GEC1010
AY22/23 Sem 2
github.com/securespider

01. Energy

By constant force

work done by a force == force * displacement
$W = FS$

Law of conservation of energy

Energy can neither be created nor destroyed, it can only be transformed from one form to another

Kinetic energy

linear motion - $K = \frac{1}{2}mv^2$

angular motion - $\frac{1}{2}I\omega^2$

- I = Moment of inertia of object (dependent on mass distribution of object)
- ω = angular velocity of the rotating object
  - Rad/second
  - $v = \omega * radius$

Gravitational potential energy

$U = mgh$

Power

Rate of doing work or rate of consumption of energy
$P = \frac{\triangle W}{\triangle t}$
Work done, W, by a system in time t

Requirements of an energy system

Energy resource

- Clean energy
  - Wind Energy
  - **Hydro energy** - Come from river and dams
  - Ocean energyOnly refers to energy coming from ocean currents etc
  - Solar energy
  - Biomass
  - Non-Renewables:
  - Geothermal
  - Nuclear
- Fossil fuels
  - Coal
    - Greater carbon content and more impurities - More carbon dioxide and greater air pollution
    - Solid so difficulty in extraction, transportation and use
  - Natural Gas
    - Cleaner alternative
  - Oil

Problems
- Unsustainable - reserves depleting
- Global warming - Enhanced greenhouse effect by earth atmosphere
- Greater absorption of long wavelength IR in earth's atmosphere
- Rising temperature anomaly from 1965-now by about 100mm
- Global sea level rising
  - Thermal expansion of water
  - Melting alpine glaciers and ice sheets
- Earlier timing of spring events
- Poleward and upward shift in plant and animal species

Solution:
Clean energy
- Replace existing supply of fossil fuels
- Use energy more efficiently and judiciously minimizing environmental pollution

High power

High energy conversion efficiency

Singapore

Singapore uses LNG primarily (95%) piped from indonesia and malaysia
Switching to **solar** and biofuels to reduce reliance

Energy conservation

- Outdoor LED initative
- Electric car sharing

02. Fundamentals of thermal energy

$Q = mc\triangle T$

Q Heat energy supplied
m mass
c Specific heat capacity of material
T temperature change resulting from heat energy

$Q = mL$

Q Heat energy supplied
m mass
L Specific latent heat of vaporization/fusion

Types

- Conduction
  - Dominant in solids
  - No bulk motion of matter
  - Heat flows from region of high temperature to region of low temperature
- Convection
  - Dominant in fluids (liquid and gases)
  - Works by circulating fluids and thermal expansion properties of materials
  - Cold fluids sink, warm fluid rise
- Radiation
  - Uneven, black bodies absorb/emit better

Stefan Boltzmann Law

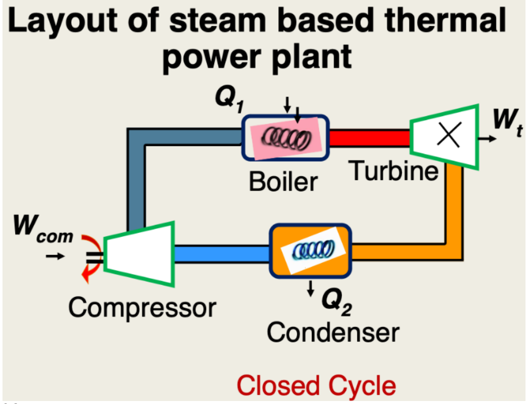
Power of black body radiation
$P = \epsilon\sigma T_0^4$

P Energy absorbed per unit second per unit area via radiation
ϵ Emissivity of surface(lies between 0-1)
σ $5.67 * 10^{-8}$ = Stefan Boltzmann constant

First law of thermodynamics

Difference between the heat absorbed Q and the work done W on object is equal to change in internal energy of the thermodynamic system
$Q - W = \triangle U$

Steam based thermal power plant



Key stages

Compression Work done on system to compress cold water to high pressure

Boiling Heat added to the system to convert cold water into steam

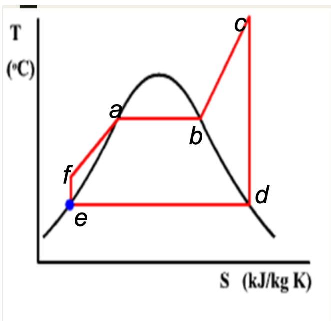
Turbine rotation Work W_t done by the system on turbine blades

