Designing for Energy and the Environment

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Outline of Talk

- Overview of energy and the environment
- Drivers of innovation
- Opportunities and needs

Human Demands for Energy

- Comfort / Safety
- Food production
- Manufacturing / Commerce
- Mobility
- Recreation
Trend in U.S. Energy Consumption

Sources of Energy

- "Renewables"
  - Biomass
  - Hydropower
  - Wind
  - Solar
  - Geothermal

- Fossil Fuels
  - Coal
  - Petroleum
  - Natural Gas

- Nuclear
  - Uranium

The U.S. Energy System

(2008 energy flows in quadrillion Btu)

~85% from fossil fuels

Most of the World’s Primary Energy Comes from Fossil Fuels

Key Drivers of Innovation

- Reduce the cost (and/or increase the convenience and reliability) of energy services
- Movement toward “sustainability”
- Reduce dependency on oil imports
- Reduce greenhouse gas emissions

Drivers of Innovation
U.S. Energy Imports

Oil imports = 66% of total (vs. 36% in 1973)

Global Climate Change

- Concentrations of greenhouse gases in the atmosphere are rising sharply due to GHG emissions from human activities
- The resulting heat-trapping effect leads to climate change on a global scale

CO₂ from Energy Use is the Dominant Greenhouse Gas

U.S. Greenhouse Gas Emissions
weighted by 100-yr Global Warming Potential (GWP)

- 7.4% CO₂
- 6.5% CH₄
- 2.2% N₂O
- 83.9% Others

The Climate Change Policy Driver

- 1992 U.N. Framework Convention on Climate Change called for “stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system”
Stabilization Requires Large Emission Reductions, Soon

Recent assessments indicate potentially serious impacts for more than a 2°C rise in average global temperature

Required change in global CO₂ equiv emissions from 2000 to 2050

−85% to −50%

Source: IPCC, 2007

Stabilizing climate change will require urgent action

Opportunities and needs for innovation

Innovation Opportunities

New or Improved Methods to:

• Reduce CO₂ emissions from energy use
• Reduce other GHG emissions from:
  • Industrial processes
  • Agricultural activities
  • Landfills /Other sources
• Enhance natural sinks
  • Afforestation /Reforestation
  • Soil management
• “Geoengineering”

General Strategies to Reduce Energy-Related Emissions

The Kaya Identity

\[
\frac{\text{CO}_2 \text{ emissions}}{\text{per year}} = \frac{\text{Population} \text{ per year}}{\text{GDP \ per \ capita}} \times \frac{\text{Energy \ use \ per \ GDP}}{\text{CO}_2 \text{ emissions \ per \ unit \ energy}}
\]

Measures to reduce the last two terms are the focus of current policies
**Sources of CO₂ Emissions**

U.S. CO₂ Emissions

<table>
<thead>
<tr>
<th>End-Use Energy Sectors</th>
<th>Residential</th>
<th>Commercial</th>
<th>Industrial</th>
<th>Transportation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity + Vehicles</td>
<td>38.1%</td>
<td>17.1%</td>
<td>28.9%</td>
<td>4.8%</td>
</tr>
</tbody>
</table>

Electricity + Vehicles emit ≈ 75% of all CO₂ (and 70% of U.S. electricity)

**Innovation Opportunities:**

**Demand-Side Measures (I)**

- Design more efficient technologies to reduce the demands for energy in all end-use sectors

<table>
<thead>
<tr>
<th>Energy Demand Sectors and Technologies</th>
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</thead>
<tbody>
<tr>
<td><strong>Residential &amp; Commercial Blgds.</strong></td>
</tr>
<tr>
<td>Lighting</td>
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<tr>
<td>Water heating</td>
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<tr>
<td>Cooking</td>
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<td>Refrigeration</td>
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<td>Space heating</td>
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<tr>
<td>Air conditioning</td>
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<tr>
<td>Ventilation</td>
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<tr>
<td>Appliances</td>
</tr>
<tr>
<td>Building structures</td>
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</tbody>
</table>

**Improving and Phasing Out Incandescent Lamps**

CFLs - Federal (Harmon) Tier 1 (2012 - 2014)

Best Fit to Existing Lamps

**Rechargeable LED Flashlights and Task Lights Already Available**

- Monkeyhead
- RiGo
- Girls XB
- Miguylight
- Treasure
- Sedge
- Craze
- Cylint
- Yuga
- Impulse
- Thuk XP

Source: A.Rosenfeld, CEC, 2007
Cool Colors Reduce Energy Demand

Cool Colors Reflect Invisible Near-Infrared Sunlight

Cool (increased solar reflectance)

Standard

Concrete Tiles
(Courtesy American Rooftile Coatings)

Old (flat, white)

New (pitched, cool, colored)

COOL ROOF TECHNOLOGIES

Coming Next: Cool Color Cars

- Toyota experiment (surface temperature 18°F cooler)
- Ford, BMW, Fiat also working on this technology

Per Capita Electricity Sales: California vs. U.S. Average

United States

California

1975-2005 Difference = 5,300kWh/capita = $165/capita

Per Capita Income in Constant 2000 $

1975 2005 % change

US GDP/capita

16,241 31,442 94%

Cal GSP/capita

18,760 33,536 79%

1975-2005 Difference = 5,300kWh/capita = $165/capita

Source: A. Rosenfeld, CEC, 2007

Per Capita Electricity Sales (kWh/person) (excluding self-generation)

Source: A. Rosenfeld, CEC, 2007

Refrigerator Energy Use in U.S.

Source: A. Rosenfeld, CEC, 2007

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Vehicle Ownership Around the World is Growing (Rapidly)

Fuel Economy for New U.S. Vehicles

Technology for Reducing Automotive Emissions

Available Now
- Improved fuel economy for conventional ICE vehicles (gasoline and diesel)
- Hybrid-electric vehicles
- Biofuels (corn/sugarcane ethanol)

Under Development
- Plug-in hybrid electric vehicles*
- Hydrogen fuel cell vehicles*
- Advanced biofuels (cellulosic ethanol)

Innovation Opportunities: Demand-Side Measures (2)

- Reduce demand for energy-intensive services and products through changes in:
  - Community planning and development
  - Transportation systems & infrastructure
  - Industrial & manufacturing infrastructure
  - Agricultural practices and products
  - Personal life-style and amenities

* Need low-carbon electricity and H₂ to get low CO₂

Some measures may require significant behavioral changes, not just new technology
Innovation Opportunities: Supply-Side Measures (1)

- Use more efficient technologies for generating and distributing electricity and other energy carriers
- Utilize alternative energy sources with lower or no GHG emissions:
  - Renewables: wind, biomass, geothermal, solar, hydro
  - Natural gas
  - Nuclear power

All options can be expanded, but deployment may be limited by technical, economic and/or societal constraints.

Innovation Opportunities: Supply-Side Measures (2)

- Capture and sequester the CO₂ produced at power plants and other large industrial sources
  - Until recently, the term “carbon sequestration” referred only to the natural uptake of CO₂ by trees and other biomass (terrestrial sequestration)
  - Today this term includes technology to capture and sequester CO₂ from industrial processes—commonly referred to as carbon capture and storage, or CCS

This option has not been seriously considered until recently, but now getting significant attention.

Conclusion

- Many opportunities energy-related design and innovations to address societal issues
- Still a need for effective/firm policy drivers
- CMU well-positioned to lead in this field

Thanks

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