From ERG to the Smart Grid: One Illini’s Journey*  
By: Peter Fox-Penner  
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I’m grateful to Martin O’Donnell and Professor William H. Sanders for giving me this chance to talk with you today.

As a proud dual graduate of UI Engineering – albeit one who’s never held a real engineering job – I look back on my time here as an extraordinary chance to learn, grow, contribute, and just plain have some fun. In the realm of fun, I’ll never forget the time we accidentally found a key to the old observatory at the south end of the Quad. When we got in, not only did we find a working telescope, but one night we learned – by randomly pushing buttons on the control panel – that one could black out the square block surrounding the building with one of those buttons. Watching the rings of Saturn from the edge of the quad in the wee hours of a Saturday morning – that was unforgettable and a lot of fun.

Beyond these fond and possibly incriminating memories, this place has given me a wonderful career, a chance to serve my country and community, and many lifelong friends and colleagues. I received an unbelievably good, well-rounded education inside and outside the classroom. One of three children of modest, middle-class parents, I graduated in 1978 with two degrees earned without any use of financial aid or debt.

So what am I doing back here after decades in Boston and Washington? I can assure you it’s not for the frequent flyer miles, or to further enlarge my carbon footprint. I’m here because I want to recognize this institution. At a time when our educational system is becoming increasingly

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As prepared for delivery. Thanks to Bruce Hannon, Clark Bullard, Bob Herendeen, John Abelson, Cliff Singer, Peter Evans, Heidi Bishop, Marianne Gray, Mark Rubel, Ahmad Faruqui, and Judy Chang. All views expressed in this paper are solely those of the author and do not represent the views of Brattle or its clients. In the interests of brevity, I have omitted any early involvement in the anti-nuclear movement and the Prairie Alliance, but in no sense is this intended as disclaiming or disowning them. Photo credits appear at the end.
unequal and unaffordable, people like me need to come back and speak up for the principle of accessible, high quality education for all.

From my vantage point as an economist, I know that investments in what we drily refer to as “human capital” are essential for economic and social progress. They repay all of society directly and indirectly. From my vantage point as a Washingtonian, I see far too many deep cuts in funding for education and other critical supports for a broadly-shared prosperity. I’m proud to see that my home state has managed to keep its universities in relatively good shape. I understand from Martin that state aid covers only 14% of the University’s budget now and is likely to diminish. Tuition, which was $800/year in my day, is now $16,000 – barely within reach for many families. Whatever the sad state of our public finances, keeping college accessible and affordable must remain a national priority.

This year marks the fortieth anniversary of my start in energy research here at the U of I. You’d think by now it might be getting boring or repetitive, like watching every new remake of the Star Trek movies. Quite the contrary. I have never seen a time when the technological and policy developments in energy have been more exciting or more essential for our health and prosperity. We’re at the start of the fourth great epoch in human energy use, and the changes it brings in every dimension of energy research and energy use will be momentous.

But let’s start at the beginning, back in the 1970s. There were no websites, no cell phones, no DVD – not even VCRs. Believe it or not, telephones were all wired and looked like this:

*Figure 1: Telephone circa 1976*
Politically, this was the Watergate era.

The Vietnam War was finally winding down and, in my sophomore year, President Nixon resigned rather than face impeachment over the Watergate break-ins. Illinois college students looked like this.

Figure 2: College of Agriculture, graduate photos, 1976 Illinois Yearbook
And I looked like this -- One of two so-called “long-hairs” in the entire college of engineering.

Figure 3: The author, circa 1976, in Evanston, IL

I came from a family of social workers, journalists, and lawyers, so you’d think I would have majored in pre-law or poly-sci. But one of the few tidbits of wisdom I possessed was that the world was going to have more than enough good lawyers, and besides, I was deeply fascinated with the role of technology in modern society. So I chose engineering.

Although energy was destined to be my life’s work, my first love was audio technology and recording. New multi-track recording studios were, for the first time, giving artists the ability to play along with themselves, many times over. This was profoundly changing the process of creating pop music. The recording studio itself became a musical instrument, much like the laptop became one in the age of sampling and Garage Band.
Audio was also just starting to go digital, replacing the ubiquitous, cheap, and lousy-sounding analog integrated circuits -- but ever the contrarian, I loved the sound of vacuum tubes, and I still do.

So when I wasn’t studying I helped found one of the very few tube-centric recording studios in the world. It’s now called Pogo Records and is still operating, soon in Nashville, run by my lifelong friend Mark Rubel. Perhaps you know Mark better as the bassist in Champaign’s classic rock band, Captain Rat and the Blind Rivets, but he’s also a world-class recording engineer and a teacher at the largest studio in Nashville.

