even filing in a handful of wealthy countries can cost hundreds of thousands of dollars in fees and associated expenses.

In patents, as in copyright, the utility of the protection gained from intellectual property rights depends on the ability to enforce. All the expenditures and effort involved in patent prosecution are in vain unless the OS commons has the credible financial capacity to sue infringers and finance the necessary litigation through to a decision, if necessary. In patents this capacity does not come cheap; each lawsuit in the United States costs millions of dollars. It is not clear whether the issue of enforcement is less serious in OS software, which is itself a pioneering commons institution, and, as such, still a work in progress.

One practical distinction between software and plant biotechnology in this regard is that infringers may have less incentive to fight to the end if they can, at low cost to themselves, cease infringing by substituting lines of new code in a relatively short time period. In plant biotechnology, however, an accused infringer is likely to have less attractive alternatives to legal warfare; switching to a non-infringing technology may forfeit an investment of years of development, back-crossing and regulatory testing because patented technology is often locked into the genome of a novel plant variety.

In light of these constraints, BiOS, for effective management to achieve unfettered access to crucial technologies, needs to be able to make centralized decisions about patenting and publishing, and to have the financial capacity to enforce its rights. Centralized decisions are not foreign to the traditional open source model; despite claims of democratic innovation by OS protagonists, the system most often depends on a hierarchy of reviewers ensuring quality control and assigning credit.[7] But even with this hierarchy, the OS quality control process lends itself to, and indeed finds strength in, its openness and immediacy. To our knowledge, BiOS and other OS biology initiatives have not addressed the issues of confidentiality, delays and capital requirements associated with extension of the OS model to patentable biotechnologies.

Open Access to End-Products

Beyond the challenges posed by the shift from copyright to patent law, further constraints to the translation of the open source model into applied biotechnology arise from fundamental differences in the characteristics of product commercialization paths. In the life sciences a significant amount of capital is often necessary to move inventions through development, field testing, manufacturing, and distribution. OS software, on the other hand, has no expensive regulatory hurdles to traverse and can be replicated and distributed at zero marginal cost.

If the goal is open access to an end-product, not to a research tool (as in BiOS), then widespread delivery of the product may depend on engaging capital to get it from the lab out into the hands of consumers. The ability to leverage patent rights can, in some cases, play a critical role. If the product has both commercial and humanitarian markets (consider, for example, an AIDS vaccine), the patent owner may license the patent rights to a company for use in the lucrative developed country market in exchange for the company's promise to manufacture and deliver the product into developing country markets at a reasonable price. This logic is not new, of course. Product development public private partnerships (PDP's), among others, have demonstrated how to leverage intellectual property rights, segmenting the market in their licensing agreements in order to achieve the ultimate goals of delivering biomedical innovations to poor and underserved populations where there are very limited commercial markets. It is in cases like these that open source licenses may *hinder* the product's commercialization by precluding the engagement of private capital. An understanding of this dynamic is in part what drove the BiOS model to focus on enabling technologies, preserving the potential for patent rights on application-level technologies.

The polio vaccine provides a historical example that seems to contradict the cautions above. It is often cited as a case where the choice not to patent resulted in a major public health success. Jonas Salk famously stated: "Who owns my polio vaccine? The people! Could you patent the sun?" It's true that Salk did not patent his work and open access was achieved, by almost anyone's standard, as the polio vaccine represents one of history's great public health success stories.

The polio vaccine was delivered through an extraordinary collaboration between individual volunteers and a public charity, the National Foundation for Infantile Paralysis (now known as the March of Dimes), founded by Franklin Delano Roosevelt. Salk's work was funded by the National Foundation. The field trials were the biggest peace-time mobilization of volunteers in U.S. history. Nearly two million school children, called the "Polio Pioneers," and thousands of healthcare workers and lay people volunteered to take part in or assist with the vaccine field trials. The results of the trials were analyzed at the University of Michigan. Millions of Americans participated by raising funds in their communities. The National Foundation for Infantile Paralysis even funded the manufacture of the vaccines by subsidizing the production of nine million dollars worth of vaccines.

The story of the polio vaccine is, indeed, an inspirational illustration of a nation mobilizing its resources to address a public health crisis. But it was developed with ample funding and without a thicket of potentially blocking patents. Remember, too, that vaccines are currently under-supplied globally. The Salk model has not been sustained. A major source of vaccines for tropical diseases is the U.S. government, which funds the necessary research to protect soldiers who might one day fight in tropical lands; any gains that accrue to locals in such countries are more or less incidental. Where there is still some doubt as to whether private sector resources may need to be engaged, the option to use IP rights as a tool to achieve the goals of open access may be valuable.

The larger point is that different IP management tools fit different circumstances. There are many instances where publishing and *not* patenting is the path to ensuring open access. Yet another important strategy, widely praised as judicious, is exemplified by the broad and non-exclusive licensing strategy implemented for the key Cohen-Boyer patents. Effective IP management plans require flexibility and knowledgeable professionals. They should be designed to support particular goals, and depend on the characteristics of a technology and surrounding circumstances as they unfold. Open source mechanisms, though, are not flexible; in terms of IP, the fate of a new invention is mandated ahead of time. This can mean missed opportunities.

Inter-operability and Parallels to Linux

The burgeoning of the OS model in software and its ability to generate serious rivals to commercial products in some market segments was dependent, in part, on two critical elements. First, the contribution of a kernel by Linus Torvalds in 1991 enabled Linux to become a complete, functional alternative to proprietary operating systems, and subsequently the flagship for OS success. Second, the creation of a set of OS licenses with different degrees of virality, allowed OS code to be used in combination with proprietary software, thereby broadening the range of business applications that could integrate OS code. The original OS license, the GNU General Public License (GPL), has a viral quality which mandates that products incorporating the original code also become additions to the commons and must be licensed under the same GPL terms. In response to needs for an OS license where interoperability brought fewer restrictions, other licenses were developed[8] which allowed OS code to be incorporated into proprietary commercial products. The range of degrees of virality among licenses reflects a trade-off. More viral licenses promote greater growth in the protected commons of code, but at a cost of reducing the range of applications for the code. Less viral licenses still can work to preserve the commons of code, but lean more toward the direction of a static commons which does not grow as quickly.

It is natural to look to OS in software to find a model for the protected commons of technology that BiOS seeks to create. Jefferson rightly identifies the need for a complete platform of enabling technologies, tools for plant genetic transformation, as an important element of OS application for agricultural biotechnology. Along with Jefferson, the press has highlighted parallels between his Transbacter™ technology, designed to work around existing, proprietarily-owned, plant transformation methods that form a crucial bottleneck in agricultural biotechnology, and the kernel of what we now know as Linux. The analogy, though, is premature, for two reasons. First, Torvald's kernel was the lynchpin to the system—with it a truly self-sufficient operating system was born. Transbacter™, though, removes only one of two current bottlenecks. There is yet another technology that remains a critical impediment to operability.[9] Second, Transbacter™ is a young technology. Its utility for plant breeders is not yet established.[10]

In any case, because of the territorial nature of patents, these bottlenecks of proprietarily owned enabling technologies exist for the most part in only a few countries (including the United States). The key patents creating the bottlenecks in the U.S. were either never issued, or have expired in many other countries. While it is true that products exported back into territories where these patent bottlenecks exist will have problems, there are many countries without these patents in which researchers can use a full set of technologies in the public domain with impunity, and with no need to consider BiOS license terms. There are other, non-IP, reasons why this is not done; access to materials, biosafety issues, liability and stewardship issues, and a weakness in scientific capacity can be more serious impediments than foreign patents in hindering progress in plant biotechnology in developing countries.

However, the path pioneered by BiOS could become a route to freedom to operate for poor countries in the future. The full effects of the global spread of patenting fostered by the TRIPS Agreement of the World Trade Organization, and even more onerous bilateral agreements, are now coming to bear on agricultural researchers in developing countries. As their scientific capacities develop, the full force of patent claims might well become a serious obstacle.

Because BiOS does not currently provide a complete and viable alternative platform, interoperability concerns are not just important, but essential. Researchers have no alternative to using technologies licensed under the BiOS terms in conjunction with patented technologies owned by others. Unfortunately the BiOS license mandates encumbrances that "infect" key complementary enabling technologies. Owners of patents on such technologies might well find these encumbrances unacceptable.

Suppose, for instance, a scientist creates a plant transformation vector (the research tool that enables a researcher to insert a gene into a plant's DNA), with a BiOS enabling technology as one of its many component technologies. Under the terms of the license, the entire vector system must be granted back to BiOS. The BiOS license, in its reservation of rights for the licensee to own application technologies (i.e. *not* enabling technologies), falls short of what is known in open source software licensing as "viral."[11] However, the BiOS license does have a viral quality to it that affects enabling technologies.

The terms of the BiOS license could mean that researchers become limited in the set of tools from which they choose. In a sense, the BiOS license could, counter-intuitively discourage, rather than encourage collaboration. To see this effect, imagine again the vector system referred to above where one component is a BiOS technology. The researcher would like to use another component that happens to be patented by a commercial firm. The commercial firm will not agree to the use of their technology knowing that the vector system, incorporating their technology will be available for free under the BiOS license. Therefore the researcher's choice of tools is effectively diminished by having chosen to use the BiOS technology; he has relinquished the ability to use certain tools because he has brought a technology into his lab under the terms of the BiOS license.

It is true that the BiOS license allows the licensee to refrain from granting back improvements if they are kept as trade secrets. (Not only can the licensees benefit from access to enabling technologies, and the improvements of others, but they can use trade secrecy, where feasible, to avoid making their own improvements available to other licensees.) The trade secrecy option is, however, unlikely to be a useful concession for universities, where disclosure is an important part of the culture and materials are regularly shared among researchers in a lab (or among labs) informally.[12]

In sum, creation of a transformation platform as a flagship application with freedom to operate has been the subject of much effort and creativity, but it is still a work in progress.

Is the BiOS Model Sustainable?

In order for BiOS to be a viable and replicable model, sustainability is essential. Richard Jefferson has generously seeded the model by placing his own patents under the BiOS license; the Rockefeller Foundation and IBM, among others, have provided financial or material support. The initiative aims to increase the commons with improvements to the existing technologies. But what about *new* technologies? The incentives for participating by signing the BiOS license are separate from the incentives needed to get people to donate new technology. Will the latter be forthcoming to BiOS as contributions from the private sector or public sector? Jefferson's own experience with BiOS is not encouraging on this point. Perhaps the BiOS approach will be sustained by replication, with each new collaboration initiated by a creative leader who sets the broad agenda. The key enabling technology for widespread adoption of the BiOS model might be a perfected BiOS license.

The culture of hackers that continues to fuel the advances of OS in software may not be replicable in the field of biology. But to the extent that it is, researchers in the public sector are likely to be crucial participants, especially in less developed economies where almost all agriculture-related research is public. In its present form, the BiOS license remains a poor contractual fit for universities (particularly those in the U.S.[13]). Some would argue that the goal of the BiOS model to provide for dissemination and access is already part of the university process. Universities publish, they collaborate, they share and exchange. Having learned from painful experiences akin to Jefferson's loss of access to a positive selection strategy, when universities license their technology they typically retain the right to publish, conduct research, and allow other universities/non-profits to do the same for research and educational purposes.

The reach of the BiOS grantback[14] goes beyond what is often found in licenses from the nonprofit sector, and could impose obligations that public sector scientists are not free to satisfy, since the rights to their inventions are often mediated by their employer institutions. This is a problem that arises when the OS approach is ported from the world of copyright to the world of patents. Universities have not wrested control of copyright on texts from the grasp of their academic authors, even if the work is produced on campus. By contrast, patents on inventions originating in U.S. university labs are assigned to the institution. It may be that a sustainable OS model in patentable biotechnologies will need to utilize a legal mechanism that is better-suited to the peculiarities of academic institutions.

Some Perspective

At this point, it is appropriate to put some perspective on the relevance of open source initiatives for global agriculture. To date, it is unlikely that massive numbers have died of hunger due to the current state of agricultural intellectual property rights. Subsidized by rich countries' agricultural policies, the world markets have offered basic foods at prices lower than ever recorded.

Furthermore, almost all currently useful agricultural biotechnology has been available, without patent protection, to most developing countries, for all purposes except incorporation in exports to countries with relevant patents in force. It has not been widely adopted for basic food production, for two reasons. First, widespread opposition to genetic modification, for reasons of biosafety and public acceptance, has discouraged this type on innovation. (For example, as of 2006, South Africa was the only country in Africa where genetically engineered crops are grown commercially).[15]

> At present, open source is a promising, but problematic, way to preserve some freedom to innovate in a world of patent thickets.

Second, the less developed countries, with a handful of notable exceptions including China, India, Brazil and Argentina, lack any real capacity to exploit the new technologies, because the substantial, sustained investments in education, research and facilities necessary to get the process under way have not been made.

Nevertheless this is the right time to be addressing patent problems in developing countries. The long downtrend in food prices has been interrupted, a reminder that the food yield increases behind recent declining price trends did not come automatically, but reflect sustained, large, largely public, investments in research. In the past year, the world has awakened from complacency about atmospheric carbon, on the one hand, and reliance on imported fuels, on the other, to support massive increases in ethanol production from crops. If these increases continue, large yield improvements in the productivity of crops will be needed to ensure that competition from gasoline consumers does not cause an increase in the numbers of the world's poor and hungry.

Considerable investments have already been made into researching the genetic modification of developing-country crops (for instance, biofortification, disease and pest resistance, and drought tolerance). These projects must consider constraints and opportunities associated with intellectual property rights in order to ensure the intended delivery of the products of their research into the hands of farmers. In its short history, there is already an accumulation of anecdotal evidence of agricultural biotechnology research projects being delayed, re-directed, or halted all together because of intellectual property rights problems (Wright and

Pardey 2006a, 2006b). A recent survey of agricultural biologists at U.S. Land Grant Universities reveals that they, as a group unusually familiar with patenting and the exchange of tools, believe that intellectual property rights, through their effects on transactions with their peers, are on balance hindering progress in their research areas (Lei et al., 2007).

There is, therefore, a sound argument that we cannot wait to find out how the global implementation of the TRIPS agreement, and subsequent bilateral negotiations on intellectual property rights, affect global innovation over the next quarter century. IPRs, among the many challenges in life sciences, require forethought. Decisions today about the ownership of and access to technologies (through patents and licenses) will affect the paths of research and development for decades ahead.

CONCLUSION

To develop BiOS, Jefferson has had to dedicate years of effort and ingenuity, calling on all his talents as scientist, entrepreneur, innovator, fund-raiser and cheerleader. To create a flagship application for BiOS, he and his colleagues have invented a novel technology for genetic transformation of plants, designed to be unencumbered by prior patent claims. To ensure its development follows the open source model, he has fashioned the BiOS license, porting the open source licensing concept from copyright to a more complex world of patent protection and biosafety regulation.

Given the magnitude of the task, it is no surprise that the development of BiOS as a sustainable institutional innovation is still a work in progress. But at this stage, the story merits a close reading. Jefferson has indisputable credibility as a witness to the multidimensional challenges of acquiring freedom to operate in agricultural biotechnology.

From a policy perspective, the major lesson is implicit. Almost the entire effort in creating BiOS constitutes expenditure of valuable, if not unique, resources that would be unnecessary, absent a patent system, or a system of efficient license agreements. This effort, then, constitutes a concrete example of the "excess burden" of the patent system, as it exists in developed countries, that is, its cost to innovators that does not get transferred to others as benefits, but is lost as economic waste.

The availability of global communication at virtually zero cost offers unprecedented opportunities for exploiting specialization and the division of labor in biotechnology research. Unfortunately, the recent revolution in patent protection, and constraints imposed by biosafety regulations, have had the opposite effect, forcing "in-house" aggregation of essential agricultural biotechnology innovation capabilities within a few vertically-integrated firms. As this has happened, the innovation race has slowed to a crawl.

Thus far, the prudent caution regarding biosafety, and the slowdown in biotechnology innovation, have had no serious effects on food consumption; past research investments, and rich-country food subsidies, have kept prices low and supplies high. Given the current surge in biofuels demand, and the continuing increase in world population, it would be foolhardy to assume that this situation will continue. At present, open source is a promising, but problematic, way to preserve some freedom to innovate in a world of patent thickets. Achievement of a less restrictive patent regime would allow the full creative potential of open source collaboration to be realized in ensuring an adequate supply of food for the years ahead.

We invite reader comments. Email <editors@innovationsjournal.net>.

Endnotes

1. Other models include patent pooling, clearinghouse mechanisms, and humanitarian licensing.
2. It is not clear that biotechnology per se is less amenable to specialization and open source collaboration, absent biosafety and intellectual property constraints. The potential efficiencies of specialization and collaboration in synthetic biology are illustrated by the BioBricks initiative <http://www.biobricks.org/>. See Endy (2005).
3. In the interest of brevity, we discuss only highlights of several differences between patent and copyright law and their significance for the translation of the OS model are provided. In fact, differences in the legal systems have wide-ranging implications for OS that deserve more in-depth analysis.
4. Robert Cook-Deegan (2003) describes how a group of academic institutions and thirteen private firms formed a consortium to ensure the SNPs remained broadly accessible and were not privately appropriated. He writes: "The SNP Consortium did not just dump the data. They filed patent applications and then characterized the SNP markers enough so that they could be sure that nobody else could patent them. At that point, they would abandon the patent. It is a very sophisticated intellectual property strategy that in the end was intended to bolster the public domain. It requires coordination, lots of paperwork, and it costs money to file and process applications, but it appears to be an effective defensive patenting strategy."
5. Lancashire (2001) reports 33 different nationalities among Linux contributors.
6. There are two principal international copyright conventions: the Universal Copyright Convention (or UCC) and the Berne Convention. To protect copyright internationally the name of the author is required and (for the UCC) the year of publication and a © symbol.
7. Jill Coffin (2006) notes: "For [an open source project] to function…an organizational and political structure must support it. Hybrid, flexible political systems based upon meritocracy motivates participants, provide rewards in the absence of capital, and encourage a community-wide sense of project ownership. In addition to the bottom–up, peer–administered hierarchy described in the analysis of Wikipedia, the benevolent dictator and consistently active personnel keep the project alive and dialog open from above, so to speak…A transparent meritocratic structure also allows for smooth succession in administrative and leadership positions."
8. For instance the Berkeley Software Distribution (BSD) style licenses.
9. Generating genetically modified crops requires several indispensable technologies including those necessary to transfer foreign DNA into a plant cell, selection gene markers to distinguish genetically modified cells from untransformed cells, and marker-excision technologies to remove superfluous DNA after successful integration of the trait gene into the plant genome. This packet of core technologies is complemented with other research-specific technologies, which may also be protected by IP. Of the transgenic crop technologies, transformation and selectable markers may

be considered "bottleneck" areas where the restricted access to the technologies can impede innovation.

10. Broothaerts et al. found that the transformation efficiency of non-*Agrobacterium* bacterial species ranged from less than 1% to almost 40% of that of *Agrobacterium*-mediated transformation, depending on the transformation assays and species used. (Gene Transfer to Plants by Diverse Species of Bacteria, Nature 433, 629-633 (10 February 2005)
11. The GPL (http://www.gnu.org/copyleft/gpl.html), requires in clause 2(b) that any works derived from the licensed software must also to be distributed under the GPL.
12. Another anomaly differentiating the commercial use of the BiOS license from academic has to do with federal funding and obligations that are common in university policy as a consequence of the adoption of the Bayh Dole Act.
13. PIPRA, The Public Intellectual Property Resource for Agriculture, www.pipra.org, has completed an in- depth analysis of the BiOS license from the perspective of a U.S. university as a potential licensee.
14. For a legal discussion of the BiOS license see Boettiger and Burk (2004).
15. See Eicher (2006).

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Yochai Benkler

Commons-Based Agricultural Innovation

Innovations Case Discussion: CAMBIA-BiOS

Computation and access to existing scientific research are important in the development of any nation, yet both still operate at a remove from the most basic needs of the world poor. On its face, it is far from obvious how the emergence of the networked information economy can grow rice to feed millions of malnourished children or deliver drugs to millions of HIV/AIDS patients. On closer observation, however, it becomes apparent that a tremendous proportion of the way modern societies grow food and develop medicines is based on scientific research and technical innovation. Important implications for the direction of innovation and for access to its products exist in the basic choice between two models: (1) a system that depends on exclusive rights and business models that use exclusion to appropriate research outputs and (2) a system that weaves together various actors—public and private, organized and individual—in a nonproprietary social network of innovation.

The failure of the exclusive rights model in meeting the needs of people in developing countries has received considerable public attention in the context of

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the HIV/AIDS crisis in Africa—particularly with regard to the lack of access to existing drugs because of their high costs. However, that crisis is merely the tip of the iceberg. It is the most visible to many because of the presence of the disease in rich countries and its cultural and political salience in the United States and Europe. The exclusive rights system is, as a general rule, a poor institutional mechanism for serving the needs of those who are worst off around the globe—not only the victims of HIV/AIDS. Its weaknesses pervade the problems of food security and agricultural research aimed at increasing the supply of nourishing food throughout the developing world, and of access to medicines in general, and to medicines for developing-world diseases in particular. Each of these areas has seen a similar shift in national and international policy toward greater reliance on exclusive rights, most important of which are patents. Each area has also begun to see the emergence of commons-based models to alleviate the problems of patents.

The failure of the exclusive rights model in meeting the needs of people in developing countries has received considerable public attention in the context of the HIV/AIDS crisis in Africa—particularly with regard to the lack of access to existing drugs because of their high costs. However, that crisis is merely the tip of the iceberg.

Leaving aside national efforts in developing nations, there are two major paths for commons-based research and development in agriculture that could serve the developing world more generally. The first is based on a loose affiliation of university scientists, nongovernmental organizations, and individuals such as played significant role in the development of free and open-source software. The second is based on existing research institutes and programs cooperating to build a commons-based system, cleared of the barriers of patents and breeders' rights, outside and alongside the proprietary system. The most promising current effort in the former vein, and probably the most ambitious commons based project for biological innovation currently contemplated, is BIOS (Biological Innovation for an Open Society). The most promising models of the latter are the PIPRA (Public Intellectual Property for Agriculture) coalition of public-sector universities in the United States, and, if it delivers on its theoretical promises, the Generation Challenge Program led by CGIAR (the Consultative Group on International Agricultural Research).

CAMBIA-BIOS

As Richard Jefferson's case narrative in this issue of *Innovations* describes, BiOS is an initiative of CAMBIA (Center for the Application of Molecular Biology to International Agriculture), a nonprofit agricultural research institute based in Australia. BiOS is based on the observation that much of contemporary agricultural research depends on access to tools and enabling technologies—such as mechanisms to identify genes or for transferring them into target plants. When these tools are appropriated by a small number of firms and available only as part of capital-intensive production techniques, they cannot serve as the basis for innovation at the local level or for research organized on nonproprietary models. One of the core insights driving the BiOS initiative is the recognition that when a subset of necessary tools is available in the public domain, but other critical tools are not, the owners of those tools appropriate the full benefits of public domain innovation without at the same time changing the basic structural barriers to use of the proprietary technology. To overcome these problems, the BiOS initiative includes both a strong informatics component and a fairly ambitious "copyleft"-like model of licensing CAMBIA's basic tools and those of other members of the BiOS initiative.[1] The informatics component builds on a patent database that has been developed by CAMBIA for a number of years, and whose ambition is to provide as complete as possible a dataset of who owns what tools, what the contours of ownership are, and by implication, who needs to be negotiated with and where research paths might emerge that are not yet appropriated and therefore may be open to unrestricted innovation.

The licensing or pooling component is more proactive, and is likely the most significant of the project. BiOS is setting up a licensing and pooling arrangement, "primed" by CAMBIA's own significant innovations in tools, which are licensed to all of the initiative's participants on a free model, with grant-back provisions that perform an openness-binding function similar to copyleft.[2] In coarse terms, this means that anyone who builds upon the contributions of others must contribute improvements back to the other participants. One aspect of this model is that it does not assume that all research comes from academic institutions or from traditional government funded, nongovernmental, or intergovernmental research institutes. It tries to create a framework that, like the open-source development community, engages commercial and noncommercial, public and private, organized and individual participants into a cooperative research network. The platform for this collaboration is "BioForge," styled after Sourceforge, one of the major free and open-source software development platforms. The commitment to engage many different innovators is most clearly seen in the efforts of BiOS to include major international commercial providers and local potential commercial breeders alongside the more likely targets of a commons-based initiative.

Central to this move is the belief that in agricultural science, the basic tools can, although this may be hard, be separated from specific applications or products. All actors, including the commercial ones, therefore have an interest in the open and efficient development of tools, leaving competition and profit making for the market in applications. At the other end of the spectrum, BiOS's focus on making tools freely available is built on the proposition that innovation for food security involves more than biotechnology alone. It involves environmental management, locale-specific adaptations, and social and economic adoption in forms that are locally and internally sustainable, as opposed to dependent on a constant inflow of commoditized seed and other inputs. The range of participants is, then, much wider than envisioned by PIPRA or the GCP. It ranges from multinational corporations through academic scientists, to farmers and local associations, pooling their efforts in a communications platform and institutional model that is very similar to the way in which the GNU/Linux operating system has been developed. As of this writing, the BiOS project is still in its early infancy, and cannot be evaluated by its outputs. However, its structure offers the crispest example of the extent to which the peer-production model in particular, and commons-based production more generally, can be transposed into other areas of innovation at the very heart of what makes for human development—the ability to feed oneself adequately.

THE PUBLIC INTELLECTUAL PROPERTY RESOURCE FOR AGRICULTURE

The Public Intellectual Property Resource for Agriculture (PIPRA) is a collaboration effort among public-sector universities and agricultural research institutes in the United States, aimed at managing their rights portfolio in a way that will give their own and other researchers freedom to operate in an institutional ecology increasingly populated by patents and other rights that make work difficult. The basic thesis and underlying problem that led to PIPRA's founding were expressed in an article in Science coauthored by fourteen university presidents.[3] They underscored the centrality of public-sector, land-grant university-based research to American agriculture, and the shift over the last twenty-five years toward increased use of intellectual property rules to cover basic discoveries and tools necessary for agricultural innovation. These strategies have been adopted by both commercial firms and, increasingly, by public-sector universities as the primary mechanism for technology transfer from the scientific institute to the commercializing firms.

