Meeting worldwide demand for electricity

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Outline

- Pre-eminent issues of the twenty-first century.
- Greatest engineering achievement of twentieth.
- Energy in 10% of world living in wealthy countries.
- Campus solar-powered charging station case study.
- Pay attention to back-of-the-envelope.
- Relevance to the other 90%?
- Greatest engineering achievement revisited.
- Prosperity and electricity consumption.
- Renewables and generation following demand.
- Demand following generation.
- Transportation electrification.
- Opportunities to make a real difference.

Pre-eminent issues of the twenty-first century.

- Climate change/emissions:
  - Energy industry generally, and
  - Electricity industry in particular.
- Issues are both:
  - Chronic, over coming decades, need to radically reduce our carbon dioxide emissions to limit effects on climate change,
  - Acute, urgently need to reduce various other emissions, particularly in China and other developing countries, to reduce harm to health.

Pre-eminent issues of the twenty-first century.

- Increasing prosperity of several billion people in China, India, South America, Southeast Asia, Africa:
  - Who want to use increasing amounts of energy, including electricity.

Greatest engineering achievement of the twentieth century

- National Academy of Engineering nominated electrification:
  - Ultimate just-in-time industry where product is generated milliseconds before consumption,
  - Kinetic energy in system holds about 8 seconds of inventory,
  - Generators are controlled to follow variation in demand by measuring frequency:
    - “generation following demand.”

Energy and energy changes in wealthy countries: US, EU.

- Europe has higher energy costs than US, and lower energy intensity.
- But both have highly electrified economies:
  - Total population around 700 million out of about 7 billion on planet,
  - Energy and electricity per unit of gross domestic product *decreasing* with improved efficiency and increasing fraction of the economy involved in provision of services.

Energy and energy changes in wealthy countries: US, EU.

- These wealthiest 10% on planet can fund essentially any choices:
  - Energiewende in Germany:
    - Solar in not-so-sunny Germany,
  - Sunrise Power Link in California:
    - Most expensive electric transmission in known universe, built to access renewable resources.
  - University of Texas solar-powered charging stations for our gadgets:
    - Fine for awareness of solar and convenience,
    - Not necessarily for large-scale deployment.

Latest technology from UT conspicuous unsustainability

Is this a technology that should be widely deployed?

Photograph taken by author in Austin in February 2016.

Pay attention to a back-of-the-envelope calculation!

- Approximate cost around $50k (according to http://reportingtexas.com/solar-stations-put-a-charge-in-ut-campus/):
  - Suppose large-scale manufacture was only a tenth of this, say $5k.
- Around 10kWh per week produced (according to https://www.utexas.edu/sustainability/documents/VisualizingSolarData_BethFerguson.pdf)

Pay attention to a back-of-the-envelope calculation!

- Over 50 year life (probably an over-estimate), energy produced would be around 25MWh,
  - Retail value around $2500,
  - Assuming all displaced generation were coal with CO_2 valued at $100/ton, would add another $2500.
- Even with highly favorable assumptions, cost does not justify energy and CO_2 benefits:
  - Fine for advertising solar as a concept,
  - Fine for delivering small amounts of high value convenience.

Relevance to other 90%?

- What lessons are useful to everyone else?
  - Actions of other 90% will eventually have much greater effect on carbon dioxide and climate change than actions in US and EU.
  - Need to actually reduce emissions, not just substitute in one industry for another.
- Arguably, California could have contributed more to reducing global warming by investing in wind production in Texas than building Sunrise Power Link to access remote solar in California.

Relevance to other 90%?

- Specific lessons from roof top solar in California (and elsewhere) can be applicable if they demonstrate a model that is transferrable:
  - Regulations,
  - Balance of system cost reduction,
  - Grid implications.
- Technology development spurred by roof top solar has led to significant cost reductions that will have global benefits.

Greatest engineering achievements, revisited?

- Founding prime minister of Singapore, Lee Kuan Yew, suggested air conditioning (powered by electricity!)
- Consumption of electricity will grow as billions achieve even modest prosperity:
  - Lighting, running water, sewage, machines, refrigeration, appliances, telecoms, radio, television, computing, internet, air-conditioning, vehicular electrification.
  - Basically everything we take for granted.

Solar panel and battery in goat-herder hut in Chile.

Photograph taken by author in 2005 in Chile.

Electricity consumption increases with prosperity.

- Growth of air-conditioning (AC):
  - When I was growing up in Sydney, not a single one of my friends had AC, except a family from Eastern Europe (window unit!).
- These days, all the people I know in Sydney have AC:
  - despite the relatively mild climate!
- Most prosperous parts of Southeast Asia are now extensively air-conditioned.

Prosperity and electricity consumption.

- Can expect similar developments in newly prosperous communities in warm to hot climates everywhere:
  - Not just 5 million Singaporeans, 7 million Hong Kongers, or 23 million Australians, but several billions living within 35 degrees North and South of the equator.
- Air-conditioning (AC) is one of highest consumers of electrical energy and drives peak demand in Texas.

Air-conditioning becomes pervasive.

The air conditioners at the back lane of Boat Quay, Singapore, by Choo Yut Shing.
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Heating in cooler climates.

- Heating will likely also become more electrified,
- Increasing prosperity of peoples in colder climates will also contribute to electricity consumption.

Prosperity and electricity consumption.

- AC/heating is not the only growing electrical demand, but it is a potentially huge burden on electricity systems, and huge contributor to carbon dioxide.
- What exactly is moral position of wealthiest 10% regarding everyone else getting electricity-hungry mod cons?
- Are there less carbon intensive alternatives for roughly equivalent services?

Generation follows demand.

- Large-scale power systems involve feedback of supply-demand balance (measured by frequency) to control generator output:
  - Modern version of Watt governor,
  - Works well if generation sources are controllable.
- Increasing amount of renewable production relying on variable wind and solar reduces controllability:
  - Complicates generator follows demand paradigm.

Alternatives to generation follows demand.

- Reversible storage of electricity allows decoupling of production from consumption:
  - Utilized in pumped storage hydro, compressed air energy storage,
  - Batteries, still rather expensive.
- Storage in end-use such as thermal:
  - Modulate consumption of electricity for AC.
- Demand follows generation:
  - Consume when renewables producing.

Modulate consumption of electricity for AC.

- In many countries, AC is a relatively new innovation for residential.
- Scope to re-think AC in such places before it becomes entrenched:
  - Greater thermal storage in buildings,
  - Better passive thermal design,
  - AC running hardest when renewables highest,
  - Alternative services: dehumidify with dessicants.

Consume when renewables producing.

- Amongst delivered energy carriers, electricity has highest potential for low carbon.
- Electric vehicles have flexible consumption:
  - Vary charge rate during the considerable time when car is idle and plugged in.
- Increase fraction of flexible load to complement increase in intermittent production:
  - Increase the demand following generation.

Opportunities to make a real difference.

- Deliver to billions of people the services provided by electricity that we take for granted, but without increasing CO_2 proportionally:
  - Lower cost renewables and other non-fossil generation,
  - Lower cost battery storage,
  - Reducing the energy required for end-uses,
  - Storage in end-uses,
  - Flexible end-uses.

Conclusion

- Pre-eminent issues of the twenty-first century.
- Opportunities to make a real difference.
- Pay attention to the back-of-the-envelope.