Introduction to Solar Energy Technology

Ilya Chernyakhovskiy, NREL

July, 2018
Global Solar Energy Growth

- **Europe**
- **Americas**
- **Middle East and Africa**
- **Asia-Pacific**
- **China**
- **Rest of the world**

**Global total:** no split-up by region available yet. Forecast for 2018.
Technology costs continue to decline
Module costs are coming down

In Q1 '17, module costs were reported between $0.31/W and $0.34/W.
- Q1 '17 costs for First Solar and Jinko Solar were, on average, 17% less than Q1 '16, though these two companies may not be representative of the industry as a whole.
- As prices have come down, fewer companies are publicly reporting manufacturing costs.
  - Canadian Solar did reiterate its $0.29/W cost target by year end.

Sources: Company figures based on Q1 '17 (and previous) SEC filings by the respective companies. Deutsche Bank (07/18/17)
Solar prices can be lower than new coal & new gas plants

Solar vs. Thermal Plant Price Comparison (2016)

<table>
<thead>
<tr>
<th>Power Plant Location and Type</th>
<th>Cents/kilowatt hour (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mexico-Sept 2016 Solar</td>
<td>2.5</td>
</tr>
<tr>
<td>Mexico-Sept 2016 Natural Gas</td>
<td>3.2</td>
</tr>
<tr>
<td>Chile-2016 Solar</td>
<td>2.9</td>
</tr>
<tr>
<td>Chile-2016 Natural Gas</td>
<td>4.8</td>
</tr>
<tr>
<td>Chile-2016 Coal</td>
<td>5.4</td>
</tr>
<tr>
<td>Chile-2016 Solar</td>
<td>2.9</td>
</tr>
<tr>
<td>UAE-2016 Solar</td>
<td>2.9</td>
</tr>
<tr>
<td>UAE-Commodity Market Natural Gas</td>
<td>5.8</td>
</tr>
<tr>
<td>UAE-Hassyan Coal</td>
<td>4.2</td>
</tr>
</tbody>
</table>
There Are More Jobs in Solar than Oil and Gas, Coal Extraction in the U.S.
Employment grew 6 percent in solar and slumped 18 percent in upstream oil and gas and support services.

Solar Energy Systems
ENERGY FROM THE SUN

EVERY 15 MINUTES ENOUGH SOLAR ENERGY REACHES THE EARTH TO SUPPLY THE EARTH'S ENERGY NEEDS FOR AN ENTIRE YEAR

- About 1350 W/m² (the solar constant) continuously reaches the edge of the earth's atmosphere
- About 1000 W/m² continuously reaches the earth's surface at the equator on a clear day
  - Remaining energy is absorbed or reflected by the atmosphere
Solar Radiation

- Some solar energy is absorbed by the atmosphere.
- The clearness index is the ratio of the radiation at the edge of the atmosphere and at the surface of the earth.

Solar Radiation Components

- **Direct normal (beam)**
  - Radiation arrives at collector in direct line from sun

- **Diffuse**
  - Radiation scattered by molecules, aerosols and clouds, arrives at collector from all directions of the sky
  - PV can use both direct and diffuse radiation

\[
\text{Global Radiation} = \text{Direct Normal} + \text{Diffuse}
\]
What is Solar PV?

- Photovoltaic (PV): Photo = light, voltaic = electricity
- The photovoltaic effect is the conversion of light into electricity
- Solid-state: no moving parts!
- A single 1 cm$^2$ cell produces about 1 W at 0.5 V

Solar cells produce DC current
• Solar cells are interconnected to form modules, which in turn can be interconnected to form arrays
Utility-scale solar PV

- Fixed tilt
- 1-axis and 2-axis tracking
- Benefits:
  - Cost (fixed)
  - Production (tracking)
  - Timing (tracking)
Distributed solar PV
Stand Alone Lighting and Charging

- Solar panel: 10x10 cm <10 Wp
- Storage
  - Lithium-ion battery:
    - High energy density: 150-200 kWh/m³ – 40kWh/ton
    - Low weight: average 7kg, compared to 35kg for lead-acid battery
    - High efficiency: 95-100%
    - Long cycle life: average life >20 years; >3000 cycles at 80% depth of discharge
- LED lights:
  - High brightness: >200 lumens/bulb, compared to 150 lumen oil lamp
  - Long life: >20 years considering 4hrs/day usage
- Charge controller:
  - Protects batter from overcharging or discharging and spikes in voltage
  - Protects PV panel from reverse polarity
Stand Alone Home System

• Generation:
  – Solar: average 10-350 W
  – Small wind turbines: typically 1-10 kW with <7m rotor diameter
  – Hydro: typically run-of-river; pico (5-20 kW), micro (<1000 kW), mini (< 1 MW)
  – Diesel: generator of any size
  – Biomass: multiple "fuels" & technologies to produce electricity
  – Can use single resource, hybrid system, or none (batteries only)

• Storage
  – Batteries - Typically lead acid or lithium ion
  – Typically 100 Ah/12Vdc

• Wiring and control: depends on configuration of generation and loads
  – Charge controller, 10A/10A/12 V DC
  – Inverter for AC loads or rectifier for DC
  – Meters and/or energy management system to balance generation with battery charge and load
Photovoltaics System (Grid Connected)
Inverter

Converts Direct Current (DC) to Alternating Current (AC)

Residential/commercial inverters

Utility-scale inverters
Influences on Solar Resource

- Clouds
  - Geography: mountains, oceans, large lakes

- Air quality
  - Pollution
  - Natural haze
  - Volcanic activity

- Altitude

- Time
  - Diurnal (daily)
  - Seasonal
  - Inter-annual variation (El Nino, La Nina, etc.)
Minor PV module shading can reduce output dramatically

I-V and P-V curves of an unshaded and shaded crystalline-silicon module - shading just 7% of the module area yields a **93% drop** in its output power!

Source: Peter McNutt, NREL
Cloud Variability

Cloud Shadows

25 MW DeSoto Plant
73 hectares

Source: Adam Kankiewicz (WindLogics)
PV Variability & Geographic Smoothing

- Aggregate variability of multiple sites is significantly smoother than individual sites.
- Spatially diversifying systems reduces impacts from single weather events to the entire grid.

Uncertainty and Variability

Variability

Source: Sherry Stout, NREL

Uncertainty

Global Horizontal Irradiance of Uzbekistan

Data Source: Vaisala (www.vaisala.com)
Spatial Resolution: 10 kilometer
Temporal Resolution: multiyear mean, 2006–2015
Variation by Month

- **Tashkent**
- **Samarkand**

![Graphs showing variation by month for Tashkent and Samarkand.](image-url)
Operating and Maintaining PV Systems

• Periodic module cleaning and inspection
• Routine inspection and maintenance
  o Clean collector surfaces
  o Support structures
  o Inspection for loose wiring connections and corrosion
Thank you