PDHonline Course G417W (2 PDH)

Alternative and Renewable Energy Sources (2-Hour Session, Live Webinar)

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Alternative Energy Sources for Water and Wastewater Facilities

Jim Newton, P.E., BCEE

INTRODUCTIONS

Energy Statistics

US Statistics

- In 2000, per capita energy consumption in US was 230 kWh/day
- Current energy demand is 100 quadrillion BTUs
- Energy usage is for
  - Direct heating
  - Turning shafts to make electricity
  - Turning shafts to move automobile
- US oil production is 2 million barrels/day

Energy densities

Home heating oil	18,921 BTUs/Pound
Natural gas	22,000 BTUs/Pound
Propane	22,584 BTUs/Pound
Gasoline	20,605 BTUs/Pound
Kerosene	20,000 BTUs/Pound
Coal	10, 500 BTUs/Pound
Wood	10,000 BTUs/Pound
Electricity	3,413 BTUs/kWh
Hydrogen	52,000 BTUs/Pound
Enriched uranium	33 billion BTUs/Pound
Battery	60 BTUs/Pound

Real cost of power

- Americans have spent over $400 billion per year on raw fuel
- Raw costs reflects the cost when delivered
- Actual costs include burning and combusting in order to extract the energy contained in them

Energy costs ($/ million BTUs)

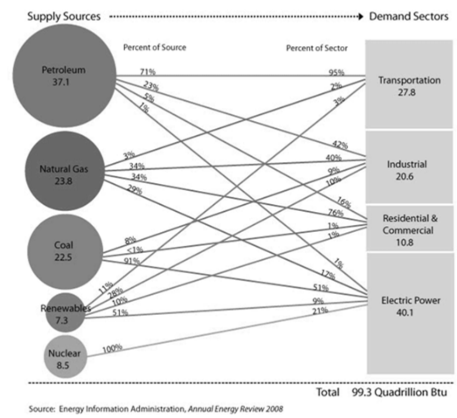
	Raw	Actual
Electricity	29.30	29.30
LPG	18.54	23.18
Gasoline	15.19	75.96
Kerosene	11.11	13.89
Heating oil	10.82	13.52
Natural gas	10.00	12.05
Coal	9.52	15.87
Wood	7.50	12.50
Uranium	0.00033	0.024

Energy consumption/per person/yr (MMBTU)

US	339
Canada	418
Mexico	65
Western Europe	149
India	13
China	33
Japan	172

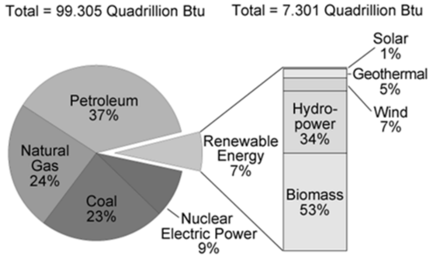
Global availability of fossil fuels

Coal	39,000
Oil	18,900
Gas	15,700
LPG	2,300
Shale	16,000
Uranium 235	2.800



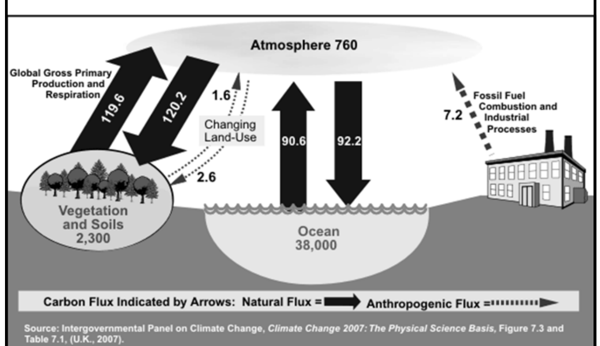
U.S. Energy Consumption by Energy Source, 2008

Total = 99.305 Quadrillion Btu Total = 7.301 Quadrillion Btu



Note: Sum of components may not equal 100% due to independent rounding.

Source: EIA, *Renewable Energy Consumption and Electricity 2008 Statistics*, Table 1: U.S. Energy Consumption by Energy Source, 2004-2008 (July 2009).