The problem they saw was that in agricultural research, innovation was incremental. It relies on access to existing germplasm and crop varieties that, with each generation of innovation, brought with them an ever-increasing set of intellectual property claims that had to be licensed in order to obtain permission to innovate further. The universities decided to use the power that ownership over roughly 24 percent of the patents in agricultural biotechnology innovations provides them as a lever with which to unravel the patent thickets and to reduce the barriers to research that they increasingly found themselves dealing with. The main story, one might say the "founding myth" of PIPRA, was the story of golden rice. Golden rice is a variety of rice that was engineered to provide dietary vitamin A. It was developed with the hope that it could introduce vitamin A supplement to populations

	Total Revenues (millions $)	Licensing and Royalties (millions $)	Licensing and Royalties % of total	Government Grants & Contracts (millions $)	Government Grants & Contracts % of total
All universities	$227,000	$ 1270	0.56%	$31,430	13.85%
Columbia University	$ 2,074	$178.4	8.6%	$532	25.65%
		$100–120[a]	4.9–5.9%		
University of California	$ 14,166	$ 81.3	0.57%	$2372	16.74%
		$ 55 (net)[b]	0.39%		
Stanford University	$ 3,475	$ 43.3	1.25%	$860	24.75%
		$ 36.8[c]	1.06%		
Florida State	$ 2,646	$ 35.6	1.35%	$238	8.99%
University of Wisconsin-Madison	$ 1,696	$ 32	1.89%	$417.4	24.61%
University of Minnesota	$ 1,237	$ 38.7	3.12%	$323.5	26.15%
Harvard	$ 2,473	$ 47.9	1.94%	$416	16.82%
				$548.7[d]	22.19%
Cal Tech	$ 531	$ 26.7[e]	5.02%	$268	50.47%
		$ 15.7[f]	2.95%		

Table 1. Selected University Gross Revenues and Patent Licensing Revenues

Sources: Aggregate revenues: U.S. Dept. of Education, National Center for Education Statistics, Enrollment in Postsecondary Institutions, Fall 2001, and Financial Statistics, Fiscal Year 2001 (2003), Table F; Association of University Technology Management, Annual Survey Summary FY 2002 (AUTM 2003), Table S-12. Individual institutions: publicly available annual reports of each university and/or its technology transfer office for FY 2003.

Notes:

a. Large ambiguity results because technology transfer office reports increased revenues for yearend 2003 as $178M without reporting expenses; University Annual Report reports licensing revenue with all "revenue from other educational and research activities," and reports a 10 percent decline in this category, "reflecting an anticipated decline in royalty and license income" from the $133M for the previous year-end, 2002. The table reflects an assumed net contribution to university revenues between $100-120M (the entire decline in the category due to royalty/royalties decreased proportionately with the category).

b. University of California Annual Report of the Office of Technology Transfer is more transparent than most in providing expenses—both net legal expenses and tech transfer direct operating expenses, which allows a clear separation of net revenues from technology transfer activities.

c. Minus direct expenses, not including expenses for unlicensed inventions.

d. Federal- and nonfederal-sponsored research.

e. Almost half of this amount is in income from a single Initial Public Offering, and therefore does not represent a recurring source of licensing revenue.

f. Technology transfer gross revenue minus the one-time event of an initial public offering of LiquidMetal Technologies.

in which vitamin A deficiency causes roughly 500,000 cases of blindness a year and contributes to more than 2 million deaths a year. However, when it came to translating the research into deliverable plants, the developers encountered more than seventy patents in a number of countries and six materials transfer agreements that restricted the work and delayed it substantially. PIPRA was launched as an effort of public-sector universities to cooperate in achieving two core goals that would respond to this type of barrier—preserving the right to pursue applications to subsistence crops and other developing-world-related crops, and preserving their own freedom to operate vis-à-vis each other's patent portfolios.

> Increasing appropriation of basic tools and enabling technologies creates barriers to entry for innovators—public-sector, nonprofit organizations, and the local farmers themselves—concerned with feeding those who cannot signal with their dollars that they are in need.

The basic insight of PIPRA, which can serve as a model for university alliances in the context of the development of medicines as well as agriculture, is that universities are not profit-seeking enterprises, and university scientists are not primarily driven by a profit motive. In a system that offers opportunities for academic and business tracks for people with similar basic skills, academia tends to attract those who are more driven by non-monetary motivations. While universities have invested a good deal of time and money since the Bayh-Dole Act of 1980 permitted and indeed encouraged them to patent innovations developed with public funding, patent and other exclusive-rights-based revenues have not generally emerged as an important part of the revenue scheme of universities. As table 1 shows, except for one or two outliers, patent revenues have been all but negligible in university budgets.[4] This fact makes it fiscally feasible for universities to use their patent portfolios to maximize the global social benefit of their research, rather than trying to maximize patent revenue. In particular, universities can aim to include provisions in their technology licensing agreements that are aimed at the dual goals of (a) delivering products embedding their innovations to developing nations at reasonable prices and (b) providing researchers and plant breeders the freedom to operate that would allow them to research, develop, and ultimately produce crops that would improve food security in the developing world.

While PIPRA shows an avenue for collaboration among universities in the public interest, it is an avenue that does not specifically rely on, or benefit in great measure from, the information networks or the networked information economy.

It continues to rely on the traditional model of publicly funded research. More explicit in its effort to leverage the cost savings made possible by networked information systems is the Generation Challenge Program (GCP). The GCP is an effort to bring the CGIAR into the biotechnology sphere, carefully, given the political resistance to genetically modified foods, and quickly, given the already relatively late start that the international research centers have had in this area. Its stated emphasis is on building an architecture of innovation, or network of research relationships, that will provide low-cost techniques for the basic contemporary technologies of agricultural research. The program has five primary foci, but the basic thrust is to generate improvements both in basic genomics science and in breeding and farmer education, in both cases for developing world agriculture. One early focus would be on building a communications system that allows participating institutions and scientists to move information efficiently and utilize computational resources to pursue research. There are hundreds of thousands of samples of germplasm, from "landrace" (that is, locally agriculturally developed) and wild varieties to modern varieties, located in databases around the world in international, national, and academic institutions.

There are tremendous high-capacity computation resources in some of the most advanced research institutes, but not in many of the national and international programs. One of the major goals articulated for the GCP is to develop Web-based interfaces to share these data and computational resources. Another is to provide a platform for sharing new questions and directions of research among participants. The work in this network will, in turn, rely on materials that have proprietary interests attached to them, and will produce outputs that could have proprietary interests attached to them as well. Just like the universities, the GCP institutes (national, international, and nonprofit) are looking for an approach aimed to secure open access to research materials and tools and to provide humanitarian access to its products, particularly for subsistence crop development and use. As of this writing, however, the GCP is still in a formative stage, more an aspiration than a working model. Whether it will succeed in overcoming the political constraints placed on the CGIAR as well as the relative latecomer status of the international public efforts to this area of work remains to be seen. But the elements of the GCP certainly exhibit an understanding of the possibilities presented by commons-based networked collaboration, and an ambition to both build upon them and contribute to their development.

CONCLUSION

The BiOS initiative PIPRA are the most salient examples of, and the most significant first steps in the development of commons-based strategies to achieve food security. Their vitality and necessity challenge the conventional wisdom that ever-increasing intellectual property rights are necessary to secure greater investment in research, or that the adoption of proprietary rights is benign. Increasing appropriation of basic tools and enabling technologies creates barriers to entry for innovators—public-sector, nonprofit organizations, and the local farmers themselves—concerned with feeding those who cannot signal with their dollars that they are in need. The emergence of commons-based techniques—particularly, of an open innovation platform that can incorporate farmers and local agronomists from around the world into the development and feedback process through networked collaboration platforms—promises the most likely avenue to achieve research oriented toward increased food security in the developing world. It promises a mechanism of development that will not increase the relative weight and control of a small number of commercial firms that specialize in agricultural production. It will instead release the products of innovation into a self-binding commons—one that is institutionally designed to defend itself against appropriation. It promises an iterative collaboration platform that would be able to collect environmental and local feedback in the way that a free software development project collects bug reports—through a continuous process of networked conversation among the user-innovators themselves.

In combination with public investments from national governments in the developing world, from the developed world, and from more traditional international research centers, agricultural research for food security may be on a path of development toward constructing a sustainable commons-based innovation ecology alongside the proprietary system. Whether it follows this path will be partly a function of the engagement of the actors themselves, but partly a function of the extent to which the international intellectual property/trade system will refrain from raising obstacles to the emergence of these commons-based efforts.

We invite reader comments. Email <editors@innovationsjournal.net>.

1. This is similar to the General Public License of the GNU project <http://www.gnu.org/copyleft/gpl.html>. For further description, see chapter 3 of Yochai Benkler (2006), *The Wealth of Networks* (New Haven, CT: Yale University Press), available for free download at <www.benkler.org>
2. Wim Broothaertz et al. (2005), "Gene Transfer to Plants by Diverse Species of Bacteria," *Nature* 433:629.
3. Richard Atkinson et al. (2003), "Public Sector Collaboration for Agricultural IP Management," *Science* 301: 174.
4. This table is a slightly expanded version of one originally published in Yochai Benkler (2004), "Commons Based Strategies and the Problems of Patents," *Science* 305:1110.

Juhani Vira

Winning Citizen Trust

The Siting of a Nuclear Waste Facility in Eurajoki, Finland

On May 18, 2001, the Finnish Parliament voted 159-3 in favor of the government's decision-in-principle (DiP) on the geological disposal of spent nuclear fuel in Finland. The government based its decision on the application of Posiva Oy, the nuclear waste management company owned by Finland's two nuclear power plant companies. It meant that the repository could be sited in the Olkiluoto area near the Olkiluoto nuclear power plant in the municipality of Eurajoki, and the disposal could be based on a technical approach originally developed by SKB, the Swedish nuclear waste management company. This was the first time in the world that a site was selected for a high-level nuclear waste repository and was accepted by the majority of local people.

Only a few years earlier this outcome looked far from likely. Opinion surveys showed a consistent lack of trust in the long-term safety of geological disposal, and the Eurajoki municipality had an official policy opposing any high-level nuclear waste repository. To the extent that the topic was discussed in the public media, most opinions were sceptical if not completely negative.

The DiP meant that Posiva could begin its underground research to characterize, or thoroughly examine, the bedrock at the Olkiluoto site. A few years earlier an official inquiry in the United Kingdom had stopped similar plans at the Sellafield site in Cumbria. In northern Sweden, referenda had stopped the SKB's plans to investigate sites. In this context, the Finnish siting decision seemed to come against all odds. Its very existence suggests that something new

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was perhaps learned or discovered. The decision was a clear commitment from all major stakeholders—the regulatory agency, the national government, the Parliament, the local government, and the municipality council—to move in the direction of geological disposal of the waste. It can also be seen as another step in the long process that had started in the early 1980s when the reprocessing of spent fuel was found to be economically impossible in Finland—and could hardly be defended on any other grounds, either.

The siting decision was not based on the idea of volunteerism: local communities electing to be considered as a prospective site for nuclear waste disposal. That principle was later adopted in Sweden, Japan, and France and is also proposed in the United Kingdom. However, since in Finland the local residents of any given municipality have the legal right to veto the siting of the repository in their municipality, their acceptance was ultimately required—and in this case they gave it!

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Throughout this process we learned and we adapted: technical and rational discussion was valid and necessary, but it was not enough. Instead of simply "informing" we began to listen to stakeholders and the public at large and to acknowledge diverse perspectives. In the end, even the Green Party members voted in favor of the DiP.

MY ROLE AND PERSPECTIVE

I am analyzing the successful siting process in Finland from an insider's perspective. I came to work in the nuclear waste program in 1990 when quite a lot of groundwork in the siting process had already been carried out. The history had started in the early 1980s, so I could only learn about it from colleagues and documents, but I lived through the most active phase of the public dialogue and decision-making in the late 1990s, and also took on the public discussion as a personal challenge. I have followed the debate around nuclear power since I began to work in the nuclear energy business in the mid-1970s. In this article I will try to combine my personal experience with facts and statements from various documents. However, it should be taken as a personal account, not as an objective description of what happened. A more multi-faceted analysis of the experience evolved during a workshop organized by the OECD Nuclear Energy Agency (NEA) in Turku in late 2001.[1]

THE 1980S FRAMEWORK: RAMIFICATIONS FOR THE 1990S

The Finnish government's decision of 1983 is often seen as the beginning point of the program to dispose of spent fuel. The first Finnish nuclear power plant units were built in the 1970s; at that time the thinking was that all spent fuel should be reprocessed. For the Loviisa power plants this was to take place in the Soviet Union; the Finnish and Soviet governments had agreed on this. The reprocessing wastes would remain in the Soviet Union.

Teollisuuden Voima Oy (TVO), the private company that owns the Olkiluoto nuclear power plant, was engaged in negotiations for reprocessing with both the British nuclear fuel cycle company BNFL and the French reprocessing company Cogema, but finally withdrew from them without any contract. In this context, in 1983, the Finnish government decided on guidelines for nuclear waste management in Finland: it ruled that TVO should either seek international arrangements similar to those already in place for the Loviisa plants, or it should start preparing to dispose of its spent fuel directly, in Finland. In practice TVO chose the latter route.

> This was the first time in the world that a site was selected for a high-level nuclear waste repository and was accepted by the majority of local people.

The decision of 1983 was a "modern" one in the sense that it defined a step-by-step process with several opportunities to evaluate progress before the actual disposal operations would begin. The first evaluations were related to progress in the process of siting the repository, which was assumed to be critical in developing the disposal solution. The emphasis on the siting process was possible because the Swedish firm SKB had already developed a technical approach for disposal; it was also considered suitable in Finland because the geological conditions in the two countries are so similar. According to this approach, given the name "KBS-3," the spent fuel assemblies are packaged in copper canisters and then buried deep in the crystalline bedrock. Tunnels are excavated at the depth of about 500 metres in bedrock, holes are drilled in the floors of these tunnels, and the canisters are placed in these holes. Between the canisters and the rock walls a "buffer" of bentonite clay is installed to protect the canisters from mechanical and chemical loads. In this way a very long expected life-time can be achieved for the canisters. After all canisters have been disposed of, all tunnels are backfilled and access routes from surface to the underground space are closed and permanently sealed.

TVO embarked on the site selection process by screening the entire coun-

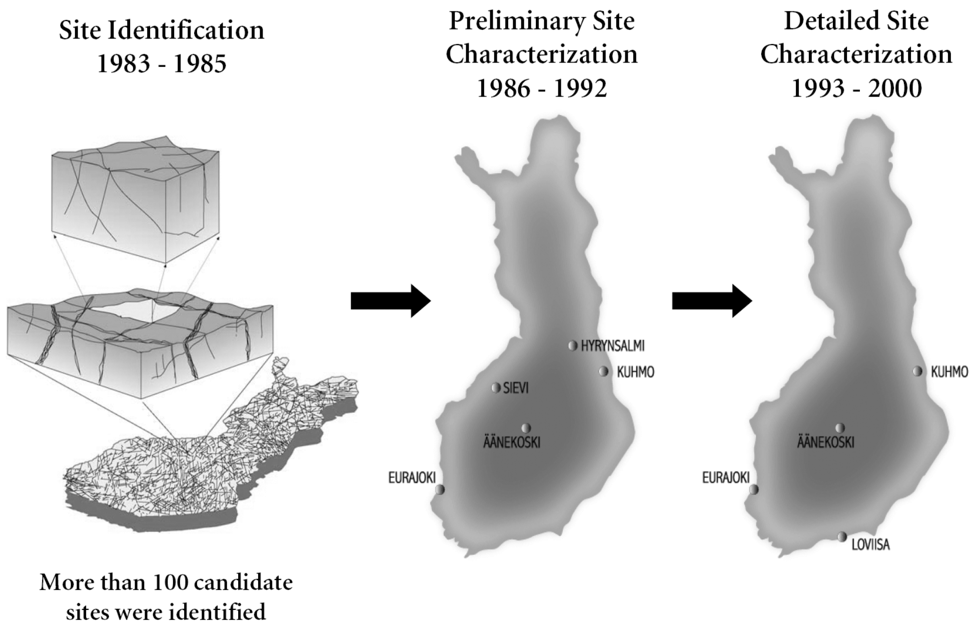

Figure 1. Site selection research program 1983-2000.

try for possible sites to investigate; in 1987 it began preliminary investigations on five candidate sites. Since Finland is situated in the Baltic shield area, where nearly all the bedrock is crystalline, TVO actually had little choice in geological terms.[2] So they believed the possible sites differed very little, but they had to confirm this by investigating. We were required to study the variability of Finnish rock conditions at depth. Actually all the five sites represent crystalline rock type (because, as it is stated earlier, there is no choice in this respect in Finland) but the sites do represent different geologic domains in the sense that their geologic histories are different. For instance, although they are all old geologic formations, their ages vary from 1.6 billion years to almost 3 billion years.

Two of the site candidates (Hyrynsalmi and Kuhmo) were situated in northern Finland, and two others (Sievi and Konginkangas, later Äänekoski) in central Finland; the fifth candidate site was Olkiluoto itself, where TVO's nuclear power plant was located (see Figure 1). TVO selected the candidate sites largely by considering geological, geographic and infrastructure factors and various constraints of land-use plans. The selection was not tied to volunteerism in the same way as it has since been applied in many other countries. However, TVO did inform the municipal administrations about its plans.

In the same year that TVO started the geological investigations a new nuclear energy act was passed by the Finnish Parliament. The new law included specific stipulations for nuclear waste management, and defined the DiP that would henceforth be needed for any new nuclear facilities. The decision would have to be made by the government and ratified by Parliament, but first it had to be endorsed by the municipality at the proposed site and the regulatory authority. Thus the law gave the municipalities a right of veto to prevent the siting of any nuclear facilities, including waste repositories, in their areas. Many said this veto power would make it impossible to site any nuclear facilities.

In 1992 TVO shortlisted three sites it would continue to investigate: the Olkiluoto site near the power plant and two inland sites, Kuhmo and Äänekoski. At that time most public opinion was still opposed to the siting plans in all three municipalities. Active opposition movements against the repository had been formed in some candidate communities. Since the TVO was the only organized entity in these areas supporting the provisional siting plans, most discussion in the public media was between TVO and the opposition groups.

INTERNATIONAL EVENTS CHANGE THE RULES

The 1980s and 1990s saw great changes in Eastern Europe; in particular the collapse of the Soviet Union led to fairly chaotic conditions in Russia. Although the government decision of 1983 had endorsed "international solutions," more and more Finnish politicians now started saying that the return of spent fuel to Russia was not ethically defensible. Meanwhile they were becoming more concerned about the implications for Finland of its accession to the European Union. What if the European Union were to decide to build a nuclear waste repository for all European wastes in a country like Finland? Why not just prohibit any such practice—including exports, for the sake of balance? In 1994 the parliament voted to ban both the import and export of nuclear waste.

This vote, which amended the Finnish Nuclear Energy Act, also meant that the spent fuel from Loviisa would have to be disposed of in Finland. For this purpose the two nuclear power companies then decided to establish a joint company, Posiva,[3] that would take over the spent fuel disposal program that TVO had been managing. For reasons of balance, the companies also decided to consider the Loviisa power plant area as another candidate for siting.

REFRAMING THE ISSUE

The general sentiment about nuclear waste disposal continued to be sceptical, if not totally negative. Judging by opinion polls, none of the candidate municipalities looked ready to accept a repository. Nor could Posiva overrule the local right of veto. Thus far, the site selection process had emphasized geological investigations and interpretations and related safety research, but now it became clear that the nuclear waste issue was not merely technical or scientific; it was also a societal and social issue. In the late 1980s and early 1990s several social scientists and media researchers had come to focus on the local waste debates, and they tended to be more sympathetic to the opposition voices. Still, they recommended more interaction between TVO—later Posiva—and the local people. And the industry took them seriously.

TVO had, of course, informed local people and the media about its activities, but until the early 1990s most interaction with local stakeholder groups was restricted to liaison groups representing the municipality. Now a clear change in attitudes was evident. Now the industry was interested in dialogue and debate. But how could it engage in a dialogue the public and stakeholders—those listed in the introduction, as well as local landowners, local business, and all others potentially acting by, or affecting, the implementation of the siting plan—if the active local interest was only on the opposition side?

The industry was not alone in reframing the nuclear waste issue: in the early 1990s the scope of the government-financed Public Nuclear Waste Research Program was extended to include research into social and media topics. At first most research focused on improving communication between Posiva (as the implementer of the plan), the authorities, and the local stakeholder groups. Posiva thought that repositories were most likely to be accepted if it could give more and better information to the public and the politicians. Here the media often looked like the main challenge for Posiva, as they seemed more opposed to nuclear power than the public itself—as long as the public could be given better, non-biased information about Posiva's plans and their safety aspects.

Posiva conducted several extensive opinion surveys, all carried out by consultants. Some looked at general attitudes toward nuclear energy and nuclear waste, but others went into the details behind people's opinions and tried to find out what people actually knew about nuclear wastes and ways to handle them. The survey results and their analysis certainly supported the view that the public held many ungrounded beliefs about nuclear waste disposal and that the attitudes could be affected by better targeted information policies. However, the results also showed that few people, especially outside the candidate site municipalities, were interested in learning about nuclear waste and plans for its disposal.

Their lack of interest was clearly due to lack of motivation: why should they be interested? Personally, I understood this attitude. If people in the municipalities had not been asked for opinions when the nuclear power plants were built, why should they now get involved? Many people apparently thought the industry should solve its problems itself and not bother ordinary people with them.

Given that view, should Posiva force people to take a stance? After the 2001 NEA workshop I mentioned earlier, I talked about this with Claire Mays, a social psychologist and rapporteur at the workshop; she found the lack of participation to be a considerable problem in processes like this. In a democracy, she felt, everyone should participate in discussing matters that could potentially affect their lives. My view is different: in a developed society the laws and institutions should protect the citizens even if they do not actively pursue their interests in every matter that potentially affects their lives.

ENVIRONMENTAL ASSESSMENT AS A TOOL TO INFORM AND ENGAGE CITIZENS

In any case, the lack of interest among the municipalities was an issue for us, especially since the apparent lack of interest could easily change into an absolute "no" if the municipality later had to take a position on the siting proposal. In this situation, the environmental impact assessment process came in handy from our point of view. As the law on environmental impact assessments (EIAs) was enacted in 1994, many industries saw it as a new burden. For us, it was a helpful instrument. It gave us a legitimate way of involving various stakeholders in discussing the nuclear waste policies and methods.

Besides actually assessing the social and environmental impact of a proposed project, the purpose of the EIA process is to allow those who may be affected by the project to influence its planning and implementation. In Finland the EIA is guided by several formal requirements, but in practice the process—for instance the way the public interaction is organized—depends very much on the implementer. Posiva decided to give the local stakeholders the main role in determining the contents of the EIA. The idea was to bring together the experts and the local people: the experts would bring their knowledge and experience on the issues, and the local people would provide information on what those facts and findings meant to them locally. Working together like this, perhaps they could build a coherent picture of the project and its alternatives.

In 1997 Posiva organised an extensive public interaction campaign—including meetings, publications, exhibitions and opinion surveys—to gather information on what people wanted to see in the EIA. For example, at the end of the campaign a special structured seminar was organized in each candidate municipality to list the issues the participants wanted covered in the EIA report. These seminars were led by an outside facilitator, who helped formulate the issues in an unbiased way. Posiva then used the opinions gathered during the campaign as the basis of its EIA process.

Of course, there was little hope of consensus on every issue related to nuclear waste disposal, but local actors generally appreciated Posiva's offer to openly discuss all their issues and concerns. Although a limited number of people participated in the meetings directly, interest in the issue was clearly growing, and the first proponent lobby groups formed. In addition to the voices critical of Posiva's work, an increasing number of letters to the editor in local newspapers pointed out possible locally realized benefits from the repository—primarily from increased employment opportunity, revenue derived from a special tax on nuclear facilities,[4] and business derived from demand for certain services needed by the nuclear waste facilities and their employees. In the two municipalities that already had nuclear power stations—Eurajoki and Loviisa—writers raised an ethical point: having enjoyed the various benefits from the nuclear power plants, the people should now recognize their responsibility for the wastes as well.

Although the opinions in most municipalities continued to be critical of a repository in their neighborhood, local politicians began to notice the changing tone of the public discussion—from sheer opposition to curiosity. In Eurajoki and Loviisa, representatives of the local government began to talk to Posiva about their mutual interests in case their municipality was chosen. In Äänekoski, the situation remained unsettled: none of the major parties wanted to become stigmatized by taking an active interest in nuclear wastes. In Kuhmo the main political parties explicitly stuck to their earlier opposing position even though new voices favoured a more versatile position, seeing the repository as a possible cure for the region's poor economic situation.

THE IMAGE PROBLEM

Posiva formulated its EIA based on the outcome of the public interaction campaign. Not surprisingly, people were interested in the safety of the disposal, both operational and long-term, and also in the safety of spent fuel transportation. However, many people seemed concerned about an aspect they called *image*. They were afraid that the repository would spoil the image of their home community.

The interest in operational and transportation safety was often quite technical: What could happen? How could that be prevented? How serious could it be for public health? The interest in long-term safety was different. Few people were directly interested in the geological, physical or chemical details of the safety assessment; instead they wanted to question the basis of expert knowledge. Could the experts really say anything meaningful about the safety of disposal in the long term? The issue here was our scientific credentials.

As the aspect of bad *image* seemed to pop up in discussions everywhere, we gave it special scrutiny: What is *image*? How is it formed and affected? What would a repository mean for the image of a community? Various definitions were proposed for image but in general we interpreted it to mean a kind of mental picture that an individual or a group of people hold on a certain matter or object. We were curious about the current image of the candidate site municipalities. It turned out that the image of Loviisa was closely associated with nuclear power. Äänekoski's image was of an industrial town with pollution problems in its past. Kuhmo elicited an image of a natural wilderness with nuances of chamber music because of its well-known summer festival. And Eurajoki was hardly known at all, as the nuclear power plant is named after Olkiluoto island, located in the municipality of Eurajoki.

Some argued that the repository would give the region's agricultural produce a negative image. We studied possible similar effects in related contexts but found out they were minimal. These days, people rarely know where their food comes from, and in fact much agricultural produce originates near existing nuclear facilities, but that has no effect on either demand or prices. Only in the case of an accident or serious incident would the repository create a negative labelling effect.

All in all, looking at previous projects, we found little evidence of significant image effects that were likely to arise around a nuclear waste repository. Personally, the more I discussed the subject with people, the more I became convinced that they were using the concept of image to denote something negative in general, something that made them uneasy. In effect, that is, they used the word to denote their negative attitudes about the matter as a whole: something that concerned or frightened them or was simply unfamiliar. It seemed that many people referred to *bad image* to avoid technical discussion of risks. Lennart Sjöberg's studies in Sweden suggest similar interpretations of individual attitudes toward risk.[5]

TECHNICAL—AND EMOTIONAL—IMPACT ASSESSMENT

Of course the EIA included a technical safety assessment based on geological data from the candidate sites. The results confirmed earlier conclusions that geological disposal would not have any significant effects on present or future generations, or on the natural environment. Moreover, the assessment concluded that no one of the candidate sites would be significantly more safe than another. The sites differed, of course, but they all had both negative and positive aspects, and it would not be possible to rank them in order of safety.