Condensation Heat lost from the system to the environment in converting steam back to cold water

- Working fluid have the same amount of energy U as it had in the beginning of the cycle
- Net heat absorbed = $Q_2 - Q_2$

Efficiency of cycle is given by
$\eta = \frac{Net\ output\ work}{heat\ input} = \frac{W_t - W_{com}}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1}$

Rankine cycle



Steam power plant energy generation (Temperature - entropy graph)

- EF - Compressor increases the pressure of water
- FA - Economiser, Water heated at high pressure until it boils
- AB - Evaporator, 2 phase mixture of water and steam is heated at constant pressure until all water converted to dry steam
- BC - Superheater, Dry steam heated at constant pressure in superheater
- CD - Dry steam enter turbine at high pressure and rotate the turbine
- DE - Steam converted to water
  - Problem: Unable to completely eliminate the formation of water droplets @ CD
  - Solution: Reheat the steam at CD to rotate the turbine again
  - Temperature is raised again, leading to greater efficiency
  - Achieve 40% efficiency
  - Cannot go beyond 650c to prevent metal fatigue

Brayton cycle

Use gas instead of water leading to no worry of water droplets and can go higher temperatures

03. Wind energy

How wind forms

Dominant

- **Coriolis Effect** - Sideward component of wind due to earth rotation
- **Solar radiation** - Warm air rise up in the equator leading to difference in densities

Other factors

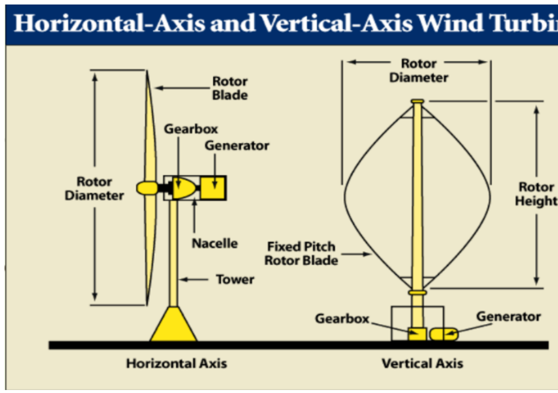
- Ocean
  - Water absorbs/releases heat slower than land
  - Day: Water less hot, sea - land
  - Night: Water hotter, land - sea
- Surface friction
- Eddy motion
- Seasonal effects

Power of wind

$P = \frac{1}{2}\rho A u^3$

Wind speed affected by height of the turbines
- Wind speed rises proportionally to 7th root of altitude

Wind turbines



- **Yaw control** - Orientates the nacelle in direction of incident wind
  - Note: Better for rotor to face the wind
  - Less wind shadowing effect
  - Blades flex less
  - Less fatigue in the blades

Forces

Drag Net force in direction of wind

Lift Net force perpendicular to wind

Blades

Turbines cause turbulence for surrounding blades so cannot have too many blades

Tip Speed Ratio (TSR) - $\frac{Speed\ of\ rotation\ of\ outer\ tip}{incident\ wind\ speed}$

Betz limit - Maximum theoretical efficiency of rotor

Capacity factor - $\frac{yield}{rated\ power}$

Dependent on wind speed

Offshore vs Onshore

+ Wind speed is faster offshore
+ Less obtrusive
+ Bigger in size
+ CF higher

- Harder to maintain cus in the sea (But easier to build because transportation over water easier)
- Might spoil faster due to seawater

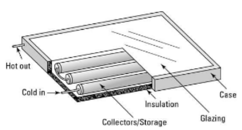
04a. Solar Power

Renewable form of energy with $3.9x10^{26}W$
Only half reach surface of earth

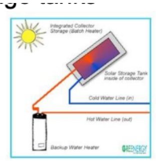
Types of systems

- **Passive** - Uses no external power
  - Allows fluid heated by the sun to circulate by natural means
- **Active** - Solar heated fluid is circulated by a fan or pump

