FUEL & POWER TECHNOLOGIES:

OUTPUTS, DELIVERY EFFICIENCIES AND NEW DEVELOPMENTS

LARRY BELL

Oakridge National Laboratory

Coal is the world's most abundant fossil fuel, providing much of the heat and electrical power.

Global concerns about pollutant emissions are prompting the US and other countries to develop "clean coal" technologies to remove CO_2 and other emissions such as sulfur and nitrogen that form droplets of weak sulfuric and nitric acid ("acid rain").

"Clean Coal" Gasification Plant

US DOE Fossil Energy Office

The clean coal technology field is moving rapidly towards gasification with CO_2 capture, offering 73% thermal efficiency.

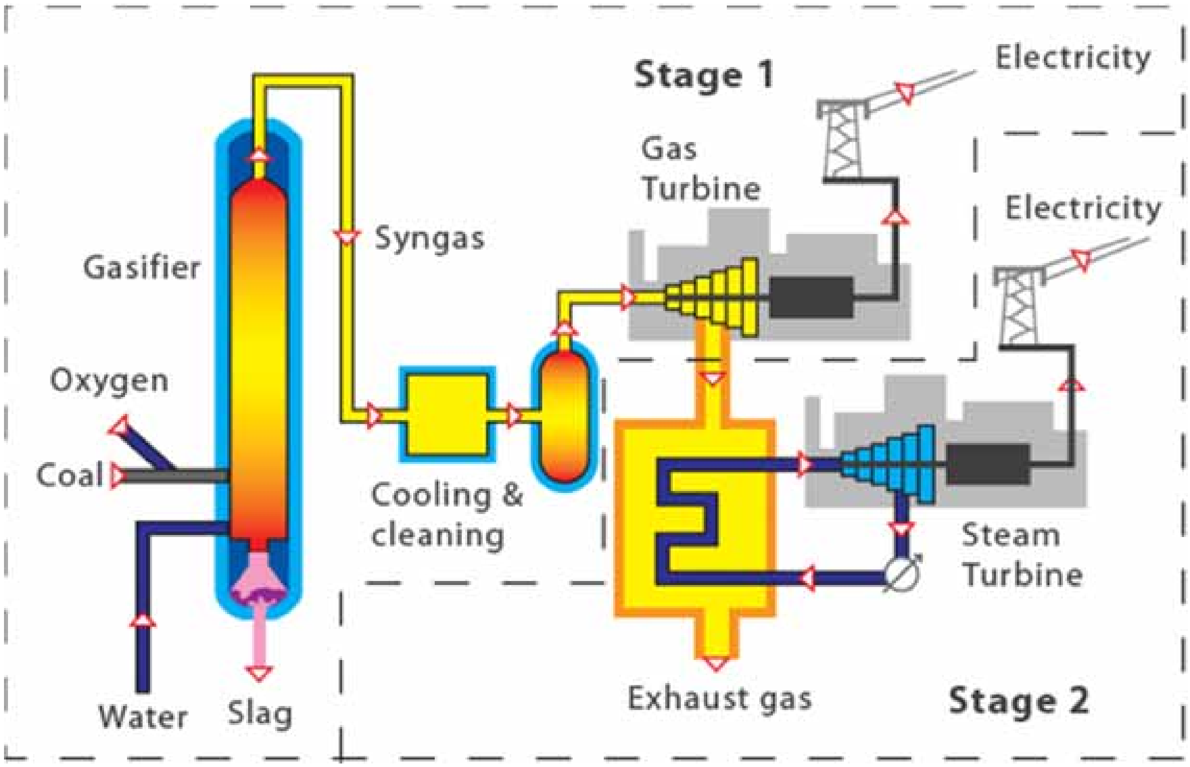
Using hydrogen produced in gas turbines for electricity may offer long-term potentials to achieve overall system efficiencies up to 60%

Coal Gasification Plants

1) The coal gas (syngas) comprised principally of hydrogen and carbon monoxide is first burned to drive a gas turbine to create electricity.
2) The exhaust gases are then heat-exchanged with water/steam to drive a steam turbine.

The second stage steam can also be exported for use by nearby factories and district heating plants.

BBC Co., UK

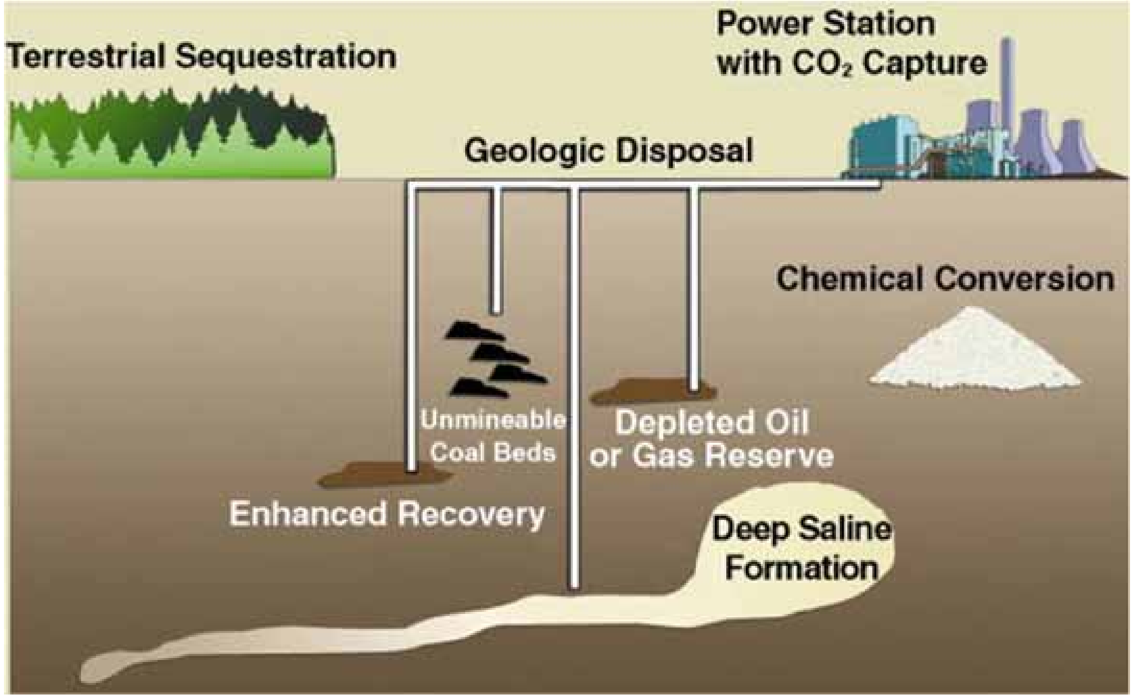


IGCC Coal Power Production Stages

US Government

Much of the CO_2 collected from current coal processing is sequestered in deep geological strata such as aquifers and depleted oil fields.

This gas can be of increasing value for enhanced oil and natural gas (methane) recovery as these resources are depleted.



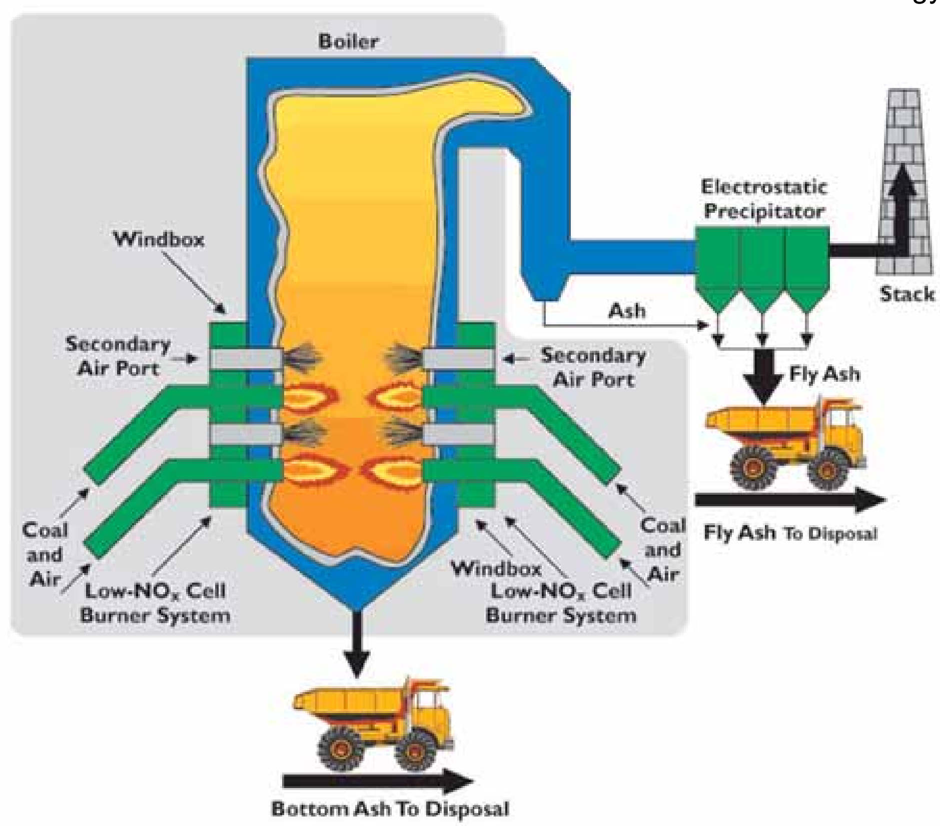
Carbon Sequestration Options

Balanced Energy

Nitrogen oxides (NOx) released into the atmosphere from combustion of coal and other fuels cause urban smog, ground-level ozone, and acid rain.

Nitrogen can be removed by chemical scrubber and staged combustion.

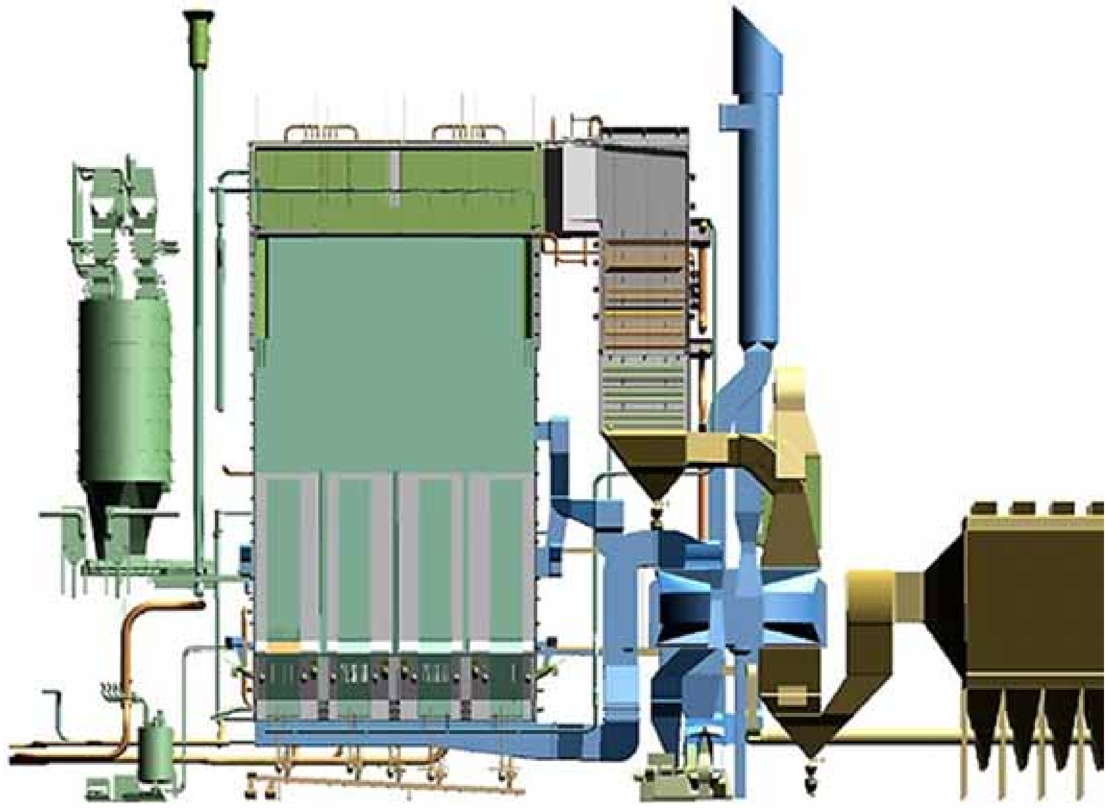
Staged combustion introduces a rich gas mixture into "low-NOx burners" that causes oxygen to combine with the fuel rather than the nitrogen, and then sends the exhaust to a second combustion chamber to be burned again.



NOx Removal from Coal Gas

Sulfuric dioxide (SO_2) components of coalgas combustion can be reduced by washing the coal to remove sulfur particulates before it arrives at the plant.

Advanced pressurized fluid bed boiler technology uses steam to remove sulfur and nitrogen pollutants and produces electricity-generating efficiencies that can be more than 50% higher than conventional plants.



SO_2 and NOx Removal from Coal Gas

Coal-Derived Liquid Fuels

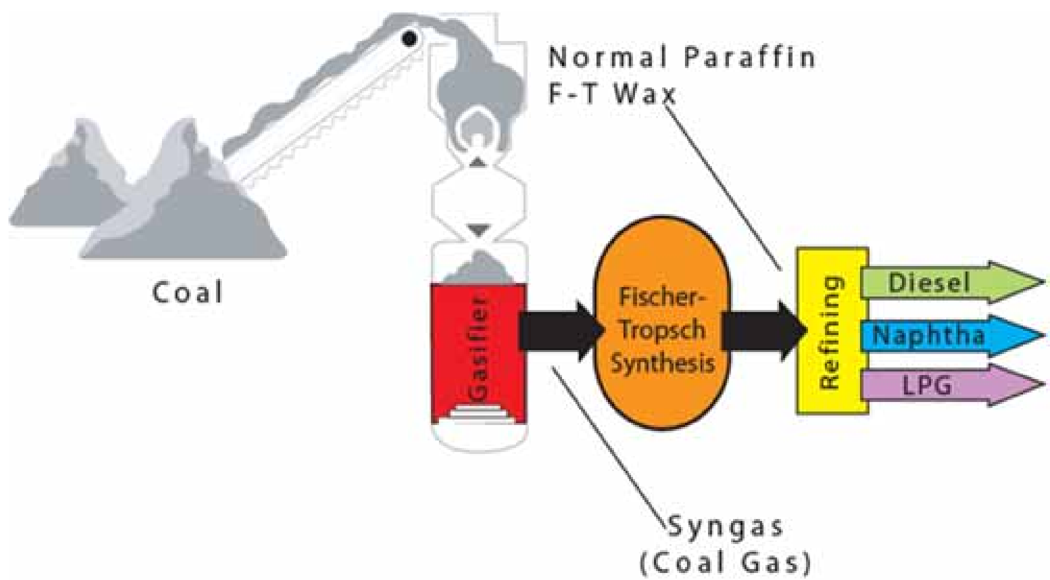
Liquid and gaseous synthetic fuels produced from coal can extend and maybe eventually replace oil-derived petroleum products.

Coal-derived fuels, including hydrogen, can potentially be processed in conventional petroleum refineries.

The original Fischer-Tropsch process to convert coal into liquid fuel was developed by German researchers during the 1920s and is still used to produce diesel fuel today in South Africa and China.

Although currently more expensive than diesel from crude oil, this approach is likely to become more cost-competitive as petroleum sources are depleted and prices rise.

Missoula News



Coal-Liquid Fuel Process

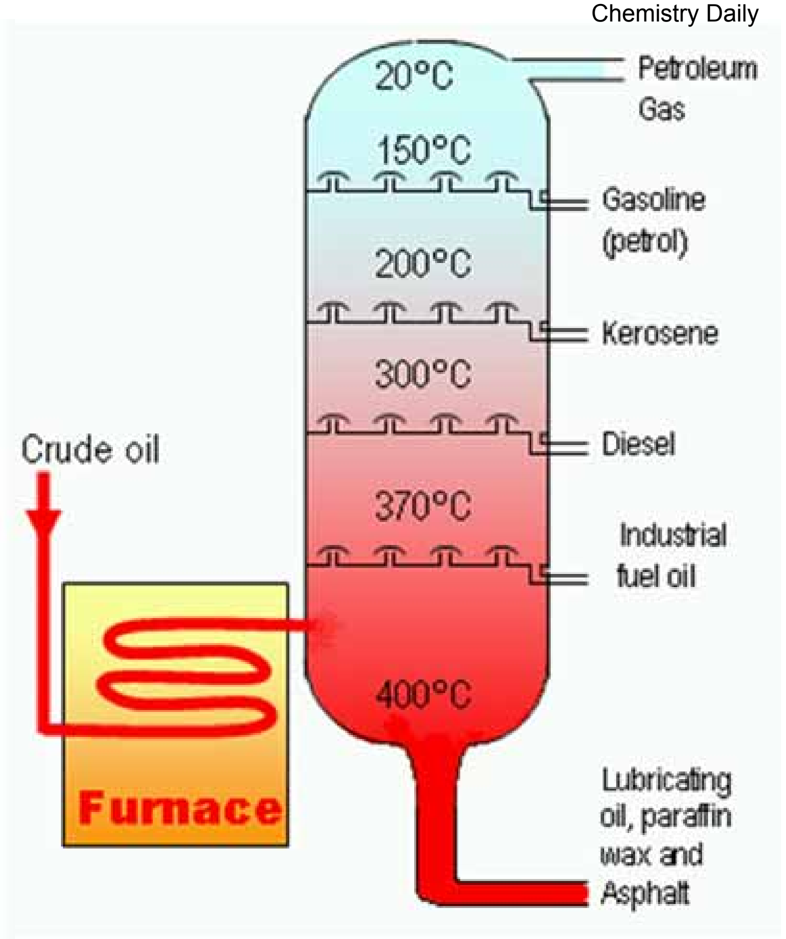
NASA

Vulnerable US Petroleum Production

Public concerns about air and wastewater contamination have resulted in no new major refineries being built in the US since 1976, although many existing plants have been expanded.

This limitation upon petroleum processing capacity makes supplies vulnerable to disruptions and shortfalls caused by hurricane damage to refineries and shutdowns for periodic maintenance.

Chemistry Daily



A variety of products compete for crude oil use and refinery operations.

Fractional distillation uses different temperatures to separate hydrocarbon molecules of various masses and chain lengths into special chemical substances tailored to particular uses.

In addition to fuels, the process can yield lubricating oil, paraffin wax, asphalt, and feedstocks for plastics.

Oil Refining and Products

Different fractional distillation product fuel streams can be recombined to meet specified octane requirements.

Octanes can also be enhanced by "catalytic reforming" to produce "aromatics".

The final step in gasoline production blends fuels of different octane ratings, vapor pressures, and other properties to meet various distributor demands.

Automotive Handbook (data), *4th Edition*, Robert Bosch GmbH, 1996

Fuel Type	MJ/l	BTU/US Gal
Naphthalene	**47.14**	**169,100**
Diesel	**40.9**	**147,000**
Gasoline	**32.0**	**125,000**
Gasohol (10% ethanol + 90% gasoline)	**28.06**	**120,900**
LPG	**22.16**	**95,475**
Ethanol	**19.59**	**84,400**
Methanol	**14.57**	**62,800**

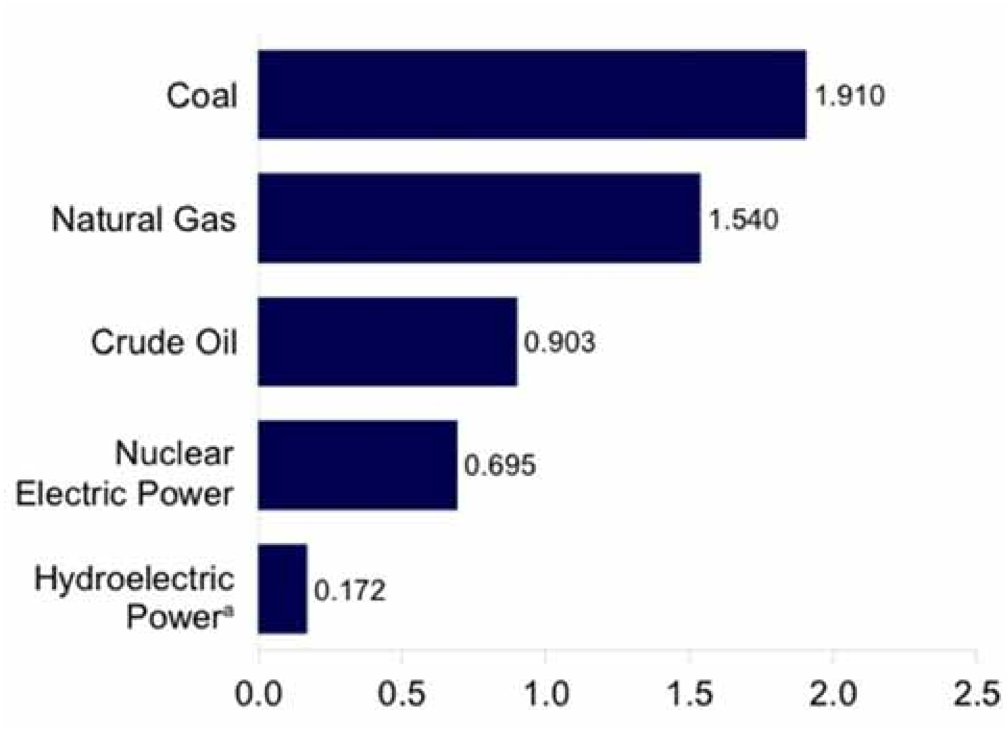
Gasoline contains about 32 megajoules per liter (MJ/L) or 131 MJ/US gallon.
** Since diesel is not used in gasoline engines, a low octane rating is not an issue.*

Energy Density Content of Different Fuels

US DOE-EIA, Monthly Energy Review, December 2006

Natural gas supplies about 23% of all US energy. This includes nearly 24% of all electrical power, about 38% of all energy for industry, 13% of all energy for commercial facilities, and heating and cooling for more than 60 million households.

The US Energy Information Administration (EIA) projects that US natural gas consumption will increase by more than 40% over the next 2 decades.



Total US Consumption by Major Sources (2006)

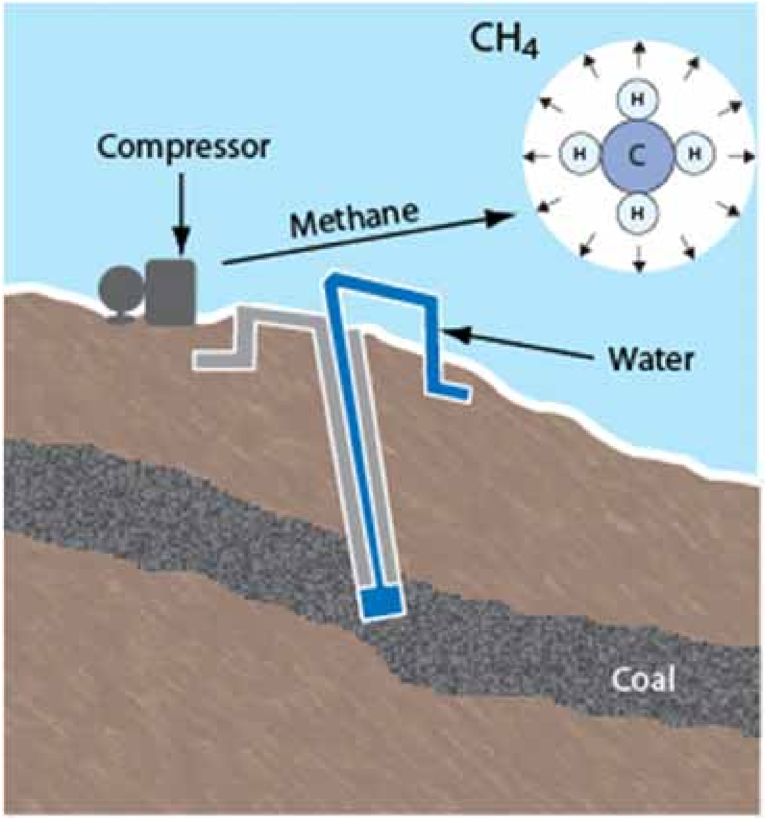
Larry Bell

Natural gas is collected from oil wells, gas fields and coal beds and cleansed up sulfur impurities prior to use.

The gas is a major source of electricity production through gas and steam turbines (often operated in combined cycles to optimize efficiency)

Compressed natural gas (CNG) is used as an alternative to liquid automotive fuel.

The gas is highly explosive when confined at concentrations of 5%-15% of air, and thiol odorants and usually added for leak detection.



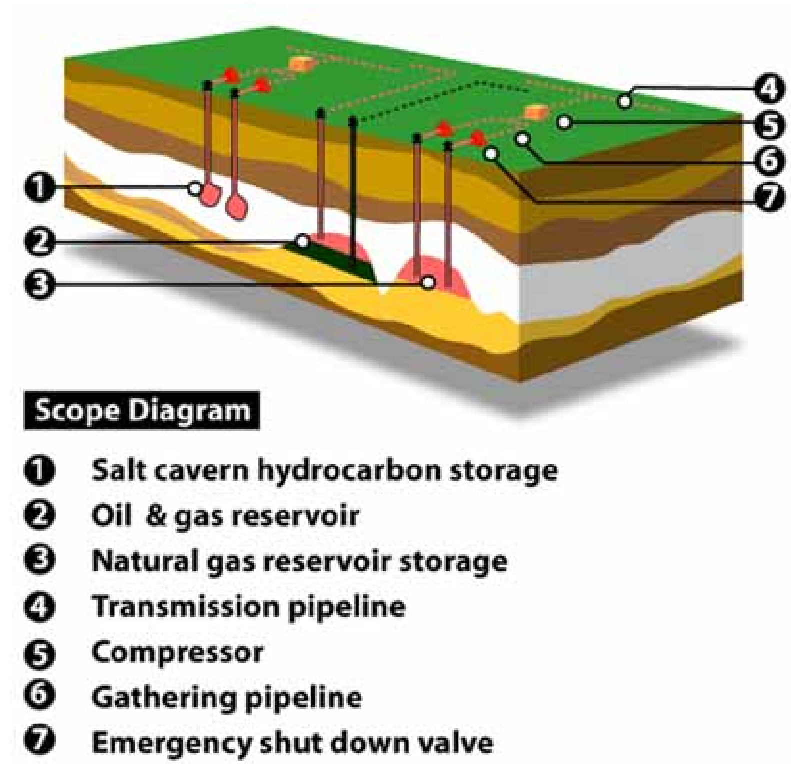
Natural Gas Collection and Processing

"Flaring" of natural gas released from oilfield operations is no longer practiced in the US because it wastes a non-renewable resource and pollutes the atmosphere.

Oilfield gas is now re-injected back into a formation, stored in underground caverns, inside depleted gas wells or salt domes, or stored in liquid natural gas (LNG) tanks.

Storage near-end users is desirable, but not always possible due to land use restrictions, limited urban space, and safety concerns.

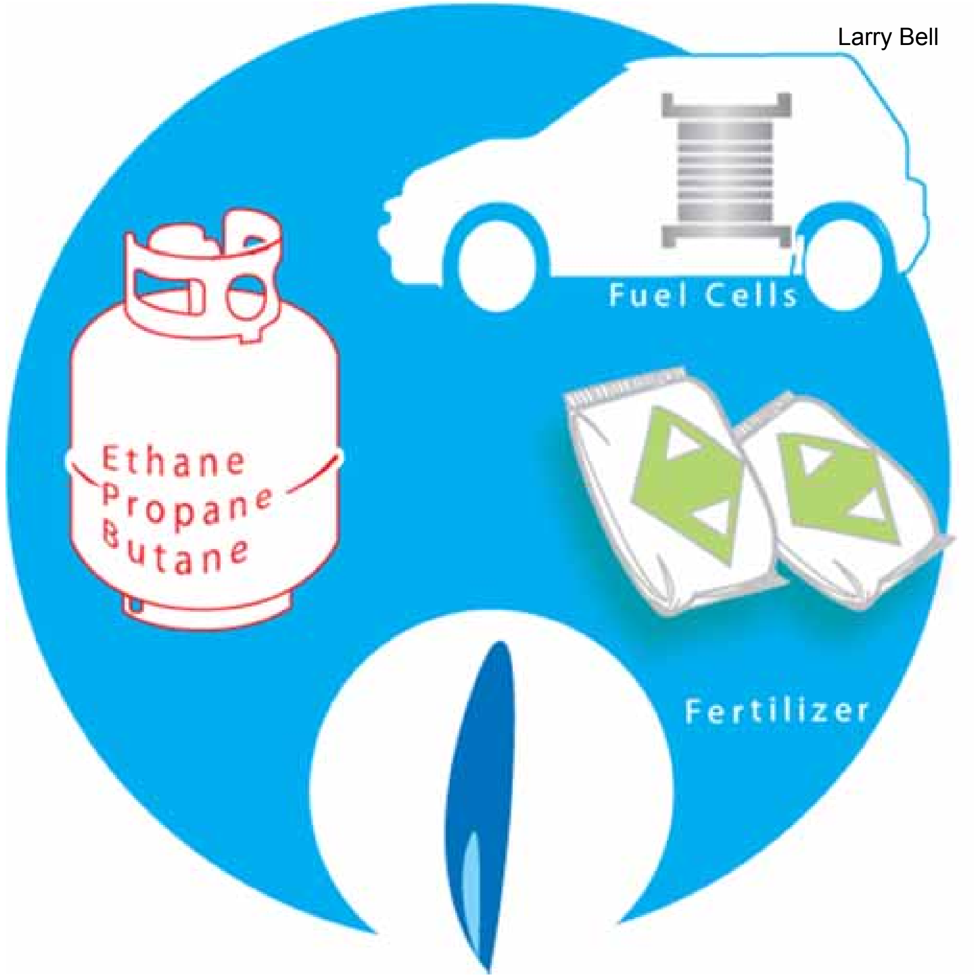
Ontario Ministry of Natural Resources



Natural Gas Storage Reservoirs

Consisting primarily of methane (CH_4) natural gas is a primary feedstock for producing secondary fuels, fertilizers, and other chemicals.

Methane is a major source of hydrogen for industrial and fuel cell use, helium, syngas, methanol, butane, propane, and ammonia.



Natural Gas Products

Steam methane reforming using natural gas is the most widely used method to produce hydrogen (along with methanol and syngas), but is an energy-costly use of this non-renewable fossil fuel.

SMR can process these products from natural gas (methane) through three optional methods:

- **Reacting methane endothermically with steam to create CO and H_2.**
- **Using partial oxidation of methane to release heat through an exothermic reaction as a step to conserve energy in producing methanol.**
- **Reacting CO and H_2 obtained from the second option with a catalyst to produce methanol.**

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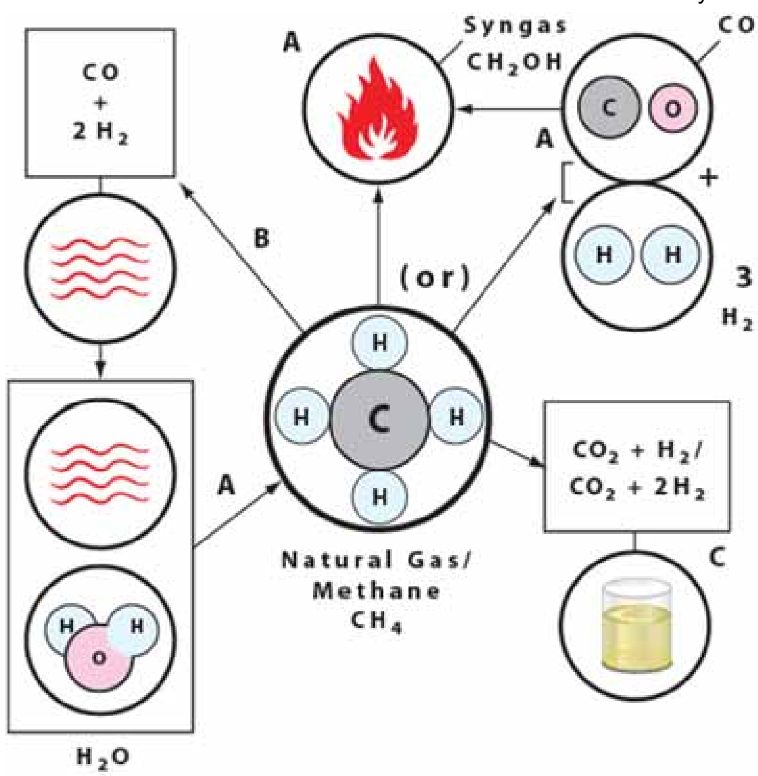

Hydrogen, Methanol, and Syngas Production Using Steam Methane Reforming (SMR)

Methanol (methyl alcohol) produced from natural gas or syngas (also a product of coal gasification) is used on a limited basis as fuel for internal combustion engines, but is not nearly as flammable as gasoline and corrodes aluminum and other metals.

It can be reacted with vegetable oils to create biodiesel, yet its largest use is to produce plastics, wood glue, paints, explosives, and permanent-press textiles.

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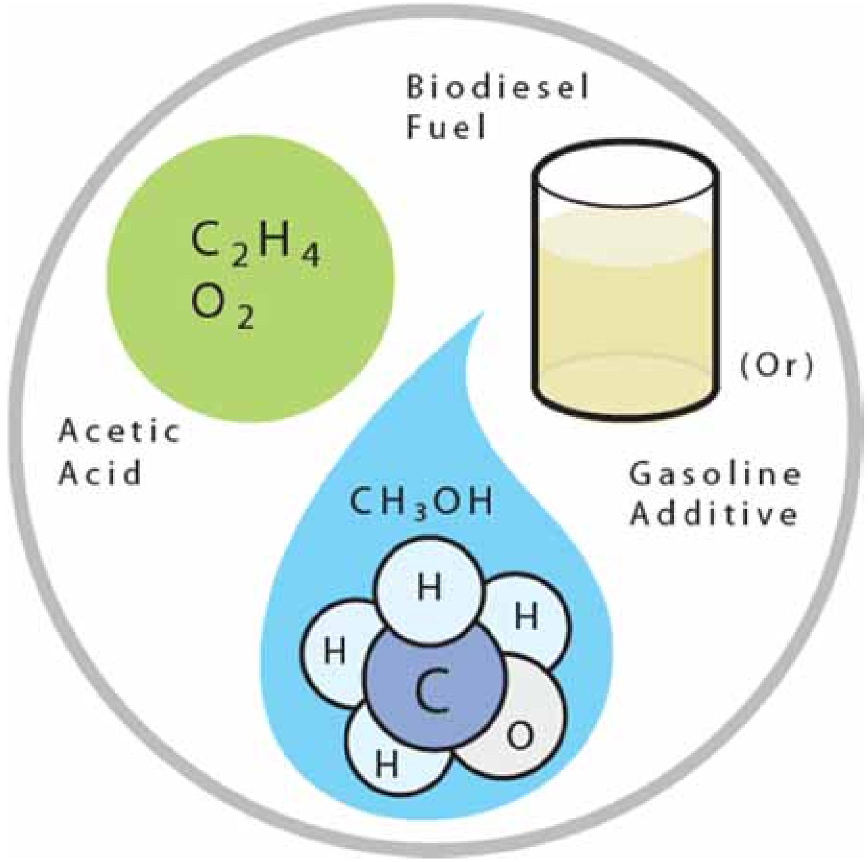


Methanol

Council of Industrial Boiler Owners

Biomass from plant and animal wastes is burned for heat and power throughout the world.

Paper mills are the largest US users of biomass power and use the electricity and heat to support recovery of pulping chemicals.

Co-firing of biomass with fossil fuels can significantly reduce sulfur dioxide and other emissions.

Direct Burning of Biomass

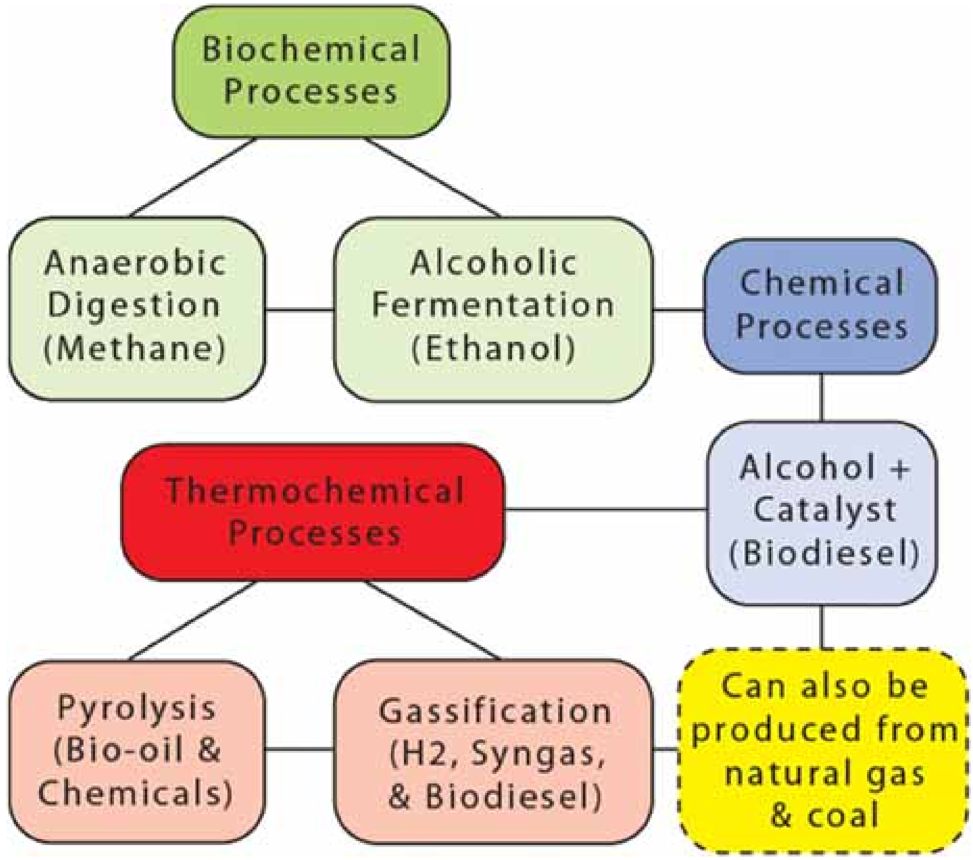
Larry Bell

In addition to direct fuel use, biomass can be converted to bio-oils, biogas, and petroleum additives through biochemical, chemical, and thermo-chemical processes.

Biochemical (organic) processes use natural decay methods.

Chemical processes use catalysts to create liquid fuels.

Thermo-chemical processes use heat to produce hydrogen, biogas, and other energy/feedstock materials.

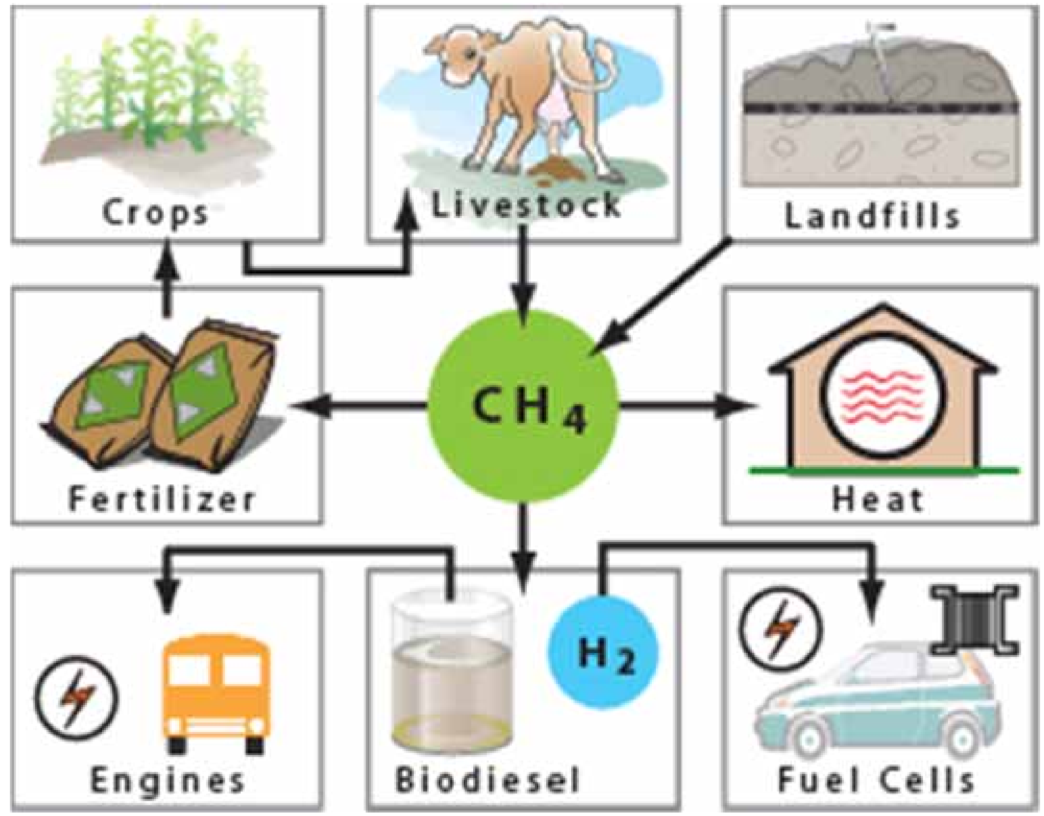


Biofuel Conversion Methods

Larry Bell

Large amounts of methane (CH_4), the primary component of natural gas, are released from renewable biomass sources through natural anaerobic digestion processes in landfills, swamps, and man-made biodigesters.

Recycled methane-derived fertilizers provide nutrients for crops and plant oils, and in turn can be combined with methane-derived methanol to create biodiesel fuel for tractors to plant and harvest the plants.

