Determining the Power Output of a Dye Sensitized Solar Cell

Wisconsin Energy Institute
Energy Institute for Educators
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Let’s Examine Some Global Trends in Energy Consumption
We live at a historic time...

**Global Wind Energy Growth**

- Estimated 6.8 GW of wind added in the US in 2016

Source: GWEC

**Global Solar PV Energy Growth**

- Estimated 13.9 GW of solar PV added in the US in 2016

Source: IEA

**Global Biofuels Growth**

- Estimated 16.9 B gal of biofuel added in the US in 2016

Source: US EIA

**Green Electricity Purchasing Growth**

Source: NREL
Record low cost clean electricity!

US Wind Energy Selling At Record Low Price of 2.5 Cents per kWh

"Wind energy prices — particularly in the central United States — have hit new lows, with utilities selecting wind as the low cost option," Berkeley Lab Senior Scientist and report co-author Ryan Wiser said.

August 19, 2015
By Andrew Burger
Contributor

Wind power prices have dropped down to an all-time low of just 2.5 cents per kWh, far below the national average of around 11 cents per kWh, according to the DOE’s 2014 ‘Wind Technologies Market Report.’

The all-time low is the weighted average of prices offered to utility buyers from projects negotiating contracts in 2014. The majority were located in the interior of the U.S., an area that includes states such as Oklahoma and Texas where wind-power potential is highest, study co-author and Berkeley Lab Electricity Markets and Policy Group research scientist Mark Bolinger pointed out in an interview.

New Low Solar Price Record Set In Chile — 2.91¢ Per kWh!

August 18th, 2016 by Saurabh Mehanatra

Originally published on sister site CleanTechnica.

Update #2: The lowest solar price bid is now 2.42¢/kWh.

Update: It was Solarpack that set the record-low bid, not SunEdison, as originally indicated in this article. The article has been updated accordingly.

A couple of companies managed to secure a huge share in the latest electricity auction held in Chile, and auction where a new record-low solar bid was set (globally) and wind projects took 40% of the auctioned power contracts.

According to media reports, Mainstream Renewable Power Ltd. and Empresa Nacional de Electricidad/Chile SA won more than two-thirds of the electricity supply auction in Chile.

Meanwhile, Solarpack set a new record-low solar bid at 2.91¢/kWh ($29.1/MWh). That beats the 2.99¢/kWh bid a Masdar Consortium provided for an 800 MW solar power project in Dubai earlier this year.
Wind Now Employs More People Than Coal

Here's a talking point in the green jobs debate: The wind industry now employs more people than coal mining in the United States.

Wind industry jobs jumped to 85,000 in 2008, a 70% increase from the previous year, according to a report released Tuesday from the American Wind Energy Association. In contrast, the coal industry employs about 81,000 workers. (Those figures are from a 2007 U.S. Department of Energy report but coal employment has remained steady in recent years though it's down by nearly 50% since 1986.) Wind industry employment includes 13,000 manufacturing jobs concentrated in regions of the country hard hit by the deindustrialization of the past two decades.

The US solar installation sector employs 77% more people than the domestic coal mining industry, according to the report. Photograph: Bloomberg/Bloomberg via Getty Images

The US solar industry now employs more workers than oil and gas, a new report from the Solar Foundation claims, with most of the jobs in power panel installation.

Last year, the US solar industry grew by 20% for a third year in a row, according to the Foundation's National Solar Job Census 2015. By the end of 2015, it employed nearly 209,000 solar workers, more than those employed in oil and gas extraction.
Trends in RE Education

2000: Few RE education programs
      Non-profit advocates and pioneers

2017: LOTS of RE education programs
      Many schools and colleges engaged
      Many new RE instructors
      Teacher Prep? Prof Dev?
      Access to curriculum?
      Access to equipment?
      Best Practices?

CREATE
Center for Renewable Energy
Advanced Technological Education
So let’s take a closer look at solar technology...
1954 – Bells Labs PV Solar Cells

*Something New Under the Sun.* It’s the Bell Solar Battery, made of thin discs of specially treated silicon, an ingredient of common sand. It converts the sun’s rays directly into usable amounts of electricity. Simple and trouble-free. (The storage batteries beside the solar battery store up its electricity for night use.)

