Renewable Energy Options

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U. S. Energy Flows

Foundational Energy

Source: Lawrence Livermore National Laboratory and U.S. DOE based on Annual Energy Review, 2008 (EIA, 2009)
From National Academies Press, America's Energy Future, 2009
U.S. Energy Flows

21st Century Foundational Energy

(2008 Quads)

U.S. Energy Flows

Renewable Energy

(2008 Quads)

Source: Lawrence Livermore National Laboratory and U.S. DOE based on Annual Energy Review, 2008 (EIA, 2009)
From National Academies Press, America’s Energy Future, 2009
Outline

I. Technology and Challenges

II. Policy

III. Discussion
“We suggest producing all new energy with WWS [Wind, Water, Solar] by 2030 and replacing the pre-existing energy by 2050.”

From: Mark Z. Jacobson and Mark A. Delucchi, Energy Science, 2010

Providing all global energy with wind, water, and solar power
Part I: Technologies, energy resources, quantities and areas of infrastructure, and materials
Part II: Reliability, system and transmission costs, and policies
## A Fully Renewable World

<table>
<thead>
<tr>
<th>Energy Type/Plants</th>
<th>Nameplate (MW)</th>
<th># by 2050*</th>
<th>MW Installed</th>
<th>Number of Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind turbines</td>
<td>5.0</td>
<td>3,800,000</td>
<td>19,000,000</td>
<td>260/day</td>
</tr>
<tr>
<td>Concentrated solar</td>
<td>300.0</td>
<td>49,000</td>
<td>14,700,000</td>
<td>3/day</td>
</tr>
<tr>
<td>Solar PV power</td>
<td>300.0</td>
<td>40,000</td>
<td>12,000,000</td>
<td>3/day</td>
</tr>
<tr>
<td>Roof top PV systems</td>
<td>0.003</td>
<td>1,700,000,000</td>
<td>5,100,000</td>
<td>116,438/day</td>
</tr>
<tr>
<td>Geothermal power</td>
<td>100.0</td>
<td>5,350</td>
<td>535,000</td>
<td>3/week</td>
</tr>
<tr>
<td>Hydroelectric power</td>
<td>1300.0</td>
<td>270</td>
<td>351,000</td>
<td>1/month</td>
</tr>
<tr>
<td>Wave devices</td>
<td>0.75</td>
<td>720,000</td>
<td>540,000</td>
<td>49/day</td>
</tr>
<tr>
<td>Tidal turbines</td>
<td>1.0</td>
<td>490,000</td>
<td>490,000</td>
<td>34/day</td>
</tr>
</tbody>
</table>

**Total**: 52,716,000

*Modified from: Mark Z. Jacobson and Mark A. Delucchi, Energy Science, 2010*
Wind Challenges

- Transmission
- Intermittency
- Energy Storage
- Siting
- Materials
- Infrastructure
Wind resource data developed by AWS Truepower, LLC for windNavigator®
Industrial Solar

Spain

**Solucar, CSP**
11 MW Nameplate

**Andusal, PV**
60 MW Nameplate

**Olmedilla de Alarcon, Parabolic Troughs**
50 MW Nameplate

Tinker, 2011
Industrial Solar

Solar Challenges

• Cost
• Intermittency
• Energy Storage
• Transmission
• Land Use
• Manufacturing
Concentrating Solar Resource of the United States

The map shows the concentration of solar resources in the United States. High solar resource areas are indicated in red, while lower resource areas are in green. The map is produced by the National Renewable Energy Laboratory for the U.S. Department of Energy.
Geothermal

Iceland

300 MW Nameplate
Geothermal Challenges

• Thermal Conversion
• Geology
Geothermal Challenges

- Thermal Conversion
- Geology

http://www.azgs.az.gov/images/geothermal_6b.jpg
Hydro Challenges

- Fresh Water Capture
- Land Use & Topography
- Drought
U. S. Energy Flows

Efficiency

(2008 Quads)