Solar fluid collectors



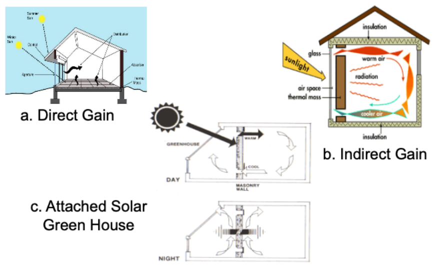
•Flat Plate Collectors



•Batch Collectors

•Evacuated Tube Solar Collectors

Passive space heating system

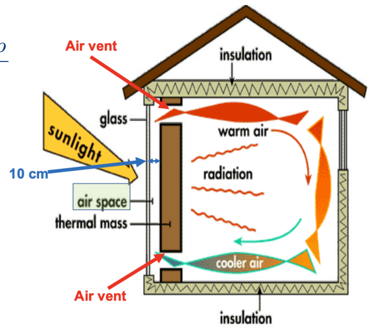


a. Direct Gain

b. Indirect Gain

c. Attached Solar Green House

Trombe wall



Principles of passive cooling

- Minimise solar heat gain
  - Increase building mass
  - Increase thermal protection
  - REflective coating on exposed surface
  - shading device
  - Air tightness in building
- Remove unwanted heat
  - Evaporative cooling
  - Nocturnal ventilation
  - Thermo-active ceiling

Solar power energy

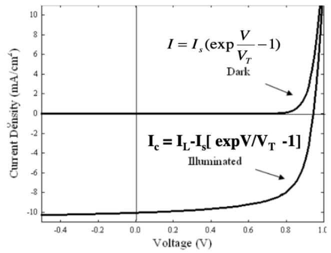
Using the heat by the sun to drive rankine cycle

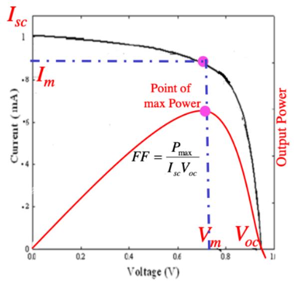
- using mirrors to focus sun light into a tower to heat molten salt
- Run focus pipes surrounded my mirrors to heat the fluid in the pipes to be used to generate heat

04b. Solar Photovoltaics

$E = hf = \frac{hc}{\lambda}| \ h = 6.63 * 10^{-34}, c = 3 * 10^8$

Solar Cell Current-Voltage (IV) Characteristics





Band gap

Minimum energy that is required to excite an electron up to a state in the conduction band where it can participate in conduction
Higher short circuit current - lower bandgap

Silicon

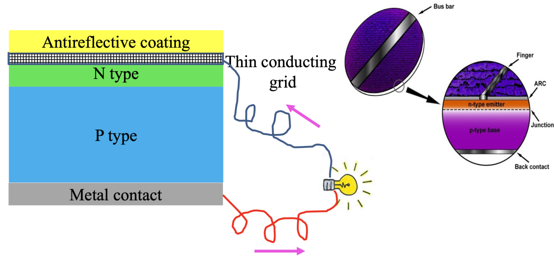
Types

- Polycrystalline
- Crystalline
- Amorphous

Mechanism

Transfer of electrons from n-types and p-types to maintain electric potential

- **N-type** - Electron rich (conduct via electrons)
  - Doped with elements with more valence electrons (P)
  - Cathode (negative terminal where current flows into when illuminated)
- **P-type** - Electron deficient (conduct via holes)
  - Doped with elements with less valence electrons (Al)
  - Anode (postive terminal where current flows out of when illuminated)
- Pink arrow denotes conventional current



Efficiency

- 23% of photons has less energy than bandgap
- 30% heat energy and 10% loss from electron hole-pair recombination
- Increase efficiency by using anti-reflective coating
- Smaller bandgap - greater photocurrent but decrease output voltage (optimum 1.4eV gap)

05a. Hydro power

Ocean vs River

River

1. Hydroelectricity

Ocean

1. Tidal power
2. Wave power
3. Ocean thermal

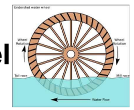
Water wheels

Water mills

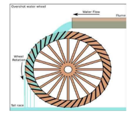
- Ancient application for replacing physical labour
- Replaced with water turbines for energy generation

Types of water wheels

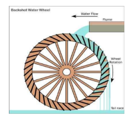
Undershot Water Wheel



Overshot Water Wheel



Backshot Water Wheel



- Undershot
  - Vertically mounted with water flowing at the bottom of the wheel
  - Cheapest and least efficient
- Overshot
  - Falling water on the top of the wheel in direction of rotation
  - Use all water flow for power production
  - Does not require rapid flow of water
  - Uses the difference in weight between the 2 sides of the wheel to turn
- Backshot

