EECE325 Fundamentals of Energy Systems

Chapter 4: Distributed Generations

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Chapter 4. Distributed Generation

- 1 Electricity Generation in Transition
- 2 Distributed Generation with Fossil Fuels
- 3 Concentrating Solar Power (CSP)
- 4 Biomass for Electricity
- 5 Micro-Hydropower Systems
- 6 Fuel-Cells

Electricity Generation in Transition

- Opening the T&D grid to independent power producers
- Small-Scale plants
- Energy Efficiency
- Economic Advantage of Co-Generation (Heat and Power) and Tri-Generation (Heat, Power, Cooling)
- Environmental Advantage → transition toward small-scale, decentralized energy systems
- Distributed Generation (DG): "small-scale power generation, in the size up to 50 MW, located on the distribution system close to the point of consumption"
- Owners of DG: Utility and Customers or Sellers to Utility

Distributed Generation

- Micro-Gas Turbine
- Reciprocal Internal Combustion Engine
- Stirling Engine
- Concentrating Solar Power
  - Solar Dish
  - Solar Parabolic Trough
  - Central Receiver System
- Micro Hydro
- Pumped Hydro
- Fuel Cells

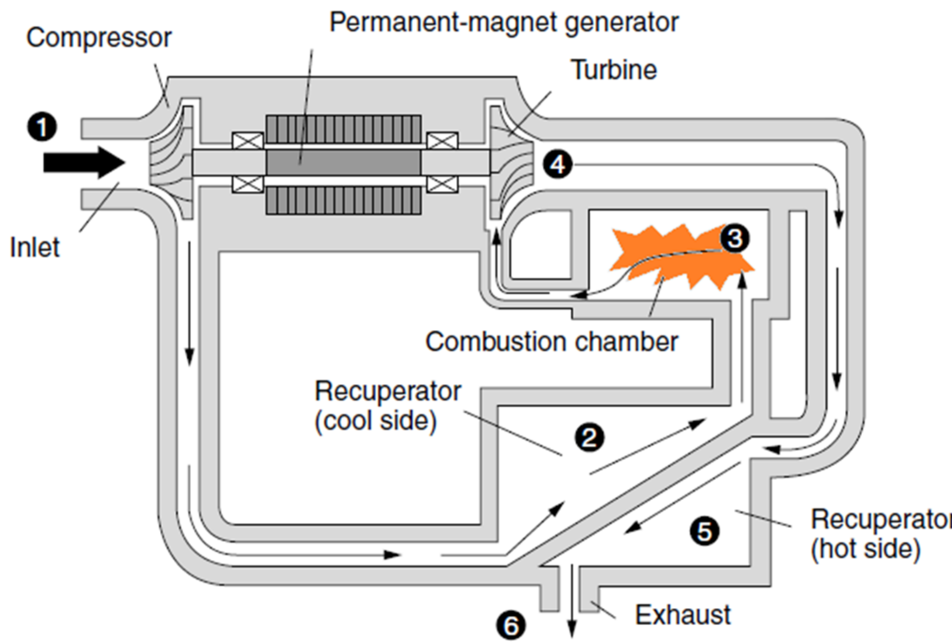
Micro-combustion Turbines

- Traditional gas turbine (for utility and industrial facilities): ~ 100 MW
- A new generation of very small gas turbines
  - Micro—turbine
  - 0.5kW – 500kW range

Specifications for Example Microturbines[a]

Manufacturer, Model	Capstone C30
Rated power	30 kW
Fuel input	390,130 Btu/hr (LHV)
Heat rate (LHV)	12,800 kJ (13,100 Btu)/kWh
Efficiency (LHV)	26%
Exhaust gas temp.	275°C (530°F)
NO_x emissions	< 9 ppmV (0.49 lb/MWh)
CO emissions	< 40 ppmV @ 15% O2
Turbine rotation	96,000 rpm
Dimensions H, W, D	1.90 × 0.71 × 1.34 m (75 × 28 × 53″)
Weight	478 kg (1052 lb)
Noise	65 dBA @ 10 m (33 ft)

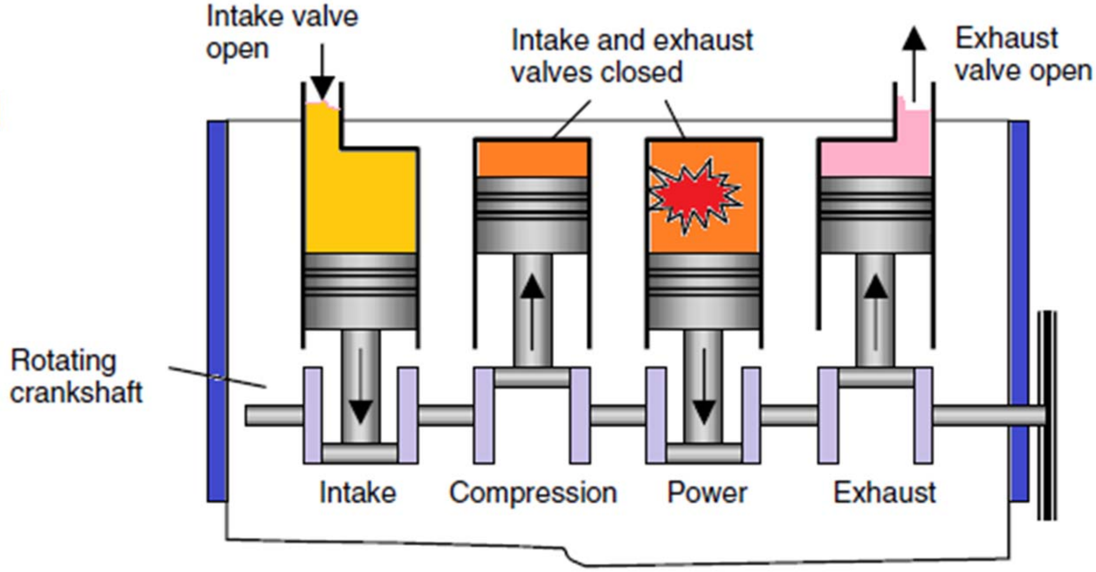
[a] Emissions are for natural gas fuel.



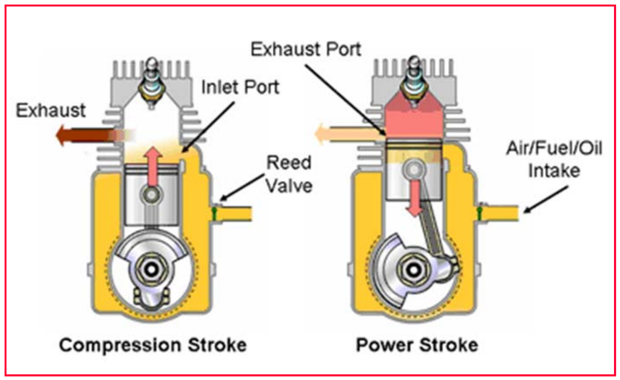
Air is compressed (1), preheated in the recuperator (2), combusted with natural gas (3), expanded through the turbine (4), cooled in the recuperator (5), and exhausted (6). From Cler and Shepard (1996).

