Renewable and Sustainable energy institute
A Joint Institute of the University of Colorado at Boulder & the National Renewable Energy Laboratory

https://rasei.colorado.edu/
The Global Energy/Climate Challenge

Global energy demand is expected to DOUBLE by mid-century.

Electricity demand to TRIPLE.

GHG emissions must be reduced (by 75%?)

Global peak oil and gas are imminent.

UNPRECEDENTED amounts of carbon free energy will be necessary in the 21st Century to provide U.S. and global energy needs, and stabilize atmospheric CO2 concentrations.
OUTLINE FOR THIS PRESENTATION

1) What is RASEI (“racy”)?

2) What is the scale of the “energy/climate” challenge?

3) What are some land use implications of developing a low-carbon energy economy?
CU-Boulder Institutes

Examples:

- Joint Institute for Laboratory Astrophysics – JILA
  (partnership with National Institute for Science and Tech. – NIST)
- Cooperative Institute for Research in Environmental Science – CIRES
  (partnership w/ National Oceanic and Atmospheric Admin. – NOAA)
- Laboratory for Atmospheric and Space Physics – LASP
  (partnership with National Aeronautics and Space Admin. – NASA)

Characteristics:

- faculty fellows from university departments and from federal agency
- focus on interdisciplinary research (complex problems)
- do not grant degrees, but important for educational mission
- combine fundamental and mission-oriented research agendas
- integrated into university research and teaching missions for >40 years
Formation Process for RASEI

• CU-Boulder faculty white paper in fall 2005

• development of Energy Initiative core programs from 2006 – 2008
  (seed and proof-of-concept grants, certificate programs,
  business outreach and commercialization, outreach events)

• Steering Committee and Leadership Council formation 2008/09

• Transition from Energy Initiative to Joint Institute 2009/10
  (University approvals, MOU with NREL, fellows selection)

• RASEI Growth Phase 2010-2014
  (development of core research themes, funding, facilities)

• RASEI Full Scale Operation 2014 – 2030 (and beyond)
Companies partner with RASEI for a variety of reasons

- Strategic Guidance (LC)
- Market Understanding
- Research Collaboration
- Commercialization
- Internship / Projects
ENTREPRENEURSHIP PROGRAMS
The Renewable and Sustainable Energy Institute in conjunction with the Deming Center and Tech Transfer Office have created an industry leading process for commercializing technologies developed within the institute. Our programs include:

Entrepreneurship Education
Internal Funding Programs
Thought Leadership Seminars

BUSINESS PARTNERSHIPS
We have a variety of programs and platforms for all businesses to engage with our institute for research, development, commercialization and insight. Depending on the level of desired engagement and governance, our standard programs should cater to most business needs.

Sponsored Research
Commercialization Partners Program (CPP)
Start-up Engagement

For more information contact trent.yang@colorado.edu
RASEI offers CU-Boulder’s cutting edge energy education programs, catalyzing student learning and enthusiasm to help solve the many scientific, technical, social and political challenges associated with meeting today's energy challenges.

- Graduate and Undergraduate Certificate Programs
- RETool Executive Retraining Workshops
- RASEI Student Association
- 40+ “open” energy-related courses available
- Professional Science Masters (PSM) Program

Contact: Paul.Komor.colorado.edu
Large units of Power and Energy:

Kilowatt (kW) - $10^3\ W$ (power to run a toaster)
Megawatt (MW) - $10^6\ W$ (output of wind turbine)
Gigawatt (GW) - $10^9\ W$ (output of nuclear power plant)
Terrawatt (TW) - $10^{12}\ W$ (power consumption of large country)

Simple projections of demand suggest that 10-20 TW of new, low carbon power will be needed by 2050.
Global Power Consumption, 1998

Total Global: 12.8 TW
U.S.: 3.3 TW (99 Quads)
Business as usual (BAU)

Stabilization triangle

Continued fossil fuel emissions

Pascala and Socolow, Science, 305, 968-971, 2004
One Wedge Represents

• Generate electricity at 60% efficiency (today’s average is 35%)
• Build wind turbines across 3% of the USA surface
• Expand photovoltaics up to 700 times today’s use
• Build 500 new nuclear power plants
• Sequester 3.5 Gigatons of CO$_2$ per year
The Sleipner Project (North Sea) as a Reference

We need 3500 of these!