– Introduced behind the apex of the wheel
– Water flows opposite the direction of rotation
– Continues to function even when water in wheel put rises beyond height of axle
– Technique useful for streams that experience extreme seasonal variations in flow

Types of Hydro Power

- Dam based
- Run of the river plants(diversion)
- Pumped storage technology
- Damless hydro power

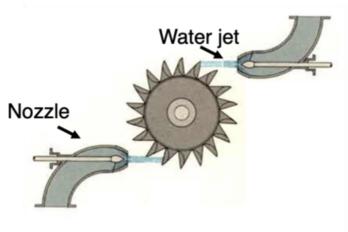
Principles of power generation

Production of electricity by using gravitational force of falling water
$P = \eta \rho g h Q$
η = efficiency, ρ = density of water, Q = Volume of water flowing per second on turbine, h = Vertical distance between turbine and water surface

Types of water turbines

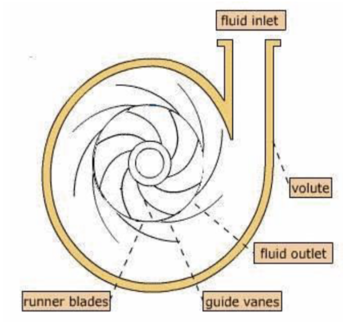
Impulse

- Simpler and cheaper design - Easier to fabricate and maintain
- Needs higher head height
- Higher volume flow rate
- Greater tolerance of sand and other particles in water
- Better access to working parts



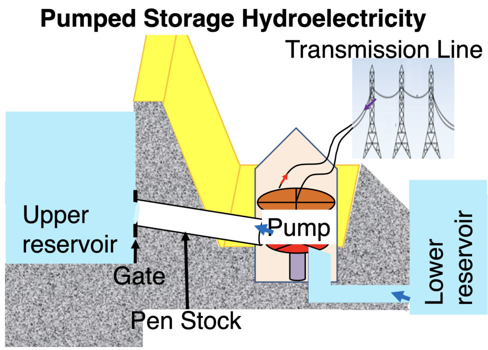
Reaction

- Rotating element in reaction turbine enclosed in pressure casing to generate energy
- Rotates faster than impulse turbines given same head and flow conditions
- More expensive



Run of the river

- Low-level diversion weir/stream bed instead of dam
- Located on fast flowing, non seasonal stream
- Minimize impact on environment



Pumped storage hydro

- Load balancing by storing energy pumped from lower elevation reservoir up
- Low cost off peak power to run pumps and released when high demand
- Net consumer of energy but largest capacity form of grid energy storage

Damless hydro

- Little to no maintenance
- Low initial setup cost and environmental impact
  – No risk of flash flooding/dam-related accidents
  – No silt accumulation and fish ladders

Advantage of hydroelectric

- Clean renewable energy (Low level of greenhouse gases)
- Low operating cost and highly automated
- Plant life is long $\approx$ 40 years
- Available on demand as flow rate is controlled

Problems with hydroelectric

- Capital cost is high and payback time is long
- Social issues with displacement of population
- Environmental impact (Diversion of water)

05b. Ocean Power

1. Tidal energy
   - Gravitational field of sun and moon
2. Ocean wave energy
3. Ocean thermal energy

Tidal energy

- Derived from gravitational interaction between Earth and Moon
- Bulge on opposite side due to earth's attraction
- Low and high tide occuring simultaneously at 2 places with longitudes differing by 90
- Interval between high tides approximately 12h
- **tidal range** - Difference between height of high and low tides
- **Spring tides** - Moon and sun align leading to unusually high tides
- **Neap tides** - Moon perpendicular to sun wrt earth leading to weak tides

Tidal barrage

- Dam built across river estuary
- High tides: Seawater flows into reservoir of barrage and rotate the turbine blades
- Low tides: Seawater stored in barrage is allowed to flow back out into sea turning turbines
- Output power $P = \frac{\eta \rho g A h^2}{T}$
  – T is tidal period (time interval between 2 successive high tides)

Advantages

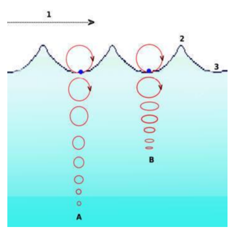
- Free, reliable and green (low maintenance)
- Turbines are cheap and do not cause large environmental impact