Reciprocating Internal Combustion Engines (ICE)

- Reciprocating (that is, "Piston-Driven") ICE
- ICE: combustion takes place inside engine
- Size: 0.5 kW – 6.5 MW
- Efficiency: 37 – 40 %(LHV)
- Fuels: Gasoline, Natural Gas, Kerosene, Propane, Alcohol, Waste Gas, Hydrogen
- Conventional 4-stroke cycle found in automobiles
- **Alternative 2-stroke engine**: (Intake + Exhaust & Power)
  - Not as efficient as 4-stroke
  - More emission

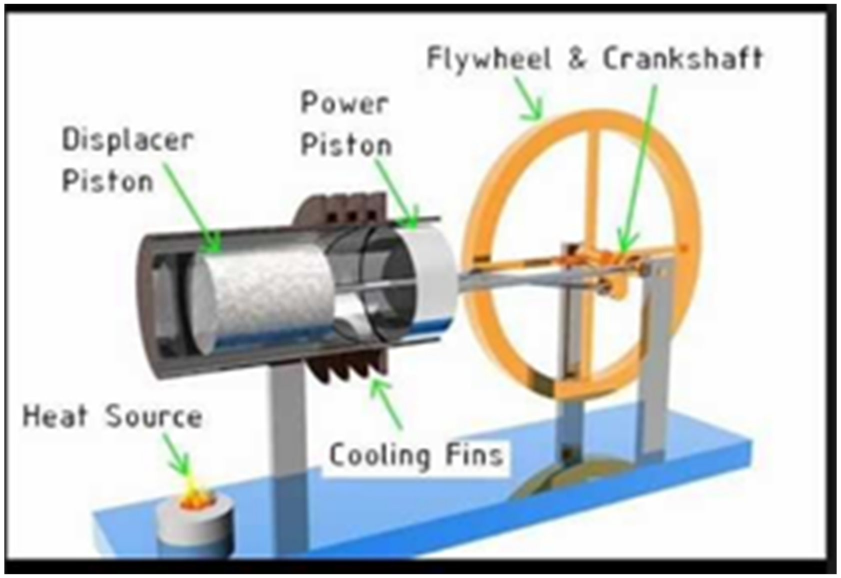


Basic four-stroke, internal combustion engine.



Stirling Engines

- External Combustion Engine (ECE) – Energy is supplied to the working fluid from a source outside of the engine →Steam Cycle Engine
- Stirling Engine: Piston-driven reciprocating engine of external combustion
- ECE: Any fuel
- Piston Movement:
  - Controlled by rotating crankshaft



Stirling, Home and Solar on Pinterest
Pinterest - 480 × 360 - Search by image

Stirling Engine → Electricity

- Engine Size: 1kW – 25 kW
- Fuel: Propane
- Efficiency: 30 % (or less)
- Quiet (fuel burns slow)
- Low Emission
- No Vibration
- Market: Automobiles, boats, RVs, small aircraft, (and submarines)
- Market for Power Generation
  - Small-scale power systems for battery charging
  - Other off-grid application
  - Co-Generation

1 kW Developer's Kit Specifications

Description	Value
Nominal Engine Power Output	1000 W
Voltage Output	390 – 450 V dc*
Propane Consumption @ 600 W Output	13 Liters/Day
Propane Consumption @ 1000 W Output	22 Liters/Day
Maximum Sustained Head Temperature	550 °C
Warranty – Engine	2 years
Warranty – Balance of Plant Components	None
Ambient Operational Environment	6 – 70 °C
Ambient Non-Operational Environment	-25 – 70 °C
Max. Sulphur Content of Fuel	30 mg/m^3
Fuel	Propane or Natural Gas
Engine Efficiency	>23%
System Efficiency	12% – 14%

sunpowerinc.com/1kw-stirling-engine/

WhisperGen on-grid Stirling Engine unit.
Source URL: http://www.whispergen.com/

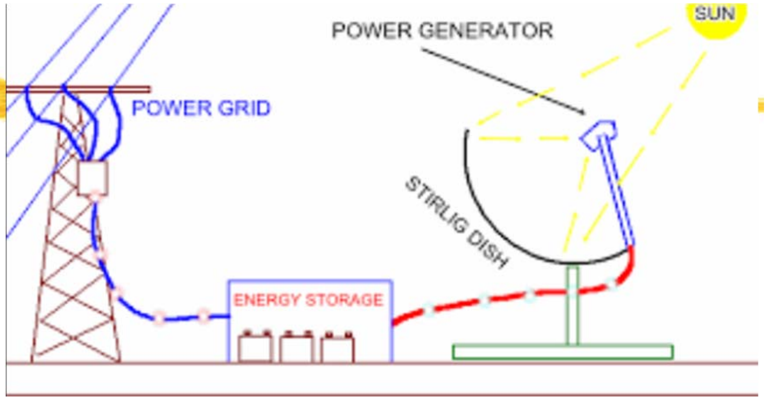
Concentrating Solar Power (CSP) Technologies

- CSP
  - 1
  - 2
  - 3
  - 4
- Prototypes
  - 1
  - 2
  - 3

love4earth - STIRLING POWER PLA.
love4earth - Home - 729 × 386 - Search by image

1 Solar Dish – Stirling Engine Power System

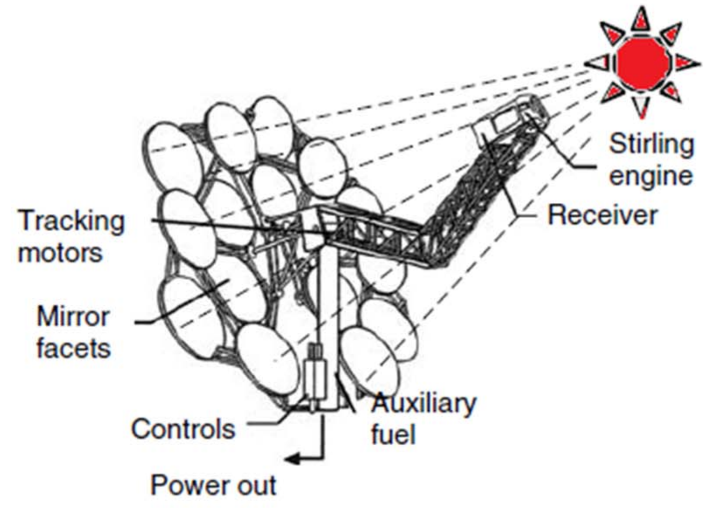
- Concentration: Multiple mirrors of a parabolic dish shape
- Dish tracking for sun and focusing on thermal receiver
- Thermal receiver converts to heat that delivers to a ( ) engine
- Heat Transfer Medium and Working fluid: ( ) or ( )
- Cold Side of Stirling engine: Water-cooled, fan-augmented radiator
- Efficiency: 20% (average), 30 %(record measured peak) → Highest Efficiency in all solar conversion technology
- Two Competing Systems: 25 kW with 20% Efficiency
  - Dish by SAIC (Science Applications International Corp), Stirling Engine by STM (Stirling Thermal Motors)
  - Boeing/SES (Stirling Energy Systems)



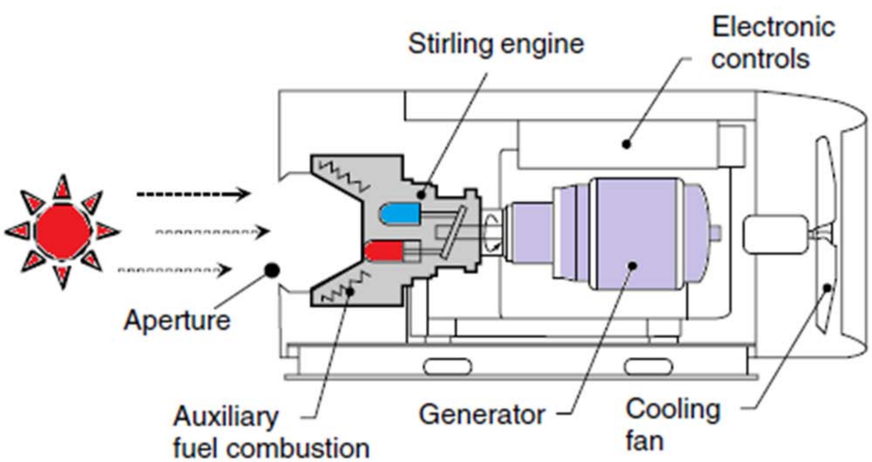
Solar Dish – Stirling Engine Power System

