ENERGY TECHNOLOGY INNOVATION LEADERSHIP IN THE 21ST CENTURY

Hal Harvey, Jeffrey Rissman, and Sonia Aggarwal

Technicians work on a 3-megawatt Alstom wind turbine and a 1.5-megawatt GE wind turbine at the National Wind Technology Center, the nation's premier wind energy technology research facility.

EXECUTIVE SUMMARY

A rich array of new energy options is a critical foundation for enduring prosperity, energy security, and the protection of the environment and public health. Smart policy can fill the pipeline with many energy technology options, bring the best of these options to market, and unleash the full power of the private sector in driving down their prices. Energy is profoundly a technology business, so it pays to understand which policies work best at stimulating energy technology innovation.

This paper unpacks innovation—from risky science, with only distant potential for application, to the intense work of commercialization, wherein companies drive down costs, increase performance, and learn to deliver reliable products. To understand the set of needed policies, this paper divides innovation into three stages: research, engineering, and commercialization. It then examines which tools and practices work best for each stage.

Research is by definition a risky business, and some projects will inevitably fail. However, well-managed research can deliver a far higher fraction of success than a piecemeal approach. For the research stage, four principals rise to the top:

1. Concentrate resources in innovation hubs;
2. Use peer review to select promising research domains that support explicit policy goals;
3. Ensure that policies intended to incentivize R&D are stable and predictable over the long time horizons (~10 years) necessary for R&D investment and technology development;
4. "Stage gate" research so that failures are recognized early and shut down.

Engineering must be built on a strong connection between the raw power of government labs, research universities, and the practical exigencies of the companies that have to build, operate, and sell products. It is critical for governments to work with the private sector during this phase of energy technology development. Three mechanisms can support this collaboration:

1. Involve industry when setting the government research agenda.
2. Enable private-sector scientists and engineers to directly participate in government research.
3. Grant industry access to costly government testing and development facilities and staff, whose specialized capabilities are beyond anything a private company could justify to its investors.

Commercializing new technologies requires the full force of the private sector—and that in turn requires a clear, long-term demand signal for new technologies. There are vast opportunities to reduce prices and improve performance of new technologies, but the cost of developing and commercializing energy technology is often in the billions of dollars, and sometimes in the tens of billions. There is not a single major energy technology that was built without a serious market signal offered by regional or national governments. Today, those signals are attenuated, variable, and short-term. To correct this, government energy policy must:

1. Ensure market signals are long-term (e.g. a feed-in tariff that declines according to a known schedule over 10 years) or permanent, to provide certainty to those making the investments necessary to commercialize energy technology.
2. Ensure market signals are large enough to influence the multi-billion dollar energy sector and drive adoption of gigawatt-scale technology.
3. Allow the market to find the price of any subsidy (*e.g*. via an auction), to ensure the government spends the minimum amount necessary to support any given energy technology.
4. Ensure tax credits are liquid and tradable, or replace them with cash grants, to avoid constraints on tax equity investment and save the government billions of dollars.

Last, but not least, is the question of **scale**. Current public and private sector commitments to energy R&D worldwide—totaling less than one percent of annual sales—simply won't get us there. Investments in energy innovation have a vast payoff from the perspective of pure economics, national security, public health, and the environment.

Energy R&D can be a game changer, but it needs to be serious, smart, and consistent.

INTRODUCTION

Countries cannot be safe, prosperous, and healthy unless they have a broad range of energy technology options. Energy technology can help meet five goals:

- Energy supplies should be **affordable**.
- Energy delivery should be **reliable**.
- Energy companies should be **competitive** and should create good **jobs**.
- Energy systems should not unduly harm the **environment**.
- Energy choices should not jeopardize **national security**.

