Balancing Efficient Use With Sustainable Generation

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Summary
We need to develop a wide range of new technology to support a more sustainable future. In the United States, this means developing a system-wide optimization for the infrastructure, understanding the connections between water, energy, food, and other built systems. In the developing world, it means pushing the most efficient clean energy-generation technology as soon as possible, to defer/avoid the deployment of fossil energy. In all cases, California can lead the world in development and implementation if we are willing to invest in the long term.

Current realities
Climate change mitigation policy is piecemeal throughout the U.S. and around the world. California is among the most aggressive areas in pursuing a clean energy and carbon mitigation agenda, and is starting to address an antiquated and unsustainable system for water distribution in the face of the current severe drought.

The state's current and proposed energy and water strategies rely heavily on efficiency: measures to reduce per capita consumption, in addition to developing new, sustainable (often local) generation of these resources. This has been a part of the leadership approach that California has taken since the 1970s. Often called the "Rosenfeld effect" (thanks to pioneering Energy Commissioner and scientist Art Rosenfeld from University of California Berkeley), California's per capita electricity use has been essentially flat (roughly 7,000 KHW/yr/person) since the early 1970s, while energy use nationwide has nearly doubled over that same time. Based on data from the early 2000s, increased electricity consumption is strongly linked with increased economic prosperity and increased quality of life, but there are diminishing returns above roughly 4,000 KHW/year/person. Although the correlations are weaker, a similar general trend is seen in water use. Based on these data, policies that focus primarily on efficiency are not healthy for many parts of the developing world. In fact, drastic increases in per capita energy and water use are likely needed to improve health and lifestyle for the approximately 9 billion to 12 billion people expected on the planet between 2050 and 2100. In the U.S. and Europe, however, we can focus on reducing consumption (or keeping it flat), while replacing existing fossil fuel power plants with renewable energy in a way that minimizes disruption. It is also worth noting that increases in efficiency driven by technological innovation tend to lead to HIGHER consumption rather than lower, but that efficiency driven by increased costs leads to LOWER consumption. This has been observed in several sectors in the past (the "Jevon's Paradox").

Scientific opportunities and challenges
The underlying desire is to reduce carbon emissions from energy sources, and reduce reliance on unsustainable generation of energy (i.e., electricity) or water. The science and technology opportunities can be split into two main areas: (i) technology to enhance the distribution/supply infrastructure, and (ii) technologies for generation, storage, and end use.

For California, as well as the rest of the U.S. and developed countries, the largest challenge currently is the distribution/supply infrastructure. Our existing infrastructure was not developed to allow renewable energy or other new energy technologies to be incorporated. There is a need to build a new system-wide control and optimization scheme that allows as much "plug and play" adoption of new technologies as possible without destabilizing the system or the electricity market.
Developing countries will need a distribution system. They can adopt newer systems more easily than in the U.S. and developed countries, but need as much energy as possible to improve

quality of life. These areas can also directly adopt the newer and more energy efficient technologies (such as LEDs instead of incandescent bulbs), and build systems from scratch that can incorporate these technologies.

In California, the biggest challenge/opportunity is to reach a holistic, system wide view of the electricity/fuel/transportation/water/food infrastructure. Again, this infrastructure is very developed, and so currently consists of trillions of dollars in long-term capital investments. Fundamental and applied research in multiscale optimization (from individual devices to coordination across the entire region/state) is required. Although we have a goal to get to 50% renewables by 2030, the biggest barrier to achieving that goal is not developing a better/cheaper solar panel; it is figuring out how to incorporate those panels into the grid in a way that doesn't destabilize the system. Furthermore, the drive to reduce CO_2 emissions from vehicles by developing electric vehicles (EVs) will significantly INCREASE electricity use. Demand response, in which customers choose to delay or defer certain energy use because of an emergent issue (or in the future, because of a price or market signal), has the potential to smooth variation and help match supply and demand, but also to destabilize the grid as a whole if pricing and control schemes are not developed and implemented carefully. Utilities and third-party service providers need to measure carefully, share data appropriately, and use that data to build the best models and the best optimization algorithms possible. We also need to develop new power electronics technologies to support this new system. As more forms of energy storage become cost effective, they can also serve to stabilize the system for renewables, but must be approached in the same way: as a part of the larger system optimization challenge.