The safety assessment was reviewed by the regulator, the Radiation and Nuclear Safety Authority (STUK), and its international review panel consisting of experts in various sciences relevant to geological disposal. In January 2000 STUK concluded (on the basis of the report of the international review panel) that geological disposal, as Posiva planned it, was not only a possibility, but a necessity. In their opinion geological disposal could be made safe, provided that Posiva continued its research and investigations.

We tried to explain the contents and conclusions of the safety analysis to the public and stakeholders. Personally, however, I do not think these attempts had much effect. Much more important were the face-to-face meetings and discussions with various stakeholders as well as interest groups—nature conservation associations, local business associations, and other non-governmental organizations. Few people were truly interested in how many "becquerels of releases" or "microsieverts of doses" our repository might be responsibile for in the distant future. Instead, many wanted to learn more about our credentials so they could judge whether or not they should take us seriously. Some said they were afraid in any case.

Judging from the psychosocial research and the interviews that were part of the opinion research we had no reason to doubt these statements. This was how we learned to distinguish between the "objective" risks as defined and estimated by the technical and scientific experts, and the "subjective" risks the lay people talked about. Moreover, the subjective risks would be decisive. In the end the most important decisions would be made by the public—and the politicians who depend on them.

The closer we came to the decision, the more we talked about alternatives.

We could try to inform the decision-makers about the expert's judgments of the risks and explain the basis of these judgments, but we could not directly persuade anyone to believe in them. What we could best do face to face was acknowledge the different views and learn about individuals' backgrounds. I am sure that this acknowledgement gained us more in trust than we ever won through our attempts at public education in safety assessment.

In the late 1990s a significant change took place at the regulatory agency, STUK. Previously, STUK had refrained from participating in local discussions about nuclear waste issues. Now it took a more active role, making spokespersons available to the media and at public meetings at the candidate municipalities—provided that the invitation came from the local community. STUK tried to keep a distance from Posiva's public activities at the municipalities, and they succeeded in demonstrating that a body of independent expertise exists on the issues. Thus the public could compare the message of these independent experts with the message coming from Posiva. Although STUK was reticent about the current maturity of the plans, Posiva could usually share STUK's view of the future primary needs for research and development work in the area of geological disposal.

ALTERNATIVES ASSESSED

The closer we came to the decision, the more we talked about alternatives. In 1998 the local communities were forming their positions about the siting issue.

In Loviisa and Eurajoki, representatives from the municipality had started talking with Posiva about possible forms of support and cooperation in case either of their areas was chosen. The Eurajoki municipality had officially changed its position on the siting issue and the majority of local residents seemed ready to accept a repository. In Loviisa the majority opinion was also favorable, but a vocal minority opposed it. In Kuhmo the opposition against nuclear wastes seemed to persist despite some individual attempts to organize a public movement in favor of the repository. In Äänekoski the interest in siting began to wane as the opposition movement succeeded in the local elections; now the ruling parties became more cautious about their future support lest they be seen as eager to site a repository in the municipality.

It was not difficult to understand the positions of the candidate municipalities. Loviisa and Eurajoki already had nuclear wastes in their areas; for them the choice was between interim storage and geological repository. Interim storage would always need maintenance and supervision, whereas a geological repository should not require any attention from future generations once it was closed. The plans included a "multi-barrier system": a container for the nuclear waste itself, with bentonite clay surrounding the canister and then the bedrock around the repository. Together these should protect people and the environment from the dangers of the wastes without any need for continued maintenance. Thus the repository would provide a safer place for spent fuel than the water storage pools already familiar to them. In addition, the repository could bring economic benefits to the local community, as described above. In the other two municipalities the question was positioned differently: the repository would not lower any pre-existing risk to local people and the local politicians saw little reason to risk their careers for abstract benefits obtainable some time in the future.

For Posiva the situation became clear early in 1999. From the point of view of both geology and safety, all the site candidates would be suitable.[6] However, according to the opinion survey, in both Kuhmo and Äänekoski about two thirds of the population opposed the repository, while in Loviisa and Eurajoki the balance was about the opposite. In many respects both Loviisa and Eurajoki would be equally suitable. Still, Loviisa had its strong, if small, local opposition movement and the siting was much less of an issue in Eurajoki. Moreover, the majority of the waste was already in Eurajoki and more would be generated there, so, the outcome of the site assessment was clear for Posiva. In its application for the DiP in May 1999, it proposed Olkiluoto in Eurajoki as the site of the repository. As mentioned above, STUK gave a positive assessment of the application in January 2000 and soon thereafter the Municipality Council of Eurajoki voted 20-7 in favor of the repository.

NATIONAL DEBATE BEGINS …

After the municipality decision the process moved to the national level. For the politicians and national authorities the question was again mainly about alternatives: What would happen if the application for the DiP were denied? What, in fact, would it mean to approve the application? Ultimately, then, the question revolved around available alternatives. At the time of the EIA some of the opposition groups referred to research on partitioning and transmutation (P&T) technology and suggested that in the future the nuclear waste could be made harmless; therefore disposal would become unnecessary and obsolete. They knew, of course, that nuclides can be changed to other nuclides by bombarding them with particles ("transmuting" them), but usually the nuclides to be transmuted must first be separated (partitioned) from each other. When first developed, the process was considered too laborious, but when geological disposal made little progress, some renewed their interest in these P&T techniques. However, those opposing geological disposal in Finland lost interest quite quickly as they realized that P&T technology would likely mean increased large-scale use of nuclear technology. Not to mention cost!

The discussion soon changed direction. Now the opponents of geological disposal focused on the alternative of "retrievable" underground storage, in which nuclear waste could later be retrieved from storage if desired. In practice, however, such storage must also be supervised and kept in good condition, in contrast to geological repositories, which could safely be forgotten.

Before the DiP application was submitted, the opposition to nuclear waste disposal was based on local groups with loose connections to national or international anti-nuclear organisations. Now international Greenpeace became more active, bringing in experts from abroad. Their main message was that the case for the safety of geological disposal was insufficient and that any decision towards such a solution should be postponed. Two British scientists, Helen Wallace and Stuart Haszeldine, were invited by some opposition groups to bring this message to the Finnish Parliament. Of course the British dimension was important because of the Sellafield inquiry a few years earlier. There, on the basis of insufficient data about underground conditions, the U.K. firm Nirex was denied permission to construct an exploratory shaft to study the bedrock in order to consider siting a repository.

Both Wallace and Haszeldine got some publicity in the media and Posiva was asked to respond to the points of safety they raised. We agreed that we still needed more information about the Olkiluoto bedrock, but that was exactly why we wanted to go ahead with our investigations and start constructing an underground facility to study the rock. According to the Finnish Nuclear Energy Act we would need the DiP to go underground.

It seems that few Parliament members bought the arguments of the British scientists. Most of them saw two alternatives: either approve the DiP application, in which case the studies would continue and the case for safety could perhaps be substantiated during the coming years, or deny it and leave the situation open without any solution in sight. However, the first alternative would still leave the option of stepping back in the future, while offering at least a possibility of something better than open-ended storage in facilities that need continued monitoring and maintenance. In this respect, it was pointed out, the underground retrievable storage proposed by some of the opposition groups would not be any major improvement. Much of the final debate focused on comparing the risk of abandoned spent fuel in interim storage against the risks of geological disposal.

…AND ENDS

As it turned out, Parliament voted almost unanimously to approve the DiP. The vote was 159-3 in favor, with 37 members absent. Remarkably, the Green Party members also voted for the DiP. According to Janina Andersson, a Green member of Parliament, the party saw itself as following up on the discussion of the 1994 amendment of the Nuclear Energy Act. The Green Party had advocated for the amendment that prohibited all exports and imports of nuclear waste.

In fact, two years before the vote on the DiP the government had decided on the general safety requirements for spent fuel disposal—and that decision included the requirement on retrievability. It had not been included in the original draft prepared by the regulator, STUK, which considered it as potentially counterproductive to long-term safety, but during the EIA process it became clear that the majority of Parliament members considered retrievability to be an essential part of the solution. Finally STUK also gave in to that idea. At the time of the DiP vote, retrievability, or more generally, reversibility, was probably a key element that helped many politicians to make a positive decision despite contradictory advice and apparent uncertainties. For them the decision was mainly a conditional "yes," in case nothing better would appear. For them, retrievability meant that the decision could be reversed in the future.

WHAT MADE THE FINNISH DECISION DIFFERENT?

As I mentioned above, in the mid-1990s it was still far from clear that we really could choose a site for the repository in 2000. Siting decisions had been very difficult in most countries in similar positions. So what was different in Finland?

Some media researchers have criticized the way the discussion in Finland was directed away from long-term safety issues to what they call a pragmatist debate on alternatives. For example, Pentti Raittila's analysis of the media discussion around the DiP suggests that this was part of Posiva's strategy.[7] In my opinion, we did not need that kind of strategy; we certainly did not see the DiP as a test of safety, but instead as a policy decision on alternatives for managing spent fuel. However, I think what most surprised Raittila was that the debate did not follow the example of other countries. The U.K. stopped the developments at Sellafield and the Swedish municipalities voted against site investigations. Why, then, was the Finnish parliament almost unanimously in favor of geological disposal?

One difference between the Swedish and Finnish situations is evident: in Finland the local right of veto is absolute (it can only be changed through a long legislative process) whereas in Sweden it can be overridden. Some of the opposition to site investigations in Sweden arose because local people did not know what else might evolve if they were to accept the site investigations. In Finland, I think it was important that we were given the chance to start the siting process—but people still knew they could say no in the end, if they wanted to.

What ... was important to our success was that we had a well-defined, sufficiently fair process that the main stakeholders could accept and follow.

A difference from the British case is also evident. We had gone through a long, well-defined siting process before the decision; in the U.K. the public was not sure why Sellafield was to be studied.

There are probably no simple explanations for the different decision in Finland. Ilkka Ruostetsaari, from the Department of Political Science and International Studies of Tampere University, suggested that the outcome of the DiP discussion could have been expected in advance, given the pragmatic political culture in Finland.[8] For instance, he said, in Finland the authorities are still well respected. This may be part of the explanation: STUK's involvement in the discussion and, later, its positive preliminary safety assessment, probably influenced the vote in the Eurajoki municipality council. However, on the national level people likely saw the DiP as just another step in a process that had started almost twenty years earlier and had proceeded through a number of milestones, of which the DiP was important, but not the final one. Pragmatism was an ingredient in the judgment by the majority of Parliament members that no real alternative was in sight for geological disposal. In 2006 similar conclusions were made in both France and the U.K..

The discussion on the DiP for nuclear waste disposal took place before the decision to build a new nuclear power plant unit at Olkiluoto; it focused on the spent fuel arising from the existing plants. However, as the EIA was prepared it allowed for possible new units as well. Parliament had voted against nuclear power in 1993, but then it became more popular among those discussing alternatives to ensure a future electricity supply, as the Kyoto Protocol placed ambitious requirements on countries like Finland. One year after the DiP on spent fuel disposal, Parliament ratified the DiP on the third nuclear power plant unit at Olkiluoto.

CONCLUSION

Since the 2001 Decision-in-Principle we have seen a lot of interest in Finnish nuclear waste management solutions. Masses of visitors have come from foreign countries and we have been invited to various meetings to describe how we did it. In particular, how was it possible to get local acceptance for the repository? Sometimes people seem to believe that if they follow what we did in Finland they will succeed in their own country as well.

I do not believe that our process, as such, can be duplicated anywhere else. But neither do I believe that the conditions were unique to Finland. What I think was important to our success was that we had a well-defined, sufficiently fair process that the main stakeholders could accept and follow. It was formulated as a stepwise approach from the very beginning because the authorities wanted to control the progress and decision-making. That control meant restrictions and extra reporting requirements for the waste producers, but it also legitimized activities connected to the site investigations in areas that had nothing to do with nuclear power. It also made the siting process a national task. Of course, by definition, the stepwise nature of the process meant that decisions could be made on the basis of incomplete information, because more information would be collected in the next phase. At the time of the DiP Posiva could simply acknowledge that more research and development issues still had to be solved before implementation. We never had to promise more than we honestly believed to be realistic.

Another important fact is that communities near nuclear power plants are apparently more trusting about nuclear waste solutions than communities elsewhere. In Sweden the siting process seems to be moving towards an outcome like the Finnish one, as in a couple of years SKB is likely to propose either Oskarshamn or Forsmark as the site of the repository. Both are nuclear power plant municipalities. Of course, such choices may not be available in all countries with nuclear power plants.

When I say that the process was "sufficiently fair" I admit that we could have done some things differently. One problem was the imbalance of resources in the EIA phase. One main purpose of the EIA is the stakeholder interaction in which all parties seek alternatives that can best minimize negative impacts and lead to a solution that will be acceptable for everyone. However, on issues like nuclear waste disposal, local stakeholders will likely lack the expertise they need to engage in such discussions. The Ministry of Trade and Industry showed an interest in the social dimensions of the waste issue by establishing a social nuclear waste research program, but it could not allot significant resources to the local communities themselves. The municipalities were empowered by the local veto on siting, but this possibility hardly encouraged them to spend money on independent experts.

Another thing that bothered me during the EIA was the apparent lack of real alternatives. The EIA was established to seek out and assess alternatives, but could we really offer any other realistic alternative than our own and the zero alternative (continued interim storage)? If we did not know of any reasonable alternatives, how could local lay people find them? Now, in 2007 I feel relieved: geological disposal has also been deemed a necessity in France and the U.K.; in the U.K. this happened after a lengthy consultation that must have considered every last possibility.

For us at Posiva the period 1990-2001 was a learning process in which some of our earlier roles were turned upside down. Instead of educating others, we started to listen to the public and other stakeholders and acknowledge different viewpoints and perspectives. This, I believe, brought us much more public trust than all the previous reports and brochures combined.

We invite reader comments. Email <editors@innovationsjournal.net>.

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1. Nuclear Energy Agency (2002). "Stakeholder involvement and confidence in the process of decision-making for the disposal of spent nuclear fuel in Finland," Nuclear Energy Agency, Paris (NEA/RWM/FSC(2002)1), available on NEA's website <www.nea.fr/html/rwm/docs/2002/rwm-fsc2002-1.pdf>. Those who participated in the workshop may recognize both similarities and differences between the ideas presented in the workshop and my comments here.
2. The name of the second nuclear power company was Imatran Voima Oy (IVO), now called Fortum Power and Heat Oyj). For further information on Posiva, see <www.posiva.fi>.
3. Based on Finnish law the nuclear facility owners pay a special municipality tax proportional to the investment value of the nuclear facility. This is a significant source of income for "nuclear" municipalities.
4. See, for example, Sjöberg, L. (2004). "Local Acceptance of a High-Level Nuclear Waste Repository." *Risk Analysis* 24:3, 737-749.
5. T. Vieno & H. Nordman (1999). "Safety assessment of spent fuel disposal," in Hästholmen, Kivetty, Olkiluoto and Romuvaara, TILA-99. Posiva Oy, Report POSIVA 99-07.
6. Pentti Raittila, ed. (2001). *Mediat ydinjätettä hautaamassa* ("Media burying the nuclear waste"), Publications of the Tampere University Institute for Media Research, Series C 34/2001.
7. NEA, *op. cit*.

Allison Macfarlane

Is It Possible To Solve The Nuclear Waste Problem?

Innovations Case Discussion:
Siting of Eurajoki Nuclear Waste Facility

With the issuance of the latest Intergovernmental Panel on Climate Change report in February 2007 the world faces the stark reality that it must reduce greenhouse gas emissions immediately or face dire consequences. Nuclear energy provides a reliable source of carbon dioxide-free electricity, and a global expansion of nuclear power could replace fossil-fuel fired plants significantly within twenty to fifty years. One of the main impediments to the expansion of nuclear energy is the unresolved problem of what to do with the nuclear waste. Though nuclear power has been with us almost fifty years, to date, not one of the 30 countries with nuclear power plants has opened a nuclear waste repository.

There is a general consensus among experts that geologic repositories are the solution to the problem of nuclear waste, and this consensus has been in place for 50 years.[1] Given that, why has no repository yet opened? In 1998, the United States opened a facility to dispose of transuranic waste from the nuclear weapons complex (plutonium-contaminated materials) in southern New Mexico, the Waste Isolation Pilot Plant. The unresolved issue for the nuclear power industry is the disposition of used ("spent") nuclear fuel and high-level nuclear waste from the reprocessing of spent nuclear fuel.

Technically, it is feasible to dispose of nuclear waste. The main issues to resolve are where to site a repository and how long such a facility can prevent the radioac-

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tivity from nuclear waste to spread into the accessible environment. In the end, any site will never contain nuclear waste indefinitely. The goal is to select a site and engineered features, such as the waste canister, that maximize the amount of time the waste is isolated. Again, this can be done with some degree of certainty.

One of the main roadblocks to opening a nuclear waste repository is public opposition.[2] Distrust in the institutions that run the repository program, "Not In My Back Yard" local and regional resistance, lack of perceived fairness in siting decisions, and worries about nuclear waste transport all add up to powerful political resistance to siting and opening nuclear waste repositories. Juhani Vira offers an alternative perspective on public/institutional interactions and provides an example of successful siting via a responsive nuclear waste institution, which has overcome the majority of public opposition to developing a nuclear waste repository.

The focus of this article is to consider the nuclear waste disposal issue, both from technical and political perspectives. Will it be possible to open a repository? If not, nuclear energy may play a limited role in climate change mitigation. Vira's article shows that the Finnish repository siting experience offers guidelines for how to handle the political and societal issues associated with nuclear waste disposal. Given their experience, it may well be possible to open a nuclear waste repository.

BACKGROUND

Nuclear power in 2002 accounted for 17% of electricity generation globally (International Energy Agency, 2004). Thirty countries had nuclear power generating capacity amounting to 369 GWe, which was produced by 440 reactors in 2005 (OECD Nuclear Energy Agency, 2005). Spent nuclear fuel is produced at a rate of about 25-30 tonnes per GWe per year for light water reactors (World Nuclear Association, 2003). As a result, about 12,000 tonnes of spent fuel are produced each year globally. The United States, which has the most nuclear power plants, produces about 2,000 tonnes of spent fuel per year and had accumulated 56,000 tonnes of spent fuel by 2005. Globally, spent fuel is located either at nuclear power plants in cooling pools or dry cask storage, or in centralized interim storage facilities.

A number of studies recently have projected a large global expansion of nuclear power in response to the need to reduce carbon dioxide emissions. Pacala and Socolow (2004) envisioned 700 GWe of new power plants over the next 50 years to fulfill one of seven "wedges" of carbon dioxide reduction to stabilize emissions at the current level of 25.6 Gt CO_2/yr. A 2003 study by a group at MIT envisioned expansion of nuclear power to 1,000–1,500 GWe by 2050 to displace 15-25% of predicted growth of carbon dioxide emissions (Ansolabehere, Deutch, Driscoll, Gray, Holdren, Joskow, Lester, Moniz and Todreas, 2003). Most of this expansion would occur in Asia, where there will be the greatest need for increased electricity resources.

Expansion of nuclear power to 700 GWe would result in 17,500–21,000 tonnes of spent fuel per year. Expansion to 1,500 GWe would produce 37,500–45,000 tonnes spent fuel per year. The site for a nuclear waste repository in the United States, Yucca Mountain, Nevada, is designed to hold 70,000 tonnes of waste. A large expansion in nuclear power in the world could produce enough waste for a Yucca-Mountain-size repository every two years. Thus, there is an urgent need to develop a solution to the problem of nuclear waste before a large expansion of nuclear power begins.

FUEL CYCLE IMPACT ON WASTE DISPOSAL

There are two potential ways to operate the nuclear fuel cycle: closed and open. In an open fuel cycle, spent fuel is treated as a waste product and placed directly in a repository. In a closed fuel cycle, unused uranium and plutonium are extracted from spent fuel via reprocessing technology and reused as fuel. The remaining waste, fission products and transuranic elements produced in the reactor are solidified into glass form (now called high-level waste) and destined for a repository. Though reprocessing is appealing because usable materials are not "thrown away," it is economically costly[3] and poses a high risk of proliferation of nuclear weapons. Reprocessing technology creates separated plutonium, one of the two materials that can be used to power nuclear bombs. Reprocessing using PUREX (plutonium-uranium extraction) technology does not largely affect the size of a repository, either. The high-level waste, because it contains the fission products (especially cesium-137 and strontium-90), is still as thermally hot as spent fuel, and therefore needs the same volume as that needed for spent fuel.

Other types of closed fuel cycles have been proposed recently, including the Global Nuclear Energy Partnership (GNEP) by the United States. GNEP proposes to close the fuel cycle using a different separations process called UREX (uranium extraction) that will separate plutonium in combination with other transuranics, in the hope that doing so will increase the barrier to using this material in a nuclear bomb. There is skepticism that such material will prove proliferation resistant.[4] The GNEP program also plans to separate cesium-137 and strontium-90 from the remaining waste, and to store them in some form (still to be decided upon) for 300 years on the surface.[5] GNEP proposes to further reduce the space required in a repository by using the plutonium and other transuranics as fuel for sodium-cooled fast reactors. All aspects of the proposal are not economically viable at this time, nor will they be unless there is scarce uranium (not expected for at least 100 years) in combination with very high carbon taxes.

In the end, then, the most cost effective nuclear waste management plan is geologic disposal, which will be needed anyway, whether a closed or open cycle is employed. The only problem is that, to date, with almost 50 years of reactor operating experience, no geologic repository for the disposal of high-level nuclear waste and spent fuel has opened and operated. There are two sources of issues with opening a repository: technical and political/societal. If both can be resolved to a reasonable degree, then a repository will open.

TECHNICAL ISUES

A geologic repository should operate using the principle of multi-barriers. The geology itself should provide a barrier to movement of radionuclides and the engineered features, such as the waste form and the waste canisters should also provide a barrier. Working in concert, the two sets of barriers should provide adequate assurance that the waste is kept from humans and the environment for millennia.

The first step in geologic disposal of nuclear waste is site selection. This is the step at which countries with repository plans have experienced the most trouble. From a technical point of view, a site should display certain characteristics. According to the International Atomic Energy Agency International Atomic Energy Agency (2003), it should:

- exhibit geologic stability, no earthquakes, no volcanoes, low heat flow;
- have low groundwater content and/or flow at depth; existing groundwater should be old and stable;
- exhibit a reducing geochemical environment at depth (no free oxygen present; materials won't "rust"), with stable geochemistry (no active alteration of the local rocks or fluids; and
- have rocks that can withstand tunneling with drifts remaining open for decades.

Repository sites, ideally, would also be far from population centers but close to transportation routes, especially rail lines or shipping channels. They would also, ideally, be located in communities that welcome them.

A number of different types of sites are currently under consideration. Sweden and Finland have chosen to use crystalline rock, granite and metamorphic gneiss to store nuclear waste. The geology of the selected areas, Okilouto in Eurajoki, Finland, and Östhammar and Oskarshamn, Sweden, is stable. All three locations under consideration have reducing chemical environments. France is considering a site in Bure, eastern France, in argillite, a clay-rich rock also containing carbonate and quartz. Again, it offers a reducing environment. The United States has selected a site at Yucca Mountain, Nevada, formed of tuff, a welded volcanic ash. The Yucca Mountain site has an oxidizing environment and is located in a tectonically active region with relatively young volcanic rocks (and therefore the potential for future volcanism) and earthquakes.

One of the main problems with nuclear waste disposal is that no site can ever be guaranteed to never leak radioactivity at some point in time in the future. As a result, it becomes imperative for each site examined to show confident you are that the site will behave as expected for as long a time as expected. Such prediction is not an easy task. Earth processes involved in containing the waste are complex and not fully understood. The best we can do is to reduce uncertainties in site behavior over time by selecting a good site (according to the criteria above) and using engineered barriers to our advantage.

Predictive models of earth system processes are used extensively in nuclear waste disposal site analysis. Unfortunately, these models cannot be validated or verified because they model open systems, subject to change over time, to inadequate starting data sets, and incomplete understating of system processes involved.[6] Modeling to predict repository behavior over time, therefore, has limited value. The best way to select a site under such circumstances is to do so comparatively, by comparing a number of sites and deciding which one has the best chance of keeping waste entombed.

A number of countries have employed a comparative site selection analysis. Sweden is now characterizing two sites, Oskarshamn and Östhammar, both of which appear to have favorable site geology. Finland, though it now has selected a final site in Okilouto, originally examined five different sites that represented five different rock types.[7] The utility of such a comparison is explained by Juhani Vira, who said that "…without a program that included several investigation sites, it would not have been possible to say anything about the comparative advantages and disadvantages of the Olkiluoto and other candidate sites."[8] Germany plans to consider five sites and then select two for detailed analysis, after consultation with the public.[9] The United States was to have considered three sites in detail according to the original Nuclear Waste Policy Act of 1982. In 1987, the U.S. Congress, in response to an increasing price tag for such analysis and a contentious political situation (no state wanted a nuclear waste "dump"), amended the 1982 Act and chose the Yucca Mountain site as the sole site to be characterized.

All selected sites intend to use engineered barriers to their advantage, to the degree possible. The Swedish and Finnish repositories plan to use copper canisters to encase the waste. In a reducing environment, copper degrades extremely slowly, as does the uranium dioxide that makes up spent fuel. The U.S. repository at Yucca Mountain has an oxidizing environment, and therefore, the presence of water must be well understood, because in such an environment in the presence of water, uranium dioxide can degrade fairly rapidly. It is difficult to find a metal material to form a canister that does not oxidize quickly. The U.S. plans to use a man-made alloy, C-22, a chromium, nickel, molybdenum alloy. In terms of uncertainties, the Swedish and Finnish plans minimize uncertainties because they have selected a favorable natural barrier (reducing environment) and are using natural analogues (copper and uranium dioxide) for which there is good understanding of how the actual elemental copper deposits and urannite deposits (uranium dioxide) behave in nature, in given geochemical conditions. As a result, the Swedish and Finnish sites have reduced the uncertainties about site performance relative to the U.S. site.

POLITICAL ISSUES

A repository program that is technically sound can still fail if it is deemed politically or socially unacceptable. This is essentially the cause of delay in opening most repositories. Success from a political or societal point of view is affected by three general factors: the political system itself, the perception of fairness and justness of those in control, and the process used in establishing the repository. I will focus on experiences in the United States, Finland, and Sweden to illustrate the significance of these factors.

