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before the Assembly Select Committee on California's Clean Energy Economy

Thursday, August, 4, 2011

Thank you Assemblyman Bob Wieckowski and Assemblywoman Nancy Skinner, for the opportunity to testify in front of your committee and to offer my insights and recommendations related to the economic benefits associated with CA's energy efficiency and clean energy policies. There is no doubt that the State provides unique leadership in creating policies that incentivize energy efficiency practices and promote, rather than impede, innovation in energy efficient technologies, as well as their adoption. In my view, creating that virtuous cycle of innovation spurring adoption and change that leads to innovation… is the key. I will also recommend some next steps I believe that the legislature and regulatory entities can take to further achieve the goals of growing the economy and reducing our impact on the environment.

Regarding my background, I have served on the faculty of the University of California, Berkeley as Professor of Computer Science since 1989, and am now Chair of the Computer Science Division. I am a member of the National Academy of Engineering and serve on several University and corporate advisory boards. My career traverses the boundary of Academia and Industry; in 2000 I took leave and served as founding Director of Intel Research, Berkeley to develop an Open Collaborative Research program in which industry and university researchers collaboratively engage in use-inspired fundamental research - like an expedition, exploring out beyond the corporate roadmaps. In 2005, I co-founded Arch Rock Corporation—a systems and software company that developed wireless sensor

network technology from its open academic roots to truly the next tier of the Internet. I served as Chairman and Chief Technology Officer until the company was acquired by CISCO Systems, Inc., and I continue to co-chair a working group of the body that standardizes the Internet, the Internet Engineering Task Force, to bring this technology to urban, building, and industry efficiency applications. I was recently appointed the faculty director of i4Energy, at the intersection of energy and information technology, and a joint effort among UC Berkeley, the Lawrence Berkeley National Lab, and the California Institute of Energy and the Environment.

I am particularly proud of my department's tradition of creating technologies that generate whole new industries, not just new companies, including electronic computer aided design, computer workstations, scalable data storage, Internet communication, and global scale Internet services. While serving as Principal Investigator on several Federal, State and Industry funding projects, my own work, has contributed to this tradition with the design of massively scalable computing platforms, or clusters, which underlie the planetary scale internet services, like Google and Yahoo, that you see today and embedded wireless sensor networks, which underlie many of the emerging energy efficiency developments, such as smart buildings, smart grids, and smart industrial processes, which will bring similarly significant advances in how we lead our lives in the future.

I would like to share with you some of the current energy efficiency R&D projects taking place at UC Berkeley, their promise for advancing to market, and their potential positive impact on the State's economy, both in terms of energy savings and creating markets for new technologies. An in doing so, I hope to illustrate some of the ways that CA energy efficiency and clean energy policy is spurring innovation and economic opportunity. For those of you who are not aware, and for general context, from 1965 to 2000, University research in Information Technology alone in this country led to 19 distinct billion dollar markets, according the a National Research Council study, in areas such as the internet, portable communication, and broadband. We are all looking forward to the next study showing the

even greater rate of innovation in this young century. In short, investment in R&D at research institutions pays off. And there is no reason why it won't continue to do so, if we stay on track and continue those investments.

However, many of these success stories reflect what I call 'acute challenges' where a discrete effort creates a new level of performance, a certain physical size, or a new capability that enables entirely new forms of use – the personal computer, the web, search, the smart phone. Energy efficiency and clean energy reflect 'chronic challenges' which are present throughout our lives, activities, and organizations and largely in the background. Well-considered policy plays an essential role in bringing them into focus, so the cycle of innovation can kick in.

Currently, at UC Berkeley, we are undertaking dozens of projects related to various aspects of energy efficiency and clean energy —including new meters, monitoring networks and control algorithms that allow buildings to be not only more energy efficient, but a better citizen of the grid, energy efficient data centers, new materials and devices for monitoring, optical thermal coatings, high performance concrete, and more. There are a number of areas with near-term commercial potential including personalized lighting and environmental control technology, printable batteries that allow electrical storage to be manufactured in to everyday devices and components, miniature energy harvesters that allow intelligence to be embedded in duct, pipes, windows and machines for the long term, and monitoring, communication and control technology that is so inexpensive that it could literally be built-in to any appliance. Others focus on long-term transformation, such as the protocols for a stable, reliable cooperative grid where intelligent loads help to increase the utility and penetration of variable, intermittent renewable resources.

To aid in advancing these technologies to market, we have developed a variety of energy research testbeds, for example turning our campus into a kind of living laboratory for the study of sustainable

energy networks. In addition, we tout a broad spectrum of relevant energy research centers -- beyond the College of Engineering—including the Green Building Research Center, the Center for the Built Environment, the Lester Center for Entrepreneurship and Innovation, the Laboratory for Manufacturing and Sustainability, Clean-tech to Market, the Center for Law, Energy, & the Environment, and the Center for Environmental Public Policy, among others.

UC Energy research has already played an important role influencing private industry in CA, offering novel ideas and guiding the development of new technologies in energy efficiency. CA companies, which have benefited from UC research in recent years, besides Arch Rock, include Adura Technologies which does wireless lighting control, Federspiel controls whose business is intelligent energy management, Dust Networks, which produces wireless sensor networks, and Eco Factor which sells adaptive comfort controls for optimized EE&DR. We also train new energy professionals and thought leaders who go on to work in companies leading the way in new these products and processes.