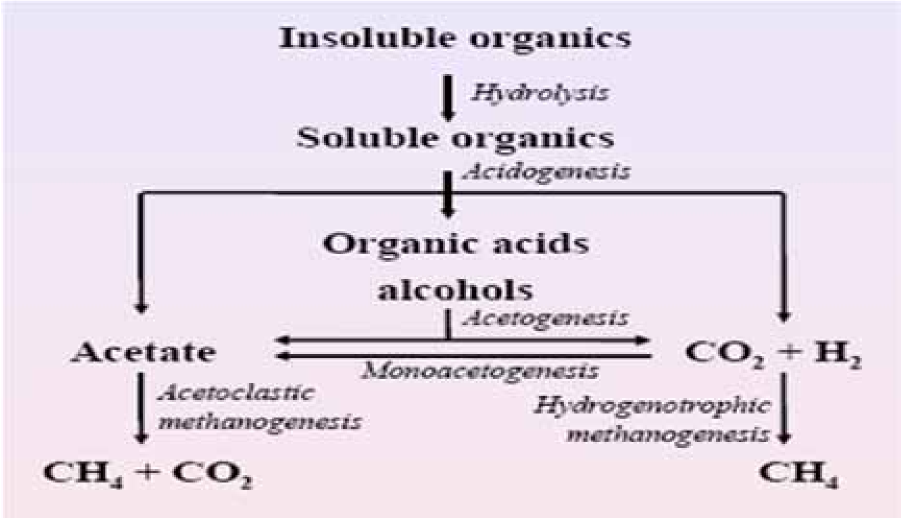


Methane Life Cycles

INRA Montpellier

Anaerobic digestion transforms organic materials under oxygen-free conditions into biogas, nutrients, salts, and cell matter. The process involves an acidification (acid) phase, and a methanogenic (methane) phase.

Anaerobic digestion is used for treatment of municipal and industrial sludge, human and animals wastes, and municipal waste waters. Benefits include energy production/conservation, waste/odor removal, pathogen control, and greenhouse gas reduction.



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Methane from Anaerobic Digestion

Methane obtained from fossil sources and anaerobic digestions can either be burned directly as fuel or serve as a feedstock for other products.

Methane combustion is often used for direct contact water heaters and industrial combined heat and power (CHP) applications.

Synthetic gas (syngas) produced from methane or natural gas through SMR and other processes can produce hydrogen, methanol, and a variety of other gaseous fuels.

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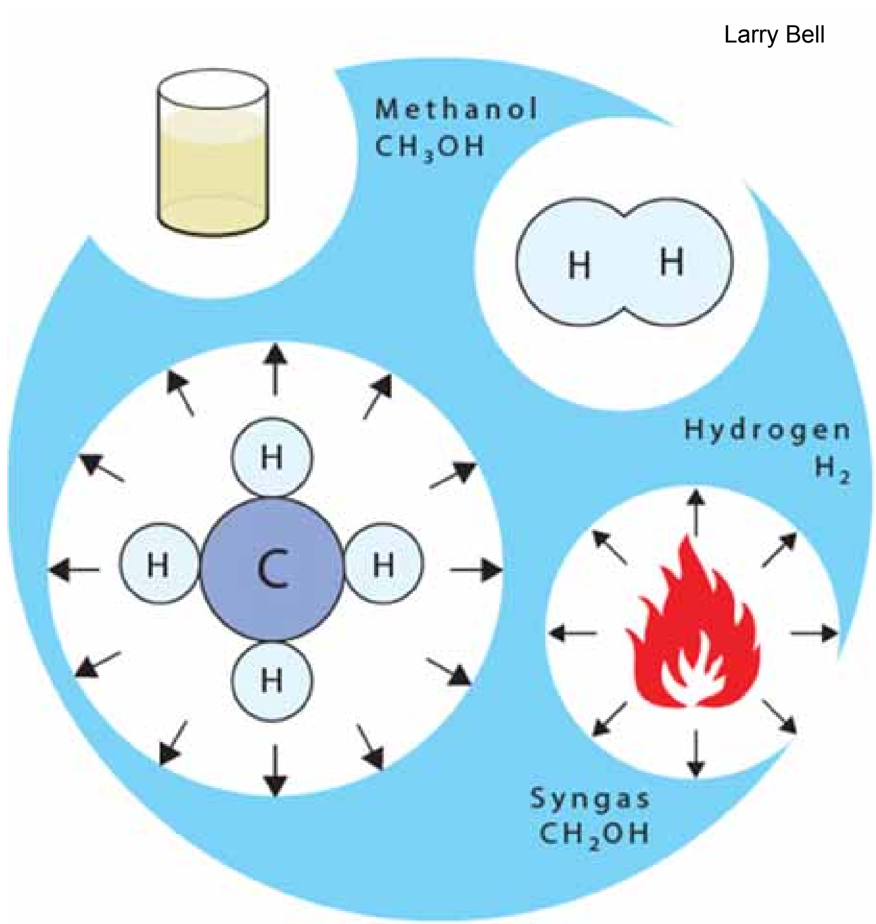


Methane Gas Products

General Sources

Electrical Power

Heat

Chemicals and Plastics

Hydrogen/Fuel Cells

Methanol

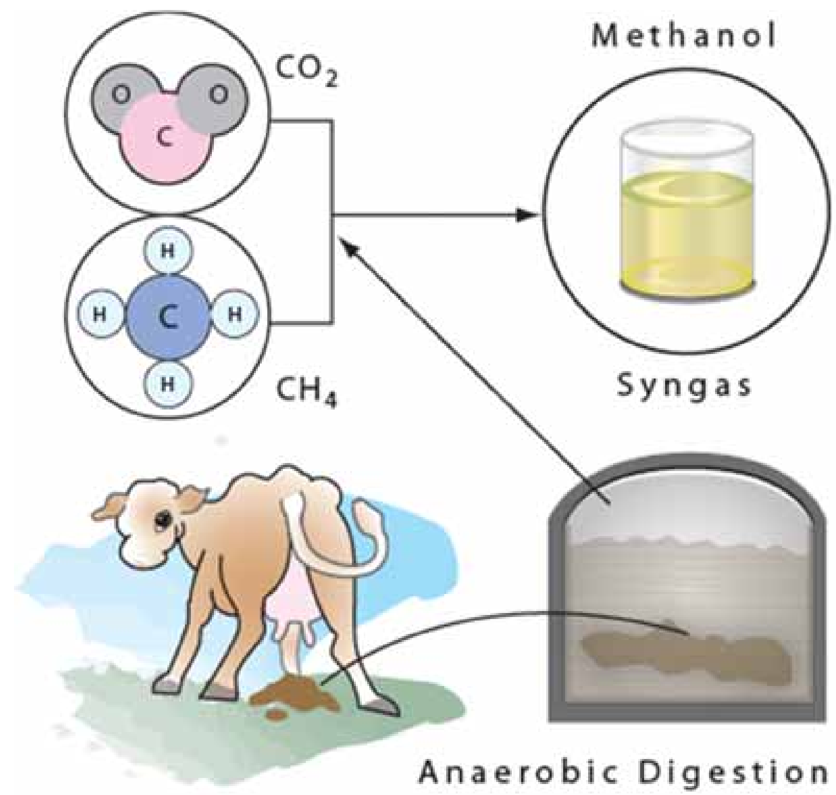
Ammonia Fertilizer

Methane/Natural Gas Uses and Derivatives

Methanol, produced in various ways, can be blended with other liquid fuels to reduce pollutant emissions in internal combustion engines or serve as a hydrogen carrier for fuel cells.

- **It can be created by reacting carbon monoxide and hydrogen from coal gasification.**
- **It can be produced using hydrogen from water electrolysis or steam methane reforming that is reacted with CO_2.**
- **Syngas from anaerobic digesters/landfills or heated biomass (pyrolysis) can be reacted with CO_2 to produce methanol.**

Larry Bell



Methanol from Biodigesters

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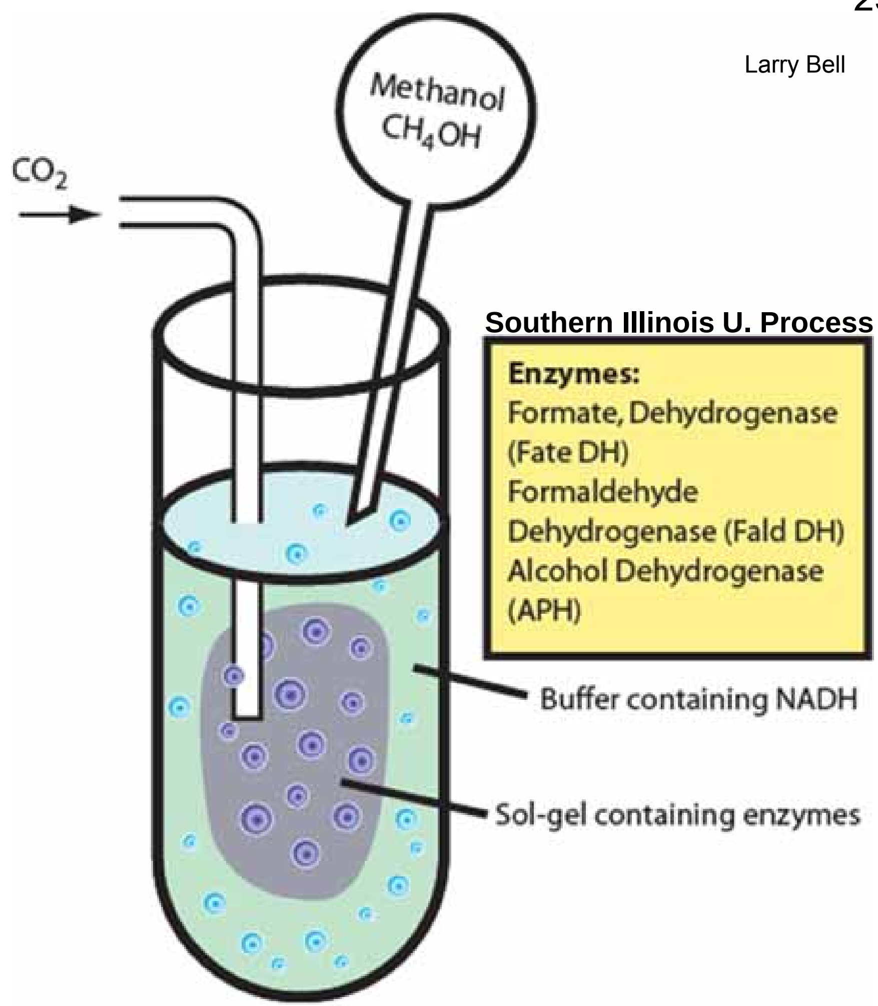
Methanol can also be created directly from CO_2 using enzyme reactions.

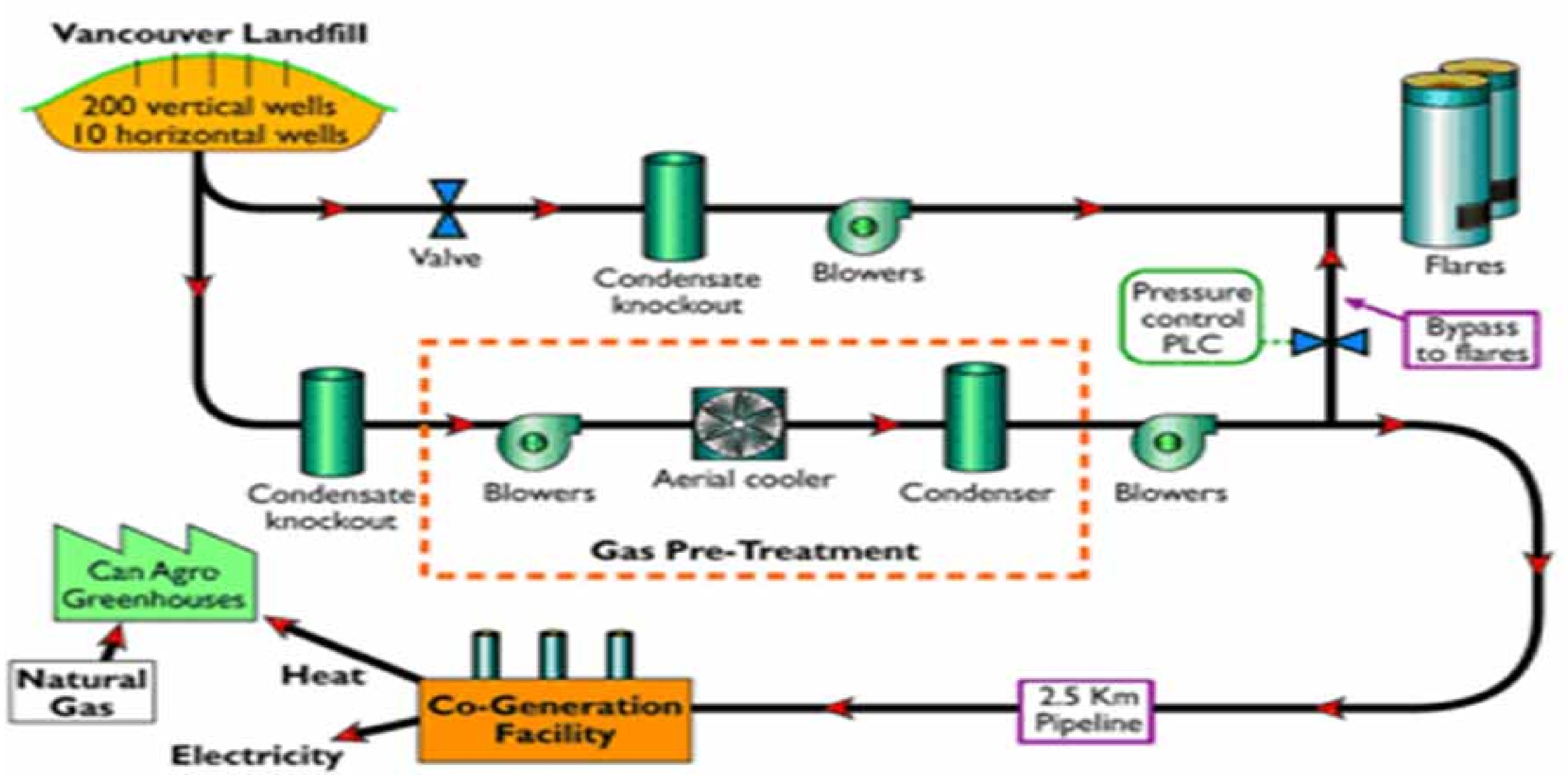
One method under study for commercial applications uses three different enzymes, including NADH, natural chemical produced in plant photosynthesis.

Southern Illinois U. Process



Methanol Production Using NADH Enzymes to Reduce CO_2

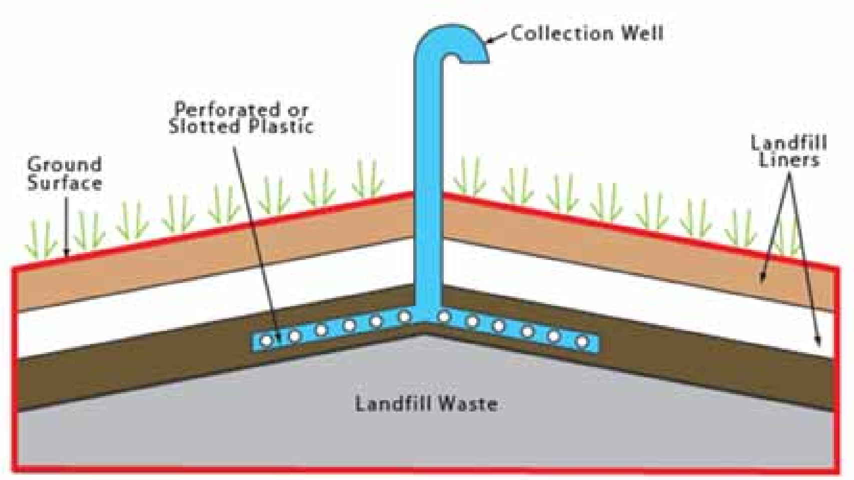
Environmental Science and Engineering Magazine, March 2004, Vancouver Landfill Operation



Landfill Gas Collection and Utilization

ATSDR

Landfill gas collectors use "wells" made of perforated or slotted plastic tubing that provide pathways for gas migration.

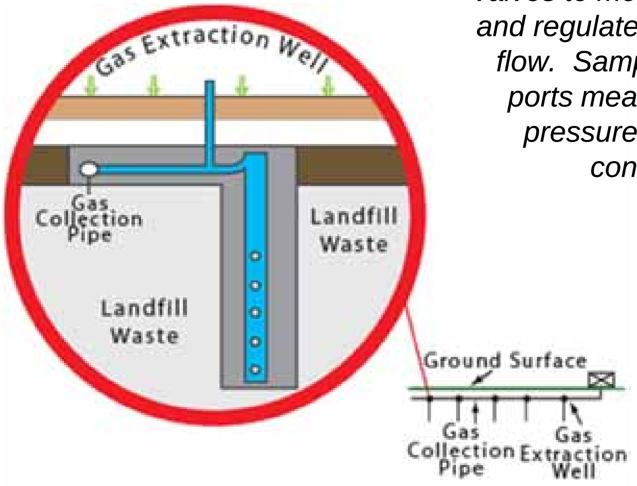


Passive systems are used in small recovery operations, and active systems provide for managed commercial capabilities.

Passive Landfill Gas Collector

Passive systems collect gas using impermeable liners on top, sides and bottom to limit venting into the atmosphere.

Active systems incorporate vacuum pumps and control valves to monitor and regulate gas flow. Sampling ports measure pressure and content.



Active Landfill Gas Collector

Auckland City Council

Although landfills present problems, operators are implementing methods to address public concerns.

Refuse separation and recycling prior to disposal reduce landfill sizes and increase labor/cost efficiencies.

Groundseal barriers and modern gas extraction technologies assist odor control and methane collection.

Landfills can ultimately be converted to public parks and sports areas.

Former landfill converted into a public park in Auckland, New Zealand.

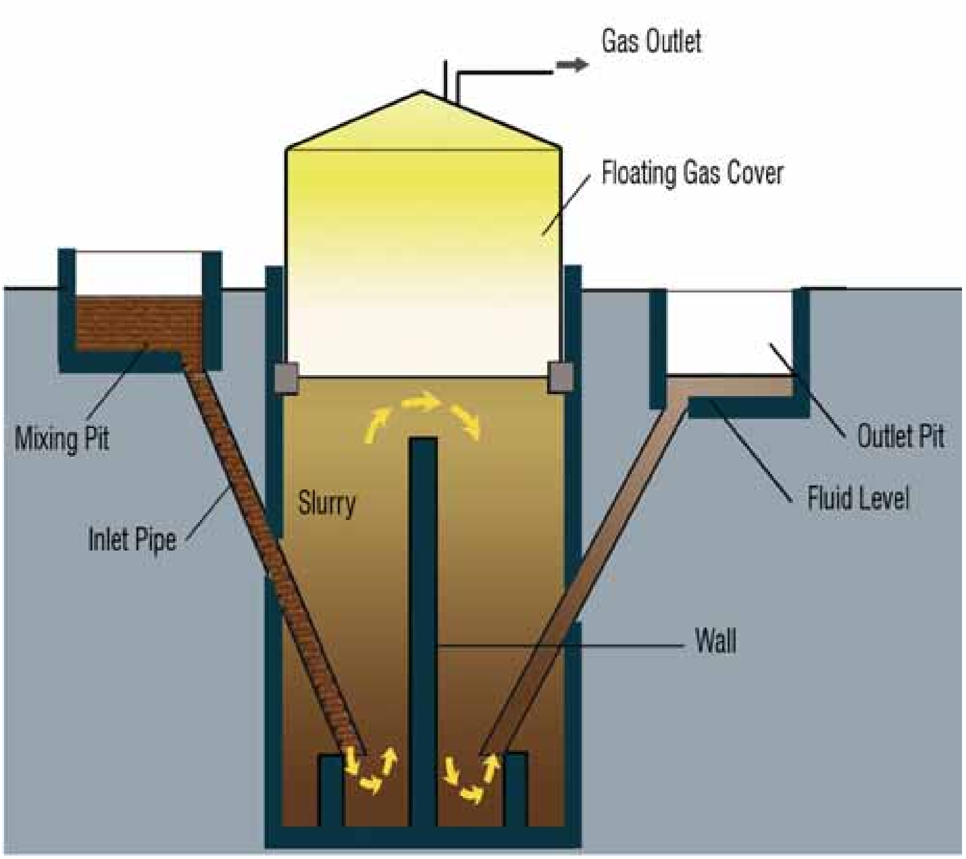
Landfill Methane Recovery

Larry Bell

Agricultural operations are collecting methane using biogas digesters that ferment animal wastes.

Floating-cover types have expanding chambers to accommodate the largest biogas capacities.

Fixed-topic digesters are simpler tanks with more limited gas storage capacities.



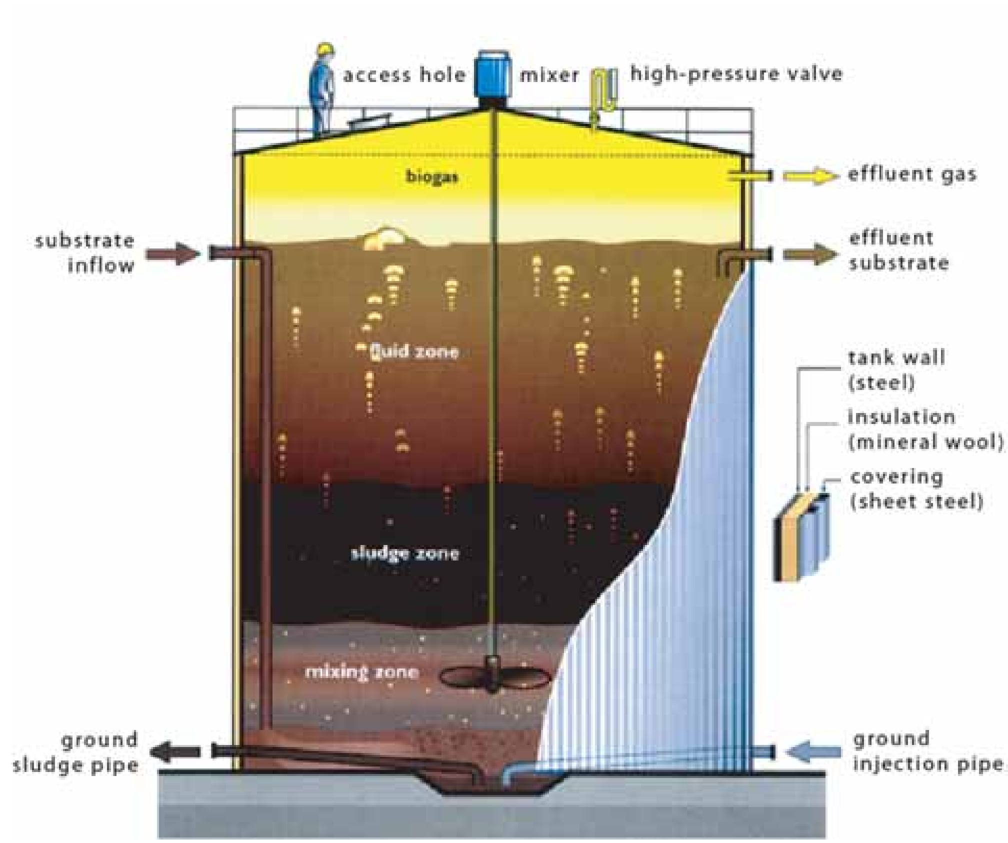
Floating-Cover Anaerobic Biogas Digester

Raw biogas is typically comprised of about 60% methane, and 40% CO_2 and water vapor with trace amounts of hydrogen sulfide.

The anaerobic methane-producing process is most efficient at warm temperatures (between 85ºF – 172ºF), requiring that heat be added in colder climates.

Digesting time ranges from weeks to months, and the outlet slurry can be used as fertilizer.

Clarke Energy



Fixed-Top Anaerobic Digester

Ethanol (ethyl alcohol) is a biofuel that is also produced biologically through a fermentation process with yeast.

When the glucose base comes from corn or other grains, it requires energy to plant and harvest the plants and convert the feedstock to alcohol.

Ethanol produced from biomass cellulose requires hydrolyzing enzymes to digest the materials, but biomass burning can provide process heat energy.

Larry Bell

1. Milling:

The corn (or other grain) is passed through hammer mills that grind it into a fine power called "meal".

2. Liquefaction:

The meal is mixed with water and alpha-amylase and passed through cookers to reduce bacteria levels.

3. Saccharification:

The mash from the cookers is cooled, and a second enzyme (gluco-amylase) is added to convert the liquefied starch to sugars.

4. Fermentation

Yeast is added to ferment sugars into ethanol and CO_2. Using several fermenters, the process continues until complete.

5. Distillation:

The fermented mash (or "beer") containing about 10% alcohol is pumped through a multi-column distillation system where alcohol is removed from unfermented solids, leaving about 96% strength.

6. Dehydration:

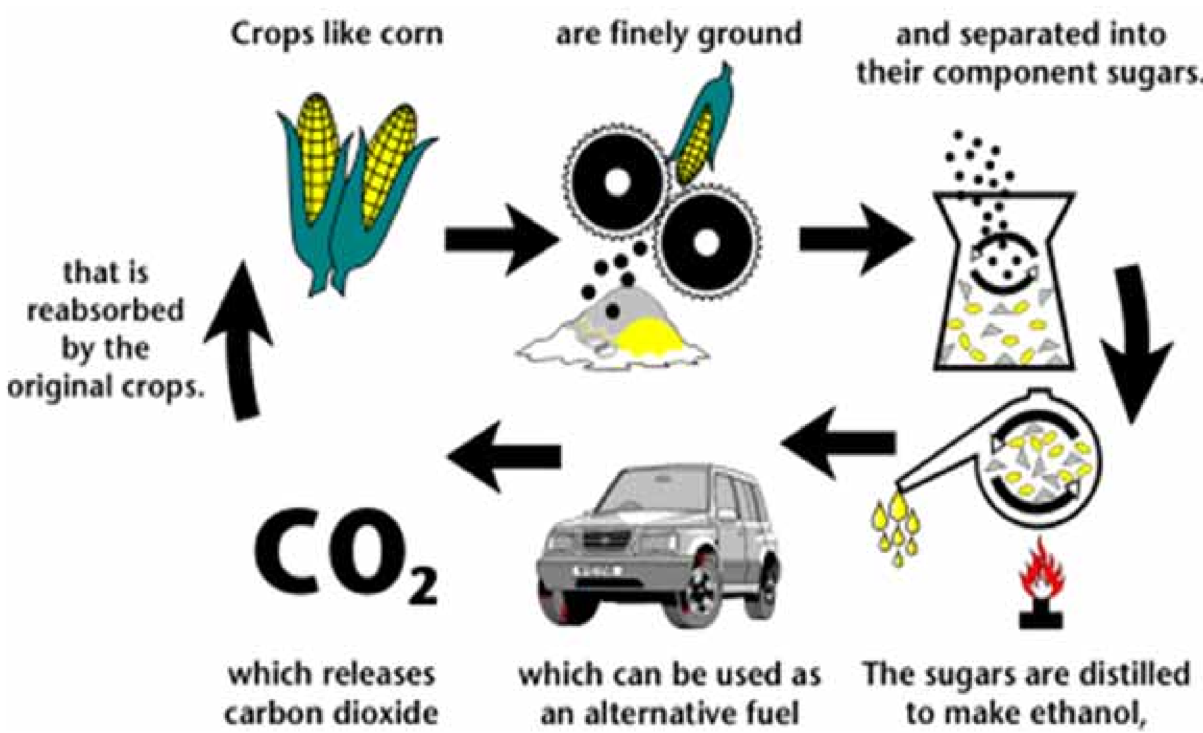
Alcohol passes through a dehydration column where water is removed. Most plants use a molecular sieve to capture any remaining water, and the anhydrous ethanol is now about 200 proof.

Typical Grain Ethanol Production Processes

US DOE-EIA

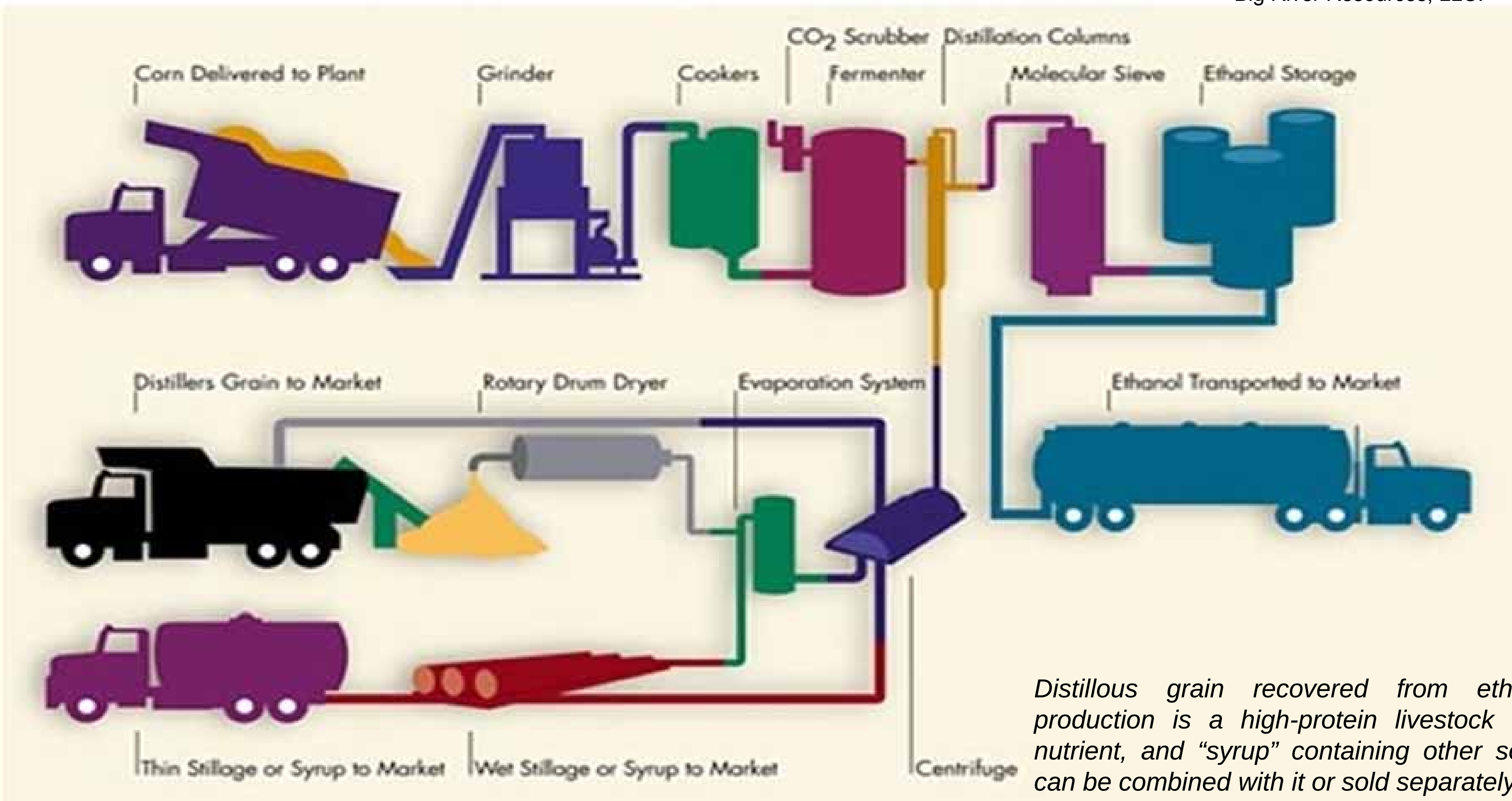
Ethanol can be used in internal combustion engines as a petroleum substitute, additive or blend.

It is also used to manufacture ethyl-tertiary-butyl-ether (ETBE), a fuel enhancer for conventional petroleum.



Ethanol Production and Benefits

Big River Resources, LLC.



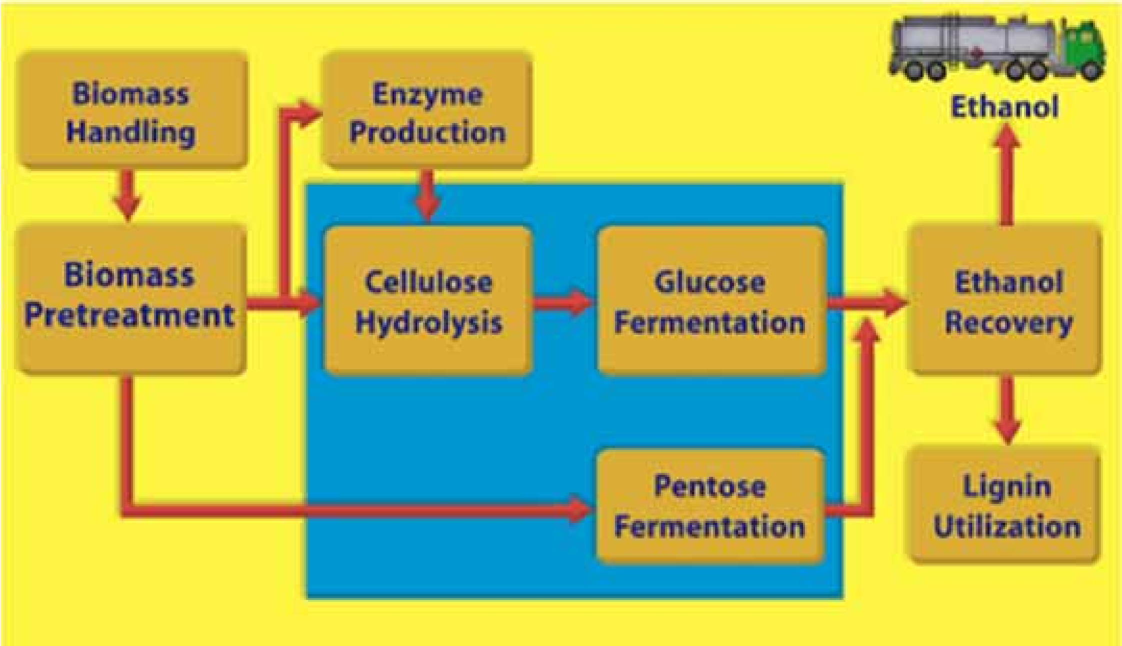
Distillous grain recovered from ethanol production is a high-protein livestock feed nutrient, and “syrup” containing other solids can be combined with it or sold separately.

Grain Ethanol Production and Products

US DOE - EERE

Biotech processing uses enzymes to break down difficult-to-digest feedstocks into simple sugars that can be fermented into alcohol and other biofuel products.

The undigested lignin can be utilized as a combustion fuel for process heat to conserve energy.



Cellulosic Biofuel

Organic biodiesel can be produced by combining methanol with methyl esters obtained from three varieties of sources:

- **Rapeseed methyl ester (RME)**
- **Vegetable methyl ester (VME)**
- **Fat methyl ester (FME)**

It burns cleanly and fully in modern diesel engines, and works with catalysts, particulate traps and exhaust recirculation to eliminate most pollutants.

National Renewable Energy Laboratory

Biodiesel Production and Benefits

Risoe

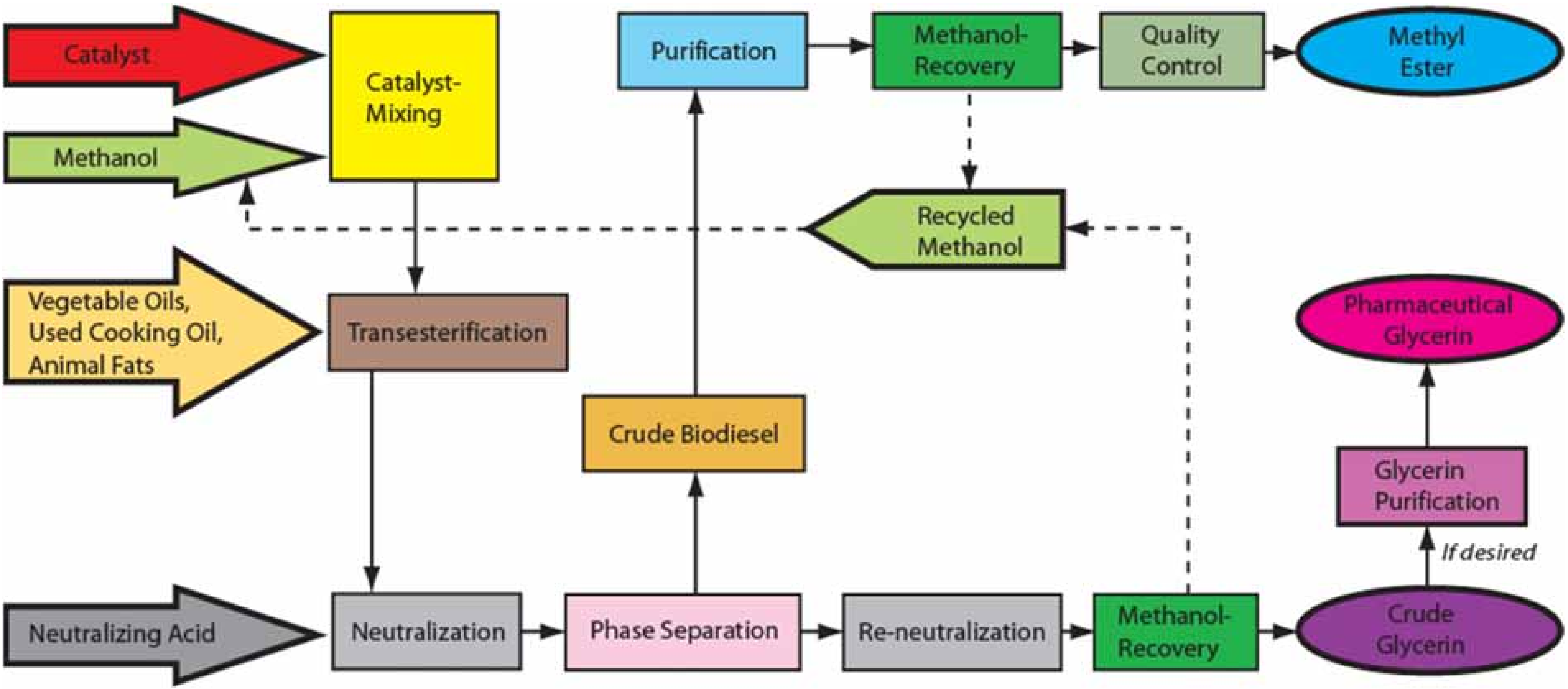
Biodiesel is produced from organically-derived oils combined with alcohol (ethanol or methanol) and a catalyst.

A variety of bio-oils can be used, including plant oils and animal fats, which are first degummed and cleaned of acids.

The ethanol or methanol and catalyst are added for esterification prior to final washing and drying.

Biodiesel Production

Fleet Challenge Canada

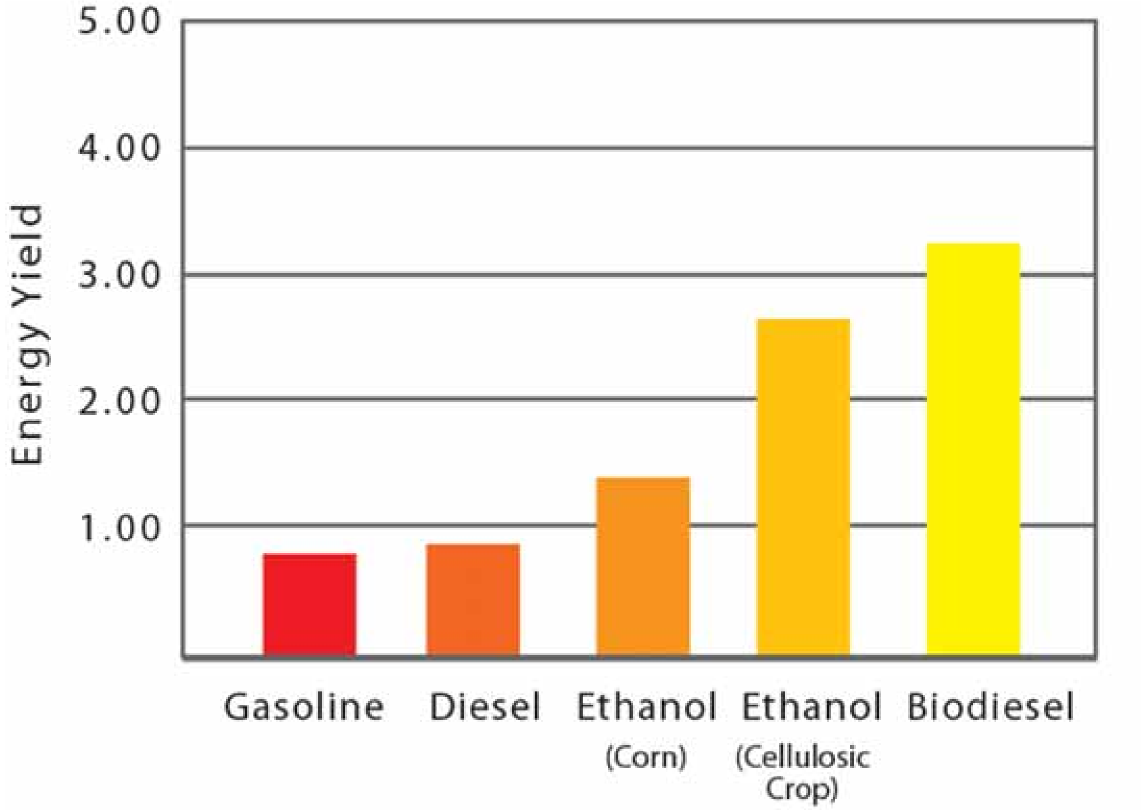


Biodiesel Production Process

US DOE-EERE

Biodiesel is often blended with petroleum diesel in a 15/85 mix for standard diesel engines.

Overall efficiencies are slightly lower than petrodiesel alone due to energy needed for processing, but fossil fuel consumption is reduced (proportional to the mix).