Figure 4: Pogo Records Recording Study in 2013
(www.pogostudio.net)

The studio was fun and rewarding, but what really shaped me and launched me on my career was an assistantship in what was then a brand new field known as energy policy research.

Now, in the year 1973 there was no such thing as the field of energy policy research. There were majors in power electronics, mining engineering, materials science, automotive engineering and all sorts of related fields -- but that’s my point. Energy was something engineers drilled or dug out and turned into power or fuel. The devices that used energy, like cars, were engineered as if their fuel was nearly free. And no one gave it a second thought.
But we now know the U.S., in particular, had become dangerously dependent on fast-growing, unsustainable and unstable energy supplies. By the seventies we were importing 40% of our oil, mostly from the Middle East.¹ In 1973, the Arab members of OPEC responded to American and Israeli actions by embargoing oil shipments to the U.S. for about six months.

The results were devastating.

Oil prices quadrupled, gasoline shortages were common, and many businesses folded. The stock market crashed and about half a million people lost their jobs -- the worst economic shock to the American economy since World War II.

Figure 5: Gasoline Shortages During the 1973 Arab Oil Embargo

And then there was the issue of electric power. Outside of this shock period, U.S. electricity demand was growing even faster than our oil imports, doubling about every ten years and leading the industry to propose ever-larger coal and nuclear plants. The oil shock triggered a proposal by President Nixon to build 1000 new nuclear power plants, the first of many Presidential calls for “energy independence.”

Here’s the first blueprint for his program:

**Figure 6: Project Independence Report**

In Response to the 1973 embargo, one forerunner agency to the Department of Energy tried to create a project to reduce U.S. oil imports. Despite the fact that world energy and non-energy markets will always be interdependent, every President since Richard Nixon has used the words “energy independence.” Today the U.S. is substantially less dependent on foreign fuels than it has been as a result of greater efficiency, new technologies, shifts away from oil, and other factors. Although much of this cannot be attributed directly to policies the overall progress on this longstanding national goal is underappreciated by many Americans.

This boom in super-large plants was soon thrown into question – and ultimately, defeated – by the 1979 reactor accident at the Three Mile Island, nuclear cost overruns, and other more gradual changes in generation scale economies and power demand. Meanwhile, the question of electric power supply choices was no longer taken for granted.

Both of these events jolted America into an awareness of something called energy policy. For the first time ever, we needed to understand our energy sources and uses as a system and as a realm of economic and environmental policymaking. To do this, we needed what amounted to a whole
new academic discipline, straddling the borders of engineering, economics, and the political and physical sciences.

The first energy policymakers were recruited from the business community or other government agencies. They quickly realized that they had no idea how much energy was needed to perform even the most basic tasks, giving them no basis for making tradeoffs or setting priorities. As an example, which used more energy to move one person one mile – a car, a train, or a Greyhound bus? Not just the energy burned in the fuel tank, but the total energy throughout the economy needed to make the steel, the roads or rails and otherwise support each of these options? Amazingly, no one knew.

Across the whole U.S., the U of I was one of only three universities that stepped up first to start research on questions like these. Four faculty members from four very different disciplines formed the Energy Research Group, or ERG as it quickly became known. The four were Chemical Engineering Professor Bruce Hannon, Aero Engineering Professor Clark Bullard, Economist Mike Reiber, and Physicist Bob Herendeen. Here's a photo I took of the group in 1973 in front of the Center for Advanced Computation, which is still there.
Figure 7: The University of Illinois Energy Research Group, circa 1974.

In the front row, (left to right): Clark Bullard, Robert Herendeen, Bruce Hannon. In the second row behind Herendeen: Nadine Abbot and Ricka Shorish. Top row: Jerry Tanaka (far left), Kelvin Shiu (second from left), Craig Z. Foster (third from left).

While I’m showing you this building, let me throw in this footnote. The building you see housed the University’s only node in what was then known as ARPA-net, the precursor to the internet. ERG was housed in this building, and occasionally used the ARPA-net, because we were one of the most computation-intensive social science groups on campus. We used to have to invert a 360 x 360 matrix to do our calculations, an operation that now takes a fraction of a second – but took an overnight run in those days.

ERG went on to have an enormous impact on national energy policy and research, producing over 300 refereed papers, 12 of them in Science. Here’s one of them I was lucky enough to co-author – one of the earliest studies of the net energy produced by corn ethanol.
Figure 8: Three of The More Than 300 Papers Produced By ERG.