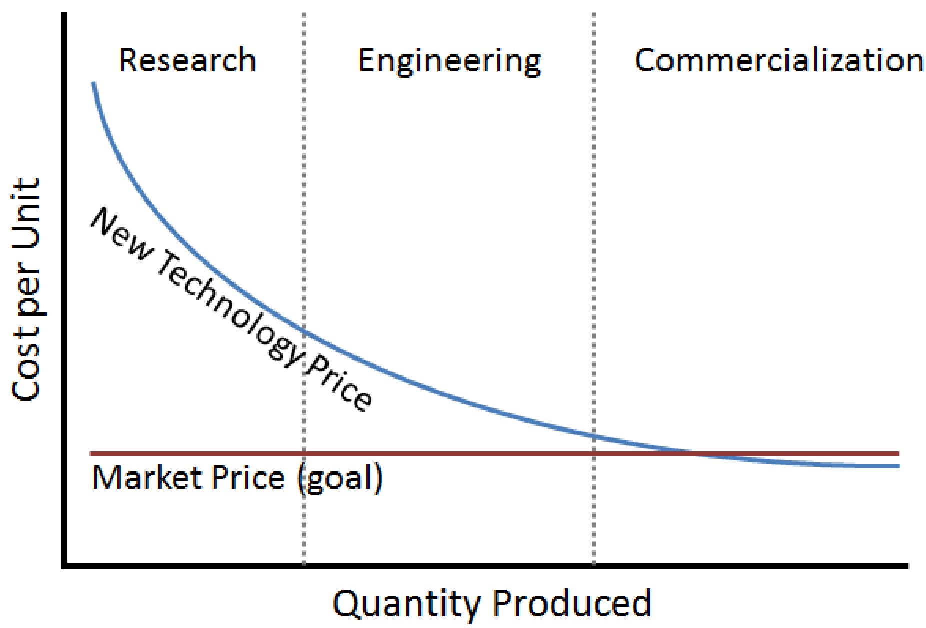
All of these goals are easier to achieve with a steady, strong offering of new technologies—for technology really is the game-changer in energy. Advances in the last two decades have opened up vast new reserves of natural gas, have made thermal power plants increasingly efficient and clean, have driven down the cost of solar and wind, and have made it possible to reduce energy consumption in appliances and buildings by 50% to 90%.

That's good news. The bad news is that we are starving future generations of the next set of options. U.S. companies spend less than one-half of one percent of their sales on new technology research and development, and U.S. government commitments to clean energy are at about the same level. This contrasts with information technology (U.S. R&D is 20 times higher as a fraction of sales) and pharmaceuticals (almost 40 times higher). A handful of nations stand out from the rest of the world as they build strong positions on energy R&D; South Korea, Finland and Japan all make substantial annual energy R&D investments. The rest of the world lags. If we do not get serious about inventing future energy technologies, energy will become a burden on economic productivity, and we will mortgage our children's futures.

That said, accelerating technology development without wasting money can be a challenge. Fortunately, there are proven methods that can dramatically increase the rate of success. This paper describes a handful of best practices that can help energy technologies advance all the way from the laboratory to the marketplace. This work is built upon experience in the field, collaboration with government, reviews of a dozen studies, and many interviews with experts from the private sector, academia, and national labs.

THE PHASES OF TECHNOLOGY DEVELOPMENT

The starting point in thinking through technology development is to understand that different strategies are required for different stages of a technology's lifecycle. Schematically, these can be seen as three phases: Research, Engineering, and Commercialization.



Each phase is necessary for success, but each requires its own unique skills, programs, funding approaches, and connections between the public and private sector. Tools that work for one will not work for the others. The next three sections describe strategies for each.

Research

Here, *research* refers to exploration at the boundary of what is known, seeking to achieve new understanding of physical, chemical, or biological systems.

Research fundamentally involves speculation and experimentation. Even with perfect policy incentives, many research projects will never become commercial products. Sometimes technical or scientific issues interfere; sometimes the marketplace changes; sometimes a more innovative approach makes a project obsolete before it can be commercialized. This reality demands that policymakers and investors **tolerate risk** and research failures. If you don't have any failures, then you will not find true successes.