This discussion of societal and political factors rests on the assumption that we are examining democracies. Given that, there are different kinds of democracies, and some may be less inclined towards approving a repository site than others. The United States, for instance, is a presidential federal republic, with a plurality or winner-takes-all voting system. It stands in contrast to Sweden, a constitutional monarchy with proportional representation, and Finland, a parliamentary democracy with proportional representation. In the United States federalism provides significant power to states, so that their interests can override those of municipalities. This power is evident in relation to nuclear waste policy decisions. In the mid-1980s, the government was looking for a community to accept a Monitored Retrievable Storage facility for spent fuel. Oak Ridge, Tennessee was interested in accepting such a facility, but the state of Tennessee, and especially the governor, Lamar Alexander, opposed the facility on the grounds that the entire state would suffer from the stigma attached to nuclear waste.[10] State opposition to nuclear waste facilities has been replayed with the main repository site (Nevada is strongly opposed) and a proposed spent fuel storage facility on the Skull Valley Band of the Goshutes reservation in Utah. Though in both cases local communities are accepting, the states form powerful opponents and fight the facilities in Congress and in the courts. As a result, the national political system can play a role in the success or failure of repository siting.

Another important variable in the political success of a repository is the perceived sense of fairness or justness of both the siting decision itself and those in control of siting decision-making. Many countries have had a difficult time siting a repository. Currently, only Finland and the United States actually have approved (or semi-approved) sites. Sweden has two sites it is considering. Many countries turned back from original siting decisions, including France, the U.K., Sweden, the U.S., Canada, Switzerland, and Germany, usually because of public opposition. Some have remained in limbo (the U.K., Canada), others have developed potential new locations (France, Switzerland, the U.S., Sweden), and others have developed a new siting plan (Germany).

In the United States, the 1982 Nuclear Waste Policy Act ensured fairness by requiring two repositories, tacitly accepted that if one were sited in the western part of the country, the other would have to be located in the east. Moreover, it required downselection to five sites, for which environmental assessment reports were to be completed. Those five would be downselected to three sites, for which in depth analysis, including underground exploration, would be done. In addition, states that were singled out as sites were to be provided with financial aid to provide for alternative analysis and offset impacts from the site analysis.[11]

Much of this was abandoned when the U.S. Congress approved the 1987 Nuclear Waste Policy Amendments Act. The 1987 Act directed the Department of Energy to consider a single site, Yucca Mountain, Nevada and rescinded many of the financial benefits for the state. By directing the DOE to focus solely on one site, Congress broke the covenant with the states that the siting process would be fair and the best site would be selected. Though Congress had asked DOE to simply decide if Yucca Mountain were a reasonable site, by selecting just one site Congress put enormous political pressure on the DOE to find that the site was adequate.

In the U.S., it now appears that more than 30 years after the passage of the Amendments Act, a repository at Yucca Mountain will still not be open. The Yucca Mountain site is technically complex and politically fraught. The state of Nevada claims it was "screwed" by the Amendments Act, especially as it has no nuclear power plants.[12] It is a general feeling in the nuclear industry that Yucca Mountain is the last hope for waste disposal in the U.S. and it must open to ensure the successful continuation and expansion of the nuclear industry there. Reconsidering the siting decision is never discussed, even in private.

Other countries have remained sensitive to the value of comparing sites, from both technical and political viewpoints. Sweden is in the process of comparing two sites. Germany has plans to do surface analysis of 3-5 sites and then do detailed underground analysis of two sites.[13] Finland compared five sites before deciding on the Olkilouoto site.[14]

There is a great advantage in convincing the public that a good site has been chosen if it is selected from a suite of possibilities. As a Utah newspaper editorial proclaimed during the 1980s U.S. siting process, "Neither Utah nor any other state can properly refuse to bear the nuclear waste burden once it (the repository site) has been established to the best of human conditions. However, the honor of making such sacrifice for time without end must confer on the luckless lamb the satisfaction of knowing first-hand that the duty couldn't have been just as well assigned elsewhere."[15]

The institution that handles the siting process must also be perceived as fair and just to open a repository site. Again, the U.S. experience offers a contrast to that of Finland. Vira, in his article in this volume, enumerates the ways in which the nuclear waste institution can have positive relations with the public. Posiva Oy, the Finnish company tasked with nuclear waste disposal, learned to listen to the public's concerns and to be responsive to them. This approach generated trust among the public of Posiva Oy—a situation essential for successful repository siting.

The U.S. agency charged with characterizing and developing the site is the Department of Energy (DOE), an agency not known for its good relations with the public. The DOE carries with it the baggage of nuclear weapons development, including a culture of secrecy,[16] and numerous examples of contamination of local areas, of which the public was not informed until long after the fact. The Department has been suspected of being insincere and manipulative.[17] Moreover, the Office of Civilian and Radioactive Waste, the department within the DOE handling the repository development, has often been subject to political influence from upper levels of DOE management.[18]

The DOE has not distinguished itself in the public arena, either. Public hearings are often stacked with talking heads providing information to the public but never actually listening or responding in a meaningful way to what they have heard. Most official documents attached to the repository, including the Final Environmental Impact Assessment, among others, all require a public comment period. The DOE dutifully collects comments from the public and attaches them to the document as appendices. It has never been apparent that the DOE has actually taken any of these comments seriously enough to make significant changes in their program. In essence, then, though the public has the appearance of a voice in the process, it is duly ignored, reinforcing the lack of trust.

Finally, the last factor important from the political viewpoint is the process of repository siting. As Vira has made clear, the Finns have followed a step-wise process, now advocated by a number of institutions including the U.S. National Academy of Science.[19] The step-wise process always allows for the option of alternatives—be it on the technical side, to do with design, or on the political side, for example, the veto given to municipalities under consideration for a site. Such a process is flexible and allows the commanding institution to respond to unforeseen issues that arise. Again, the U.S. provides a contrast in that it downselected its sites to one early on in the siting process. In addition, the DOE established an engineered design for the repository prior to collection of all relevant scientific data. A flexible siting process lessens the political pressure to succeed and makes it possible to address contingencies as they arise.

CONCLUSIONS

It should be clear from the analysis above that the Finns are much better positioned to open a geologic repository for nuclear waste than the Americans. In part this is because they have chosen a site that is less burdened with technical uncertainties than the U.S. Yucca Mountain site. In part, this is because they have been more successful in generating trust among their citizens to grant approval to the project.

Resolving the nuclear waste problem is important for the continuation of nuclear power, especially in light of impending climate change. Nuclear waste is only one of a number of issues impeding the expansion of nuclear power, though. Others include high capital costs of bringing new plants online, ensuring the safety of reactors, avoiding the proliferation of nuclear weapons via nuclear fuel cycle processes such as uranium enrichment and spent fuel reprocessing, and, in this day and age of terrorism, ensuring the security of nuclear power plants against attack. This list is not short, but as Vira has suggested, perhaps at least some countries will solve one of these issues: that of nuclear waste. With a concerted effort to engage the public in siting decisions, address their concerns, and make institutions honest about the issues, the likelihood of successfully opening a nuclear waste repository increases, especially if the site selected is technically sound.

We invite reader comments. Email <editors@innovationsjournal.net>.

Endnotes

1. See for example, National Research Council (1957) and National Research Council (2001).
2. National Research Council (2001).
3. See for example Ansolabehere et al. (2003) and Bunn et al. (2005).
4. See for example Fetter and von Hippel (2005).
5. Office of Nuclear Energy (2007).
6. Macfarlane (2006); Oreskes and Belitz (2001); Oreskes et al. (1994).
7. Lidskog and Andersson (2002).
8. Vira (2001), p. 31.
9. AkEnd (2002).
10. Flynn et al. (1998).
11. Colglazier and Langum (1988).
12. Nevada has always termed the 1987 Nuclear Waste Policy Amendments Act the "Screw Nevada Bill."
13. AkEnd, (Arkeitskreis Auswahlverfahren Endlagerstandorte) (2002).
14. Vira (2001).
15. As quoted in Colglazier and Langum (1988), p. 352.
16. Flynn and Slovic (1995).
17. Short and Rosa (2004).
18. Carter (2006).
19. National Research Council (2003).

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Boru Douthwaite

Enabling Innovation

Technology- and System-Level Approaches that Capitalize on Complexity

Making innovation happen is central to what many engineers do. However, when we finish our training most of us believe that it is our job to conceptualize designs, develop products and worry little about what happens after they have been introduced. Our courses are generally too practical to bother with theories about how innovation occurs, who it affects and how we might better manage the process. Diesel, inventor of the diesel engine, distinguished between two phases in technological progress: the conception and carrying out of the idea, which is a happy period of creative mental work in which technical challenges are overcome, and the introduction of the innovation, which is a "struggle against stupidity and envy, apathy and evil, secret opposition and open conflict of interests, a horrible period of struggle with man, a martyrdom even if success ensues."[1] Diesel is perhaps overstating the difficulties of managing innovation, but nevertheless as engineers we are still taught to prefer technical "invention" and leave dealing with people and the "innovation" side to others. However, engineers ignore the innovation process at their peril. Enabling innovation means building on peoples' ingenuity and motivations, rather than working against them.

In this paper I describe the learning selection approach to enabling innovation that capitalizes on the complexity of social systems at different scales of analysis. In the first part of the paper I describe the approach and how it can be used to guide the early stages of setting up a "grassroots" innovation process. In the second part of the paper I look at how the learn selection model can be used "top-down" to guide research investments to trigger large-scale systemic change.

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This paper draws heavily on his book Enabling Innovation: A Practical Guide to Understanding and Fostering Technological Change *(London: Zed Books) published in 2002.*

Boru Douthwaite

WHY INNOVATION APPROACHES MATTER

In 1995 the Burmese military junta, the State Law and Order Restoration Council (SLORC) decided that, to boost production, the country's rice farmers should grow two crops of rice each year instead of one. There was a good reason why most Burmese rice farmers grew only one crop, however: growing two meant harvesting the second in the middle of the monsoon and, without very fast harvesting and drying, the grain would go moldy and spoil. The traditional single crop meant that the grain could be dried in the field after the rainy season and that there was far less rush. SLORC realized this, of course, and had asked the director of the Agricultural Mechanisation Department (AMD), part of the Ministry of Agriculture, in just 6 months to come up with a rice harvester that could save the first crop by working in wet conditions.

By July 1995, when AMD's search had become frantic, somebody, and I still don't know who, gave the department the drawings of a rice harvester. These drawings were the fruit of five years of research and development I'd carried out with a team I'd led at the International Rice Research Institute (IRRI) in the Philippines, and with help from local manufacturers and the Philippine Rice Research Institute. The harvester my team had designed and built is known as a stripper-gatherer because, rather than cutting the rice so that it can be carried elsewhere for threshing to extract the grain, it moves through the field gathering the grain by stripping it from the standing stalks.

Desperate for a solution, AMD set about building one immediately from the drawings. When it seemed to work they videotaped it in action and AMD's Director showed the footage to the Minister of Agriculture and then to the whole of SLORC. Four weeks after the drawings arrived, and without anyone using the machine more than twice, SLORC decided to build two thousand units, one thousand of which were to be ready within three months to then be distributed to the country's tractor stations. I did not find out about what was happening until production had already begun, and traveled to Burma soon afterwards.

Hardly any of the machines were ever used. Thankfully, only the first 1000 machines were made, but all of these ended dumped in sheds or in the bush to rust away. In the rush to build the machines quickly, quality control had been scrapped and substandard materials had been used, making the machines inoperable without significant modification.

The few harvesters that were used were rejected by the farmers because the machines did not cut the straw but rather left it in the field making it unavailable for animal fodder and making subsequent land preparation much harder.

Why had this happened? When I asked the factory manager why there was no quality control he admitted that he knew that there were problems with the machines but fixing them would mean he would not reach his quota. He was worried that any delays or negative reports from him would cost him his job, and was relying on the tractor station managers to keep quiet as well. When I visited a few tractor stations I quickly realized that this was the way things were done in Burma.

I found that the stripper harvesters had been abandoned next to foot-operated rice threshers, rice-hull stoves and other equipment that had been manufactured by AMD in previous years. Neither farmers nor the tractor stations had been asked if they wanted the equipment. It had just been assumed that the AMD engineers knew best and could develop what was needed with little consultation.

When I left Burma for the last time I learned that AMD was starting to build seven thousand mechanical rice reaper harvesters which were much more complicated that the stripper harvester, and so even less likely to work. Nothing had been learned. I realized that the Burmese Ministry of Agriculture, AMD and the tractor stations were all locked into a top-down model of technology transfer that people said was working when it wasn't because they were too afraid of the consequences of feeding back stories of failure.

It would be easy to dismiss what happened in Burma as the inevitable outcome of having a military junta running a centrally controlled government through fear. This, however, would be a mistake, because the only way this story differs from others I came across in the eight years I worked in Asia is that it is more extreme and its lessons are consequently clearer to see. The fact is that similar centrally-made decisions about what is "good" for farmers have led to even greater wastage of resources in other countries.

My Burma experience, as well as the realization that it was not isolated, led me to two conclusions: firstly, the way people think about and plan for innovation is vitally important; and secondly, an adequate model of the early innovation process, where products move from concept to initial manufacturing, did not exist. I discovered that most people thought little about how innovation would happen, and when they did, tended to assume a model that had worked well for distributing the high yielding plant varieties responsible for the Green Revolution.

This is a top-down model, very much like that used by SLORC on the stripper harvester, which sees formal Research and Development (R&D) laboratories as the source of an innovation which is then passed on to others to implement. The key stakeholders—the people who will reproduce and use the technology—are not seen as sources of innovations or ideas in their own right. And I also found out that a similar model is also mistakenly used in the developed world. As Von Hippel comments: "It has long been assumed that product innovations are typically developed by product manufacturers. Because this assumption deals with the basic matter of who the innovator is, it has inevitably had a major impact on innovation-related research, on firms' management of research and development, and on government innovation policy. However, it now appears that this basic assumption is often wrong."[2]

These realizations motivated me to learn from other successful and unsuccessful attempts to introduce harvesting and drying equipment into Asia. I researched 13 cases in total and as a result developed a model of the early innovation process, called the learning selection model.

LEARNING SELECTION

The main finding from the research, and the most striking, was that the successful technologies were the ones which manufactures and users had modified the most. The research showed that engineers and designers were often singularly unable to develop machine designs that people adopted, without a great deal of further co-development with the manufactures who would build the machine and the people who would use it.

This co-development occurred when manufacturers and users believed that the first commercial prototype made a "plausible promise" of being of benefit to them, thus motivating them to become co-developers. In the co-development process the key stakeholders learned about the equipment and developed their own procedures and protocols that often increased the performance of the equipment in ways that the engineers had not envisaged. In short, the successful equipment evolved after launch through adaptations made by the key stakeholders, increased in fitness as a result, while unsuccessful equipment did not evolve.

I developed the learning selection model to describe this process.[3] As the name suggests, the learning selection model is based on an analogy with natural selection, which is the algorithm that drives biological evolution. Natural selection consists of three mechanisms. These are:

- *Novelty generation.* As a result of random genetic mutations and sexual recombination of differing genetic material, differences between individual members of a species crop up from time to time.
- *Selection.* This is the mechanism which retains random changes that turn out to be beneficial to the species because they enable those possessing the trait to achieve better survival and breeding rates. It also rejects detrimental changes.
- *Diffusion and promulgation.* These are the mechanisms by which the beneficial differences are spread to other areas.

The learning selection model is depicted graphically in Figure 1. It shows a technology, shown as a cogwheel, beginning as a "plausible promise" that motivates the key stakeholders to co-develop it. The technology then increases in fitness by gaining knowledge and becoming "meshed in" to existing systems through the adaptation and learning that takes place. Here, fitness is taken in the biological sense to mean improvements in the likelihood that the technology will be adopted and promulgated. The "meshing in" of the technology, or its "social construction" as it might also be termed, is represented by the move from a single cogwheel to three inter-locked ones. The increase in knowledge is represented by the increase in size of the cogwheels.

Learning selection is shown inside the black box in Figure 1 and is responsible for the evolution. Learning selection is a process built on Kolb's 4-stage experiential learning cycle,[4] and is perhaps best explained using an example.

- *Experience.* Suppose a farmer finds that the rice miller pays her a low price for the grain dried in her dryer because some of it is not properly dried.

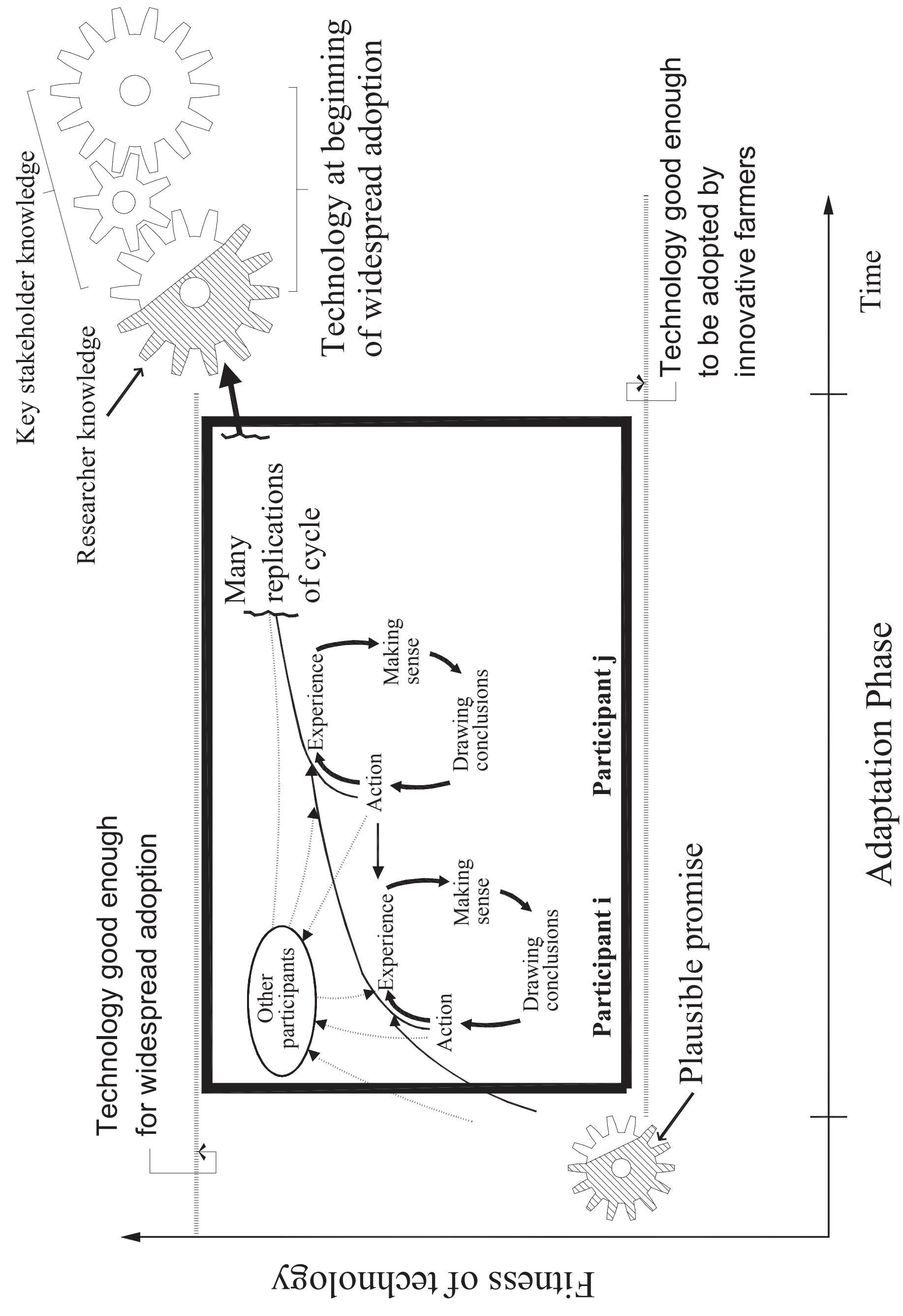

Figure 1. The Learning Selection Model

- *Making Sense.* She reflects and makes sense of the experience. She realizes that uneven drying is loosing her money and that it might be sensible to try and improve the dryer's performance.
- *Drawing Conclusions.* She then develops personal explanations of what happened from her own or others previous experience or theories. She hypotheses that if she reduces the amount of rice she loads into the dryer then drying will be more uniform.
- *Action.* She then decides to test her hypothesis, and in so doing generates a novelty.

Testing the novelty begins another learning cycle. Her selection decision to adopt or reject the novelty will depend on whether the rice miller pays her more for her product. The miller will make this price decision after going through his own learning cycle when he tests a sample of her rice for milling quality. If the farmer is participant *i* in Figure 1 then the miller represents participant *j.*

So far the third component of the evolutionary system—the promulgation and diffusion mechanism—is missing. In the example, promulgation of the novelty occurs when the farmer tells people in her social network, represented in Figure 1 by the "other participants" box, about the benefits of her novelty and they choose to experiment with it themselves.

The farmer, the miller and the people they are connected to them through their social networks will be going through their own learning cycles creating the conditions for the recombination of differing observations and experiences that can lead to novelties that have "hybrid vigor." In the process the technology evolves and with it the participants' opinions and knowledge of it and the way they organize themselves to use and promote it. These processes are all involved in learning selection.

The learning selection model is most useful when key stakeholder "learning by using" and "learning by doing" are important in the early adoption phase, which is the case for technologies that open up new markets. The learning selection process works best when users are able to modify the technology, and if there are ways of evaluating changes.

Wind turbines

The wind turbine industry is a good one for describing the applicability of the learning selection model. Excitingly, it shows that learning-selection-type innovation processes are able to harness the innovative potential of the people who are directly affected by technology. A grassroots development process in Denmark was able to produce a wind turbine industry that had a 55% share of a billion dollar a year world market in 2000, beating the U.S. who spent over 300 million dollars funding a top-down development program led by the National Aeronautics and Space Administration (NASA). The origins of the Danish industry were a few agricultural machinery manufacturers and ideologically motivated "hobbyists" who began building, owning, and tinkering with wind turbines (generating novelty).

There were many early teething problems but the owners organized themselves into a group who lobbied successfully for design improvements (selection), working closely with manufacturers to solve the problems. The owners' group developed a co-operative ownership model and pressured politicians to support the sale of their electricity to the national grid at a fair price (promulgation and diffusion). In contrast, the NASA led a top-down science development approach that implicitly assumed that scientists could develop the "perfect" wind turbine with little input from the owners and users. NASA's approach failed.

Computer Software

Another example, *now very well-known*, of the power that a grassroots innovation model can harness is the computer operating system Linux. Linux is a "a world-class operating system" that has coalesced "as if by magic out of part-time hacking by several thousand developers all over the planet connected only by the tenuous strands of the Internet."[5]

Linux started life when a Finnish computer science student started to write a Unix-like operating system that he could run on his PC; he had become tired of having to queue for hours to gain access to Unix on the University's main frame. When he finally got the core of an operating system working he posted it on the Internet so that others could try it out. Importantly he gave the source-code so other people could understand the program and modify it if they wanted. Just like the first Danish wind turbines, early versions of Linux were not technically sophisticated or elegant, but they were simple, understandable, and touched a chord with "hackers"—people like Torvalds himself who got a kick out of generating novelty for the sake of being creative, not for money.

Torvalds' main role in the development of Linux after the first release was not to write code for features people wanted but to select and propagate improvements to the system from the ideas that streamed in. Ten people downloaded version 0.02 and five of these sent him bug fixes, code improvements and new features. Torvalds added the best of these to the existing program along with others he had written himself and released the composite as version 0.12. The rate of learning selection accelerated as the number of Linux users increased and, to cope with the volume of hacks (novelties) coming in, Torvalds began choosing and relying on a type of peer review. Rather than evaluate every modification himself he based his decisions on the recommendation of people he trusted and on whether people were already using the patch (modification) successfully. He in fact played a similar role to that of an editor of an academic journal who makes sure submitted articles are reviewed but retains final control over what is published and what is not. This approach allowed Torvalds to keep the program on track as it grew.[6]

The learning selection approach to co-developing innovations with users

The wind turbine and Linux examples show that the learning selection model can provide a powerful way of understanding the research, development and early adoption process and of managing it. Figure 2 shows an innovation process beginning with a bright idea that individuals or small teams of researchers then develop in relative isolation. While the R&D team may ask the key stakeholders—the people who will ultimately take ownership of their idea, replicate it and make it work—for some advice, they are driving the process.

Mokyr argues it has to be this way because the process of inventing "plausible promises" is by its nature something that "occurs at the level of the individual." He says creating a plausible promise is "an attack by an individual on a constraint that everyone else has taken for granted." It is not something that lends itself to a broad consensus approach.[7]

At some point the R&D team crystallizes the knowledge they have generated into a prototype: their "best-bet" of what the key stakeholders want. Then, in what marks the beginning of the start-up phase, they begin to demonstrate their best-bet to the key stakeholders. It may take several prototype iterations before the R&D team has received and incorporated sufficient feedback for at least a few innovators to adopt it.

It is this adoption, based on the belief that the new technology makes a "plausible promise" of bringing benefit, which marks the beginning of the adaptation phase. It also marks the beginning of a period of co-development and learning selection in which the technology evolves and its fitness improves, through the process shown in Figure 1.

Learning selection works when people make changes to a technology and then select and promulgate the ones that they find beneficial. This improves the fitness of the technology—its suitability to the environment in which it is used—and hence its market appeal. At a certain point the attributes of the technology are good enough for the second category of adopters, Rogers' early adopters,[8] to start to show an interest. This marks the point at which the key stakeholders begin to take over ownership of the technology.

However, the analogy between natural selection and learning selection is not perfect. One important difference is that natural selection is blind and learning selection is not—genetic mutations occur at random but technology and system change can be directed. Hence, learning selection does not necessarily happen. It only comes about if the key stakeholders are sufficiently motivated to adopt and modify a technology and carry out sensible learning selection on it. They must also understand the technology well enough to do so themselves. Consequently, at least one stakeholder, often from the R&D team, must champion it and fill knowledge gaps until the other stakeholders have learned enough to take over. This take-over marks the end of the early adoption process and is the point at which market selection begins to work.

The take-over also marks the beginning of the expansion phase when the technology becomes mainstream. As this happens, the people adopting the technology change from hackers (innovators) and early adopters to people who want the technology to work reliably and profitably. Increasingly the market becomes the main selection mechanism. Manufacturers and researchers are able to gather and codify more and more information that can be used to build predictive models. This allows them to move from "learning by using" which requires adopters to be co-developers, to "learning by modeling," where learning comes from virtual tests carried out on computer rather than field experience. In so doing, the learning selection model of the innovation process becomes less relevant and the conventional assumption that manufacturers or R&D departments can and do develop finished technology begins to fit better.

A TEN-STEP APPROACH TO ENABLING INNOVATION

It is possible to derive a ten-step approach to enabling grass-roots innovation based on the learning selection model.