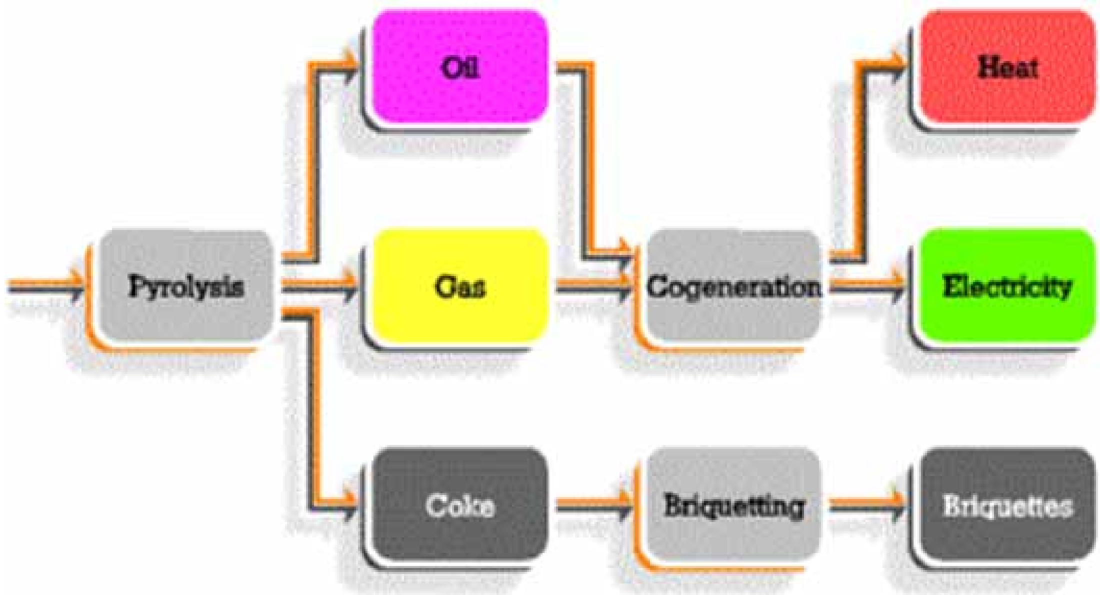
Plant oil blended with petroleum diesel can reduce fossil fuel consumption along with fossil (old source) CO_2 emissions per unit of engine work.

Energy Yield/Unit of Fossil Fuel Consumed on a Life Cycle Basis

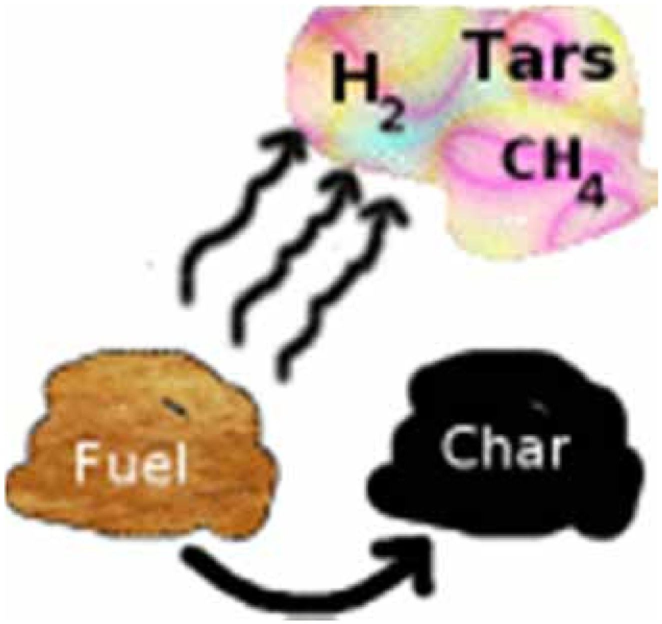
When biomass decomposes at elevated temperatures, three primary products are formed: gas, bio-oil and char. At high temperatures the bio-oil decomposes again into secondary gases and polymetric tar.

Ancient use of anhydrous pyrolysis produced charcoal, and the process is currently used on a massive scale to turn coal into coke for metallurgy (particularly steelmaking).

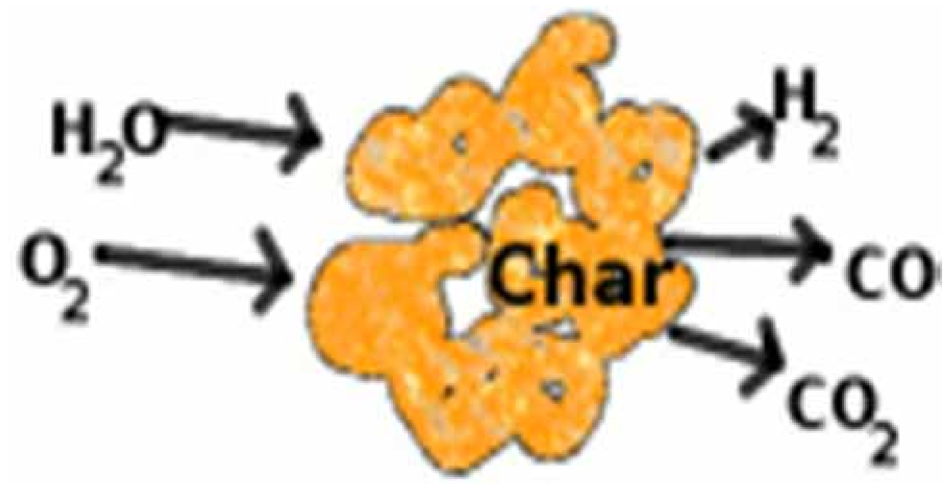
Alcyon Engineering



Pyrolysis Fuel and Power Products



Pyrolysis of Carbonaceous Materials



Gasification of Char Product

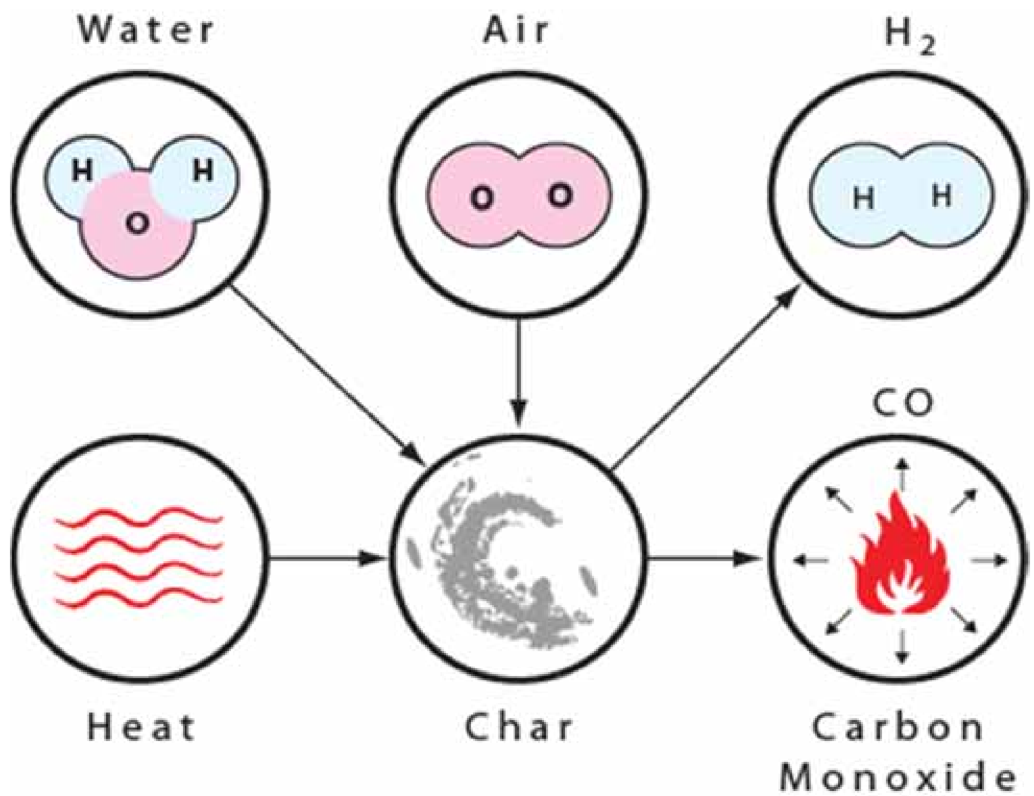
Pyrolysis and gasification convert organic materials into solids, liquids, and gasses in sealed vessels under low-oxygen, high-temperature/pressure conditions.

Larry Bell

Gasification is used to produce a synthetic gas fuel comprised mostly of hydrogen and carbon monoxide ("syngas" or biogas").

The synthetic gas can then be converted to "Fisher-Tropsch diesel" which is similar to petroleum diesel.

The same fuel can be produced from natural gas.

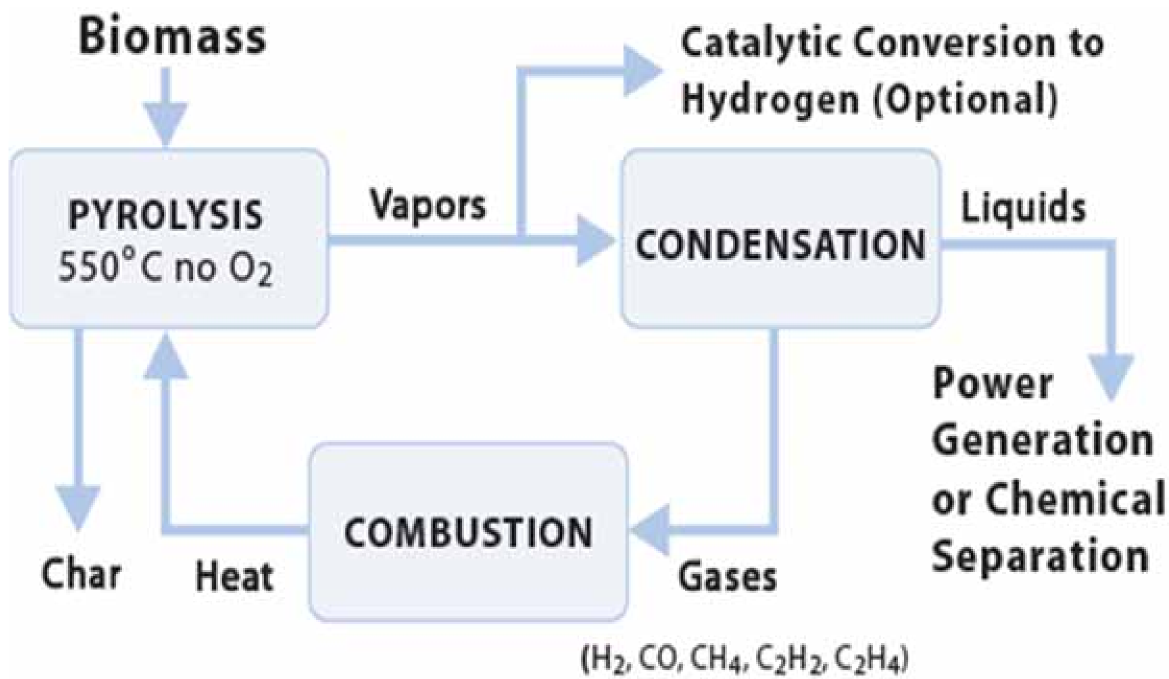


Gasification of Char

US DOE-EERE

Fast pyrolysis of biomass is a thermal decomposition process that produces a liquid bio-oil that can be readily stored and transported.

Pyrolysis oil has been successfully tested in engines, turbines and boilers, and has been upgraded to high- quality fuels, although presently, at uncompetitive energetic and financial costs.

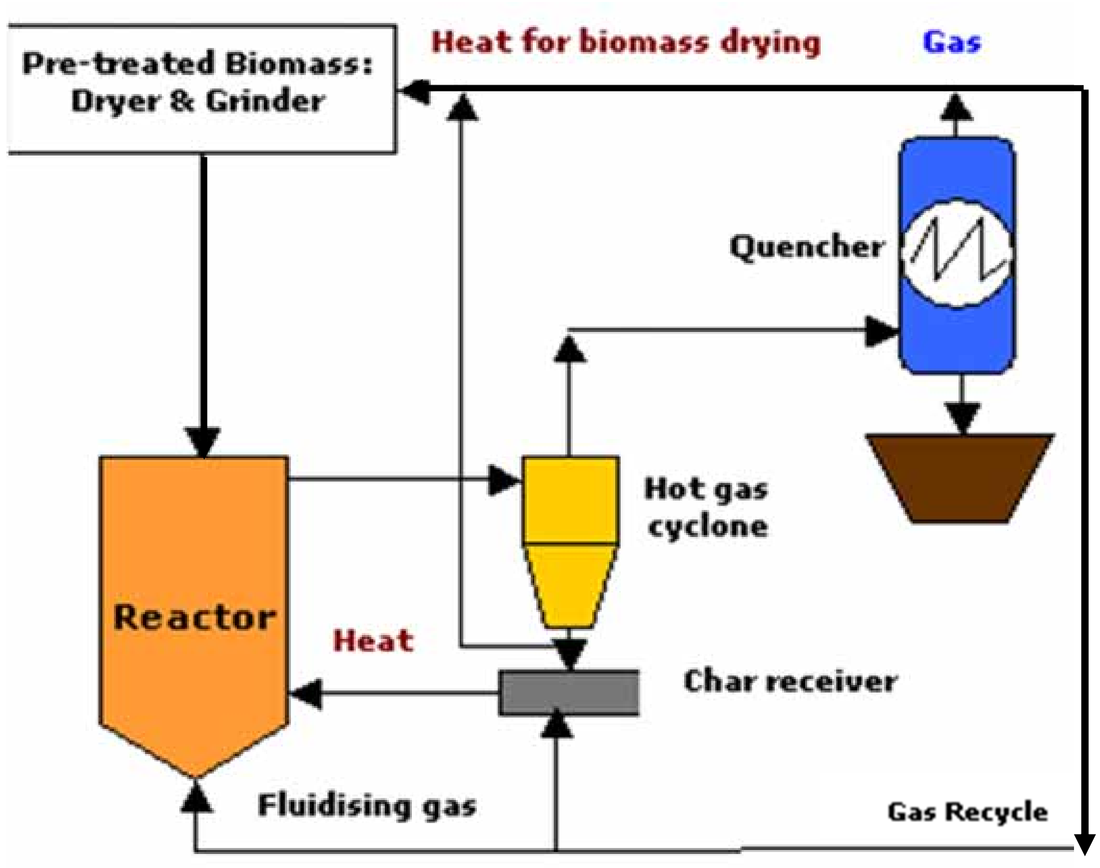


Bio-Oil Production

European Commission, DG Research

Fast pyrolysis can yield up to 75% liquid energy fuel based upon starting biomass weigh.

The rapid heating greatly reduces char-forming reactions to optimize the fuel product.

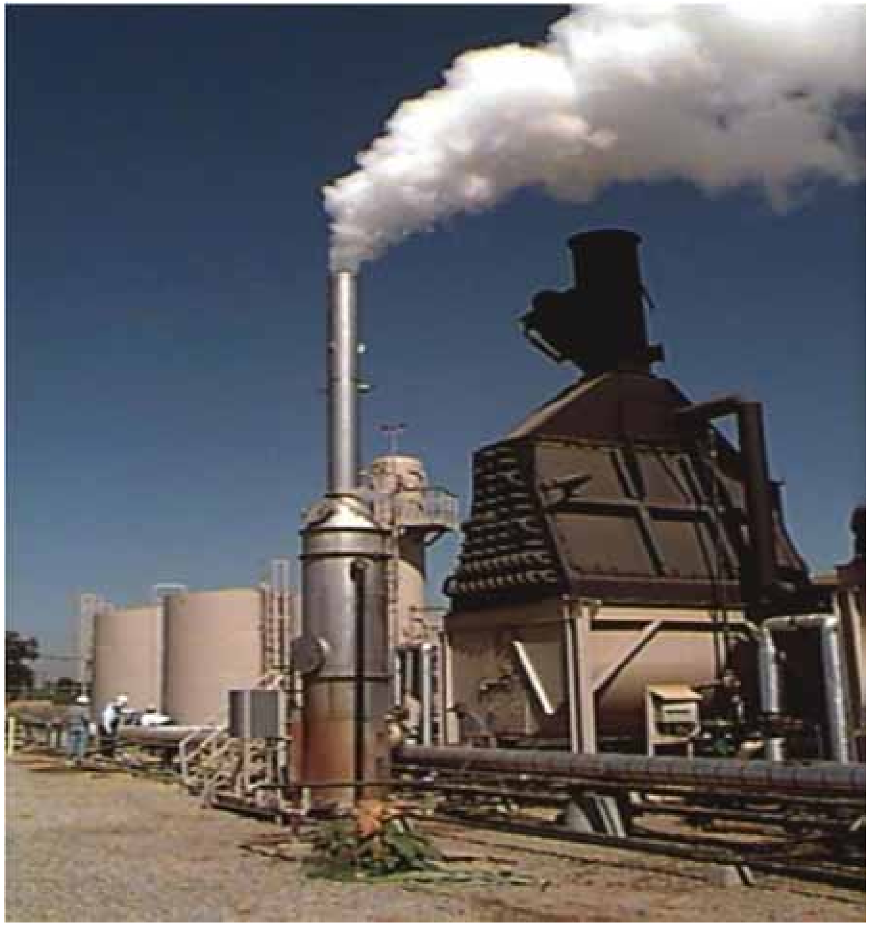


Fast Pyrolysis Processing

Pyrolysis bio-oil can be used as a feedstock for valuable chemicals and materials as well as be directly combusted as a fuel.

Fast pyrolysis is used commercially to produce oil for engines, turbines, and boilers, and can be upgraded to high-quality fuels (but currently only at high cots).

Yields and products depend upon feedstocks, processes used, and product collection requirements.



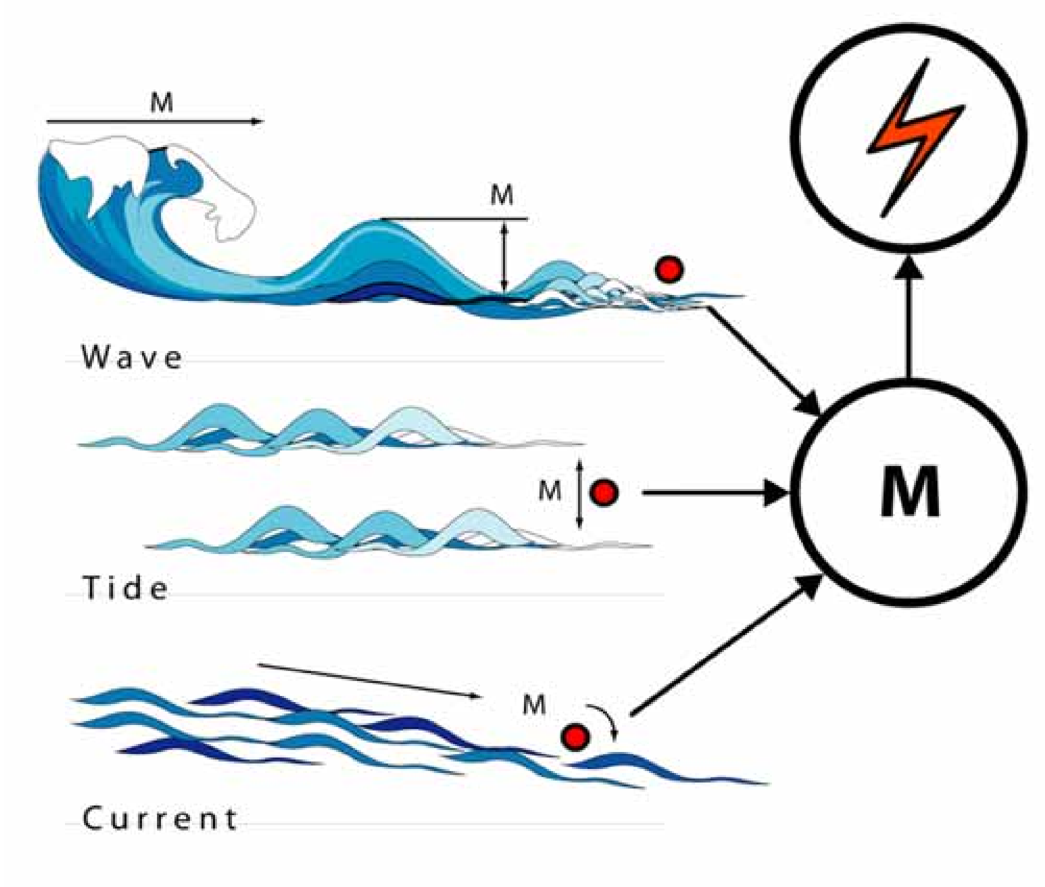
Pyrolysis Bio-Oil Production Facility

Larry Bell

Hydropower systems convert mechanical energy from falling and moving water to electricity by various means.

Turbines use the gravitational force of falling water or flowing currents to drive electrical generators.

Power take-off systems convert energy from wave or tidal motions to electricity using pumps, air turbines, or other devices to drive generators.



Hydro-Mechanical Sources

Many small-scale hydro systems apply very old and inexpensive technologies.

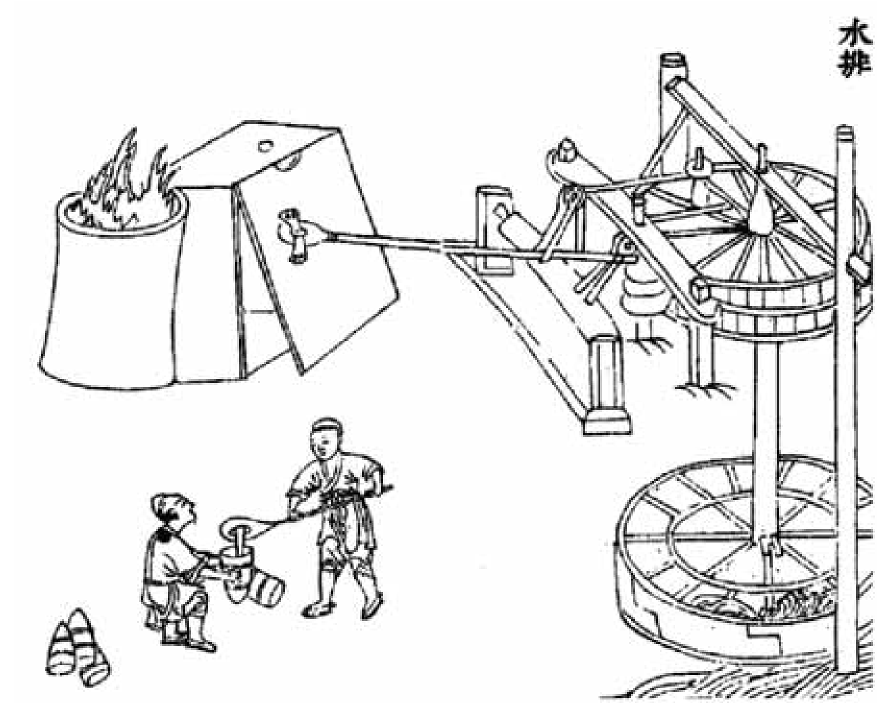
Waterwheels move slowly, but can provide large torque forces.

Turbines are more modern developments that drive electrical generators or alternators.

Water Wheel Factory

Waterwheel

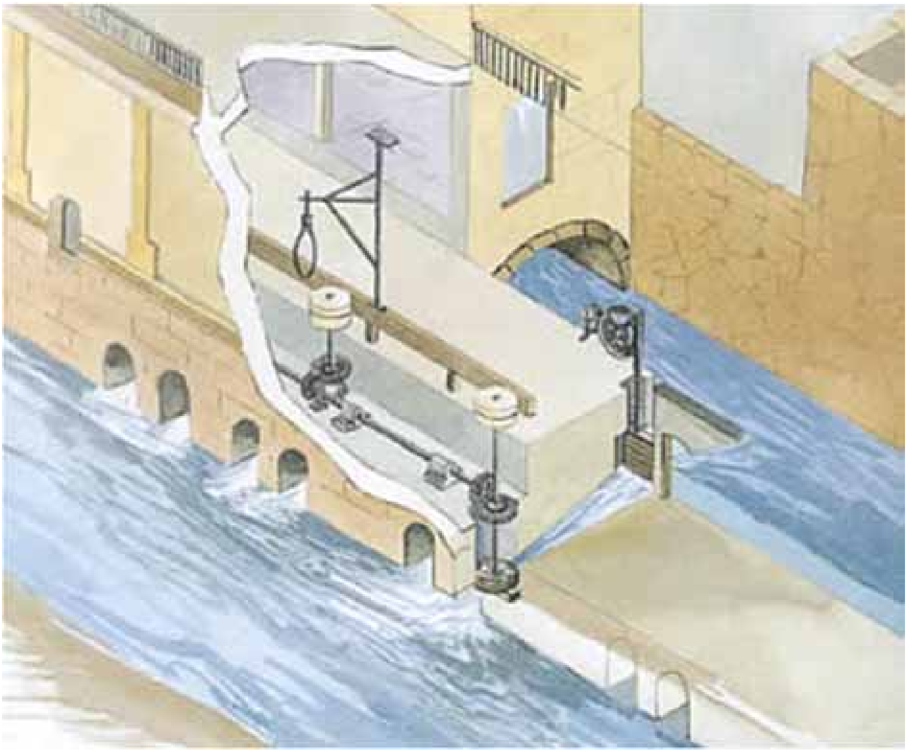
Waterwheels were used in ancient China dating back to 31AD to operate bellows used for casting iron, and during the late Middle Ages to pump water from mines, grind ore, run blast furnace forges, and operate metal smith hammers.



Water Pump in Ancient China

Water Pump in the Middle Ages

Eighteenth century horizontal waterwheels powered gristmills in Spain, and are still operating gristmills in Turkey using water from urban runoff that is diverted into elevated tanks that release water from above.

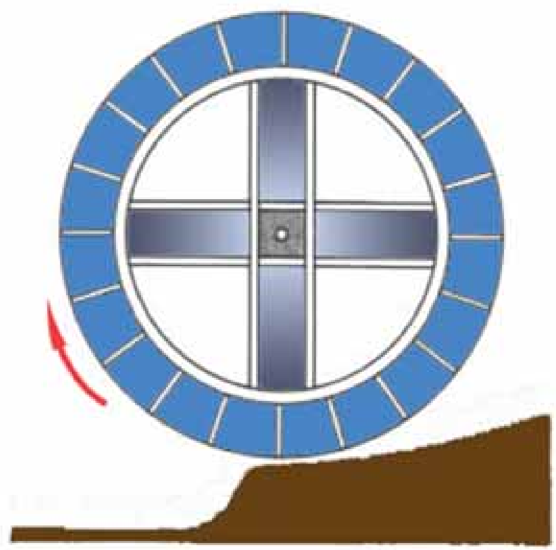


Eighteenth Century Waterwheel Gristmill

Recent Waterwheel Gristmill in Turkey

Water History

***Overshot**: use an elevated stream and require gears.*



***Undershot**: are driven from below and require gears.*

***Norse**: apply power directly*

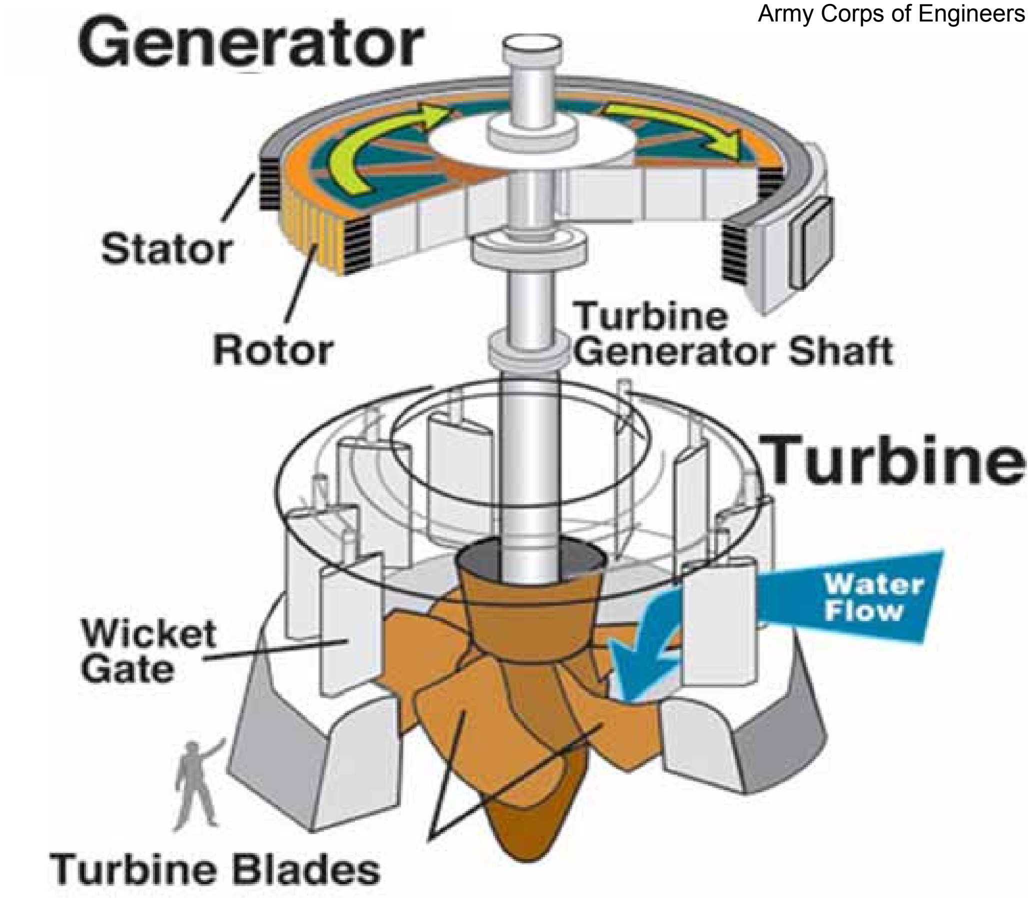
Waterwheel Types

Modern turbines direct water pressure force onto blades of a spinning "runner" to drive a generator.

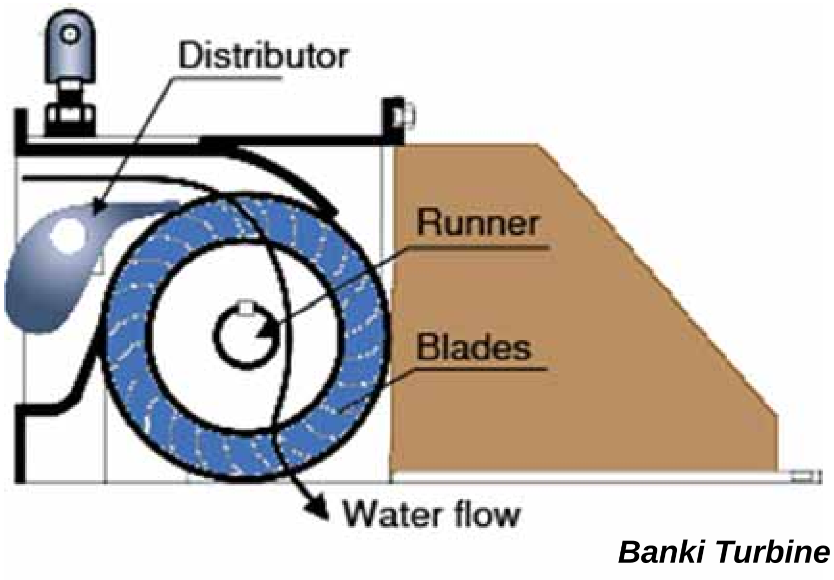
The turn much faster than waterwheels, enabling them to harness greater "heads" to process force more efficiently.

Very large and small types meet high and low power needs.

Army Corps of Engineers

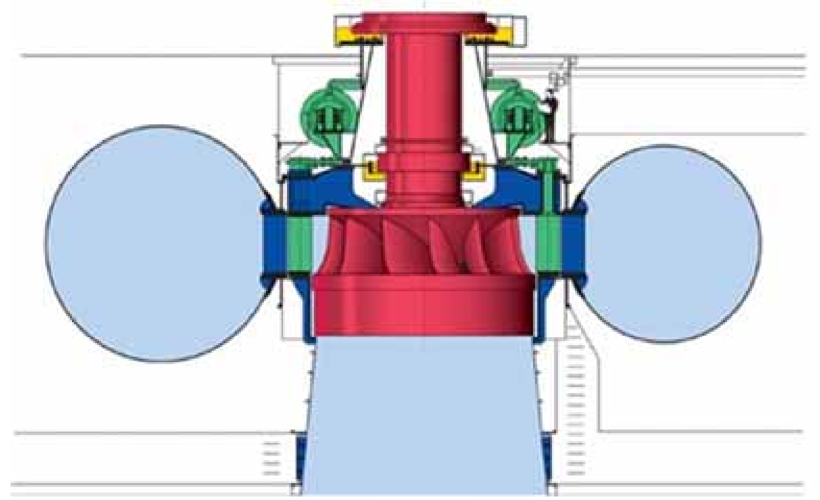


Commercial-Scale Water Turbine-Generator



Banki Turbine

Voith Siemens; European Small Hydropower Association



Francis Turbine

Although the efficiency of a Banki turbine is lower, it enjoys a niche market for low-cost and home-made applications.

Other Power

Small Banki turbines enjoy a niche for very low-cost applications and can be constructed from home-built parts.

A small installation can operate in a low-head stream with a 20 gallon/minute flow.

Small Home-Made Banki Turbine

Forcefield

This home-made squirrel cage waterwheel generator in a small stream produces a steady 1-2 amps of power 24 hours/day.

"Mini-hydro" and "micro-hydro" power affords an alternative energy source in remote locations.

These small-scale devices can provide useful supplements to solar power offering 24 hour/day capabilities.

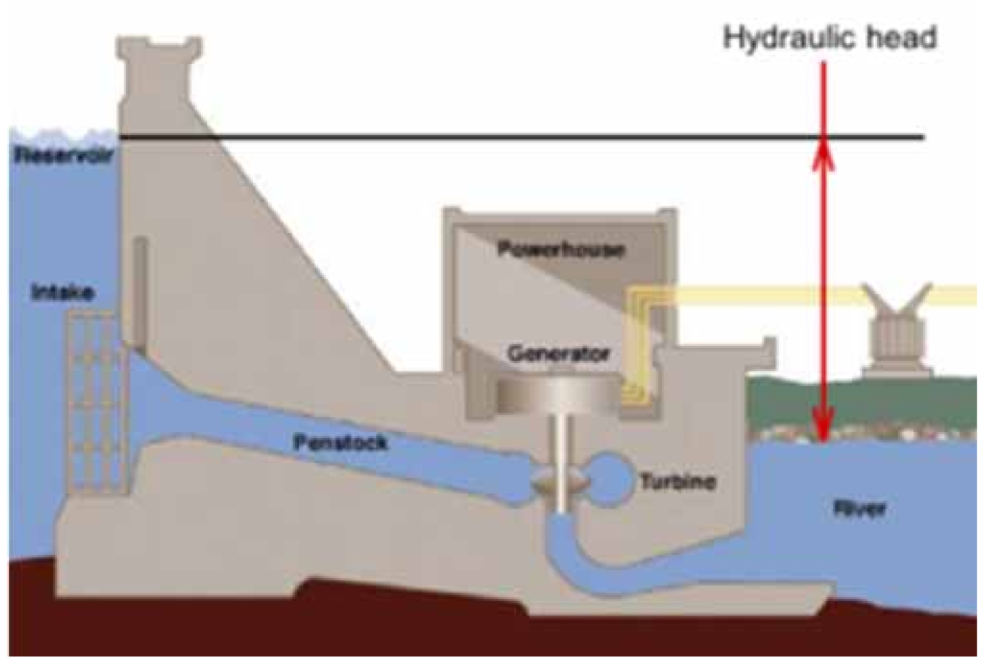
Small Scale Hydro Applications

In the case of falling water, power is the function of "hydraulic head" and rate of flow, where:

- **Hydraulic head = change in water level.**
- **Each unit of water produces work equal to weight × head.**
- **Energy (E) released by lowering the water of unit mass (M) by height (h) is:**

  E = Mgh (where g is acceleration due to gravity).

Tennessee Valley Authority



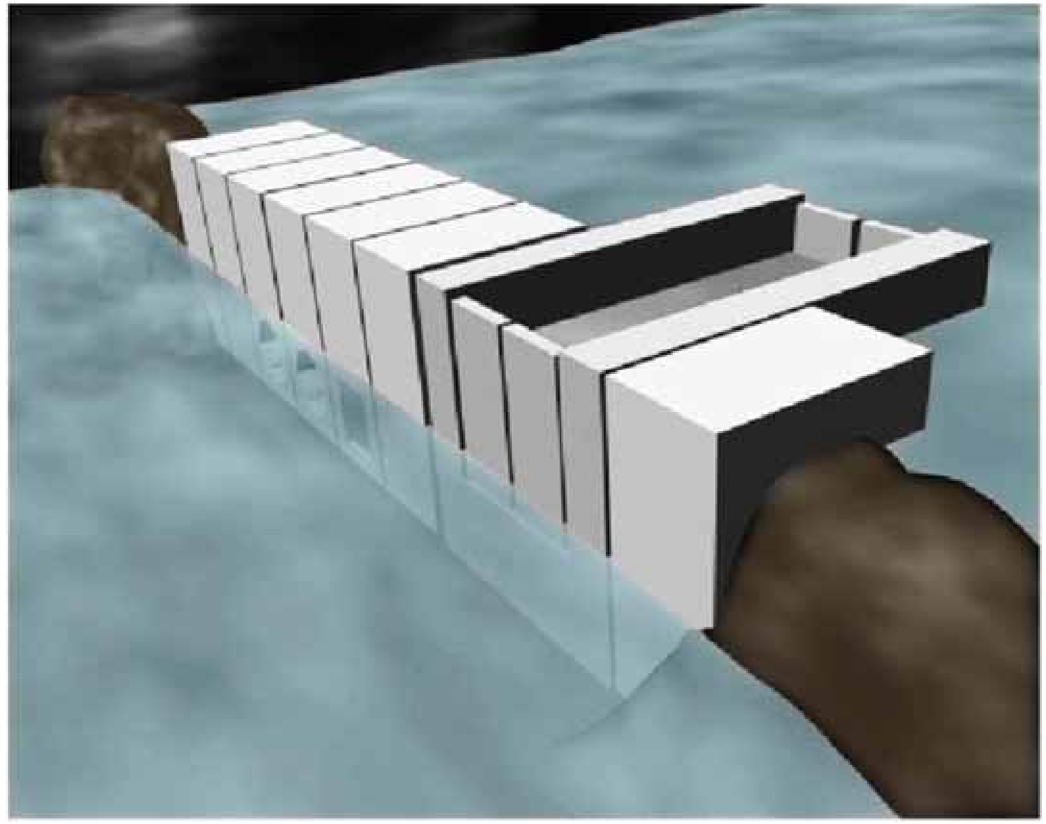
Hydraulic Head in a Reservoir

Evgeni Sergeev

Tidal power is driven by orbital mechanics of the Solar System (Sun and Moon), generating power about 15 hours/day.

Tidal barrages are similar to large dams and are costly to build.

Barrages also present maintenance and environmental problems, including sediment accumulations and sewage concentrations, impacting local ecologies and destruction of fish populations.



Conceptual illustration of a tidal barrage, including embankments, a ship lock, caissons housing, a sluice and turbines.

Tidal Barrage

Many young salmon in the Northwest are killed by turbine blades as they swim downstream towards the ocean, and adult fish attempting to swim upstream to reproduce are blocked by dams.

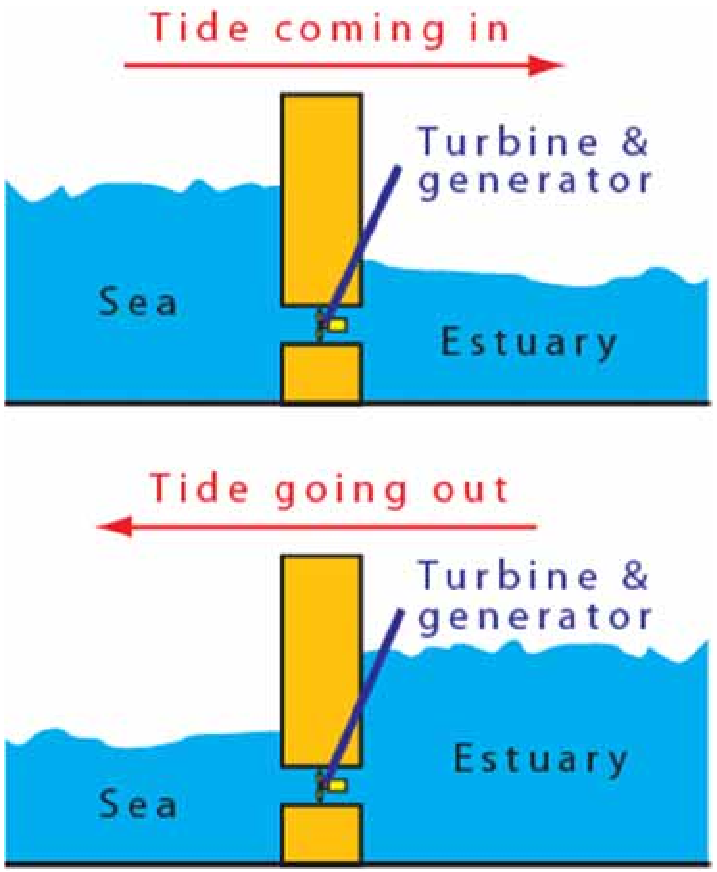
After salmon populations were dramatically reduced in the Northwest Columbia Basin, many fish ladders and side channels were built.

