Sustainable Energy

Lecture 16: Storage, Transportation and Distribution of Energy

Overview of Energy Supply Infrastructure

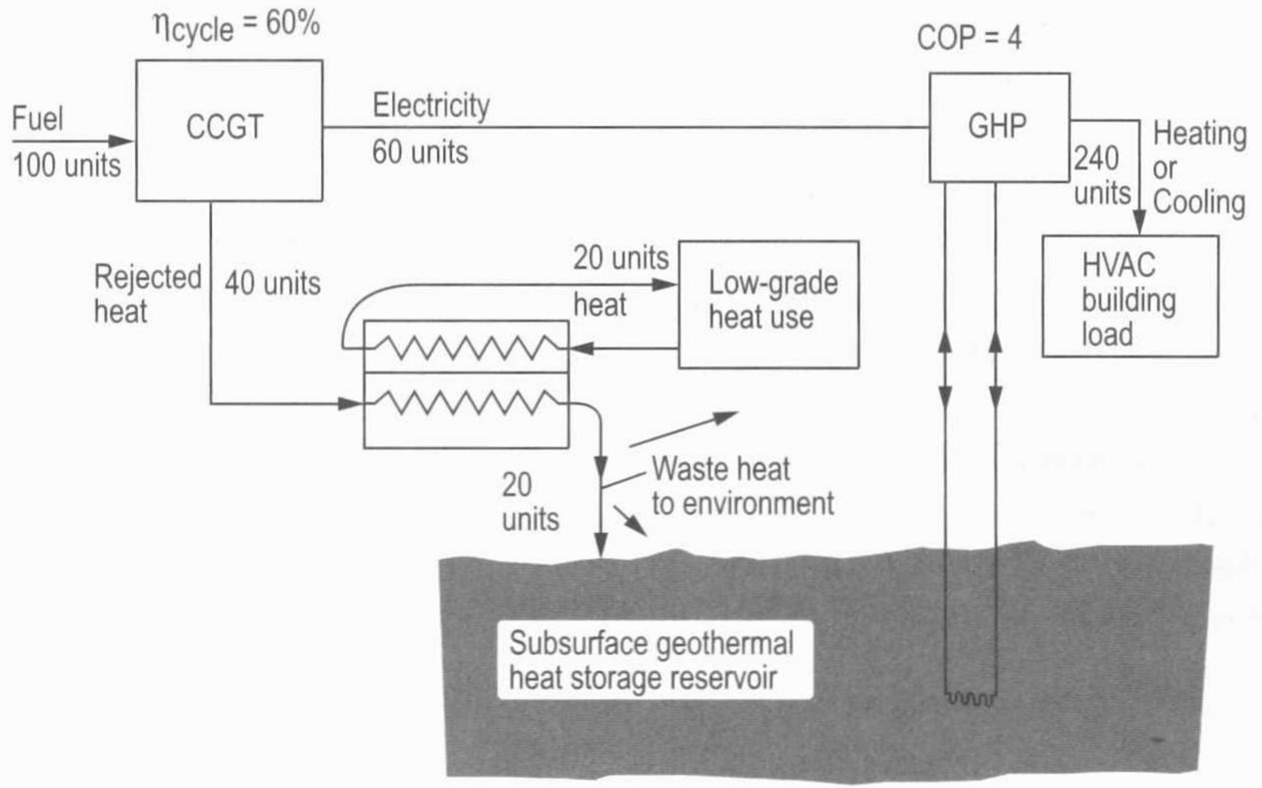
- There are four major needs that storage of energy addresses:
  - Dispatchability – responding to fluctuations in electricity demand
  - Interruptibility – reacting to intermittent energy supplies like wind and solar energy, the seasonal variations of hydropower and biomass, and the periodic instabilities that occur in fossil fuel supplies.
  - Efficiency – recovering wasted energy
  - Regulatory driven needs – meeting distribution and other transmission capacity expansion requirements

- Storage Options
  - Natural gas – liquefied natural gas storage
  - Pumped storage hydropower
  - Electrochemical storage batteries
  - Recovery of waste energy
    - Hybrid cars
    - cogeneration

Connected Efficiences and Energy Crisis

- Overall efficiency is a product of the individual process efficiencies.
- The efficiency calculation can be misleading….just remember you cannot violate the laws of thermodynamics.   See Figure 16.3…..for a confusing example!