- ⌘ Dish (SAIC)
- ⌘ Stirling Engine (STM)

- ⌘ Best for sunny deserts: CA, AZ, NV
- ⌘ Short construction time
- ⌘ Easy permit
- ⌘ No emission



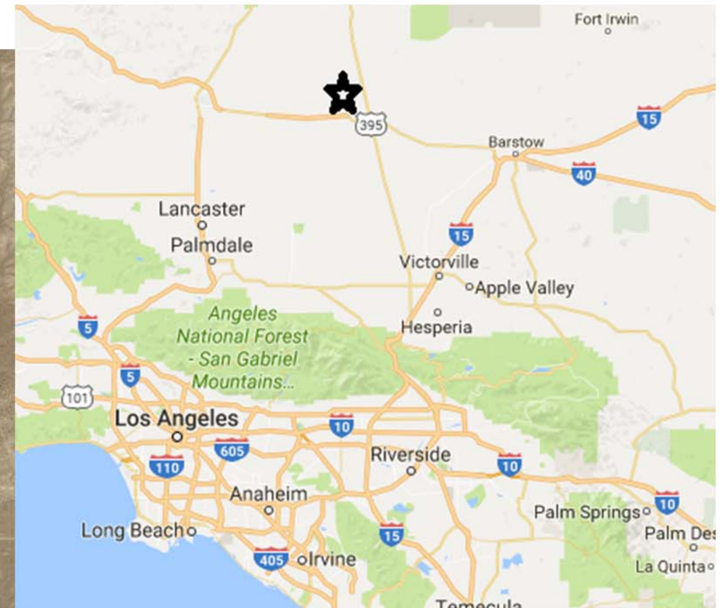
(a) The complete SAIC/STM system



(b) The STM Stirling engine.

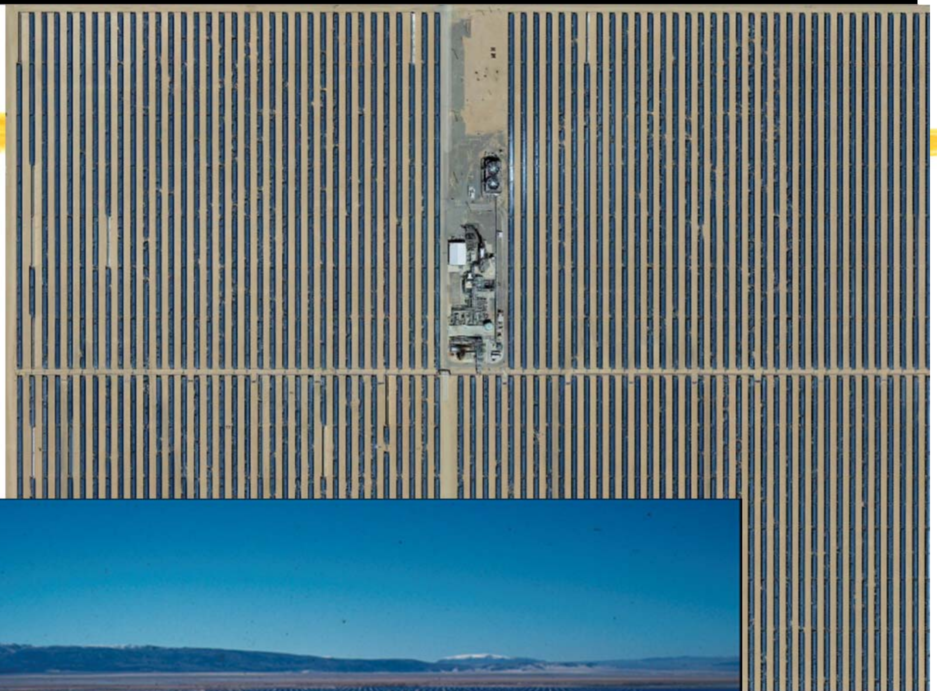
2 Parabolic Trough

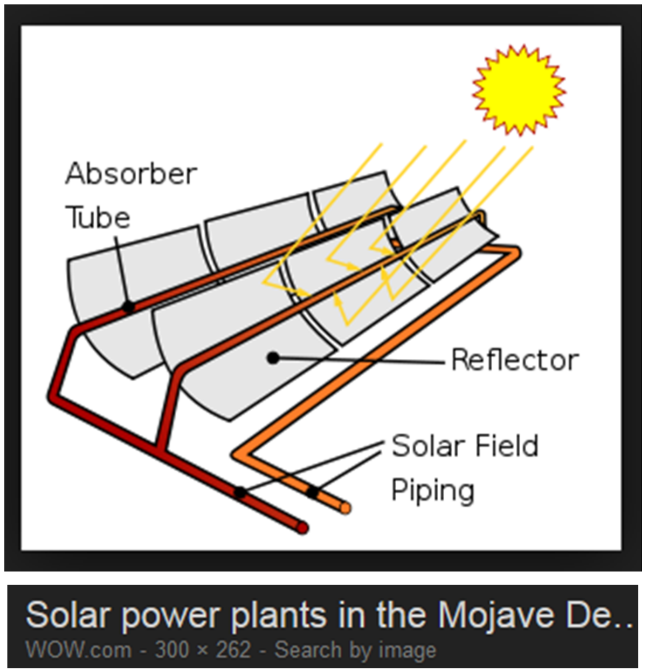
- SEGS (Solar Electric Generation Systems): 354 MW parabolic trough solar plant. Mojave Desert, Barstow, CA



Parabolic Trough

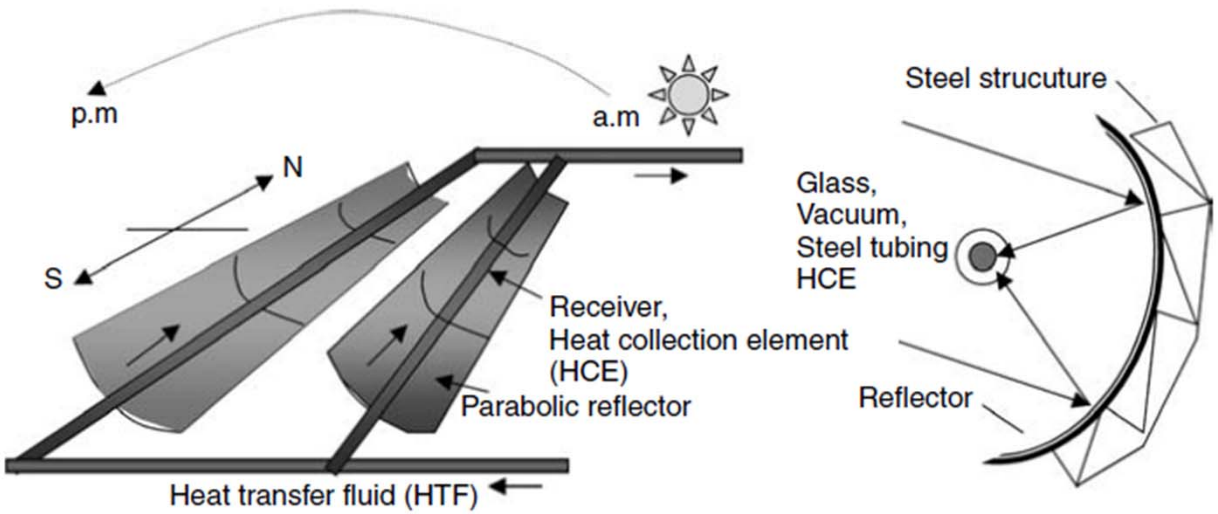
- SEGS (Solar Electric Generation Systems): 354 MW parabolic trough solar plant.
- Receiver (at focal point) or Heat Collection Elements (HCE)
- Thermal (   ) – Heat Transfer Fluid