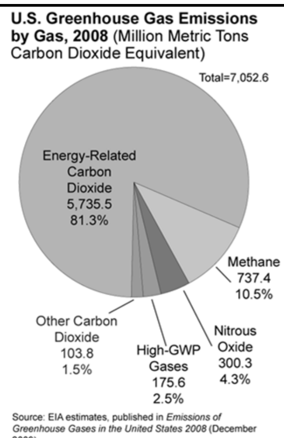


Evidence of global warming

- Endangering wildlife
- Shifting agricultural centers
- Melting ice shelves and glaciers
- Mounting violence in weather
- Rising sea levels

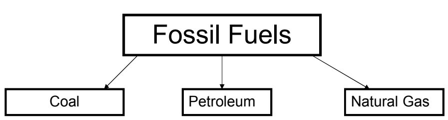
Greenhouse Gases

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Water vapor (H_2O)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulfur hexaflouride (SF_6)

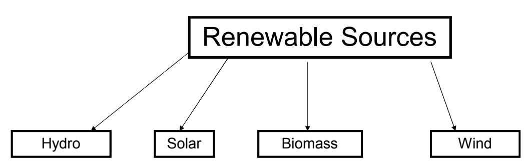


Energy Sources

- Fossil fuel
- Renewable
- Other
- Almost all derived from solar energy

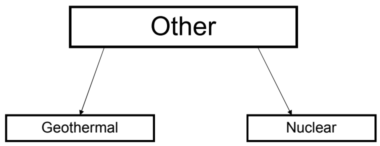


Derived from organisms primarily ocean plankton that grew over several hundred million years ago, storing the solar energy that reached the earth's surface.



Directly or indirectly derived from current solar energy

Note: not all renewable energy is good for the environment



Derived from uranium nuclei contained in the earth (nuclear) that existed when the solar system was formed or residual heat created from the nuclear decay of uranium within the earth (geothermal)

RENEWABLE ENERGY OPTIONS

Reasons to switch

- Pollution mitigation
- Political desirability
- Local jobs
- Sustainable economy
- Keeping money local (not to the Mideast)
- Diversification of the energy supply options
- Security to the US economy
- Increasing the supply of energy options reduces costs
  - Increase competition
  - Making inexpensive energy more available

Disadvantages of electrical power generated by alterative means

- Wind generators cover hillsides with noisy, ugly turbines; birds and bats get killed; pristine compared to other alternatives
- Hydroelectric systems dam up rivers and affect wildlife; dams create underwater decay that releases carbon dioxide
- Geothermal wells release arsenic
- Power lines emit radiation, heat the air, buzz and catch birds and planes

Options

- Solar energy
- Hydropower energy
- Wind energy
- Geothermal energy
- Biomass Energy
- Fuel cells

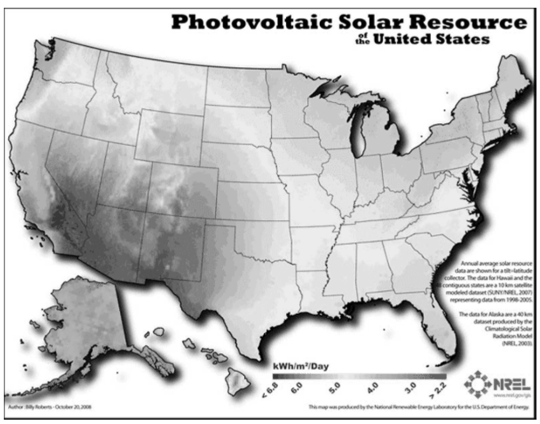
SOLAR POWER

Solar power

- Created by energy from the sun
- Can be passive
  - Solar HVAC
  - Solar drying
  - Solar water heating
- Can be active
  - Photovoltaic
- Available only during daylight hours
- Ocean Thermal Energy Conversion (OTEC)

Solar energy reaching the earth

- 35% reflected back into space
- 43% absorbed as heat radiation (ground and atmosphere)
- 22% evaporates water, creating rain and water distribution
- 0.2% creates wind energy
- 0.02% is used for photosynthesis by plants



Economics of solar

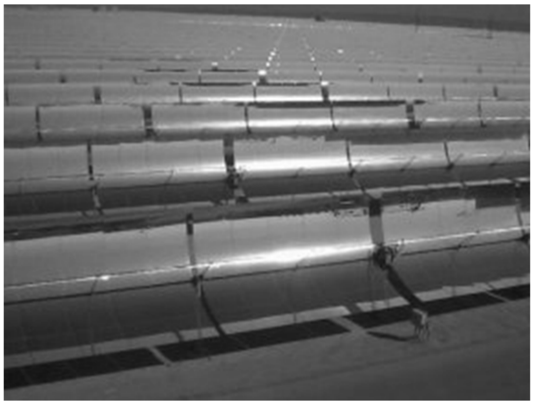
- Viable economically mostly in sunshine rich environments: Southwest, Pacific coast
- Solar communities
  - Are cleaner, less air pollution
  - Experience lower carbon dioxide emissions
  - Support recycling programs
  - Much less of community's money goes out of the region
  - Local jobs are created
  - Jobs created are stable and sustainable
  - Jobs created offer high pay and good benefits

