Solar Energy: Some Challenges and Opportunities

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Outline

- Why Solar Energy?
- Getting Familiar With Solar Energy
- Modeling & Analysis of Solar Energy Systems
- Experimental Research
  - Biofuels
  - Solar Cells
- Conclusions
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Human Population Growth

Photo: Graph showing human population estimates over time with data points highlighting the year 1769, indicating a significant increase.

Data source: Wikipedia & UN
James Watt and his 1769 steam engine

Source: David J.C. Mackay 2009
What are the primary energy sources?
Primary Energy Sources

Oil
Coal
Natural gas
Solar
Wind
Geothermal
Bioenergy
Hydropower
Nuclear
Categorization of Energy Sources

Oil
Coal
Natural gas

Solar
Wind
Geothermal
Bioenergy
Hydropower

Fossil
Renewable
Nuclear
What are the sources of different Primary Energies?
Categorization of Energy Sources

- Oil
- Coal
- Natural gas
- Solar
- Wind
- Geothermal
- Bioenergy
- Hydropower
- Nuclear

Fossil

Renewable
Solar Energy!

- Oil
- Coal
- Natural gas
- Solar
- Wind
- Geothermal
- Bioenergy
- Hydropower
- Nuclear

Fossil

Renewable

Nuclear
Energy in Context of Human Civilization

Fossil fuel period

Data source: Wikipedia & UN

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Energy: Fundamental to Our Lives!

Therefore, we must understand energy transformation and use issues to develop alternative energy strategies.

Data source: Wikipedia & UN
Beyond Fossil Fuels: Solar Economy

Human Population estimates over time

Fossil fuel period

Solar Economy period

Data source: Wikipedia & UN

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Why Solar Energy?

• Solar energy incident on earth in 1 hour
  \[ \sim 4.3 \times 10^{20} \text{ J} \]

• 2012 World primary energy consumption
  \[ \sim 5.1 \times 10^{20} \text{ J} \]

**Solar** is the only easily available energy source that can *alone* meet all the energy needs.

1. Lewis and Nocera, PNAS, 2006
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Then why is solar use not prevalent?
I drove in the morning from my garage and then returned in the evening to the garage.

Where Did Gasoline Energy Go?
I drove in the morning from my garage and then returned in the evening to the garage.

Where Did Gasoline Energy Go?

It went to Outer Space!!
The Journey of Solar Photons

Looking through the lens of time
Absorption & Radiation from Earth’s surface

Time spent $\sim O(10^0 \text{s})$

$\sim$ few seconds
Dissipation during water cycle

Heat dissipation in condensation

Time spent

$\sim O(10^4 \text{ s})$
Dissipation during carbon cycle

Solar Energy

Dissipation
Time spent

O(10⁵ s)
O(10⁶ s)
O(10¹² s)

Soil carbon

Fossil fuel

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Essence of Solar Economy

Transform and use solar photons on a much smaller time scale $\sim O(10^3-10^6 \text{ s})$!
1. How Dense is Solar Energy?

~10 gallons per minute

Or

~20 MW of power supply

Area: ~20,000 m²

Source: epa.gov, Wikipedia
Observation 1
Low density of solar energy is a challenge for its use
2. Energy is Needed on a Large Scale

Estimated U.S. Energy use in 2012

= 95.1 Quads

= 95.1 \times 10^{15} \text{ BTUs}

= 761 \text{ billion gallons gasoline equivalent}

= 7.2 \text{ million eq. gallons per minute to be produced}^*

* Assuming average solar energy availability of 20% of a day
Observation 2
Large-scale only possible if cost-effective
Observation 3
Harnessing solar energy **efficiently** is vital
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Solar Economy Vision

- Sun to Chemicals
- Sun to Food
- Sun to Heat
- Sun to Wheels
- Sun to Electricity

Observation 4
Systems analysis critical for Transportation
Observation 5

Energy storage needed at all levels

- $\sim 10^2$ W
- $\sim 10^3$ W
- $\sim 10^6$ W
- $\sim 10^8$ W
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Biomass

e.g. Poplar

~20% Hemicellulose

~25% Lignin

~45% Cellulose
H₂Bioil Process

Rapid heating of biomass in H₂ atmosphere followed by catalytic deoxygenation & upgrading to directly produce a liquid fuel

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Our Process Steps for Solar Cells

1. Nanocrystal Synthesis
   - Argon/Purge
   - Metal-Salt Cation / Anion Precursor Injection
   - Temp. Controller

2. Ink Formulation & 3. Coating
   - 'Ink' Argon/Purge
   - Precursor Injection
   - Coat / Anneal

4. Selenization
   - Se$_{(g)}$
   - Sintered CZTSSe

5. Device Completion
   - CdS Deposition
   - RF-Sputter ZnO/ITO
   - Grids/MgF$_2$
Photovoltaic Device Performance

Cu(In,Ga)(S,Se)$_2$ Solar Cell

Efficiency = 15.0%
Conclusions

For Engineering a Solar Energy Future:

- **Challenges are:**
  - Dilute nature of solar energy
  - Intermittency
  - Identification of complex interaction and synergy between various usage
  - Impact on overall economy

- **Opportunities are for:**
  - More process solutions with lower cost
  - Identifying novel insights
  - Guiding research/Policy effort

- **Problem Centric Engineering is needed requiring**
  - A diverse tool chest
  - Interdisciplinary collaborations
Emerging Picture of a Solar Economy

One Big Jig-Saw Puzzle!
Emerging Picture of a Solar Economy

One Big Jig-Saw Puzzle!

“A Great time to be a Scientist / Engineer”
Acknowledgments

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The Research Team
Thank you
Observation 2
Large-scale only possible if cost-effective