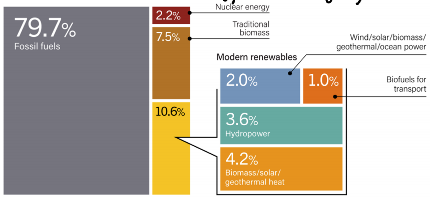
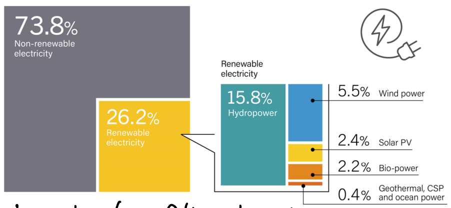
1. energy: kWh, J, Therm, Btu. toe, tce 2. Energy demand in China and India 10% 1990; 24% 2010; 34% 2040, US. consuming 20% of energy.

fossil fuels 79.7% of energy consumption (2017); Nuclear 2.2% of energy and 11% of electricity.; Renewable energy 18.1% energy consumption (2017).

Modern renewable energy (including hydro) 10.6% commercial energy: Renewable 26.2% of electricity (2018) mainly hydro





energy source in China: 58% coal; 20% petroleum. 8% hydro; 8% natrual gas. 2% nuclear. 5% other renewable.

3. Pollutants: CO_2, NO_x, dust, Particulate, CO, Hydrocarbon (碳氢), Radioactive waste, Leaks, Heat emission.

EPA: CO, lead, NO_2, O_3, particulate matter, sulfur dioxide (SO_2)

4. green house: Solar radiation pass through clear atmosphere (1). Some reflect by earth and atmosphere (2), most is absorbed by earth's surface, warm it (3). Infrared radiation is emitted from Earth surface (4). Some infrared passes through atmosphere, some absorbed and re-emitted. in all direction by green house gas, warm the earth surface and lower atmosphere. (4). / 2016 warmest, 1.02 °C above average. / effects: snow and floating ice decreased; global sea level risen; influence the patterns and amounts of precipitation. / CO_2, Methane (CH_4), Nitrous oxide N_2O., Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) sulfur hexafluoride (SF_6). / MMTCE = (Tg of gas) × GWP × (12/44) $1 Tg = 10^6$ tons.

5. Methods to Capture CO_2 Solvent Scrubbing System

- Solvent scrubbing systems (Absorption): These are well established and are usually based on use of amines (often monoethanolamine - MEA) for removing CO_2 from exhaust gases.
- Membranes: These can be used to separate gases by exploiting differences in physical or chemical interactions between gases and the membrane material.
- Adsorption: Some solids can be used to separate CO_2 from gas mixtures. These include certain zeolites and activated carbon.
- Bio-energy with carbon capture and storage (BECCS): a process of extracting bioenergy from biomass and capturing and storing the carbon, thereby removing it from the atmosphere

What is the status of CO_2 capture?

- CO_2 is already being captured in the oil and gas and chemical industries. Indeed several plants capture CO_2 from power station flue gases for use in the food industry. However, only a fraction of the CO_2 in the flue gas stream is captured.
- To reduce emissions from a typical power plant by 75%, the equipment would need to be 10 times larger.
- As of 2019 there are 17 operating CCS projects in the world, capturing 31.5Mt of CO_2 per year, of which 3.7 is stored geologically. Most are industrial not power plants.

Other technologies for CO_2 capture

- Direct air capture (DAC): it is the process of removing CO_2 directly from the ambient air. Work in this area is still in its infancy. It is estimated the cost at US\$94–\$232 per tonne of atmospheric CO_2 removed.
- Pre-combustion: The fossil fuel is partially oxidized. The resulting CO_2 can be captured from a relatively pure exhaust stream and removed before combustion takes place.
- Oxy-fuel combustion: it is the process of burning a fuel using pure oxygen instead of air as the primary oxidant. Oxy-fuel combustion produces approximately 75% less flue gas than air fueled combustion and produces exhaust consisting primarily of CO_2 and H_2O.

What is the status of CO_2 storage?

- Underground storage of CO_2 has taken place for many years as a consequence of injecting CO_2 into oil fields to enhance recovery.
- Major reservoirs, suitable for storage, have been identified under the earth's surface. Work to develop many of these options is in progress.
- CO_2 needs to be stored securely for hundreds or even thousands of years, in order to avoid it reaching the atmosphere.
- Sequestration refers only to the terrestrial storage of CO_2.

Storage: Unminable Coal Beds; Deep Saline; Depleted Oil or gas Reservoirs; Ocean (no longer feasible). + for eastern.

6. major factors effect of solar radiation: locan of the Sun in the sky; clearness of atmosphere; location of plane; orientation of plane.

N solar altitude β azimuth angle ϕ. latitude (L) hour angle LST (H) declination (δ)

7. elliptical orbit / January 4. closest, July 5. farthest / solstice, vernal (3/21), Autumnal (9/22). / Local civil time (LCT) = local standard time (中心时间) − 4(L_{LW} − L_S).

LST (local solar time) = LCT + EOT. Standard Meridion (LS).: eastern 75°, central 90. mountain 105, Pacific 120. Alaska 135. Hawaii 150°; Local standard time = local daylight − 1hr

$\sin\beta = \cos L\cos H\cos\delta + \sin L\sin\delta$, $\cos\phi = \frac{\sin\delta\cos L - \cos\delta\sin L\cos H}{\cos\beta}$, H (15°/hour, 0 at local solar noon, H>0 afternoon) ϕ for LST<12, 360−ϕ for LST>12 / Incident angle θ $\cos\theta = \cos\beta\cos\gamma\sin\alpha + \sin\beta\cos\alpha$.