US Geological Service

The Atlas of North America

Hydropower, Fish and Natural Habitat Issues

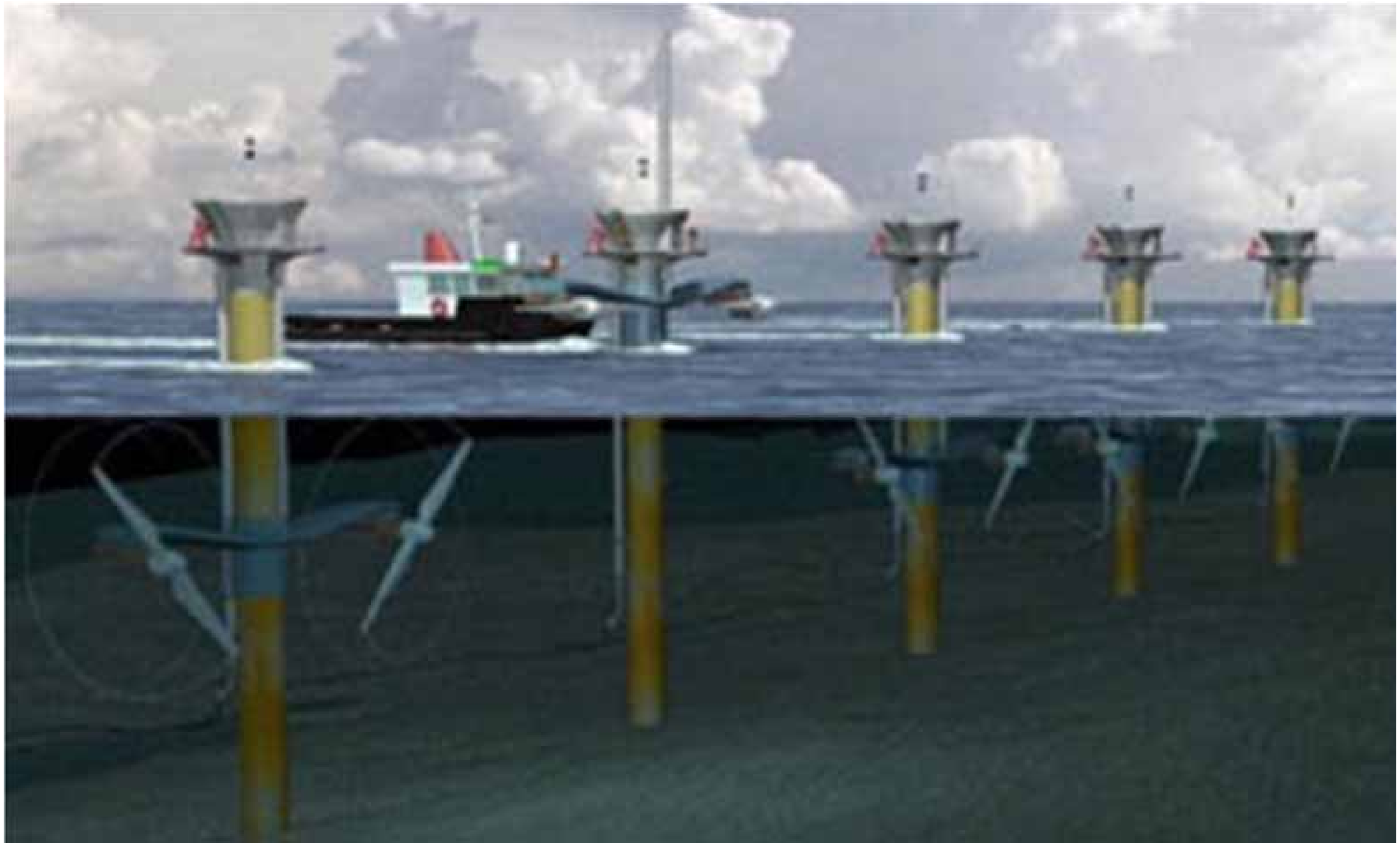
Andy Darvill



Barrage Operations

Sluices and freewheeling turbines allow barrage basins to fill during high tides and close when the tides go out to provide water pressure that drives turbines.

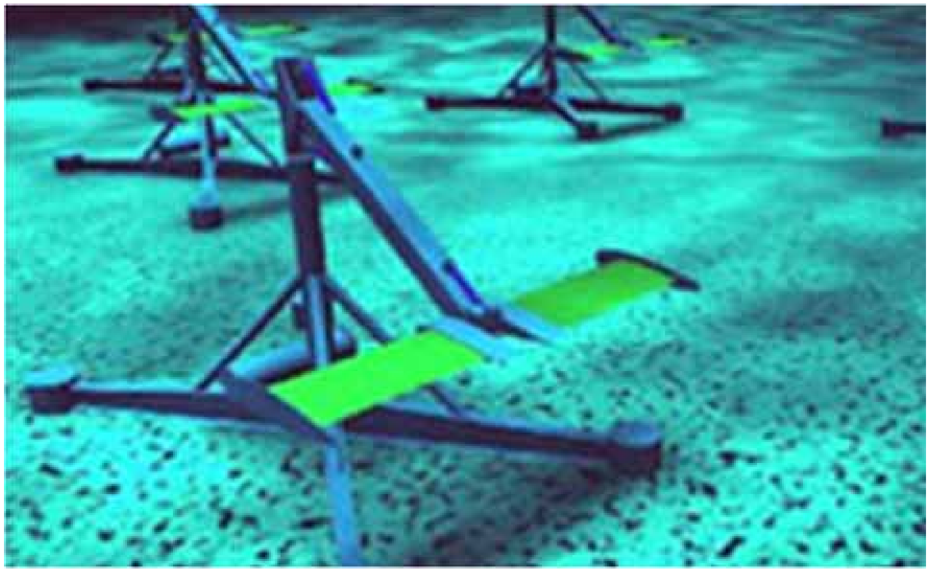
As with wind power, practical locations for large-scale application benefits are limited.



Relatively new technology uses tidal stream generators that draw energy from underwater currents in a manner similar to generators powered by wind. "Seagen" in Northern Ireland uses sets of rotor turbines rated at about 1 MW that can be raised above the surface for maintenance.

The Seagen Tidal Generator

Engineering Business (EB)



The Stingray uses the flow of the tidal stream over a hydroplane to create an oscillating motion that operates hydraulic cylinders that drive motor generators. The devices are mounted to the seabed at depths of up to 330 ft (100m).

The Stingray Tidal Flow Generator

SMD Hydrovision

SMD Hydrovision's TidEL device consists of a pair of contra-rotating 500 kW turbines mounted together on a crossbeam. Mooring chains that tether the buoyant assembly to the seabed, allow the turbines to align to the prevailing tidal flow.

The TidEL Tidal Flow Generator

Dicander & Co.

Wave power may eventually provide more energy than tides using generators coupled to floating devices or turned by air displaced by waves.

It is more continuous than tides since it is produced by ocean currents.

Power generation is influenced by wave height/speed/wavelength and water density.

Wave size is influenced by wind speed and seafloor depth/topography.

Wave Power

Larry Bell

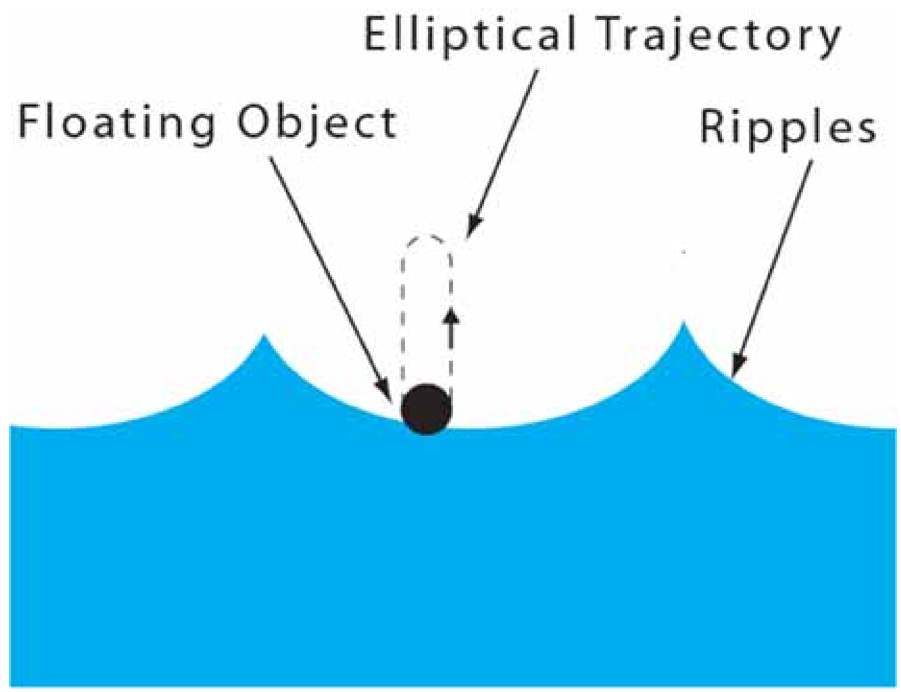
When an object bobs up and down on the surface of water it experiences an elliptical trajectory.

The energy transferred to the object from the water's movement can be harnessed to do useful work (such as to drive an electrical turbine generator).

$$Power = KH^2T \approx 0.5H^2T$$

where:

K=constant; H=height (m); and T=period (sec)



Harnessing Wave Energy

BWEA Marine
Wavegen

Wave power generators are characterized by ways they capture energy, their locations, and how energy is converted.

Capture methods include "point absorbers" (small area devices), wave "power attenuators" (aligned parallel to waves), and "power terminators" (aligned perpendicular to propagation).

Locations include shorelines, offshore, and deep water.

Converters include hydraulic rams, various pumps, and hydroelectric or air turbines.

The Pelamis Wave Energy Converter is a point absorber that is flexibly moored near shore to swing head-on into incoming waves.

Wavegen's Land Installed Marine Powered Energy Transformer captures wave energy along a shoreline in Scotland.

Shoreline Wave Energy Converters

Ocean Power Delivery

Wave Dragon

The Pelamis is a semi-submerged, articulated structure composed of cylindrical sections linked by hinged joints. Wave-induced motions of the joints are resisted by hydraulic rams that pump high-pressure oil through hydraulic motors that drive electrical generators. Many sections can be tethered to the shore by a single cable.

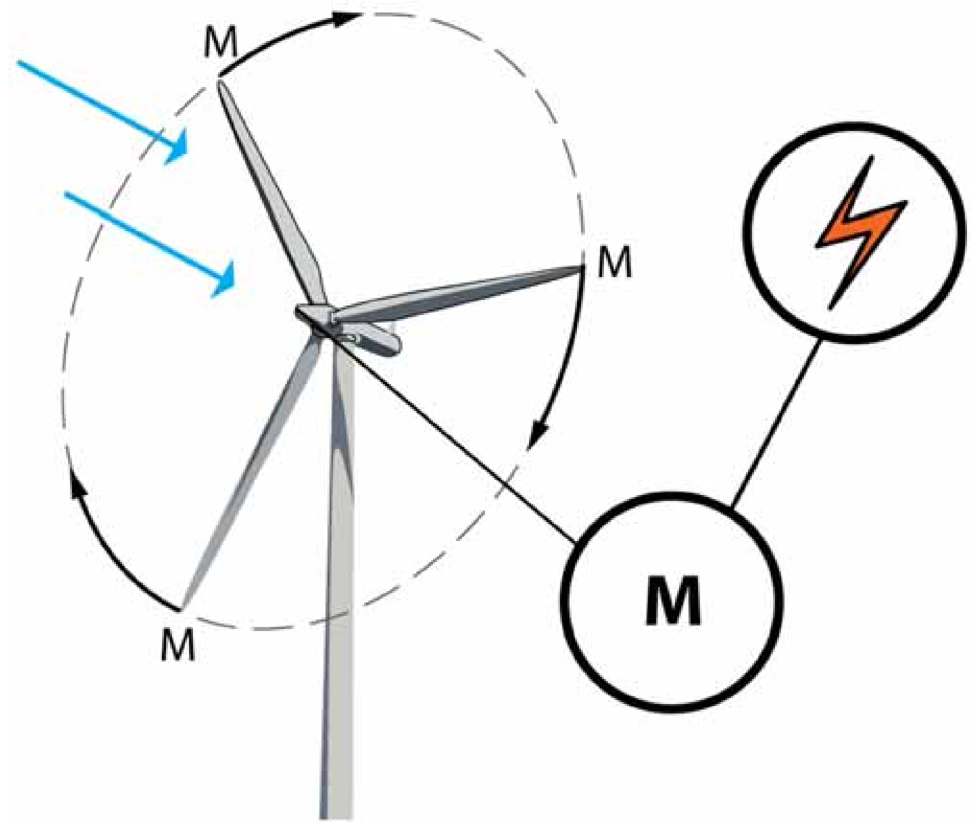
Wave Dragon consists of collectors that channel waves towards a double-curved ramp structure to create a water storage reservoir. A set of propeller turbines convert water head in the reservoir into electricity. The design is unique among wave energy converters because it produces electricity through a one-step system using turbines.

The Pelamis Wave Energy Converter

The Wave Dragon

Since the theoretical energy generated by a wind turbine equals the cube of wind speed, small increases in wind speed produce large increases in power.

If wind speed is doubled, theoretical power increases by a factor of eight (although in actual practice, it is less).



Natural Resources Canada

Traditional Rural Windmill

Civilizations have used wind energy since the beginning of recorded history:

- **To propel boats on the Nile in 5000 BC.**
- **To pump water and grind grain in China and the Middle East since 200 BC.**
- **To drain lakes and marshes in Holland since 1100 AD.**
- **To pump water and provide electricity in North America since the late-1800s.**

Derek Jensen

Small Independent Unit

Contemporary wind turbines range in size from small ones used in rural areas to supplement electricity from public grids, to large units that are linked together for multi-megawatt, utility-scale applications.

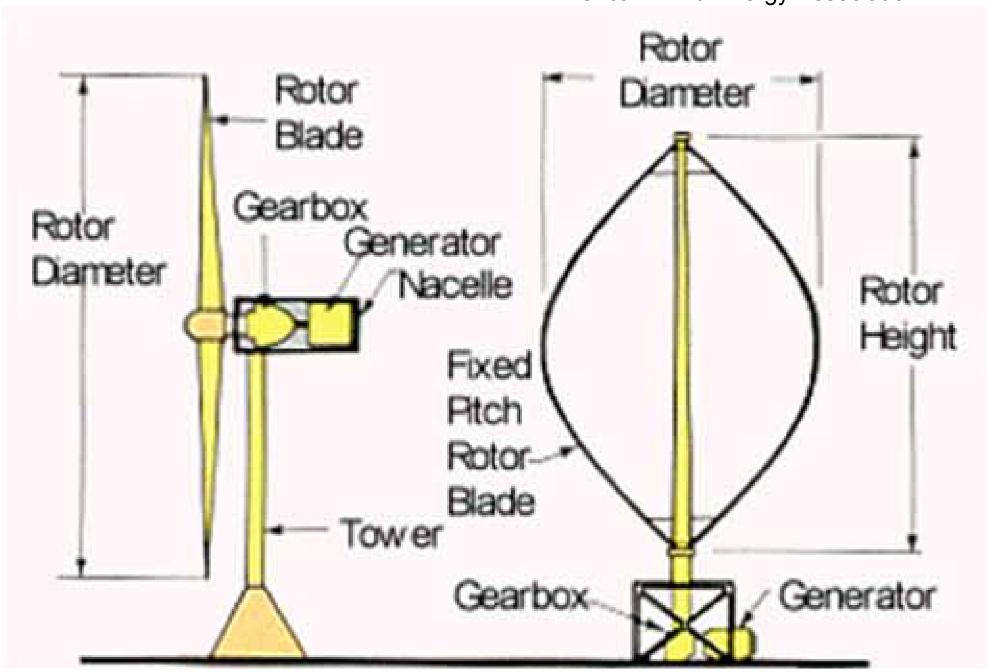
SatCon Technology

Wind Farm

Horizontal-axis wind turbines are the most common type used today, including 3-bladed versions placed upwind with blades facing into the wind and 2-bladed placed downwind.

Vertical-axis include large and small Darrieus models that operate in "eggbeater-style" forms.

American Wind Energy Association



Horizontal-Axis **Vertical-Axis**

Wind Turbine Configurations

Tree Hugger

Familiar Horizontal-Axis Types

DOE-EERE

Vertical-Axis System

Air density (the number of molecules in a unit volume of air) influences the mass that moves turbine blades.

Density decreases slightly with humidity and altitude.

Air is more dense in winter than in summer, producing more power with the same wind speeds.

Density is also less at high mountain altitudes (lower air pressure), but wind speeds are higher

Theoretical wind power is determined by the equation:

$W = 1/2rAv^3$, where W = power; r = air density; A = rotor area; v = wind speed.

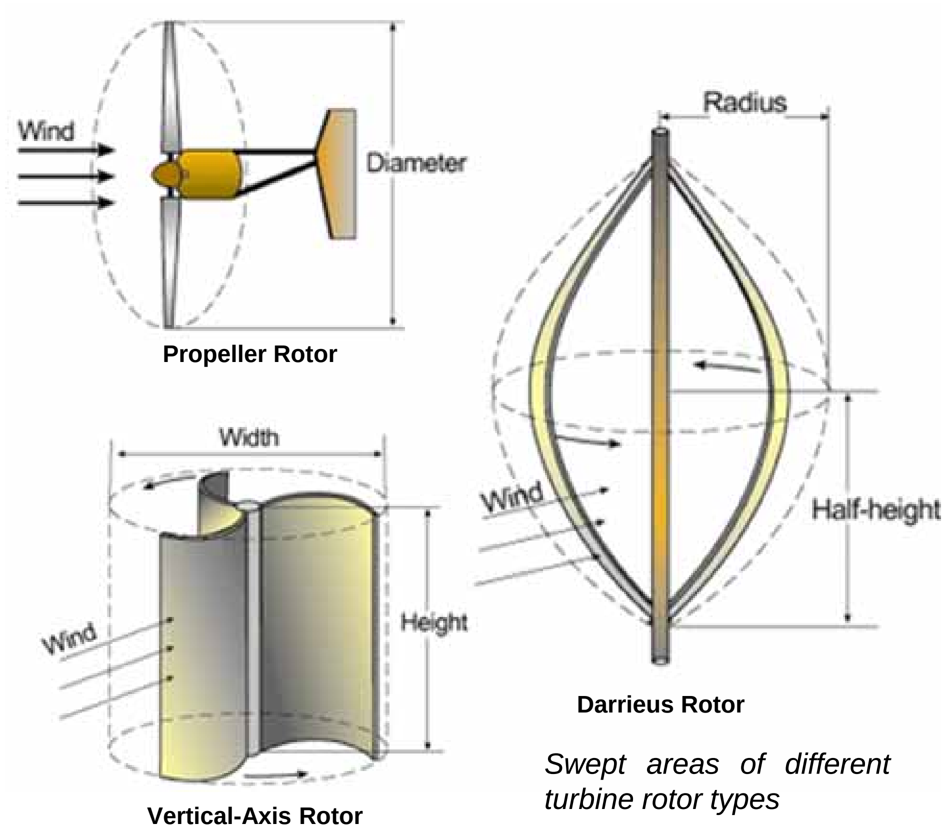
Influences on Rotor Power

Iowa Energy Center

Although the power equation shows an exponential increase with wind speed, the actual power increase is somewhat more linear.

Applying the formula $W = 1/2rAv^3$ to determine power generated (W), the swept rotor area (A) for each turbine is determined according to an adjusted power curve number (n) times the square of the rotor radius:

$A = nr^2$

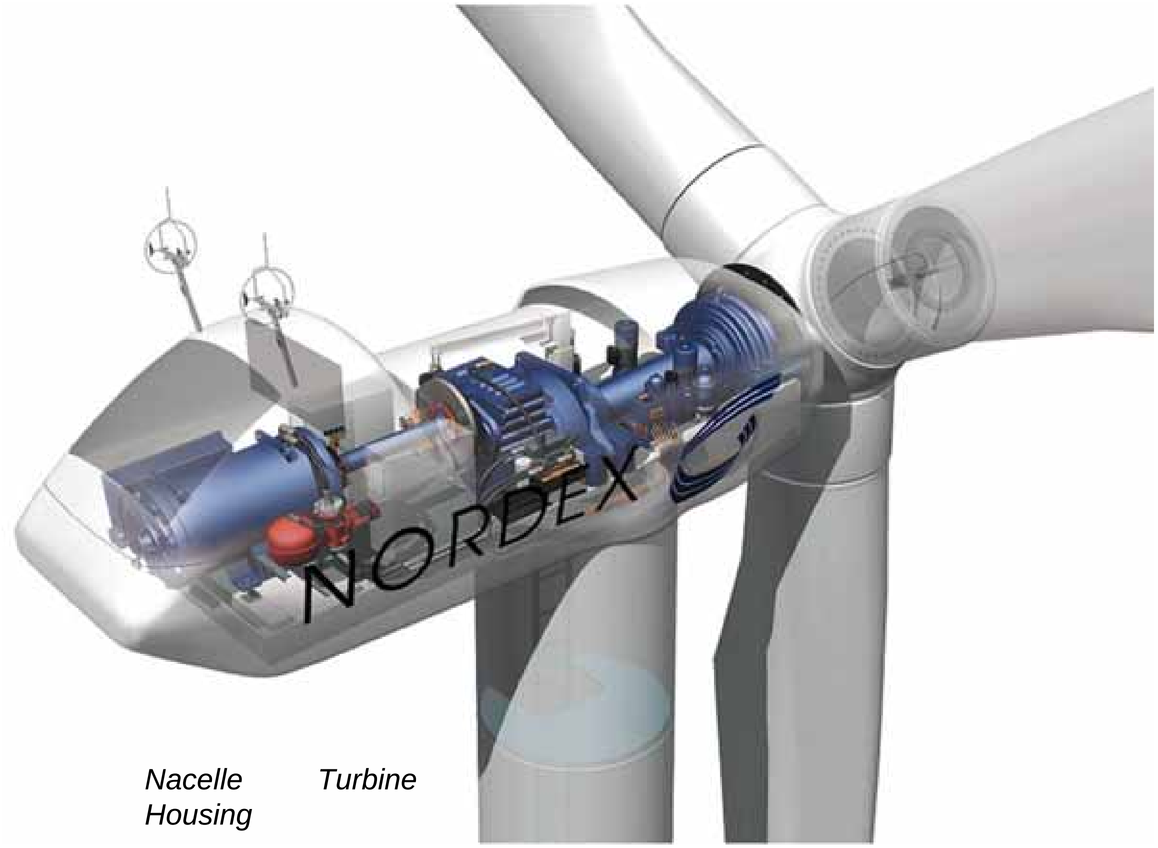


Swept areas of different turbine rotor types

Wind Turbine Rotor Influences

Most commercial wind turbines are 3-blade horizontal-axis types grouped at distances of 5-15 times blade-diameter apart.

Mechanical transmission maintain efficient operations throughout a range of wind speeds.

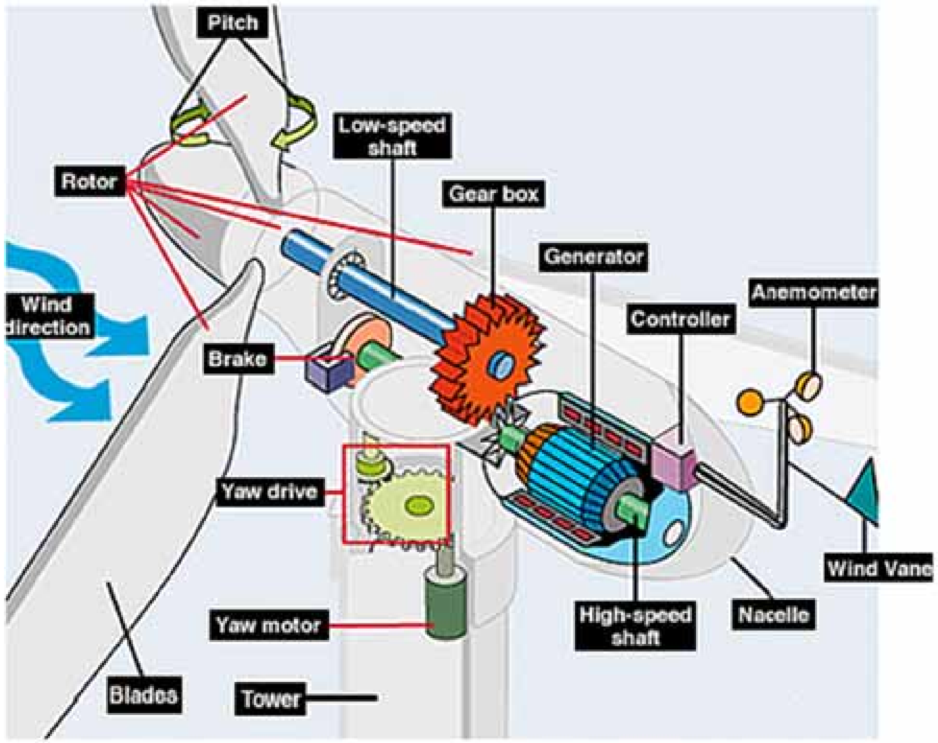


Commercial Horizontal-Axis Turbine

The "nacelle" turbine housing contains a variety of important mechanisms:

- **Anemometer**: measures wind speed and sends data to a controller.
- **Controller**: starts up/shuts off the machine at maximum speeds.
- **Generator**: often an AC 60-cycle induction type.
- **Rotor assembly**: includes the blades that capture wind energy and a spinning hub.
- **Gears**: connect low-speed and high-speed shafts that drive the generator.
- **Wind vane**: orients the turbine to the wind using a yaw drive.

USDOE-EERE



Internal Wind Turbine Components

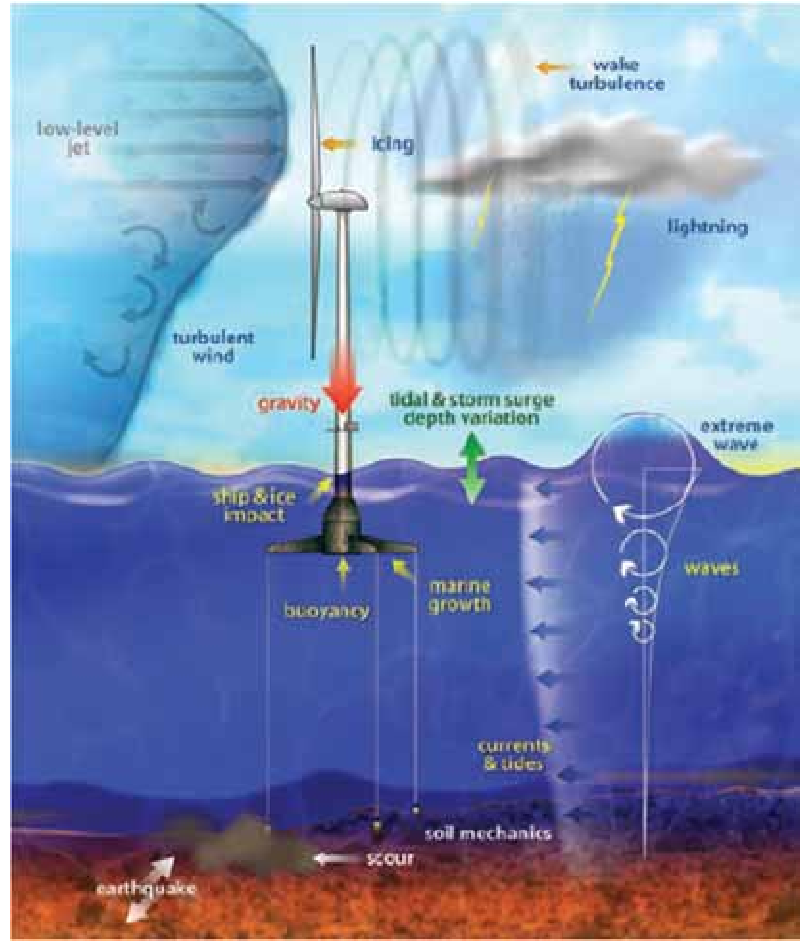
US DOE-EERE

Coastlines are often excellent potential locations offshore wind turbine locations.

Although the US DOE estimates that wind farms placed 50-60 miles offshore could provide high capacities, only about 18 such facilities currently exist in the world.

All are locate in relatively shallow waters (less than 60 feet deep).

More of these wind farms are planned in Europe, and a few are undergoing permitting processes in the US.



Offshore Installations

Small-Scale Applications

Small-scale wind turbines are useful for off-grid agricultural, industrial, and domestic applications.

Many are used in combination with solar and other renewable resources.

Since wind is not always available, means to provide electrical storage is often required and used to electrolyze water into hydrogen for fuel cells in one option.

US DOE-EERE
Treehugger Enviro-Energy Technologies

Off-grid wind applications are diverse:

- **Water-pumping windmills have been used for generations to supply water for livestock, irrigation, households, and even small communities.**
- **Wind energy systems can power lights, electric fences, and a range of appliances.**
- **Hybrid wind systems combined with PV, diesel generators, and electric power grids can afford inexpensive non-polluting backup energy.**

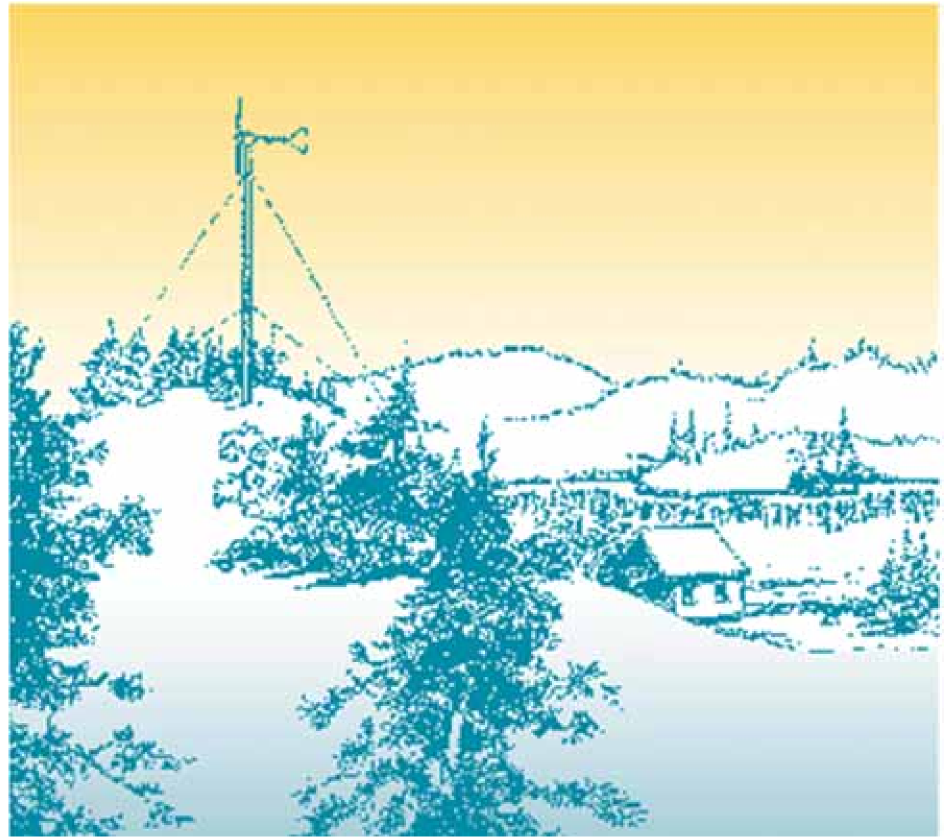
Natural Resources Canada

Wind is created by uneven warming and cooling of the Earth's surface which produces pressure zones that causes airflow from high-to-how pressure areas.

Daily and seasonal changes have important influences (often strongest in afternoons and weaker in mornings; strongest in early spring and weaker in the summer).

Upward Air Currents

Canadian Renewable Energy Network



Geographical land features can produce important wind influences:

- Hills, plateaus, and bluffs raise wind speeds.
- Valley, oriented perpendicular to wind directions, tend to lower wind speeds, but oriented parallel can channel winds to increase velocities.
- Valley constrictions can funnel wind flow into smaller areas to further increase velocities.

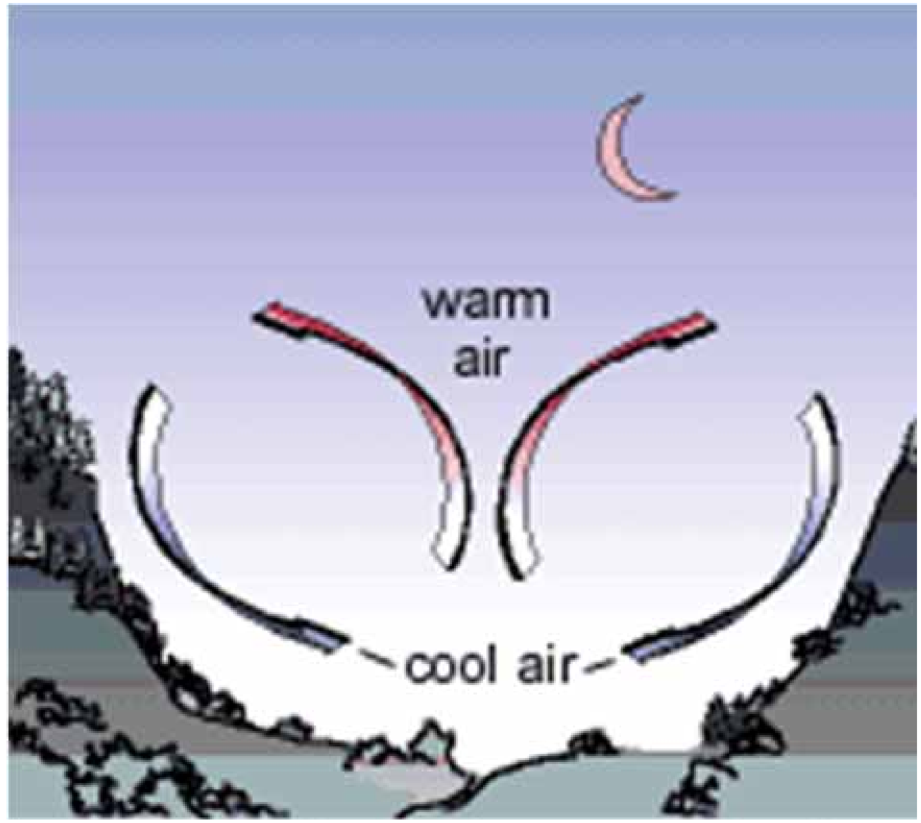
Surface-Driven Effects

Valleys can often have calm conditions when adjacent hilltops are windy.

Cool, heavy air moving downwards collects below and is removed from the general air flow above.

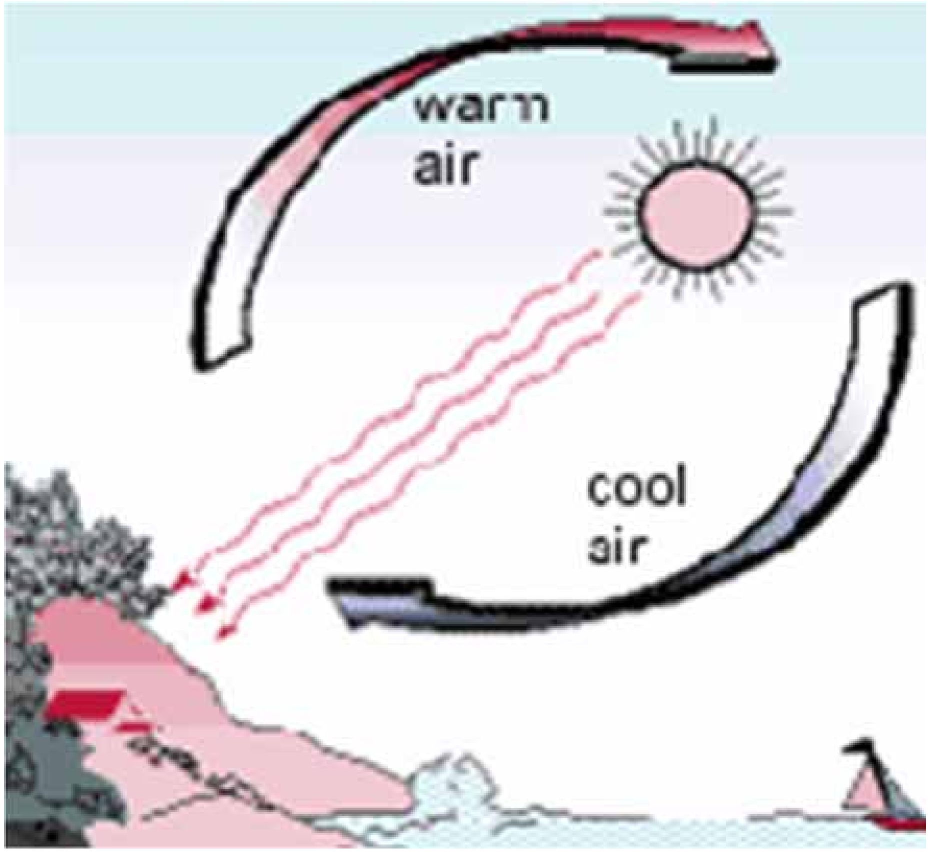
Wind turbines placed at the higher areas may produce all night, even when those at lower elevations are idle.

Iowa Energy Center



Evening Wind Effects

Iowa Energy Center



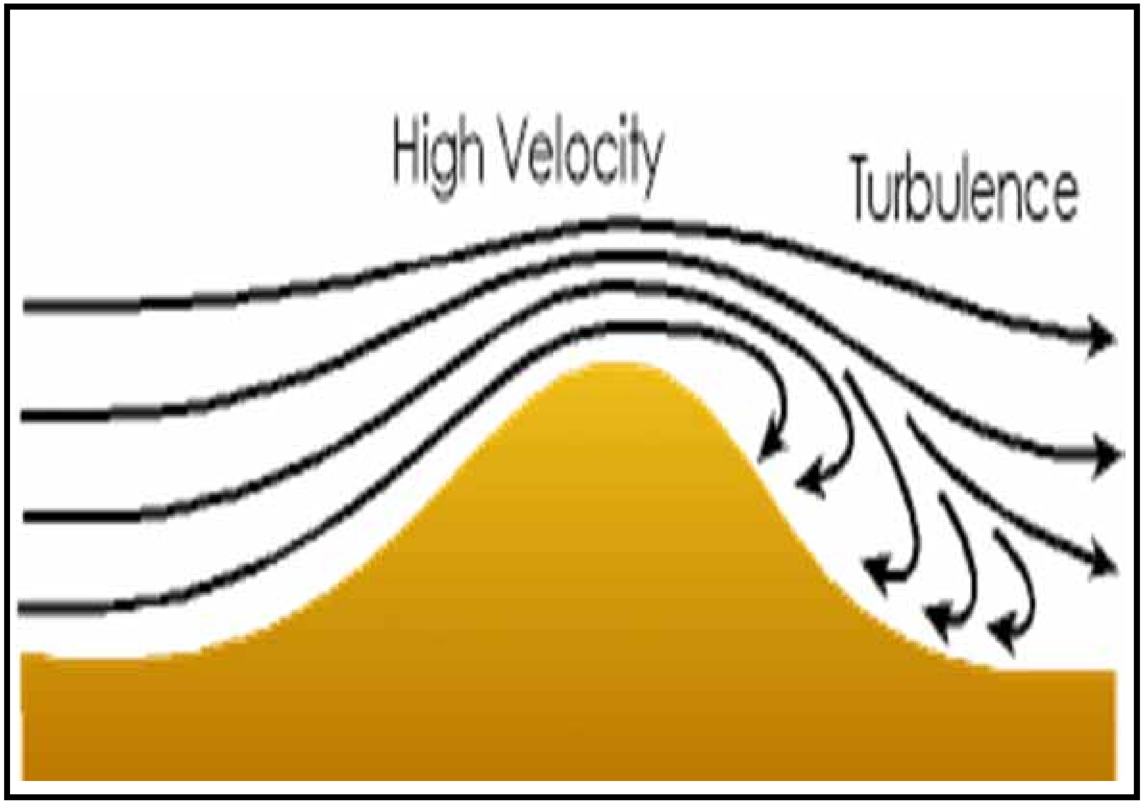
Sites Near Water Bodies

Land areas adjacent to large water bodies can be excellent wind turbine sites, particularly where the prevailing wind direction is "on-shore".

These winds occur when warm, rising air over land is replaced by cooler air over water during the day, and when this condition reverses at night as land cools more quickly.

High terrain features can accelerate wind by squeezing an approaching air mass into a thinner layer causing it to speed up.

This occurs when wind is perpendicular to a hill or mountain ridge line, particularly if the ridge line is long so that air can't flow around it.



Air flow accelerates when squeezed as it passes over hill and mountain ridges, producing turbulent areas on the lee side.

Terrain Effects

Rough surfaces created by trees, buildings, and other features produce more friction and turbulence than smooth surfaces such as lakes or open croplands.

- **The approximate increase of wind speed with height for different surfaces can be calculated by the equation:**

$v_2 = v_1 \times (h_2/h_1)^n$, where:

v_1 = known (reference) wind speed at height h_1 above the ground

v_2 = speed at second height h_2

n = the exponent of determining wind change based upon different types of ground cover.