1. Start with a plausible promise

The first step to induce change through learning selection is to produce a "plausible promise;" something that convinces potential stakeholders that it can evolve into something that they really want. Experience shows that it is difficult to enlist co-developers if the whole project is abstract and up in the air.

The plausible promise does not need to be refined or polished: it can be imperfect and incomplete. In fact the less finished it is, the more scope there is for the stakeholders to innovate and thus gain ownership of the technology. On the other hand the more problems there are then the greater the chances that the key stakeholders will give up in frustration. A delicate balance must be found.

2. Find a product champion

The next step is to identify the innovation or product champion. He or she needs to be highly motivated and have the knowledge and resources to sort problems out.

Someone from the R&D team is likely to be suitable because he or she will probably have both the necessary technical knowledge and the motivation as they already have a stake in the technology. He or she must also have good people and communication skills as, in order to build a development community, they will need to attract people, interest them in what they are doing, and keep them happy working for the common cause. The product champion's personality is therefore crucial.

3. Keep it simple

Don't attempt to dazzle people with the cleverness and ingenuity of the prototype's design. A plausible promise should be simple, flexible enough to allow revision, and robust enough to work well even when not perfectly optimized. The critical comments of your colleagues don't matter. Your potential co-developers' needs and knowledge levels do. For example, if you are designing a combine harvester and you know the manufacturers and farmers you'll be working with are familiar with a certain type of thresher, then use that in your design, even if it is technically not the most elegant solution. To quote John Gall, "A complex system that works is invariably found to have evolved from a simple system that worked."[9]

4. Work with innovative and motivated partners

Allow the participants in your learning selection process to select themselves through the amount of resources they are prepared to commit. Advertise or write about your plausible promise in the media, by doing field demonstrations, or on the Internet and then wait for people to make the effort to contact you. Don't give inquirers anything with a resale value for free. For example, if your prototype has an engine, then charge the market value for it. Otherwise people may be motivated to adopt in order to get something for nothing. In addition, people generally value something more highly if they have paid for it and they will be more committed to sort out the problems that emerge.

On the other hand you must make it clear to the first adopters that they are adopting an unperfected product and that they are working with you as co-developers. You need to reassure them that you will be contributing your own resources to the project and will not abandon them with a lemon. You should be prepared to offset some, but not all, of the risk they are taking in working with you. Getting the balance right is very important here too.

5. Work in a pilot site or sites where the need for the innovation is great

Your co-developers will be influenced by their environment. Their motivation levels will be sustained for longer if they live or operate in an environment where your innovation promises to provide great benefit. In addition, they are more likely to receive encouraging feedback from members of their community.

6. Set up open and unbiased selection mechanisms

(i) The product champion

Once you have the key stakeholders working with you and generating novelties, you need ways of selecting and promulgating the beneficial changes. Initially the product champion usually plays this role. An effective selector must be able and prepared to recognize good design ideas from others. This means that, if he or she is also the inventor, they must be receptive and able to accept that others might have better ideas.

Very few people are capable of being effective at both championing their product and selecting novelties simultaneously. This is because to be good at the former they need to believe deeply in the product's benefits and be able to defend it against criticism.

To be effective selectors, on the other hand, they need to keep an open mind and be able to work with others to question fundamental design decisions.

If a product champion defends the technology too strongly, or shows bias, then "forking" occurs and the disaffected person or group branches off on its own to do

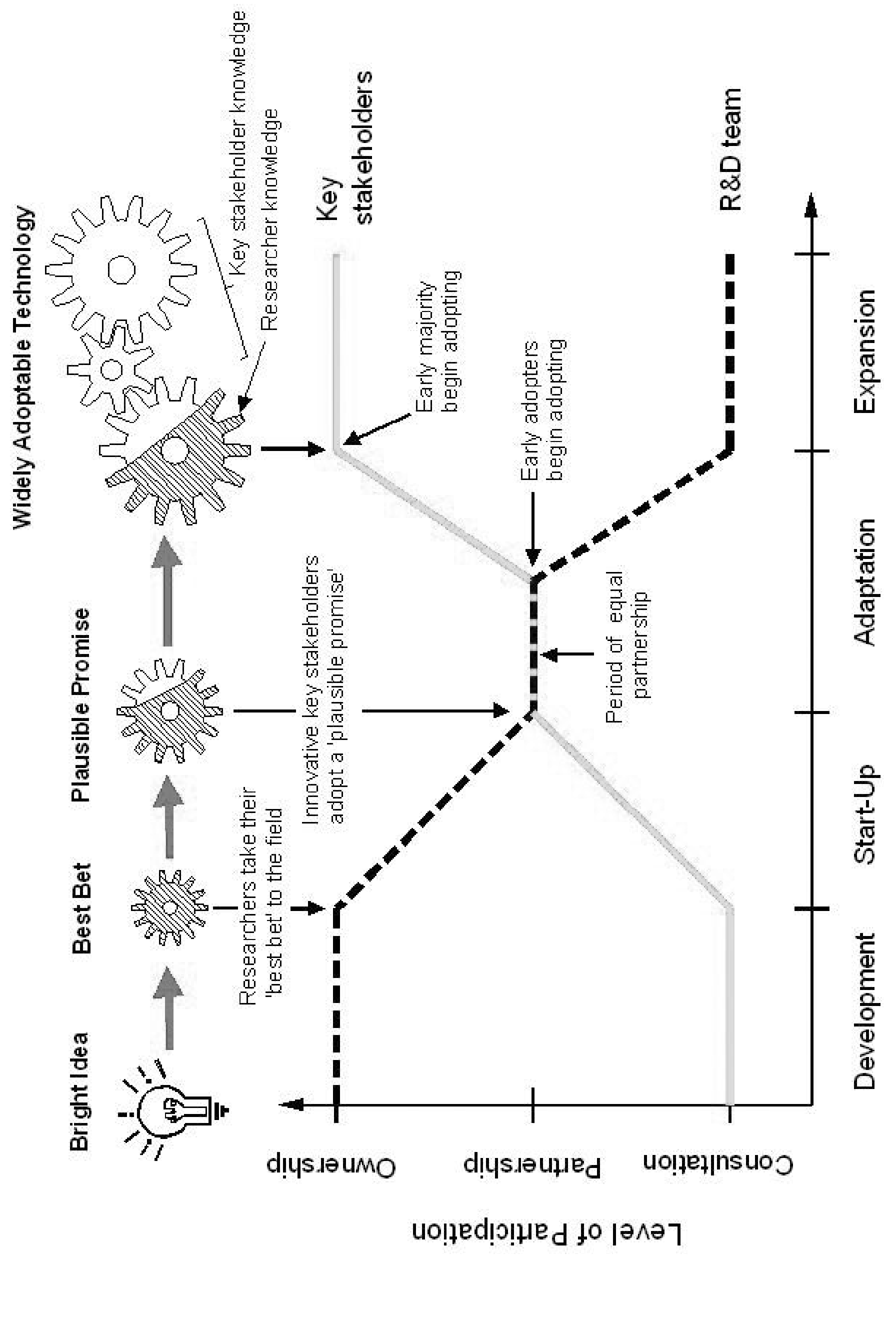

Figure 2. Stages and Participation in a Learning Selection Innovation Process.

what they felt prevented from doing by the selector. It is good to have people test alternative design paths but if it is done in frustration or spite then cliques form, making any comparison and subsequent selection between rival branches difficult.

Creative talent is split and energies can be dissipated in turf wars.

(ii) Alternative selection mechanisms

Even if the product champion can be open-minded and unbiased he or she may have problems convincing others. One option is to set up a review mechanism that is well respected by your key stakeholder community. There are a number of ways of doing this. Three that work are: (i) review by an independent organization; (ii) peer review; and (iii) providing potential adopters with enough information to make informed selection decisions themselves.

7. Don't release the innovation too widely too soon

For the innovation to evolve satisfactorily, the changes the stakeholders make to it need to be largely beneficial and, as those generating the novelties will have gaps in their knowledge, product champions should restrict the number of co-developers so that they can work with them effectively. When people show enthusiasm for a prototype it is very tempting to release it as widely as possible but this should be resisted. The technology will always be less perfect than one initially thinks.

However promising the technology might appear, there are many things that can and will go wrong. First adopters need to be aware of this and have ready access to the product champion. Otherwise, their enthusiasm will quickly turn to frustration and the product champion will end up defending the technology against their criticisms. Once the product champion becomes defensive, he or she will be far less useful at sorting out problems.

8. Don't patent anything unless it is to stop someone else trying to privatize the technology.

In learning selection, people co-operate with each other because they believe that all will gain if they do. The process is, therefore, seriously damaged if one person or group tries to gain intellectual property rights over what is emerging. Firstly, the communitarian spirit is damaged. Secondly, patents are monopolies that immediately reduce the novelty generation rate and thus slow down future development and the flow of ideas.

9. Realize that culture makes a difference

Culture can influence the degree to which knowledge is guarded within a particular group, or spread around. Learning selection is going to be greatly impeded in cultures where new knowledge is carefully guarded, either through secrecy or the taking out and enforcement of intellectual property rights.

10. Know when to let go

Product champions need to become personally involved and emotionally attached to their projects to do their jobs properly. This makes it easy for them to go on flogging dead horses long after it has become clear to everyone else that the technology is not going to succeed. Equally, project champions can continue trying to nurture their babies long after they have grown up and market selection has begun. It is, therefore, a good idea to put a time limit on the product champion's activities.

In the following section I describe how ideas from learning selection can help trigger systemic change.

BEYOND LEARNING SELECTION: RESEARCH TO TRIGGER A "BLUE REVOLUTION" IN AGRICULTURE

I work for one of the 15 international agricultural research centers based in Africa, Asia, Latin America, Europe and the United States of America that constitute the Consultative Group on International Agricultural Research (CGIAR). In the 1960 and 1970s research in CGIAR Centers helped spark the Green Revolution by breeding improved higher yielding crop varieties that were then disseminated to farmers by national agricultural research and extension systems. This "pipeline" approach is effective for developing certain types of technology, like seed and vaccines—technologies that have some characteristics of magic bullets. In the case of seed and the Green Revolution, farmers planted improved seed, harvested more grain, sold it for more, decided to plant it again and gave some seed to their neighbors. Adoption of new varieties and improved yields spread like a virus. The role of research was clear—keep breeding improved varieties to replace those in the field when inherent resistance to pests and diseases breaks down. But the pipeline approach does not work for more complex technologies than seed, as the Burma story at the beginning of the article showed.

Today the CGIAR is confronting a new challenge: catalyzing a "blue revolution" to content with the global challenge of water scarcity. Unless water use patterns change substantially, within 25 years agriculture can be expected to be using an additional 500 km^3 of water if the world is to feed the additional billions who will live on the planet by then. This is more water than flows down the Mekong River in one year. This water would have to come from the world's major rivers, aquifers, wetlands and lakes that are already under pressure. Already many large rivers now run dry or clog up before they reach the sea, and an estimated half of the world's five million lakes are endangered. Unless there is "more crop per drop," many aquatic ecosystems will collapse and conflicts over water will increase. Climate change only makes the challenge greater.

In contrast to the Green Revolution, there is no magic bullet for a Blue Revolution. As a consequence, a pipeline approach to research will not be effective. What is more, the feedback between innovation and a successful outcome is far less direct in the case of water conservation than it is in the case of increased agricultural yields. Water flows between groups of people. Most of the time, when farmers save water it is people downstream who benefit, often people they don't know. Improving how water is managed often requires technical innovation, but is at least as much about linking people together, improving social processes of negotiation and changing norms.

Realizing this, the CGIAR researchers focused on the task of improving global water management have sought not simply to develop new technologies to push into target regions, but rather to build the capacity of networks of water and agricultural scientists to develop local solutions with the people who would use them. The result is the Challenge Program on Water and Food (CPWF), an international, multi-institutional research initiative with a strong emphasis on "north-south" and "south-south" partnerships. The initiative brings together research scientists, development specialists, and river basin communities in Africa, Asia and Latin America.

With a budget of $15 million/year, the CPWF is extended over nine of the world's largest and most important river basins including the Nile, Mekong, Limpopo, Volta and Yellow River. One way these scarce resources can effect change at the needed scale is if they motivate large-scale learning-selection-type innovation processes. This is possible as the case study in Appendix A shows—a story of adoption of a no-till technology saved 1.16 km^3 of irrigation water in India and Pakistan.

The learning selection model can also help guide top-down system-level interventions. The model and complexity theory[10] suggests that rate of innovation in a system can be changed by three sets of interventions: 1) changes in the variation or novelty of system components (i.e., types of stakeholders involved and the strategies and technologies they use); 2) changes in interaction patterns between stakeholders, in particular through changes to social networks; and, 3) changes in the way selection decisions are made.The research that helped trigger the Green Revolution focused mainly on developing and introducing novelty. Research for a Blue Revolution needs to be more balanced, as we now explore.

Many of the solutions to water management problems already exist. Consequently, part of the CPWF research should be to identify promising local solutions. Once identified these "best bets" have the potential to spark similar improvements in similar systems.

Although many solutions may exist, too much novelty and variation creates uncertainty in people and can prevent them from adopting and innovating. Research is needed to reduce this uncertainty by describing the variation that already exists. People have been managing water for millennia and do not need more variation so much as better understanding of what already exists.

Much more research is also needed on understanding how changing interaction patterns and selection processes can help people manage their water properly. As we've already discussed, in some ways the Green Revolution was easy. Farmers clearly saw the benefit in growing improved seed varieties in terms of higher yields and incomes. Those making the changes directly benefited. Feedback was strong and clear and adoption increased quickly. Politicians too understood and adoption was supported by massive state endorsement, subsidies on fertilizers, the building of irrigation schemes and numerous policy changes.

Improving how water is managed is a different story. When farmers improve the way they manage water the benefits may not accrue to them but to other water users downstream. Conversely, if farmers use excessive amounts of water the effects are not felt by them but by people downstream for whom water becomes unavailable. Feedback is weak or non existent so there is almost no incentive to select and promulgate better water management practices. Learning selection cannot work. Hence it is research on changing interaction patterns, promulgation pathways and selection mechanisms to improve information flow, feedback, negotiation and decision making which probably offers the greatest potential for triggering a Blue Revolution.

Research to trigger a Blue Revolution should further develop a twin strategy of fostering local "pilot site" changes while looking for opportunities to catalyze much larger scale changes. This requires mechanisms, such as innovation funds, that can support potential winners. It also means using research to improve systemic understanding to become better at spotting early winners, and knowing in which systems they are likely to first emerge.

At the level of project management, a practical approach to making the most of complexity is to facilitate a collaborative process in which project staff and stakeholders come to a common understanding of how they see a project achieving outcomes and impacts. Doing so can help the project achieve impact by mapping out promising "impact pathways." Monitoring and evaluation of projects' progress along their impact pathways enables early identification of opportunities and challenges, which if acted on also makes impact more likely.

Finally, to effect change, research findings further need to be packaged into plausible promises. Without being packaged as plausible promises, key stakeholders will not engage with the novelty. Without engagement there will be no behavior change and no impact. Packaging of plausible promises is needed as much for research outputs such as policy briefs, models and methodologies as it is for rice harvesters and wind turbines. Packaging of plausible promises usually involves a learning selection process with the key stakeholders.

CONCLUSION

The world faces huge challenges in the 21st Century, of which triggering a Blue Revolution to improve water use in agriculture is one. Much of the response to these challenges will come through innovation. Research can and does enable innovation, but the way that research and innovation processes are conceptualized and managed makes a huge difference to the ability of engineers and researchers to foster change. The paper describes the learning selection model that can guide setting up and managing grassroots innovation processes that capitalize on complexity by building on peoples' ingenuity, motivations, and their implicit theories of how change occurs. Enabling innovation requires fostering change at different scales. The learning selection model can also help guide "top-down" changes by identifying three sets of interventions that alter innovation rate in a system: 1) changes to novelty and variation of actors and technologies in the system; 2) changes to interaction patterns between actors; and 3) changes to the way selection decisions are made. Traditionally agricultural research has attempted to leverage change by changing system novelty, through, for example, breeding new crop varieties. The learning selection model helps us see that bringing about a Blue Revolution is more about changing how people interact and make decisions, and less about developing new technology.

We invite reader comments. Email <editors@innovationsjournal.net>.

Acknowledgements

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APPENDIX. A GRASSROOTS INNOVATION THAT SAVES WATER[12]

No-till wheat after rice is currently being planted on over 3 million ha. of the Indo-Gangetic plains, producing net benefits of around USD 239 million per season, along with a 1.18 km^3 reduction in the extraction of irrigation water.[13]

Work on no-till began in the Indian Punjab in about 1970. It was restricted to hand-sown, small-plot, on-station trials, with little or no scientist-farmer interaction. Trials as designed masked the true advantages of zero-till: earlier sowing, higher yields, reduced costs, and improved weed control. In the mid-1980s, researchers in the Pakistan Punjab began a separate program. A key factor was access to a "best bet"—a no-till implement from New Zealand. These were, however, expensive, heavy and few in number. Although appropriate for research, they were not very well suited for farmer use. Researchers sponsored the development of a local prototype but this, also being too heavy, was not well received. It did not make a plausible promise of being useful.

From here, the initiative passed to India. An international scientist, familiar with the no-till work in Pakistan, donated four imported implements to colleagues in India. On-farm testing with one of these began in 1990 at Pantnagar University. Zero till wheat performed well, with good crop establishment, higher yields and lower costs. Nonetheless, progress was slow. The implement was again too heavy, and openers were prone to breakage and unable slice through rice stubble. In the following season, one of the scientists took a simple "recombination" step, attaching "inverted-t" cross-slot openers from the imported drill to his own frame design. This was the original "Pantnagar drill" and the first plausible promise.

As it happened, there was near Pantnagar a dealership for National Agro Industries, a Ludhiana-based farm implement company. The local dealer became aware of the Pantnagar drill and in 1992 introduced the researchers to one of the company's owners. Subsequently, National learned to forge its own inverted-t openers, which then were installed on the frame of a National conventional-till drill. This was the "Pantnagar drill" Mark II. National was soon joined by another company, Amritsar-based ASS Foundries. Several dozen design changes were progressively introduced, largely inspired by farmer testing. By 1995, a well-adapted design was ready for commercial production. And just at this time, an emergency occurred which sent researchers looking for just such a drill.

In the Indo-Gangetic Plains, continuous rice-wheat rotations favor a weed called Phalaris minor. For many years this weed caused little damage—farmers had learned to control it with isoproturon herbicides. But with millions of farmers using isoproturon for Phalaris control over many years, a herbicide-resistant Phalaris evolved. It was during the 1992-93 wheat season that a scientist working at Haryana Agricultural University (HAU) first reported such strains. By the 1995-96 season, the weed problem had been become a crisis. The affected area in Haryana continued to expand and began to move into neighboring states. Farmers grew desperate for a solution.

Some scientists felt that "desperate times call for desperate measures", with zero tillage being one of the "desperate measures". In order to test the effect of zero tillage and new herbicides on Phalaris populations, researchers needed zero till drills. The new Pantnagar drill had just become available. The newly-formed Rice-Wheat Consortium donated to HAU four new National no-till drills. These were delivered in October of 1996, as the Phalaris crisis peaked. With wheat sowing just weeks away, researchers moved to organize a research program, but encountered an unexpected obstacle: farmers placed a high value on tillage and wished to have nothing to do with "zero tillage". No-till was an invention that challenged a constraint long taken for granted: the need to till the soil to prepare for the next crop. In the end, however, a combination of new herbicides plus zero tillage worked well. Phalaris populations fell dramatically, and yields were excellent.

Although the very first zero till trials in Haryana were established by HAU scientists, farmer experimentation with the zero tillage soon followed. This happened for one simple reason: instead of returning the drills to the university campus after sowing the experiments, scientists decided to leave them in those villages where the trials were located. Farmers were encouraged to try out the drills on their own, and were provided with training and technical support. Learning selection began. Farmer experimenters found that zero till helped control Phalaris—but also very substantially reduced production costs. With this, adoption of no-till began to spread through farmers' networks.

This was spurred by the purchase (by ACIAR and the Rice Wheat Consortium) of additional drills for farmer testing. These still-scarce zero till drills were shifted from one village to another each wheat season. Farmers interested in no-till were invited to purchase their own drills—which they began to do in large numbers. By 1997, 150 drills had been sold to universities, ICAR institutions, and individual farmers. The Rice-Wheat Consortium, who became one of the product champions, began to organize study tours, whereby farmers from different districts—and even different States—could see for themselves the progress being made in Haryana on zero till wheat. There were even study tour participants from Pakistan!

Finally, adoption of zero till wheat in Haryana was further accelerated by an unexpected event. An agricultural department official was testing zero tillage on his own farm, with excellent results. In 1998, his daughter got married. The wedding happened during the wheat season and was celebrated in his own home. The no-till plots were located near the path leading up from the road. As a consequence, hundreds of the most influential farmers and state officials saw for themselves the extraordinary performance of zero till. This led to further adoption.

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Xue Lan and Nancy Forbes

Will China Become a Science and Technology Superpower by 2020?

An Assessment based on a National Innovation System Framework

Becoming a full-fledged member of the 21st knowledge economy through the absorption and creation of new knowledge, particularly in science and technology (S&T), has become a major national priority for China, comprising an important element of future national development. Since China's opening up to the outside world in the late 1970's, government policies have promoted a more liberalized, market economy, and a strengthening of the national innovation system to foster scientific research and technology acquisition. The seriousness of this commitment is evidenced by the new comprehensive plan for S&T development for 2006-2020 unveiled at the National Science and Technology Congress in January 2006. The plan was prepared under the leadership of Premier Wen Jibao and State Councilor Chen Zhili from 2003 to 2005. Over 3000 experts in natural sciences, engineering, and social sciences participated in the planning process.

Reforms over the last few decades have entailed major revamping of S&T

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institutions and policies, moving from a centralized, highly controlled Soviet-style model to a more autonomous, entrepreneurial, market-based model. Other governmental strategies have included allocating increased funds for domestic R&D programs, and actively encouraging international cooperation in S&T activities as well as foreign direct investment in R&D through various incentive programs.

The desired end result of these efforts would be a world class S&T industrial base, with the infrastructure, private and public sector R&D capabilities, and educational institutions equal to those in the developed world. It would be capable of world-class technological innovation, producing a broad range of products and patents traded and licensed in global markets. It would boast cutting-edge capabilities in critical areas such as biotechnology, microelectronics, telecommunications, advanced materials, aerospace, advanced manufacturing and information technology, as well as a highly-skilled science and engineering workforce.

Given today's global interconnectedness, the rest of the world should have a great interest in how China's science and high-technology industrial base ... will adapt to the needs of a changing society, the increasing globalization of science and technology (S&T), and the challenges of developing truly innovative, indigenous, intellectual and R&D capabilities.

China also needs to build up its S&T base in order to meet its goal of quadrupling Gross Domestic Product (GDP) by 2020, and to address urgent energy, environmental, and public health challenges. The country is also striving to develop a business workforce skilled in design, production, marketing, distribution, advertising, sales and corporate know-how in order to compete in the 21st century knowledge economy. Given today's global inter-connectedness, the rest of the world should have a great interest in how China's science and high-technology industrial base—currently a geographic and technological patchwork—will adapt to the needs of a changing society, the increasing globalization of S&T, and the challenges of developing truly innovative, indigenous, intellectual and R&D capabilities.

Despite its recent high technology growth, overall the country is still far from achieving its goals. China has to create 10 million new employment opportunities every year for people who join the labor market. While the official unemployment rate hovers around 4-5%, the real unemployment rate is much higher if one takes into account those who lost their jobs as the result of the privatization of state-owned enterprises and the extra labor in the countryside—millions of whom have come to the cities trying to find jobs. If current high-technology growth cannot translate into concrete economic opportunities, the enthusiasm surrounding it will sooner or later lose steam.

Other challenges entail being able to accommodate the considerable institutional variety which one now sees in Chinese industry, as well as great regional disparities. Chinese firms must learn to assume the expenses and risks of innovation on their own, independent of government support, and develop the managerial expertise needed for effective corporate innovation, along with the best practices, independent spirit and respect for intellectual property so important for today's sophisticated high technology innovations.

Many observers state that China has the potential to become a major global high-tech superpower. To make sense of this prediction one must first understand the nature and style of China's national innovation system as it evolves and adapts to a fast-paced domestic and international marketplace and to new government reforms. The national innovation system framework is a systematic way of characterizing the dynamic network of S&T-related institutions, actors, government policies and practices that make up a country's overall S&T capabilities. In other words, it is what enables a nation to make scientific discoveries, to advance knowledge, and innovate technologically, producing novel products.

The national innovation system framework is a systematic way of characterizing the dynamic network of S&T-related institutions, actors, government policies and practices that make up a country's overall S&T capabilities.

A national innovation system is typically made up of educational and training institutions such as universities, R&D organizations, government policies supporting S&T development, regulations that protect the products of high-tech R&D (such as patent systems and intellectual property rights laws), and financial resources for funding R&D (including government funds, venture capital or foreign direct investments). The knowledge- and people-flow between these institutions are what enable innovation and learning to take place.

CHINA'S NATIONAL INNOVATION SYSTEM IN TRANSITION

In order to become a part of the 21st century knowledge and information revolution, China has continued moving away from a natural resource-intensive economy into broad-based, knowledge-intensive industries and services. This has required updating the economic, institutional and regulatory regime to nurture basic, applied and commercializable R&D, strengthening their educational facilities, building the requisite information infrastructure to support a knowledge economy, and continuing to exploit existing global S&T knowledge from the outside. Acquiring knowledge from foreign companies—either by training, joint ventures, reverse engineering existing products, or ignoring intellectual property rights—has been a highly effective way for many Asian tigers, such as Japan and Taiwan, to build up their high-tech know-how.

China's current rapid economic growth, due primarily to the shifting of workers and resources from low productivity agriculture to industry, and to very high rates of domestic and foreign investment, has aided these efforts greatly. Maintaining current growth rates will be difficult, however, given the burden of inefficient state-owned enterprises and a large portfolio of non performing loans.

Geographical disparities remain significant. The country's fastest industrial growth has been concentrated in coastal regions, which are the most open to international trade and receive the greatest share of foreign direct investment. The highly developed cities of the coast are home to dynamic businesses, industrial parks similar to those in South Korea or Taiwan, and massive tracts of new office buildings and infrastructure (such as superhighways, public transport systems, municipal water and sewage plants, power grids, and advanced information networks).

Not that far away, in central and western China, poverty is still prevalent, and educational, public health, and information infrastructure remain in poor condition. To overcome inadequate access to capital, education, and other assets in these areas, regional governments have engaged in a campaign to encourage new domestic and foreign investment. In part as a consequence of such efforts, IBM, Intel, Hewlett-Packard, Time Warner, Coca Cola, and other foreign companies opened businesses in the central and western provinces, where labor and start-up costs are cheaper.