Government incentives

- Federal government favors
  - Solar power is ideal for peak power generating
  - Solar power is cleanest and most efficient source of energy
  - Solar power does not come from one large centralized source
- Federal tax credits
  - Typically 30% of capital cost can be recovered
  - Investment tax credit
  - ARRA (Stimulus)
  - RECs
- State incentives
  - Vary by state

Photovoltaic (PV) Solar

- Convert light energy to electrical energy
- Light photons act as both matter and radiation
- Current efficiency is 16%
- A m^2 of PV will output about 0.18 kW with 1kW of sunlight impacting it
- Two current options
  - Monocrystalline silicon
    - Made of one type of crystal only
    - Best material for PV since efficiency is high, but so are costs
  - Polycrystalline silicon
    - Take up more roof space
    - Lower efficiency
    - Lower costs



Solar Chimney

Financing alternatives

- Through utility companies
  - Pay the utility back via the bill
- Via various leasing arrangements
  - Company pays for the installation and customer agrees to a lease amount
- Buying into solar farms
  - Through a utility and designate a portion for use
- Mandating and amortizing
  - Requiring new homes and buildings to have it
- Government incentives

Solar Farm at KCRWTF

Between April 2011 and February 2013 generated 3.1 GWh about 15%

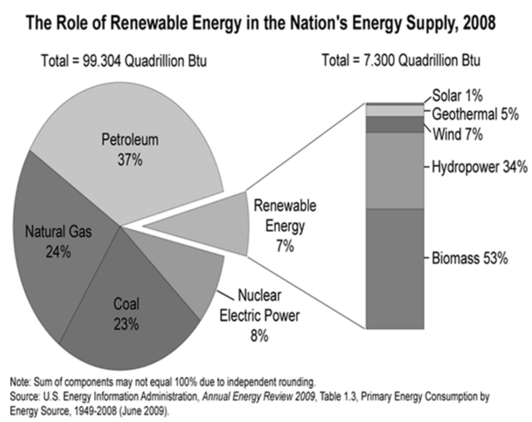
Passive sludge drying

- Parkson Thermo-System
- Being installed at Kent County Regional Wastewater Treatment Facility
- Combination of passive solar during the day
- Natural gas/geothermal at night
- Class A achieved
- Can reach 85% solids
  - Substitute for pulverized coal at cement kilns

Saving about $11,000 per week in natural gas costs compared to current system

From 18% solids to 90% solids in 4 weeks w/o floor hearing

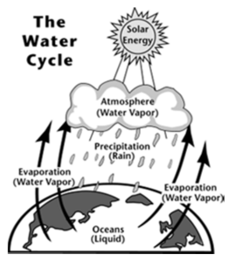
HYDRO POWER



Hydropower

- Created by moving water
- Can be determined based on height differences or flow
- Includes dammed water plants
- Includes tidal power
- Includes wave power

Hydropower



- Solar driven
  - Solar radiation causes evaporation
  - Condensation causes rain
  - Rain falls over the land
  - Streams form into rivers
  - Water flows back to the ocean via gravity
- Combination of solar energy and gravitation potential energy

Stored Potential Energy

PE is the energy stored by water held at a given height

PE = M*g*H

Where M = Mass (kilograms)

g = acceleration of gravity, 9.81m/s^2

H = Height water is raised, aka Head (m)

Power, Head and Flow rate

- Power is energy delivered.
- Theoretical Power
  P(W) = 1000 * Q * g * H

Energy losses affect this:
Frictional drag
Turbulence losses

Effective head

- Theoretical power – losses
- 75-95%
- Efficiency includes other losses due to the generator and other effects

Actual Power

- Actual power

P = 1000 * n * Q * g * H

Where n is the efficiency
H is the effective head

Simplifying:

P (kW) = 10 * n * Q * H

Types of hydropower

- Impoundment systems
- River systems
- Tidal systems
- Wave energy

Tidal Power

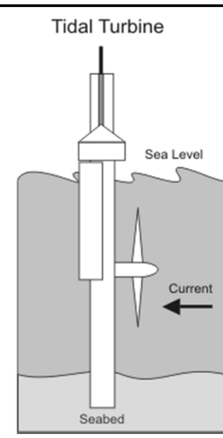
- Tidal barrages (dams)
- Tidal fences
- Tidal turbines

Tidal Power Advantages

- Tides are renewable, sustainable and predictable
- Some areas feature very large differentials between high and low tides
- Produce no air pollution
- Barrage can serve as a power generator and a road across an inlet
- Tidal barrage systems are easy to maintain
- Turbines are beneath the surface so they aren't visually polluting

