Challenges, Innovations, and Venture Opportunities to Improve Delivered Exergy Efficiency

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November 16, 2012
Morgantown, West Virginia

What is ‘Exergy’

- Exergy is the ability of a unit of input energy to perform useful work.
  - Concept of exergy developed in 18th and 19th century, given a name in mid 1950’s
  - Not in common parlance because one cannot directly measure exergy
  - Concept is absolutely vital to design of more efficient energy system

What is “Delivered Exergy Efficiency”?

- Energy efficiency metric -- first law efficiency – is widely used, but is nearly useless for making energy production and delivery decisions. Look at current efficiency metrics:
  - Appliance efficiency: Btus out divided by Btus in
  - Generation efficiency: Btus of fuel per kWh of power, at the generator
  - Boiler efficiency: Btus of fuel per Btu of steam or hot water.

- Needed: second law efficiency metric -- useful energy services delivered divided by potential useful energy input.

- This is “***Delivered Exergy Efficiency***”
  - DOE/EPA rates home heating systems with first law. My condensing gas furnace is top in class, 94% efficiency on the stamp
  - The ***Exergy Efficiency*** of my system is ~ 6%; the system destroys 94% of the potential exergy.
  - First law electric generation efficiency for the U.S. is 33%, second law efficiency is ~ 50%, 90?% is possible

The rule of sevens

- A rule of thumb from my Dutch friend;
  - It takes seven times as much energy to move a unit of electric energy as it takes to move a unit of chemical energy (i.e. fuel)
  - It takes seven times as much energy to move a unit of thermal energy as it takes to move a unit of electric energy
  - Therefore, it takes 49 times as much energy to move a unit of thermal energy as it takes to move a unit of chemical energy.

- For example, we move a MMBtu of energy as natural gas a thousand miles with 6 to 8% of the gas, but,
  - We move electricity, on average 150 miles with the same 6% to 8% line losses, and
  - We move steam or hot water 2 miles with 6% to 8% losses: no one moves thermal energy more than 3 to 5 miles.

- Could innovations cut this to a ‘Rule of threes?”

Implications of measuring "Delivered Exergy Efficiency"

1. All megawatts are not equal;
   - One MWh of distributed generation displaces, on average 1.2 to 1.5 MWh of central generation, but regulation treats them as equal, thus underpays DG, overpays CG
   - One MW of DG capacity displaces ~ 2 MW of CG capacity at the system peak, and we design generation wires to meet the system peak
2. Combining heat and power generation must be done near thermal user, due to 'rule of sevens'; allows economic recycling of normally wasted thermal energy from electric production
3. A universal 'Exergy Efficiency' measure would transform energy policy, direct innovations towards extracting more useful energy services from each unit of input energy, whether fossil, biomass, or solar.
4. Enormous policy changes and innovation opportunities flow from developing and using a new metric of '***delivered exergy efficiency***'.