China's current industrial base is a much more integrated system than the stovepipes and strict division of labor that existed prior to the country's opening-up. This has enabled a greater number and variety of players to become engaged in building technological capacity. However, significant weaknesses exist: poorly developed formal and informal information networks; corruption and lack of accounting transparency; uneven application of industrial standards and quality control; lack of respect for intellectual property rights; excessive government control of the detailed management of S&T research institutions; and scarce venture capital.

Currently over 60% of the country's R&D is carried out in industry. This work is still primarily low-and middle-end technology, involving mostly re-engineering of foreign technologies or creative duplication of their designs. China remains in transition: despite being such a large and diverse country, the majority of Chinese firms are still not at the level where they can truly innovate. There have been a few exceptions, however, such as new Chinese 3rd generation telecom wireless standards and a Chinese language word-processing technology.

In terms of strategy, China has not followed the Korean national innovation system model of developing big high tech corporations (*chaebols*) with known brand names such as Daewo or Hyundai. Instead, it has steered more towards the model of Taiwan, which achieved more as an original equipment supplier to foreign companies than it did by developing its own brand names. In fact, Chinese companies could be considered hybrids—a mix of foreign technology and managers with raw domestic talent.

BACK TO BASICS: THE UNIVERSITY SYSTEM AFTER THE MAJOR EXPANSION

University education in China has become much more widespread since the Cultural Revolution, which prevented a generation of Chinese from completing their education. Considering that China's first PhD was granted in 1983, the higher educational system has made phenomenal progress in a short time period. Particularly since 1999, college admission achieved double-digit growth consecutively for the next few years, raising total enrollment (excluding adult higher education services) in universities from 3.41 million in 1998 to 7.19 million in 2001, and to 13.34 million in 2004. The gross enrollment rate in China has reached 22% by 2006, compared to 5% in the early 1990s. Almost half of Chinese undergraduates major in science or engineering. Like the U.S., China is one of the few countries where doctoral students must continue to take courses, rather than going directly to thesis work as many EU countries, implying greater rigor in their degrees.

The challenge of teaching independent thought and creativity has been complicated by several factors, including a legacy of centuries of Confucian philosophy, which places a priority on respect for authority and seniority; years of central planning in the economy; and widespread rote-learning, long considered the best approach for preparing students for national college entrance exams. To address this challenge, and focus students on practical questions, Chinese universities have been trying to develop close ties to industry . Curricula may emphasize commercial interests in order to better prepare students for a career as competition grows for good jobs.

China has over 1000 institutions of higher learning, although few outside the top 30 get much recognition. Top universities—Beida, Tsinghua, Fudan, Zhejiang, Nanjing, Shanghai Jiaotong, Xian Jiaotong, Harbin Institute of Technology, among others—get most of the research money from government and industry. Chinese universities are not funded exclusively by the government, so they have to develop alternative sources of funding (which include the generation of high-tech spin-offs). Most graduate education is free; reformers are urging the government to charge tuition for graduate school and introduce a system of research or teaching fellowships as in the U.S.. The few private universities specialize in business, management, and similar disciplines, and typically offer only the equivalent of an associate degree.

The most prestigious universities in science and engineering are Tsinghua University, Zhejiang University, Shanghai Jiaotong University, and a few others. Many of their faculty are quite accomplished, however, in order to maintain their reputations they are pressed to produce research results, publish, travel to give talks, and obtain patents on their inventions, leaving them little time to teach.

Lately, the government has sought to improve the quality of less well-known universities, especially in the poorest areas of the country, through a focused support program based on specialized disciplines. Other needed educations reforms include integrating the private higher education system into the official system; enabling poor but talented students to attend college; revamping vocational training to make it more responsive to industry needs; providing retraining programs for displaced workers; and continuing to develop distance learning and adult education.

IN SEARCH OF DIRECTIONS: RESEARCH INSTITUTES AFTER "ZHUANZHI"

Basic Science Research

China is not yet a world leader in basic science, despite sustained government efforts in recent years. China's investments in basic research had increased by a factor of almost 6.5 between 1991 and 2001, a 17 percent average increase per year, reaching the level of $84.6 billion USD in the year 2003.[1] But both total investment in basic research and investment per researcher are lower than in developed countries. Indeed, basic research spending as the percentage of the total research and development (R&D) expenditures actually decreased from 7.5 percent in the 1990s to its current level of 6 percent in 2002. There are currently 957,000 people engaged in R&D in China, 79,000 of them in basic research, so the percentage of basic research scientists to the total R&D personnel is 8.3 percent.

The most important institutions conducting basic research in China are the research institutes of the Chinese Academy of Sciences. During the early stages of China's economic reform, funding was cut for many Chinese Academy of Sciences' and other research institutes. This pushed the institutes to seek funding from industry. In 1998, the Chinese Academy of Sciences succeeded in persuading the government to provide concentrated support for both basic and strategic research at the Academy through a "knowledge innovation" program. Subsequently, many Chinese Academy of Sciences institutes consolidated their research areas and established new ones to better attract overseas Chinese students.[2]

In terms of quantity, the volume of Chinese basic research has clearly increased, as is evident from the rise in China's ranking in terms of papers published in international journals. China's contribution to world scientific publications rose to 6.5% of the world total in 2004, compared with 2% in 1995; the 2004 figure ranked China 5th after the U.S., Japan, the U.K., and Germany. In specific research fields, China's progress is even more significant. For example, China ranked third in publications in nanotechnology, following only the U.S. and Japan. Yet despite rapid growth in the number of papers published, quality indicators of these publications in general have not measured up to those of developed countries. For example, Sir David King, The Chief Scientist of the U.K., ranked China in 19th position, based on its share of the most highly cited publications between 1993 and 2001.[3] A study by Leydesdorff and Zhou similarly found that citation rates for papers published by Chinese scholars are relatively low.[4] The take-away is that China still does not have enough world-class scientists to support its aspirations.

Brain drain has been a problem in China since the early 1900's when China began sending its best and brightest students abroad to study. In the last few decades, many of these students have not been returning; the U.S. has been a favorite place for many of them to stay. From 1988-1996, of the over 43,000 Chinese students receiving U.S. doctoral degrees in science and engineering, roughly 48% of them had firm plans to stay abroad. As a consequence, China has implemented a variety programs at different levels to lure back home U.S.- and EU- trained Chinese students, as well as top-ranked U.S. Chinese-American scientists and engineers. The lure of booming high tech industries in China, higher wages, incentives offered by companies, and better living conditions entice some to return. These returnees bring with them the benefits of S&T knowledge and know-how from more advanced countries like the U.S. China's capacity to harness this momentum and make large strides in developing their technological capabilities, especially in the information technology sector, should not be underestimated.

Government S&T Policies and Programs

Government policies have had a profound effect on China's ability to transform itself into a knowledge economy and build a science and technology industrial base, with reforms dating back to the mid-1980s when policies focused on orienting the S&T system towards economic growth and increased investment in S&T and education (they aimed at making each 1.5% and 4% of GDP respectively by the year 2000, a goal not reached; in 2002, R&D as share of GDP was 1.22).[5] This strategy has had the full support of Chinese leadership.

China's original Soviet-style, centrally-planned governmental system for S&T, dating from the 1950's, was rigid, overly-bureaucratic and hierarchical, though still with good administrative control. The system indulged far too much in long-term central planning and stymied efforts to develop and modernize S&T in China. The system was, however, able to mobilize some Chinese S&T resources to bolster its military technology, for example in nuclear weapons and ballistic missile technology, along with help from the Soviets—although this required an enormous amount of effort and coordination.

The shift in relations with the Soviets in the 1960's, together with the political, economic and social upheavals during the Cultural Revolution greatly stifled the development of S&T in China. During this period universities were closed and the intelligentsia was silenced, banished or imprisoned, resulting today in a lost generation of academics, educated professionals and intellectual talent.

This was followed by Deng Xiaoping's "Open Door" policies, which brought increased foreign trade and market-oriented economic reforms, and greater absorption of S&T from the West, opening the way for some foreign companies to enter the country. The government realized that research must be tied to the commercial sector, and become more market-oriented, technology-based and focused on industrial development.

The latest government policies formulated at the National Conference on Science and Technology in Beijing in 1995, the *kejiao xingguo* (Reinvigorating China through Science and Education) strategy, set the direction for S&T for the next ten years to twenty years. Under this effort, Chinese Premier Li Peng founded the State Leading Group for Science, Technology and Education, composed of the chiefs of the leading S&T, education, and economic agencies, in addition to himself and the Vice-Premier. The Group has the responsibility for coordinating and evaluating the nation's overall strategy for S&T and educational development and is often briefed by leading scientists, particularly to inform them on "hot topics" such as nanotechnology, electronics, software, e-government, biomedical, and environmental technologies.

Currently, the most important governmental organizations in science and technology research are the Ministry of Science and Technology (MOST), the National Natural Science Foundation of China, the Chinese Academy of Sciences and the Chinese Academy of Engineering. Along with MOST, the Commission on Science and Technology and Industry for National Defense, and the Ministry of Education have policy-making authority; the Chinese Academy of Sciences (which also administrates about 100 national research institutes, mostly in basic science) and Chinese Academy of Engineering have advisory power; and National Natural Science Foundation of China provides research funds.

MOST is responsible for the nation's civilian S&T activities, devising programs and policies for strengthening the S&T base in the private and public sector; for continuing systemic reforms, and for administration of China's high tech industrial development zones. In recent years, most of its activities have focused on developing S&T strategies, particularly in high tech, to accelerate economic growth.

The National Natural Science Foundation of China (NSFC), founded in 1996, modeled very closely on the U.S. National Science Foundation (NSF) model, funds basic research activities, although, unlike NSF, only in the natural sciences. They do this by soliciting research proposals and awarding grants based on peer review. Competition is strong—only about one in seven research proposals are successful. The NSFC received USD 425 million in government funding in 2005, a 25% increase over the previous year. By 2010 the NSFC's budget is expected to double to reach $850 million. Life sciences usually receive the most funding, followed by engineering and materials science, mathematics and physical sciences, and management science.

How successful have these government policies been? Despite its single-mindedness, and the injection of huge amounts of money into research and S&T personnel, the country did not reach its goal of making R&D 1.5% and educational spending 4% of GDP by 2002. There are still lacunae in the country's national innovation system, especially the weak industrial R&D capabilities and the fragile linkages among different players in the national innovation system, which serve as vital channels for technology transfer among sectors, and help build up knowledge capital. Further, some say there are too many bureaucratic fiefdoms dispensing scarce resources based on self-interest. Coupled with turf battles, the result may be ineffective R&D spending. Scientific personnel (2 million scientists and engineers in 2000), is unevenly distributed, with the best in academia rather than industry. Most senior positions are dominated by older scientists, most of whom are soon to retire.

High tech exports are still mostly from multinational corporations, and are low and middle-end rather than high end products, indicating an inability to truly take intellectual risks and innovate. There may also have been a decline in first-class achievements: from 1989-2001, there were no winners of first class prize in China's biennial Natural Science Award.

Nonetheless, China has already traversed a long, uphill road to scientific achievement, and the concrete knowledge and experience gained will undoubtedly aid the country in scaling even greater heights. The government's single minded commitment to building its S&T capabilities, sustained for over three decades, continues to be strong, with R&D expenditures averaging over 25% growth per year in the last five years. There is now a vibrant and growing industrial community, with a variety of types of enterprises other than state-owned—township and village, joint-venture, private, and foreign—that did not exist before the reforms. These enterprises are beginning to compete and cooperate, and this new industrial pluralism will help promote the exchange of ideas and S&T overall in the industrial sector.

A TALE OF TWO CITIES: INNOVATION IN DOMESTIC FIRMS AND MULTINATIONAL CORPORATIONS

China's efforts to build a domestic technology capacity began by using public research institutes and state-owned enterprises as their main vehicles. However, state-owned enterprises were still part of the centralized bureaucracy and too encumbered by rules, too controlled and bureaucratic, and too disconnected from market forces to be successful. By 1995, realizing their failure to make state-owned enterprises the agents of change for high tech development, the government declared that the marketplace, rather than government control, would be the predominant force in developing technological capabilities. While some state-owned enterprises recently have turned around and become profitable, overall the massive debt state-owned enterprises have accumulated continues to be a financial burden for the government.

The number of privately-owned companies in China has grown quickly over the last few decades, although with great variance over different regions and industries. Private firms have boomed in coastal regions of the country, such as Zhejiang, Jiangsu and Guangdong provinces—the most successful industries being information and communications technology. Indigenous companies benefit from knowledge of the local market, preferential treatment by the government (such as tax waivers, land deals, contracts and financial incentives), and the low costs of producing, marketing and selling their product.

Most indigenous R&D primarily consists of reverse engineering or slightly modifying older generation foreign technologies, such as legacy wireless devices or communications switching devices. However some domestic Chinese companies have emerged as true innovators in selected industries, such as the Founder Group, a 1986 spin-off from Beijing University and now a leading producer of Chinese digital language printing systems, and Huawei, a leading player in the global telecom market with R&D centers in Silicon Valley and Dallas, TX.

In terms of quality control and strict adherence to standards—either international, such as ISO 9000, or domestic—the record is spotty. Yet, for particular firms, meeting such standards is essential in order to compete successfully in global manufacturing markets. It is likely that within 10 years a significant number of Chinese companies will have successfully implemented international standards.

China has been the world's biggest exporter of information technologies (or information and communications technology, "ICT," as it is frequently termed in EU countries) products since 2004, accounting for about $180 B USD and 30% of all of China's exports in 2005. Most has been computer and related equipment used to assemble computer, audio, video and telecommunications equipment; China still has to import most high value electronic components needed for ICT manufacture. Domestic demand is strong for these products, so industry growth has averaged a dramatic 27-30% a year. Their present level of success is due to demand, foreign direct investment and government's role in driving the industry forward in the last 15 years.

Most Chinese ICT firms are small in term of revenues and employees—only China Telecom ranks in the world's top 250 ICT companies. The main challenges facing this industry center on building management skills, innovative capabilities, global brands and reducing over dependency on foreign companies for core technologies, although joint ventures with U.S. firms like Motorola, IBM, Intel, Hewlett-Packard, Compaq and Dell have improved domestic production capabilities and technology absorption. In software, China still lags way behind more developed countries, despite having over 6000 software companies in 2002 and a firm commitment from the Chinese government to foster industry growth. High domestic demand, a growing local skill base and greater intellectual property protection will facilitate this trend.

As the world's largest telecommunications market by subscriber base, China has emerged as a significant player in the global telecom industry, both as supplier and buyer. In 2005, of every 100 households, about 111 had cell phones in urban environments and over 24 in rural; there were about 33 PCs (urban) and almost 2 (rural). In the same year, there were about 111 million Internet users, and a high penetration of television and cable TV. All these devices require an extensive information infrastructure in order to function. Since the country first encouraged telecom multinational corporations to come to China, much of the technology for this sector has been absorbed from the outside, however the landscape is rapidly changing due to the improved production and export capacity of domestic firms. For example, three major Chinese telecom firms, Huawei, ZTE Corp. and TCL almost doubled their annual revenues from 2000 to 2005, reaching $5.9B, $2.7B and $4.4B respectively.

Most indigenous telecom manufacturers spend about 10% of revenues on R&D and many have links to China's universities or governmental basic research facilities. Now that 3rd generation wireless technologies have started to be used worldwide, companies such as Huawei are considered to be at roughly the same level as global competitors, having shortened their learning curve over time. In fact, China has developed its own third generation wireless telecom standard, called TD-SCDMA, which is now considered as one of the three official world standards for wireless technologies.

In addition to R&D, many foreign companies are investing in manufacturing in China, given the low cost labor and huge highly skilled and disciplined work force. Most is still not terribly advanced in design or sophistication. This requires high tech equipment which is highly automated and optimized, modern management techniques and systems integration skills which are only now starting to be seen in China.

Multinational corporations

Many U.S. and foreign multinational corporations have been involved in Chinese markets since the early to mid-1980's, primarily with low-end manufacturing activities. However, with China's World Trade Organization membership, more companies are securing a higher position in value-added production chains and have built their own R&D centers in China. The official government figure puts it at 750, with the most recent estimate reaching as high as over 900.[6] Most of these centers are located in Beijing and Shanghai to take full advantage of regional government incentives. Many are close to the major universities or research institutes. Over half are in the ICT sector.

Most of the activity in these R&D centers is more "D" than "R", yet it is still a big step up from low-end assembly of high tech components. Most of the important U.S. multinational corporations, such as Motorola, Google, IBM, Nortel, Lucent, Microsoft, Oracle and others have research centers in China, as well as Alcatel (France), Ericsson (Sweden) and Infosys (India). Most higher level employees are recruited from top Chinese universities and trained in U.S. engineering and managerial tasks. In addition to R&D, these centers also carry out other forms of knowledge transfer such as education and training programs, technology licensing agreements, contract research with local university researchers and equipment donations. Experts claim that it is hard to judge whether these MNC R&D centers have been successful due to lack of reliable indicators.

Intellectual Property Rights

The Chinese patent system was established in 1984, as part of the economic and legal reform effort. Government's objective was to create an environment conducive to foreign investment and technology transfer, as well as stimulate Chinese scientists and engineers to innovate. The current system is modeled on those of developing countries, and conforms to most international norms for patent protection, such as those embodied in the Agreement on Trade-Related Intellectual Property Rights (TRIPS).

There are still major problems with enforcement, piracy and counterfeiting; a 2003 report by the China State Council's Development Research Center put the market value of counterfeit goods in China between $19-24 B from infringement of patent rights, copyright, trademarks and other property rights. Many U.S. companies complain that police are either not interested in pursuing intellectual property rights infringement, or lack the training and resources. Other factors that discourage intellectual property rights enforcement include lack of coordination among government ministries and agencies, corruption and regional protectionism.

That said, "acquiring" ideas from abroad has historically been a highly effective means for newly industrializing countries to build their S&T capabilities. For example, American colonial entrepreneurs learned as many trade secrets as they could from visiting British textile mills in the early 19^{th} century in order to establish the industry in their own country.

To address these problems in China, the U.S. government has recommended measures such as lower thresholds for prosecution or higher penalties. The Chinese government is displaying a greater willingness to prosecute, with more resources to support enforcement and more coordination among the various entities involved in intellectual property rights.

Though a well-functioning patent system would clearly help to encourage more foreign high tech involvement in China, the idea of a legal system to protect intellectual property runs counter to several important traditions in China. One is a Confucian tradition indicating that inventions or creations belonged to all members of society by definition and also Socialist ideals don't adhere to the idea of private property.

China has been a member of the World Trade Organization for only a few years, after 15 years of negotiations, and as such, is committed to implementing wide reforms in areas such as intellectual property rights, limiting preferential treatment of domestic companies, general transparency in business and trade, and other changes to bring its legal and regulatory system in line with those of other World Trade Organization members. In addition, as more Chinese patent their own products, they will have a vested interest in protecting their own intellectual property rights.

Ingredients for NIS Success?

Richard Nelson (2004) identifies several elements involved in building up a successful National Innovation System that were shared by the "Asian Miracle" countries, such as South Korea, Taiwan or Singapore. These may help shed light on China's current technological trajectory. The elements are:

- Transborder flows of people, with people from industrializing countries going abroad to learn and then returning, and people from advanced countries coming in as advisors or to establish businesses in the host country.
- Active government support in technological catch-up activities, by offering subsidies to fledgling domestic firms, government encouragement of entrepreneurship and other forms of protection.
- Poor enforcement of IPR regimes at early stages of the catch-up process, so as not to hamper the industrializing country in copying or imitating mature foreign technologies.
- Governments with outward-looking, export-led industrial policies.
- Firms that gradually learn technological capabilities via a difficult trial and error experimental process, involving investments in training and slowly moving from simple assembly of technology to slight design modification to more complex tasks and eventual R&D.

Nelson, R.R., "The Challenge of Building Effective Innovation Systems for Catch-up", *Oxford Development Studies*, Vol. 32, No. 3, September 2004, pp. 365-374.

FUTURE PROSPECTS

China has experienced incredible economic growth and buildup of its technological capabilities in the last three decades. Barring unforeseen disasters, it will no doubt continue on this upward trajectory. The Chinese national innovation system has also made enormous strides in the last three decades and shows no sign of slowing down—as long as foreign direct investment continues to flow, and with it technology and knowledge acquisition opportunities. Government reform in S&T continues, with increasing amounts of money going into R&D on a national scale. In terms of percent of GDP spent on R&D, China has made important progress in the last few years, reaching at 1.4% in 2006. Japan spends currently about 3.1% (2002) and the U.S. about 2.7%. The U.S. number is expected to remain flat for some time. The *Wall Street Journal* has stated that if Chinese R&D spending can reach 2% of GDP by 2010, given their massive yearly production of science and engineering graduates (over 57% of undergraduate degrees in 2002), it will make them a veritable global S&T powerhouse.

As China's national innovation system evolves, it will continue to absorb knowledge, basic science and engineering know-how, technical and corporate management skills, design and production techniques, and sales and marketing savvy—largely by trial and error. These will serve to grow the system organically, conforming to international trends and best practices as well as to domestic realities—given China's intrinsic strengths and weaknesses, unique cultural characteristics and legacies from the past. China's government has made it clear that, policy-wise, S&T will continue to be a fundamental priority and driver for economic growth, allowing both quantity and quality of innovation to improve. It is also likely that in selected areas such as nanotechnology, biotechnology and information technology, China will become one of the major research clusters in the world.

There are still obstacles in the upward path of China's national innovation system. Perhaps the most significant come from macroeconomic and social challenges that now confronting the Chinese leadership. Notable examples include the growing disparities between rural and urban areas, and among different regions; the financial burden of many thousands of nonperforming loans to the state-owned enterprises; corruption and inefficiency in the government; lack of jobs for millions migrating from the country to the large cities; social unrest; a weak legal regime underlying commercial activities and intellectual property rights; and wide-spread environmental problems.

> Support and help from the global S&T community will ... aid China in becoming more integrated in the global knowledge economy, and will work against internal sentiments of "techno-nationalism" and external views of the country as newly emerging high-tech threat.

Within China's national innovation system itself there are problems which must be surmounted: first of all, China's industrial R&D capabilities are still relatively weak, relying mostly on low cost labor as their major competitive advantage. Cultivating these capabilities is the most important task of the system. Second, the weak linkages among industry, research institutes, and universities have also prevented knowledge from being created and efficiently diffused among sectors. Chinese universities and research institutes have had some interesting history in establishing close ties with the market by running spin-off companies themselves over the last two decades. However, in recent years, scandals and corruption in these companies have fostered doubts about the viability of this model as an effective mode of "technology transfer." In addition, many Chinese national research institutes have to struggle to define their roles in China's national innovation system after many of their peers have been pushed to join the market as full-fledged, for-profit companies, or self-sufficient NGOs.

It may be that the invisible hand of the market will resolve these issues over time, although that is doubtful. Support and help from the global S&T community will have to play a major role. This will aid China in becoming more integrated in the global knowledge economy, and will work against internal sentiments of "techno-nationalism" and external views of the country as newly emerging high-tech threat. A stronger Chinese national innovation system will in turn serve the rest of the world by expanding and exploiting the global market for foreign goods and services, and by opening up new investment avenues for high tech companies and multinationals. As much of the industrial R&D carried on at present in China is for multinational corporations, the intellectual property is channeled back to the host country in one way or another.

The new global geography of science and technology is not a zero-sum game. Instead of becoming a major technological superpower in head-to-head competition with the U.S., Japan, and Europe, China will ultimately join others in a shared leadership role. As China continues to develop, we expect that it will fully integrate into, but in no way come to dominate, the global innovation system and related business value chains. Such a relationship with the world S&T community will enable flows of knowledge, commerce, and people that sustain China's development, while permitting the country to make its own very unique contribution to the advancement of knowledge and technological innovation on a global scale.

We invite reader comments. Email <editors@innovationsjournal.net>.

1. In purchasing-power-parity (PPP) dollars, according to *OECD, Main Science, Technology and Industry Scoreboard: 2005* pg. 21.
2. See Peter Suttemeir and Cao Cong (2006). "Chinese Academy of Sciences (CAS) Knowledge Innovation Program," *Physics Today* 39 (December); see also a paper by the same authors with Denis Simon in the previous issue of this journal.
3. David A. King (2004). "The Scientific Impact of Nations," *Nature* 430 (15 July), pp. 311-316. See also Wilsdon, James, and James Keeley (2007). "China: the Next Science Superpower?," *Demos* January 2007. <http://www.demos.co.U.K./files/China_Final.pdf> last accessed 3/7/07.
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5. National Science Foundation (2006) *NSF Science and Engineering Indicators*: *2006*, pp. 4-45.
6. Presentation given by Prof. Dennis Simon of State University of New York at a conference organized by DEMOS in London in January, 2007.

Keith E. Maskus

Reforming U.S. Patent Policy
Getting the Incentives Right

The U.S. patent system comes under much criticism these days. In a lightning-rod case, the maker of the popular BlackBerry communication device, Research in Motion (RIM), chose to pay a $612.5 million settlement in order to avoid a court-ordered shutdown. In this case, the judge supported a patent infringement case brought by NTP Inc. despite the fact that the U.S. Patent and Trademark Office (USPTO) had preliminarily ruled that all five NTP patents were invalid. Moreover, NTP did not provide email service or compete with RIM. In an April 2005 speech, Brad Smith, Microsoft's general counsel, said that his company spends $100 million per year defending itself against thirty-five to forty lawsuits at a time.[1] He observed a "need to ensure that high-quality patents are approved and low-quality patents are not." Microsoft has called for patent law to be reformed in order to make it easier to challenge the validity of patents after they are issued and to reduce runaway patent litigation costs. The company has also cited a need to increase

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funding to improve patent examination procedures at USPTO. The BlackBerry case and Microsoft's calls for reform symbolize an American patent system that is increasingly inefficient and costly for innovative firms. Its numerous structural problems are rooted in two fundamental misconceptions:

- The view—predominant in Congress and the courts—that patents are like tangible property and that owners of such property have the basic right to sell and license it (or not) as they wish; and
- The virtually unchallenged view that more patent protection necessarily provides greater incentives for innovation and commercialization of technologies.

Neither view makes for good policy.

Patent policy needs to be balanced to protect the investments of original innovators as well as to encourage access to technologies and products. Ever stronger exclusive rights generate overlapping claims, monopoly power, and litigation costs that actually discourage competitive innovation. Striking the proper balance requires that U.S. policy relax the modern notion that intellectual property rights are basic rights and return to the tradition of limiting the scope of patents in order to encourage the use of new technologies and information.