Figure 16.3



$$\text{Overall fuel efficiency} = \eta_{fuel} = \frac{60 \times 4 + 20}{100} = \frac{260}{100} \text{ or } 260\%!$$

Figure 16.3. Efficiency of a combined gas turbine-steam Rankine cycle (CCGT) coupled to a geothermal heat pump system with heat integration and waste heat recovery for supplying heating and cooling loads in a building application.

Modes of Energy Storage

- Tables 16.1 and 16.2 list common energy storage types and their characteristics.
- Short period energy storage technologies:
  - Capacitors
  - Batteries (electrochemical energy storage)
  - Flywheels (kinetic energy storage)
- Long period energy storage technologies:
  - Pumped hydropower (above and underground)
  - Compressed air storage (CAES)
  - Hot water or molten salts – for thermal loads
  - Natural gas liquefaction
  - Chemical energy storage – hydrogen, other fuel conversions
  - Superconducting magnetic energy storage (SMES)
  - See Table 16.3 for capital costs of storage systems.

Table 16.1

Table 16.1. Conversion Energy Storage Modes

Mode	Primary Energy Type	Characteristic Energy Density kJ/kg	Primary Application Sector
Pumped Hydropower	Potential	1 (100 m head)	Electric
Compressed Air Energy Storage	Potential	15,000 in kJ/m^3	Electric
Flywheels	Kinetic	30–360	Transport
Thermal	Enthalpy (sensible + latent)	Water (100– 40°C)—250 Rock (250–50°C)—180 Salt (latent)—300	Buildings
Fossil Fuels	Reaction Enthalpy	Gas—47,000 Oil—42,000 Coal—32,000	Transport, Electric, Industrial, Buildings
Biomass	Reaction Enthalpy	Drywood—15,000	Transport, Electric, Industrial, Building
Batteries	Electrochemical	Lead acid—60–180 Nickel metal hydride—370 Li-ion—400– 600 Li-polymer ~ 1,400	Transport, Buildings
Superconducting Magnetic Energy Storage (SMES)	Electromagnetic	100–10,000	Electric
Supercapacitors	Electrostatic	18–36	Transport

Table 16.2

Table 16.2. Energy Storage Technology Characteristics

Characteristic	Pumped Hydro	CAES[a]	Flywheels	Thermal	Batteries	Super-capacitors	SMES[b]
Energy Range	1.8×10^6 – 36×10^6 MJ	180,000– 18×10^6 MJ	1–18,000 MJ	1–100 MJ	1,800– 180,000 MJ	1–10 MJ	1,800 – 5.4×10^6
Power Range	100–1,000 MWe	100–100 MWe	1–10 MWe	0.1–10 MWe	0.1–10 MWe	0.1–10 MWe	10–1,000 MWe
Overall Cycle Efficiency[c]	64–80%	60–70%	~90%	~80–90%	~75%	~90%	~95%
Charge/ Discharge Time	Hours	Hours	Minutes	Hours	Hours	Seconds	Minutes to hours
Cycle Life	≥10,000	≥10,000	≤10,000	>10,000	≤2,000	>100,000	≥10,000
Footprint/ Unit Size	Large if above ground	Moderate if under ground	Small	Moderate	Small	Small	Large
Siting Ease	Difficult	Difficult to moderate	N/A	Easy	N/A	N/A	Unknown
Maturity	Mature	Early development	Early development	Mature	Lead acid mature, others under development	Available	Early R&D stage, under development

[a]CAES = Compressed Air Energy Storage

[b]SMES = Superconducting Magnetic Energy Storage

[c]For 1 full charge-discharge cycle

Sources: Jensen and Sorensen (1984), Schoenung et al. (1996), Boes et al. (2000).