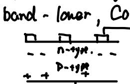
γ − wall solar azimuth $\gamma = |\phi - \psi|$, α 0 for horizontal, 90° for vertical, ψ. N 0 E 90, S 180 W 270 8. Air mass = $h_2/h_1 = 1/\sin\beta$ 9 $G_{sc} = 1367 W/m^2$. $G_{ND} = \frac{A}{\exp(B/\sin\beta)} \cdot C_N$, $G_D = G_{ND} \cdot \cos\theta$

9. solar technology: 1. solar heating and cooling. (Active heat or Passive heating). 2. PV 3. CSP 9. diff between Active and Passive: whether use pumps to circulate or natural convection to move water

Direct circulation system VS Thermosyphon system 12. 1. Evacuated tube collector 10-150↗ 2. Line focus 50-150↗ steam. 3. Point focus >100↗ steam 4. unglazed panels 0-10↗ swimming pool 5. Flat-plate 0-50↗ water/Air

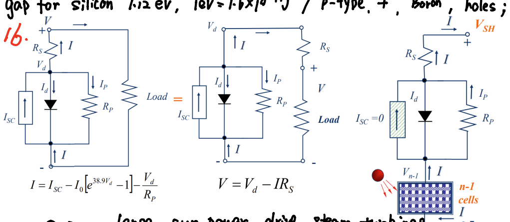
13. Design passive solar house: 1. conservatory 2. Trombe wall 3 Direct gain. a. well insulated to ↓ heat losses b. face south, glazing face south, south-main use room. c. avoid overshading to benefit from essential mid-winter sun. d. thermal massive to avoid-heating in summer e. should be a responsive, efficient heating system. 4. Summer colling features 5. Solar hot water collectors 6. PV. 7. Insulating technology. 8 energy monitoring. solar energy of China 71%., US 4% 14. Valence band - lower, Conduction band: upper / $E = hf$, $h = 6.626 \times 10^{-34}$ J·s, $f = c/\lambda$, $c = 3 \times 10^8$ m/s, λ(m)

gap for silicon 1.12 eV, $1eV = 1.6 \times 10^{-19}$ J / P-type "+", Boron, holes; n-type. "−", phosphorus, free electrons.



15. max theoretical eff 33.7%; max for silicon 29.4% with gap. 1.34 eV.; mult-junction, 51.8% in theory (1.93, 1.39, 0.94) 40% in practice (1.7-1.9, 1.3-1.4, 0.67)

16.



$I = I_{SC} - I_0\left[e^{38.9V_d} - 1\right] - \frac{V_d}{R_P}$

$V = V_d - IR_S$

$V_{SH} = V_{n-1} - I(R_p + R_S)$

$V_{n-1} = \left(\frac{n-1}{n}\right)V$

$\Delta V = V - V_{SH} = \frac{V}{n} + I(R_P + R_S)$

$\cong \frac{V}{n} + IR_P$

21. Grid-connected PV
Solar panels, Invert, Electrical distribution Panel, Utility Power. Utility meter.
Battery Charging Stand Alone: PV module, charge controller, battery bank, Inverter, distribution board, AC load.
Grid-Tied with battery: + charge controller, battery bank, back up ac load, dual purpose inverter. service panel. electric meter, utility grid

22. fill factor: actual max / Isc·Vco

20 PV system Sizing: 1. Determin power Consumption demands 2. optimize power system demand 3. size battery bank 4. Determine sun hours available per day 5. Size array 6. Specify a kit or custom systems components.

22 CF = Annual-energy / Pk (kW) × 8760
capacity factor

CSP. lense, sun power, drive steam turbines

23. 1. Parabolic trough Receive n-s axis, follow sun. HTF (usually oil) eff 15%
Rankine cycle Steam turbine.
SEGS.

2. Concentrating Linear Fresenel Reflector. receiver. n-s axis. adv: Flat mirror cheaper than parabolic; high eff use of land; fix absorber. no wind loads reduce on reflector strips; high pressure joints / thermal expansion bellow; No vacuum tech / metal-to glass sealing

3. Stirling solar Dish.

adv: highest eff 31.4%. (achieve ↗ temp) scalability: modular design. dis: maintance: moving parts for heat to e conversion. Structure: heavy engine - moving. need. rigid frame, strong tracking system.
Tracking: Parabolic. trackin must be dual axis.

4. Solar power tower: adv: high eff, better energy storage capability.

2019. wind take 7.3% of US electricity, 20% for 2030. China 28.4 of world production. US 27.2%.

$V = V_0\left(\frac{H}{H_0}\right)^a$, $P = P_0\left(\frac{H}{H_0}\right)^{3a}$, $PV = nRT$

P	atm
V	m^3
T	K
n	mol
R	8.2056×10^{-5}

smooth ground	α = 0.1
Tall grass	α = 0.14
High crop.	α = 0.2
wood country	α = 0.25
Small town	α = 0.3
large city	α = 0.4

$\rho = \frac{n \times M.W\,(g/mol) \times 10^{-3}\,(kg/g)}{V\,(m^3)}$

M.W air = 28.97 g/mol.

