Renewable Energy Resources – an Overview
Part I

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World Electricity Generation by Source (2015)

- Fossil fuel: 15714.5 TWh (66.8%)
- Hydro: 3884.6 TWh (16.5%)
- Nuclear: 2536.8 TWh (10.8%)
- Wind: 706.2 TWh (3.0%)
- Solar: 185.9 TWh (0.8%)
- Other renewable: 508.5 TWh (2.2%)

Source: US Energy Information Administration (EIA)
US Sources of Electricity Generation, 2017

Total = 4.01 trillion kilowatthours

- hydro: 7.5%
- wind: 6.3%
- biomass: 1.6%
- solar: 1.3%
- geothermal: 0.4%

- renewables: 17% (including nuclear and solar)
- petroleum: 1%
- coal: 30%
- natural gas: 32%

Note: Electricity generation from utility-scale facilities.
Efficiency of Heat Engines

- Note that nearly 80% of the US electricity is generated in power plants that convert heat into mechanical power.
- A heat engine extracts heat $q_H$ from a high-temperature source, converts part of it into work $w$, and rejects the remaining heat $q_L$ into a low-temperature sink.
- Thermal efficiency $\eta = \frac{q_H - q_L}{q_H} = \frac{w}{q_H}$
- Maximum possible efficiency $\eta_{max} = \frac{T_H - T_L}{T_H}$ (where $T$ is in °K)
- The average thermal efficiency of a thermal power plant is around 30%, while the maximum possible (Carnot) efficiency is nearly double this amount.
Overview

- Solar-derived renewables
  - Photovoltaic (PV)
  - Concentrating Power Systems
  - Biomass
  - Ocean Power
  - Wind Power
  - Hydro Power

- Earth derived renewables
  - Geothermal
Electricity production from renewables

Diagram showing the flow of energy from renewable sources:
- Solar Derived Energy
- HYDRO
- OCEAN ΔT
- CLEAN RENEWABLE FUELS
- THERMAL COLLECTOR
- WIND
- GEO-THERMAL
- POWER PLANT
- ELECTRICITY
What is driving the fast growth?

The growth in renewables over the past decade is driven mainly by the following:

- Global concern over the environment. Furthermore, fossil fuel resources are being drained.
- Renewable technologies are becoming more efficient and cost effective.
- The Renewable Electricity Production Tax Credit, a federal incentive, encourages the installation of renewable energy generation systems.
- Many countries have Renewable Portfolio Standards (RPS), which require electricity providers to generate or acquire a percentage of power generation from renewable resources.
Electricity production from renewables

Diagram showing various renewable energy sources:
- Wind
- Solar
- Ocean
- Hydro
- Geothermal

Conversion pathways:
- Direct Conversion
- Indirect Conversion

Central node: Power Plant

Outputs:
- Electricity
Primary Resource on Photovoltaics

https://www.energy.gov/eere/solar/photovoltaics
Growth in Solar Photovoltaics

Top 10 countries in 2016 based on total PV installed

- China: 78,100 MW (25.8%)
- Japan: 42,800 MW (14.1%)
- Germany: 41,200 MW (13.6%)
- United States: 40,300 MW (13.3%)
- Italy: 19,300 MW (6.4%)
- United Kingdom: 11,600 MW (3.8%)
- India: 9,000 MW (3.0%)
- France: 7,100 MW (2.3%)
World’s Largest PV Plants

State Rankings of PV Installations

See https://openpv.nrel.gov/rankings
PV systems in Nevada

https://www.nvenergy.com/renewablesenvironment/renewables/solar.cfm
Locate Solar Plants in the US

https://www.eia.gov/state/maps.php
Trend of PV cell efficiencies
Trend of bulk PV price/watt (peak)

Price history of silicon PV cells
in US$ per watt

Source: Bloomberg New Energy Finance & pv.energytrend.com
SunShot Progress and Goals

*Levelized cost of electricity (LCOE) progress and targets are calculated based on average U.S. climate and without the ITC or state/local incentives. The residential and commercial goals have been adjusted for inflation from 2010-17.
Renewable Resources

Earth Derived Energy

Solar Derived Energy

Hydro

Clean Renewable Fuels

Ocean ΔT

Wind

GEO-Thermal

Direct Conversion

Direct Conversion

Indirect Conversion

Power Plant

SOLAR CELLS

Direct Conversion

Thermal Collector

Solar Radiation
Linear CSP Systems

- Linear CSP collectors capture the sun’s energy with large mirrors that reflect and focus the sunlight onto a linear receiver tube.
- The receiver contains a fluid that is heated by the sunlight and then used to create steam that spins a turbine driving a generator to produce electricity.
Linear CSP in Nevada: NV Solar I (65 MW)
Power Tower CSP Systems

- Sun-tracking mirrors (heliostats) focus sunlight onto a receiver at the top of a tower. A heat-transfer fluid heated in the receiver is used to generate steam, which in turn is used by turbine generator to produce electricity.

- Some power towers use water/steam as the heat transfer fluid. Other advanced designs are experimenting with molten nitrate salt because of its superior heat-transfer capabilities.
Power Tower CSP in Nevada: Tonopah – 110 MW
World’s largest - Ivanpah Solar: 350 MW
Dish/Engine CSP Systems

- A sun-tracking solar concentrator, reflects the beams sunlight onto a thermal receiver that collects the solar heat.
- The PCU includes the thermal receiver and the engine/generator. A thermal receiver can be a bank of tubes with a cooling fluid—usually hydrogen—that typically is the heat transfer medium and also the working fluid for an engine.
Currently, the most common type of heat engine used in dish/engine systems is the Sterling engine where the heated gas moves pistons and create mechanical power. Grid connection is through an induction machine.
Dish-Engine CSP Testing @ UNLV