**Bell System Solar Battery Converts Sun’s Rays into Electricity!**
Traditional Silicon Solar Cell Construction

Approx. ~ 0.5 Volts DC
A low-cost, high-efficiency solar cell based on dye-sensitized colloidal TiO$_2$ films

Brian O'Regan* & Michael Grätzel†

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The large-scale use of photovoltaic devices for electricity generation is prohibitively expensive at present: generation from existing commercial devices costs about ten times more than conventional methods. Here we describe a photovoltaic cell, created from low-to medium-purity materials through low-cost processes, which exhibits a commercially realistic energy-conversion efficiency. The device is based on a 10-μm-thick, optically transparent film of titanium dioxide particles a few nanometres in size, coated with a monolayer of a charge-transfer dye to sensitize the film for light harvesting. Because of the high surface area of the semiconductor film and the ideal spectral characteristics of the dye, the device harvests a high proportion of the incident solar energy flux (46%) and shows exceptionally high efficiencies for the conversion of incident photons to electrical current (more than 80%). The overall light-to-electric energy conversion yield is 7.1–7.9% in simulated solar light and 12% in diffuse daylight. The large current densities (greater than 12 mA cm$^{-2}$) and exceptional stability (sustaining at least five million turnovers without decomposition), as well as the low cost, make practical applications feasible.
Dye Sensitized Solar Cell Construction
**Electrical Terms and Measures**

**Electric Potential (aka Voltage)**– How much energy is available to push each charge
Measured in Volts (Joules/Coulomb) while the meter is in PARALLEL with the load

**Current (aka Amperage)** – The rate at which charge flows through a circuit
Measured in Amps (Coulombs/second) while the meter is in SERIES with the load

**Power (aka Wattage)** – The rate at which energy is transferred
Measured in Watts (Joules/second)
Power = Current * EMF
(Watts = Amps*Volts)

**Direct Current** – the charges move in only one direction.
Electrochemical devices all produce DC (batteries, capacitors, fuel cells, solar cells)

**Alternating Current** – the charges back and forth reversing direction
Spinning devices (machines) typically produce AC (alternators, turbines, etc.)
Now, Let’s Build a Dye Sensitized Solar Cell!

Institute for Chemical Education: Overview

Communicating Science—that’s what ICE is all about. We are a national center for science educators to develop and disseminate ideas. Our efforts are evident in kits and publications, in programs for students and for teachers, and in research in chemical education. Since its founding in 1983, ICE has led the drive to help teachers revitalize science in schools throughout the United States. From "approachable" science for K-3 teachers (Super Science Connections) through nanoscale exhibits for the public to research experiences for teachers, ICE has something for you:
1. Apply a coat of titanium dioxide suspension on conductive glass and use heat to dry.

This Step was done for you ahead of time…
Crush 5 or 6 berries with 2mL of Deionized water and filter to remove solid material.

Soak TiO2 coated slide for ~ 5 min to absorb dye. Remove and air dry.
3. Coat a second piece of glass with the carbon from a pencil.

Use multimeter to determine which side of the glass has the conductive coating (resistance of ~ 10-30 ohms)

Color the conductive side of the glass using a graphite pencil to deposit a uniform layer of the graphite catalyst.
4. Put the two pieces of glass together with the conductive sides facing one another. Add a light source and hook the cell up to multimeters to collect output data.
Questions
- What is the effective resistance of the “load” in this circuit?
- How much current will flow in this situation?
-- How much power does the panel produce in this situation?

Let’s Measure OPEN CIRCUIT Voltage (Voc)

1000 W/m²

DC Volts

load
Now Measure Short Circuit Current (Isc)

Questions
- What is the effective resistance of the “load” in this circuit?
- What is the Voltage in this situation?
- What can we say about the magnitude of the current under short circuit conditions?
- How much power does the solar panel produce in this situation?
For a solar panel to deliver power, it must be operated under conditions where it can supply BOTH Electric Potential (in Volts) and Current (in Amps)

We can tweak the system to determine the MAXIMUM Power, by adjusting the load that we place in the circuit
How a potentiometer works:

Potentiometer - AKA Rheostat - AKA Variable Resistor – AKA variable Load
Commonly encountered as dimmer switches and volume knobs