$\rho = \frac{P \cdot M.W \cdot 10^{-3}}{RT}$

$P = P_0 e^{-1.185 \times 10^{-4} H}$, $P_0 = 1$ atm

revolutions per min (rpm) N radian per second (rad/s) Ω $\Omega = \frac{2\pi \cdot N}{60}$

tip speed 叶尖速 $U = \frac{2\pi \cdot R \cdot N}{60}$ m/s

$TSR = \frac{U}{V}$

solidity, swept area.

Mechanical power $P_b = \Omega \cdot T_q$, T_q as torque.

rotor eff $C_p = \frac{P_b}{P_{wind}}$

$P_b = \frac{1}{2}\rho A\left(\frac{V+V_d}{2}\right)(V^2 - V_d^2)$

Ratio of down to up stream wind speed λ

$P_b = \frac{1}{2}\rho AV^3\left[\frac{1}{2}(1+\lambda)(1-\lambda^2)\right]$

$C_p = \frac{1}{2}(1+\lambda)(1-\lambda^2)$

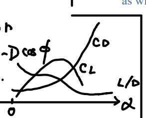
C_p max at $\lambda = \frac{1}{3}$, $C_p = \frac{16}{27} < 60\%$

overall eff $\eta = \frac{P_{ele}}{P_{wind}} = \frac{P_{ele}}{P_b} \cdot \frac{P_b}{P_{wind}} = \frac{P_e}{P_b} \cdot C_p$

38. Wind turbine type.
1. Vertical axis wind turbines
2. horizontal axis wind turbines 常见

39. Lift force. perpendicular to air steam
Drag force. in line with air steam.

Bernoulli's principle: ↗ of V occurs with ↓ in P
equal transit-time
drag force $D = C_D(\frac{1}{2}\rho A_b V^2)$
A_b. blade area.
Lift force $L = C_L(\frac{1}{2}\rho A_b V^2)$
total power from turbine
$P = \Omega T_q \cdot$ # of blade
$T_q = \sum F_{net} \cdot r$
$F_{net} = L\sin\phi - D\cos\phi$
attack angle.



25 R&D Activities

- Minimizing optical and thermal efficiency losses in the system
- Reducing the cost of the solar field
- Increasing system efficiency through higher-temperature operations
- Developing a novel low-cost heliostat design
- Developing a new set of technology elements, including advanced reflective films, optically accurate reflector panels, low-cost space frames, adaptive optics, and accurate tracking drives
- Developing advanced heat transfer fluids and novel thermal storage
- Develop highly thermal conductive foam for high-temperature and high-efficiency thermal energy storage (TES) system with rapid charging and discharging times.

For HAWT: ϕ wind angle. β. blade pitch angle
W - relative wind velocity

Turbine Power Control

- Active pitch-control system: The pitch of the turbine blades is adjusted to shed some of the wind by changing the attack angle. Physically, a hydraulic system slowly rotates the blades about their axes, turning them a few degrees at a time to reduce or increase their efficiency as conditions dictate.
- Passive stall-control: The blades (twist) are carefully designed to reduce the lift gradually as the blades rotate faster. The angle of attack is approaching the stall angle (large turbines).
- Active stall-control: The blades are rotated to increase the attack angle to induce stall (very large turbines).
- Passive yaw control: To move the axis of the turbine off the wind as wind speed increases (small turbines).

1. Yaw control
Cable twist Counter
3. power control.

2. Brake system.
a. Aerodynamic braking system Spring operated.
b. Mechanical braking - . parkin brake

Rayleigh dis $f(v) = \frac{\pi v}{2\bar{v}^2}\exp\left(-\frac{\pi}{4}\left(\frac{v}{\bar{v}}\right)^2\right)$

$\bar{P} = \frac{6}{\pi} \cdot \frac{1}{2}\rho A\bar{v}^3$

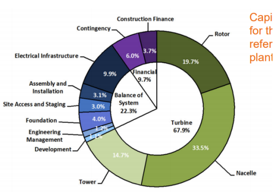
Annual-energy $= \sum P_v(kW) \times Hrs\,(h/yr)$
$= P_R \times 8760 \times CF$

P_R rated Power.
CF capacity factor $0.2 \le CF \le 0.5$
$CF = 0.087\bar{V} - \frac{P_R}{D^2}$, D 直径.
Optimum generator.
$0.087\bar{V} - \frac{2P_R}{D^2} = 0.$
$P_R = 0.0435\,\bar{V} \times D^2$

Annual Pay
$A = P \cdot \left(\frac{i(1+i)^n}{(1+i)^n - 1}\right)$
A (\$/yr)
P borrowed (\$)
i interest rate
n loan term (year)

wind data
location.
turbine size.

Cost Analysis (land-based)



Capi for th refer plant

- The maximum capacity of generation must be pre-decided.
- Distances from key points such as roads, domestic facilities and other private properties.
- Proximity to areas sensitive to noise emissions and shadow flickering
- The minimum distance between wind turbines
- Interruption to signal towers and microwave pathways
- The wind farm should also be compliant with the local regulations and constraints

Disadvantages of Wind Power

- Intermittent source, non-dispatchable power
- Cost: wind power must compete with conventional generation sources on a cost basis
- Remote location and land
- Noise produced by the rotor blades
- Aesthetic (visual) impacts
- Sometimes birds have been killed

54. source of geothermal energy: radioactive decay of element such as uranium 238, thorium 232 ..
Heat flows 7000 °c at center.
gradient 25 k / km of depth., mean heat flow: 60 mW/m². , max at boundaries : 300 mW/m².