Disadvantages

- Capital equipment is expensive
- Technology is relatively new
- Turbines can be difficult to install; setting foundations can be problematic
- Tidal systems can affect the surrounding ecosystem
- Failure of the system can cause flooding in the region around the basin



Wave Power

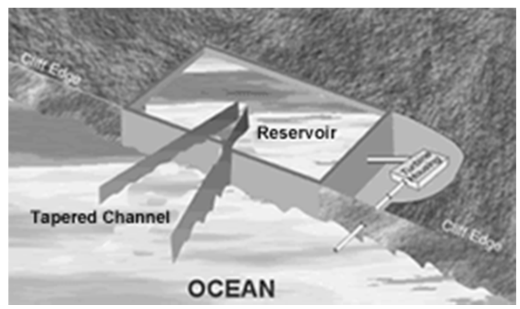
- 3 main areas of research
  - Floats and bobbing devices used to capture the energy in rising and falling waves
  - Oscillating water columns in a cylindrical shaft that increases and decreases air pressure in the shaft as waves pass by. The pressure differential is used to power a turbine
  - Wave focusing systems constructed near a shoreline that directs waves into an elevated reservoir; when the water flows out towards the ocean, the pressure is used to spin a turbine

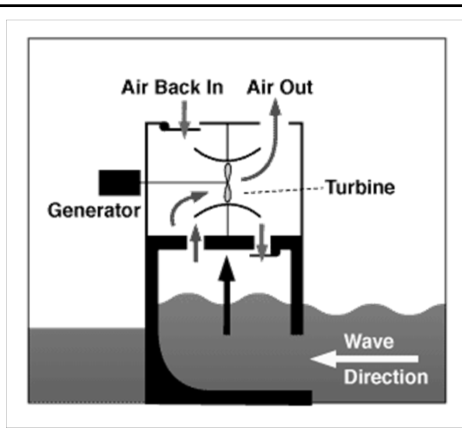
Advantages

- Turbulence of the ocean is a renewable energy source
- No GHG emissions, nor any other air pollution
- Generators are not expensive to install or maintain
- Wave farms can use combined outputs from individual generators
- Wave generators have very low profiles

Disadvantages

- When there are no waves, there is no electricity generated
- They make a sucking noise due to air pressure changes
- Big storms can destroy a system
- Boats may inadvertently run into and damage the systems





WIND POWER

Wind

- Due to temperature differences between different locations on the surface of the earth and between different altitudes
- Solar heating driven
- Motion of a mass of air

Wind power formula

Power = $k^* \, Cp^* \, 1/2 \, ^*\rho^* \, A^*V^3$

Where

P = Power output, kilowatts

Cp = Maximum power coefficient, ranging from 0.25 to 0.45,dimension less (theoretical maximum = 0.59)

ρ = Air density, lb/ft^3

A = Rotor swept area, ft^2 or $\pi D^2/4$ (D is the rotor diameter in ft, π = 3.1416)

V = Wind speed, mph

k = 0.000133 A constant to yield power in kilowatts.

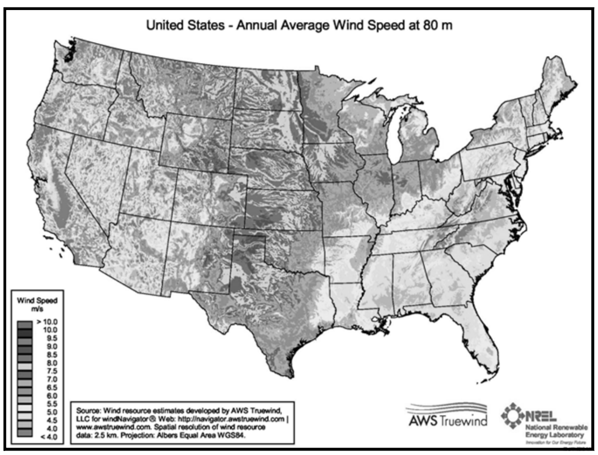
(Multiplying the above kilowatt answer by1.340 converts it to horsepower. [i.e., 1 kW = 1.340 horsepower]).