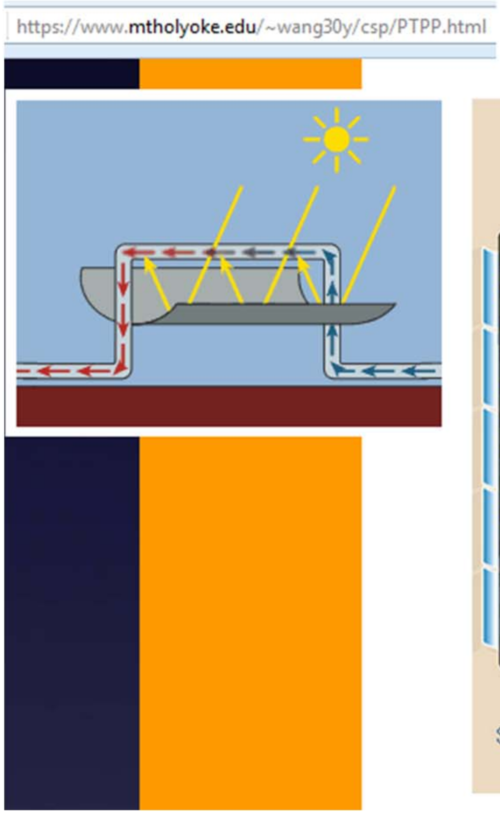
Parabolic Trough

- SEGS (Solar Electric Generation Systems)
- HCE (Heat collection element): Heat transfer fluid → steam turbine/generator
- Heat Transfer Fluid: (   ), (   ), (   )
- Night-hour consideration
  - Heat Storage in (   )
  - Grid-connection

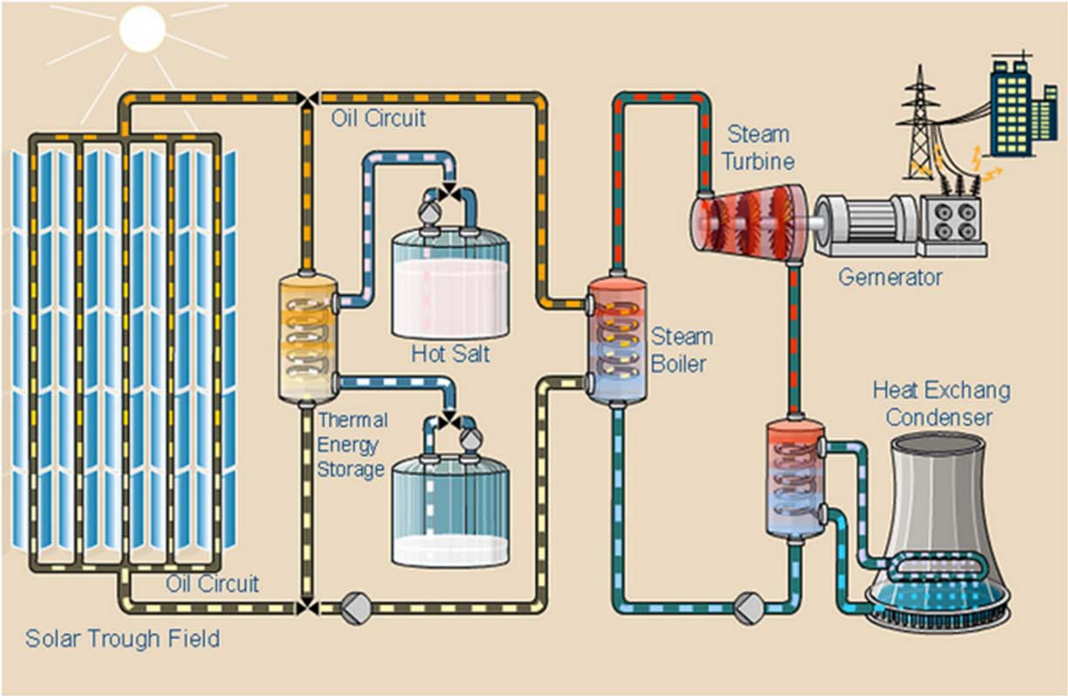


Parabolic Trough

- SEGS (Solar Electric Generation Systems)
- Solar-to-Energy Efficiency at 10%
- Generation cost at $0.12/kWh (least expensive solar electricity)

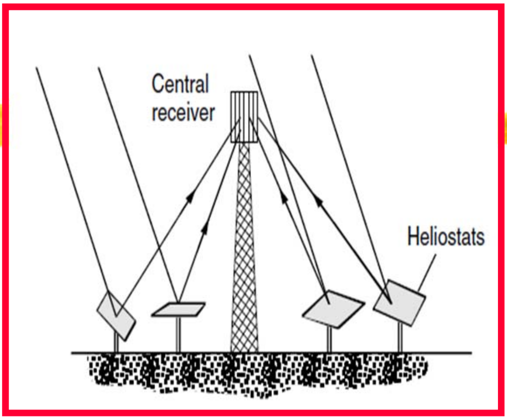


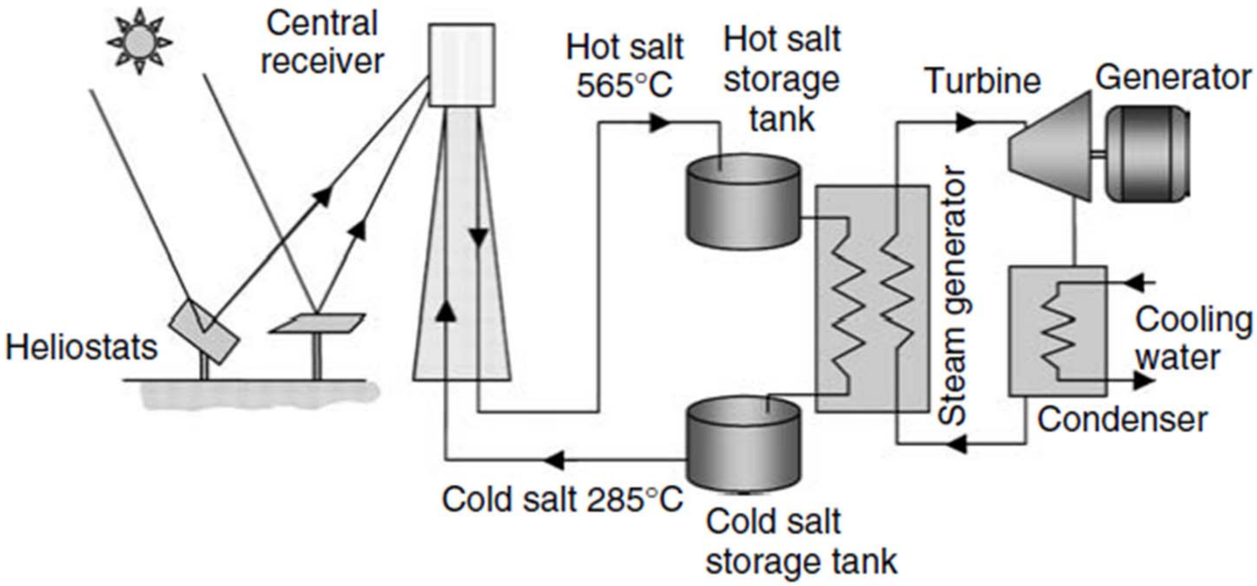
Schematic of a PTPP with a thermal storage system