55: classification:
1. high enthapy >180 °c — Medium 100-180 °c — Low enthapy < 100 °c
2. high temperature. t>150° — Intermediate. 90°c < t < 150° — Low. t < 90°

electricity generation 14 GW in the world. 3450 MW in US.
geothermal heating 51 GW.
geothermal heat pumps

electric generation is generally not economical for resources t<150°c

57
- An Enhanced Geothermal System (EGS) is a man-made reservoir, created where there is hot rock but insufficient or little natural permeability or fluid saturation. In an EGS, fluid is injected into the subsurface under carefully controlled conditions, which cause pre-existing fractures to re-open, creating permeability.
- EGS is a loop-cycle system that pumps water into bedrock and the naturally heated water is then pumped back to the surface, which creates steam that is then converted into energy.

Step 1: Identify a Site.: determin if necessary char to create EGS
Step 2: Creat a Reservoir: Drill a injection well, Inject water, continue untill enough volumn for reservoir., Drill a production well.
Step 3: operate power plant and Maintain.

58. Refrigaration: compressor, condenser, thermal expansion valve, Evaporator

59
$$COP_c = \frac{Q_i\,(Btu)}{W(Btu)},\quad EER = \frac{Q_i\,(Btu)}{W\,(w\text{-}hr)} = 3.412 \cdot COP_c,\quad COP_c = \frac{EER}{3.412},\quad COP_h = \frac{Q_o\,(Btu)}{W\,(Btu)}$$

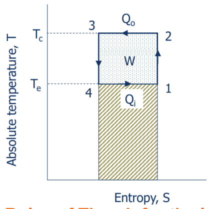
Q_i, heat absorb in evaporator, Q_o. heat emission in Condenser. W power in Compressor

$$COP_c = \frac{T_e}{T_c - T_e},\quad COP_h = \frac{T_c}{T_c - T_e}$$

T_c. condensing temp T_e evaporating temp

$$T_K = t_3 + 273.16.\quad T_R = t_F + 459.19$$

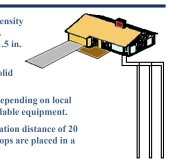
open loop (ground water from a well).



1-2: adiabatic compression
2-3: isothermal heat rejection
3-4: adiabatic expansion
4-1: isothermal heat absorption
T_c – condensing temperature
T_e – evaporating temperature
W – net energy input
Q_i – heat absorbed from lower T
Q_o – heat rejected to higl

Closed Loop (Vertical GSHP)

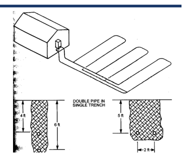
- Two small-diameter, high-density polyethylene (HDPE) tubes. Nominal diameter: 0.75 to 1.5 in.
- A vertical borehole that is subsequently filled with a solid medium.
- Bore depths: 50 to 600 ft., depending on local drilling conditions and available equipment.
- A minimum borehole separation distance of 20 ft. is recommended when loops are placed in a grid pattern.



Closed Loop (Horizontal GSHP)

- Single pipe
- Multiple-pipe
- Spiral

Generally requires 1500-3000 ft² land area per ton.



Advantages of the Vertical GCHP

1. It requires relatively small plots of ground.
2. It is in contact with soil that varies very little in temperature and thermal properties.
3. It requires the smallest amount of pipe and pumping energy.
4. It can yield the most efficient GCHP system performance.

Disadvantages are:

1. Typically higher cost because of expensive equipment needed to drill the borehole.
2. The limited availability of contractors to perform such work.

Advantages of the Horizontal GCHP

1. They are typically less expensive than vertical GCHPs.
2. Many residential applications have adequate ground area.
3. Trained equipment operators are more widely available.

Disadvantages are:

1. A larger ground area requirement.
2. Greater adverse variations in performance because:
   a. ground temperatures and thermal properties fluctuate with season, rainfall and burial depth,
   b. slightly higher pumping-energy requirements, and
   c. lower system efficiencies.

Rules of Thumb for the Initial Planning and Cost Estimate

- 150 to 200 feet/ton (13 to 17 m/kW) for vertical loops.
- Approximately 30% to 50% longer for horizontal loops under the same conditions.
- \$750-\$1500/ton for horizontal ground loop installation.
- \$1,050-\$2400/ton for vertical ground loop installation.
- \$2,500-\$5,000/ton total installed cost for the GSHP system (loop, heat pump, etc.)
- Typical U.S. residence of 2,000 - 2,400 ft² (186 to 223 m²) requires 3 to 4 tons (10.6 to 11.4 kW) of heating supply, depending on climate.