Disadvantages

- Only provides power for about 10 hours each day (when tides moving)
- Tidal barrage sites are limited
- Fish ladders have to be installed and total cost is expensive

Ocean current and waves

- Horizontal movement of seawater in the ocean
- Factors affecting:
  – Intensity of solar radiation
    * Fast moving air from sea surface to land
    * Water dragged along the wind
  – Air temperature
  – Wind speed and direction
  – Gravitational pull of sun and moon
- Moving up and down in circles



Motion of a particle in an ocean wave.
A - At deep water. The orbital motion of fluid particles decreases rapidly with increasing depth below the surface.
B - At shallow water (ocean floor is now at B). The elliptical movement of a fluid particle flattens with increasing depth.
1 - Direction of propagation of wave.
2 - Wave crest.
3 - Wave trough.

Types of devices

- Oscillating water column devices
  – Traps air which increases and decreases in volume as the sea surface moves up and down
- Buoyant moored device
  – Floating on surface of water and rotate to generate electricity
  – Requires depth of 80m with almost constant tension to mooring cables
- Archimedes Wave Swing
  – Hydraulic system that compresses air within cylinder when pressure on top of cylinder increases (crest approaching) and vice versa
  – Only one moving part so more reliable with less maintenance
- Pelamis (Hinged countour device)
  – Semi submerged construction generating power from motion at joints
  – Rocking back and forth with waves activates hydraulic pumps driving electricity generators

Impacts

- Large global potential
- Destroys scenic beauty and generates noise pollution
- Have to withstand extreme weather conditions at sea

Ocean Thermal Energy Conversion (OTEC)

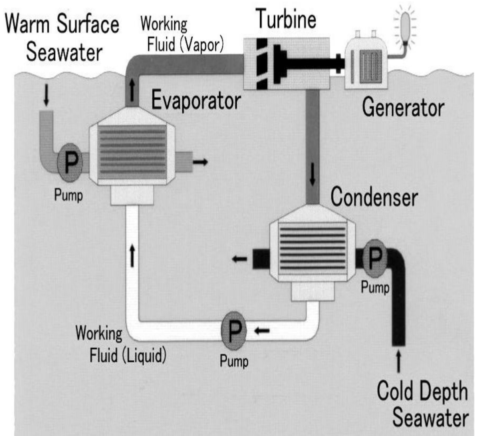
- Using heat energy stored in oceans to generate electricity (best $\approx$ 20c at 1000m)
- Difference in high[shallow] and low[deep] temp to rotate turbine
- Uses rankine cycle (closed/open/hybrid cycles) in low-pressure turbine and ammonia

Benefits

- Provides air conditioning for buildings and refrigeration
- Rich in mineral - used for aquaculture
- Production of fuels concurrently (hydrogen, ammonia and methanol)

Concerns

- Marine organism entrainment and impingement from water current
- Chemicals used to reduce/control biofouling buildup
- **Upwelling** - Rise of deep cold water to surface



06. Biofuels

- Plant and animal derived materials that are renewable and carbon neutral
- Efficiency of photosynthesis $\tilde{0}.5\%$
- Items: Corn, soy, sorghum, sugar cane, waste, sawdust
- Low energy content per kilogram and low density - bulky and expensive

Methods of conversion

Thermochemical

1. Direct conversion
   - Burning solid biomass and production of thermal energy
2. Gasification
   (a) Decompose starting material without oxygen to produce hydrocarbon gases and tar by-product
   (b) Heat char again with oxygen to synthesize more gases
   - Advantage: Gaseous fuels mix better than liquid and burns more efficiently and cleanly
   - Most economically competitive use of biomass
3. Pyrolysis
   - Liquefied by heating in the absence of air

Biochemical

1. Anaerobic digestion
   - Decomposition of organic matter in the absence of air by bacteria
   - Occurs naturally at 30-60c producing methane for heating, cooking and powering generators
   - **biogas** - Methane and C02
2. Fermentation
   - Using yeast or bacteria to convert to ethanol and CO2

Extraction

- **trans esterification** - Reaction with oil using sodium/potassium hydroxide as catalyst to form ethyl/methyl esters (biodiesel)

Impact

- Energy security since biomass is more evenly distributed over earth's surface
- Rural economic growth
- Good and easy storage options