Source: Lawrence Livermore National Laboratory and U.S. DOE based on Annual Energy Review, 2008 (EIA, 2009)
From National Academies Press, America’s Energy Future, 2009
Efficiency: Energy Use in the U.S.
1980 Energy Use Per Dollar of GDP & Per Capita Set to 1.0

Year

Energy use relative to 1980

Historical
Projected

Energy use per capita

Energy use per dollar of GDP

Source: Energy Information Administration, 2008
From National Academies Press, America’s Energy Future, 2009
Efficiency: Energy Use in the U.S.
1980 Energy Use Per Dollar of GDP & Per Capita Set to 1.0

http://www.eia.gov/iea/wecbtu.html
Efficiency

- Fuel
- Lighting
- Electronics
- Insulation

Energy efficiency can be improved across all consumption sectors.
Outline

I. Technology and Challenges

II. Policy

III. Discussion
“We suggest producing all new energy with WWS by 2030 and replacing the pre-existing energy by 2050.”

“Barriers to the plan are primarily social and political, not technological or economic.”

Challenges

Social and Political
- Land Use, Access, Permitting, Regulation

Science and Technology
- Intermittency
- Energy Storage
- Transmission
- Manufacturing, Infrastructure

Resources
- Geology, Land
- Fresh Water
- Materials

Economics
- Cost
2013 High Wind Week - Generation by Fuel Type

Note - no changes to existing reserves requirements were assumed for this analysis.
To Address Intermittency

- interconnect dispersed resources
- complementary and non-variable sources
- demand-response management
- store electric power on site
- over-size peak generation capacity; produce hydrogen with excess power
- store electric power in vehicle batteries
- forecast weather to project energy supplies

From: Mark Z. Jacobson and Mark A. Delucchi, Energy Science, 2010
Challenges

Social and Political
• Land Use, Access, Permitting, Regulation

Science and Technology
• Intermittency
• Energy Storage
• Transmission
• Manufacturing, Infrastructure

Resources
• Geology, Land
• Fresh Water
• Materials

Economics
• Cost
## Cost

<table>
<thead>
<tr>
<th>Energy Type/Plants</th>
<th>$/Kw*</th>
<th>$ per Unit</th>
<th>Total Cost by 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind turbines</td>
<td>$1,966</td>
<td>$9,830,000</td>
<td>$37,354,000,000,000</td>
</tr>
<tr>
<td>Concentrated solar</td>
<td>$5,132</td>
<td>$1,539,600,000</td>
<td>$75,440,400,000,000</td>
</tr>
<tr>
<td>Solar PV power</td>
<td>$6,171</td>
<td>$1,851,300,000</td>
<td>$74,052,000,000,000</td>
</tr>
<tr>
<td>Roof top PV systems</td>
<td>$6,171</td>
<td>$18,513</td>
<td>$31,472,100,000,000</td>
</tr>
<tr>
<td>Geothermal power</td>
<td>$1,749</td>
<td>$174,900,000</td>
<td>$935,715,000,000,000</td>
</tr>
<tr>
<td>Hydroelectric power</td>
<td>$2,291</td>
<td>$2,978,300,000</td>
<td>$804,141,000,000,000</td>
</tr>
<tr>
<td>Wave devices</td>
<td>$9,250</td>
<td>$6,937,500</td>
<td>$4,995,000,000,000,000</td>
</tr>
<tr>
<td>Tidal turbines</td>
<td>0</td>
<td>$10,000,000</td>
<td>$4,900,000,000,000,000</td>
</tr>
</tbody>
</table>

~$230 Trillion

Global Annual GDP

~$60 Trillion

*source: EIA 2010 AEO

overnight costs, 5th of a kind units, excluding investment tax credits
Economic “Policies” to Stimulate Renewable Activity

Feed-in tariffs
  • difference between generation cost and wholesale electricity prices

Output (production) subsidies

Investment subsidies

Output quotas (renewable portfolio standards)

Carbon Pricing

After: Schmalensee (2009)
Another Approach

Rather than “picking energy winners”, develop and support targets for:

• Efficiency
• Reliability
• Emissions
• Footprint
• Cost

and let markets compete.