Values for n:

Smooth ocean sand: n = 0.1 | **Low grass area: n = 0.16**

High grass/low crops: n = 0.18 | **Tall crops/low woods: n = 0.2**

High woods/forest: n = 0.3 | **Small towns: n = 0.3**

Example wind speed calculations:

- **Assume an average 10 mph wind speed measured at 30 ft above the surface in an area of low woods (n = 0.2) and you wish to estimate wind speed of a 100-foot high wind turbine:**

v_2 = 10 mph × $(100/30)^{0.2}$

$v_2 = 10 \times (3.33)^{0.2}$ **$v_2 = 10 \times 1.27$**

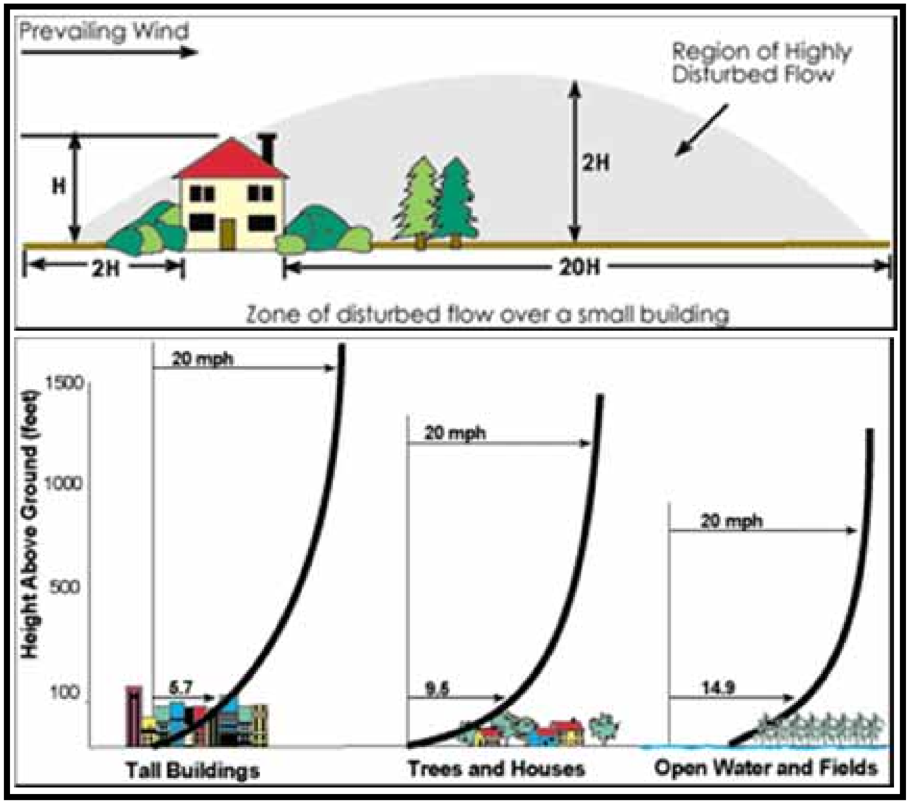
v_2 = 12.7 mph (average at wind turbine)

Surface Effects of Wind Speeds

Iowa Energy Center

Some rules of thumb for reducing wind obstacle interferences:

- Site the turbine upwind at a distance of more than two times the height of the obstruction.
- Site the turbine downwind at a minimum of 10 times (preferably 20 times) the obstruction height.
- Site the turbine hub at least twice the obstruction height above the ground if it is immediately downwind from the obstruction.

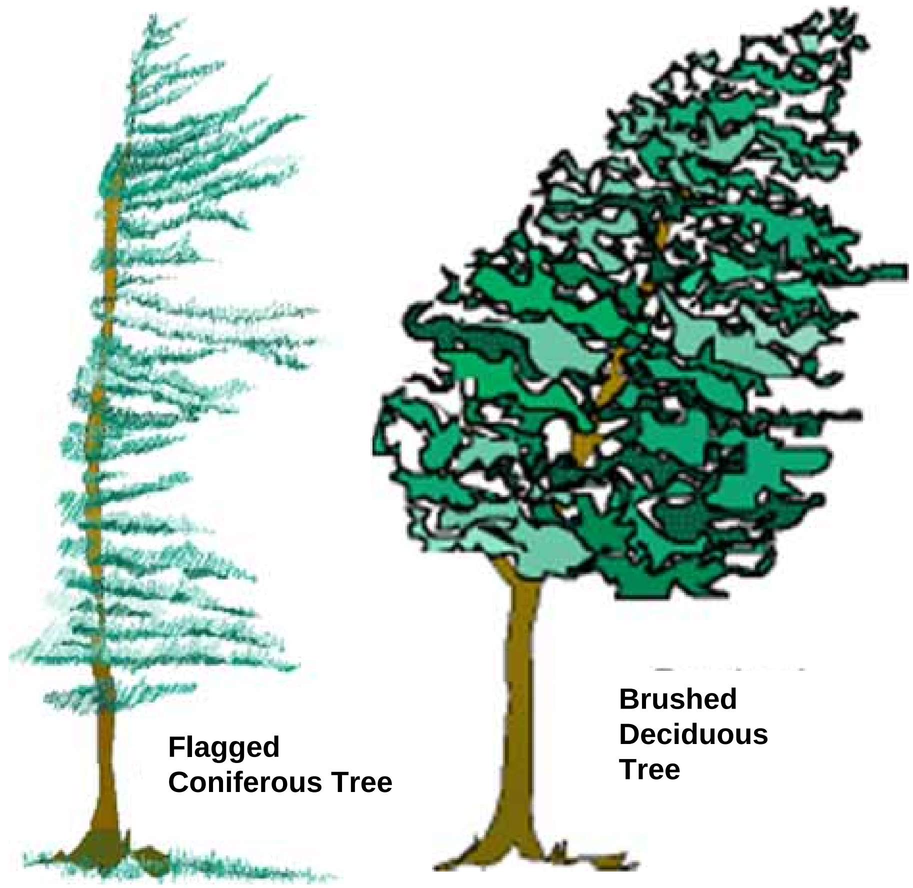


Minimizing Obstruction Influences

Tree deformations offer indications of reasonable wind power sites.

“Brushing” or “flagging” typically occurs where trees are exposed to wind speeds between 8-18 mph when the dominate direction is consistent.

Flagging is common in coniferous trees (pine and spruce) reflected by short/missing upwind branches and long branches oriented downwind.



Trees as Wind Indicators

Solar energy is most broadly used for low-power electrical and heating applications where other sources are not available.

Photovoltaic systems power emergency roadside telephones, home lighting and appliances, irrigation water pumps, and other services.

Solar thermal systems are used for space heating, hot water, and steam production to drive large electrical power generators.

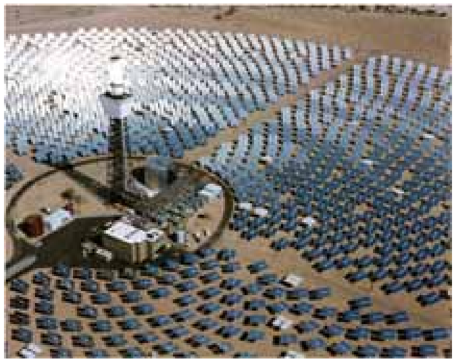
ePrairie, Inc.
National Renewable Energy Laboratory

Off-Grid Electrical Power

Genersys Ireland
US DOE-EERE

Water and Space Heating

Solar-Thermal Power Plant



Solar Photovoltaic Power Plant

PV systems that convert sunlight directly into DC electricity are reliable, but only during periods when sunlight exposure is available.

The devices are typically lightweight, modular, and foldable for easy transportation and installation.

While used for supplementary power, nearly everywhere PV systems are most applicable to locations that afford frequent access to sunshine.

Some PV customers receive credits from utility providers for the excess electricity they return to connecting grids.

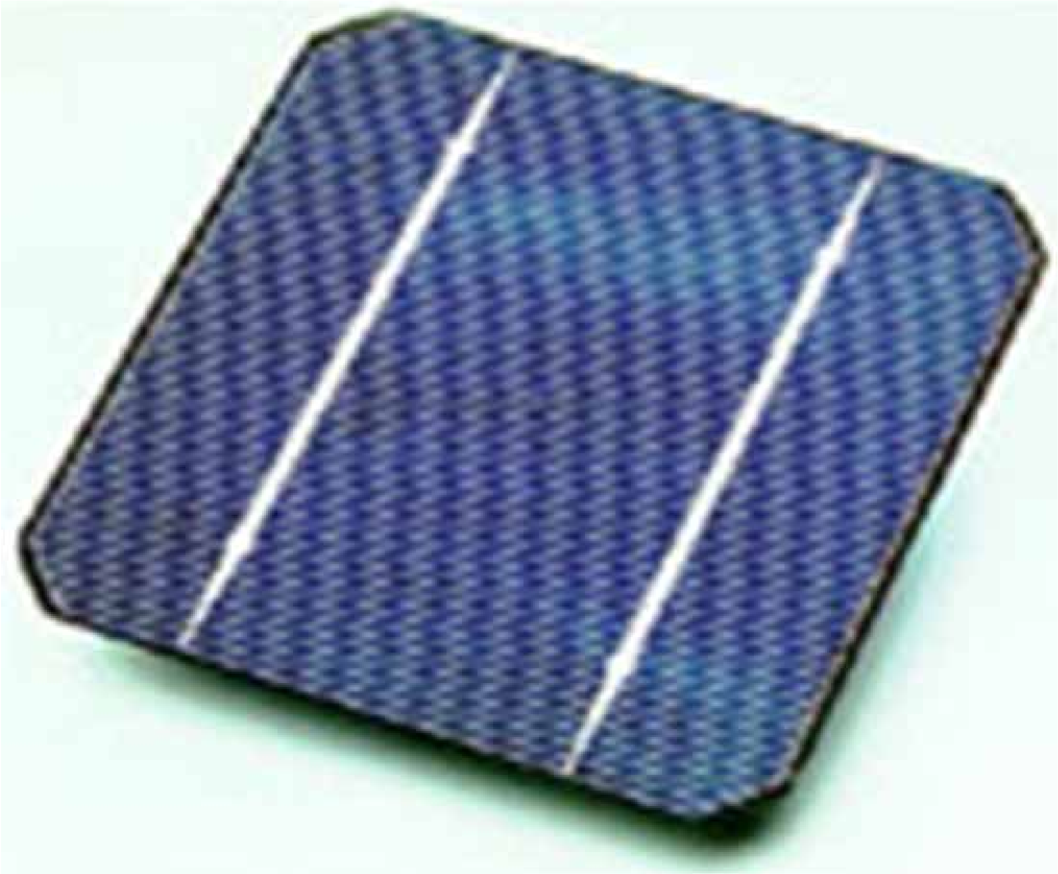
Pacific Environment

Converting Sunlight to Electricity

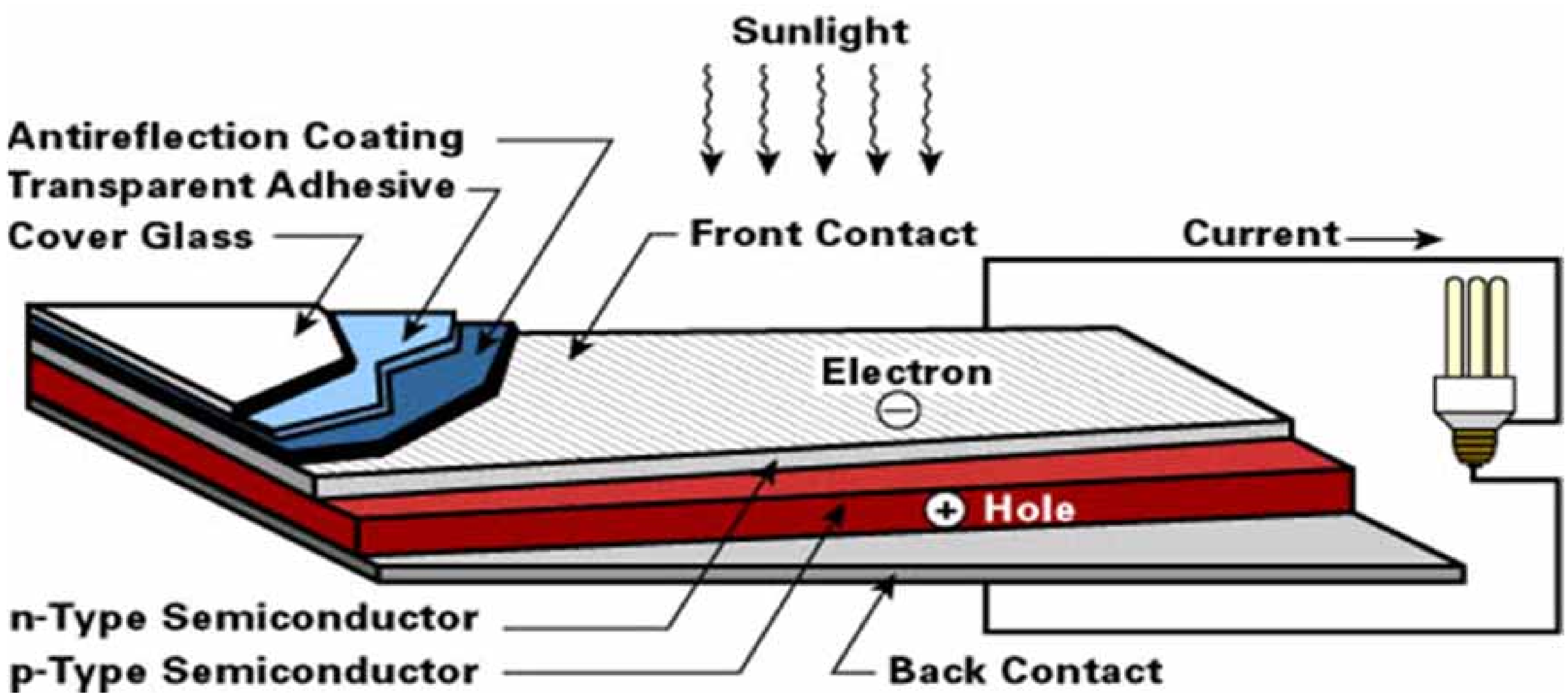
PV systems produce electricity when light photons of sufficient energy knock electrons free in the silicon crystal structure of solar cells.

The cells are usually wired together in series (+ to -) in modules containing about 30-36 cells each.

Modules in turn can then be wired together either in a series or parallel to form larger arrays to meet desired power outputs.



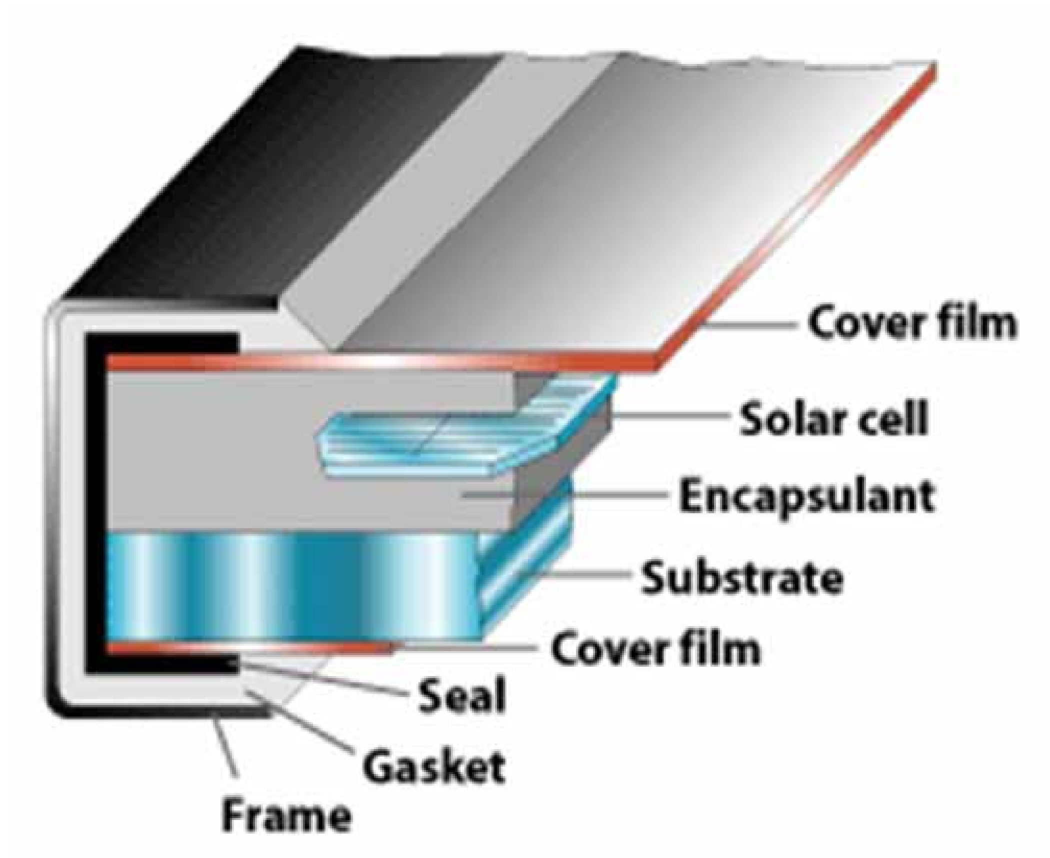
Solar Electric Conversion



A typical solar cell consists of a glass or plastic cover or other encapsulant, an antireflective layer, a front contact to allow electrons to enter a circuit, and the semiconductor layers that create a current.

US DOE-EERE

Typical flat plate module design uses a substrate of metal, glass or plastic to provide structural support on the back, an encapsulant material to protect the cells, and a transparent glass or plastic cover.



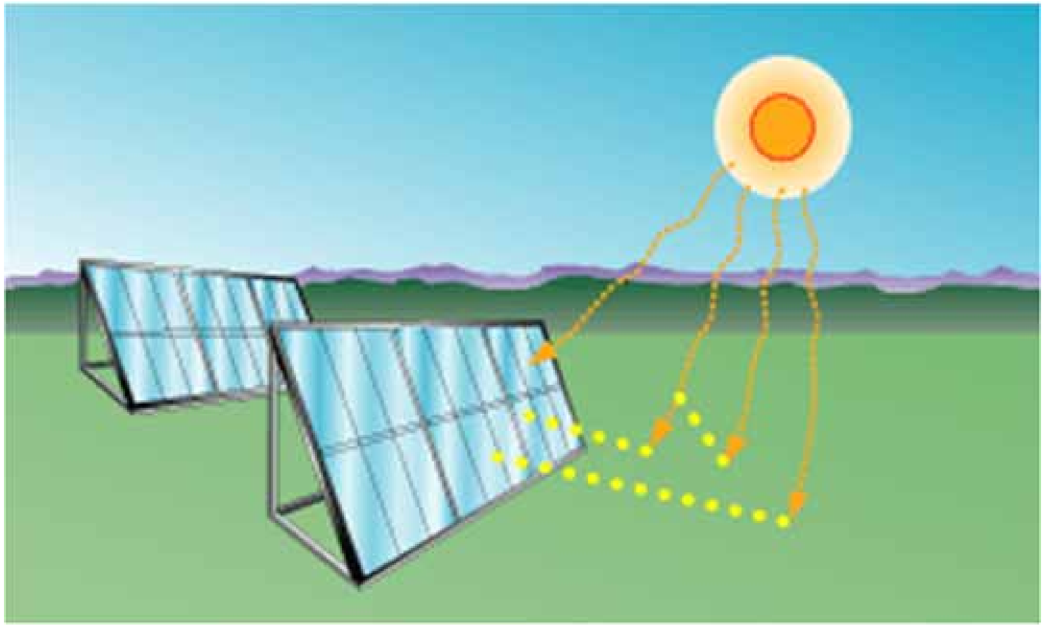
Flat Plate PV Design

PV arrays must be mounted on stable, durable structures that can withstand wind, rain, hail, and other adverse conditions.

Much solar energy is captured from diffuse radiation:

- **In clear skies, the diffuse component of sunlight accounts for 10-20% of the total solar radiation on a horizontal surface.**
- **On partially sunny days, up to 50% of radiation is diffuse.**
- **On cloudy days, 100% of the radiation is diffuse.**

US DOE-EERE



Diffuse Energy Collection

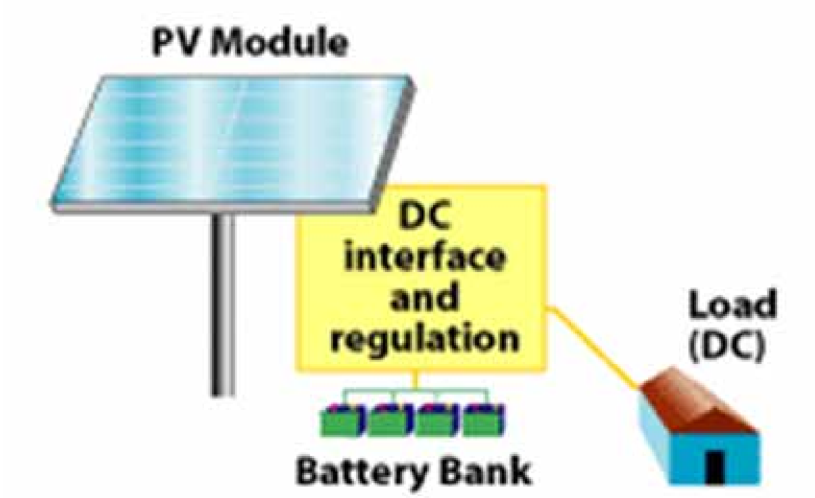
Sacred Power Corporation

PV inverters convert DC to AC (resulting in a 4-12% energy penalty).

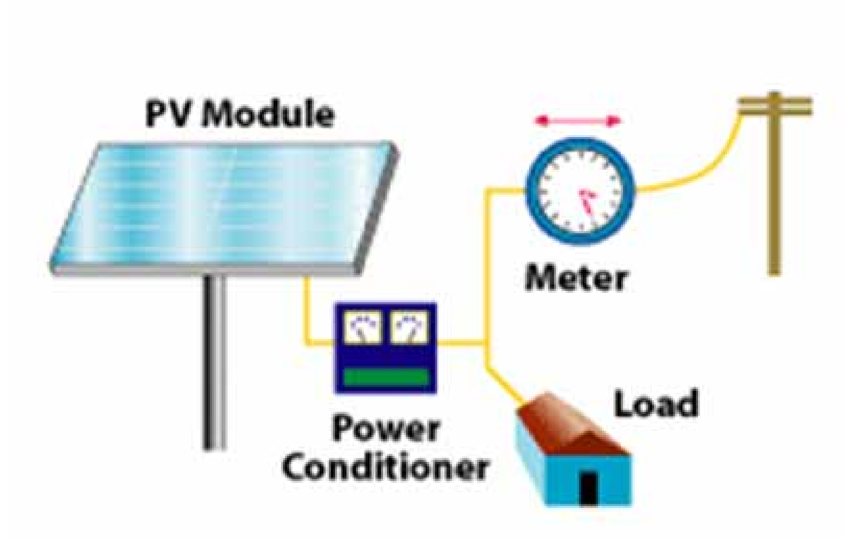
The use of solar power inverters has expanded opportunities for off-grid rural electrification.

Power from wind generators can be combined with PVs to provide more continuous hybrid capabilities.

PV-Wind Generator Hybrid System



Stand-Alone System

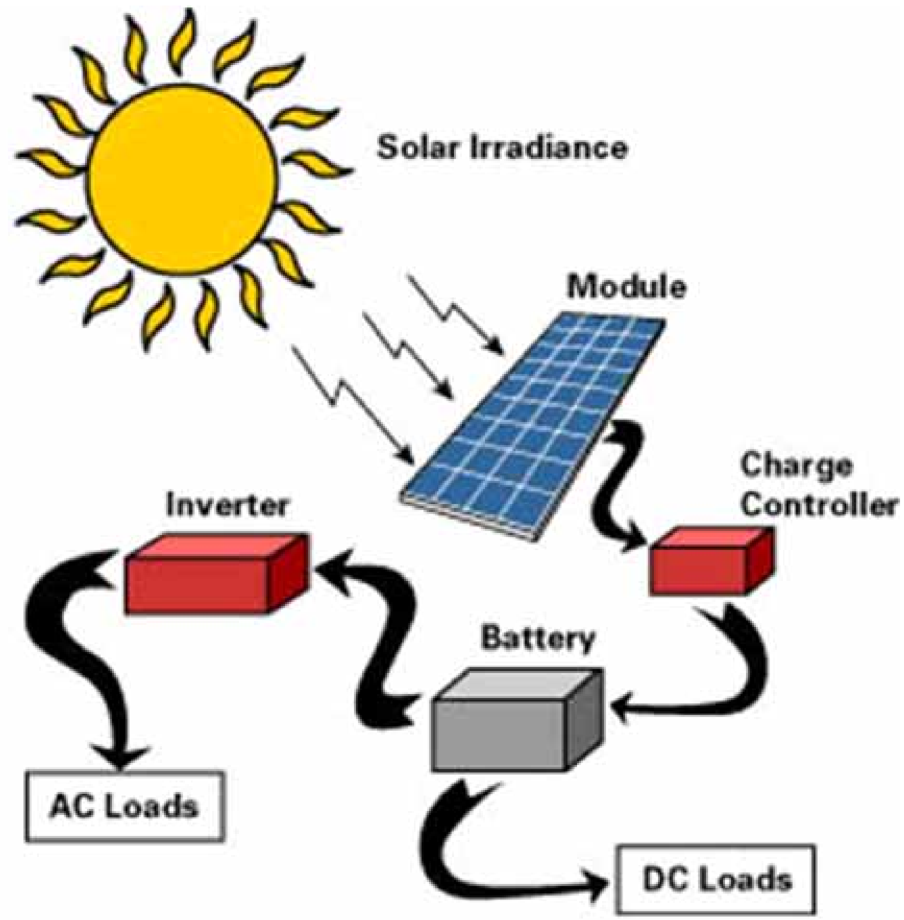


Grid-Connected System

NJ Solar Power

A typical small-scale PV installation consists of the following:

- **PV array- often a series of 9-54 solar panels (residential) that generates DC electricity.**
- **Inverter- an electronic device that converts the DC to standard AC electricity compatible with the electrical grid.**
- **Rails- are mounted to a roof or ground installation to hold PV panels in place.**
- **Battery backup- charged by the solar system to provide power at night and cover outages. (This is optional since most systems are "grid-ties" and utilize the electrical grid for storage.)**



PV System Components

Pyron Solar

The Pyron Solar Generator is a new high-efficiency photovoltaic system that combines advanced semiconductor cells and short-focal-length lenses that concentrate sunlight.

The system can produce 800 times more electricity than conventional non-concentrating cells of the same size.

Pyron Solar Generator

German Energy Agency

Village PV System Installation

PV systems are becoming vitally important in threshold and developing nations where more than two billion people lack access to an electricity grid.

Off-grid OV systems usually requires means to supply or store power where use at night and on cloudy days.

Battery back-up and storage systems are commonly used, but lower energy efficiency about 20% and require replacement every 50-10 years.

Batteries also require a considerable amount of space, and have relatively poor performance under cold weather conditions.

Fraunhofer Institute for Solar Energy Systems

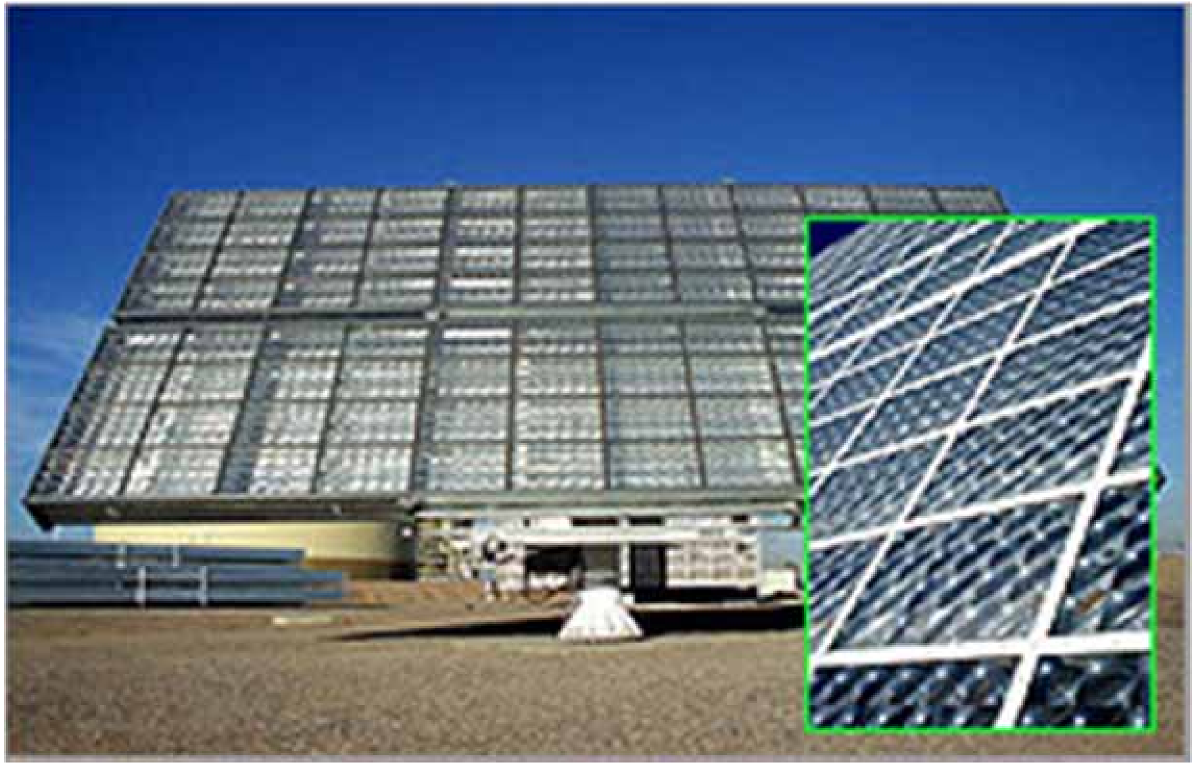
Storage Batteries in Indonesian Village

US DOE-EERE

Solar concentrator PV systems focus solar energy onto cells to increase power output.

These devices are generally used for large-scale power generation.

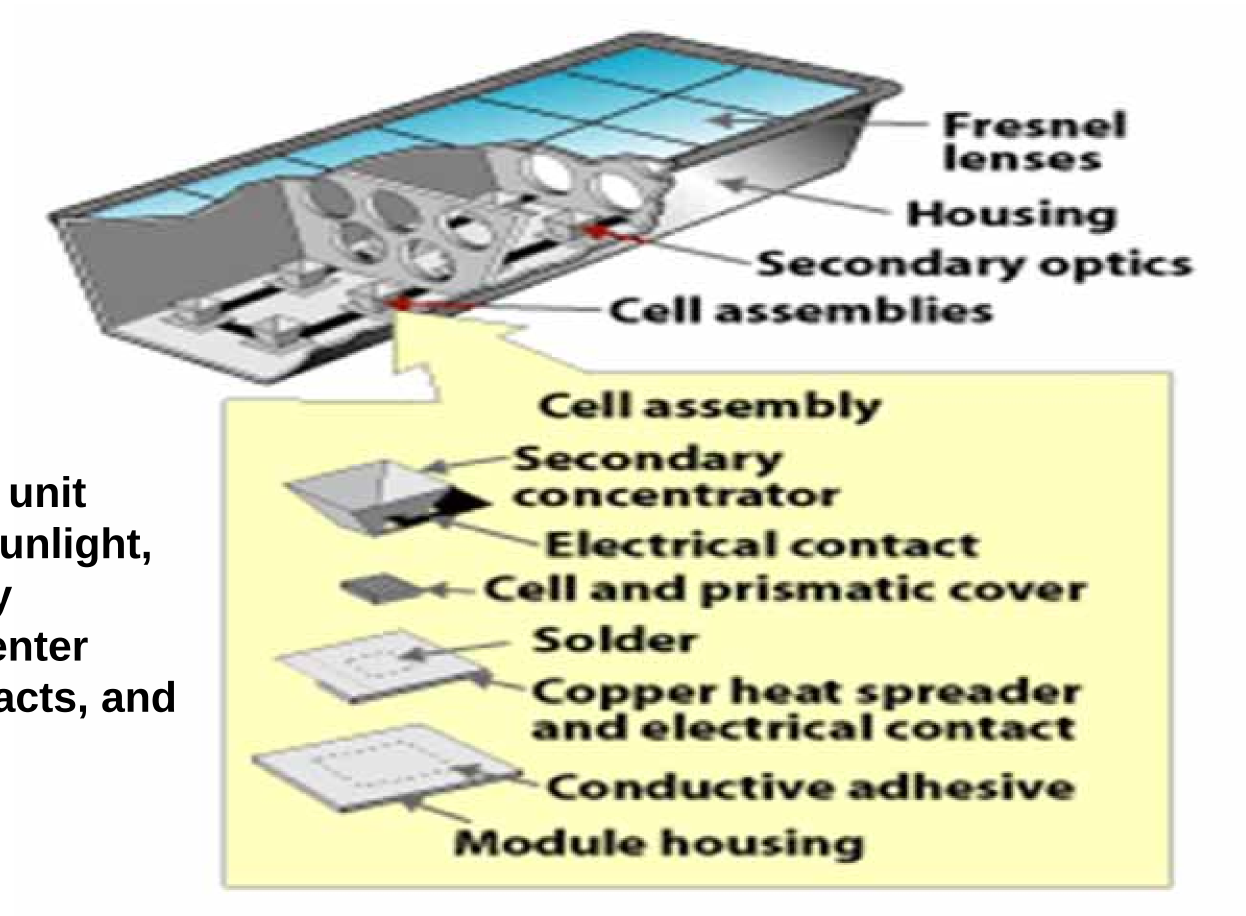
Important advantages over standard PV approaches are that relatively fewer of the expensive solar cells are needed since the systems more efficiently use concentrated light.



This high-performance solar power generator has been developed for the Arizona Public Service Company's Solar Test and Research (STAR) center.

Concentrator PV System

US DOE-EERE



A typical basic concentrator unit consists of a lens to focus sunlight, cell assemblies, a secondary concentrator to reflect off-center light, various electrical contacts, and support housings.

Typical Concentrator Design

James Fraser

Concentrating solar power (CSP) systems use lenses or mirrors that track the Sun to focus a small beam of radiation onto a thermal collector or PV cells to produce electricity.

The systems range in size from about 10 kW to more than 100 MW.

Since they require direct sunlight (not diffuse light), use is limited to sunbelt locations.

Electrical Power Production

US Dept. of Labor - OSHA

Solar thermal power CSP systems heat fluids and gases to high temperatures that drive steam or gas engine-turbines.

Power towers or "heliostat" plants use flat, movable mirrors to focus energy upon collectors that reflect it back to absorbers that store heat for later use.

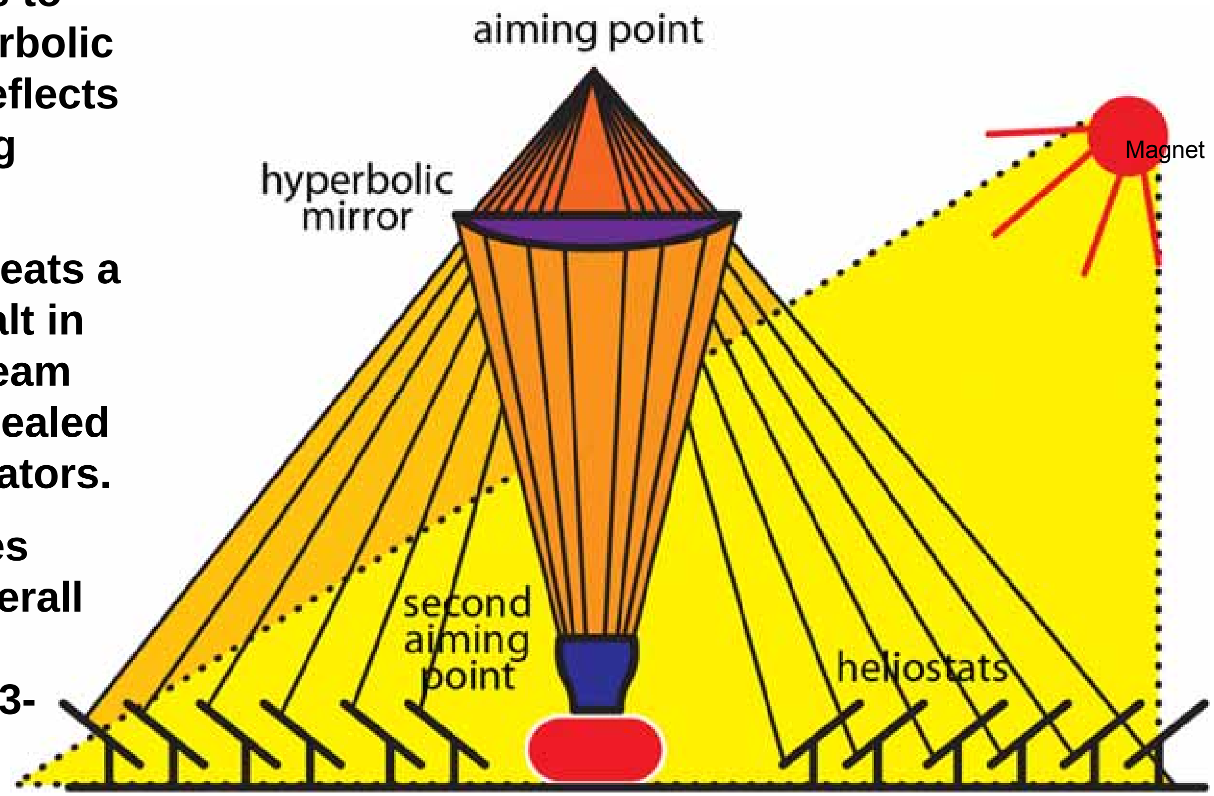
Dish and trough collectors track the Sun to concentrate energy that drives electrical turbines.

Concentrating Solar Power Tower

Power tower CSP systems use numerous heliostat mirrors to focus sunlight onto a hyperbolic receiver at the top which reflects it back to secondary aiming points.

The concentrated energy heats a transfer fluid or a nitrate salt in the receiver to generate steam power or hot gas to drive sealed closed-cycle turbine generators.

Thermal-electric efficiencies range from 25-50% with overall solar-electric conversion efficiencies ranging from 13-25%.



Concentrating Solar Power Tower

US DOE-EERE

Concentrating Solar Dish-Engine

Solar dish-engine CSP systems are stand-alone electric generators that use a solar concentrator that reflects energy onto a receiver.

The receiver transfers the collected heat through a bank of gas tubes or heat pipes to an engine-turbine.

Although not yet commercially available, demonstrations indicate generating potentials of up to about 35 kW.

US DOE - EERE

Trough-type CSP systems are comprised of many parabolicly-curved trough-shaped reflectors that transmit thermal energy onto inside receiver pipes.

Parallel rows of the troughs are aligned on a north-south axis to track the Sun from east to west, requiring no mechanical pointing mechanisms.

Thermal storage can enable electricity generation to continue several hours into the evening.

Trough systems are the simplest and least expensive of all CSP devices, and may eventually be competitive with fossil fuel energy.

Concentrating Parabolic Troughs

Jennifer Boyer
US DOE OCRWM

Geothermal and Nuclear Plants

In addition to solar thermal concentrators heat energy is also converted into electricity using geothermal and nuclear sources.

Both typically heat a fluid to produce steam that drives a turbine generators, although geothermal is also used to provide direct building heating.

While geothermal is generally limited to near-source locations with relatively low heat/power conversion efficiencies, nuclear is a substantial electricity generator for regional and national grids.

Geothermal sources currently account for about 5% of US renewable energy production (about 0.3% of US total energy).

Future growth is limited by a scarcity of sites with suitably high temperatures (225°F-600°F).

The largest production site (The Geysers north of San Francisco) provides about 1,000 MW, with smaller plants in California, Nevada, Oregon, Idaho, Arizona, and Utah.

US DOE-EERE

Geothermal power is limited to certain western US locations, and is presently not cost-competitive with fossil or nuclear due to lower energy and conversion efficiencies.

Geothermal Energy

Geothermal Energy Association

Low-to-moderate temperature geothermal water reservoirs (68°F-302°F) provide heat for direct use or electrical power in many parts of the world.

Moderate-temperature sites are most abundant and commonly use binary-cycle plants for electricity generation.

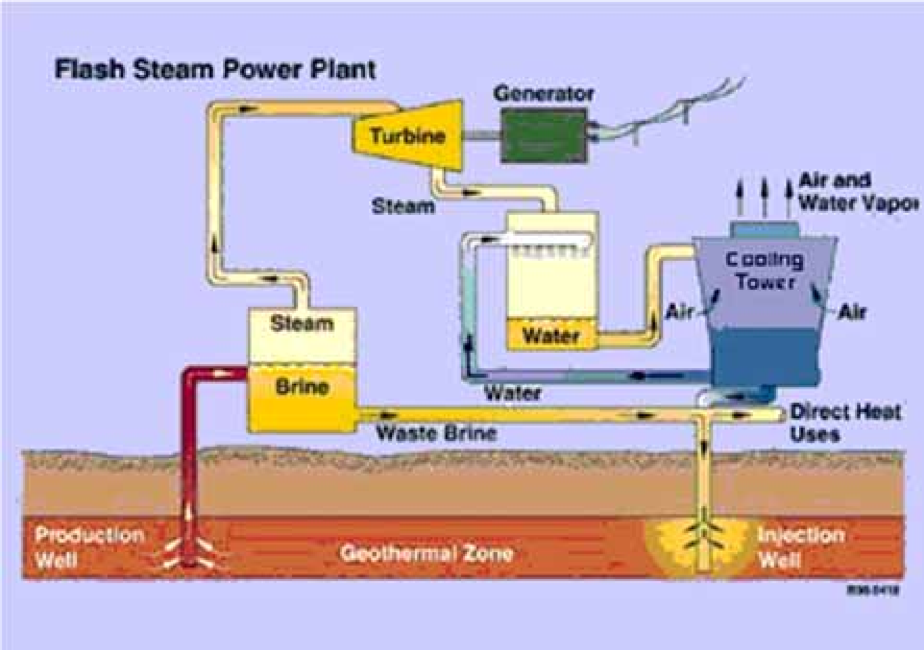
Technology advancements are needed to make these sources more cost-competitive with other options before geothermal energy becomes a more important part of the US energy infrastructure.

Harnessing the Earth's Heat

Geothermal Energy Association

Flash steam power plants convert high-temperature subterranean water (above 360ºF) to steam for electrical power generation.

The hot water is sprayed into a low-pressure tank, causing it to vaporize ("flash") and drive a generator.