Failure to rein in the patent regime could have global repercussions. To hinder innovation is to hinder the dynamic competitiveness of U.S. companies. While some aspects of the IPR system (such as copyrights) for American firms largely remain sound, significant problems with patents put the U.S. system at a disadvantage vis-à-vis more balanced and less costly foreign ones.

At present, Congress is considering whether to reform domestic patent law. In 2005, Representative Lamar Smith (R–TX) introduced HR 2795, which would enact a number of reforms, some of which are advocated later in this report. That legislation has languished in the House of Representatives.

In the upper chamber, Senators Orrin Hatch (R–UT) and Patrick Leahy (D–VT) jointly introduced a Patent Reform Act in August 2006. The proposed act has the support of the information technology and financial services sectors, but it is viewed warily by pharmaceutical and biotechnology companies, which are concerned that large changes to the system—especially the possibility of patent challenges long after a patent is issued—may reduce their patents' value. The proposed reforms would be the most sweeping in many years, but they still would not do enough to improve the functioning of the clogged and costly patent system. The final section of this report will give suggestions for more comprehensive reform.

In contrast to the proposed domestic reforms (limited as they are), there seems to be little interest in achieving greater balance in the U.S. approach to international patent rules. The United States continues to pursue an aggressive trade strategy to harmonize global patent standards at U.S. levels. The approach achieved its first major victory in 1995 with the adoption at the World Trade Organization of the TRIPS agreement, which requires all members of the WTO to implement and enforce a comprehensive set of minimum standards protecting the intellectual property of both domestic and foreign firms. For many developing countries, TRIPS forced a strengthening of their patent laws.

However, it permits members substantial flexibility in limiting the market power of patent holders. U.S. trade authorities still found the agreement insufficient for protecting the international economic interests of major American companies in certain industries, so they have pushed the harmonization agenda far beyond that level.

Such extensive harmonization is difficult to achieve. It is not surprising, therefore, that the efforts have only borne fruit in a series of bilateral trade agreements with small nations. Even when the efforts have succeeded, they have made questionable contributions to global development and have generated resentment among citizens in trading partners—resentment that bodes ill for the rest of the U.S. trade agenda. It is advisable to abandon this high-level harmonization agenda. Unfortunately, at present there are few major economic interests pushing for such rationalization in trade policy.

The current U.S. trade strategy appears even more senseless when we consider the fact that the problem for most major U.S. companies is not that patent laws abroad are inadequate, but that they are poorly enforced. A more effective strategy to protect international economic interests would be to increase the pressure on major developing countries, such as China, to improve their record on enforcing patents and other forms of IPR.

A combination of carrots and sticks could be used to achieve this end. The carrot would be to collaborate more fully with other developed economies and international organizations to increase the amount of technical and financial assistance available for improving enforcement. The stick would be for the United States and other major developed economies, especially the EU and Japan, to marshal evidence and arguments for a formal complaint at the WTO that specific countries have failed to meet their enforcement obligations under TRIPS. A coordinated effort would reaffirm that the United States is committed to a multilateral approach to resolving tough trade problems and would deflect criticism that the United States is a solitary and aggressive demander in global patent policy.

PATENTS AND INNOVATION

Innovation results from the interaction of norms, markets, incentives, regulations, and infrastructure for the creation and use of technology. Education systems encourage skills and technical competence. Venture capital markets finance the investments of small U.S. companies in biotechnology, software, and related new technologies. Mass communication systems foster access to knowledge. These and other elements contribute to the skills, talents, capital, and competition that support innovation.

Most importantly for our purposes, innovation thrives under openness to dynamic competition. Open markets encourage firms to enter and exit, restructure through efficient takeovers, gain access to important inputs and suppliers, and develop and sell new products and process technologies. Information and new products diffused throughout the economy generate greater competition and spur more innovation. Finally, openness to international trade, investment, and licensing is essential for facilitating technology transfer across borders.

Patents—the focus of this report—and other forms of IPR are only one part of this system. Nevertheless, they often play a vital role in fostering innovation, a role that becomes apparent after considering what would happen without IPR protection. Without protection, an inventor could spend considerable money, time, and effort developing an idea that a rival could easily copy and sell for a fraction of the cost. The inventor may be left not only without a profit but also with a sizable loss—and a clear disincentive against future innovation.

Patents are the most direct incentive for developing commercially useful new technologies and products. They facilitate dynamic gains—new products and greater variety—by temporarily supporting exclusive market power. That is the classic trade-off in the traditional view of patents, which sees innovation as the discrete birth of a single-idea technology covered by a patent. Whether actual patents match this view is widely debated and will be examined in the next section.

Patents also help to ensure the adoption and diffusion of innovative ideas. The publication of patent applications guarantees that inventions are disclosed and not kept secret.

Commercialization—turning a new idea into a marketable product, service, or technology—can be costly. Exclusive rights provide an incentive for firms to shoulder those costs. The exchange of technologies is made easier because patents provide a legal foundation for that exchange. Without that foundation, contract negotiations over the terms of agreement might prove difficult or impossible. This is also true for the specialized technology transfer services that are made possible by patents.[2] These economic roles—sufficient innovation, commercialization, and diffusion— could be achieved in a number of ways. A major advantage of patents and other IPR is that they work through the markets themselves. If new products fail to attract consumers, the associated patent is virtually worthless, and consumers do not suffer monopoly prices.

IPR therefore channel investment into new knowledge goods that are anticipated to provide consumer benefits.

Patent Standards

Despite the dynamic innovation that patents can facilitate, they also inject new monopolies into markets. Accordingly, it is essential to develop the standards under which patents are granted and protected with an eye to achieving the right balance. In general terms, the major patent standards are eligibility rules, length and breadth of patents, and limitations on rights.

Eligibility rules cover the elements of knowledge that may not be patented. Most countries exclude fundamental scientific discoveries flowing from basic physical laws of nature, including mathematical algorithms. Other subject matter may be excluded in order to preserve national security or public health.

In all countries where patents are awarded, for an invention to be patented it must: (1) be novel (that is, previously unknown), (2) contain an inventive step (that is, a step that is not obvious to one skilled in the area of technology it represents), and (3) demonstrate utility by being reduced to an item of commercial applicability. Determining whether an invention meets these criteria is the job of patent examiners. To be declared novel, an invention must survive a search of the prior art, which is the total of relevant published knowledge. The inventive-step standard is important to prevent obvious inventions from being patented. The utility standard determines the dividing line between unpatentable knowledge derived from basic science and patentable applied arts. Clearly, it is possible for examiners to make mistakes and issue patents that do not truly meet one or more of these standards. To mitigate that risk, most systems permit interested parties to bring prior art to the attention of examiners before a patent award, contest the validity of a patent after it is issued, or both.

Patent applications are published within a certain time period in order to disclose the technical claims made and the mode of operating a technology or making a product.

Timely publication is important for diffusing new technical information into the economy and informing firms that particular technologies are protected.

After eligibility standards come standards determining the length and breadth of a patent. The global standard for duration is twenty years from the filing date. In terms of breadth, inventors make claims about the protectable novelty of their inventions, although examiners can narrow or reject those claims. Some countries permit only narrow claims on singly defined uses of information while others permit multiple claims of novelty within a patent. To illustrate, a narrow patent on a chemical formulation might claim rights only to a single resulting drug or acid without covering products that use closely similar formulations. A broad and multiple-claim patent could cover the chemical process, specific products it achieves, and close chemical substitutes.

Equally significant is the extent to which inventors can claim rights to uses not specifically listed in the patent. For example, biotechnological research tools may be developed for a particular genetic application, but under a system allowing broad claims, inventors may claim rights to later uses in different research areas. To give another example, genome patents protect claims on long stretches of genetic sequences whose potential future uses are not currently known. Where a country recognizes a "doctrine of equivalents," patent owners may litigate against competing products and technologies shown to rely on techniques that, in essence, perform the same functions in the same ways for the same results as those in the patent grant.

A final set of standards is the set of limitations placed on the exercise of patent rights. These exist for a variety of reasons, most prominently to protect public health and other public goods and to maintain competition. Many countries permit free use of patented goods by governments. Governments also issue compulsory licenses, which force the patentee to surrender the technology on a nonexclusive basis to another firm in return for a license fee, either to ensure domestic production of essential technologies (such as medicines or environmental inputs) or to enforce anti-monopoly provisions. Some countries recognize a prior-use exception to patents, under which firms that can demonstrate their earlier use of an innovation that was later patented by another firm are able to continue using the technology without having to pay royalties.

EMERGING COMPETITIVE PROBLEMS IN THE U.S. PATENT REGIME

Patent regimes exist along a spectrum, from weak rights that permit consumers and rivals cheap access to new information goods to highly protected rights that favor exclusivity for inventors. Recent trends in U.S. intellectual property protection have increasingly favored those who invent and own patents. At the same time, standards for approving patents are weakening. As a consequence, the number of questionable patents has increased, and litigation and transaction costs have risen for competing firms.

Patent Pathologies

The most important change in patent regulations since 1980 has been the expansion of subject matter eligible for patent protection. In 1980, the Supreme Court ruled in Diamond v. Chakrabarty that genetically engineered bacteria could be patented. This ruling established that virtually all forms of life could be patented, including genetic discoveries and research tools. In 1981, the Supreme Court recognized in Diamond v. Diehr that software could be patented, radically expanding the ability of programmers to assert rights over their computer code. In 1998, a federal circuit court approved the eligibility for patents of business methods and financial service products in State Street Bank & Trust Company v. Signature Financial Group. This case, involving protection of a method of managing mutual funds, opened the door to a proliferation of business methods patents, including Amazon.com's one-click Internet ordering process and Priceline.com's reverse auction for buying Internet products.[3]

The second major development came with the Bayh-Dole Act in 1980, which gave universities control of inventions that resulted from federally funded research. University patenting accelerated, and research universities established technology transfer offices to facilitate licensing to private and faculty-based companies.

The third development was the 1982 creation of the Court of Appeals for the Federal Circuit (CAFC), a special court managing appeals on IPR disputes and other complex business litigation. The goal was to create expertise and predictability in patent cases, but predictability has largely benefited patent holders. Before 1980, 62 percent of cases in which patents were found to be valid and infringed were upheld on appeal; after 1990, that proportion rose to 90 percent. In cases where a patent was ruled invalid or not infringed, the fraction of decisions reversed rose from 12 percent to 28 percent. In addition, after the introduction of the CAFC, the rate at which courts issued preliminary injunctions to block the use of patented items during infringement proceedings rose sharply.[4] The final contribution to stronger patents was the lengthening of effective patent terms. To meet the requirements of TRIPS, U.S. patent length was extended from seventeen years (from the date of grant) to twenty years (from the date of application).

The Hatch-Waxman Act of 1984 extended patent terms by up to five years for pharmaceutical products where issuance of the patent had been delayed by lengthy approval processes at the Food and Drug Administration (FDA).[5]

Dilution of Patent Standards

At the same time that policy was strengthening U.S. patent protection, its patent standards were being weakened.[6] It has become common to ridicule the USPTO for issuing questionable patents, such as the J. M. Smucker Company's patent for a "method of making crustless peanut butter sandwiches." A patent is of high quality if it protects an invention that is truly novel, inventive, and commercially useful—requirements that form the essence of a well-functioning patent system. Patents have low quality if they are issued to inventions that are obvious, ignore the prior art, or duplicate existing technologies. The decline in patent quality is exacerbated if patent holders choose not to commercialize their inventions, instead waiting to litigate against other firms that bring a similar technology, independently invented, to market.

Many factors have led to the dilution of patent standards. The first problem is a shortage of patent examiners. The average patent gets only eighteen hours of review, and many are only cursorily examined, yet there is still a backlog of more than 400,000 applications at USPTO. Second, the expansion of patents to biotechnology, software, and business methods means there may not be sufficient written prior art to reject applications on what might seem to be obvious technologies, and examiners may not be adequately trained in those areas. Therefore, both the novelty and nonobviousness standards have diminished sharply as applied, even in cutting-edge technologies.

Third, all patents, even dubious ones, are buttressed by courts and regulation. U.S. courts presume that an issued patent is valid; challenging that validity to defend against infringement litigation is therefore difficult. In fact, it is hard to challenge validity in any forum, as the United States is uniquely hostile to procedures to vacate patents. The USPTO may be asked by interested third parties to reexamine the validity of an awarded patent, but its procedures sharply restrict the scope of the challenge to the patent. No challenges may be made to utility, even though such challenges could, for instance, invalidate certain genome patents. Third parties may challenge a patent by demonstrating a lack of novelty or inventiveness, but only published prior art may be admitted as evidence. Requiring that prior art be in published form can exclude critical evidence of earlier knowledge in elements of new technologies. Software code, for instance, is not ordinarily published but could contain information demonstrating that an invention had already been developed. If the challenge is not upheld upon reexamination, the ability of the parties raising the challenge to vacate the patent in court is greatly restricted.

Moreover, a lawsuit by a rival firm to invalidate a patent is only possible if the patent holder has threatened the rival with infringement litigation.

In addition to concerns about quality, it is increasingly common for patents to be written broadly, covering several technological claims, including "reach-through" claims to uses of research tools. As noted below, in technological areas where products incorporate several interrelated ideas, and technical change builds on earlier innovation, overly broad patents make it difficult for competing innovators to discern the boundaries of what is protected, increase transactions costs in licensing, and raise the market power of individual patentees.

A final concern has to do with the progressive lowering of the utility standard. Technologies are supposed to be reduced to a commercially useful form in order to qualify for patents. However, under Bayh-Dole and legal interpretations of eligibility rules by the courts, patents have been issued increasingly to subject matter that previously would have been considered unpatentable, such as basic discoveries of nature, which have no direct commercial application.

Potential Problems for Innovation

Policy changes have made patents both stronger in scope (broader claims, longer duration, extended eligibility, greater likelihood of prevailing in lawsuits) and cheaper to acquire (diluted standards, lower quality). The resulting proliferation of patent applications and grants in the United States is remarkable, with the former rising from 164,000 in 1990 to 357,000 in 2004 and the latter from 90,000 to 164,000 over the same period.[7] This increase in patents, however, does not necessarily correspond to an increase in innovation. Available evidence does not support the view that enhanced patent protection necessarily stimulates more innovation. For example, surveys of technology officers reveal that, except in pharmaceuticals, biotechnology, and some forms of machinery, inventing firms do not view patents as significant reasons to invest in technology.[8] Rather, they rely more on lead-time advantages, trade secrecy, learning-by-doing, and complementary services. Instead of representing more innovation, then, the recent surge of patents may have created more impediments to innovation from litigation, transactions costs in licensing and research, anti-competitive blockages, and a slowdown in sequential innovation.

The decrease in the quality of patents, as well as the increase in quantity and breadth, has raised uncertainty about the boundaries of the rights owned by patentees. It has also fed an explosion in litigation costs, which may deter small companies from entering the market for fear of infringing on patents with vaguely defined boundaries.

Patent litigation is complex, uncertain, and more expensive than most other civil lawsuits. It is estimated that for patent suits with less than $1 million under contention, median discovery costs and legal fees are $790,000; for suits between $1 million and $25 million these costs are $3 million; and for suits with more than $25 million at stake they rise to $6.5 million.[9] These figures do not include damages, which may be treble in cases where willful infringement is found.

In 2000, there were 2,000 patent lawsuits filed involving around 3,000 patents—double the number of lawsuits in 1990. About 2 percent of these lawsuits ultimately went to trial, a rate above that for civil cases in general. It is evident from these figures that litigation costs may be a deterrent for small companies as regards entry into competition that may infringe existing patents. It is also clear that companies generally prefer to settle out of court rather than risk an adverse judgment. Moreover, the United States is unique in providing a right to a jury trial in IPR lawsuits, and juries are more likely than judges to favor patent holders.

In addition to the costs of individual patents, researchers have to contend with "patent thickets." That is, complex technologies, such as biomedical research tools, embody a number of technological inputs, many of which are patented. A different company, in turn, could own each patent. Negotiating these thickets raises the cost of securing rights. Weaker patent standards encourage patent proliferation and an enlargement of the thickets for research in areas such as biotechnology, agricultural chemicals, and pharmaceuticals.

Whether thickets are a significant problem is the subject of much debate. One important survey found little evidence that thickets have prevented biomedical research from fully utilizing the most recent technologies.[10] However, a statistical analysis of citation patterns of publications in biotechnology and life science journals before and after a patent is granted suggested that patents in these areas have a modest research-diminishing effect, with additional evidence of a shift in research priorities toward less protected, and presumably less promising, areas.[11] That suggests patent thickets and transactions costs may slow down the diffusion of scientific research.

This concern was heightened by the CAFC decision in 2002 in Madey v. Duke, which is described in box 1. Prior to this case, universities engaged in research under a traditional research exemption permitting them to use patented technologies freely without paying license fees. The court ruled that research supported potential commercial activities, thereby narrowing the legal scope of the exemption substantially. The decision ultimately could force university scientists to negotiate licenses with multiple patent holders to continue basic research programs. Anecdotal evidence since Madey v. Duke suggests that campus legal offices have become more nervous about their scientists using patented technologies despite the nonprofit status of universities. It remains to be seen whether the case will slow down or shift the priorities of research programs at public laboratories and universities.

A way around these potential problems is licensing patented technologies. Large firms could build extensive patent portfolios that they cross-license with others to avoid infringement and gain access to knowledge. Under cross-licensing agreements, each firm lists a large number of patents it owns and other partici-

Box 1. Madey v. Duke

John Madey was a tenured professor at Stanford University, where he developed the technology for two patents on an electron laser gun that is important for electron research. In 1988, he moved to Duke University, which built a special laboratory for his lasers. A fallingout caused Duke to remove him as lab director in 1998, but researchers at Duke continued to use machines embodying his technologies, and Madey sued for patent infringement. Duke claimed its use was protected under the experimental use defense for noncommercial entities.

Madey's claim was upheld by the CAFC, which, in essence, ruled that because Duke was using the patented technologies in research that could generate outcomes with licensing revenues, it was a commercial enterprise for this purpose.

Source: Carmella Stephens, "Madey v. Duke University: Federal Circuit Sets Limitations on the Common Law Experimental Use Exemption," Baker Botts LLP Intellectual Property Report 3, no. 27, July 7, 2003.

pants are allowed to use any of the patents listed, with perhaps some net payments to firms with larger portfolios. A related solution is a patent pool, in which two or more firms combine ownership of specified patents but may not license them more widely. Such arrangements may reduce transactions costs enough to offset losses due to greater competition and may avoid litigation costs.

Although such arrangements seem sensible, they pose practical problems. First, they give firms an incentive to build the largest patent portfolio to improve their negotiating positions, a factor underlying the proliferation of patents. Second, patent pools can be operated in anti-competitive ways. For example, Summit Technology Inc. and VISX Inc., which pioneered the development of equipment for laser eye surgery, created a jointly owned partnership that was given control of both companies' primary patents. The partnership could license to third parties but only if both companies agreed, giving each a veto over decisions of the other to license. This agreement eliminated competition between them to offer such licenses.[12] A third problem is that it may be difficult to draft contracts across multiple claims when, as noted above, those claims may be of uncertain validity. Finally, patent thickets may be an entry barrier to the extent that new firms must build a patent portfolio quickly in order to be able to cross-license with other firms.

Of course, cross-licensing also depends on firms' willingness to license their technologies, and holders of U.S. patents have no legal requirement to do so. If companies build portfolios solely for the purpose of extracting payments, they may find it most profitable simply to litigate, especially if lawsuits emerge against a threat of preliminary injunctions and treble damages for willful infringement.

This possibility limits the willingness of firms to invest in technologies that might infringe patents of even questionable validity.

Similarly, patent holders with broad claims on platform technologies may try to use those claims to discourage competitors through licensing restrictions and litigation against technologies on similar products. A prominent example is the Chiron Corporation, which in the 1980s collaborated with the Centers for Disease Control (CDC) in the discovery of the hepatitis C virus. It was an expensive process, requiring the cloning of the virus through extensive trial and error. The breakthrough discovery, made in 1987, led to a reliable blood test for the disease and sparked further efforts to develop a cure. Chiron applied for a patent on the cloned virus but did not name the CDC or Daniel Bradley, the CDC virologist who had provided essential blood samples from infected chimpanzees, in the patent. Robert Lanman of the National Institutes of Health argued that Chiron should provide the government some control over licensing of the virus and blood test so that other researchers would have access on reasonable terms. Chiron disagreed but in 1990 signed an agreement with the CDC giving Chiron full rights to the patent in return for a payment of $2.2 million. Since that time Chiron has aggressively enforced its patent, and critics claim that its enforcement has held up research by other firms and agencies for years. For example, a French scientist working with bioMérieux stated, “whether you are working on an antiviral or a vaccine, you have to consider that the Chiron patent is going to be a problem.”[13] A 2003 study by the National Academy of Sciences also singled out Chiron as a company with a reputation for limiting access to its patents. Moreover, a number of small companies interested in extending research on hepatitis C claim to have abandoned that research because of an inability to license the Chiron patent.[14] Yet another problem with cross-licensing and patent pooling is that patented technologies may be components of technologies that make up important product or technical standards, or become standards themselves. Product interface standards are necessary for various components and programs to work in telecommunications and computer networks. To compete, companies must be able to design products that are compatible with these standards. For example, the application programming interfaces that define compatibility with the Microsoft Windows operating system is a critical industry standard. Yet it is possible that one company may own patents that limit access to the standard or, increasingly, that multiple companies claim rights that cover some portion of it. Indeed, Microsoft’s traditional approach has been to keep its patented standards proprietary. Such situations may give the patent holder considerable market power and raise licensing problems similar to those above. Such “holdup” problems in patenting basic technologies can be severe in their effects on follow-on innovation.

The patent system was designed under the classical image of innovation as a discrete technology with clear claims. Yet, as the emergence of these issues indicates, that model increasingly is inconsistent with important new technologies that rely on deep interrelationships across inventions. Firms in high-technology sectors frequently build sequentially on existing inventions to achieve improvements and often embed patented technologies into their own products. In this kind of system, future discoveries are more probable if there are more innovators. Stronger patents may thus reduce profits and innovation.

To illustrate this inconsistency between the patent system and modern innovation, one might ask why the U.S. software industry was highly innovative in the 1980s, even though it was not eligible for patents. The sequential, cumulative, and complementary nature of innovation in software pushed product development forward into many areas of technology. The classical view of patents predicts that innovation should have increased after the Supreme Court affirmed in 1990 that computer programs may be patented.

However, the firms that acquired the bulk of these patents actually reduced their research and development (R&D) spending as a proportion of sales, suggesting a flattening of innovation incentives.[15] The reason could be that patents are overly strong protection for the industry. Patents last twenty years, which is far longer than the typical life cycle of a software product. In platform programs with network economies among users, patents can lock in an already significant market advantage, deterring competing innovation.

The Role of Antitrust Policy

Many of the measures that companies take to restrict access to technology fall under the jurisdiction of antitrust authorities. For example, it is anti-competitive to extend market power beyond individual patent claims by tying sales of unrelated or complementary goods to access to patented goods. Under some circumstances, refusals to license a critical enabling technology or important intermediate input may also excessively restrict competition. Antitrust policy could play a role in such cases by ordering licensing.

U.S. antitrust authorities have taken action in some patent cases by issuing nonexclusive compulsory licensing orders and negotiating breakups of patent pools. However, such actions are rare, as antitrust policy has been almost completely benign toward patents. For example, U.S. policy generally will not interfere in cases of "dependent patents," the licensing of which is necessary for the marketing of a later application. This antitrust stance is founded on the same policy presumptions that prevail in U.S. patent law: that patents are property and the state should not limit or order their exploitation, and that technology markets are generally more efficient in the absence of competition regulation.

Given the proliferation of questionable and overlapping patents in an era of rapid technical change, antitrust policy could be a powerful tool for preserving dynamic competition when the patent system fails to do so. The Federal Trade Commission took a step in that direction recently when it raised concerns about the wisdom of maintaining a strong separation between IPR and anti-monopoly policy.[16]

INTERNATIONAL DIMENSIONS

Difficulties in the U.S. patent regime may be limiting innovation, but it is a problem for international competitiveness only if competitors' systems are more supportive of technological innovation. The first step is to identify variations between the U.S. patent regime and those of other significant countries.

Canada

Taken broadly, the Canadian and American patent systems are similar. Both provide patents for twenty years. Both systems award proprietary rights to exclude others from making, using, and selling the patented processes or products of claimed subject matter.

However, there are significant differences, which reveal the Canadian system to be more cautious in striking a balance between inventors and the users of new information.

Canada has more restrictive eligibility for patents. The Canadian Supreme Court affirmed that transgenic, higher-order animals are not eligible for patents. Canada does not patent business methods, surgical methods, medical treatments, or computer programs. (Computer-related devices that integrate processes and apparatuses may be patented.) Like the United States, Canada publishes all patent applications within eighteen months of filing, but it does not allow inventors to prevent publication if they choose not to file abroad. Canada has stronger standards for what must be disclosed in a patent application. Further, it is possible in Canada for any interested party to challenge patent validity before the patent is granted by making prior art available. And, although procedures exist in both nations to oppose the validity of patents after a grant is made, the U.S. courts have made such challenges difficult to sustain.

For a long time, Canada has viewed compulsory licensing as an appropriate form of transferring technology for purposes of industrial policy (although it has rarely been used), while the United States has confined its use largely to antitrust remedies. The question of interest is whether Canada's approach of more limited rights has generated less innovation growth than has the U.S. approach of strong exclusive rights.

Evidence suggests that this is not the case. During the 1990s, when the United States was considerably expanding the scope of its IPR regime, Canadian R&D expenditures and innovation (as measured by patents registered abroad) rose relative to those in the United States. No definitive inference may be made, because other factors could be at work, but the simple evidence does not favor the hypothesis that the U.S. approach generates more investment in information creation.

European Union

The EU has a strongly protective IPR system. Although traditionally more reluctant about patenting life forms than the United States, the EU has made patents available for biotechnological inventions since 1998. However, the European

Patent Office (EPO) has taken a more cautious approach than the USPTO in issuing patents with broad claims in core technologies, such as genetic research tools. The EU treatment of software patents is similar to that in Canada. Computer programs, per se, are not eligible for patents, but they can be protected to the extent that they give effect to the operation of a related apparatus or process.[17] This basic principle has supported an increasing number of patents for computer software and Internet programs, although there is no clear definition of what constitutes a "business method" in the EU.

The most important differences are the standards for patents. The EPO tends not to permit overly broad claims in patent applications, and post-grant opposition is more robust in the EU, where there is less of a legal presumption of patent validity. Unlike the United States, the EU recognizes a prior-use exception to patents.