Resistance is measured in Ohms
You are using 1K Ohm Potentiometers, they are rated for up to 3 Watts
Questions
- How does the Potential (in Volts) and Current (in mAmps) change as you adjust the load?
- Under what circumstances would the PV panel produce the MAXIMUM power?
Goal – Determine $P_{\text{max}}$ for your solar cell

- Use a potentiometer as an adjustable load
- Gather pairs of $(x,y)$ data points (Volts, mAmps)
- Collect 5 to 10 points ranging from your minimum to your maximum voltage *
- Find the point that appears to give reasonably high potential (in volts) and high current (in mAmps). Calculate the power output $\text{Power} = \text{Current} \times \text{Electric Potential}$ ($P = I \times E$)

Extra Credit:
- Create a scatter plot of Current vs Potential for your data using graph paper or an excel spreadsheet
- Determine the efficiency of your solar panel
  
  $\text{Efficiency} = \frac{P_{\text{max \; electric\; out}}}{P_{\text{solar\; in}}}$
The remaining slides are for discussion purposes after the experiment is completed.
Typical Solar IV Curve
Typical Solar IV Curve

$I_{sc}$

$P_{mp}$

$V_{mp}$

$V_{oc}$

Current (A)

Power (W)
Global Leaders in Dye Solar Cell Technology
NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.
Where can you learn more about Renewable Energy and Solar Power?
Wisconsin K-12 Energy Education Program

KEEP Energy Education Courses

KEEP is a program of the Wisconsin Center for Environmental Education (WCEE). The WCEE offers environmental education courses that qualify for Wisconsin continuing education credits including these KEEP energy education courses (click on these links to read course descriptions):

- **NRES 630** - Energy Education in the Classroom
- **NRES 631** - Selected Topics in Energy Education (Topics Vary)
- **NRES 632** - Doable Renewables: Renewable Energy Education in the Classroom
- **NRES 633** - Energy Education: Concepts and Practices - Online Course
- **NRES 634** - School Building Energy Efficiency Education
- **NRES 635** - Renewable Energy Education - Online Course

KEEP courses help educators in all grade levels and subject areas integrate energy concepts into the curriculum using various teaching strategies and assessment techniques. Prepare your students to be innovative leaders while they gain 21st century skills to solve energy issues.
Energy Institute for Teachers
The NREL Energy Institute for Teachers is a five-day workshop that offers educators lessons and resources to integrate renewable energy and energy efficiency components into existing courses in subjects ranging from chemistry and physics to biology and environmental science classes.

During the week-long workshop, teachers participate in a variety of activities tied to NREL research including:

- Building and testing wind turbine blades utilizing multi-meters and water pumps
- Testing solar panels creating current voltage curves using rheostats and multimeters
- Determining the optimum form of lighting based on the bulb's brightness, its cost and its power requirements
- Chemically producing biodiesel fuel and performing quality control viscosity tests
- Meeting scientists and touring the world class facilities at National Renewable Energy Laboratory.

Who: Middle and High School STEM Teachers
When: July 18–22, 2016, from 8 a.m. – 4:30 p.m.
Where: NREL Education Center, 15013 Denver West Parkway, Golden, CO 80401

Program Requirements
- Participate in the 1 week summer program.
- Implement one lesson in the fall 2016 or spring 2017.
- Receive a stipend of $250 for the 1 week program.
- $250 for submission of completed lesson plan.
- $300 follow-up fall implementation.
- Receive resource books and materials.
- Receive credit, which is available through Colorado School of Mines.

Applications due March 4, 2016. Space is limited.
The Third Annual
STEM Educator Solar Institute
Sponsored by the
Center for Renewable Energy Advanced Technological Education

Learn how to teach solar principles in effective, engaging ways in your classroom! Join us in Madison for the third annual STEM Educator Solar Institute. At the Institute, you’ll install and commission a residential size solar photovoltaic array. In addition, you’ll perform (and take with you) hands-on classroom lab activities that will enable you to bring solar energy to life in your classroom.

Madison WI, July 25-27, 2017
Seattle, WA Aug 8-10, 2017
See www.CreateEnergy.Org for more info, newsletter, webinars, email list etc.
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Questions?