EER

- EER (energy efficiency ratio) is a measure of how efficiently a cooling system will operate when the outdoor temperature is at a specific level (usually 95°F).
- A higher EER means the system is more efficient. The term EER is most commonly used when referring to window and unitary air conditioners and heat pumps, as well as water-source and geothermal heat pumps.
- The formula for calculating EER is:

$$EER = \frac{\text{Btu/hr of cooling at 95°F}}{\text{Watts used at 95°F}}$$

SEER

- SEER (seasonal energy efficiency ratio) measures how efficiently a residential central cooling system (air conditioner or heat pump) will operate over an entire cooling season, as opposed to a single outdoor temperature condition.
- A higher SEER reflects a more efficient cooling system. SEER is calculated based on the total amount of cooling (in Btu) the system will provide over the entire season divided by the total number of watt-hours it will consume:

$$SEER = \frac{\text{Seasonal Btu of cooling}}{\text{Seasonal W-hrs used}}$$

COP

- COP (coefficient of performance) is the measurement of how efficiently a heating or cooling system (particularly a heat pump in its heating mode and a chiller for cooling) will operate at a single outdoor temperature condition.
- When applied to the heating modes of heat pumps, that temperature condition is usually 47°F DB/ 43°F WB. The higher the COP, the more efficient the system. COP can be calculated by two different methods.
- The formula for calculating COP is:

$$COP = \frac{\text{Btu of heat produced at 47°F}}{\text{Btu worth of electricity used at 47°F}}$$

HSPF

- HSPF (heating seasonal performance factor) is the measurement of how efficiently all residential and some commercial heat pumps will operate in their heating mode over an entire normal heating season.
- The higher the HSPF, the more efficient the system.
- The formula for calculating HSPF is:

$$HSPF = \frac{\text{Btu of heat produced over the heating season}}{\text{W-hrs of electricity used}}$$

The efficiency (%) is calculated by dividing the HSPF by 3.412.

COP vs. Temperature Difference

- ENERGY STAR® label (for single package equipment), Central AC: EER ≥ 11, or *SEER* ≥ 14; ASHP: HSPF ≥ 8.
- A typical air-source heat pump has a COP of 3 to 4 on a mild day. On a very cold day, it takes more work to move the same amount of heat indoors than on a mild day. At around -18°C (0°F) outdoor temperature, COP = 1. The average COP over seasonal variation is typically 2.5-2.8.
- GSHP: COP is in the range of 3.5-4.0.
- GSHP (at 10°C ground): COP =7.2 (35°C), 5.0 (45°C), 3.7 (55°C), 2.9 (65°C), 2.4 (75°C)

Costs

Higher initial cost: On average, a geothermal heat pump system costs about \$2,500 per ton of capacity, or roughly \$7,500 for a 3-ton unit (a typical residential size). A system using horizontal ground loops will generally cost less than a system with vertical loops. In comparison, other systems would cost about \$4,000 with air conditioning.

Lower operating and maintenance cost: Annual energy savings range from 30% to 60%.

Energy Costs

- **Gas Furnace:**

$$\$ = \frac{(q_{heating})(unit\ cost)}{(\eta)(HVF)}$$

Where: $q_{heating}$ = Heat requirement over one heating season, Btu
HVF = heating value of the fuel,
Natural gas 1.03 million Btu/1000 ft³
Natural gas cost: \$9/1000 ft³
η = heating system efficiency, or Annual Fuel Utilization Efficiency (AFUE). Energy Star: > 90%

- **Heat pump:**

$$\$ = \frac{(q_{heating})(unit\ cost, \$/kWh)}{1000 \cdot (HSPF)}$$

Bio mass.

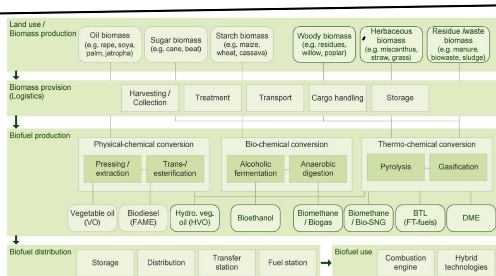
Biomass Resources

- Biomass resources include any organic matter available on a **renewable** basis.
  - energy crops and trees
  - agricultural food and feed crops
  - agricultural crop wastes and residues
  - wood wastes and residues
  - aquatic plants
  - animal wastes
  - municipal wastes
  - other waste materials.

Lecture 18.3

Biomass Technologies

- Biomass technologies use renewable biomass resources to produce an array of energy-related products, including electricity, liquid, solid, and gaseous fuels, heat, chemicals, and other materials.
  - ✓ Biopower – electricity and heat generation.
  - ✓ Biofuels – a variety of fuels can be made from biomass resources.
  - ✓ Biobased Chemicals and Materials – commercial or industrial products derived from biomass feedstocks.



Direct Combustion

- Direct combustion involves the burning of biomass with excess air, producing hot flue gases that are used to produce steam in the heat exchange sections of boilers.
- The steam is used to produce electricity in steam turbine generators.
- Lower stack density than fossil fuels.

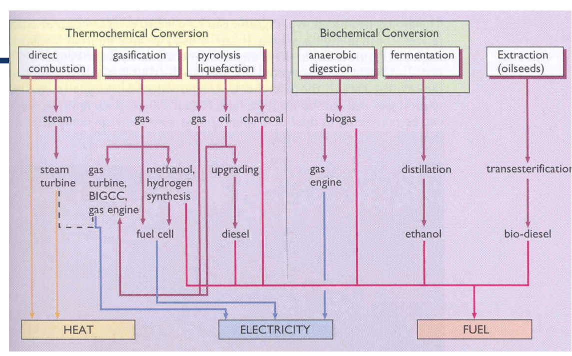
- Co-firing refers to the practice of introducing biomass in high-efficiency coal fired boilers as a supplementary energy source.
- Co-firing has been evaluated for a variety of boiler technologies, including pulverized coal, cyclone, fluidized bed, and spreader stokers.
- For utilities and power generating companies with coal-fired capacity, co-firing with biomass may represent one of the least-cost renewable energy options.