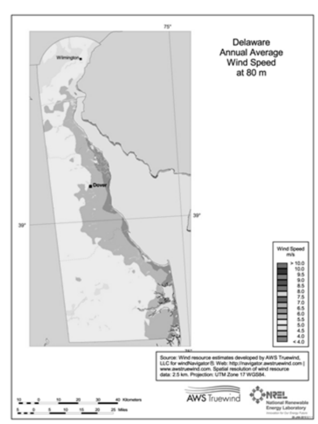
Largest US states generation output, 2006 (MW)

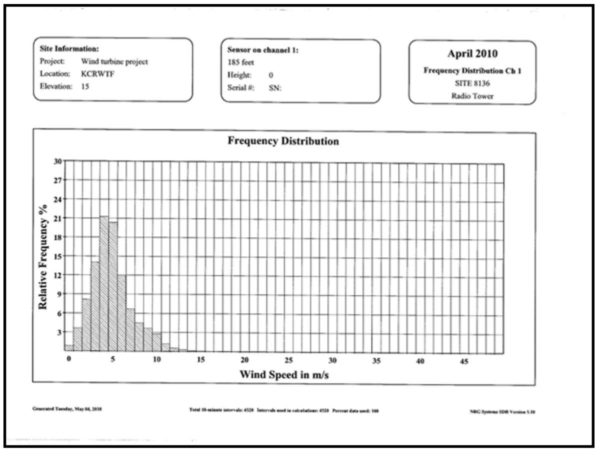
California	2,118
Texas	1,293
Iowa	782
Minnesota	718
Wyoming	285
New Mexico	267
Oregon	263
Washington	240
Colorado	229

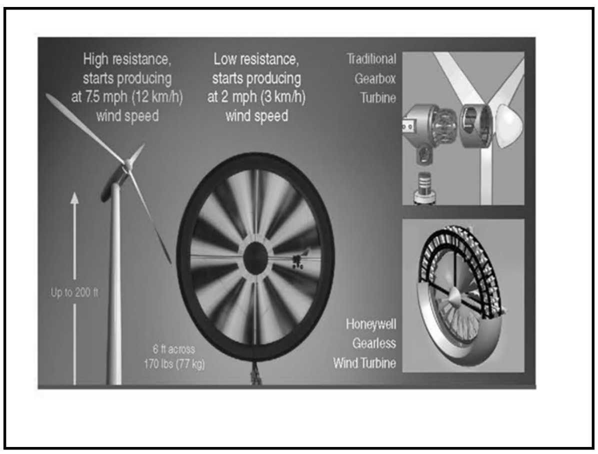
Estimating wind data

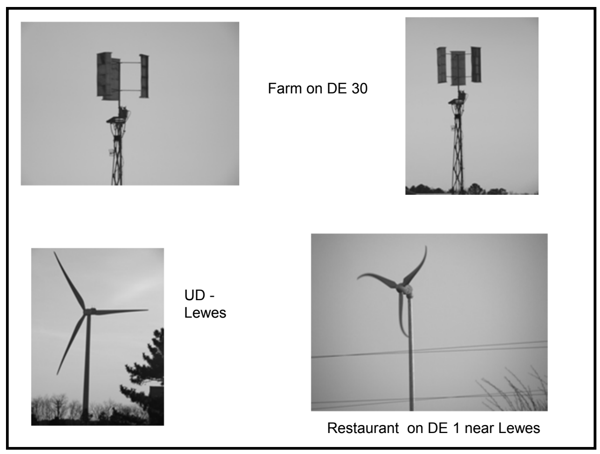
- Wind varies over time and based on terrain
- Use national and state wind maps
- Some places have sufficient wind 24 hours 7 days per week
- Use computer models
  - Example is WinDs, from NREL
  - Need monitoring towers near the planned location
  - Monitor wind speed and direction over time
  - At least a year's worth of data
  - Look at frequency distribution and wind rose
  - Example is Kent County