But, for the purposes of this hearing, I want to share with you a bit about the exciting emerging energy efficient technologies "in the wings" which will be ready for market in both the near and long term—and certainly within the next 3-5 years. There is a great deal of "Energy Systems Engineering" taking place at Berkeley's College of Engineering that provides "energy efficiency and productivity." Focus areas in this field include:

- Renewable power integration
- Improved combustion and conversion
- Distributed energy storage systems
- Distributed power generation including solar-thermal and building energy systems
- Advanced instrumentation, modeling, and model-predictive control
- Energy information networks and human-centered energy management … to name a few.

These technologies will all contribute to addressing energy consumption in buildings and the ability to shift toward clean energy. As you may be aware, building energy consumption in the US is enormous. Buildings consume 72% of total US electricity, 40% of total US energy—21% residential and 18% commercial. Let me offer a couple illustrative examples of the virtuous cycle of innovation. In connection with a CEC sponsored building-to-grid testbed developed to investigate how buildings can cooperate with the grid in a kind of continuous demand response, we deployed several thousand sensor channels of many types in a WWII era, highly retrofitted building that houses the Electrical Engineering division, including what for the past 30 years was the most advanced academic clean room. To make access to all this physical information seamless and easy, the i4Energy team developed the information technology to turn this all into a kind of *real-world web*. A post-doctoral researcher used this information infrastructure to deploy advanced machine-learning based control algorithms on a standard single-stage heat pump cooling a live instructional laboratory and reduced the energy consumption by 30 to 70%. Imagine if we can routinely get these kinds of savings by updating the software latent in buildings.

By connecting this rich information processing infrastructure to traditional building automation and control networks (BACNet), we have gained visibility and control, in a secure manner, into the internal operation of building systems using capabilities that are largely already in place. This may well lead to a building-CAD ecosystem as rich as electronic-CAD, but it also creates a platform for 'building Apps'. Again, as a simple example, upon observing the frustration of students in a large open office environment with the state-of-the-art commercial lighting control used to promote energy efficiency, a graduate student on the project 'built an app for that'. With simple personalized lighting control on their smartphones and laptops, they cut their lighting energy usage by nearly two-thirds.

These are the innovation cycles that present great opportunity for creating markets for new technologies which will not only result in real energy savings, but at the same time, will generate new businesses and industries.

Therefore—you ask, what can you--California's lawmakers-- and regulators do to help spur this growth further and faster? As you know, CA has a proud history of leading the country in adopting energy efficient policies ,which accounted for billions of dollars of energy savings from the enactment of a policy on Decoupling for Investor Owned Utilities, and setting appliance standards, between 1978 and 1980 –this outcome is known as the "Rosenfeld Effect" after former CEC Commissioner Art Rosenfeld. What was proven effective then, can certainly be replicated in this decade. ***A*** National Academy of Sciences report estimates the economic benefits of EE R&D, from LBNL technologies through 2001, to be between $23 and $30 billion in savings, from advances in areas such as Advanced Window Coatings, Electronic Fluorescent Ballasts, and Appliance Efficiency Standards.

In my view, a key element of this success story is the use of performance-based standards, not just design standards; and the pervasive availability of intelligent monitoring makes this imminently practical going forward. For example, appliance standards limiting standby power, which were pioneered in California, fundamentally changed design practice. A typical Energy Star printer uses a tiny fraction of peak power when idle, whereas typical desktop computer or server might consume 50-80% of peak in a similar state. "Doing Nothing Well" is a hallmark of energy systems engineering, which good policy has inspired. Unfortunately, when observed as a whole-system, rather individual components in isolation, our buildings, data centers, and industrial processes that may perform well under peak demand, are very wasteful under typical use. They do nothing very poorly. More generally, policy should encourage power proportional design, where the rate of energy consumption tracks actual productivity.

Going forward, as well described in the recent California Council on Science and Technology report "California's Energy Future – The View to 2050", the combination of AB32, Executive Order S-3-05 and the Renewable Portfolio Standards define a "moonshot" for sustainable energy. The body of technical challenges represented by this goal, especially energy efficiency and Zero Emissions Load Balancing, which deals with the variability of renewable supplies without resorting to fossil fuel based generation to fill the holes, is precisely the kind of driver that creates the virtuous cycles of innovation that lead to profound advance, economic productivity and industrial leadership. In a world where two billion people are interconnected through the Internet and cell phone users outnumber toothbrush users, we cannot let the silos and stovepipes of the industrial revolution stand in the way of achieving the kind of integrated, information rich, energy network that is needed for future generations to be able to live as we would live.

My recommendations are, therefore, to encourage you to continue to: 1) set building standards, and other standards, that will promote innovation, incentivize businesses and influence the marketplace and; 2) to utilize the purchasing power of the State of CA via procurements , by buying new EE products and processes for State-owned and operated facilities; 3) to adopt an overarching strategic plan for how CA will incentivize the creation of EE technology and adoption of EE behavior; and 4) to continue to make strategic investments in R&D , with programs such as the Public Interest Energy Research Program, which has funding hundreds of projects at research institutions in CA, leading to the growth of new businesses and industries. And, finally, I'd be remiss if I didn't mention a word about the future of our public higher education system in CA and the UC in particular….. Investment in the State's research universities is critical if CA hopes to grow out of the current recession—indeed it is the only option for growing out of this recession. I am hopeful that CA, its lawmakers and voters alike, will prioritize funding for what will inevitably GROW our economy. UC has been a driver of CA's economy

throughout its history, and we can continue that in the green energy era! Thank you for inviting me, and for this honor to come before you today.