Tuesday, December 11th….

Announcements….

• Homework 10 (paper/project topics, etc.) due on Thursday (last class).
• Final papers/projects will be due by 5PM on Friday, December 21st.

To be handed in both as a hard copy (in my mailbox in LGRT 1127A) and on SPARK (as a turnitin assignment).
Are Feed-in Tariffs a Possibility in California?

The California commission is set to recommend renewable energy feed-in tariffs; this would be the first formal endorsement of the policy in the U.S.

by Paul Gipe

In a dramatic about face from previous policy, the California Energy Commission is expected today to recommend that the state adopt feed-in tariffs to spur renewable energy development.

The recommendation is contained within the Energy Commission's 2007 Integrated Energy Policy Report. The Energy Commission is expected to approve the report December 5 at its regularly-scheduled meeting.

The 300-page report concludes in part that the state's current programs have failed to deliver significant amounts of new renewable generation and California will not meet its renewable energy objectives unless corrective action is taken soon.

Feed-in tariffs are widely used in Europe, notably in Germany, France, and Spain.

Renewable sources of energy now supply nearly 12% of Germany's electricity, much of which was installed as a result of the country's groundbreaking Renewable Energy Sources Act or feed-in law.

Under the German program, renewable energy producers are paid a fixed-price for feeding their electricity into the grid. This has led to a boom in the construction of wind turbines, rooftop solar systems and on-farm biogas plants.

Feed-in tariffs "turn homes, farms, and businesses into entrepreneurs who will accelerate our path to clean energy," says Terry Tamminen about the Energy Commission's recommendation. Tamminen is a former Secretary of the California Environmental Protection Agency and was the Chief Policy Advisor to Governor Arnold Schwarzenegger.

The Energy Commission's policy reversal follows the poor results from several years of unfulfilled expectations for renewable energy development in California. California's Renewable Portfolio Standard, the state's current program intended to develop renewable energy, was passed as SB 1078 in 2002 and set a target of 20% renewables by 2017. Though thousands of megawatts of new renewable generation have been contracted in the five years since the program was launched, only 242 megawatts (MW) has actually been built.

In 2006 alone, German farmers installed 300 MW of solar photovoltaics on barn roofs. German homeowners installed an equal amount. Altogether, Germans installed 4,000 MW of new renewables last year.

"[Feed-in tariffs] turn homes, farms, and businesses into entrepreneurs who will accelerate our path to clean energy."

Terry Tamminen, former Secretary of the California Environmental Protection Agency
Letter from Silicon Valley: Now Hiring, Green Collar Jobs

by David Hochschild

In the coming weeks, the President and Congress are expected to vote on legislation that could dramatically increase the production of renewable energy in the United States, improve fuel-economy, and create a long-term tax credit that will bring solar power into the mainstream. The backdrop to this conversation looks very different than it did only a few years ago. This year's Nobel Peace Prize bestowed the ultimate legitimacy on the science of global warming and escalating instability in the Middle East is highlighting, as never before, America's need for greater energy independence.

What remains unchanged, however, is the primary argument made by opponents of bold legislation to reduce pollution and promote renewable energy—that it will harm the economy. In truth, the opposite is more likely to be true. A failure to fully embrace solar and other clean technologies could undermine the biggest opportunity for job growth that America possesses.

As the dollar plummets to all-time lows and new jobless claims rise, supporters of the status quo argue that now, when our economy appears vulnerable, is when we can least afford to tackle an issue like global warming and devote scarce resources to promoting clean energy. But a look across the Atlantic shows that our economic competitors are discovering otherwise.

A recent study by the German government found that 245,000 people were employed by the renewable energy industry in Germany in 2006, up 50% since 2004. Almost two-thirds of the green collar jobs created in the German renewable energy economy are the result of a single law—the German Renewable Energy Sources Act—which was instituted at a time when Germany's economy was weak. The majority of these workers are involved in designing, manufacturing and installing solar panels and wind turbines, using skills that are similar to those of American workers in industries like auto manufacturing that have cut jobs in recent years. Today, Germany's economy is vibrant. According to current market trends, the German renewable energy industry is expected to surpass the German auto industry in just ten years.

To critics who suggest the American economy is simply ill-suited to adapt to transformations this big, there is news to report. It is already starting to happen. This year, California is on track to install more solar power than it has in the last 25 years combined, and innovative new solar companies are opening up shop and hiring new workers at an unprecedented rate around the state. This rapid growth is the result of a state law passed last year to create the largest solar incentive program in the country. If a Republican governor and a Democratic legislature can come together to get the job done for the largest economy in the union, surely Congress and the White House can get it done for the nation.

David Hochschild is vice president at Solaria Corporation, a solar technology company in Silicon Valley. He also serves as a commissioner on the San Francisco Public Utilities Commission.
We’re working on the question of how **photovoltaic panels** work?

How do they turn sunlight into electricity?