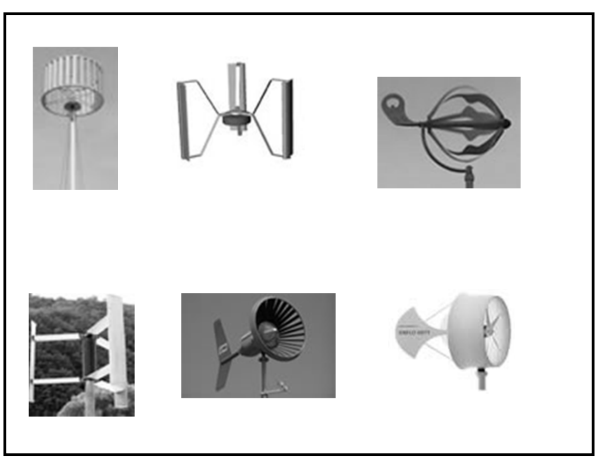


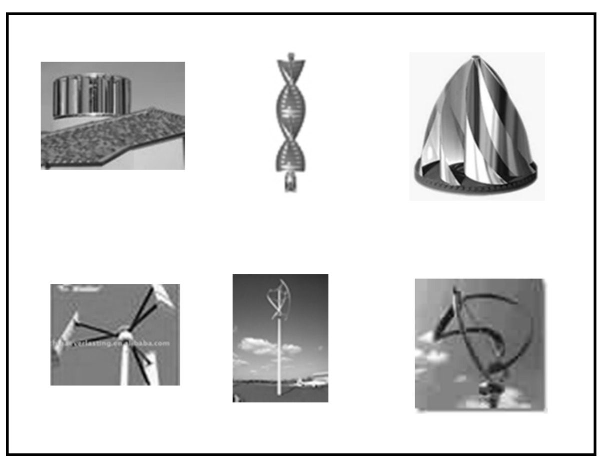



Site Information:
Project: Wind turbine project
Location: KCRWTF
Elevation: 15
Sensor on channel 1:
185 feet
Height: 0
Serial #: SN:
April 2010
Frequency Distribution Ch 1
SITE 8136
Radio Tower
Frequency Distribution
Relative Frequency %
30 27 24 21 18 15 12 9 6 3
0 5 10 15 20 25 30 35 40 45
Wind Speed in m/s


High resistance, starts producing at 7.5 mph (12 km/h) wind speed
Low resistance, starts producing at 2 mph (3 km/h) wind speed
Traditional Gearbox Turbine
Up to 200 ft
6 ft across 170 lbs (77 kg)
Honeywell Gearless Wind Turbine


Farm on DE 30
UD - Lewes
Restaurant on DE 1 near Lewes





GEOTHERMAL POWER

Geothermal

- Based on the heat contained within the earth
- About 10% is residual heat from 4.5 billion years ago
- 90% is due to radioactive decay of uranium, thorium and potassium contained within the earth
- Available across the US, but more prevalent in certain locations
- Both electricity generation and heating and cooling options
- High enthalpy (heat content of a substance per unit mass)

Geothermal information

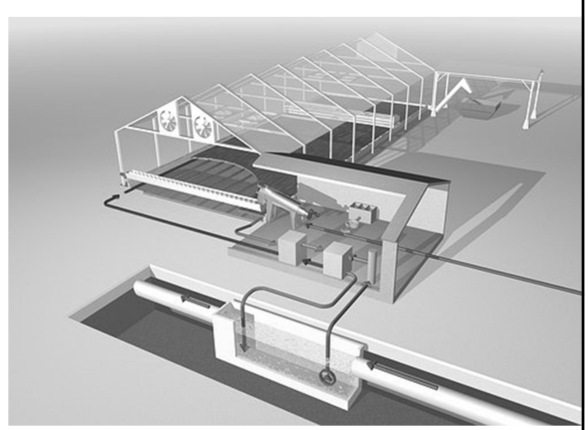
- Earth's core estimated at $8,000^{o}$F
- Heat radiated outward from core towards the surface
- Each mile of depth, temperature increases about 80^{o}F
- Classifications of geothermal fields
  - High grade sources: 400-$1,300^{o}$F
  - Medium grade sources: 300-400^{o}F
  - Low grade sources: 212-300^{o}F
  - Different temperatures require different engineering methods to exploit the energy

Top Geothermal States, 2007

Source: Energy Information Administration, *State Renewable Electricity Profiles 2007* (June 2009).

Geothermal heat pumps

- Using geothermal directly is very simple
  - Capital cost is about $2500/kW
- Direct uses:
  - Heat a home or community
  - Warm water on fish farms
  - Heat greenhouses
  - Pasteurize milk
  - Dehydrate fruits, vegetables and grains
  - Warm underlying soil on farms to increase crop production
  - Sanitize and regulate the temperatures in stables
  - Pump beneath roads and walkways to prevent ice buildup