Global oil production 4 Gt/yr
Kaya Identity: Four Factors that Determine Global Energy Use and GHG Emissions

1. POPULATION (number of people) - currently increasing
2. CONSUMPTION or WEALTH (unit of GDP per person)
3. ENERGY EFFICIENCY (energy consumed per unit of GDP)
4. CARBON INTENSITY (GHG emitted per energy consumed)

Energy Use (Demand) = 1 x 2 x 3

GHG Emissions = 1 x 2 x 3 x 4
### GETTING TO 1 TW BY 2030 (20 years)

<table>
<thead>
<tr>
<th>AVE Annual Power In 2010</th>
<th>AVE Annual Power in 2030</th>
<th>Required AVE Annual growth rate</th>
</tr>
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<tbody>
<tr>
<td>1 kW</td>
<td>1 TW</td>
<td>280%</td>
</tr>
<tr>
<td>1 MW</td>
<td>1 TW</td>
<td>100%</td>
</tr>
<tr>
<td>1 GW</td>
<td>1 TW</td>
<td>41%</td>
</tr>
<tr>
<td>10 GW</td>
<td>1 TW</td>
<td>26%</td>
</tr>
<tr>
<td>100 GW</td>
<td>1 TW</td>
<td>12%</td>
</tr>
</tbody>
</table>

- these growth rates apply to all energy technologies, (e.g. oil shale, CCS, etc.) not just renewable energy
- growing industries at >20%/yr for decades is difficult (facilities, employees, investment capital, materials, supply chains, ROI, etc.)
U.S. ENERGY COMPARISON

to produce 20 Q/yr
(20% U.S. Energy with today’s technology)
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SOLAR
20 acres/turbine
175,000Kwh/turbine
33 million turbines

WIND

BIOMASS
1 million kg biomass/km²
16,000BTU/kg = 0.2 Q/4000km²
Renewable Energy and Land Use

• Generation of electricity and fuels from fossil energy involves below ground activity (mining) and relatively small amounts of land (refineries, power plants, etc.)
• Generation of electricity and fuels from renewable energy will be above ground and will require enormous amounts of land
• Renewable energy resources are often not located near population centers in the US
• Land acquisition, permitting, and transmission will be huge issues in developing a low-carbon energy economy based on renewable energy
Emissions Reductions Approaches and Costs

**Make C-Free Energy**
(costs $$ to reduce carbon)

**Reduce Energy Consumption**
(saves $$ to reduce carbon)

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**Exhibit 11**

**U.S. MID-RANGE ABATEMENT CURVE – 2030**

<table>
<thead>
<tr>
<th>Cost</th>
<th>Real 2005 dollars per ton CO₂e</th>
</tr>
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<tbody>
<tr>
<td>90</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td></td>
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<tr>
<td>30</td>
<td></td>
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<td>0</td>
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</tbody>
</table>

- Residential electronics
- Fuel economy packages – Light trucks
- Residential buildings – Lighting
- Commercial buildings – Combined heat and power
- Industrial process improvements
- Coal mining – Methane mgmt.
- Residential buildings – Shell retrofits
- Active forest management
- Commercial buildings – Control systems
- Nuclear new-build
- Distributed solar
- Afforestation of cropland
- Coal power plants – CCS new builds with EOR
- Commercial buildings – HVAC equipment efficiency
- Residential buildings – HVAC equipment efficiency
- Commercial buildings – New shell improvements
- Existing power plant conversion efficiency improvements
- Cellulosic biofuels
- Industry – Combined heat and power
- Conservation and efficiency
- Winter cover crops
- Offshore wind – Low penetration
- Offshore wind – High penetration
- Biomass power – Co-firing
- Manufacturing – HFCs mgmt
- Coal power plants – CCS new builds on carbon-intensive processes
- Car hybridization
- Natural gas and petroleum systems management
- Afforestation of pastureland
- Coal power plants – CCS new builds
- Coal power plants – CCS new builds
- Coal-to-gas shift – dispatch of existing plants

Source: McKinsey analysis

McKinsey, 2007
Energy Efficiency and the Built Environment

• Low hanging fruit for a low carbon energy economy in developed counties (U.S) is energy efficiency
  - more efficient transportation and manufacturing
  - more efficient/flexible electricity systems (smart grids)
  - more efficient energy management systems for buildings
• Energy efficiency considerations will be increasing important in new construction and urban planning
• Incentives and other economic advantages associated with improving energy efficiency for existing buildings