There are four lessons in organizing successful research:

1. Concentrate efforts in **innovation hubs** to build a critical mass.
2. Use **peer review** to set priorities.
3. Set **long-term** strategies—or else major discoveries are unlikely.
4. Create a set of **gates** for projects to pass at periodic intervals to decide when to stop failing experiments and to continue those that are promising.

1. <u>Concentrate efforts in **innovation hubs**.</u>

Innovation hubs—or "centers of excellence"—are an outstanding machine to accelerate new ideas and products. When many academic, private sector, and government researchers work on the same family of problems, alchemy occurs. Researchers feed off each other's ideas. Students gain technical skills through internships and university-industry partnerships, and businesses have access to talent. Business interests working side-by-side with academia make technologies' transitions from lab to market faster and more reliable. Venture capital quickly moves in and works as a further accelerant. Intelligent national programs can back up this work with research grants, sophisticated equipment, and public momentum.

2. <u>Use **peer review** to evaluate potential research project options.</u>

Selecting research projects among many competitors is difficult and complex. Peer review, especially when it involves experts from industry, academia, and government, is a critical tool for evaluating the field of options and zeroing in on those most likely to be successful. Peer review panels should include a mixture of representatives from government (such as scientists at national labs), industry, and academia.

For example, the United States Department of Energy (DOE) recently developed a *Quadrennial Technology Review* that considered the potential for breakthroughs in many areas, and overlaid them with national priorities—such as reducing dependence on imported oil. The work engaged some 600 experts from the private sector, national labs, and academia. The experts were asked to consider the technologies' leverage against a list of national policy goals and against three explicit measures of potential:

Maturity
Technologies that have significant technical headroom yet could be demonstrated at commercial scale within a decade.

Materiality
Technologies that could have a consequential impact on meeting national energy goals in two decades. "Consequential" is defined as roughly 1% of primary energy.

Market Potential
Technologies that could be expected to be adopted by the relevant markets, understanding that these markets are driven by economics but shaped by public policy.

This process helped the U.S. DOE identify issues with its past funding methodology (such as the need to achieve a better balance between projects with near-, medium-, and long-term impacts), and helped identify where to focus efforts to better achieve national priorities.

3. <u>Set **long-term** strategies.</u>

One of the most challenging issues at the interface of legislation and technology development is the need for a **long-term outlook** for technology policy. Private sector companies need consistency and reliability before they make big bets. Federally supported labs must buy equipment, recruit experts, and build and run careful experiments. Policies that promote R&D therefore must match the long time horizons of technologies, or we will squander opportunities and waste money.

Policymakers, confronted with political and budgetary challenges, tend to fund things a year at a time. But it cannot be over-emphasized just how deleterious stop-and-start policy is to serious energy innovation. For example, the U.S. R&D tax credit has been repeatedly extended for short periods of time and allowed to expire. One CEO of an especially research-driven energy technology company told us that, as a result, they “consider the R&D tax credits just to be a windfall, with no impact on the company’s R&D choices.” By ensuring that credits last for long periods (~10 years), companies will have the confidence to rely on the tax credit when making R&D investments.

4. <u>Create a set of **gates** projects must pass to receive continued funding.</u>

Finally, there is the difficult question of when to terminate research that is not panning out. Research is more often characterized by failure than success. That means research leaders need great methods to cull the losers. The best method for this is **gating**, which forces research through a series strong, predefined assessments, in which benchmarks are met, and the work proceeds; or they are not, and the work is shut down.

Without a robust gating mechanism, valuable research dollars can be wasted funding a project for years after it is clear that it is not valuable, or its time has not come. While some research failures are inevitable, a strong gating procedure helps ensure that when you fail, you "fail early and fail fast," before vast quantities of money have been expended.[1]

Gating Example:

Purpose of the Review

- **To ensure significant progress towards the goals of the R&D project.**
- **To determine changes in priority and direction.**
- **To determine goals for next period.**
- **To stop the project and redirect resources.**

Regular stage gate reviews determine continuation of project

- **Clear criteria for continuation are established during previous reviews.**
- **An updated business case is very important part of the consideration.**
- **Project goals often change significantly during the toll-gate review.**
- **Projects often stopped for economic rather than scientific reasons.**

What does a Review Team look like?