We gained quite a lot of attention, too -- here’s a rather young Professor Hannon pictured in Newsweek magazine discussing ERG’s findings that returnable bottles used only half the energy of recycled glass – far less than was expected in those days. Bruce also won the first Mitchell prize, an essay contest sponsored by the man who is now universally known as the father of hydraulic fracturing.
Figure 9: Professor Bruce Hannon in *Newsweek*, November 1972

**ENERGY:**
**Counting the Cost**

The cornucopia of American industry has been built on a seemingly inexhaustible supply of cheap energy—or such was the illusion. In recent years, a startled nation has begun to realize the hidden cost of energy in the form of pollution, depletion and the despoliation of vast stretches of land. And as the ecological campaigns coincide with growing shortages of some forms of fossil fuels, one fact seems clear: in the future, energy of all kinds will be a lot more costly in dollar terms as well.

Just what this will mean for the economy is far from clear, but a few scientists and academicians are exploring the problem by counting the costs of familiar products not in dollars, but British thermal units or BTUs: the amount of energy needed to heat 1 pound of water by 1 degree Fahrenheit. Among the conclusions: human labor may wind up being "cheaper" than many materials, and other materials such as wood and steel may be more desirable than such energy-demanding materials as aluminum. In short, as with much environmental accounting in BTUs, economic and social tables often calls for a return to the old way of doing things.

**Recycling:** As ecological crusaders have argued, this is particularly true in the beer and soft-drink industry. Bruce Hannon of the Center for Advanced Computation at the University of Illinois estimated at a recent symposium of the American Association for the Advancement of Science that the industry could cut its energy use in half by going back to selling its wares in returnable bottles. Attempts to recycle throwway bottles and cans, he said, would be worse than useless, since recycling actually costs more energy than it saves.

To be sure, soft-drink and beer containers account for only 0.34 per cent of the nation's annual energy production. But enormous savings are possible in the construction industry, which consumes about 7.5 per cent of the total electricity supply in 1970. According to New York architect Richard G. Stein, fully 70 per cent of the material in new buildings could be safely eliminated by using more man-hours in painstaking construction methods and waiving unnecessary clauses in building codes. In the cement industry alone, this would mean a saving of 50 billion kilowatt-hours each year.

Fortunately for cement producers and electric utilities, among others, nobody expects a transition to BTU accounting methods to take place overnight. But in the long pull, a greater recognition of energy costs seems inevitable—and it may bring with it esthetic and spiritual benefits as well. Stein, for one, predicts "a renewed enjoyment of the tact, the tense, the spare." It is the difference between an electric carving knife and a Shaker rocking chair.
ERG frequently advised the brand new crop of federal and state energy agencies on brand new questions. Here’s a guide to doing energy cost studies Professor Bullard lead for the Energy Research and Development Administration, the precursor agency to DOE.

Figure 10: The Energy Research and Development Administration

The Energy Research and Development Administration was another precursor agency to U.S. Department of Energy. The handbook laid part of the foundation for the “carbon footprint” concept used today.

When President Carter formed the U.S. Department of Energy in 1977, Clark became one of its first senior appointees.

The final and perhaps most important point I want to make about ERG is that Professors Hannon and Bullard went on to spend the rest of their careers here at the University, producing more great research and many more generations of scholars and practitioners in the field. They have since been joined by so many other energy-related faculty here, that I can’t name them all. But thanks to the efforts of Professors John Abelson and Cliff Singer, the college’s energy-related courses are now found in a new concentration here called Energy and Sustainability Engineering.
By the time I left Urbana with my master’s degree, I was a permanent convert to energy policy. In the years since, I’ve had the honor of working for the State of Illinois, the Department of Energy, The White House, dozens of energy company clients, and for almost 20 years at The Brattle Group.

Among many memories, I’ll never forget the time I watched Vice President Gore give one of the first versions of his climate slideshow at the White House, or the California power crisis of 2000 and the subsequent demise of Enron, which I have been investigating for over a decade now. I was also inside the White House during the 1994 shutdown of the federal government, which was in large part a standoff over energy appropriations.

But I hope it doesn’t sound like I am wistful for the good old days, or feeling like the exciting and pioneering challenges are all behind us. We are facing energy policy challenges today that are as large, important, and fascinating as you can possibly imagine. And to demonstrate this, let me conclude by showing you a little of what my colleagues at The Brattle Group and I are doing in our research today.