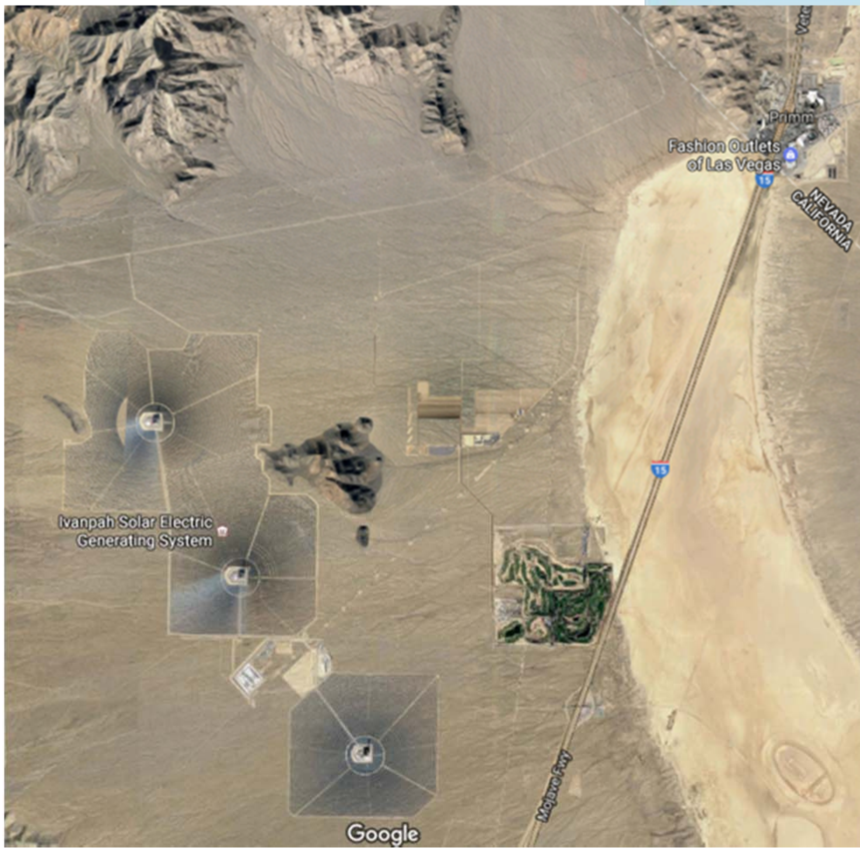
3 Solar Central Receiver Systems (CRS)

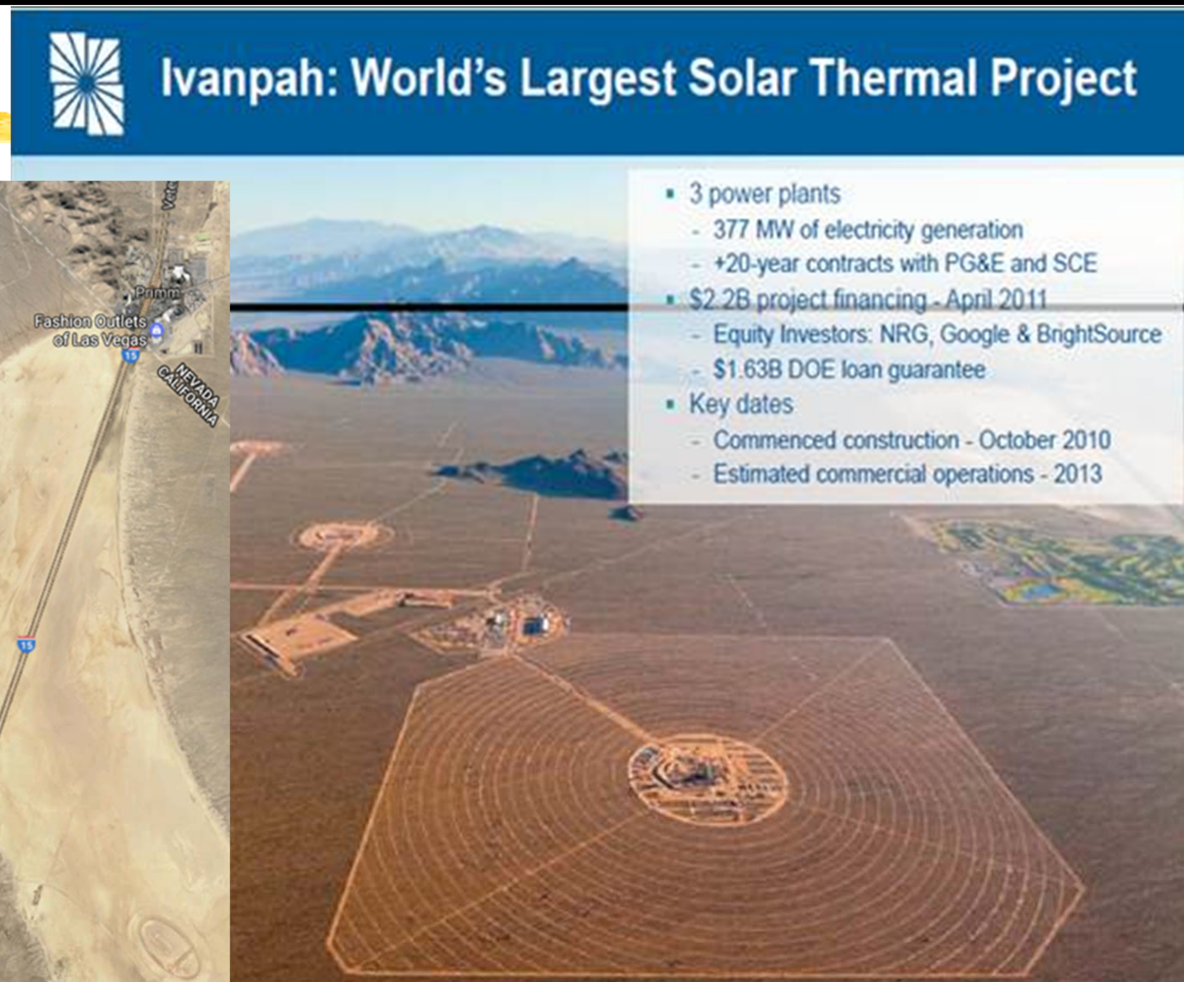
- CRS
- Heliostats: Computer controlled mirrors
- Receiver Tower – (   )
  Thermal Storage