- **Representative of funding department.**
- **Outside technical expertise.**
- **Internal technical expertise.**
- **Representatives of proposed end users.**
- **Representative of financial department.**
- **Members of the R&D team.**

Funded projects can generate entrenched interests, making it more challenging to remove funding from an existing project than to fund a new project. Therefore, it is critical that gating include independent experts with a combination of **scientific and industrial expertise** in the relevant field. By adding an industry perspective, project funding decisions can be made based on a project's scientific merits and ultimate commercialization potential, not on political considerations.

ENGINEERING

It may be possible to produce a single solar cell with spectacular sunlight-to-energy conversion efficiency, but have no way to cheaply build that cell, or make it robust for decades of continuous operation, or make it reliable, or reasonably priced. Many scientific discoveries fail because they cannot be translated into a practical product.

The engineering phase of the technology lifecycle is the work to make a new discovery into a practical, if not yet market-ready, product. Like research, it is a risky endeavor: Many great ideas, tested in the lab, cannot be made to work at scale.

The German approach suggests a world standard. Fraunhofer-Gesellschaft is the largest organization for applied research in Europe. In more than 80 research units across the country, the institute undertakes applied research of direct utility to private and public enterprise, and of wide benefit to society. The vast majority of its 20,000 staff members are scientists and engineers, and Fraunhofer operates with an annual budget of about $2.3 billion.

A review of work in applied research centers around the world reveals three lessons:

[1] http://www1.eere.energy.gov/manufacturing/financial/pdfs/itp_stage_gate_overview.pdf

1. The research agenda must be set with serious involvement by industry.
2. Research should directly involve industry scientists where possible.
3. There can be large economies of scale, and new breakthroughs, if government research facilities build the expensive testing and development "platforms" that are beyond the reach of individual companies, and makes them available for industry.

1. The research agenda must be set with **serious involvement by industry**.

This will ensure that more of the technology developed by government labs will eventually make its way into commercial products.

For instance, the U.S. Department of Energy ran a program called "Industries of the Future" (IOF). They collected experts from within an industry cluster (e.g. pulp and paper, or steel, or chemicals) and asked them to jointly describe problems they faced, but for which they did not have a solution, nor the technical resources (personnel, facilities, etc.) to come up with one. The DOE then shopped this list around to the national labs and DOE program managers to see who could make real progress against the problems. This design—with the agenda set by industries, and DOE searching for national assets to help solve their problems—produced significant gains in energy technology, as documented by a National Academy of Sciences study.[2]

2. Research should **directly involve industry scientists** where possible.

Collaboration results in superior sharing of ideas between government researchers and industry personnel, and helps ensure the government researchers understand which work is important to industry on a more detailed, technical level than can be achieved through goal-setting alone.

In 2009, Japan launched the Innovation Network Corporation, a $1.9 billion collaboration between the public and private sectors to achieve advances in energy, infrastructure, and other high technology sectors. The Japanese government invested more than 90 percent of the up-front capital to create the joint research center, and 27 private companies made up the final 10 percent investment. The program also includes about $2.5 billion of loan guarantees for the joint research center's investments.[3] This structure enables a smooth working relationship between government technicians and private sector players, which has already resulted in a strong pipeline of innovations in energy and other fields.

The U.S. government also has a tool for connecting private-sector industry and national labs: the Cooperative Research and Development Agreement.[4] Under these agreements, the lab

[2] National Academy of Sciences. *Materials Technologies for the Process Industries of the Future: Management Strategies and Research Opportunities.* Washington, DC: The National Academies Press, 2000.
[3] http://www.incj.co.jp/english/index.html
[4] For an excellent, brief description of CRADAs, see: http://tinyurl.com/7n7z6sl

brings equipment and scientific talent to the project that the industry partner could not afford or justify to its investors, while the industry partner adds product development expertise and deep experience in the relevant market. For example, Cummins Inc. and Oak Ridge National Laboratory (ORNL) have worked together under a series of these agreements to build better catalytic converters for heavy duty trucks. ORNL had great laboratory equipment and deep knowledge of catalytic reactions. Cummins had real-world experience with catalysts, knowledge of on-board diagnostics, and manufacturing talent. Together they built catalysts with far greater efficiency and durability, and lower costs, than existed before.[5]

3. There can be large economies of scale, and new breakthroughs, if **the government builds the expensive "platforms"** for testing and development that are beyond the reach of individual companies.