Figure 16.6a

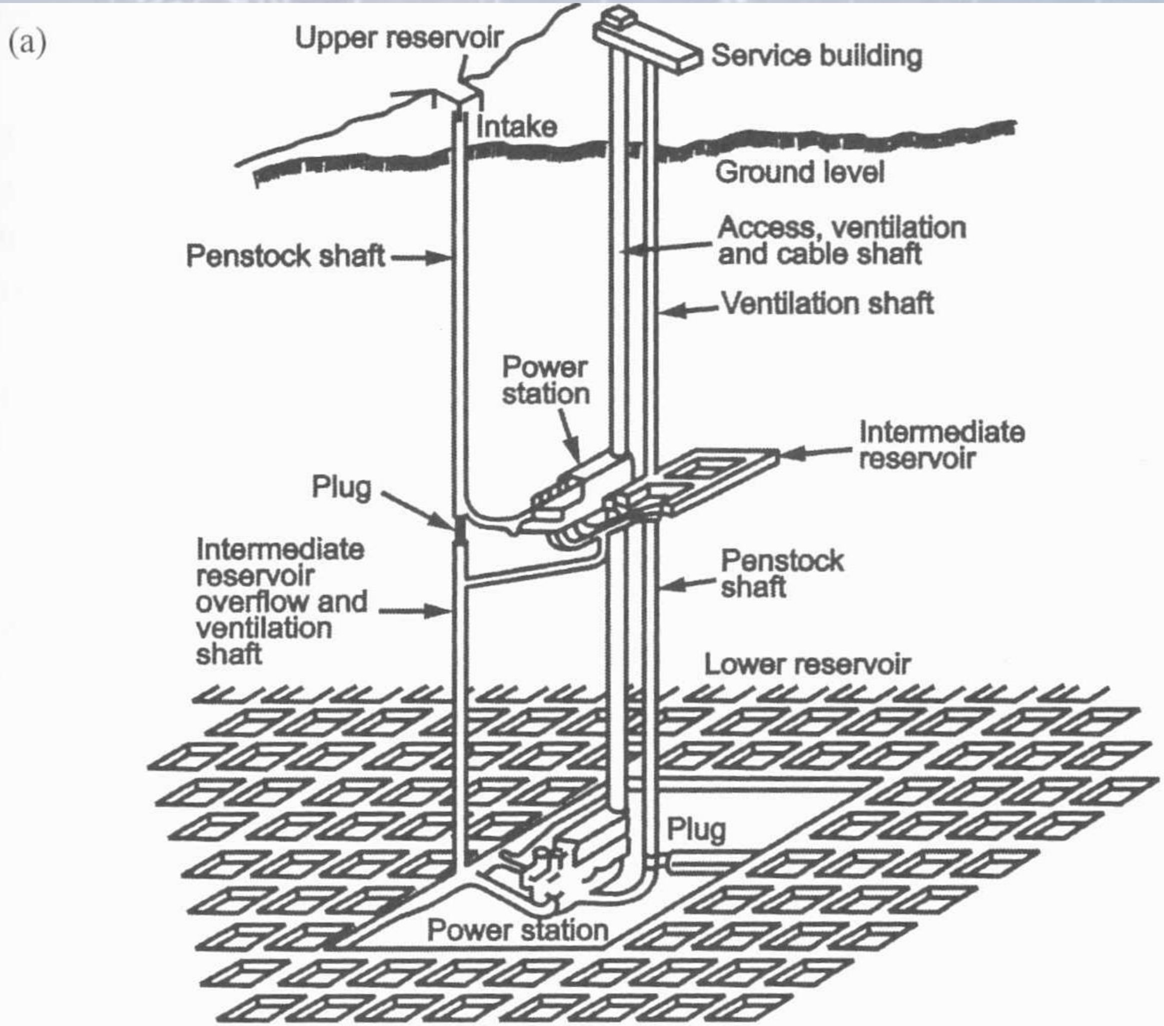


Figure 16.6a. Schematic illustrations of several energy storage technologies: *Aboveground and underground pumped hydro*. Source: Jensen and Sorensen (1984). Reprinted with permission of Elsevier.