Right now the world’s electricity systems are adding solar and wind energy at a rapid pace. U.S. photovoltaic installations rose by almost one gigawatt last year and in some parts of Europe they are getting as much as 40% of their instantaneous power from renewables. We have seen wind or solar installation rise by as much as 1,000% in a year in some markets.

We’re building new analytic tools that join power grid simulation models like Powerworld – developed here at the U I – with economic and financial models. These systems allow us to look at how the cost of integrating higher levels of renewables can be minimized and allocated. This is a slide showing how one of our renewables integration models works. The goal of the model is to find the lowest-cost combination of resources the California power grid must add to
accommodate the 33% variable renewable resources mandated under state law. The model determines the amount of “regulation” – power generators whose output can be increased or decreased within a few seconds – necessary to match immediate demand with supply.

**Figure 10: Brattle’s Renewable Integration Modeling**

To find the lowest-cost forward path, the model combines engineering calculations based on reliability limits with cost-minimization logic from microeconomics.

Judy Chang, one of my Brattle colleagues, used this model to show that adding 50,000 megawatts of wind in the Western U.S. would require a surprisingly modest 1,300 MW of additional regulation, demonstrating – among other things – the value of geographic diversity in managing large wind resources.

Another area we are studying intensively is the link between electricity pricing, system control, and energy conservation. With the advent of the smart grid, we have the technical ability to charge electric customers different prices each hour of the day, tracking the true costs of electricity production. But which pricing schemes save the most energy?
Figure 11: Peak Demand Savings in Electricity Pricing Experiments

This chart shows the reduction in peak demand in electricity pricing experiments plotted against the ratio of prices charged during peak and off-peak times of the day. The two lines on the chart show the best-fit line for two kinds of experiments. The lower black line shows experiments where customers are charged peak and off-peak prices that vary between a ratio of one, on the left to more than 20 to 1 on the right. Customers save more on average as the ratio grows until about ten to one; above that level there isn’t much more payoff.

The upper blue line shows the same relation between peak load reductions and price ratios, but now customers have been given thermostats and other appliances that can be programmed to shift their times of use. As you can see, you nearly double your peak reductions when these so-called “enabling technologies” are made a part of the market. Now you know one reason why utilities such as National Grid will give you a rebate if you have a programmable thermostat – it saves them quite a lot of peak energy. This also suggests that demand response may be useful for
balancing variable renewables, and there is great work going on in this area, led at Brattle by Ahmad Faruqui and others.

We’re also just starting to research a fascinating new area, energy systems resilience. Due to the onset of climate change and our increasingly urbanized coastlines, the damage from severe weather events is increasing dramatically. Large storms caused more than $300 billion of damage in 2011, more than triple the thirty year average. You can see the 30-trend easily on this slide from Munich Re.

**Figure 12: World-Wide Natural Disaster Trends by Type of Event**


Superstorm Sandy created gas and power outages that were totally unprecedented – 8.5 million customers without power from a single storm, many for a period of several days. This worrying trend is prompting us to look at the vulnerability of energy systems and what can be done to make them more resilient. Working for Public Service Electric and Gas (of New Jersey), we recently did the first study that placed a customer value on resilience investments.
This next slide shows work by the World Bank ranking the riskiness of power grids as a result of climate change around the world by quartiles, plotted against the size of the grid, indicated by the size of the circles for each country. Note that the U.S. is only in the second quartile of vulnerability, while China and much of Asia – where urbanization and energy growth are both very high – are all in higher risk tiers.

**Figure 13: World Bank Assessment of Power Systems Climate Risk**

![World Bank Assessment of Power Systems Climate Risk](image)


The final Brattle research I want to mention is my work on new business models for the utility industry. As you can see from this next slide, electricity sales growth has dropped since the 1970’s to near zero today, and carbon policies are likely to bring it even closer to zero.

**Figure 14**
U.S. Electricity Sales Growth

(3 year rolling average)

At the same time, the price of distributed generation, especially photovoltaic solar power, has dropped 75% in the last 8 years and is gradually driving net central grid sales growth rates below zero. As an example, California now estimates that the average new home in 2020 will require ZERO net new power over its lifetime!

So what do you do about an industry whose entire business model revolves around selling more and more kilowatt-hours to pay for the trillions of dollars it will cost to fund the essential common good we call the grid? I think the answer is two or three new business models for the industry. In my book, Smart Power, I call them the Smart Integrator, the Energy Service Utility, and community or cooperative power, including community microgrids.
Establishing these new business models is an especially complicated mixture of Wall Street finance, state regulatory change, and organizational redesign, but I think we are starting to make progress.

