CHEM 210: Solar + Storage

How Chemistry is Driving the Clean Energy Revolution!

Created by Ray Hickey & Sam Hill-Cristol
Reminder…Why do we need clean energy?

- Greenhouse gases causing climate change
- Local pollutants (SOx, NOx, diesel particulates)
- Clean energy is particularly important as we electrify other things (transportation, water heating etc.)
Electrical Grid Primer

• Demand must equal supply at all times to have a balanced system
The Role of Solar

• Can replace the “generation” part of our electrical grid primer
• Average annual growth rate is 59% over the last 10 years
## Energy sector performance in 2016 versus federal agency scenarios

<table>
<thead>
<tr>
<th>Category</th>
<th>Ten-year prediction error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar capacity (GW)</td>
<td>4,813%</td>
</tr>
<tr>
<td>Wind &amp; solar generation (TWh)</td>
<td>383</td>
</tr>
<tr>
<td>Wind capacity (GW)</td>
<td>361</td>
</tr>
<tr>
<td>Nat. gas generation (TWh)</td>
<td>79</td>
</tr>
<tr>
<td>Total energy use</td>
<td>-17</td>
</tr>
<tr>
<td>CO2 emissions</td>
<td>-24</td>
</tr>
<tr>
<td>Coal generation (TWh)</td>
<td>-45</td>
</tr>
</tbody>
</table>

Source: The US government keeps spectacularly underestimating solar energy installation, Quartz, October 2017

Data: National Resources Defense Council, Department of Energy
The Potential of Solar

- Covering an area in Texas of 100 mi by 100 mi with solar panels would provide enough electricity to power the United States.

Source: Elon Musk

But...its not that easy
Photoelectric Effect

Light (photons!)

Matter (metal)

Electrons
Properties of Light

- Electromagnetic radiation
- Characteristic wavelength (frequency)
- Particle and wave
- Interaction with matter: 1 photon, 1 electron
Semiconductors

- Selective conductivity
- Highly tunable electrical properties
- Silicon is used for most integrated circuit (computer) chips, and most photovoltaics
Molecular Orbitals

Energy

1st “orbital”

2nd “orbital”

3rd “orbital”

Etc.

Nucleus

Bonding

Anti-Bonding
Sp3 Hybridization

109.5°

Source: Jfmelero
Bonding in Materials

* $10^{23}$

Anti-bonding

Bonding
Differences in Materials

Metals – overlapping bands

Semiconductors and insulators – energy gap between bands
Conduction in Semiconductors

Photon energy absorbed

Generation of charge carriers

Electrons (negative)

Holes (positive)
Recombination

- Given the opportunity, the electron will “fall” back into the valence band

- Factors that influence recombination:
  - Impurity concentration
  - Grain boundaries (poly-silicon)
  - Surface quality

- How can we prevent this?
Doping of Semiconductors

n-doped silicon
- extra electron
- group V atom

p-doped silicon
- missing electron (hole)
- group III atom
P-N Junction

“Built-in” Voltage

Hole-rich

Electron-rich

One-way flow of current
The Goal

Current * Voltage = Power
Now that we understand the chemistry let’s take a look at a real panel!
The Challenge of Solar (and other renewables)

• Intermittency!
• Remember supply most always equal demand, so when the sun goes down we have a problem
• Can anyone think of something that might help with this problem?
California’s Challenge – “The Duck Curve”

- Draw electricity demand during the day
- Draw electrical output of solar panel
California’s Challenge – “The Duck Curve”

Sample Net Load – March 31, 2012

The duck curve shows steep ramping needs and overgeneration risk

(ramp need ~13,000 MW in three hours)

overgeneration risk

(from the California Independent System Operator)
Storage is exploding

Source: GTM Energy Storage Monitor 2017
Storage is exploding

- The U.S. storage market will grow 12x in dollar value between 2017 and 2023
- The market will cross the threshold of $18 in annual value in 2019
- In 2023, the U.S. energy storage market’s annual value will reach $3.77 billion

Source: GTM Energy Storage Monitor 2017
Solar + Storage = Match Made in Heaven

• Solar + Storage is like bacon, it makes everything better
• Solar + Storage is useful at any level of our electrical grid outline!

Source: Rocky Mountain Institute, 2015
The duck curve shows steep ramping needs and overgeneration risk.

Sample Net Load – March 31, 2012

Storage can be the ramp

(from the California Independent System Operator)
More Chemistry! - Batteries

• Key aspects of batteries for grid-scale energy storage:
  – Energy density: total energy that can be stored at full charge per weight of battery
  – Power density: power than can be discharged per weight of battery
  – Response time: time to ramp up to maximum power output
  – Lifetime cycles: number of charge/discharge cycles the battery can undergo
  – Efficiency: the amount of the stored energy that is converted into useful work to the grid
Battery Feasibility

- Non-performance factors influencing battery viability:
  - Safety
    - Toxicity
    - Flammability
    - High temperature / pressure
  - Environmental Impact
    - Rare/mining intensive components
    - Recyclability
Lithium Ion Battery

Schematic of Cylindrical Cell

Top cover
Gasket
Insulator
Anode can
Insulator
Cathode
Anode

Cathode lead
Safety vent and CID (PTC)
Separator
Anode lead

Schematic of Prismatic Cell

Terminal plate
Insulator
Gasket
Safety vent
CID
Separator
Cathode lead
Cathode pin
Top cover
Insulator case
Spring plate
Anode can
Anode
Cathode

https://commons.wikimedia.org/wiki/File:Liion-18650-AA-battery.jpg

January 12-13, 2016, California Community Colleges
Zinc-Air Battery

Zinc-air battery functional schematic
Courtesy ReVolt. Source: DOE/EPRI 2013 Electricity Storage Handbook

January 12-13, 2016, California Community Colleges
Vanadium Redox Flow Battery

Principles of the Vanadium Redox Battery
Source: DOE/EPRI 2013 Electricity Storage Handbook

January 12-13, 2016, California Community Colleges
Another real world example - Puerto Rico

More Puerto Ricans are looking for a life beyond the grid.

Photo Credit: Sonnen

Source: greentechmedia.com
Takeaways

• Solar has great potential to power our societies without the devastating effects of emissions
• Storage is a key to realizing solar’s potential!
• There is a lot of opportunity in the solar + storage market space, go forth and conquer!!

We want to talk to you!

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