Gasification

- Biomass gasification for power production involves heating biomass in an oxygen-starved environment (steam needed) to produce a medium or low calorific gas (carbon monoxide and hydrogen).
- This "syngas" is then used as fuel in a combined cycle power generation plant that includes a gas turbine topping cycle and a steam turbine bottoming cycle.

Pyrolysis

- Biomass pyrolysis refers to a process where biomass is exposed to high temperatures in the absence of air, causing the biomass to decompose.
- The end product of pyrolysis is a mixture of solids (char), liquids (oxygenated oils), tars, and gases (methane, carbon monoxide, carbon dioxide, and other organic gases).



Pros and Cons of Direct Combustion

- Advantage: It employs commercially well-developed technology.
- Disadvantages:
  - Penalties associated with burning high-moisture fuels.
  - Agglomeration and ash fouling due to c compounds. (Slagging is the partial or complete melting of ash, whereas fouling is the accumulation of sticky ash particles on heat exchange surfaces.)
  - Relatively low thermodynamic efficiencies (wood - 12,500 Btu/kWh vs. coal -10,250 Btu/kWh).

Alternatives to Direct Combustion

- Co-firing:
  - ✓ Less costly than landfilling of wastes.
  - ✓ Compliance of federal regulation (PM 0.05 to 0.1 lb/MBtu, less Surfur).
  - ✓ Fuel flexibility.
  - × Lower energy density (high moisture content).
  - × Limit of fly ash market (concrete admixtures).
- Converting the solid biomass to a gaseous or liquid fuel by heating it with limited oxygen prior to combustion can greatly increase the overall efficiency.

Lecture 19.13

Gasification

- Heating and drying: endothermic processes.
- Pyrolysis: a complicated series of thermally driven chemical reactions (300-400°C). CO, CO_2, H_2, light hydrocarbons, tar, etc. More pores.
- Gas-solid reactions: these reactions convert solid carbon into gaseous CO, H_2 and CH_4.
- Gas-phase reactions: determine the final mix of gaseous products.

Biomass Gasification

- Gasification is the high temperature (750-850°C) conversion of solid, carbonaceous fuels into flammable gas mixtures (CO, CO_2, H_2, CH_4, N_2, etc.) with a controlled amount of oxygen and/or steam.
- Biomass is an ideal gasification fuel: high volatile content of biomass (70-90 wt-%) (coal 30-40%); high reactivity of its char.

Pros and Cons of Gasification

Advantages:

- The combined heat and power (CHP) generation via biomass gasification techniques connected to gas-fired engines or gas turbines can achieve significantly higher electrical efficiencies between 22% and 37% (combustion: 15% to 18%).
- Due to the improved electrical efficiency of the energy conversion via gasification, the potential reduction in CO_2 is greater than with combustion.
- The formation of NOx compounds can also be largely prevented and the removal of pollutants is easier for various substances.

Pros and Cons of Gasification

Disadvantages:

- Processing of biomass material into finely divided particles.
- Low heating value of the product gases (10-20% of natural gas) due to nitrogen dilution (air blown).
- Contaminants: tar and particulate matter.
- Thermodynamic efficiency (40-90%).
- Cost.

Pyrolysis

- Biomass pyrolysis refers to a process where biomass is exposed to high temperatures in the absence of air, causing the biomass to decompose.
- The end product of pyrolysis is a mixture of solids (char), liquids (oxygenated oils), tars, and gases (methane, carbon monoxide, carbon dioxide, and other organic gases).

Pyrolysis

- Slow pyrolysis: reduce wood to charcoal, several hours.
- Fast pyrolysis (flash pyrolysis) takes place in less than two seconds with temperatures between 300 and 550°C.
- For flash pyrolysis the biomass must be ground into fine particles. The insulating char layer that forms at the surface of the reacting particles must be continuously removed.

Fast Pyrolysis

- Fast pyrolysis is the rapid thermal decomposition of organic compounds in the absence of oxygen to produce liquids, gases and biochar. The final products depends on the biomass composition and rate and duration of heating. Liquid (bio-oil) yields as high as 78%.
- Rapid quenching is essential. Otherwise liquids will be further decomposed to gases (syngas).

Fast Pyrolysis

- Fast pyrolysis of biomass produces a liquid product, pyrolysis oil or bio-oil that can be readily stored and transported. Liquid: low viscosity, dark-brown fluid with up to 15-20% water. Heating value: 17-20 MJ/kg.
- Fast pyrolysis has now achieved a success for production of chemicals and is being actively developed for producing liquid fuels.
- Reactors: bubbling fluid beds, circulating and transported beds, cyclonic reactors, and ablative

Essential Features of a Fast Pyrolysis

Very high heating and heat transfer rates, which require a finely ground feed.

Carefully controlled reaction temperature of around 500°C in the vapour phase.

Residence time of pyrolysis vapours in the reactor less than 1 sec

Quenching (rapid cooling) of the pyrolysis vapours to give the bio-oil product.

Pros and Cons of Pyrolysis

Advantages:

- Liquid bio-oil that can be readily stored and transported.
- Pyrolysis oil is a renewable liquid fuel and can also be used for production of chemicals.
- Efficiency: as high as 75% based on the starting dry biomass weight.
- Pyrolysis oil has been successfully tested in engines, turbines and boilers, and has been upgraded to high quality hydrocarbon fuels although at a presently unacceptable energetic and financial cost.