The basic ingredient is a semiconductor device called a PN-junction, a layer of N-doped silicon on top of a layer of P-doped silicon.

Recall that N-doping means an excess of negatively charged electrons, while P-doping means an excess of holes, which carry positive charge.
PN-junctions...

- The excess electrons near the N-side of the junction will tend to migrate to fill the holes near the P-side of the junction.
- This leaves the N-side with a net positive charge (because some electrons have left) and the P-side with a negative charge.
- An electric field builds up pointing from the N-side of the junction to the P-side.
- This field opposes the motion of further electrons from the N-side to the P-side.

The migration of charges stops when the energy required for electrons to move against the electric field balances out the energy gain from the electrons filling the unfulfilled bonds on the P-side of the junction.
Let’s understand the physics of the region around the junction in more detail.

- We can make a simple model of this region as a sheet of positive charge in the N-type region separated by some distance from a sheet of negative charge in the P-type region.
- The electric field in between is then constant with magnitude $E$.
- If a free electron starts out at the - sheet it will be accelerated by the electric field over to the + sheet. In the process it will pick up kinetic energy.

$$\varepsilon = q E d$$

Energy  Electron charge  Separation between charge sheets
Energy = q E d

For the electron this is just like rolling down a hill.
- At the top (- sheet) it has potential energy = \( \varepsilon \), but no kinetic energy.
- At the bottom (+ sheet) it has kinetic energy = \( \varepsilon \), but no potential energy.

\[
\varepsilon = q E d
\]

\[
\varepsilon = m g h
\]

Electrical potential energy

Gravitational potential energy
A closely related quantity is known as the **electric potential**

\[ V = \varepsilon / q \]

The electric potential depends only on the electric field configuration and not on the charge that is being accelerated by the electric field.
A closely related quantity is known as the **electric potential**

\[ V = \varepsilon / q \]

The SI unit for electric charge is the Coulomb. Therefore the unit of electric potential is Joules per Coulomb. The name for this unit is the **Volt**, which should sound familiar.

This is the same volt that shows up in all practical electrical things, e.g. a 9 volt battery, the 120 volt electricity in our homes, or high voltage transmission lines.

An electric potential is like a hill that electrons can roll down. As they roll down they pick up energy. This energy can be used to do useful things, the same way that water flowing over a waterfall can be used to turn a waterwheel…..
In class assignment……

How much kinetic energy does an electron pick up in moving through a 1 Volt potential?

\[ V = \frac{\varepsilon}{q} \quad \leftrightarrow \quad \varepsilon = q \cdot V \]

What do you need to know?
In class assignment……

How much kinetic energy does an electron pick up in moving through a 1 Volt potential?

\[ V = \frac{\varepsilon}{q} \quad \Leftrightarrow \quad \varepsilon = q \cdot V \]

What do you need to know?

The charge on an electron is \( q = 1.6 \times 10^{-19} \text{ C} \).
In class assignment……

How much kinetic energy does an electron pick up in moving through a 1 Volt potential?

\[ \varepsilon = q V \]
\[ = (1.6 \times 10^{-19} \text{ C})(1 \text{ Volt}) \]
\[ = (1.6 \times 10^{-19} \text{ C})(1 \text{ J/C}) \]
\[ = 1.6 \times 10^{-19} \text{ J} \]

The charge on an electron is
\[ q = 1.6 \times 10^{-19} \text{ C.} \]

1 electron volt (1 eV) is the amount of kinetic energy an electron picks up by accelerating across a 1 V potential difference.
\[ 1 \text{ eV} = (1.6 \times 10^{-19} \text{ C})(1 \text{ J/C}) = 1.6 \times 10^{-19} \text{ J} \]
Finally, back to PN-junctions and solar cells. How does the sun come into this?

- The electric field in the junction region is characterized by an electric potential $V$.
- If a photon with sufficient energy hits an electron in the P-type region, it can knock loose an electron, creating a mobile electron and a mobile hole.
- If the hole is near the junction, it will be swept into the N-type region by the electric field picking up energy $\varepsilon = qV$.
- If there is a conducting path back to the P-type side, the hole will flow back there to restore charge neutrality. Along the way it can transfer the energy it has picked up in going across the junction!
- If the photon hits in the N-type region, it is the hole that does the moving, but the result is still a net current flowing in the same direction.

This might be a light bulb, or the whole electrical grid.
An actual solar cell has a few more layers……
- antireflective coating because silicon itself is quite reflective.
- glass cover to protect the solar cell from damage.
- Front and back electrical contacts to carry the electric current between the sides of the cell.
When the sun shines on a PV cell, a current flows. A current is a rate of flow of charge. The unit of current is **Amperes**.

1 Ampere = 1 Coulomb/second

Recall that Coulomb is the basic SI unit of electric charge.

When sun is shining on a solar cell and current is flowing, how much electrical power does it generate?
When the sun is shining on a solar cell and current is flowing, how much electrical power does it generate?