07. Geothermal

- Energy extracted from heat stored in the earth
- Formation of the planet, radioactive decay of mineral, volcanic activity and from solar energy absorbed by surface
- Flowing from the hot core by conduction and convection
- Dissipates to atmosphere and space
- Strongest along tectonic plate boundaries

Methods

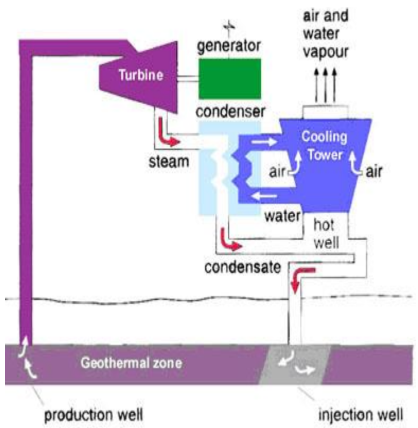
1. Borehole heat exchangers
   - Heat extraction from ambient rock formation
2. Hydrothermal systems
   - Heat extraction from thermal groundwater
3. Hot-dry rock
   - Water circulation through stimulated fractured rock

Sources

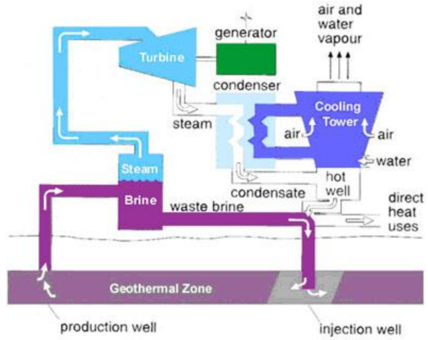
- Hot springs
  - Gushes of hot water found on land surface
  - Water vapor emission from cooling molten which rises through rocks to condense at surface
- Fumaroles
  - Vents from which volcanic gas escapes into the atmosphere
  - Persistent for decades and centuries
  - Dangerous gas at around 70-100c
- Geysers
  - Hot spring erupting periodically ejecting a column of hot water and steam

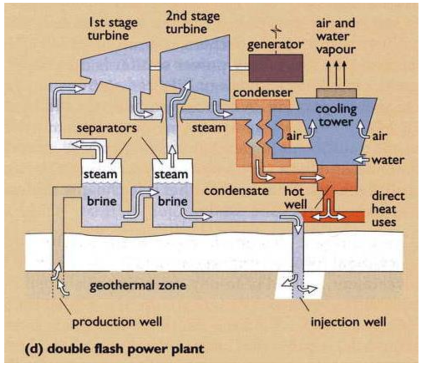
Extraction

1. Dry steam system
   - 180-225c, 4-8 MPa at 200km/h
   - Drive steam generator at 1 kWh/6.5kg of steam
   - Suitable where geothermal steam is not mixed with water
   - Wells drilled to aquifer and superheated pressurised steam brought to surface at high speeds
   - Efficiency: 30%, simplest and most economical technology

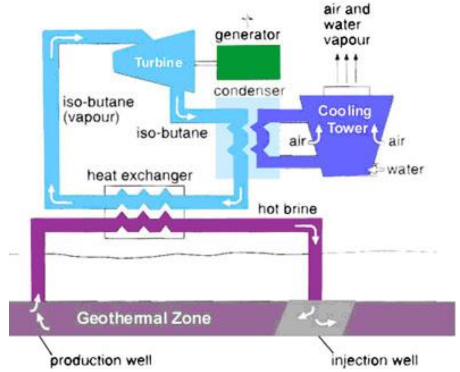


2. Flash system
   - Steam with water extracted and water flashes to steam when pressure drops suddenly
   - Steam separated from water and used to drive a turbine
   - Generates 5-100MW using 6-9 tonnes of steam per hour
   - Single or double[More efficient but higher cost] flashed systems





3. Binary cycle system
   - Used for geothermal resource with low temperatures with liquids with low boiling points
   - Liquids boiled to drive turbine which condenses and recycles continuously
   - 7-12% efficient
   - More expensive but can have higher efficiencies than flash plants



4. Geothermal heat pumps
   - Storing and retrieving heat from earth using anti-freeze/water solution circulated in plastic pipe loops 200m into ground

Concerns

- Environmental impacts (tremors, **subsidence** - sinking of ground)
- Non-steady state source
- High initial capital cost but minimal operating cost