Compressed air energy storage

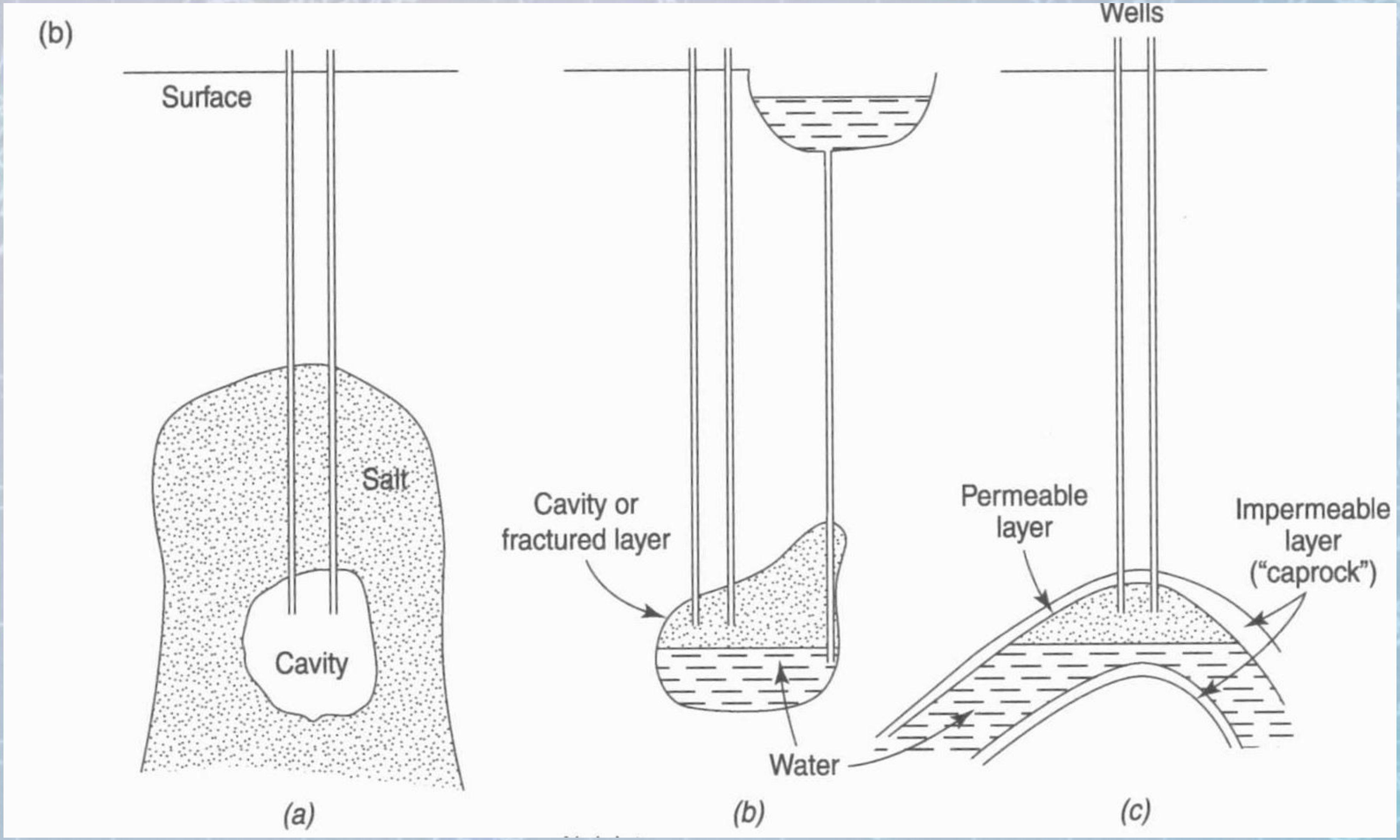


Table 16.3

Table 16.3. Estimated Capital Costs for Representative Energy Storage Systems for Supplying Electric Power

System	Typical Size Range MWe	$/kWe	$/kWh
Pumped hydropower	100–1000	600–1000	10–15
Batteries			
Lead acid	0.5–100	100–200	
Nickel metal hydride	0.5–50	200– 400	150–300
Li-ion	0.5–50	200– 400	
Mechanical flywheels	1–10	200–500	100–800
Compressed-air energy storage (CAES)	50–1,000	500–1,000	10–15
Superconducting magnetic energy storage (SMES)	10–1,000	300–1,000	300–3,000
Supercapacitors	1–10	300	3,600

Sources: Turkenberg et al. (2000), Schoenung et al. (1996), and Boes et al. (2000).