Finally, the EU antitrust body—the European Commission—is more inclined to order licensing or related remedies where it finds excessive use of market power from IPR. A prominent example was the decision in 2004 to order Microsoft to make protocol technologies for Windows available to software firms upon payment of royalties.

Microsoft developed a licensing program, but in July 2006 the commission determined that it was insufficient to meet the terms of the licensing order and issued fines that will remain in place until compliance is achieved.

It is not possible to state definitively whether this approach has limited or spurred innovation growth in the EU relative to the United States, as member countries of the EU vary widely in their innovation capacities. However, in 2003, the United States ranked behind the United Kingdom, Germany, Sweden, Finland, and France in terms of patents received in the USPTO and the EPO per million dollars of R&D spending.[18]

China

Like the United States, Canada, and the EU, China has a system of IPR that is fully consistent (on paper) with the TRIPS agreement. However, China's legal regime makes greater use of TRIPS-consistent authority to limit exclusive rights and encourage access to information. China does not permit patenting of business methods, medical treatments, surgical methods, or plant and animal varieties—in particular, higher-order life forms or biological research tools. (However, one way China does bolster patent rights is by not permitting experimental use of patented materials.) Software users have a limited right to decompile computer code in order to develop new programs, although the government is considering extending patents to computer programs. The country has liberal standards covering government use and compulsory licenses of patented technology.

The familiar problem in China is that patents are poorly enforced, a deficiency that encourages massive copying and imitation. In this context, there is anecdotal evidence, based on interviews of domestic enterprise managers, that China's failure to enforce patents is becoming a greater drag on its own firms' ability to innovate and grow.

The remarkable aspect of China's economy is that, despite this weak technology protection and inadequate enforcement, massive amounts of technology have flowed into the economy via foreign direct investment and joint ventures or licensing deals.[19] To date, most such transfers have been second-tier and mature technologies, because foreign firms wished to limit the loss of cutting-edge knowledge. Increasingly, however, international firms are shifting higher-technology production facilities and research centers there. It seems likely that this trend will accelerate as greater enforcement of the new laws takes hold.

Potential Implications

There are two potential implications of these differences across countries that American policy-makers should consider. First, patent systems can provide significant incentives for investments at the same time that they safeguard opportunities for dynamic competition and access. Many countries prefer to strike a balance more in line with the needs of technology users, while transparently recognizing the importance of innovation incentives. In contrast, the U.S. patent system has become so protective of exclusive rights that it diminishes incentives for competitive innovation in some respects.

Second, even if international regimes remain less protective of inventors' rights, the fact that they have become stronger and more transparent in recent decades increases the probability that firms will transfer technology and R&D to international locations.[20] Indeed, numerous software companies and high-technology firms recently have opened research facilities in China and India.

This dynamic poses a challenge for U.S. policy-makers. They are understandably concerned about the loss of technologies to imitation, industrial espionage, and reverse engineering in new industrial competitors. Thus, the United States has a strong interest in pushing China and similar countries to strengthen their patent standards, trade secrets, and enforcement efforts. Paradoxically, though, such a change ultimately would shift technology transfer away from older technology toward first-tier technologies and research facilities as firms feel more confident about their ability to protect proprietary knowledge. Because some portion of this research off-shoring would be due to the competitive problems of the U.S. patent system, the United States would be encouraging excessively rapid technology transfer.

Despite that problem, more active enforcement by China and other nations that misappropriate proprietary knowledge and confidential information would generate significant gains for American technology exporters. Those gains would include higher returns to licensing and longer periods within which firms would benefit from market exclusivity in growing and dynamic economies. Therefore, U.S. trade authorities should place greater emphasis on pushing governments in major developing countries to meet their international obligations to enforce patents. As discussed more fully in the recommendations, a positive incentive would be to expand the global resources available for providing technical and financial assistance to these countries in order to improve their judicial systems and enforcement regimes. This relaxation in technical and budget constraints should reduce opposition to investments of scarce development resources in enforcement. However, real progress may require coordinated legal action at the WTO to demand serious efforts to clean up infringement. This combined approach should shift the politics of piracy in developing nations in favor of emphasizing the dynamic gains from stronger protection for domestic and international technologies.

While enforcement initiatives have not been absent from trade policy, the United States has devoted far more effort to negotiating globally harmonized patent standards or, failing that, to markedly strengthening patent regulations in developing countries through trade agreements. Indeed, U.S. trade policy places a strong priority on international patent harmonization at high levels of protection—a questionable ranking of priorities.

International Harmonization

There is a good reason to achieve some harmonization of patent rules, since it could reduce transaction costs of inventive companies. Dealing with different patent standards and fees is costly. There is an alternative to harmonization, however: to increase coordination among patent offices to mutually recognize patent grants and reduce fees.

Mutual recognition would mean that a patent application considered in one major IPR office would, if granted, be ruled presumptively valid in other participating countries, subject to local opposition procedures.

Mutual recognition would not tighten patent standards significantly. The U.S. policy, in contrast, emphasizes the need for far stronger regulations, suggesting that strategic objectives are in play. First, such harmonization would increase the profits of U.S. firms in biotechnology, agribusiness, software, and other industries. Second, a strong harmonization agenda could make competitive differences in the U.S. system and international regimes less glaring.

The harmonization drive has come in three forums. First, the TRIPS agreement established a comprehensive set of minimum standards that all member countries must implement and enforce. For most developing countries, the changes required were significant, particularly regarding patents, the confidential treatment of clinical test data for marketing approval, and compulsory licenses. The TRIPS standards, however, contain room for favoring competitive access over strong exclusive rights. Countries may define their own standards for nonobviousness, utility, and novelty, and many countries (such as Brazil and China) have chosen rigorous standards to prevent awarding property rights to minimal changes in technology. If enforced, these minimum standards provide some certainty for investors but fall well below the U.S. standards in patents. Further, TRIPS has not forced convergence of patenting standards and exceptions among the developed economies.

A second important effort has been the currently stalled negotiation of a Substantive Patent Law Treaty (SPLT) at the World Intellectual Property Organization (WIPO). The SPLT would largely harmonize patent examination standards across member nations. U.S. negotiators have pushed for a global regime that would adopt many of the American standards for eligibility, including of subject matter. This negotiation has been an attempt by the United States (and the EU to some extent) to ratchet up patenting standards that were left more discretionary under TRIPS. Many developing countries, led by Brazil and India, have resisted this approach, while difficulties in achieving agreement among the United States, the EU, Japan, and other developed countries have sidetracked the negotiations further.

The third and most controversial U.S. approach has been the negotiation of bilateral free trade agreements with developing countries in order to push patent standards higher than TRIPS levels and closer to the U.S. model. This so-called TRIPSplus agenda (see box 2) has expanded over time, culminating in strong IPR chapters in the agreements with Morocco, Jordan, Bahrain, Singapore, Peru, and Colombia.[21] TRIPSplus requirements have been controversial among health authorities in developing countries because they place strict limits on the ability of governments to encourage generic entry or issue compulsory licenses in pharmaceutical products.[22] They also are resisted by information and education ministries for their restraints on fair use in copyrights.

For all of this controversy, the benefits to innovation are questionable. Most of the markets involved are small, so it is unlikely that research-based international companies would perceive additional incentives for general investments or undertake investments specific to those markets. These policies will not encourage innovation by firms in the signatory countries because they do not provide much additional market access in the United States. It is difficult, therefore, to see much reason to expect more R&D induced by the patent components of these FTAs. A more likely outcome is that local innovation will actually be discouraged by patent standards that exceed what would be sensible for development.

In addition to the damage done to innovation in smaller markets, initiatives to open larger markets to U.S. exports may fall victim to the American focus on patents.

The bilateral FTAs are not likely to go beyond agreements with relatively small economies, as larger and middle-income countries have domestic interests that would resist substantially stronger standards than those in TRIPS, and their governments are better positioned to resist the restrictive aspects of patent policy in TRIPS-plus. Brazil, for example, has resisted negotiating an FTA with the United States—concerns about IPR being a central reason—and has further opposed a hemispheric Free Trade Agreement of the Americas. China in particular sees little need for an agreement that would ratchet up its standards. Clearly, pursuit of harmonization in these cases carries severe costs that merit consideration.

Box 2. The U.S. TRIPS-plus Agenda

The expression "TRIPS-plus" refers to demands made by the United States and other developed economies that trading partners agree to IPR standards that exceed those required in WTO rules.

In the area of pharmaceuticals, the Doha Declaration clarified TRIPS by permitting the least-developed countries to delay implementation and enforcement of patent rules until 2016, stating that governments could accord priority to public health needs over intellectual property requirements and asserting that developing nations could take full advantage of the flexibilities in TRIPS. In its negotiations of bilateral free trade agreements (FTAs), the United States has systematically ignored these provisions in favor of strong protection in pharmaceuticals in particular and in IPR more generally.

In operational terms, TRIPS-plus means the following. First, for items that are not negotiated within an FTA, the relevant TRIPS standards pertain. Second, the FTA might negotiate standards that exceed those of TRIPS. Third, newer areas of IPR that were not covered by TRIPS may be subject to negotiations in FTAs. This approach meets U.S. negotiating priorities, including requirements that IPR provisions of agreements "reflect a standard of protection similar to that found in U.S. law" and that standards strongly protect new technologies and embodied intellectual property.

Primary items of TRIPS-plus include the following. Regarding patents, the United States prefers that countries provide extensions to patent coverage and scope in a number of ways. One way is to narrow the exclusions from patentability and, in particular, to make eligible life forms, including genetic sequences. Other areas in which patents could be provided are plant varieties, software, and business methods. A second way to extend coverage is to provide patent-term extensions for drugs in cases where health authorities issued patents with undue delay. Another is to issue second-use patents, which effectively extend patent protection for chemical entities beyond original terms. Yet another is to limit experimental use of patented materials and also to restrict their use by potential generic firms in preparation for entry as patents expire. But perhaps the most significant one is the demand that health authorities ban the registration of any generic drugs during the lifetime of a patent. That would effectively end access to compulsory licensing except in rare circumstances.

Next, a central demand of the United States is exclusive use rights for confidential clinical and field trial test data on behalf of original applicants for a period of at least five years for pharmaceutical products and ten for agricultural chemicals. Recent FTAs go beyond that and effectively permit ten-year exclusivity (by giving firms up to five years to apply for marketing approval in the country and then adding data rights) before data may be used. That is a strong restriction on competition, even in medicines where no patent is issued.

Is Harmonization worth the Cost?

TRIPS-plus raises profits of major U.S. industries selling products abroad, but the agenda offers few innovation benefits for American consumers and may impose costs on citizens in partner countries. In return, however, the United States pays an incalculable, but substantial, cost in terms of its foreign relations. These one-sided demands in patent standards increase suspicion in developing countries that trade agreements are designed unfairly and do not consider development needs. Indeed, concerns about the rules governing regulation of pharmaceuticals held up negotiations with Colombia until the public objections of the health minister could be neutralized. In both Colombia and Peru, the recently signed trade agreements with the United States are unpopular among many citizens primarily because of the IPR provisions.

Attempts to internationalize U.S. patent practices raise considerable opposition more generally abroad. The U.S. Basmati rice patent (see box 3) raised widespread concerns in developing countries, despite the fact that central claims in the patent were overturned, that the American patent system could be used to appropriate traditional technologies. Those countries fear that it will fall to their companies and governments, rather than the U.S. patent examiners, to overturn obviously invalid U.S. patents.

SUGGESTED REFORMS

Based on the analysis in this report, the United States should pursue the following policy recommendations to build coalitions for reform.

Domestic Reforms

Given the evolution of patent doctrine and judicial practice, it is impossible to remove whole technologies (such as software and business methods) from patent eligibility.

Instead, the United States should return, at least in part, to the first principles of examining patents. As noted in the introduction, legislation has been introduced in both houses of Congress that would make some progress in reforming the patent system. The House bill would:

- shift the U.S. system from a first-to-invent patent award to a first-to-file award, thus eliminating litigation to determine the first inventor and making our system more consistent with the rest of the world;
- require publication of virtually all applications within eighteen months of the filing date;
- permit interested parties to challenge the validity of a patent within six months of its granting by filing a petition at USPTO rather than engage in costly lawsuits; and

Box 3. Basmati Rice

In late 1997, an American company, RiceTec Inc., was granted a patent by the U.S. patent office to grow the aromatic rice known as Basmati and label such rice grown outside India with that name. RiceTec had been trying, with little success, to enter the international Basmati market with brands like Kasmati and Texmati described as Basmati-type rice. However, with the Basmati patent rights, RiceTec would have been able not only to call its aromatic rice Basmati within the United States, but also to label it Basmati for its exports. Farmers in India and Pakistan were outraged because they would lose access to the large U.S. import market and also face greater competition for traditional Basmati exports in such crucial markets as the EU, the Middle East, and west Asia. Many observers in the Indian media suggested that patenting Basmati in the United States was akin to diminishing their history and culture. The Indian government protested three (of twenty) claims in the patent, pointing out that its exclusive titles to growing rice plants with certain characteristics identical to Basmati, the grains they produce, and the method of selecting plants based on a starch index, all related to items that had been known for many years and should be considered prior art. In 2001, the USPTO invalidated these claims in the patent but permitted RiceTec to sustain its patent on rice-breeding innovations unrelated to this prior art of indigenous farmers.

- permit third parties to submit published materials to USPTO prior to its issuing a patent, in order to make sure that patents are not granted on inventions that were already known.

The Senate bill would:

- shift to a first-to-file system;
- provide more structure for judges in determining patent damages;
- permit third-party submission of prior published materials; 33
- limit sharply the definition of "willful infringement" under which treble damages may be awarded; and
- provide a second window for post-grant opposition, during which firms accused of infringement could challenge the patent's validity.

These bills may be as much as can be accomplished due to countervailing political pressures. Unfortunately, they would not go far enough to achieve a fully effective balance in the patent system. Thus, domestic reform should remain on the agenda for the near term until it incorporates all of the following:

- Congress should require that more rigorous standards for determining whether an invention is obvious or novel be applied to patent applications. To this end, it should permit the USPTO to keep enough fees to fund an expansion of examination professionals to serve as a "second set of eyes" for business methods patents, software patents, and other relevant applications. This financial shift would reduce the granting of dubious patents.

- Third parties should be permitted to submit additional prior art upon publication of patent applications. This requirement would also reduce the granting of patents to inventions that are obvious or not novel.
- Congress should lay the groundwork for an effective and expeditious post-grant opposition system. Legislation to that end should permit any interested party, not just those involved in litigation, to petition the USPTO within nine to twelve months to reconsider the scope and validity of a patent. It should also allow an alleged infringer to request reconsideration of the patent within six months of receiving notice of infringement from a patent holder. The goal is to provide a cheaper and faster means of reviewing patent validity than the current costly and one-sided court procedures.
- Congress should scrap the requirement that a competitor cannot challenge a patent until and unless it is sued for infringement, as it raises substantial uncertainty. It should also weaken considerably the strong legal presumption that issued patents are valid simply because they were issued.
- Congress should eliminate the presumption that preliminary injunctions should be issued by courts in cases of alleged patent infringement and replace it with an approach considering all relevant business factors in deciding whether to issue an injunction or to stay an injunction. For example, plaintiffs should be asked to show that they would suffer irreparable damage that could not be compensated monetarily before a court issues an injunction against a defendant.
- Congress should limit the grounds on which willful infringement is found. For example, the presumption of a willful violation when the infringer did not first obtain a lawyer's opinion should be ended. Generally, punitive damages should be awarded only in circumstances of egregious conduct, not where defendants acted with no intent to infringe. These measures would reduce the hesitancy of researchers to take advantage of published patents and other forms of available information.
- Congress should implement a legitimate prior-use right against patent infringement suits.
- The United States should establish an office of competition advocacy within USPTO to consider the economic implications of broad patent claims before they are granted. This examination should be restricted to patent applications on technologies that would have significant market power, an approach similar to the antitrust role of staff economists at the Federal Trade Commission and the Department of Justice.

International Reforms

- The United States should pursue mutual patent recognition among the United States, the EU, Japan, Canada, Australia, China, and other nations. This would lower overall costs of the global patent regime.

- The U.S. harmonization agenda should be softened to involve accommodation by the United States at least as much as the other way around. This would include the following steps:
  - A shift in U.S. practice to award patents on a first-to-file (rather than first-to-invent) basis.
  - Pursuit of limited convergence of global patent standards, perhaps through procedures that differ by region or development level. One could imagine a patent application that would cover the United States, Canada, Europe, and Japan and that would be examined in any of those patent offices under a systematized procedures manual. There might also be a single patent application for the Association of Southeast Asian Nations (ASEAN) in conjunction with China, wherein China would undertake primary responsibility for examination under a developing-country set of standards. This technical arrangement would not absolve China of its international obligation to enforce patents.
  - Abandonment of the TRIPS-plus objectives in bilateral trade agreements, especially in regard to patents and procedures in medicines that could negatively affect the ability of developing countries to manage health policy. Specifically, U.S. trade authorities should stop demanding strict concessions regarding compulsory licensing, experimental use, second-use patents, and extended periods of test data exclusivity.

Developing a Consensus

U.S. pharmaceutical companies, biotechnology firms, and others that rely on international patent protection will oppose these international reforms. Firms in other sectors do not place a high priority on these ideas, as they are more focused on domestic patent reforms.

However, all IPR-exporting companies would gain if there were serious progress on enforcement of their rights in major developing countries. Piracy and counterfeiting are important in their own right for many industries but also matter to patent holders, who sell goods using complementary copyrights and trademarks. In truth, there has been virtually no progress in dealing with patent infringement, copyright piracy, and trademark counterfeiting in China and elsewhere. This situation blunts interest in wider reforms and therefore is an important roadblock to achieving them.

Thus, to generate consensus on a relaxation of the international harmonization agenda, there must be serious progress in enforcement. Industry estimates suggest that U.S. firms suffer tens of billions of dollars in lost sales annually to infringement of various kinds. The United States—in concert with the EU and Japan, where firms experience similar losses—should place more emphasis on achieving a global consensus to ensure effective IPR enforcement, particularly in such large markets as China, Turkey, and South Africa. Greater enforcement would have the direct benefit of expanding sales opportunities for international firms and the indirect benefit of reducing concerns in Congress about the rapid loss of technologies.

For their part, middle-income and emerging industrial powers have good reason to strive for greater enforcement, since simple piracy and counterfeiting, however profitable, do little to promote technical change and are an increasing burden on the expansion of domestic enterprises. At the same time, the domestic political economy in those countries militates against reforms, because in the short run the primary beneficiaries would be IPR owners from abroad while the losers would be domestic infringing firms, which are often well connected. Further, major enforcement activities would demand large public investments, thereby commanding a greater share of scarce development resources.

A consensus needs to be reached that would coordinate the long-term interests of dynamic firms in developing economies with the medium-term interests of patent-intensive companies in developed countries. This coordinated approach to enhancing enforcement should be built around two basic principles. First, because international firms from all technologically advanced nations suffer losses from infringement, a joint effort among countries in the Organization for Economic Cooperation and Development (OECD) to considerably expand technical and financial assistance for IPR enforcement would be a positive inducement for change. The technical assistance should involve additional training in judicial principles and enforcement procedures. Developed countries should also commit to providing greater financial assistance for effective enforcement procedures in order to relax budget constraints. To a substantial degree this additional assistance could be paid for through nominal fees imposed on international patent and trademark applications at WIPO, which would have the advantage of charging beneficiaries—global patent registrants—a portion of the costs of improving their competitive landscape. In brief, the carrot of substantial assistance, in combination with a relaxation of U.S. pressure for higher global patent standards, should provide positive incentives to developing countries for upgrading enforcement.

Scattered financial and technical assistance of this kind has been offered for years, and the United States has complained strongly about the enforcement issue in China, India, Thailand, and elsewhere. However, neither assistance nor jawboning has been effective in raising the incentives of governments to improve markedly their enforcement activities. It is naive to expect the provision of further assistance to achieve meaningful progress except over a lengthy time period, so an external stick may be required to change domestic politics in favor of rapidly implementing effective enforcement mechanisms. Thus, the second principle is to hold major developing economies accountable for their unwillingness or inability to enforce patents, trademarks, and copyrights in their own laws. China, for example, has undertaken extensive reforms to its laws governing IPR but has made only minor investments in enforcement and continues to turn a blind eye to extensive infringement, piracy, and counterfeiting. A similar situation exists in other large developing countries.

This lack of progress is inconsistent with commitments made in Part III of TRIPS to "ensure that enforcement procedures…are available under the law so as to permit effective action against any act of infringement of intellectual property rights." Developed countries could use this as the basis for a substantive WTO dispute that their rights have been nullified or impaired by weak enforcement efforts. Demonstrating damages would not be difficult, and such a case could help establish a better framework for improved enforcement.

A WTO case is far more likely to be effective if it is undertaken as a multilateral effort by developed countries. A broader complaint will get more attention from plaintiff countries because any prospective trade sanctions imposed would restrict access to all their most important export markets. It would also spread the costs of preparing the case and suffering the damages from potential trade barriers among multiple countries that stand to benefit from stronger enforcement.

The prospect of better enforcement over the medium term, along with achieving some efficiencies in international patent procedures, may not be sufficient to induce U.S. firms to support the call made here for scaling back the harmonization agenda. Without it, however, the overall reform package advocated here cannot proceed. Ultimately, what should matter is the ability of the domestic and international patent systems to support those firms' ability to compete in technology development and to protect their rights. The needs of innovation will be better served by a more flexible—and better enforced— global regime than by the harmonization agenda being pushed by U.S. trade negotiators.

CONCLUSION

For more than twenty years, the United States has increasingly strengthened the exclusive rights of inventors at the expense of those who need access to new technologies, while patents have been granted too easily and written too broadly. These policies reflect the misguided belief that stronger rights will always expand incentives for innovation.

Instead, the patent system raises roadblocks for licensing and cumulative innovation, becoming a threat to competitiveness and growth.

The dogmatic assertion that "more is better" also drives U.S. trade policy in setting global patent rules. The global trading system cannot thrive under a "one size fits all" approach to any major regulatory regime, including patents. Countries need the flexibility provided under TRIPS—the multilaterally agreed regime—to manage and support their own innovation and competition policies. Pushing a high-level harmonization agenda has not been fruitful but has generated resentment in trading partners and raises risks for the future of U.S. bilateral trade policy.

Thus, the fundamental approach of protecting low-quality patents with ever-stronger domestic rights, while pressing for more harmonized global patent standards, should give way to a framework that emphasizes flexibility and gets the incentives for innovation right. On the domestic front, this requires significant reforms in patent law and judicial practice. On the international front, a willingness to relax demands for harmonization and TRIPS-plus standards should be combined with greater assistance for reforms and an insistence on effective enforcement in major developing countries. This two-pronged reformation in the stance of domestic and international patent policy would move a long way toward restoring sense to the patent system and expanding confidence that true innovation will be rewarded, wherever it occurs.

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Endnotes

1. Declan McCullagh, "Microsoft, Oracle Call for Patent Reform," CNETnews.com, April 25, 2005.
2. This important point is documented, in the context of international technology transfer, by Ashish Arora, Andrea Fosfuri, and Alfonso Gambardella, in *Markets for Technology: The Economics of Innovation and Corporate Strategy* (Cambridge, MA: MIT Press, 2001).
3. The latter was overturned upon litigation.
4. Figures in this paragraph are from Adam Jaffe, "The U.S. Patent System in Transition: Policy Innovation and the Innovation Process," *Research Policy* 29, April 2000, pp. 531–57; and Jean Olson Lanjouw and Josh Lerner, "Tilting the Table? The Use of Preliminary Injunctions," *Journal of Law and Economics* 44, October 2001, pp. 573–603.
5. The TRIPS requirement is for a minimum term of twenty years and countries are free to offer

longer protection. Thus, there is no inconsistency between TRIPS and Hatch-Waxman on patent duration.

6. Adam B. Jaffe and Josh Lerner offer several examples and discuss the general decline in patent quality in their book *Innovation and Its Discontents: How Our Broken Patent System Is Endangering Innovation and Progress, and What to Do about It* (Princeton: Princeton University Press, 2004).
7. U.S. (Federal) Government Patenting, 1/1977–12/2005 (Washington, DC: U.S. Patent and Trademark Office, September 2006), see <http://www.uspto.gov/web/offices/ac/ido/oeip/taf/us_stat.htm>.
8. The most recent survey is by Wesley M. Cohen, Richard R. Nelson, and John P. Walsh, "Protecting Their Intellectual Assets: Appropriability Conditions and Why U.S. Manufacturing Firms Prefer to Patent (or Not)," *National Bureau of Economic Research Working Paper* no. 7552, February 2000.
9. Data from American Intellectual Property Law Association, *Report of the Economic Survey 2003* (Washington, DC: Fetzer-Kraus, Inc., 2003).
10. See John P. Walsh, Ashish Arora, and Wesley M. Cohen, "The Patenting and Licensing of Research Tools and Biomedical Innovation," paper prepared for the U.S. National Academies of Science, Technology, and Economic Policy Board, 2002.
11. See Fiona Murray and Scott Stern, "Do Formal Intellectual Property Rights Hinder the Free Flow of Scientific Knowledge? An Empirical Test of the Anti-Commons Hypothesis," *National Bureau of Economic Research Working Paper* no. 11465, July 2005.
12. In 1998, the Federal Trade Commission challenged the arrangement as anti-competitive. The companies dissolved the partnership and replaced it with a cross-licensing agreement.
13. Quoted in. Mike McGraw, "Patent Agreement Draws Federal Review," Kansas City Star, February 15, 2004.
14. Ibid. A recent report by the Federal Trade Commission, To Promote Innovation: The Proper Balance of Competition and Patent Law and Policy (Washington, DC: Federal Trade Commission, October 2003), provides further examples.
15. James Bessen and Robert M. Hunt, "An Empirical Look at Software Patents," *Federal Reserve Bank of Philadelphia Working Paper* no. 03-17/R, March 2004.
16. Federal Trade Commission, *To Promote Innovation* (2003).
17. After extensive lobbying over several years, the European Parliament in July 2006 rejected a draft law to make computer programs directly eligible for patents.
18. Figures from OECD, *Main Science and Technology Indicators 2005* (December 2005).
19. It should be recognized that multinational firms have somewhat greater ability to enforce their patents in China than domestic enterprises.
20. There is substantial evidence that strengthening patent rights attracts more technology flows to middleincome developing countries. For an extensive review and analysis, see Keith E. Maskus, "Encouraging International Technology Transfer," *UNCTAD-ICTSD Project on IPR and Sustainable Development Issue Paper* no. 7, May 2004.
21. Australia also agreed to strengthen its rules in its bilateral trade agreement with the United States.
22. These agreements generally contain a side letter that affirms the ability of partner countries to take actions to protect public health in the event of a health emergency.

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