An individual company may not be able to justify the costs of, say, a combustion test facility. A government-run test facility has the potential to benefit the entire sector by providing many private companies with a capability that none of them would have possessed otherwise.

For example, India's Central Power Research Institute has housed R&D facilities for use by government, industry, and utilities alike over the past fifty years. The public-private research facilities have helped India make progress on high voltage transmission, power system resilience, and other electricity distribution components.[6]

Meanwhile, the U.S. National Renewable Energy Laboratory has built more than a dozen centralized testing facilities—such as the Energy Systems Integration Laboratory, which studies grid modernization. Similarly, the Plasma Materials Test Facility at Sandia National Laboratories permits researchers from private companies and universities to visit and use the facility, or to contract directly with Sandia to perform their testing. Under this program, the Plasma Materials Test Facility has performed research under 60 different agreements with private industry.[7]

There are very few companies that can afford this sort of test facility, so making the platform available to the private sector greatly accelerates private development efforts.

COMMERCIALIZATION

The last stage of developing an energy technology focuses on driving down cost and driving up performance. At this stage, the technology is not yet fully market competitive, but it shows promise to ultimately cross that threshold. The policy challenge is to create a demand signal

[5] http://www1.eere.energy.gov/vehiclesandfuels/pdfs/merit_review_2012/adv_combustion/ace032_partridge_2012_o.pdf
[6] http://www.cpri.in/about-us/about-cpri/history.html
[7] http://energy.sandia.gov/?page_id=1498

that spurs companies to invest seriously enough, over a sustained time period, to make the new technology market competitive without wasting money or establishing permanent subsidies.

A smart, strong, and consistent policy signal will reward companies that hit ever-more-aggressive price and performance goals.

Recommendations to achieve better commercialization:

1. Policy must provide a stable environment for long-term investment decisions.
2. Ensure market signals are large enough to influence the multi-billion dollar energy sector and drive adoption of gigawatt-scale technology.
3. Allow the market to find the price of any subsidy (*e.g.* via an auction), to ensure the government spends the minimum amount necessary to support any given energy technology.
4. Ensure tax credits are liquid and tradable, or replace them with cash grants, to avoid constraints on tax equity investment and save the government billions of dollars.

1. <u>Policies must provide a stable environment for investment.</u>

Energy generation and transmission facilities often have lifetimes of 40 years or more, so utilities will not be able to take account of clean energy incentives unless they have confidence that those incentives will exist several years down the road. In a recent set of detailed interviews with R&D directors of 16 large, innovation-driven companies[8], they stated repeatedly that a steady, serious, long-term demand signal was the best possible way to stimulate clean energy innovation. The signal is powerful at driving all stages of research. Energy legislation should make a constant and reliable demand signal a priority. Note that the *cost* of that demand signal will decline rapidly if it is well-designed (see recommendation 3, below).

For instance, in the United States, the Production Tax Credit (PTC) is aimed at supporting the commercialization and deployment of energy technologies that are approaching market competitiveness, but the PTC has been repeatedly allowed to expire and then been extended for short periods, severely limiting its effectiveness.