Energy Transmission

- **Figure 16.7 gives estimated costs for energy transmission.**
- **US transmission and distribution losses average 11% of the power supplied.**

Figure 16.7

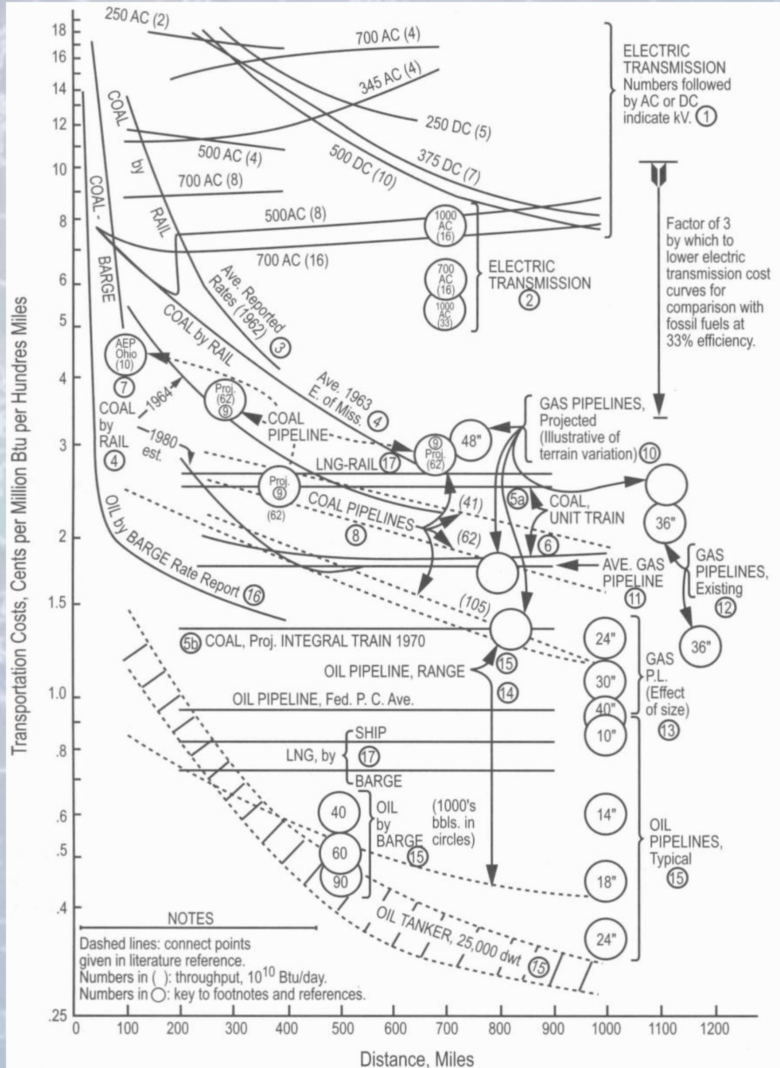


Figure 16.7. Estimated costs in 2000 US$ for energy transmission. Adapted and updated from Hottel and Howard (1973).

Energy Distribution Systems

- Central distribution systems
- Distributed generation systems
  - ICEs
  - Small gas turbines
  - Fuel cells
  - PV
  - Wind
  - Micro-hydro
- Table 16.5 compares central and distributed generation systems.
- CHP systems provide increases in overall efficiency

Table 16.5a

Table 16.5a. Comparison of Central Station and Distributed Generation Systems

Characteristic	Distributed Generation	Central Station
Proximity	Variable, but typically, < 100 mi	Large Cities – 10 to 100 mi All others – 10 to 1,000 mi
Scale	1 kWe to 100^{+} MWe	100 to 2,000 MWe
Energy form	Electricity or combined heat and power (CHP)	Electricity only
Fuel or energy source	Fossil, renewable (solar, wind, geothermal, biomass), or hybrid	Gas or coal, hydro, and possibly concentrating solar or geothermal
Grid connection	Optional	Required

Sustainability Attributes

- Access to storage will enable renewable technologies to be more effective and may lead to higher energy capture and utilization efficiencies.
- Distributed energy systems may reduce environmental and safety concerns associated with centralized systems.
- Energy storage systems costs can be high but the availability and long-term advantages to the infrastructure investment are large.
- Revamping our energy system infrastructure (production, transmission and distribution/delivery systems) will require a significant investment and commitment.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