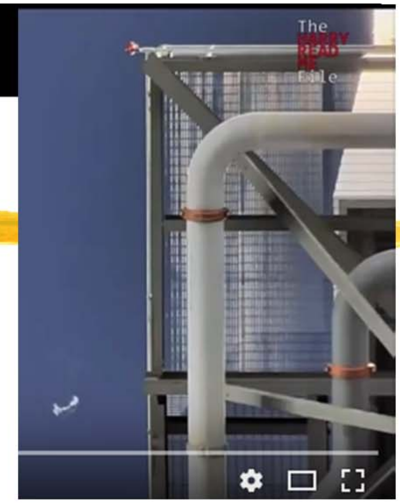


Central Receiver System





Central Receiver System



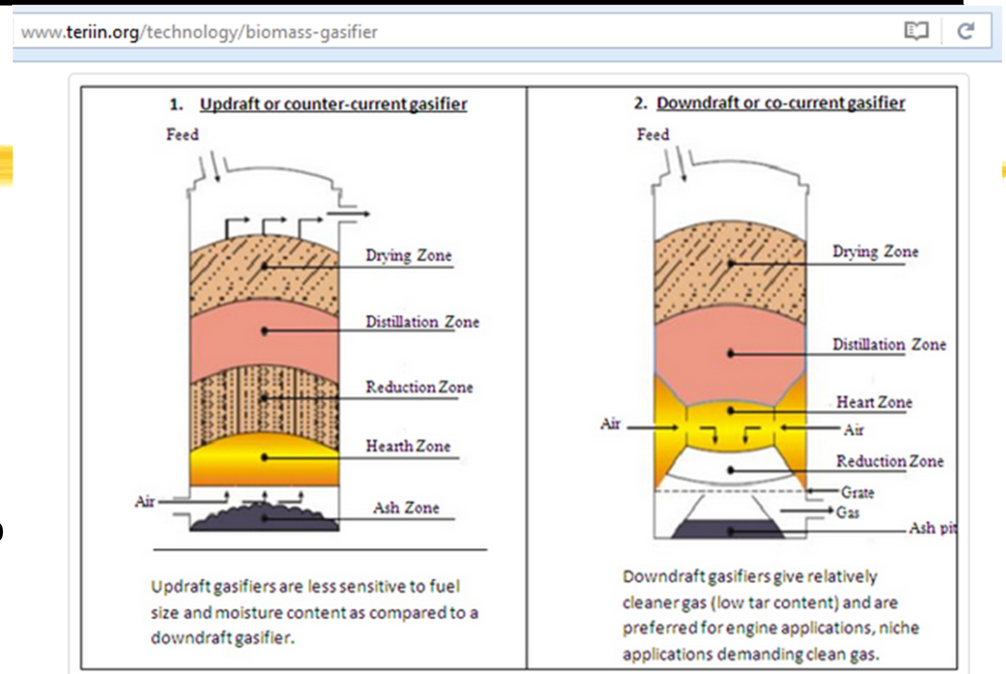
USGS releases bird and insect incineration footage from Ivanpah Solar Electric Facility

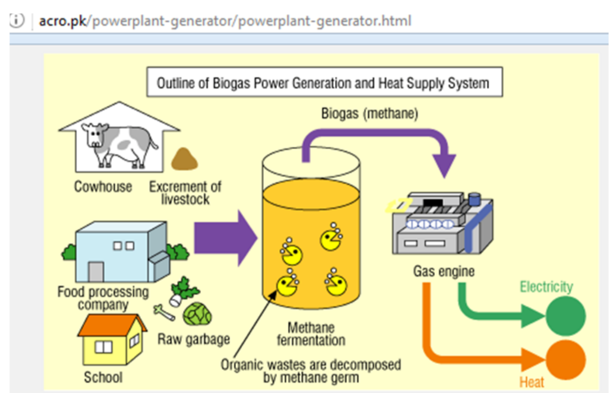
Comparison of Concentrating Solar Power Systems

	1 Dish Stirling	2 Parabolic Trough	3 Central Receiver
Intensity of solar radiation focused on to receiver ("sun")	3000 suns * 1 sun = 1 kW/m^2	100 suns	1000 suns
Efficiency	21%	14%	16%
Land Area Required/MW	4 acres	5 acres	8 acres
Electricity Supply Reliability (with Thermal Storage)	Low	Better	Better
Cooling Needs	No cooling required (Best)	Yes (Poor)	Yes (Poor)

Biomass for Electricity

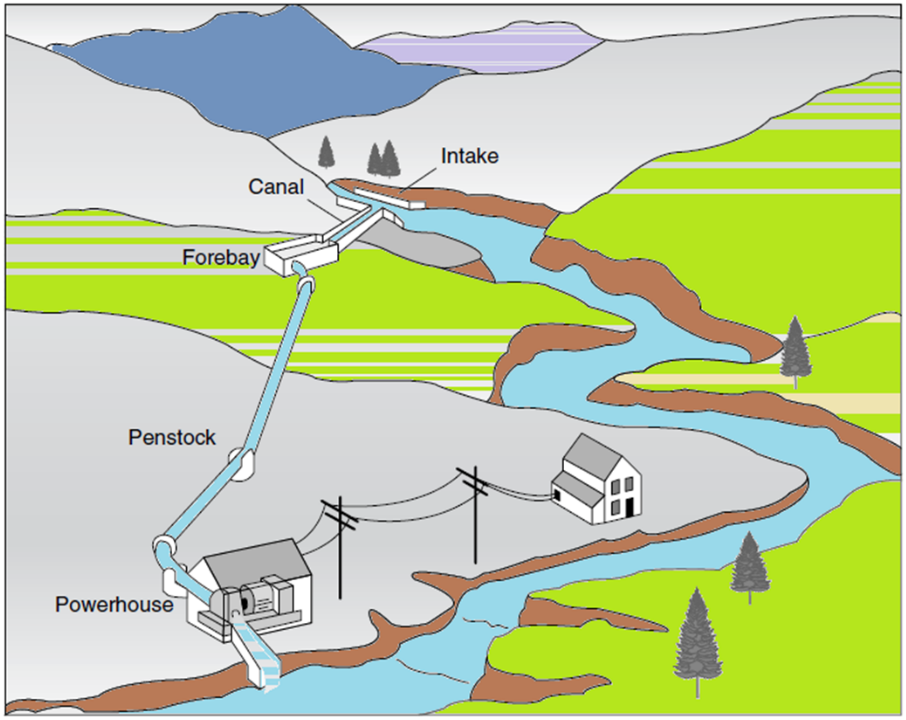
- Waste Residues → Fuel → Steam Turbine/Generator
- 20% efficiency
- Generation cost at $0.09/kWh
- Co-firing approach: Burn Biomass along with coal (less emission)
- Biomass for Gas Turbine
  - Gasification: Conversion of biomass fuel to gaseous combustible gas (“producer gas”) through a thermochemical reactions. Low heating value gas.
- CIG/GT (Coal-Integrated Gasifier/Gas Turbine) System
- BIG/GT (Biomass-Integrated Gasifier/Gas Turbine)System: $0.05/kWh





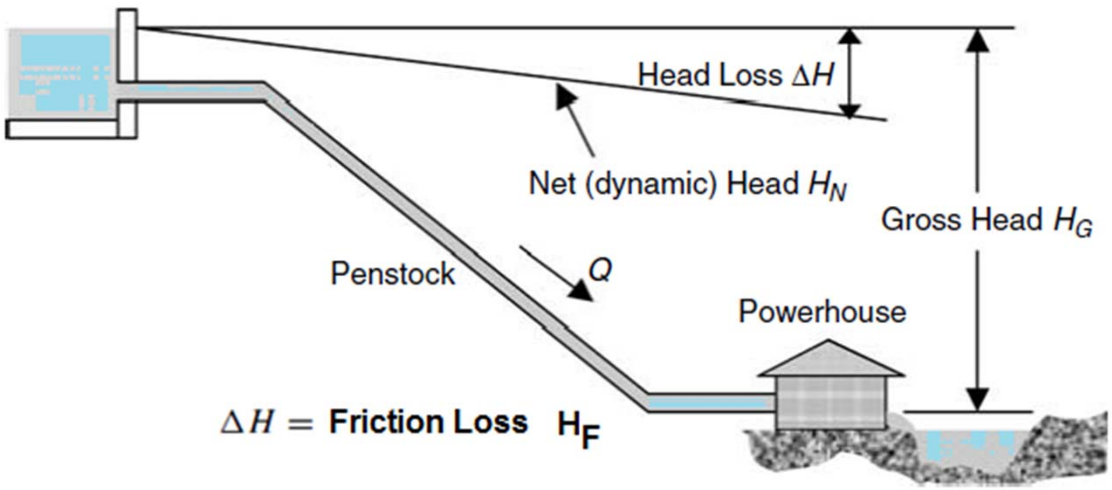
Micro-Hydropower Systems

- Hydropower generation: 9% of U. S. electricity
- Large scale – 30 MW or bigger
- Small-Scale Hydropower: 100 kW – 30 MW
- Micro-Scale Hydropower: smaller than 100 kW
- "Run-of-the-river" System:
  No dam; no ecosystem disruption
- "Penstock": A sluice or gate of intake
  structure for controlling water flow.
- River → Penstock → Hydraulic Turbine
  → Generator