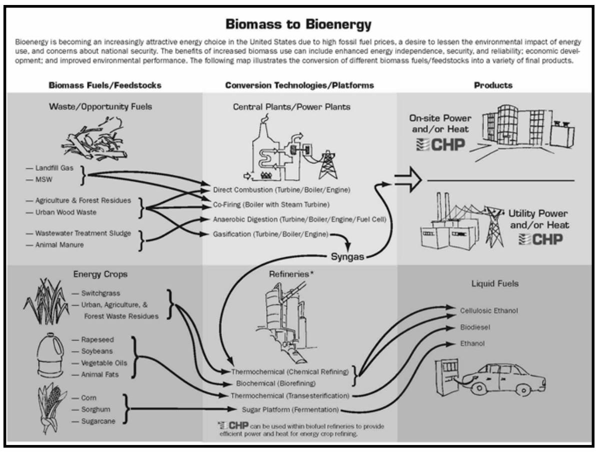


BIOMASS ENERGY

Biomass

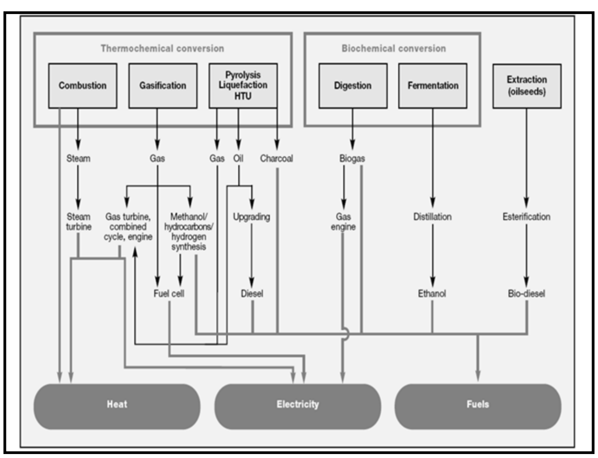
- Living or dead biologic material which can serve as a source of energy
- Produced directly or indirectly through photosynthesis
- Been used for over 1.4 million years
- Renewable because the timescale is within that of a human lifetime
- Cellulose based plants are not good for liquid petroleum supplants

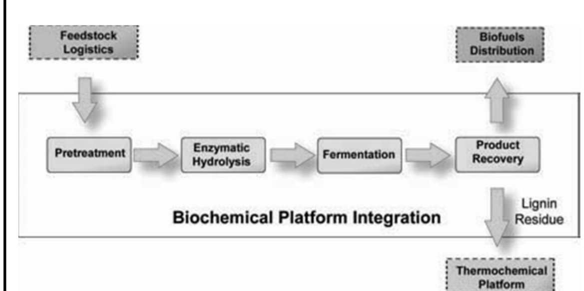
Wood and trees	Corn, soy beans
Sewage Sludge	Animal wastes
Microalgae	Landfill gases
Grasses	

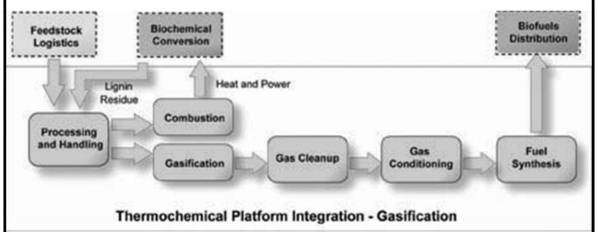


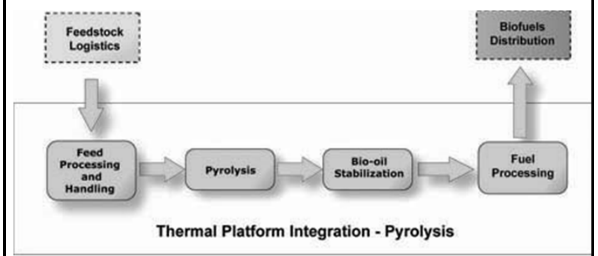
Benefits

- Combustion does not add to the carbon dioxide buildup since carbon dioxide emitted is collected by the next crop of biomass
- Supports local agriculture and forestry industries
- Supports the development of new domestic industries
- Production can be either local and can occur on a large scale
- Effectively carbon neutral because if emits as much carbon dioxide when burned compared to being decayed







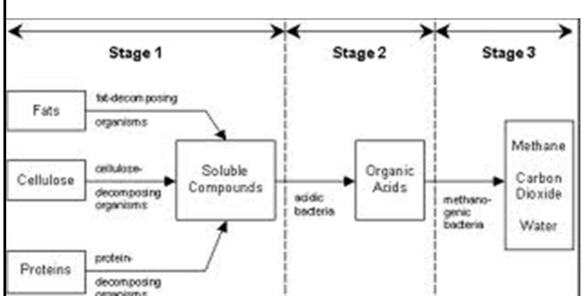


Anaerobic digestion

- Decomposition of organic matter and inorganic matter in the absence of molecular oxygen
- One of the oldest processes used to stabilize wastewater sludge
- Well understood process
- Process can generate sufficient digester gas to meet most of the energy needs for plant operation

Processes

- Hydrolysis
  - Large polymers are broken down by enzymes
- Fermentation (acidogenesis)
  - The formation of soluble organic compounds and short-chain organic acids
  - Volatile acids are produced along with carbon dioxide and hydrogen
- Methanogenesis
  - Bacterial conversion of organic acids into methane and carbon dioxide
  - Acetate, formaldehyde, hydrogen and carbon dioxide are converted to methane and water



