Energy: the Next Fifty Years

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Messages

Energy determines the aspirations and limitations of society

Vibrant global society in fifty years requires strategic energy decisions now

Top priorities for energy and society in fifty years

Discovery science is the low cost engine of innovation for energy and society
Energy Determines Aspirations and Limitations of Life

Energy

the prime mover of society
The World in Fifty Years . . .

. . . depends on the energy choices we develop now

Steven Chu and Arun Majumdar, 
Nature 488, 294 (2012)
Planning for the Energy Future

Conventional approach
Project energy futures based on today’s technologies
Extrapolate trends in efficiency and cost
The energy future is a continuous extension of the present

Proactive approach
Define the global society we want in fifty years
Identify the strategic energy outcomes needed to enable that society
Target R&D to obtain those energy outcomes

Fifty years is long enough for energy R&D to work
Steer the energy – society nexus toward strategic global targets
The Global Society We Want in Fifty Years

- rapid growth of developing economies
- steady growth of developed economies
- aggressive pursuit of discovery science and innovation
- rapid deployment of innovative technologies
- lively communication, trade and exchange of people and ideas across national and regional boundaries
- globalization of opportunity and participation in scientific, technological, economic, social and cultural advances

“a vibrant, interactive, inclusive and rapidly advancing global society”
Energy Outcomes for a Vibrant Global Society in Fifty Years

Top Three Energy Outcomes

Energy security: adequate, affordable, sustainable, predictable
  basic to personal, social, professional, civic and commercial life

Stable climate
  Global discretionary resources are finite – after food, shelter, public health
  Cost of climate change depletes discretionary resources for advancing society
    e.g., discovery science, new technologies and improving the quality of life
  Curb carbon emissions to avoid the human and economic costs of climate change

Economic development and growth
  the natural aspiration of people and countries, the source of discretionary resources
  requires inexpensive, abundant energy
Energy Science for Society in Fifty Years

On the road

- Replace fossil with wind and solar electricity

On the road but not sustainable

- Replace coal and gas electricity with nuclear electricity
- Replace coal and oil with abundant, safe and inexpensive shale gas

Not on the road

- Mitigate carbon emissions: mineralize carbon dioxide to rocks
- Develop electricity storage for cars and the grid
- Make chemical fuel a sustainable energy carrier
Wind and Solar Electricity

✅ Stable climate
✅ Energy security

Viable technologies on deployment path

Remaining science challenges
improve efficiency
lower cost

US Wind and Solar Electricity
Cumulative Installed Capacity

Ave output: 10 GW
US ave use: 450 GW

~ 2.2% of US electricity
15% growth/yr → 27% renewable electricity by 2030
Safe, Higher Performing Nuclear Electricity

Heat without combustion or carbon dioxide
Established experience curve

Challenges
Safety
1960s technology
Spent fuel

Now: 35% efficiency
2050: 50%

Materials for
• Higher temperature
• Higher radiation damage
• Corrosive environments

Reprocessing for
• More electricity/fuel
• Less spent fuel storage
• Shorter storage time

4 to 10 times smaller volume
Thousands of years instead of hundreds of thousands of years

Cu-Nb interfaces
Michael Demkowicz-MIT
**Shale Gas and Hydraulic Fracturing**

Abundant worldwide sources
- Inexpensive
- Lower carbon emissions than coal or oil

$/MBTU
- Peak 05-08: $12
- Non-peak 05-08: $8
- Since Jan 2012: $2 - $4

Potential Game Changer
- Lower carbon emissions
- Energy security
- Diversity of sources and uses
- Replace coal for power production
- Oil for transportation

US Natural Gas Production
Source: EIA

EIA World Shale Gas Resources
http://www.eia.gov/analysis/studies/worldshalegas/
Hydraulic Fracturing Challenges – Science Needed

Operation
Distant horizontal drilling into thin shale layers
Local explosions fracture rock
High pressure hydraulic fluid opens fissures
Sand driven into fissures to prop open
Gas and oil flow out

Challenges
Flow of fluids in mesoporous rock
Contamination of water, air
Initial rush of gas
Sharp decline in first year
Only 15% of shale gas recovered

Science Challenges
Understand and control
Fissure mechanics, pore formation, fluid flow in fractured rock

Carbon Dioxide Mineralization

**MO + CO₂ → MCO₃ + energy**

\[
\text{Mg}_2\text{Si}_2\text{O}_4 + 2\text{CO}_2 \rightarrow 2\text{MgCO}_3 + \text{SiO}_2 + \sim 1.4 \text{ MJ/kg CO}_2
\]

Also Ca, Fe, . . .