The two ingredients are the voltage of the solar cell (which characterizes the strength of the PN-junction’s electric field) and the size of the current running through the cell.

A charge moving across the PN-junction picks up kinetic energy

\[ \epsilon = q V \]

Power is the amount of energy per second. The amount of charge going through the PN-junction per second is the current \( I \).

Therefore…….

\[ P = I V \]

\[ \text{power} = (\text{current})(\text{voltage}) \]
power = (current)(voltage)

\[ P = I \cdot V \]

- The voltage of a typical silicon solar cell is about 0.5 Volts.
- The current depends on the area of the cell and on how much light is shining. For a typical (10 cm) x (10 cm) cell in 1000W/m² sunlight, the current would be about 2 Amperes.
- The power would then be \( P = (2 \text{ Amperes}) \cdot (0.5 \text{ Volts}) = 1 \text{ Watt} \)
I = 2 Amperes  \quad V = 0.5 Volts
P = (2 Amperes) (0.5 Volts) = 1 Watt

Typically in applications we want large numbers for all these quantities…. This is accomplished by combining solar cells in **series** and in **parallel**.

Combining cells in **series** increases the voltage. Voltages add in series.

Combining cells in **parallel** increases the current. Currents add in parallel.
The solar cells are wired together and assembled into **panels** with the desired specifications (voltage, current and power). This panel has 72 solar cells.

Solar panels are then assembled into arrays to get more power.
Solar panels produce DC (direct) current, whereas most household appliances work on AC (alternating current).

PV arrays are connected to devices called **inverters** which convert DC to AC.

Most residential PV systems are tied into the electric grid. If at any given time, the home is producing more electricity than it is using, that power flows into the grid and the home meter runs backwards! This is called “net metering” and is mandated by the federal Energy Act of 2005.

Unfortunately, if your residence produces more electricity than it uses over the course of a billing period, the electric company isn’t required to pay you anything for it.
Germany has been very successful at promoting the growth of renewable energy technologies by requiring electric companies to pay a premium for small scale renewable energy.
Getting back to technologies….

Solar thermal is another route for getting electricity from the sun’s energy.

A more technical name is **Concentrated Solar Power** (CSP) plants. The key features of CSP schemes are

1) A configuration of mirrors to **concentrate** the sun’s energy.

2) A mechanism to change the orientation of these mirrors to **track** the sun’s movement through the sky.

3) A **heat engine** of some sort to turn the concentrated thermal energy into electricity.

Often this involves steam driving a standard turbine generator.
**Parabolic trough reflectors** concentrate solar energy on an heat transfer material (usually oil) that runs through tubes that run along the focal line of the trough.

The heat transfer material runs through the tubing to the central generating plant.

The parabolic mirrors tilt to track the angle of the sun’s rays.
Solar Electric Generating Systems (SEGS) is the collective name for 9 adjacent solar power plants in California’s Mojave desert (in Kramer Junction, CA) all using parabolic troughs.

The plants have total capacity of 354 MW, making them the largest solar plant of any kind in the world.
Another strategy is the Solar Power Tower. A collection of flat tracking mirrors focus the sun’s energy on a heat transfer material at the top of the tower.

The PS10 solar tower near Seville in southern Spain has 624 mirrors (each 120 m² in area). The tower is 35 stories tall and holds both the heat transfer medium (water) and the steam turbine generator. The power output is 11 MW, enough for about 6000 homes.

Opened in March 2007, it is the first of a complex of adjacent plants totalling 300 MW to be built.
• Power from the PS 10 plant is 3 times more expensive than fossil fuel plants. PS 10 was built with EU assistance meant to encourage growth in the renewable energy industry.

• Costs are expected to fall (as they have for wind power) with improved technologies and economies of scale.

• Molten salts, which have better heat storing properties than water, can also be used as heat transfer materials.

• Thermal energy in the molten salt can be stored until night and used to smooth out the electrical generation from the plant over the day-night cycle.
Small totals, but huge increases each year.
Wind & Biofuels show tremendous growth

The data only shows marketed power. So, the growth in residential and commercial based small scale solar power doesn’t show up.

### Table ES-1. Renewable Energy Profile, 2006

<table>
<thead>
<tr>
<th>Renewable Energy Consumption</th>
<th>Quadrillion Btu</th>
<th>Change 2005-2006 (Percent)</th>
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</thead>
<tbody>
<tr>
<td>Total</td>
<td>5.844</td>
<td>6.9</td>
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<tr>
<td>Biomass</td>
<td>3.277</td>
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<td>Biofuels</td>
<td>0.758</td>
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<td>Waste</td>
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<tr>
<td>Wood Derived Fuels</td>
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<tr>
<td>Geothermal Energy</td>
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<td>Hydroelectric Conventional</td>
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<tr>
<td>Solar/ PV Energy</td>
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<td>6.5</td>
</tr>
<tr>
<td>Wind Energy</td>
<td>0.268</td>
<td>45.1</td>
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</tbody>
</table>

Source: Table 1 of this report.