I am told that many of the speakers in this lecture series use these talks as recruiting tools. If you are thinking about a career in consulting with a strong emphasis on economic skills, I want to say from the heart that you won’t find a better place than The Brattle Group. We are a self-owned, self-governed firm with tremendously smart people and a good culture. Our work is fascinating and rewarding, mentally and monetarily.

But whether or not you choose us, or choose even consulting at all, I am recruiting you. As we sit here today, we have largely lost the race to prevent a two degree average change to our climate system and we’re scrambling to keep the damage to three or four degrees C. This is going to wreak havoc on our society in the form of severe storms, droughts, and loss of biodiversity, all of which will tend to more greatly harm the people in emerging economics.
Meanwhile, during our lifetime five billion people will be increasing their energy and calorie use. This includes 1.3 billion people who have no electricity today and another 1.2 billion with minimal access. For these people, many of whom still get their energy from wood, coal, kerosene, or diesel fuel, clean power is a touchstone for their escape from poverty.

Whatever your field of engineering, for the rest of your career you will share in the nearly inconceivable challenge of providing energy to the world in an era of deep and pervasive constraints. This challenge is made all the more difficult by the reality that energy use and endowments are deeply unequal, and that the total supply of energy – including sustainable food energy, and water – must be expanded to reach the billions of people with little or no access to these supplies. All this must be done using occasionally weak or outmoded institutions and with ever growing physical and cyber threats to all our networks and grids. This is a challenge so deeply embedded in our technical, economic, and social systems that it nearly defies the imagination.

But this should spark your imagination and ambition, not defy it. It is going to take one heck of a crowdsourcing effort to ease us onto the right path, and we need all of you in the crowd. It may not be quite the same as firing up an old tube amplifier, or creating the coolest app in all of Silicon Valley, and it is bound to be deeply disheartening at times. If my experience is any guide, though, it will be interesting and rewarding and sometimes even fun. And if along the way you find another key to the old Observatory, do give me a call.

Thank you very much for your kind attention, and the very best of luck with your education and your career.
References and Additional Readings

Recent Brattle Work


“Governing Global Shocks,” by Peter Evans, Presented at the International Law University of Georgia, School of Law, February 3, 2012.


“Partnering Natural Gas and Renewables in ERCOT,” *Prepared for the Texas Clean Energy Coalition; sponsored by the Cynthia and George Mitchell Foundation*, By Dr. Jurgen Weiss, Heidi Bishop, Dr. Peter Fox-Penner and Dr. Ira Shavel, The Brattle Group, June 11, 2013.

“Review of PJM’s Market Power Mitigation Practices in Comparison to Other Organized Electricity Markets” by James D. Reitzes, Johannes P. Pfeifenberger, Peter S. Fox-Penner,
Gregory N. Basheda, José Antonio García, Samuel A. Newell, and Adam C. Schumacher, prepared for PJM Interconnection by The Brattle Group, September 2007.


**Historical and Retrospectives on Energy Policy**


For University of Illinois resources, please see [www.ease.illinois.edu](http://www.ease.illinois.edu) and [www.cleanenergy.illinois.edu](http://www.cleanenergy.illinois.edu). The complete works of the University of Illinois Energy Research Group are in the University of Illinois archives.

**Picture Sources:**

Figure 1 – “ATTtelephone-large.jpg,” contributed to Wikimedia Commons by Shizhao, August 23, 2005.

Figure 2 - Illio76, Volume 83 (University of Illinois Magazine Format Yearbook).

Figure 3 - Peter Fox-Penner, private photos.

Figure 4 – Mark B. Rubel, Pogo Studios.
Figure 5 – Library of Congress Prints and Photographs Division, U.S. News & World Report Magazine Photograph Collection, Warren K. Leffler.

Figure 6 - “Project Independence Report,” The Federal Energy Administration, November 1974.

Figure 7 - Peter Fox-Penner, personal photos.

Figure 8 – Energy Research Group, University of Illinois.

Figure 9 - “Energy: Counting the Cost,” Newsweek, February 21, 1972, p. 92.

Figure 10 - “Energy Analysis: Handbook for Combining Process and Input-Output Analysis,” by Clark Bullard, Peter S. Penner, and David A. Pilati, October 1978.

Figure 15 - “Smart Power” Climate Change, The Smart Grid, and The Future of Electric Utilities,” Island Press, 2010.