Micro-Hydropower Systems

- P(W) = ???
- Net Head (H_N) = Gross Head (H_G) – Friction Head (Pipe Loss)(H_F)



With 50% Efficiency:

$$P(\mathrm{kW}) \approx 5Q(\mathrm{m}^3/\mathrm{s})\ H_N(\mathrm{m})$$

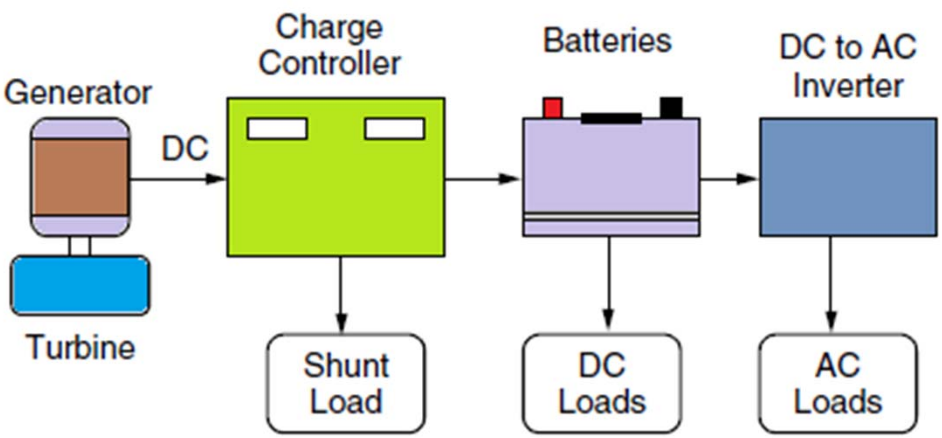
$$P(W) \approx \frac{Q(\mathrm{gpm})\ H_N(\mathrm{ft})}{10}$$

$H_F \propto Q^2$

- Theoretical maximum power delivered by a pipeline occurs when the Friction Loss (head) of the pipeline is 1/3 of the Gross Head.

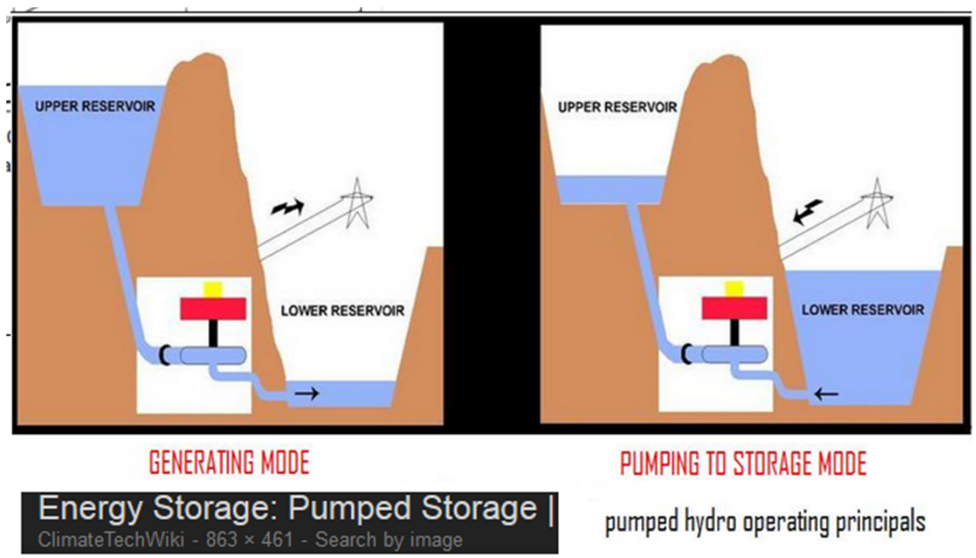
Micro-Hydropower Systems – Energy Storage

- Battery-Based Micro-Hydro System
  - Small size to meet the average daily demand
  - Smaller size battery would do because of very low intermittency - 2 day storage
  - Shunt Load is to divert excessive energy to protect battery of overcharging



Micro-Hydropower Systems – Energy Storage

- Pumped-Hydro System
  - Run the pump during the low-cost off-peak hours
  - Generate and sell electricity during peak hours
  - Alleviate the intermittency of solar/wind electricity
  - Round trip energy efficiency: 70 – 80 %
  - Wind–Hydro Integration: Wind energy (pump run) stored as potential (water) energy
  - Challenges:
    - High capital cost
    - Long construction time
    - Dependent on market structure (dynamic and buy-back price)



Micro-Hydropower Systems – Pumped Hydro

Czech Republic

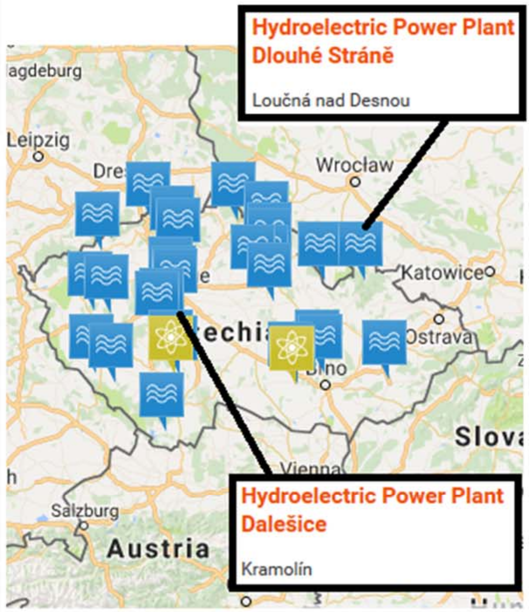
Dalešice Pumped Storage Power Plant

The Dalešice waterworks was built as a part of the nearby Dukovany Nuclear Power Station project. It includes the Dalešice water reservoir with the capacity of 127 million m3 of water, the Mohelno equalization basin, the Dalešice Pumped-Storage Hydroelectric Power Station, and the Mohelno run-off-river hydroelectric power station.

The pumped-storage hydroelectric power station is equipped with four sets of reversing Francis turbines (112.5 MW ea) for a 90 m head.

Rated Power in kW	450,000

CEZ GROUP



Czech Republic

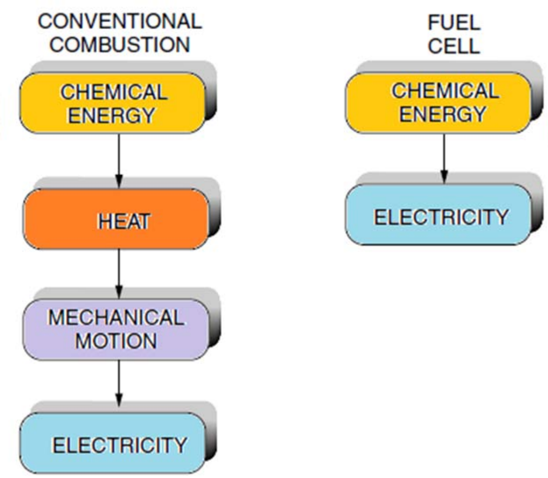
Dlouhé Stráně Pumped Storage Power Plant

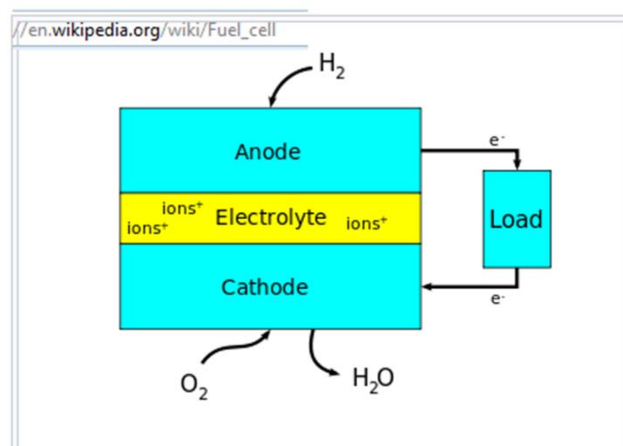
The Dlouhé Stráně Hydroelectric Power Station is situated in Moravia, near Loučná nad Desnou in the district of Šumperk. It has the largest reversing water turbine in Europe, 325 MW; it has the largest head of all power stations in the Czech Republic, 510.7 m; and it has the largest installed capacity in the Czech Republic, 2 x 325 MW. Total capacity is 3,200 MWh.