Pros and Cons of Pyrolysis

Disadvantages:

- Difficulty in phase-separation and polymerization of the liquids.
- Corrosion of the containers.
- Incompatible with conventional hydrocarbon fuels due to high O_2 and water content.
- Much lower quality. Upgrading is needed.
- High cost.

Requirements as Fuel

Availability

Transportability

Energy density

Direct Hydrothermal Liquefaction

- Direct hydrothermal liquefaction involves converting biomass to an oily liquid by contacting the biomass with water at elevated temperatures (300-350°C) with sufficient pressure to maintain the water primarily in the liquid phase (12-20 MPa) for residence times up to 30 minutes.
  - Aqueous phase (vs. dry feedstock).
  - Low T (vs. 450-600°C) and high P (vs. 1 atm).
  - Long time (vs. 0.5-2 s).

Direct Hydrothermal Liquefaction

- Alkali may be added to promote organic conversion.
- The primary product is an organic liquid with reduced oxygen content (about 10%) and the primary byproduct is water containing soluble organic compounds.
- Liquid product: Heating value – 36MJ/kg, Overall thermal efficiency – 80-90%.
- Difficulty in practical implementation due to high pressure.

Indirect Liquefaction

- Indirect liquefaction produces liquid fuel by gasifying low-value organic materials to a mixture of H_2 and CO, known as syngas, followed by catalytic or biological synthesis to ethanol, methanol or other chemical compounds.
- Two distinct approaches to converting syngas to chemicals are possible.
  - The traditional approach involves a moderate-temperature, high-pressure catalytic chemical synthesis of methanol or synthetic gasoline.
  - A more recently developed approach, yet to be commercially applied, employs microorganisms that are able to grow on one-carbon compounds to convert syngas into organic acids or alcohols.

Anaerobic Digestion

- Anaerobic digestion is a process by which organic matter is decomposed by bacteria in the **absence of oxygen** to produce methane and other byproducts.
- The process occurs in stages, each involving specific types of bacteria that successively break down the organic matter into simpler organic compounds – biogas, which is a mixture of CH_4, CO_2 and some trace gases.

Pros and Cons of Digestion

Advantages:

- The ability to use non-sterile reaction vessels.
- Automatic product separation by outgassing.
- Relatively simple equipment and operations.
- Its adaptability to numerous feedstocks.

Pros and Cons of Digestion

Disadvantages:

- Slow reaction rates: The breakdown of cellulose to sugars may require reaction times as long as a month to achieve high yields of methane.
- Low methane yields: Although the theoretical weight yield of methane from glucose is 27wt-%, the complex of lignin and cellulose known as lignocellulose in plant materials results in substantially lower yields of methane than might otherwise be expected from cellulose.
- Toxic and corrosive gas: Microbial reduction of sulfate and other sulfur compounds to hydrogen sulfide that complicates the use of biogas.

Fermentation

- Fermentation refers to the process of deriving energy from the oxidation of organic compounds using an endogenous electron acceptor, which is usually an organic compound.
- Respiration uses an exogenous electron acceptor, such as oxygen, via an electron transport chain.
- Fermentation requires no oxygen.
- Some of the products from fermentation include ethanol, lactic acid, hydrogen, and butyric acid.

Ever-increasing corn ethanol production raises concerns over food prices, use of fertilizers and pesticides, water resources, and so on.

Advantages: production of valuable co-products, e.g., corn oils.
Disadvantages: use of SO2, expensive equipment.

Lecture 21.19

Current Status and Challenges

- Ethanol production from lignocellulose is a feasible technology and can utilize many biomass resources as the feedstock.
- Cellulosic ethanol is still expensive ($4.33 per gallon vs. $1.30~$1.90 per gallon corn ethanol).
- There is no commercially viable bio-refinery in existence to convert lignocellulosic biomass to fuel. In the short term, cellulosic ethanol cannot meet the energy security and environmental goals of a gasoline alternative.
- It is a hot research topic. Efforts include growing high-yield energy crops, improving biomass harvesting, storage and transportation, finding highly active enzymes and catalysts for pretreatment, and cellulolysis.

Type:
1. Kinetic : Flywheel . $E=\frac{1}{2}I\omega^2$, high charge discharge rate., high cycling capability.
2. potential : Pumped Hydro $E=mgh$. high power capacity, high storage capacity., cycle eff 70~85%, service 50~100 yr.
3. compressed Air energy :
4. electrochemical : Batteries. : low self discharge, easy to install, maintain, limited lifetime, ↑T improve power but ↓ life
5. electrostatic energy : Super capacitors $E=\frac{1}{2}CV^2$. Low self discharge, extremely high charge/disch rate, cyc eff 85~98%
6. electromagnetic energy : SMES. cyc eff >95%, superconductivity at cryogenic temperature, store in magnetic filed
7 Thermal : sensible heat storage $\Delta T>0$. $Q=mC_p(T_2-T_1)$. Hot water Storage
Latent heat ... $\Delta T=0$ $Q=mL$, Molten Salt Storage
8 Chemical Hydrogen. hight specific energy. low energy density, common storage method
pressurized tanks / pipeline
metal hydride, Liquefaction
carbon nanofibers

LEED level. certified 45~59 ; silver 60~74 ; gold 75~89 ; platinum 90-136

Green Building

"Buildings of tomorrow should be self-sufficient in energy and have carbon neutral emissions. This can be done by incorporating renewable energy sources into a building's design, optimizing energy efficiency of support systems and taking advantage of geographic and culturally acceptable building practices."