Regardless of global location, eventually more efficient solar and wind clean energy technologies will become the major barriers to higher adoption of renewables. Fundamental and applied research is needed now to make sure that technology is being developed and can be deployed as rapidly as makes economic sense. Current photovoltaic (PV) technology on the market is pushing 20% efficiency, but thermodynamics tells us that we should be able to capture 50%–60% realistically (more than 80% theoretically). In the developing world, the sooner we can increase these technologies' efficiency (or lower their cost), the sooner we can raise production and make development of new fossil energy in those areas unnecessary. In the U.S., the infrastructure upgrades are more likely to drive increased solar and wind adoption for the short term, as these technologies are already (or nearly) cost effective for individuals.

In addition to solar storage and distribution infrastructure, similar efficiency thinking can be applied to natural gas/fuel development (whether this is conventionally developed, "fracked," or developed from a renewable source), and to water treatment and distribution. We need to understand how to effectively convert between electricity and gas and build an infrastructure that allows such conversion, and also develop systems for doing this as efficiently as possible. Fuel cell technology is promising, as the efficiency is high, but research is needed to improve cell costs and lifetimes. Reversible fuel cells can be developed that convert fuel into electricity and also can convert electricity back into fuel, to make the system as resilient as possible by providing energy storage. In addition, membrane technology and other process improvements to make water treatment as efficient (in terms of water wasted and energy used) will require significant new research, even as current systems can now be deployed.

Policy issues

The above state-of-the-art and new technology development needs are driven by support from the federal and state governments, largely through research grants and tax breaks. Direct subsidies for solar power are being phased out at the federal and state levels. California lawmakers have recently laid out a package of new bills for consideration to increase renewable energy use and decrease carbon emissions between now and 2030. These measures are a good start, but we need to emphasize a bigger vision, highlighted below.

It is worth noting that both energy and water are areas where cost-effectiveness is considered essential for new technology to be deployed, but where that concept is often hard to define or quantify. As the end goal is to provide broad societal benefit, a different, still somewhat undefined, accounting may be required to understand cost-effectiveness, and this must be supported by the policies enacted. For instance, taking into account societal costs for business as usual in a quantitative way can help define a baseline cost.

Focus on the long term:

- Support the development of new technologies that can really change the game over the next 30–50 years. These technologies include new, renewable, high efficiency energy generation as well as those that support the control of a complex, dynamical system, creating an overall efficient system. It is essential that funding from the U.S. Department of Energy, the California Energy Commission, and other federal, state and local agencies should be invested in basic research, not just demonstration projects.
- Support development of a system that is as adaptable to these technologies as possible, and create as much certainty in that support as possible for effective planning.
- Sustained support at every point along the research and development pipeline is required. Currently, the state is too focused on pilot and demonstration projects. Also, almost all funding currently available for energy research from the state is funded through ratepayer surcharges, and must show benefit to the ratepayers in somewhat strict terms.

Focus on the big picture:

- Support for the system has been limited, and generally pieced together from smaller programs. In California this has been a major problem, as there are numerous proceedings at the Public Utilities Commission that all relate to one another, but they are taken in isolation.
- Smart communications systems are enabling for all of the infrastructure challenges, but we need to understand how to share data effectively across the electricity system.

Focus on the right incentives:

- Drop the false dichotomy between sustainability and jobs. We can support the development of new technologies here and create jobs as we invent, design, test, scale and deploy them around the region and the world.
- Remember Jevon's paradox. We care more about the system efficiency than about any one person's/organization's use. Focus on policy to support the most efficient system possible.
- Support end-use efficiency appropriately, with support for those at the low end, but with rates/taxes/penalties that really encourage careful use rather than additional consumption. Note this is especially true in water where we need to reduce real consumption considerably, and have not been pushed to do so before.

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