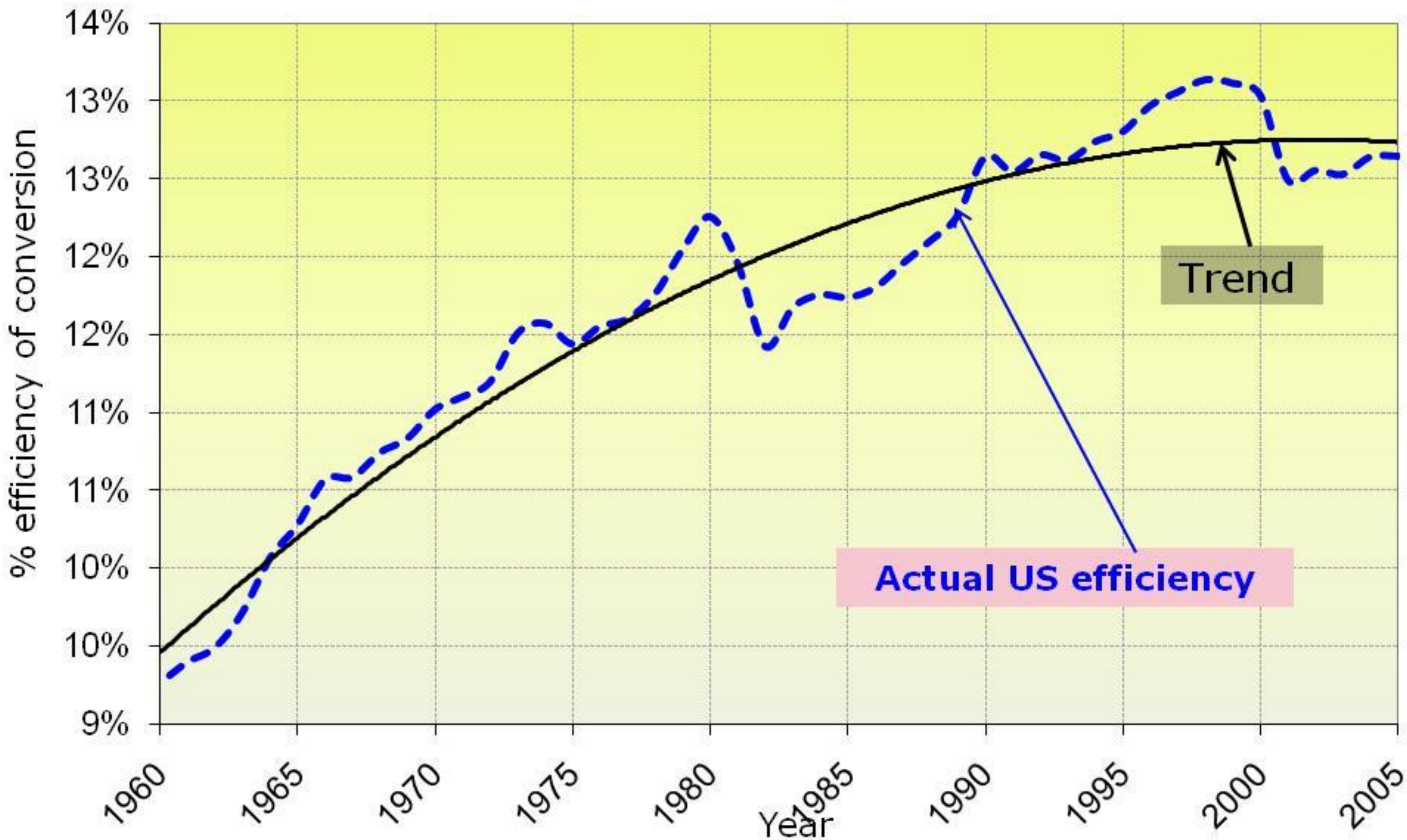
First innovation

- ARPA develop universal measures of delivered exergy efficiency
  - Build on work of physicists Robert U. Ayres and Benjamin Warr to compare each process and each state and every country on delivered exergy efficiency of their energy system.
  - Allow policy to reflect the insights of second law thermodynamics

First innovation: Universal system measuring delivered exergy efficiency

- ARPA create a universal system of measuring exergy efficiency, enabling policy makers, regulators, energy system operators and entrepreneurs to measure what really matters, the delivered exergy efficiency.
  - Make clear to all how much gain is available from improving exergy efficiency
  - For example, home heating systems seem nearly perfect at 94% efficiency, but are in fact 6% exergy efficient. Japanese home-scale CHP system burning gas in a small engine to produce electricity as a byproduct of home's thermal needs is 60% exergy efficient.

Fuel to useful energy services since 1960



Second innovation: Electric grid model

- ARPA create software of entire U.S. electric system to calculate impact on line losses and capacity needs from installing DG in any selected location. Build on the work of Professor Marija Ilic at Carnegie Mellon and MIT
  - Give regulators a tool to measure and reward differential benefits of DG versus CG
  - Enable grid planners to determine optimal location of all new generation
  - Incorporate value of active VAR support from DG to cut line losses in half.

Third innovation to improve delivered exergy efficiency

- Develop system to move low-grade thermal energy with chemical process
  - Use presently wasted thermal energy to separate two chemicals
  - Pump the two chemicals long distances to thermal users
  - Combine the two chemicals at the point of thermal use to generate hot air, hot water or low pressure steam.
  - Pump the combined molecules back to the source of thermal energy
  - Create a system that uses waste heat at multiple locations to separate chemicals and at multiple locations to combine the chemicals to release needed thermal energy
- A techno-economic solution could virtually eliminate burning of fossil fuel to create low grade thermal energy, could deliver all low-grade thermal needs from recycled waste energy

Fourth innovation: Develop vertical flood condensing heat exchangers

- Vertical flood heat exchangers (already commercial) capture much of condensate energy loss from shell and tube heat exchangers
  - Steam condenses at atmospheric pressure, leaving 212F condensate, but vertical flood heat exchanger captures most of remaining heat, down to 5 to 10 degrees above entering temperature of water being heated

- Innovation is to develop vertical flood to operate at a vacuum, enabling replacement of PRVs with backpressure condensing steam turbines.
  - This recycles most of the exergy in distribution steam, leads to 4,000 Btu per kWh power that displaces 10,000 to 14,000 Btus of central generation fuel.

Fifth innovation to improve delivered exergy efficiency

- Software to model industrial/commercial thermal distribution system that identifies how replacing pressure reducing valves (which destroy exergy) with backpressure turbine generators would improve exergy efficiency
  - Enable simple conversion to economics to identify the cost and savings of recycling the exergy in a typical steam distribution system

Overarching vision

- Develop metrics, software and multiple technical innovations to convert the 'rule of sevens' into a rule of threes or a rule of fours.
    - Enable DG value and locations to cut line losses of T&D system in half, so moving electricity only takes three times as much energy per unit as moving chemical energy
    - Enable recognition of waste energy recycling to avoid prohibitive costs of moving thermal energy
    - Develop chemical system to move thermal energy to cut losses in half, move thermal with 3 to 4 times the energy loss of moving electricity

Thank You

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