Jan van Dokkum, President, UTC Power

What LEED Is

- LEED, or **Leadership in Energy and Environmental Design**, is an internationally-recognized green building certification system. Developed by the **U.S. Green Building Council** (USGBC) in March 2000, LEED provides building owners and operators with a framework for identifying and implementing practical and measurable green building designs, constructions, operations, and maintenance solutions.

LEED Rating Systems

LEED promotes a whole-building approach to sustainability. Key areas include:

- **Sustainable Sites**: minimize a building's impact on ecosystems and waterways.
- **Water Efficiency**: encourage smarter use of water.
- **Energy and Atmosphere**: encourages energy saving.
- **Materials and Resources**: encourages sustainably grown, harvested, produced, and transported products and materials. It promotes waste reduction as well as reuse and recycling.

LEED Rating Systems

- **Indoor Environmental Quality**: improve indoor air as well as natural daylight and views, acoustics.
- **Locations and Linkages**: encourages building on previously developed or infill sites.
- **Awareness and Education**: educate building owners to use green features to maximum effect.
- **Innovation in Design**: use innovative technologies and strategies.
- **Regional Priority**: address most important local environmental concerns.

How to Utilize these Alternativ

- Solar Energy
  - Solar passive heating
  - Solar water heater
  - Solar photovoltaics
- Wind Energy – wind turbine
- Geothermal Energy – heat pump
- Biomass – corn burner
- Hydrogen Energy – fuel cell

Design of a Zero Energy Building

- Electricity: Photovoltaic (PV) solar pane. Fuel cell. Wind turbine.
- Heating: Passive solar heating. Ground Coupled Heat Pump (GCHP)-geothermal energy. Biomass.
- Cooling: GCHP. Solar powered (hot water-fired) air-cooled absorption chiller. Evaporative cooling.
- Lighting: Hybrid solar lighting.
- Construction: Insulations.

Life Cycle Energy Analysis

- Life Cycle Energy Analysis (LCEA) is an approach in which all energy inputs to a product are accounted for, not only direct energy inputs during manufacture, but also all energy inputs needed to produce components, materials and services needed for the manufacturing process. Early expression used for the approach is energy analysis.
- Net Energy Content is the final energy content of the energy product minus all energy input expended durin the extraction and conversion processes, directly or indirectly.

Problem with Energy Analysis

- A problem that energy analysis method can not resolve is that different energy forms (heat, electricity, chemical energy, etc.) have different quality and value even in natural sciences.
- The conflict is resolved in one of the following ways:
  - Value difference between energy inputs are ignored.
  - Arbitrary assignment of a value ratio, e.g., a joule of electricity is 2.6 times more valuable than a joule of heat or fuel input.
  - The analysis is supplemented by economic (monetary) cost analysis.

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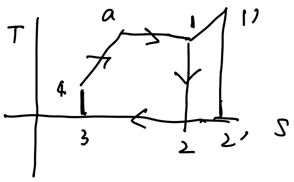
ideal Rankine cycle.
$S_1=S_2$,
$h=h_f+x(h_g+h_f)$.
$s=s_f+x(s_g-s_f)$.

turbine $w_t=m(h_1-h_2)$
condenser $Q_{out}=m(h_2-h_3)$
pump $w_p=m(h_4-h_3)$
Boiler $Q_{in}=m(h_1-h_4)$



$\eta=1-\frac{(h_2-h_3)}{(h_1-h_4)}=\frac{\frac{w_t}{m}-\frac{w_p}{m}}{\frac{Q_{in}}{m}}$

$\eta_{max}=1-\frac{T_c}{T_H}$

for a turbine $x=\frac{S_1-S_{2f}}{S_{2g}-S_{2f}}$

gear ratio = $\frac{1000}{N}$.

0°c → $T_e=-20°c$ $COP=\frac{T_c}{T_c-T_e}$ T_e 要减20
34°c → $T_c=44°c$. 变K, T_c 要+20.

$COP_h=\frac{Q_o}{w}=\frac{Q_i+w}{w}$

70% Betz limit, eff of gearing and generator

$C_p=0.593\times70\%$.

$\eta=C_p\cdot\frac{P_e}{P_b}$, $P_b=\frac{P_e\cdot C_p}{\eta}$

power in the wind : $P=0.5\rho AV^3$. $\rho=1.2kg/m^3$

$P(W/m^2)$ = A 代 1m³

Raley :
average wind power 用 $P_{ave}=\frac{6}{\pi}\cdot\frac{1}{2}\rho AV_{avg}^3$

Hrs = 8760.

给表, V_{ave} 所有时间×V / 24×365, 没有 Relay. average 用 $P_{ave}=\frac{1}{2}\rho AV_{ave}^3$

给 V, pow 表, 算 annual 电表.

overall average eff = $\frac{P_表}{P_风}$, $P_风$用 $\bar{P}=\frac{6}{\pi}\times\frac{1}{2}\rho\bar{V}^3A$

average eff = $\frac{P_R\cdot CF}{\bar{P}}$