"… every time the PTC has been allowed to expire, renewable energy capacity growth has dwindled to a fraction of the growth that occurred when the tax credit was in place. For instance, when Congress let the program expire in 2000, 2002, and 2004, wind capacity installations in those three years fell 93 percent, 73 percent, and 77 percent, respectively, from the previous year."
Nate Gorence and Sasha Mackler,
http://bipartisanpolicy.org/sites/default/files/BPC_RE%20Issue%20Brief_3-22.pdf

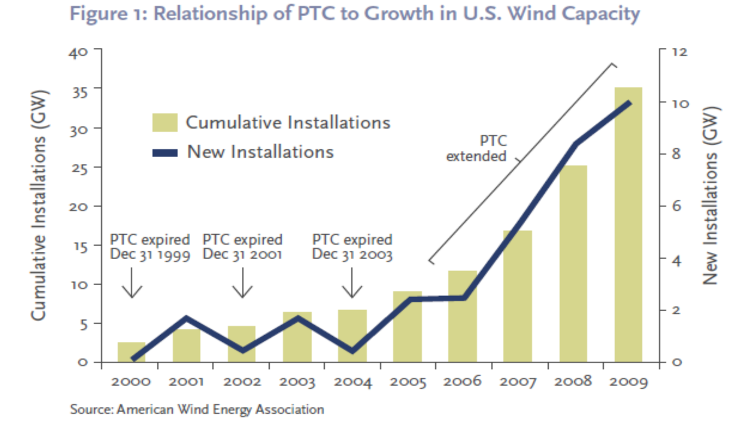


Figure 1: Relationship of PTC to Growth in U.S. Wind Capacity

2. Ensure market signals are large enough to influence the multi-billion dollar energy sector and drive adoption of gigawatt-scale technology.

The government cannot afford to purchase all the necessary technology we need. Rather, government spending must ultimately help drive down costs so the market can take over.

Some governments have used **feed-in tariffs** to stimulate new technologies. Germany has famously offered high payments for solar energy. It is easy to dismiss Germany's policy as having over-rewarded solar providers, but the policy succeeded in dramatically driving down the cost of solar power systems. The benefit the Germans bought was not just the electricity generated from their subsidy: it was the achievement of a dramatic, irreversible price reduction for solar energy. Getting serious about driving down the cost of energy technologies will have vast long-term rewards.

3. Allow the market to find the price of any subsidy.

If the government chooses a fixed price for a subsidy or tax credit, it will almost certainly be too high or too low. Even if a fixed subsidy is right today, it will be wrong in the future, when breakthroughs in energy technology have brought costs down.

The best way to set the price of a subsidy is through a method called a **reverse auction**. In a reverse auction, the government or a public utility commission offers a subsidy for clean energy and awards that subsidy to the lowest bidder. The funds are delivered when energy is provided. If a company can build a solar plant for 12 cents per kilowatt-hour and sell the electricity for 9 cents, it would bid for a 3-cent subsidy. They might lose the bid to someone with an 11-cent cost basis. The market will find the lowest required subsidy, saving the government money.

Since energy technology investments are long-term, the prices set at each auction must last long enough to incentivize the capital investment. For instance, each auction might set the subsidy price for a fixed quantity of electricity produced from that project for the next 10 years. This gives companies an incentive to drive down their costs. The government also benefits, as each subsequent auction costs the government less and less money, until full market competitiveness is achieved, and the subsidy is ended.

4. Lastly, tax credits and subsidies should be made as liquid and tradable as possible.

It can be difficult for energy project developers to secure investors with sufficient tax liability to take advantage of non-refundable tax credits, so it is far more cost-effective to make them fungible than illiquid. A study by the Bipartisan Policy Center and Bloomberg New Energy Finance found that instead of giving out $10.3 billion in clean energy tax credits, the same results could have been achieved through $5 billion in cash grants issued at the time of each project's commissioning.[9] By using cash grants rather than tax credits, or making the tax credits refundable, the government can save billions of dollars while achieving the same level of energy technology deployment.

Conclusion

For a modest cost, using best policy practices outlined in this paper, national governments can accelerate their countries' transitions to clean energy. There is no dispute that a broad set of new energy technology options will help achieve security, economic, and environmental goals.

[9] http://bipartisanpolicy.org/library/staff-paper/reassessing-renewable-energy-subsidies-issue-brief