Factors to consider

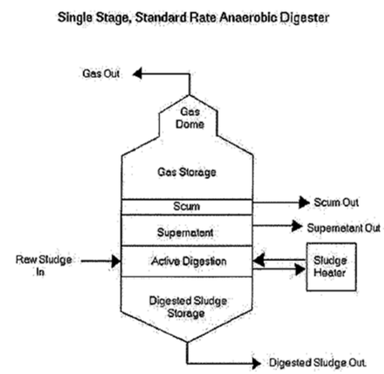
- Solids retention time
- Hydraulic retention time
- Temperature
- Alkalinity
- pH
- Presence of inhibitory substances
- Bioavailability of nutrient and trace metals

Conditions for Sludge Digestion

Temperature	Optimum General Range	98°F 85-95°F
pH	Optimum General Range	7.0-7.1 6.7-7.4
Gas production	Per pound volatile solids added Per pound volatile solids destroyed	8-12 cu. ft. 16-18 cu. ft.
Gas Composition	Methane Carbon Dioxide Hydrogen Sulfide	65-69% 31-35% Trace
Volatile Acid Concentration As Ascetic Acid	Normal Maximum	200-800 mg/L 2000 mg/L
Alkalinity Concentration As Calcium Carbonate	Normal	2000-3500 mg/L

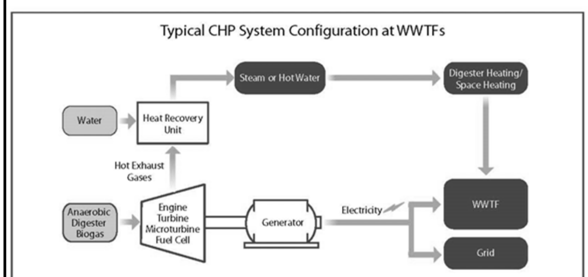
Loading and Detention Times

	Single Stage Digester	High Rate Digeseter (First Stage)
Loading (1 lb.cu.ft./day of VS	.02 - .05	.1 - .2
Detention time (days)	30 - 90	10 - 15
Capacity of Digester (cu.ft./pop. equivalent)		
Primary	2 - 1	.4 - .6
Primary and Secondary	4 - 6	.7 - 1.5
Volatile Solids Reduction	50 - 70	50



Combine heat and power (CHP)

- Production of both power and electricity from a single fuel (digester gas)
- A reliable and cost effective option for a WWTP
- Requires anaerobic digestion
- Generate power via a microturbine, a turbine, a fuel cell or a reciprocating engine
- Thermal energy produced by the CHP when generating electricity is used to heat the digester and for space heating



http://www.epa.gov/chp/markets/wastewater.html

CHP engineering details

- About 1 ft^3 of digester gas can be produced per person per day
- 1 ft^3 of digester gas can provide 2.2 watts of power
- Heating value of digester gas is 600 BTUs per ft^3
- For each 4.5 MGD processed at a WWTP, the generated digester gas can produce 100 kW of electricity and 12.5 million BTUs of thermal energy

CHP facility

- Produces power at a cost below retail electricity
- Reduces operating costs by displacing purchased fuels for thermal needs
- Ensures the availability of reliable heat and electricity supply
- Increases energy efficiency, reduces GHG emissions, and generates renewable power

CHP electricity/heat

- Sell back to the grid as green power
- Used to operate pumps and blowers used throughout the WWTP
- Used to maintain optimal digester gas temperatures, dry the biosolids and provide space heating

Generating technology

- Reciprocating engines best for any WWTP and most widely used technology
- Microturbines and fuel cells can be used to generate up to 1 MW with wastewater flows <50 MGD
- Combustion turbines can be used to generate >1 MW and for wastewater flows >50 MGD

CHP cost data

- $.03-$.065/ kWh for a 126 kW microturbine
- $.091 - $.102/ kWh for a 300 kW fuel cell
- $.001 – $.038/ reciprocating engine

WWTP questions

- Flow >5 MGD
- Pay more than $0.06/kWh for electricity
- Reliable high quality power and thermal energy important
- Important to reduce energy costs and increase overall energy efficiency
- Increase facility's environmental performance

Power Generation - Microturbines

- Advantages
  - Low gas flow
  - Lower temperature
  - Lower emissions of pollutants
  - Flexible
- Disadvantages
  - Low flow range
  - New technology

More info

USEPA

www.epa.gov/chp

MICROBIAL FUEL CELLS

Additional Reading

- Alternative Energy for Dummies, DeGunther, Wiley Publishing, Inc., 2009.
- Our Energy Future, Ngo and Natowitz, Wiley Publishing, Inc., 2009.
- Fundamentals of Renewable Energy Processes, 2nd Ed., da Rosa, Academic Press, 2009.
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- US DOE Energy Information Administration, http://www.eia.doe.gov