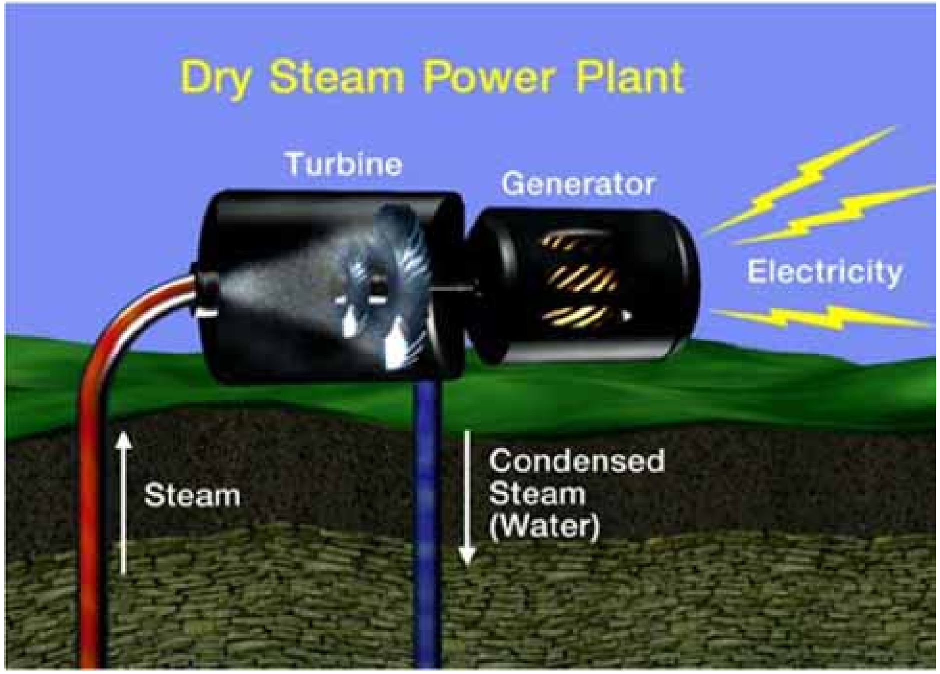


Flash Steam Power Plant

Dry steam power plants use hydrothermal fluids that are primarily steam which goes directly into a turbine to drive a generator.

This is the technology used at The Geysers plant in northern California (the world's largest single geothermal power operation).

Geothermal Energy Association



Dry Steam Power Plant

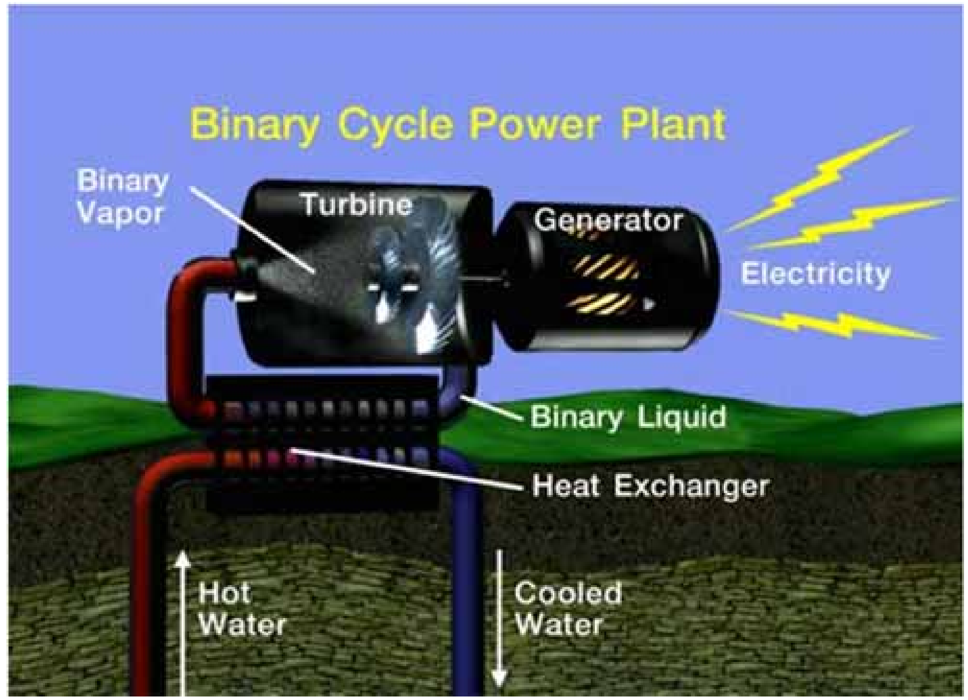
Binary-cycle plants use moderate-temperature water (below 400ºF).

Energy is extracted from the water by a second ("binary") fluid with a much lower boiling point than water in a heat exchanger.

The vaporization (flash) of the binary fluid drives a turbine.

Most future geothermal plants will be binary types.

Geothermal Energy Association



Binary-Cycle Power Plant

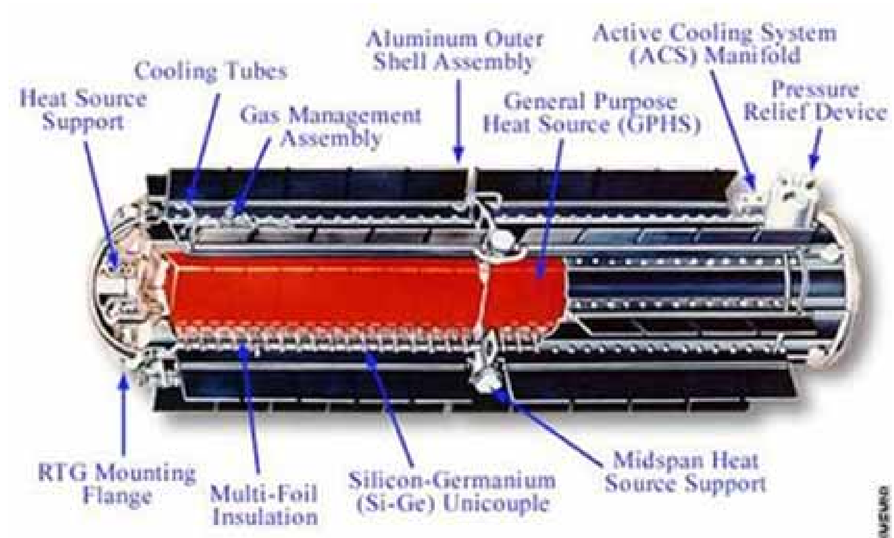
The radioactive decay of certain isotopes (or “radio nuclides”) releases heat that can be used to generate electricity or applied directly.

Tomorrow Bulletin

Nuclear Power Plant

Nuclear fission reactors split nuclei of heavy atoms such as uranium to produce commercial quantities of electricity.

NASA



Radioisotopic Thermal Generator

Radioisotope thermal generators (RTGs) use the decay of plutonium-238 to produce much lower heat energy levels for small-scale uses such as space applications.

Renewed international interest in nuclear power is being motivated by increasing oil prices, improvements in plant safety design, and concerns about fossil fuel greenhouse emissions.

One ton of uranium produces about the same amount of energy as 3 millions tons of coal or 12 million barrels of oil.

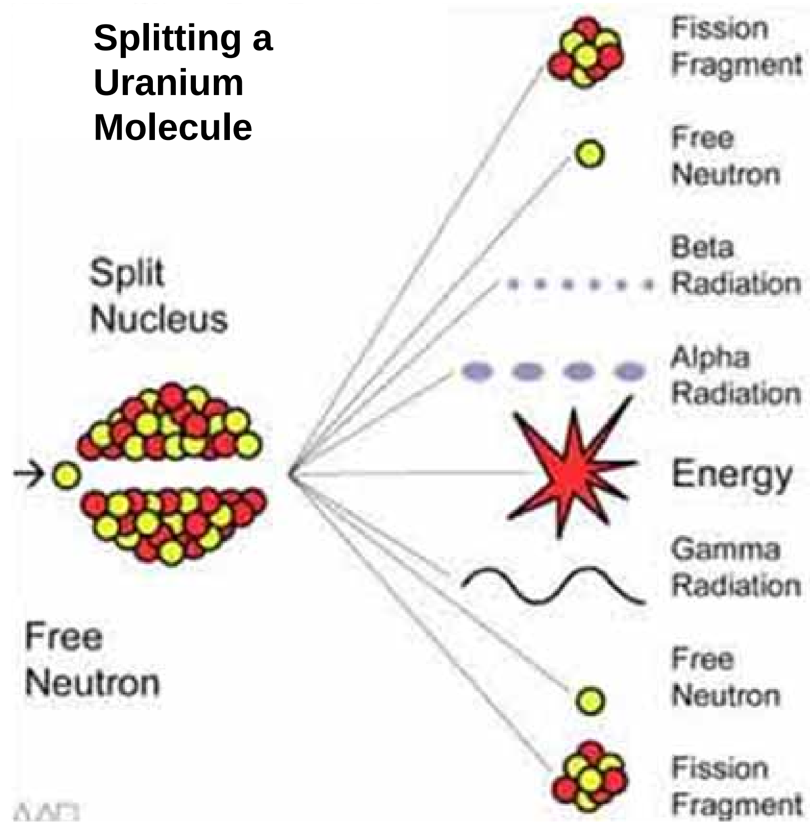
Uranium and plutonium are abundant in the Earth's crust, and are relatively inexpensive.

Stephan Kuehn

Nuclear Reactors

Kansas Energy Education Foundation

Splitting a Uranium Molecule



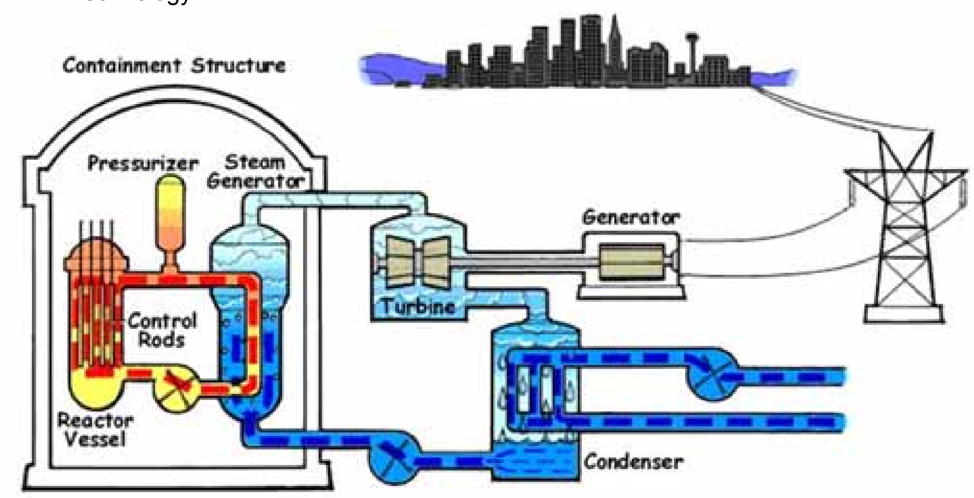
Nuclear fission is a controlled steady-state reaction where large fissile atomic nuclei divide into two or three more nuclei when struck by a neutron, releasing heat in the process.

Fission rates are not capable of reaching levels sufficient to trigger nuclear explosions because the commercial grade of the fuel used is not high enough.C

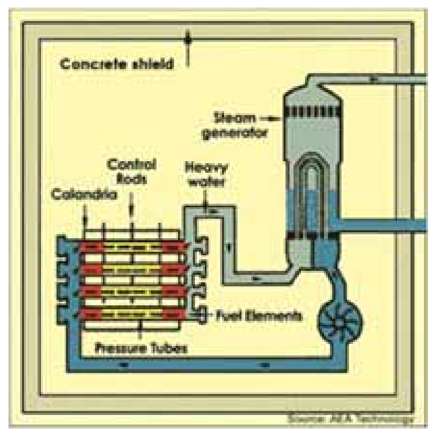
Light water moderated reactors (LWRs) use ordinary water to moderate and cool the nuclear reactions.

Graphite moderated reactors and heavy water reactors are more thermally efficient and can use lower grade uranium fuel mixes (about 0.72% uranium-235 and the rest uranium-238).

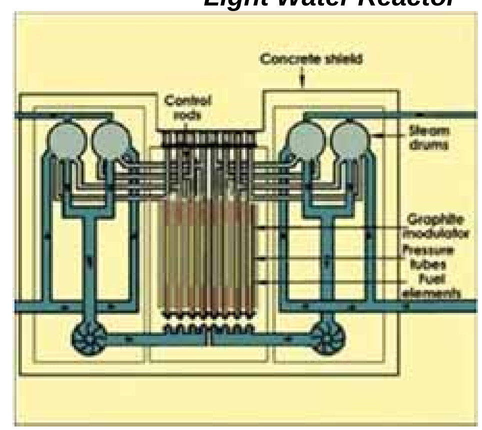
US Nuclear Regulatory Commission
AEA Technology



Light Water Reactor



Graphite Moderated Reactor

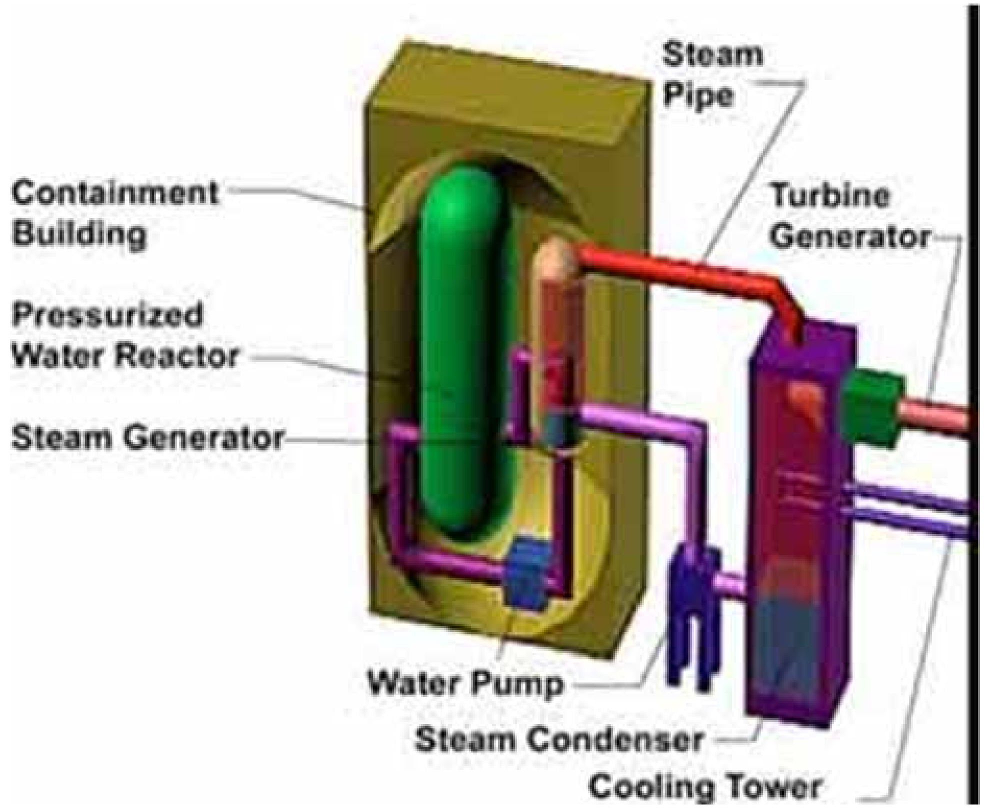


Heavy Water Reactor

Most nuclear reactors use pressurized or boiling water steam systems to produce electrical power.

Pressurized water reactors (PWRs) are most prevalent, and are generally considered to be safest for large-scale use.

Boiling water reactors (BWRs) operate under slightly lower pressure and have higher thermal efficiency, but can require more maintenance to prevent water leaks.



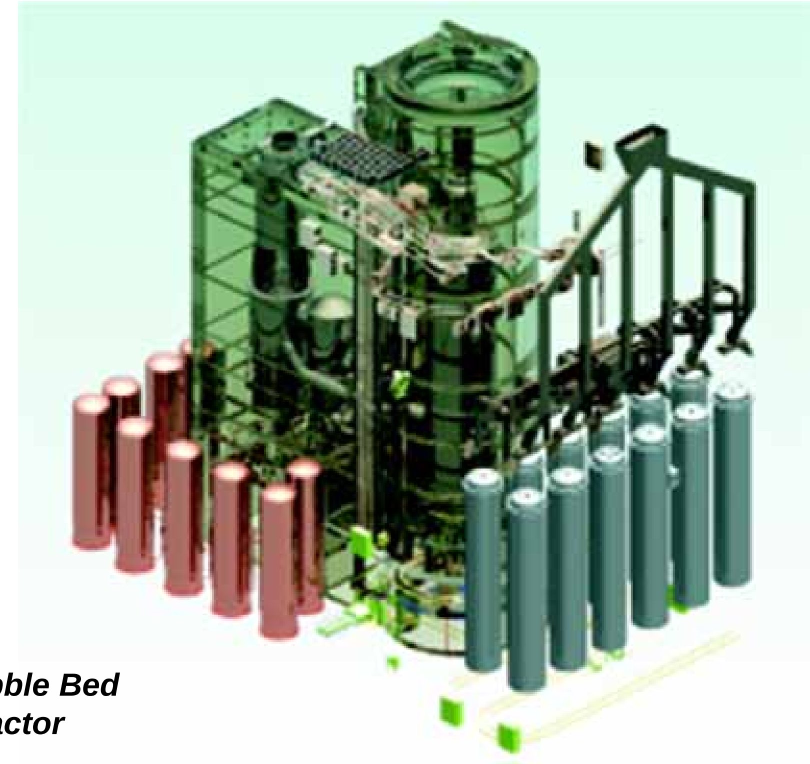
Pressurized Water Reactor Steam Supply System

Wikipedia Commons

Graphite pebbles containing nuclear fuel in ceramic form are self-controlling because as the reactor gets hotter, the energy spectrum of neutrons released by fission are randomized by the Doppler effect. As the fuel heats, the reaction rate lowers the fuel temperature, placing a natural limit on power produced without mechanical aids. As a result, a containment failure would release at most only a 0.02 in (0.5 mm) sphere of radioactive material.

ESI Africa

South Africa seeks a global role in next-generation nuclear technology and is constructing an advanced pebble bed reactor demonstration plant near Pretoria, and may build many more throughout the country. China currently has the only operational plant of this type, an experimental model in Beijing, and also plans to build several more.



Pebble Bed Reactor

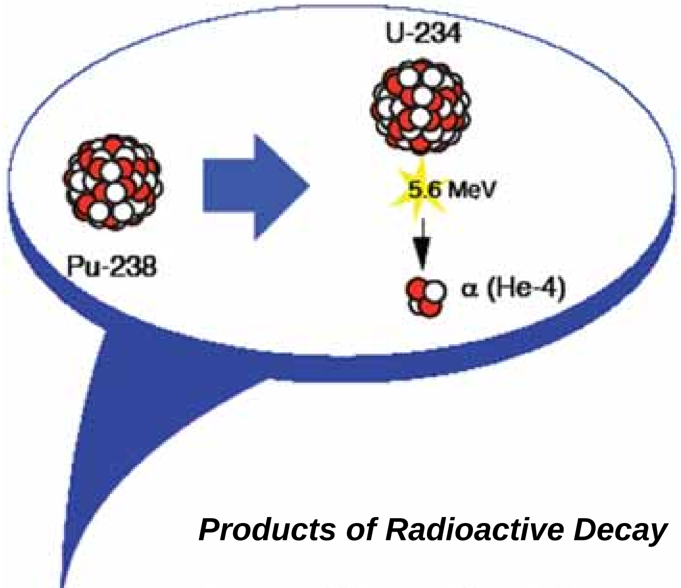
Advanced Pebble Bed Reactor

NASA / STAIF

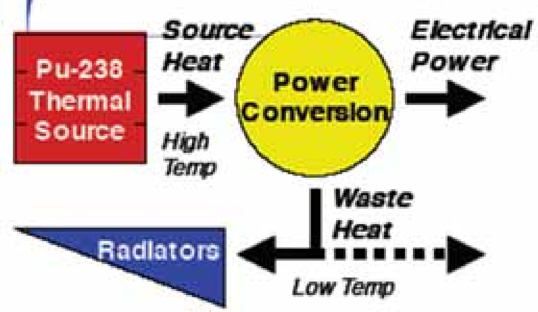
Radioisotopic thermal generators (RTGs) are principally used in space applications for heat and power.

Heat produced from the decay of plutonium-238 is converted to electricity through either a passive thermoelectric or dynamic nuclear generator process.

The process heat is often used for thermal control of spacecraft subsystems in cold extraterrestrial environments.



Products of Radioactive Decay

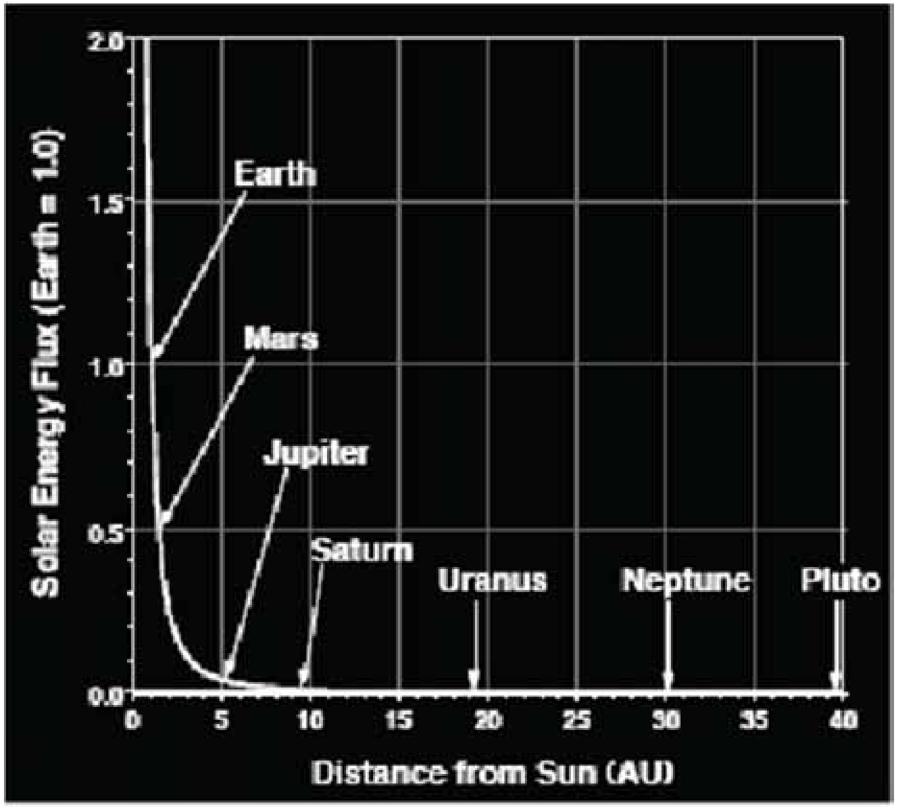


Radioisotopic Thermal Generators

NASA / STAIF

RTGs offer a variety of advantages for space uses:

- **They provide steady power regardless of distance and orientation relative to the Sun.**
- **They operate in shadowed and heavily clouded regions/locations such as in craters and thick atmospheres.**
- **They function in extreme temperature and radiation environments.**
- **They can be reliable over long periods of time (tens of years or more).**



Solar Energy Flux as a Function of Distance from the Sun (AU)

RTGs have proven effective on many unmanned spacecrafts.

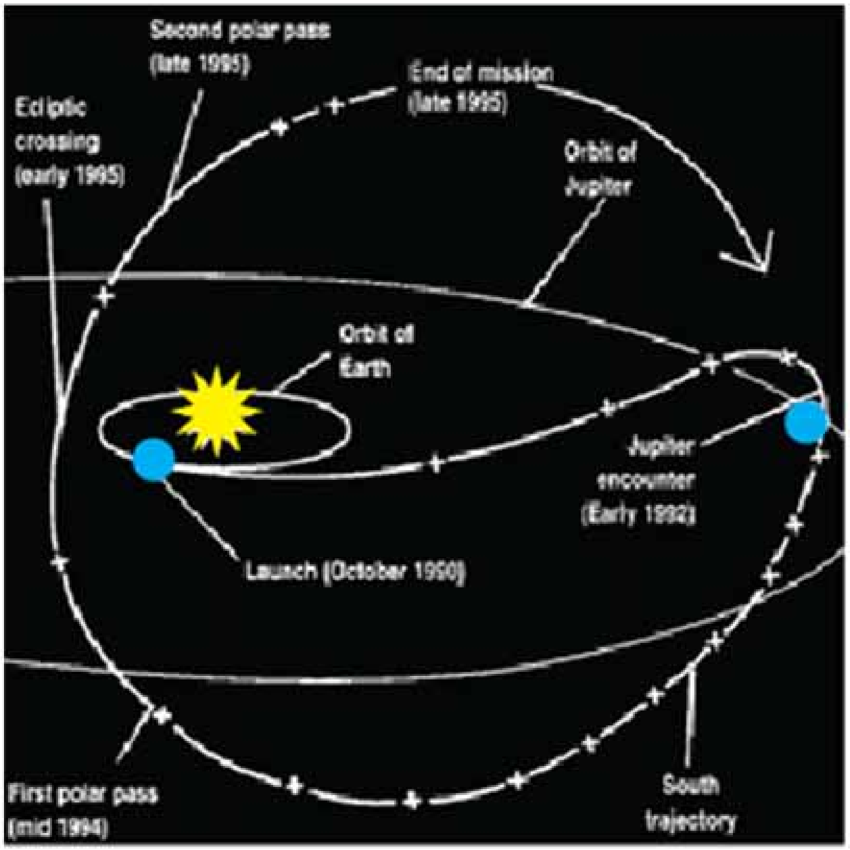
- **They powered scientific experiments left on the Moon by Apollo crews.**
- **They were used on Voyager 1 and 2 spacecraft that traveled beyond Uranus and Neptune (70 times further from the Sun than Earth where there is little solar energy).**
- **They powered Pioneer 10 and 11 spacecraft that traveled past Jupiter, Saturn and Pluto, the Ulysses spacecraft that went into orbit around the Sun, and Cassini that explored Saturn's rings and moons.**

NASA

Cassini mission equipment included three RTGs providing a total of 850 watts of power.

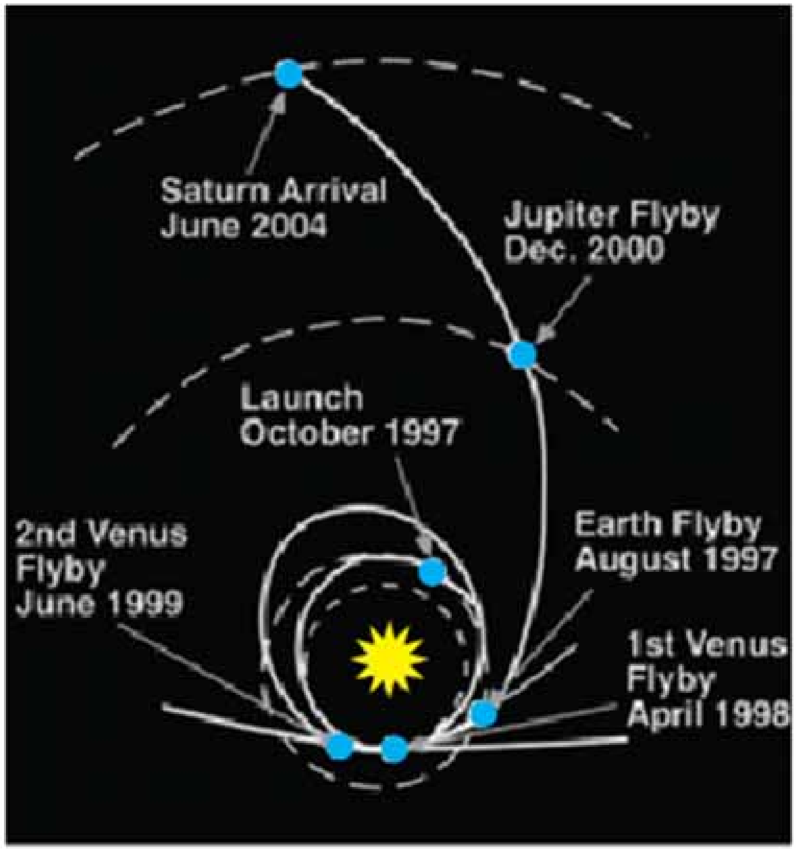
Cassini RTG Inspection Before Launch

US Department of Energy



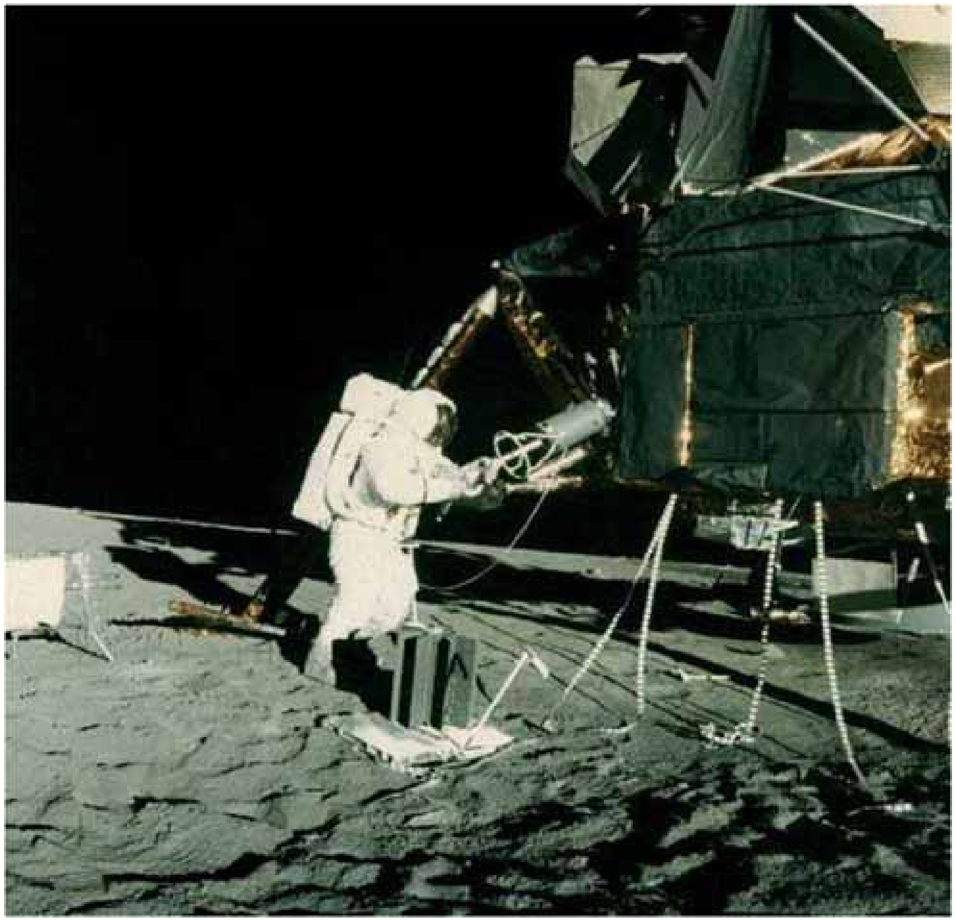
Ulysses Jupiter Spacecraft Trajectory

US Department of Energy



Cassini Saturn Spacecraft Trajectory

NASA



RTGs have been indispensable parts of US and international space programs.

They have been used in more than 25 missions that have orbited Earth, travelled to other planets and their moons, and explored surfaces of Earth's Moon on rovers.

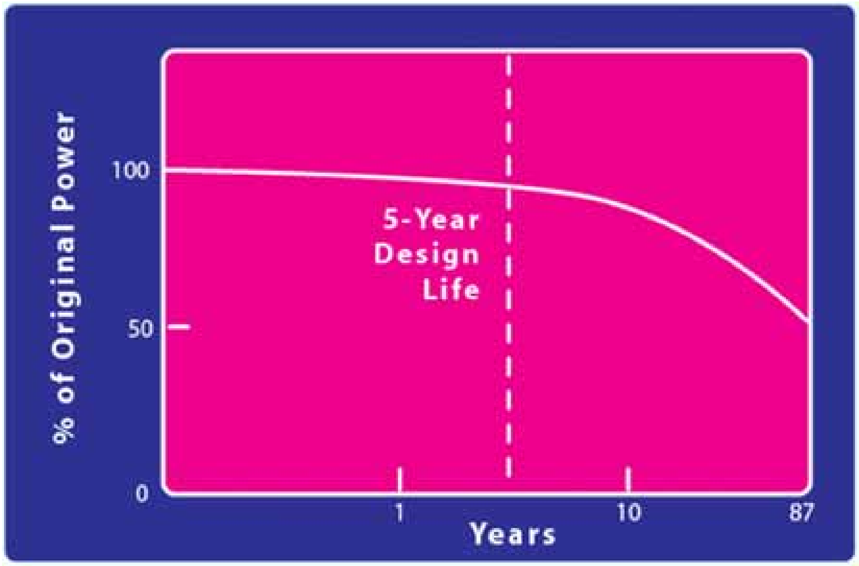
One lunar RTG produced 75 watts of power on a lunar experiment package for nearly 8 years.

Apollo 12: Alan Bean Loading a Plutonium Heat Source into an RTG

RTGs using plutonium-238 produce relatively low penetration alpha radiation, which is only harmful if product dust is inhaled or digested.

The 87.74 year half-life of plutonium-238 is very short in contrast with the 24,110 half-life of plutonium-239 used in nuclear weapons and reactors. As a consequence of the shorter half-life, Pu-238 is about 275 times more toxic by weight.

US Department of Energy



87 Year Half-Life of Pu-238

Radiation events are rare, but they do occur.

- **Six known accidents have involved RTG-powered spacecraft:**
  - **April 12, 1964: a failed US Transit-5BN-3 navigation satellite launch burned up upon re-entry near Madagascar with traces of Pu-238 detected.**
  - **May 21, 1968: a Nimbus B-1 weather satellite in an erratic trajectory was deliberately destroyed (its fuel container was recovered intact).**
  - **1969: two Soviet Cosmos missions containing RTG-powered rovers failed, releasing radioactivity. (Five other Soviet/Russian spacecraft failures between 1973 – 1993 carried nuclear reactors.)**
  - **April 1970: an Apollo 13 failure plunged a SNAP-27 RTG into the Pacific Ocean with its container intact.**
  - **November 1996: a Russian Mars 96 launch failed (2 RTGs are assumed to have survived re-entry).**

Nuclear fuel modules within RTGs must be designed to withstand a variety of accidents:

- **Fire**: Direct exposure to solid propellant fires such as might be encountered during a launch accident must not produce damage or nuclear fuel release.
- **Blast**: Fuel modules must be able to survive high temperatures associated with collisions with debris and atmospheric re-entry.
- **Earth Impact**: Modules must survive impacts at 120 mph (200 km/hr) (approximate top speed for an aeroshell falling to Earth) on sand, water, soil, or rock surfaces without release of fuel.
- **Water Immersion**: Fuel capsules must be able to resist long-term corrosive effects of seawater in the event that ocean recovery is not possible.

RTG Risks in Space Applications

RTGs have also been used in various terrestrial applications, ranging in size from heart pacemakers to power sources for remote lighthouses and navigation beacons.

It is estimated that the former Soviet Union may have discarded as many as 1,000 RTGs that have exhausted their engineered life spans and now exist in hazardous dilapidated and vandalized conditions.

Finland Regional Government

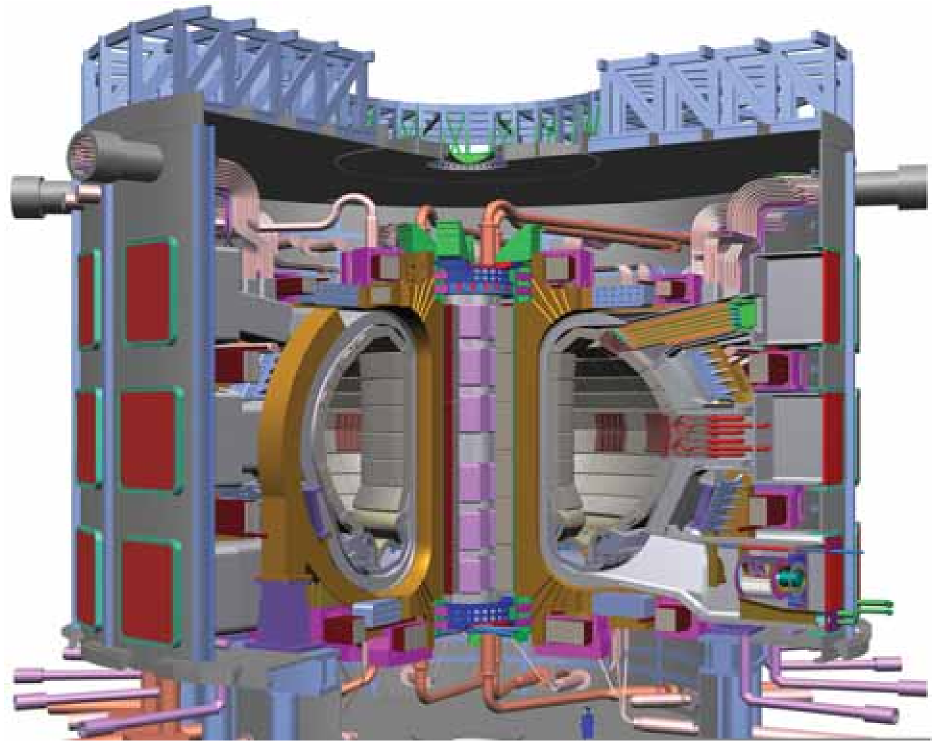
Discarded Soviet RTGs

An "International Thermonuclear Experimental Reactor" (ITER) is being developed to determine potentials for fusion power through a partnership involving the EU, US, Japan, Russia, China, and India.

Construction is expected to require a decade, and there are no assurances that the venture will ever produce a commercial technology.

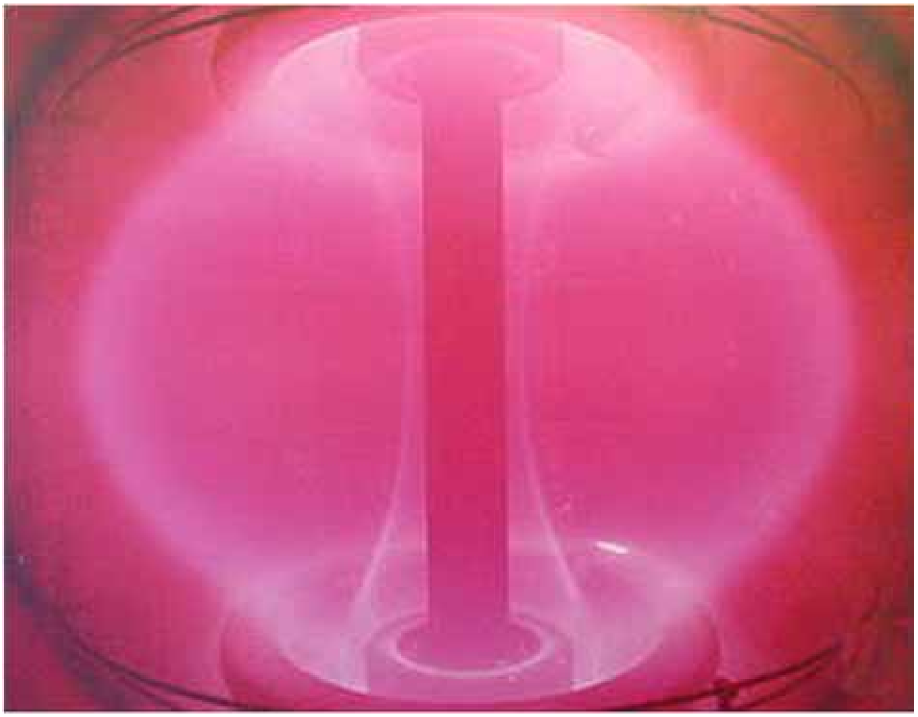
A potential advantage of nuclear fusion is that radioactive waste will be safe to handle in a relatively modest time scale (50 – 100 years) compared with many thousands of years for fission reactor wastes.

Fusion Energy for Future Generations



Planned International Thermonuclear Experimental Reactor Fusion Device in Cadarache, France.

BBC News



The largest previous experimental nuclear fusion device, the Joint European Torus in Colham, UK, heated plasma to a temperature of 300 million degrees and produce an output of 16 MW for only a few seconds. It consumed slightly more energy than it created.

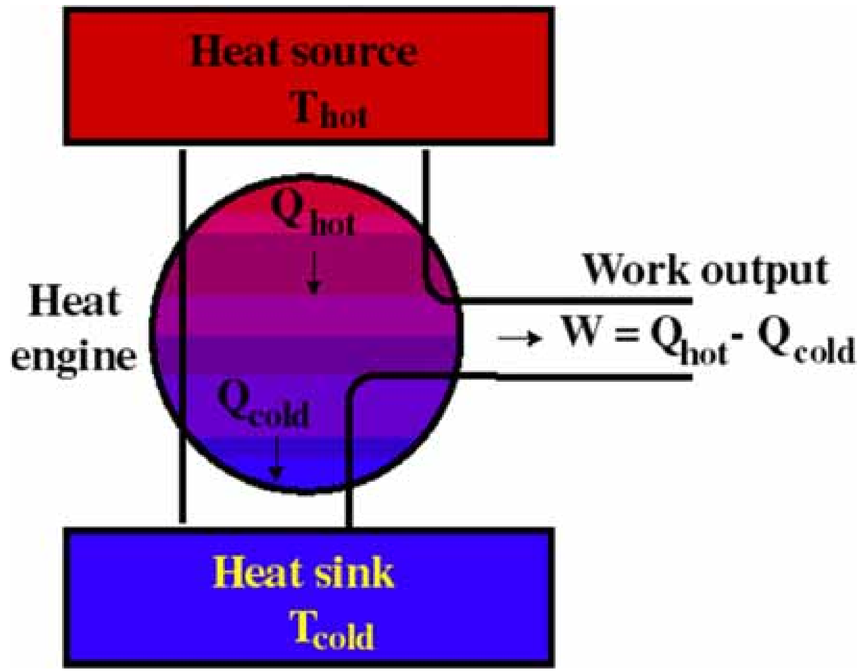
Experimental Nuclear Fusion Demonstration

Heat engines (including steam, gasoline, and diesel types) extract mechanical energy from a temperature difference between a hot source and cold body (heat sink).