Rated Power in kW	650,000

Fuel Cells

- "Gaseous Voltaic Battery" by William Grove in 1839
- "Fuel-Cell" by Mond and Langer, 1.5W-cell with 50% efficiency
- Francis Bacon, 5-kW alkaline fuel cell (AFC) which powered 2-ton capacity fork-lift in 1952
- NASA on-board electric power source
- Fuel Cell: Conversion of Energy Contained in a Fuel (Hydrogen, natural Gas, Methanol, Gasoline, etc) directly into electrical power
- Fuel-to-Electric Efficiency: 65%
- Fuel Cell Co-Generation (Electricity + Heat): Efficiency 80%

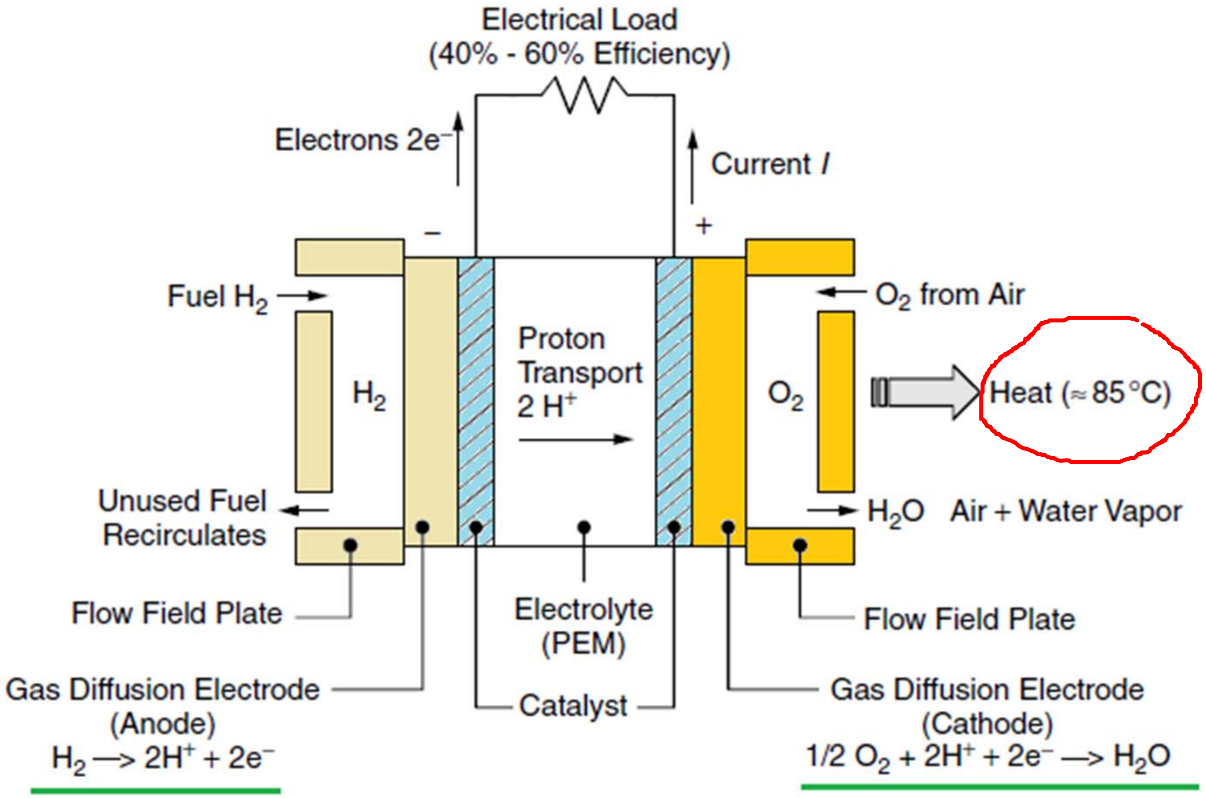




A block diagram of a fuel cell

Fuel Cells – Basic Configuration

- Basic Configuration
- Membrane: **Proton-Exchange Membrane** (PEM): capable of conducting positive ions only (not electrons nor neutrons)
- **Fuel (H2)** is dissociate in to **Protons (H+) and Electrons (e-)**
- Catalyst: Help drive the reaction to the right
- At the Cathode, the protons (H+) combines with Oxygen (O2) and the (Returning) Electrons (e-) to become **water (H2O)**



Basic configuration of a proton-exchange membrane (PEM) fuel cell.

Fuel Cells – Electrical Output

Current Through the Load (I)

I = n*N*q

$$I\,(\mathrm{A}) = n\left(\frac{\mathrm{mol}}{\mathrm{s}}\right)\cdot 6.022\times 10^{23}\left(\frac{\text{molecules } \mathrm{H_2}}{\mathrm{mol}}\right)\cdot\frac{2\text{ electrons}}{\text{molecule } \mathrm{H_2}}\cdot 1.602\times 10^{-19}\left(\frac{\text{coulombs}}{\text{electron}}\right)$$

$$I\,(\mathrm{A}) = 192,945n$$

q = charge on an electron = 1.602×10^{-19} coulombs

N = Avogadro's number = 6.022×10^{23} molecules/mol

v = volume of 1 mole of ideal gas at STP = 22.4 liter/mol

n = rate of flow of hydrogen into the cell (mol/s)

I = current (A), where 1 A = 1 coulomb/s

V_R = ideal (reversible) voltage across the two electrodes (volts)

P = electrical power delivered (W)

Work or Electricity a fuel cell can deliver

Maximum Electrical Output (We)

We = 237.2 kJ/{mol of H2}

Power [Watts] Delivered to the Load

$$P(\mathrm{W}) = 237.2(\mathrm{kJ/mol}) \times n(\mathrm{mol/s}) \times 1000(\mathrm{J/kJ}) \cdot \frac{1\ \mathrm{W}}{\mathrm{J/s}} = 237{,}200n$$

Fuel Cells – Electrical Output

Power [Watts] Delivered to the Load

$$P(\text{W}) = 237.2(\text{kJ/mol}) \times n(\text{mol/s}) \times 1000(\text{J/kJ}) \cdot \frac{1\ \text{W}}{\text{J/s}} = 237{,}200n$$

$$I(\text{A}) = 192,945n$$

Voltage across terminal

$$V_R = \frac{P(\text{W})}{I(\text{A})} = \frac{237{,}200n}{192{,}945n} = 1.229\ V$$

Hydrogen Rate: Hydrogen needed to ideal fuel cell per kWh

$$\text{Hydrogen rate} = \frac{n(\text{mol/s}) \times 2(\text{g/mol}) \times 3600\ \text{s/h}}{237{,}200n(\text{W}) \times 10^{-3}(\text{kW/W})} = 30.35\ \text{g}\,H_2/\text{kWh}$$