- Permanent, benign storage
- No follow up monitoring
- Capacity >> emissions

Challenges / science solutions:
- Slow reaction kinetics – find catalysts
- Non-reactive coating – control surface chemistry

**Carbon Dioxide Mineralization**

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Gigatons Carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmosphere</td>
<td>720</td>
</tr>
<tr>
<td>Surface Ocean</td>
<td>670</td>
</tr>
<tr>
<td>Deep Ocean</td>
<td>36,730</td>
</tr>
<tr>
<td>Carbonate Rocks</td>
<td>&gt;60,000,000</td>
</tr>
<tr>
<td>Fossil fuels</td>
<td>4,120</td>
</tr>
</tbody>
</table>

CO₂ carbon

\[
\text{carbonate}
\]

\[
\text{carbon}
\]

394 kJ/mol

90 kJ/mol

Tannock Hall of Education, University of Notre Dame, Australia 2010

Carbonate powder

American Physical Society
Energy Workshop
Baltimore MD March 17, 2013
40% of US primary energy devoted to electricity production

source: EPRI
Electricity as a Sustainable Energy Carrier

- Solar thermal
- Hydro wind
- Solar electric
- Nuclear fission
- Coal gas

35% of primary energy
34% of CO₂ emissions
63% of energy lost

Mechanical motion
Electrical power
Fuel cells

Power grid

Clean, efficient, versatile
Accommodates many sources and uses
Fossil and renewable

- Electric cars
- Digital electronics
- Communication
- Transportation
- Industry
- Lighting
- Heating
- Refrigeration

Load

American Physical Society
Energy Workshop
Baltimore MD March 17, 2013
Storing Electricity for Renewable Energy and Transportation

store variable solar and wind electricity for later use

higher energy density batteries for greater driving range

Chevy Volt
Joint Center for Energy Storage Research (JCESR)

Argonne +13 university, national lab and industry partners
Electricity storage beyond lithium ion

multivalent intercalation
Li$^+$ \rightarrow Mg$^{++}$, Y$^{+++}$

Intercalation \rightarrow chemical transformation
Li-O$_2$, Li-S, Na-S

Non-aqueous redox low batteries
High capacity, efficient, inexpensive
Many unexplored redox couples

Science Challenges
5 times energy density at 1/5 the cost in 5 years
Develop Chemical Fuel as a Sustainable Energy Carrier

Hydrogen
requires infrastructure, storage, renewable production
2003 →

Cellulosic biofuels
requires land, low efficiency, limited capacity
2007 →

Carbon dioxide + water (hydrogen)
recycled chemical fuels
Significant science breakthrough

Drop-in replacement for fossil
Incremental change to established combustion infrastructure
Promotes carbon mitigation, energy security

Graves, Ebbesen, Mogensen, Lackner
Renewable and Sustainable Energy Reviews 15,1 (2011)
Develop Chemical Bonds as a Sustainable Energy Carrier

CO₂ + H₂O → many opportunities for sustainable chemical fuel

Graves, Ebbesen, Mogensen, Lackner
Renewable and Sustainable Energy Reviews 15,1 (2011)
The Cost of Doing Things

$ discovery

$ development

deployment
Why Discovery Science?

• The cost is low

• It stimulates innovation the lifeblood of economic competitiveness and growth

• It tells you what will fail before you attempt to develop it

• It pays back more than it costs in economic return

• It primes the innovation ecosystem
The world is undergoing an historic transition. Get on board.

An intense immersion in sustainable energy.

- lectures
- panel discussions
- energy tours
- career counseling
- networking opportunities
- collaborative research projects

August 5-16, 2013
http://sise.phy.uic.edu
Perspective

Energy determines the aspirations and limitations of society

A vibrant, interactive, inclusive and rapidly advancing global society in fifty years requires strategic energy outcomes

- adequate, affordable, sustainable, predictable energy
- stable climate
- global economic development and growth

Discovery science targets for strategic energy outcomes

- wind and solar electricity
- safe, high performing nuclear electricity
- safe, inexpensive shale gas to replace coal and oil
- mineralization of carbon emissions to carbonate rocks
- electricity storage for transportation and the grid
- sustainable chemical energy carriers

Discovery science is the low cost engine of innovation for energy and society

George Crabtree, Elizabeth Kocs, Thomas Lipsmeyer, Energy, Society and Science: the Fifty Year Scenario to appear in Futures and available at http://ei.phy.uic.edu/res_publications.html