As decreed by the Second Law of Thermodynamics, no known engine can convert all input heat energy into work. Efficiency is measured according to work output (W) = temperature gradient (Qhot – Qcold), where:

$$\text{Efficiency} = W/Q_{hot} = (Q_{hot}-Q_{cold})/Q_{hot}$$

University of Oregon



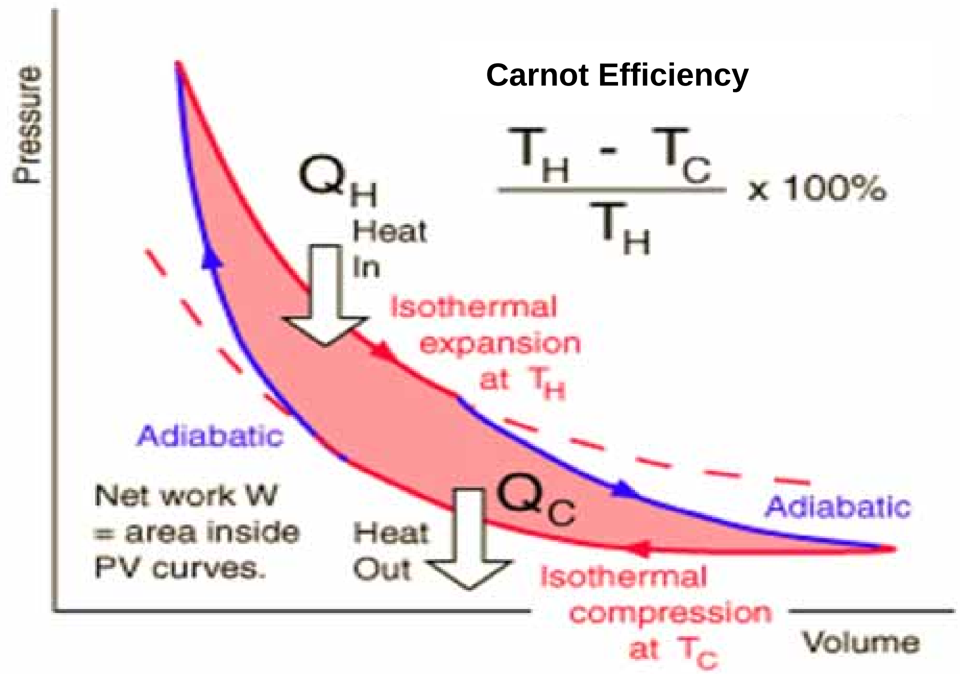
C.R. Nave

Heat engines operate in thermodynamic cycles that occur each time heat is converted to mechanical energy and back.

The same general principle applies to heat pumps such as refrigerators, but in reverse.

No heat engine can operate reversibly as a heat pump without putting more energy back in because energy conversion isn't 100% efficient.

Theoretical efficiency limits are set by a "Carnot" engine cycle, a perfect but impossible device.



A theoretical Carnot engine is an enclosed gas piston consisting of two basic reversable processes:

- *Adiabatic Compression (T_c – T_H)*
- *Isothermic expansion of the gas in contact with heat from T_h.*

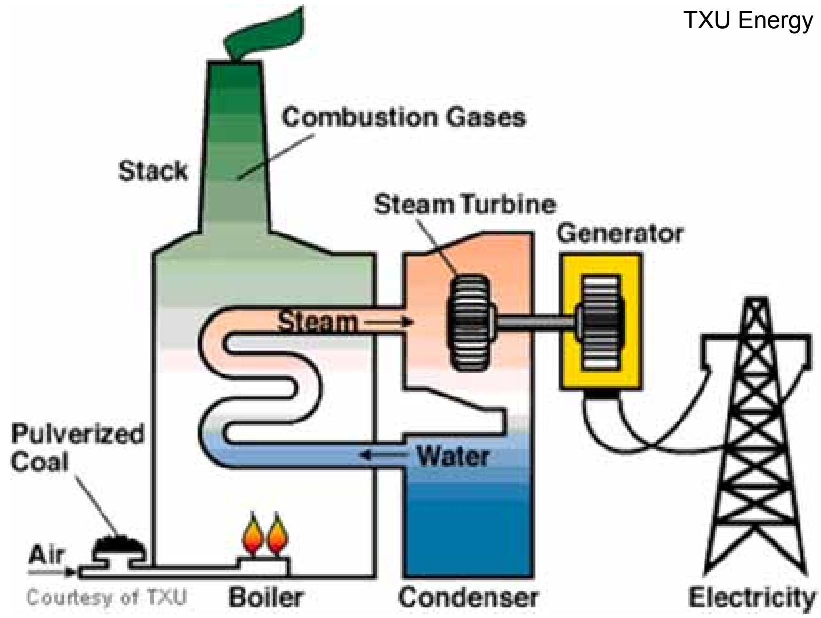
The Carnot Cycle

Steam turbines operate somewhat like water turbines, using thermodynamic force rather than water pressure for mechanical energy.

Turbines have replaced steam engines to drive generators that produce the majority of all US and world electricity.

Thermal conversion efficiencies range from 20-40% depending upon types and applications.

TXU Energy

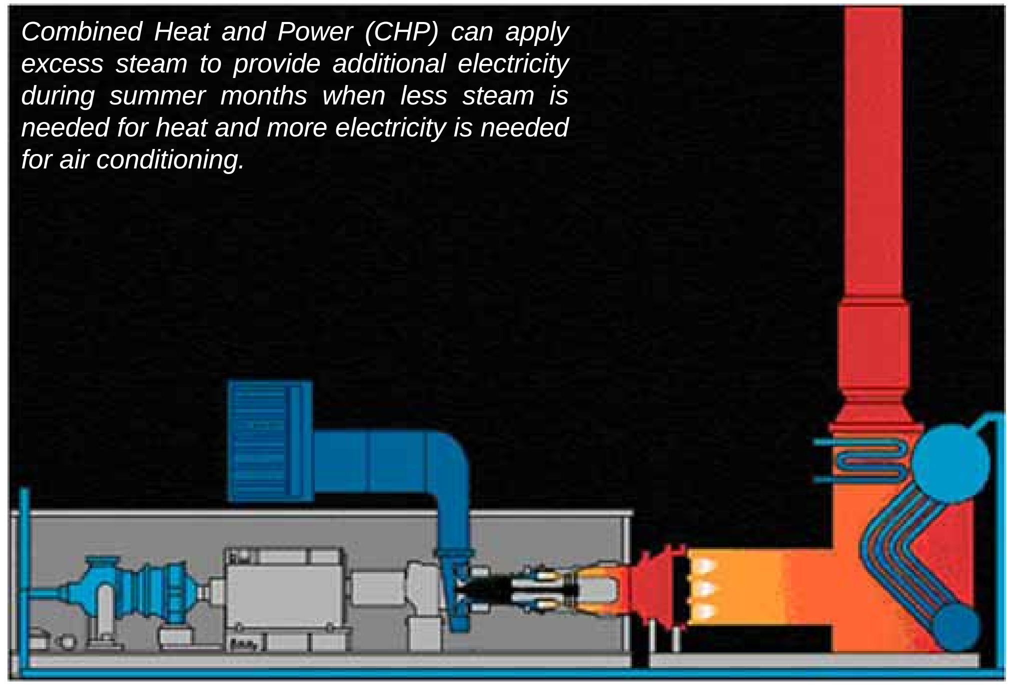


Steam turbines operate on a "Brayton" cycle, using stationary sets of blades (called nozzles) and moving sets of adjacent blades (impellers) to produce kinetic energy.

High pressure in front of the impeller and low temperature behind provides a pressure and thermal gradient.

Exhaust heat can be recycled back to the burners to produce more power or used for other purposes.

Consumer Energy Council of America

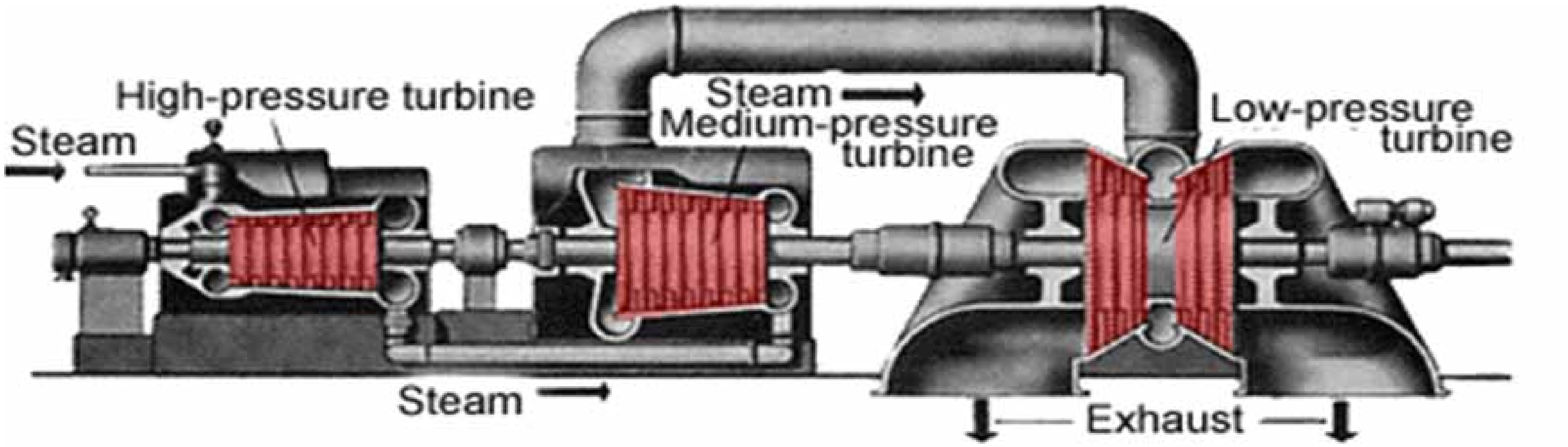


Combined Heat and Power (CHP) can apply excess steam to provide additional electricity during summer months when less steam is needed for heat and more electricity is needed for air conditioning.

About 80% of all bulk utility-scale fossil fuel plants, and all nuclear plants, use turbines to produce electricity and apply waste exhaust heat for supplementary power, thermal processes and other applications.

Combined Cycle Heat and Power Turbines

Helmut Huetten



Steam cools and expands as it passes through each impeller, requiring larger, conical-shaped impellers in sequence. Coupled with a generator and fired by a nuclear reactor, they can produce large amounts of electricity, exceeding 1,000 MW.

After passage through the system, condensed water can be returned to a boiler by a pump (a special advantage in nuclear plants where radioactive thermal water is clearly separated from cooling water).

Coupling of Steam Turbines

Siemens

Dal Engineering Group

Most large power plant steam turbine applications use condensing types where steam exhausted by each stage passes through a series of condensers to optimize thermal efficiency.

Condensing Steam Turbines

Non-condensing (back pressure) steam turbines are used in combination with condensing types or as separate units where large amounts of low-pressure steam are available.

These systems are usually smaller and less efficient than condensing types (15-35% efficiencies) but are also less expensive.

Back pressure steam turbines are often used in connection with industrial processes that have a need for low- or medium- pressure steam.

Global Power Resources

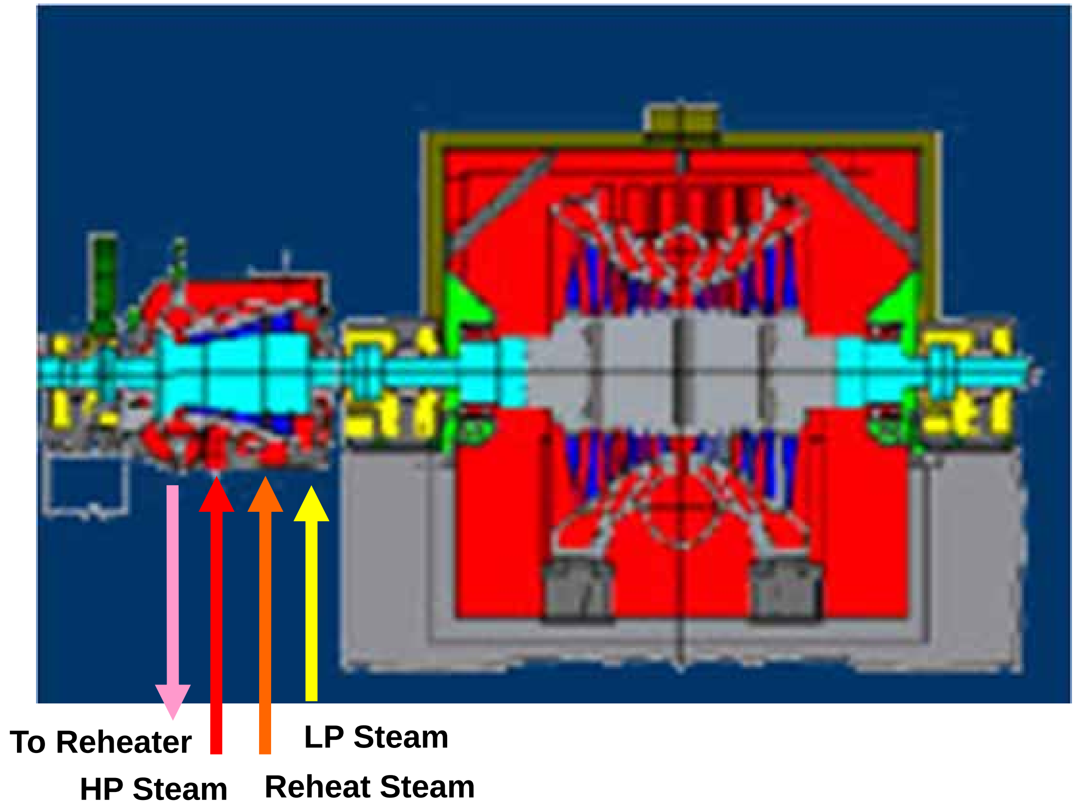
Non-Condensing Steam Turbines

Turbine energy conversion is most efficient when pressure gradients from input through output is as high as possible.

This is an advantage for nuclear sources, and a disadvantage for geothermal.

Many utility-scale applications return low-pressure steam from the outlet back into the boiler to conserve heat energy (a form of energy recycling).

Ansaldo Energia

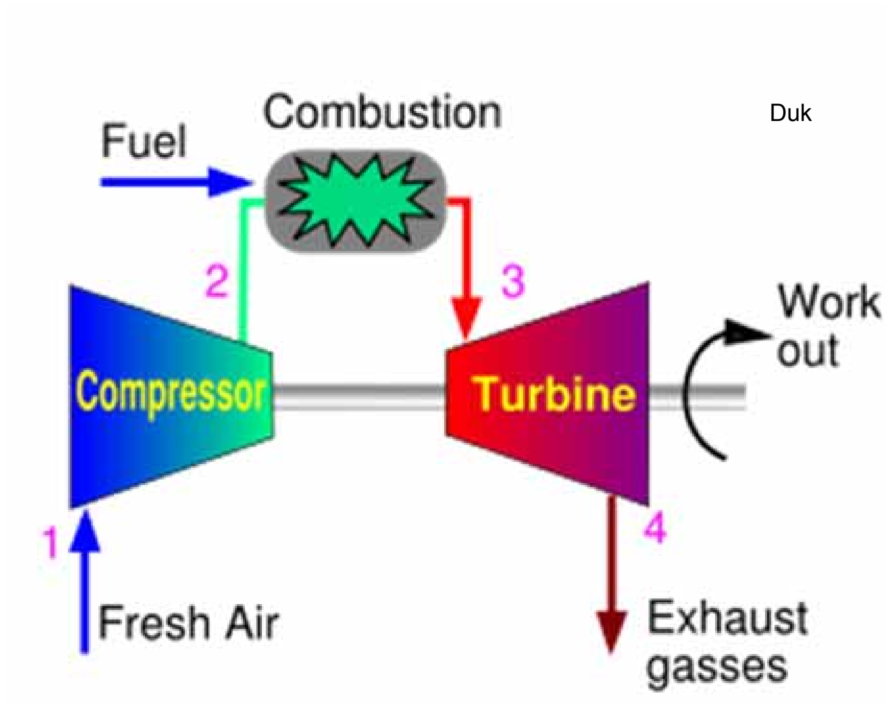


Reheat Steam Turbines

Gas turbines (or combustion turbines) are rotary heat engines that extract energy from a low of gas.

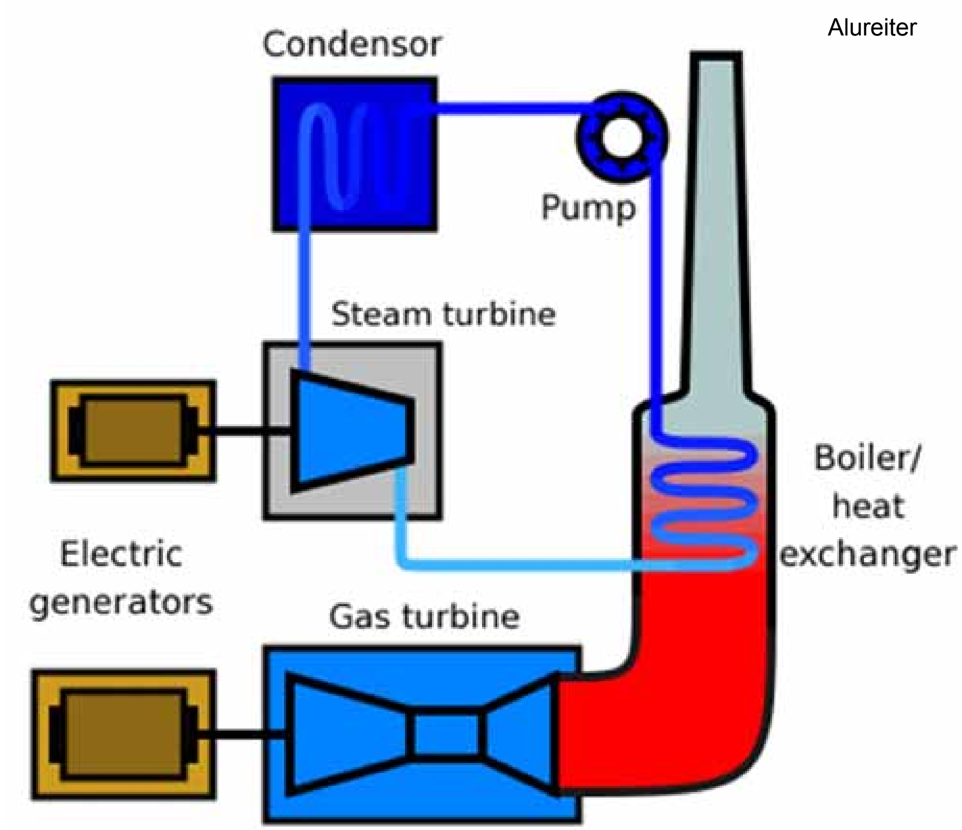
They operate using a constant pressure Brayton (or Joule) cycle and have three types of components:

- Compressors intake and pressurize ambient air.
- Burners (or combustion chambers) use fuel to heat air to a constant pressure.
- Expansion turbines extract heat energy to produce work output and exhaust (or recycle) excess heat.



Gas turbines are often used in combined-cycle operations with high-pressure steam turbines to recycle exhaust heat. This improves thermal power efficiencies and provides cogeneration of heat and electricity.

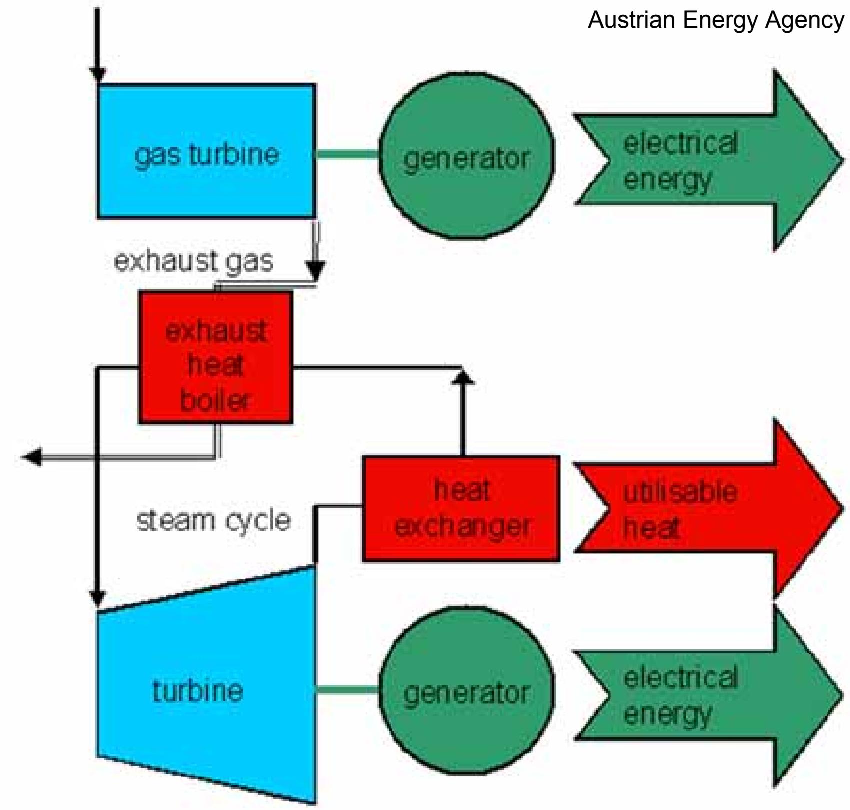
Combined heat and power (CHP) installations can provide efficiencies up to 70-80%, while simple-cycle operations where a single turbine is used for power only have typical efficiencies of about 40%.



Combined Cycle Gas/Steam Turbines

Simple-cycle, combined-cycle, and combination gas-steam turbine installations each have special advantages for certain applications:

- **Simple-cycle gas turbines for power only are less expensive than CHP and are most useful where power needs are limited.**
- **Combined-cycle gas turbines using single stand-alone units can be installed more rapidly and less expensively than complex gas-steam turbine configurations.**
- **Combination gas-steam turbines are most efficient and applicable for bulk utility cogeneration plants.**



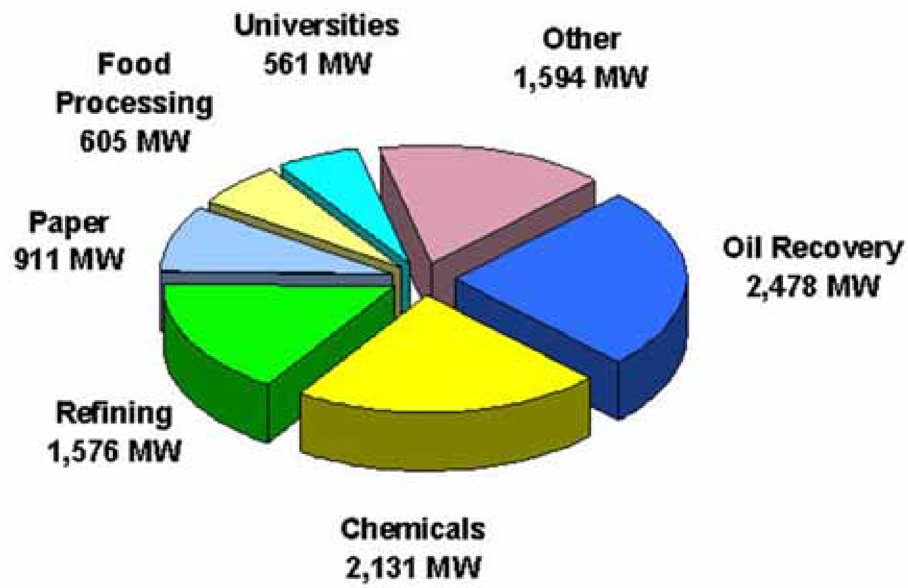
Gas turbines can provide power and heat in stand-alone applications, or can be combined with steam turbines for greater power and efficiencies.

Gas Turbine Applications

Stand-alone simple-cycle gas turbines offer versatility for many industrial, institutional, and commercial uses:

- **Steel industries use them to drive air compressors for blast furnaces, and process industries use them for chemical, paper, and other material production.**
- **Large commercial and institutional organizations use them for CHP, including space/water heating and to drive air-conditioning and refrigeration systems.**
- **Small turbines drive compressors for natural gas pipelines and petrochemical refinery processes.**

Energy and Environmental Analysis, Inc.



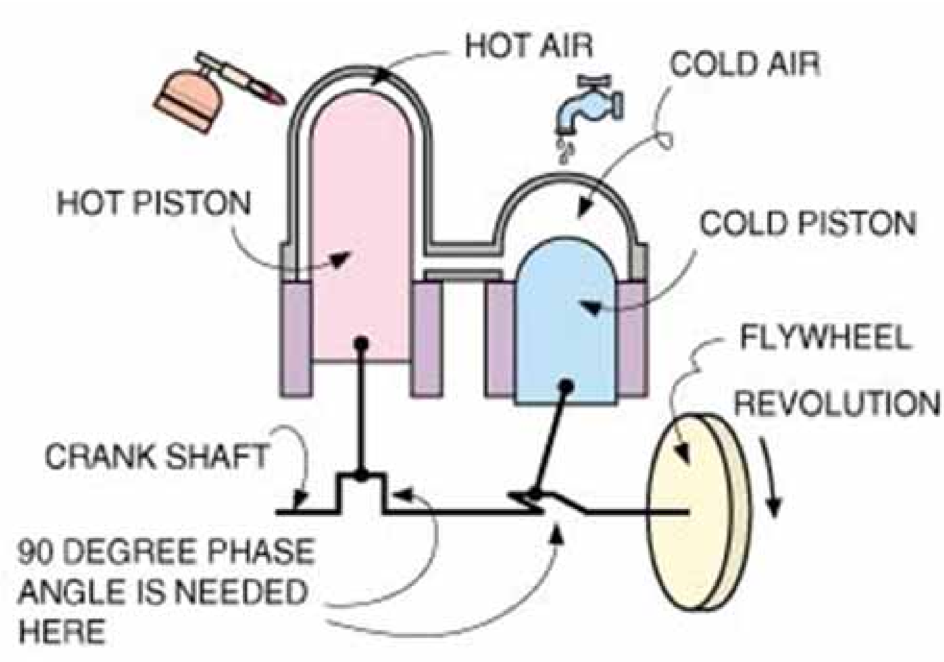
Simple-cycle gas turbine-based CHP systems are most prevalent in smaller installations (typically less than 40 MW).

Existing Simple-Cycle Gas CHP Capacities at 359 US Sites

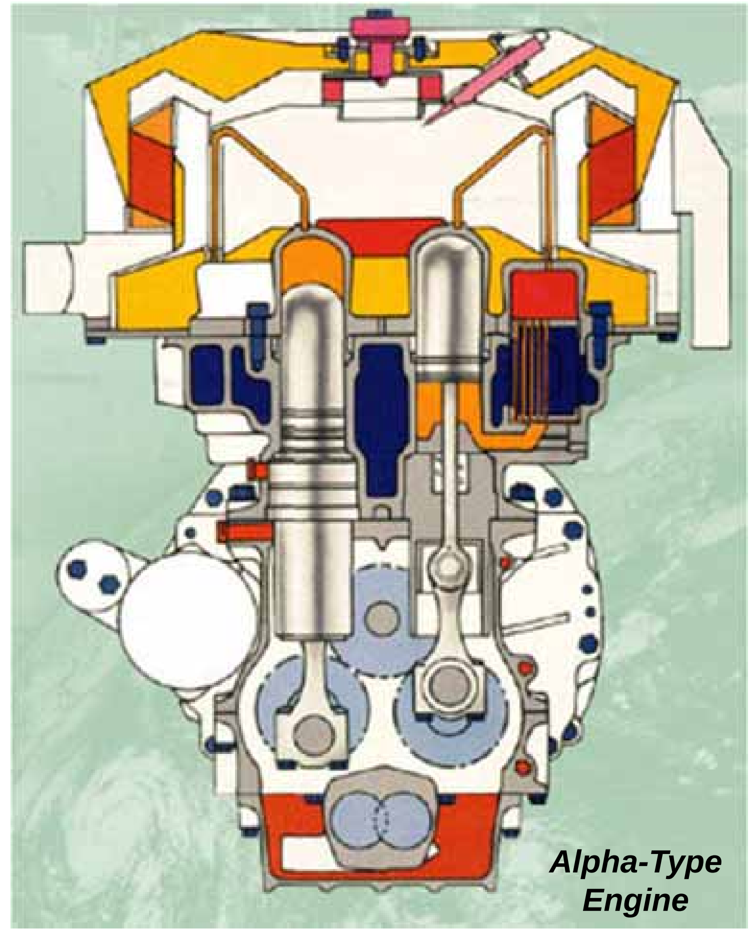
Stirling cycle engines are high-efficiency piston-operated devices that use temperature gradients to produce relatively low electrical power levels (up to a few kW).

This two-piston Alpha-type version incorporates a crankshaft and flywheel drive mechanism to convert thermal expansion and contraction of a working gas contained in the engine to mechanical energy. Other design approaches are also being developed.

National Maritime Research Institute of Japan



PES Network



Many Stirling cycle engines remain in experimental development stages.

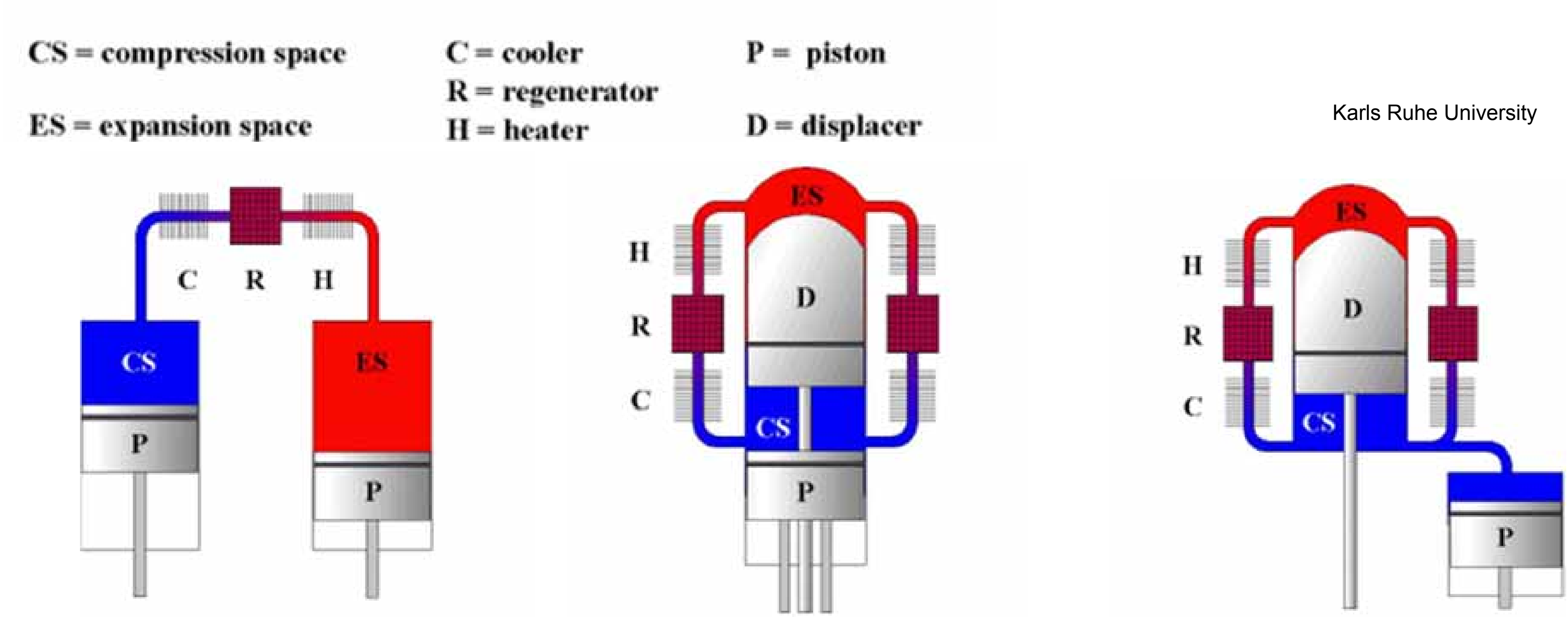
They typically use a contained working gas (often helium or hydrogen) which is rapidly heated and cooled, causing expansion to drive one or two pistons.

A “regenerator” (wire mesh) positioned between cold and hot regions stores thermal energy between cycles.

The same process is applied in reverse to convert mechanical energy into heat or cold using Stirling heat pumps and refrigerators.

Stirling Cycle Engines

Karls Ruhe University



The Alpha engine contains two pistons in separate cylinders (one hot and one cold), each driven by different heat exchangers. It has a very high power-to-volume ratio, but presents some technical problems associated with the hot piston seals.

The Beta engine has a single piston within the same cylinder and on a common shaft with a displacer piston that functions only to move working gas between hot and cold heat exchangers. It is usually combined with a flywheel, and avoids a need for moving seals.

The Gamma engine has a single power piston and displacer piston mounted in separate adjacent cylinders connected to the same flywheel. Gas flows freely between the two cylinders within a single body. This configuration is the simplest, but has a lower compression.

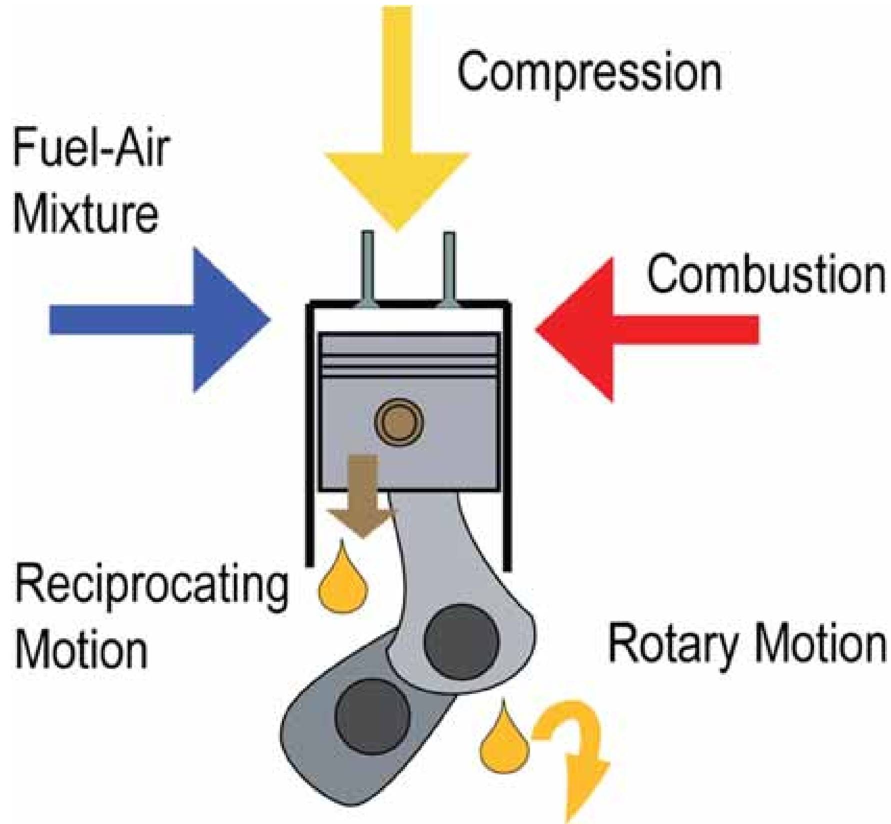
Representative Stirling Engine Types

Larry Bell

The term “internal combustion engine” can be applied to gas turbines but is usually used in reference to reciprocating piston engines that run on petroleum hydrocarbons.

Common fuels are diesel, gasoline, liquefied petroleum gas (LPG) and biofuels.

While some engines can use hydrogen, special modifications must be made to a cylinder block, head, and gasket to safely seal in the explosive gas.



Internal Combustion Engines

Matthia Sebulke
Madgasters Photos

Diesel and Gasoline Vehicles

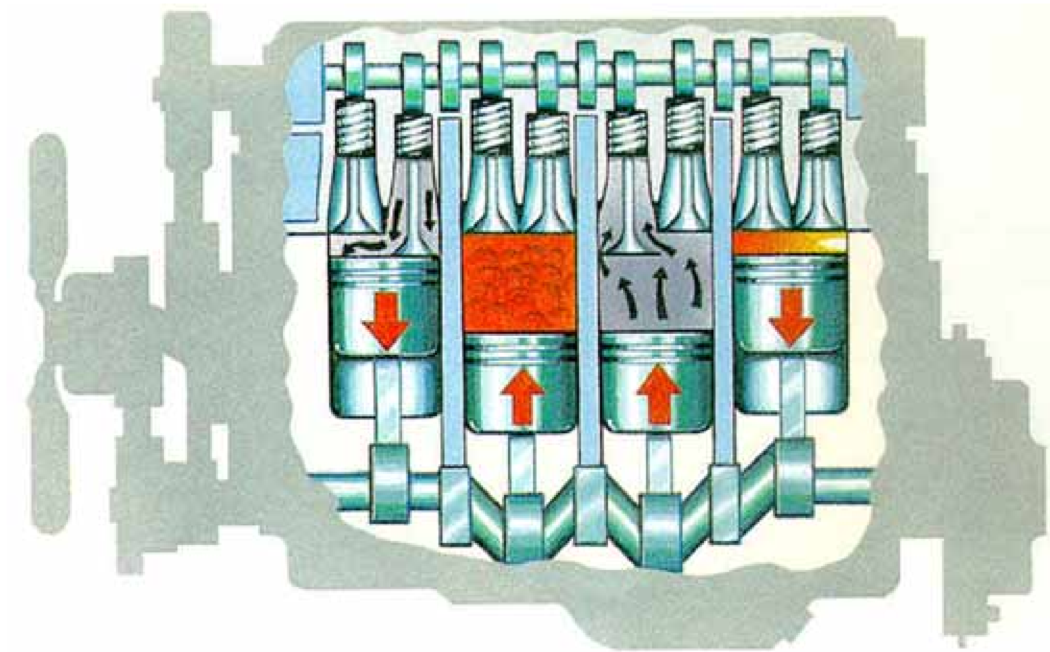
Although engines that use gases for fuel are properly called gas engines and those that use liquid hydrocarbons are called oil engines, gasoline engines are often referred to as gas engines also.

Diesel engines are generally heavier, noisier, and more powerful than gasoline and often more fuel-efficient.

Gasoline engines usually tend to be cleaner burning than diesel, producing fewer particulate emissions.

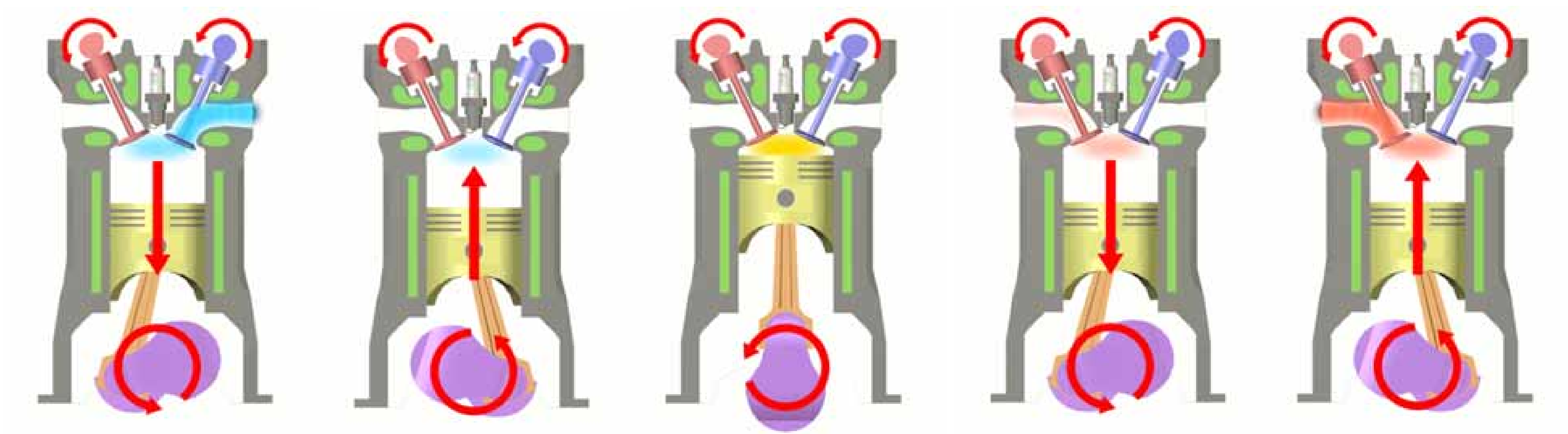
NCERT India

Diesel engines are similar to gasoline engines except that air alone enters on the intake stroke and the fuel is injected or sprayed into the cylinder at the end of the compression stroke to be ignited by heat rather than a spark.



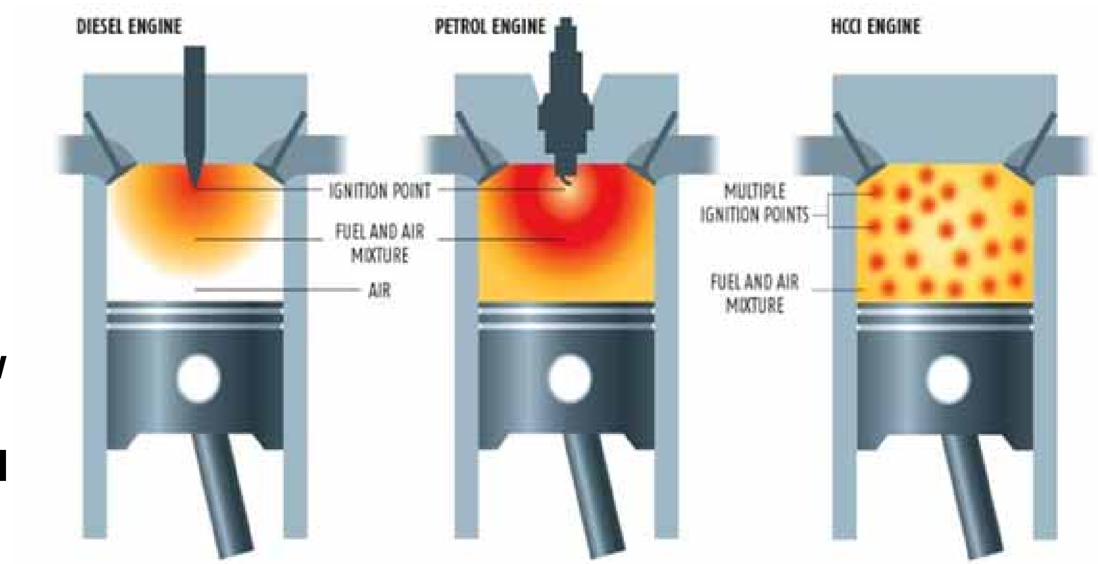
Diesel Engines

Eric Pierce



Sequences in a Four-Stroke Gasoline Engine

Popular Mechanics



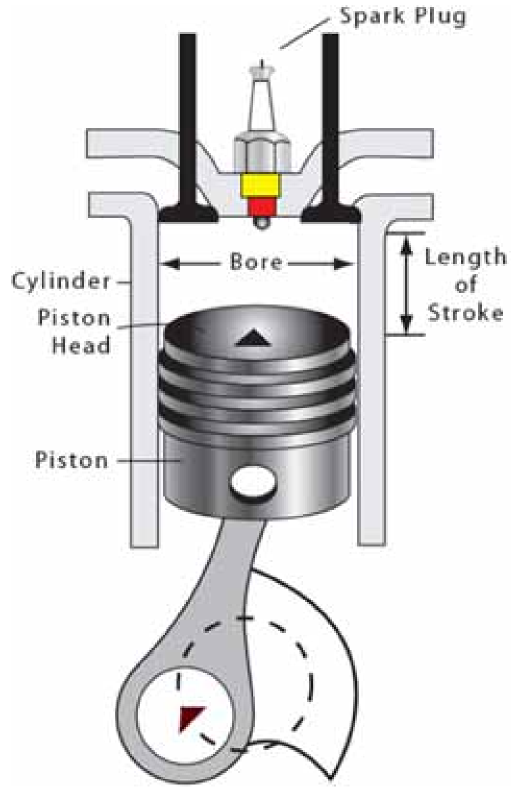
Homogeneous charge compression ignition (HCCI) engines are an emerging new technology that combines features of gasoline electrical and diesel compression types.

In HCCI and petrol engines, fuel and air are mixed before combustion, preventing soot emissions associated with diesel engines. Only HCCI engines have multiple ignition points throughout the chamber which enable lean combustion at low temperatures to offer higher efficiency and avoid formation of nitrogen oxides (NOX). Ignition relies upon heat from compression rather than a spark.

Hawaii Community College

Having more cylinders provides advantages and disadvantages:

- **More cylinders can provide larger displacements with smaller reciprocating mass, causing an engine to run smoother.**
- **Larger displacement vs. mass can enable more fuel to be combusted for more power (more strokes per given time).**
- **More cylinders can add weight and friction (pistons rubbing against cylinders) to reduce efficiencies.**



An engine's total piston displacement is determined by multiplying the area of the piston head (diameter of the cylinder bore) by the height of the cylinder (length of stroke).

Total engine displacement (size) is the number of cylinders times the displacement of one of the pistons measured in liters or cubic inches.

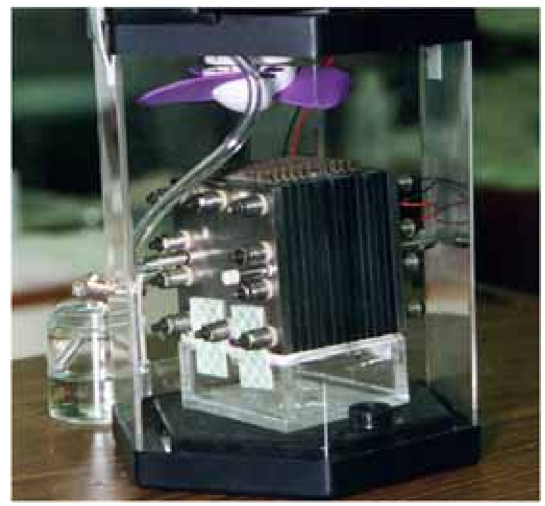
Engine Capacity/Volume

Portable generators running on natural gas, propane, gasoline, and diesel fuels provide electricity in off-grid locations and also provide backup power.

Units range in size from almost 1-30 kW for homes, shops, and offices to more than 2,500 kW for large office complexes, factories, and power stations.

Watt Power Canada

Diesel Generator



Transportation, Conversion, and Storage

FUEL AND POWER TECHNOLOGIES

CONVERSION, STORAGE AND DELIVERY

Various energy conversion and storage devices differ significantly in capacities to generate and deliver power efficiently:

- **Energy densities of fuels influence internal combustion processes.**
- **Effectiveness of electro-chemical conversion influences operations of batteries and fuel cells.**
- **The amount of "free energy" that can be extracted to do work (vs. heat energy wasted) influences all systems.**

> ***Power is the rate at which work is done (e.g., kW hours or Joules/second).***
> ***Energy density is the amount of energy stored in a unit weight or volume (e.g., W hours/kg or W hours/liter).***

Colorado State U.
Milica Sekulic

Alan D.
US DOE-EERIE

For internal combustion engines, fuel efficiency is essentially the same as thermal efficiency.

Unlike batteries which store chemical energy, fuel cells require continuous replenishment of fuel and reactants.

For internal combustion engines, the fuel's conversion energy content ("heat of combustion") is the amount of heat produced when it is burned.

Fuel efficiency refers to either thermal or fuel energy available that can be converted to kinetic energy or other work per unit inputs vs. outputs (such as miles per gallon).

Energy efficiency is similar to fuel efficiency, but measured in terms of heat (such as BTUs) or electricity (such as kWh).

Fuel Types	Heat Values			
	MJ/L	MJ/kg	BTU/Gal.[2]	Octane[3]
Gasoline	32.90	45.00	125,000	97-98
Diesel	40.90	63.47	147,000	N/A[4]
Gasohol[1]	28.06	43.54	120,900	93-94
Ethanol	19.59	30.40	84,400	129
Methanol	14.57	22.61	62,800	123
LPG	22.16	34.39	95,475	115

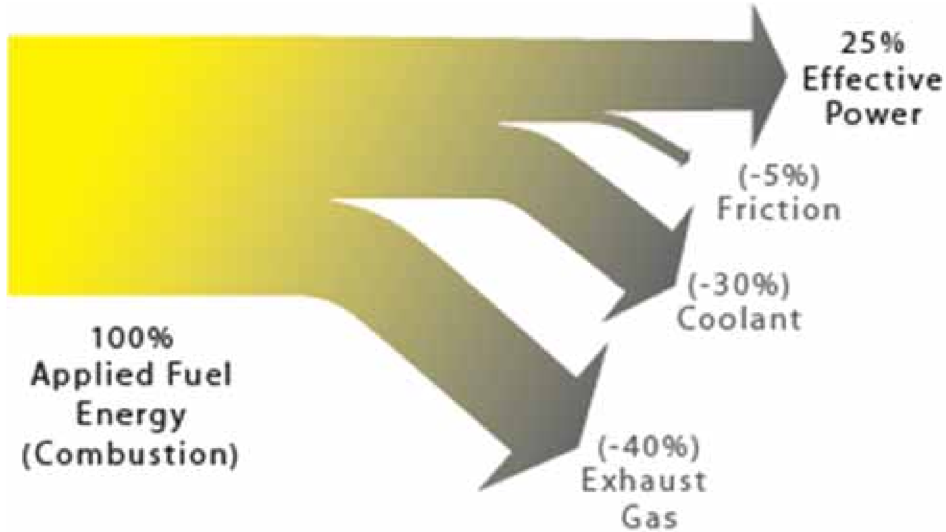
1. 10% ethanol / 90% gasoline
2. US gallon (0.833 x imperial gallon)
3. Research Octane Number (RON)
4. Applies to spark ignition engines only

Energy Contents of Various Fuels

In general, diesel engines are about 40% more efficient than gasoline engines in terms of miles per gallon.

Gasoline engines are relatively inefficient in the actual driving cycle. It converts about 65% of the gasoline to heat, and only about 30% to mechanical energy. Of this, only about two-thirds of the mechanical energy reaches the wheels.

Chevron: Fuels/ bulletin, fuel economy
Passenger car in EPA urban cycle (F7P75)

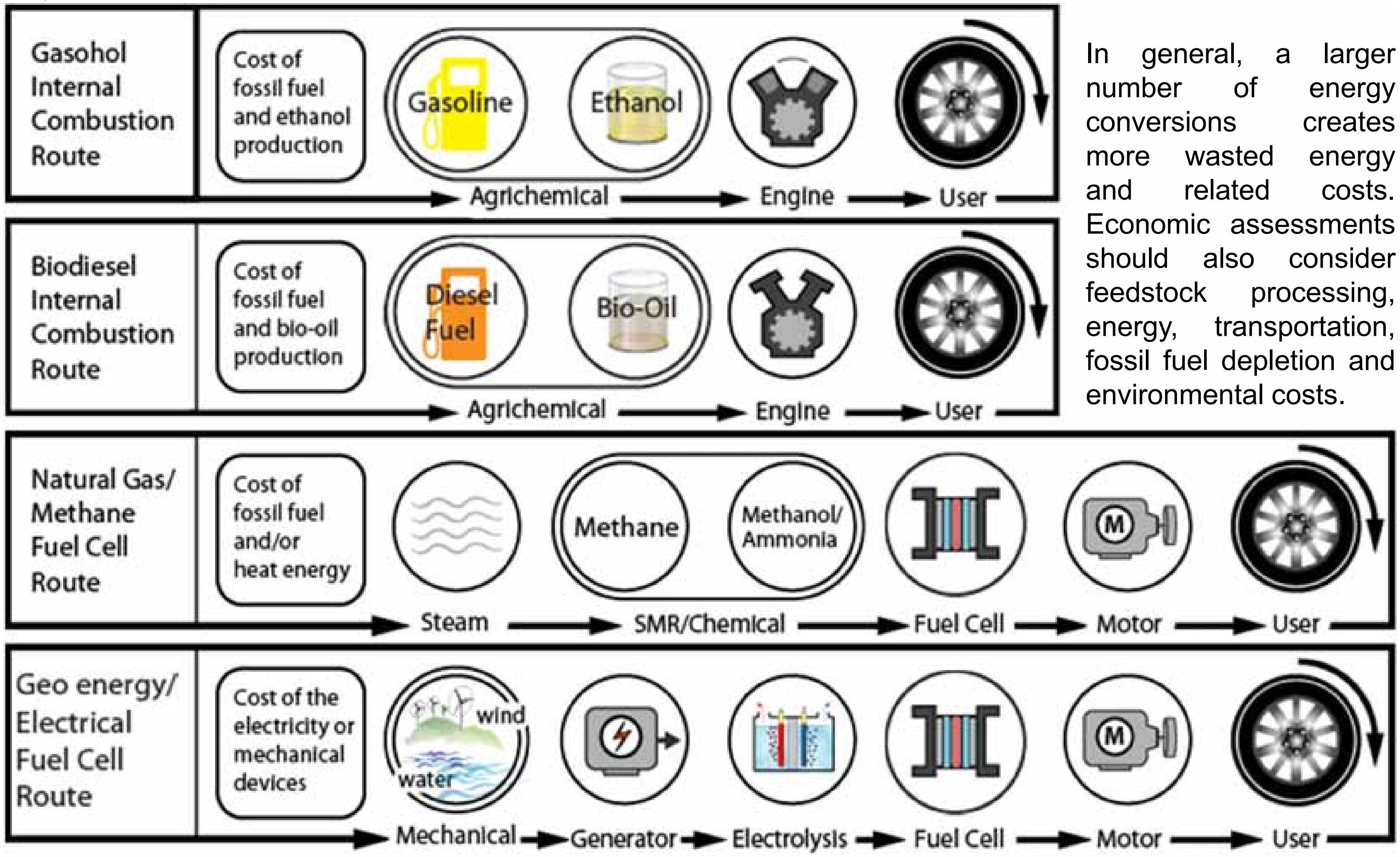


Typical Energy Split in Gasoline Internal Combustion Engines

Although direct chemical conversions tend to be most efficient for producing electrical power, internal combustion engines are most efficient to produce mechanical power for automotive purposes because they avoid an intermediate electric motor stage. Fuel/hydrogen costs influence relative overall economies.

Conversion Devices	Conversion Processes	Wheel Efficiencies
Diesel Fuel Engines	Chemical-Mechanical	Approx. 33%
Gasoline Fuel Engines	Chemical-Mechanical	Approx. 25%
Generators/ Motors	Mechanical-Electrical	30%- 60%
Fuel Cells Compressed (CH_2)	Chemical-Electrical	Approx. 22%
Fuel Cells Liquid (LH_2)	Chemical-Electrical	Approx. 17%

Mechanical Wheel Power Efficiencies



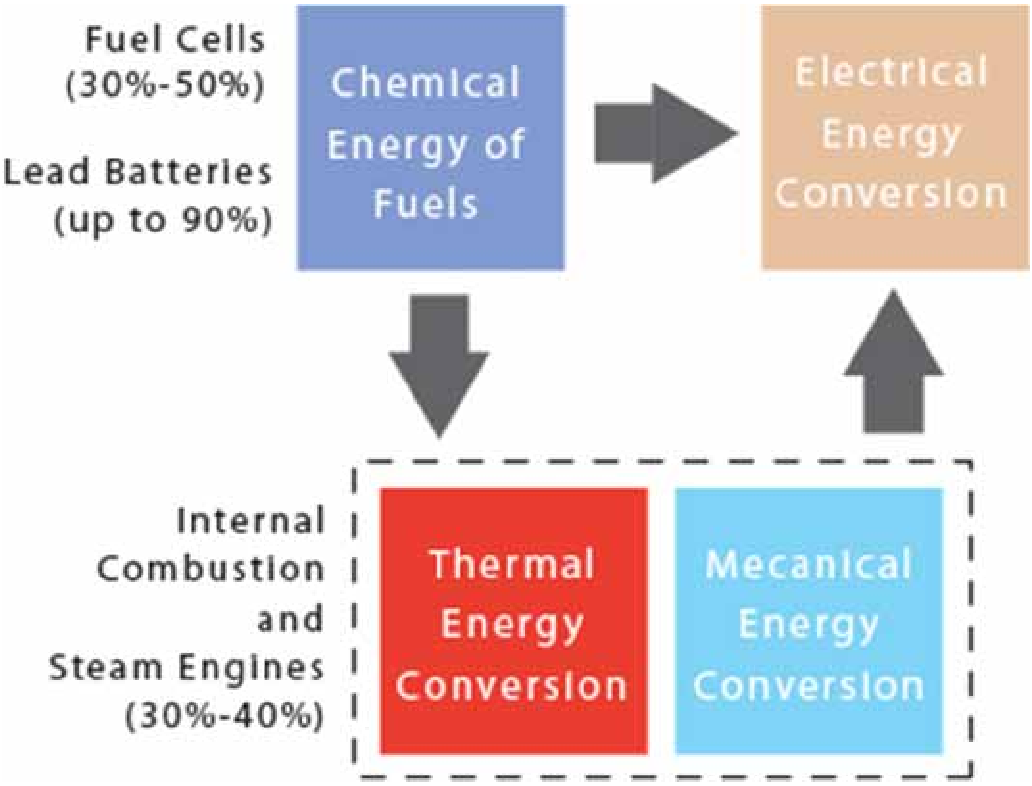
In general, a larger number of energy conversions creates more wasted energy and related costs. Economic assessments should also consider feedstock processing, energy, transportation, fossil fuel depletion and environmental costs.

Mechanical Power Conversion Efficiencies and Cost Penalties

Larry Bell

Batteries and fuel cells are efficient ways to convert chemical energy into electricity because they bypass intermediate thermal and mechanical stages associated with heat engines (the 30-40% Carnot limits).

Combined-cycle systems that recycle heat operate at higher efficiencies than other engines (55-60%) but are limited to higher power applications.



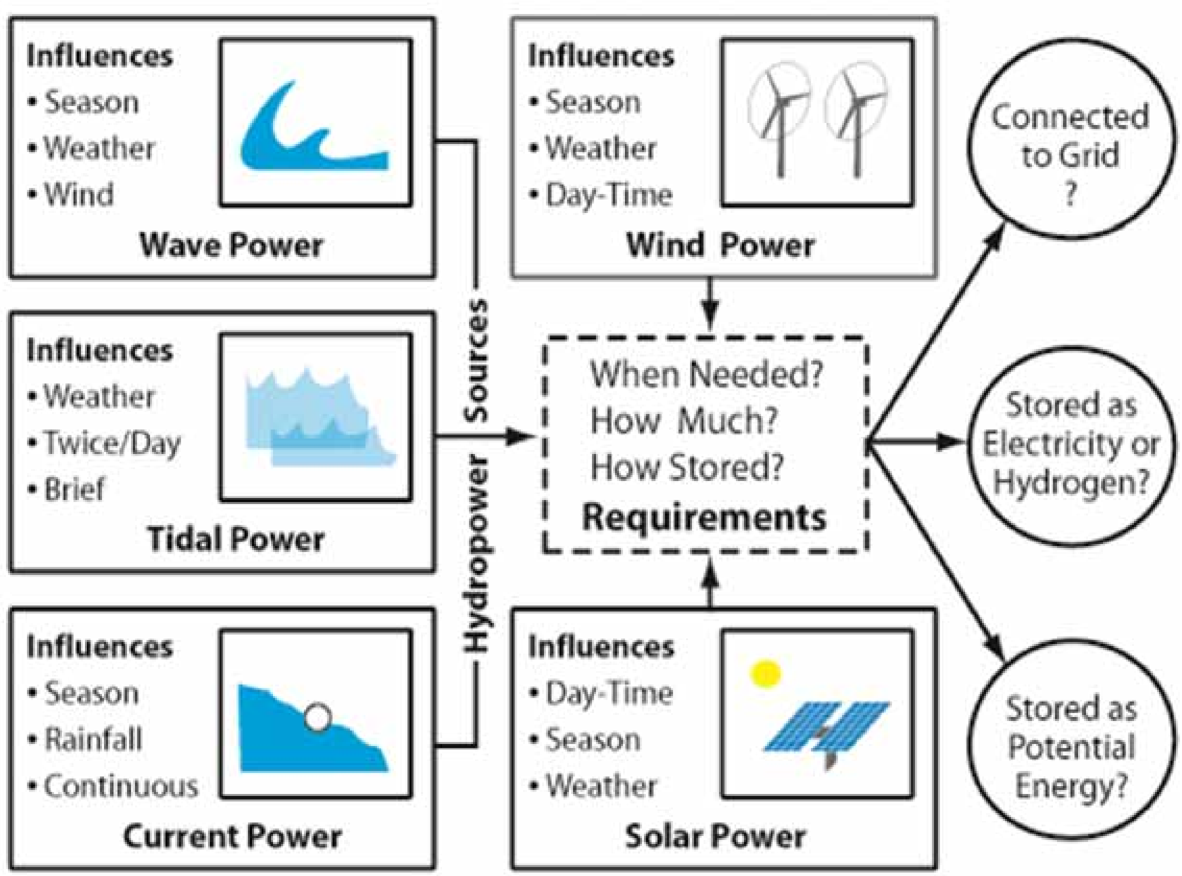
Direct chemical-to-electrical conversions are more efficient because they avoid the need to convert from chemical-to-thermal- to mechanical-to-electrical.

Electricity Conversion Efficiencies

Larry Bell

Wind, solar, and most types of hydropower are intermittent power sources.

Two or more types are often combined in hybrid configurations to overcome this disadvantage.

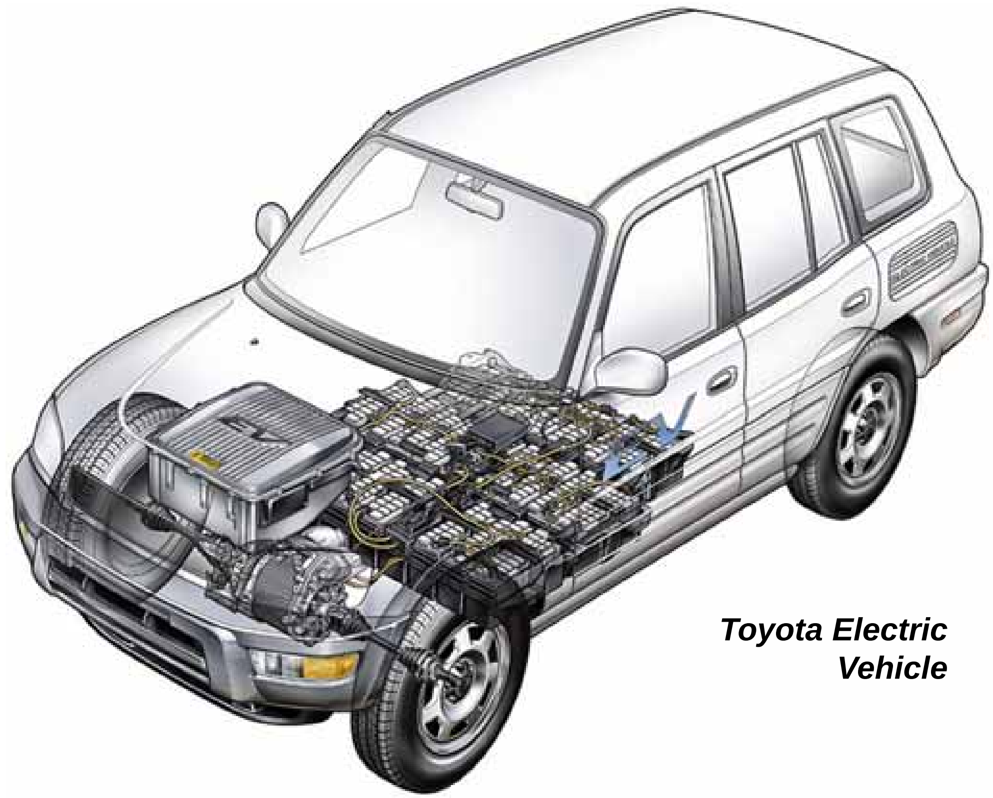


Energy Use/Storage from Intermittent Sources

Kelvin Hulsey Illustration, Inc.

Energy can be stored in a variety of forms, including electrochemically in batteries, electrostatically in supercapacitors, mechanically in flywheels, and chemically in hydrogen and other fuels.

Batteries play important roles in low-moderate storage applications, and improved technologies are vital to advance electric vehicle (EV) and hybrid electric vehicle (HEV) performance.

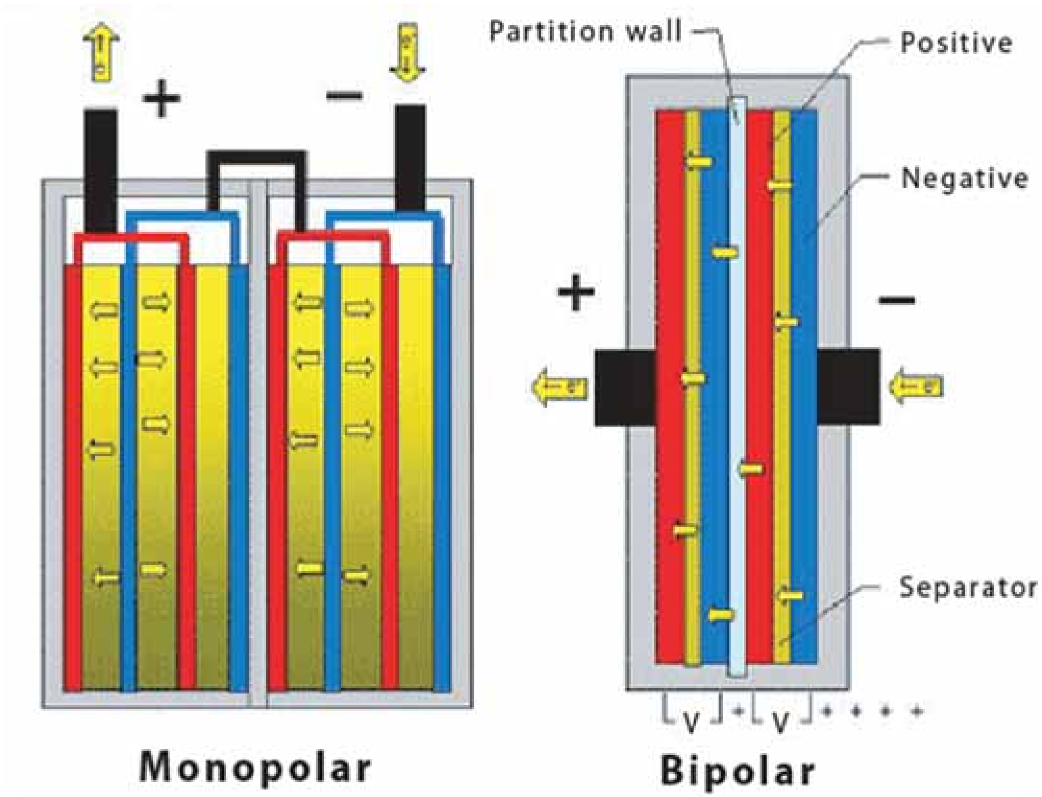


Toyota Electric Vehicle

Battery Storage

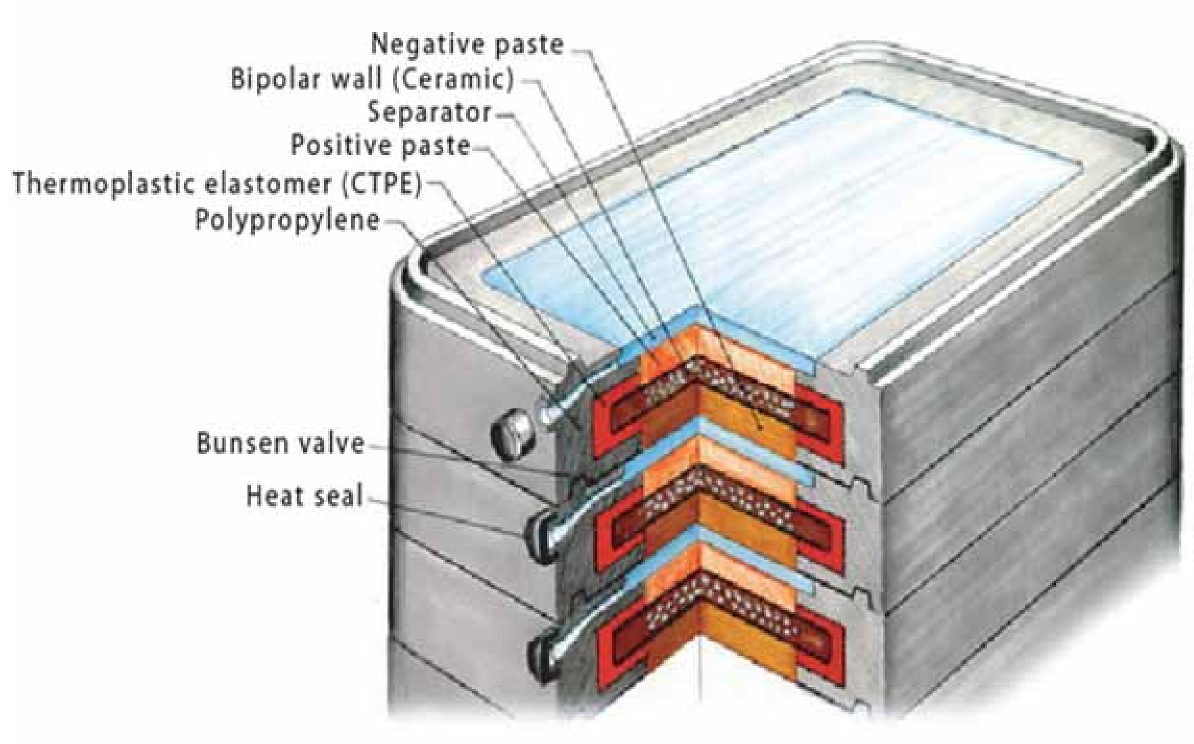
Effpower Sweden

Standard monopolar batteries introduce current in one post at an upper end and have it exit at a positive post on the opposite upper side, producing unevenly distributed higher currents in the upper section near the posts. Bipolar batters use a stack of serially-coupled bipolar electrodes that distribute current more evenly and apply conducting materials more efficiently, creating less resistance and providing more compact high energy.



Effpower LIC^{TM} Bipolar Concept

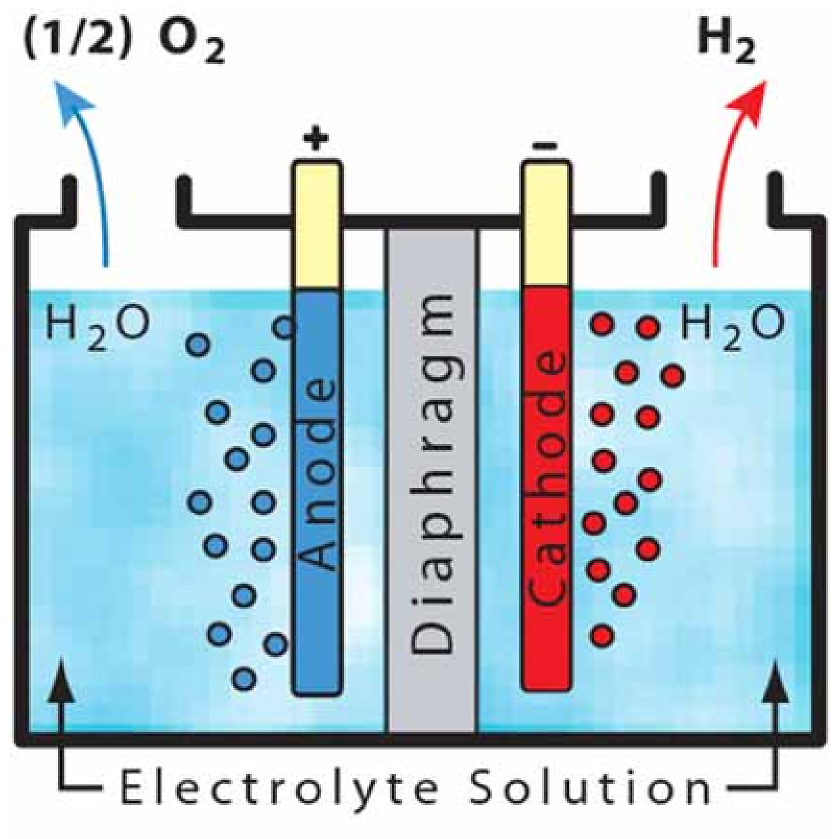
This bi-polar lead-acid battery design uses lead-infiltrated-ceramic (LIC^{TM}) plates as partitioning walls between cells which are connected in series (2 volts per stacked cell).



Lead-Acid Bi-Polar Battery

Larry Bell

Since pure water conducts electricity very poorly, a water-soluble electrolyte (acid, base or salt) is added to close the circuit. Each electrode attracts ions of the opposite charge. Platinum is typically used because other metals tend to react with oxygen at the anode instead of being released as a gas.



Electrolysis to Produce Hydrogen

Hydrogen Gas (H_2)

- Highly combustible, will burn in concentrations as low as 4% H_2 in air.
- Hydrogen explodes upon ignition when mixed with oxygen.
- Reacts violently in contact with chlorine and fluorine.
- Readily leaks due to small molecular size through porous materials, cracks or bad joints.
- Has good energy density per weight, but poor density per volume (compared with gasoline).

Liquid Hydrogen (H_2)

- Has higher volumetric energy density than gaseous H_2, but requires low temperature storage.
- Has much worse energy density per volume than gasoline.
- Expensive tank insulation is required to prevent boil-off (LH_2 boils at about -423°F [-253°C]).
- LH_2 is cold enough to freeze air, and can cause valves to plug up in automotive fuel applications.
- Production and transportation of LH2 or H2 can require more than twice the energy recovered.

Hydrogen Form Characteristics as Energy Carriers

Hydrogen can be stored in ammonia (NH3) to facilitate transport, and released in a catalytic converter at the destination.

Since ammonia is the second most commonly produced chemical in the world, a large production, transportations, and distribution infrastructure already exists.

Although it burns poorly at atmospheric pressures, it is a reasonable fuel under compression in engines.

Advantages:

- Provides very high storage densities as a liquid with mild pressurization and cryogenic constraints.
- Can be stored at room temperature and pressure when mixed with water.
- Can be reformed to produce H_2 with no harmful waste, and can be mixed with existing fuels to burn efficiently.
- Can be used as a suitable fuel in conventional engines with slight modifications.

Disadvantages:

- Is very energy-expensive to produce.
- Is a toxic gas with a potent odor at ambient temperatures.

Hydrogen can be stored in metal hydrides (liquid and solids) such as sodium borohydride, lithium aluminum hydride, and ammonia burane for use in fuel cell applications:

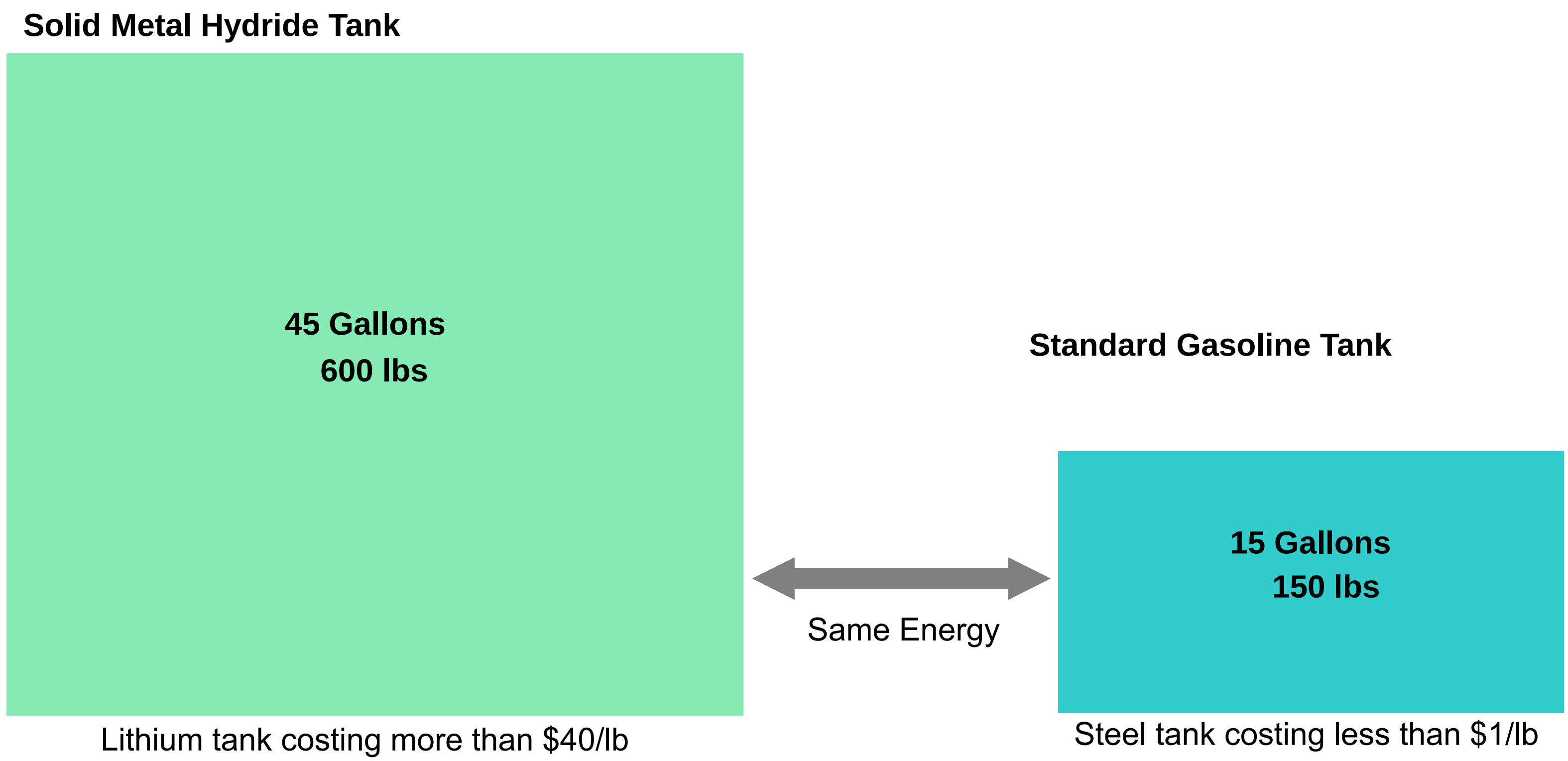
- **Sodium borohydride and ammonia burane can be stored as liquids when mixed with water, but require complicated recycling within fuel cells.**
- **Sodium borohydride can enable less expensive fuel cells to be used, but is energy-expensive and will require recycling plants.**

Advantages:

- Some are easy-to-fuel liquids at ambient temperatures and pressures.
- Can also be constituted as pellets.
- Have good energy density/volume.

Disadvantages:

- Have much worse energy density/weight for standard cars than gasoline tanks with the same energy.
- Hydrides present safety hazards for H_2 storage densities (above 10% of total weight).
- A hydride will need to be recharged with H_2 either onboard a vehicle, or at a recycling plant.
- Fuel cell design will need to be appropriately correlated with the particular hydride used.



Metal hydride hydrogen storage for automotive fuel cells will require lithium vessels that are much larger and more expensive than standard gasoline tanks.

An alternative to hydrides is to use regular hydrocarbon fuels as hydrogen carriers with small onboard vehicle reformers to extract the H_2 by the fuel cells.

The reformers break the long hydrocarbon molecules into simpler molecules (hydrogen, water, and carbon) and the gas is then purified.

The reformate product emerges with about 40% H_2, 100 ppm CO, and the rest CO_2 and nitrogen.

Advantages

- Can run on multiple hydrocarbon fuel types allowing motorists to choose the cheapest/most available options.
- Avoids storage problems/complexities associated with high-pressure H_2 and cryogenic LH_2 approaches.
- Hydrocarbon fuels are currently established within the energy production and distribution networks.
- Direct methane fuel cells do not require reformers to operate (but have lower energy densities than conventional fuel cells).

Disadvantages

- Reformers can add costs and complexities along with associated system maintenance/longevity problems.
- Current reformers tend to be slow, limiting power generation.
- Present fuel cells tend to be less energy-efficient than internal combustion engines (offering advantages to methanol/ethanol).

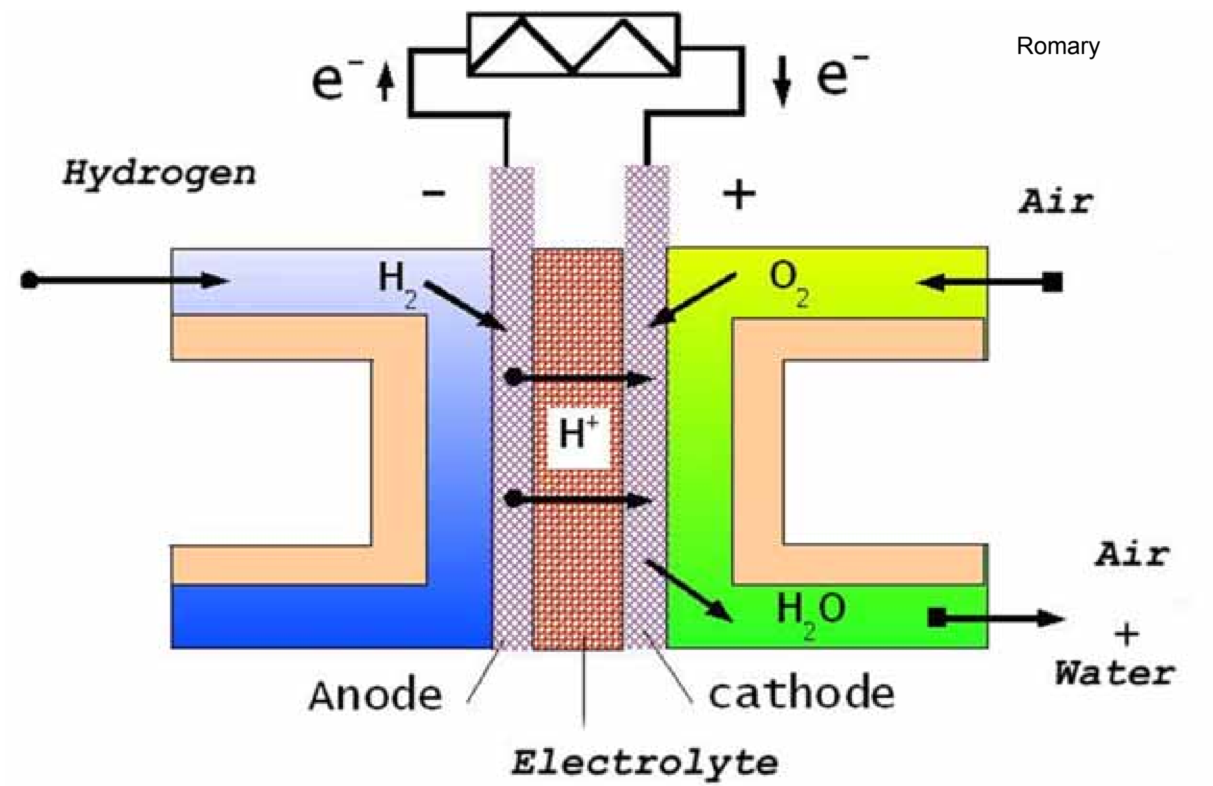
On-Board H_2 Fuel Cell Reformers

$H_2 \rightarrow 2H^+ + 2e^-$

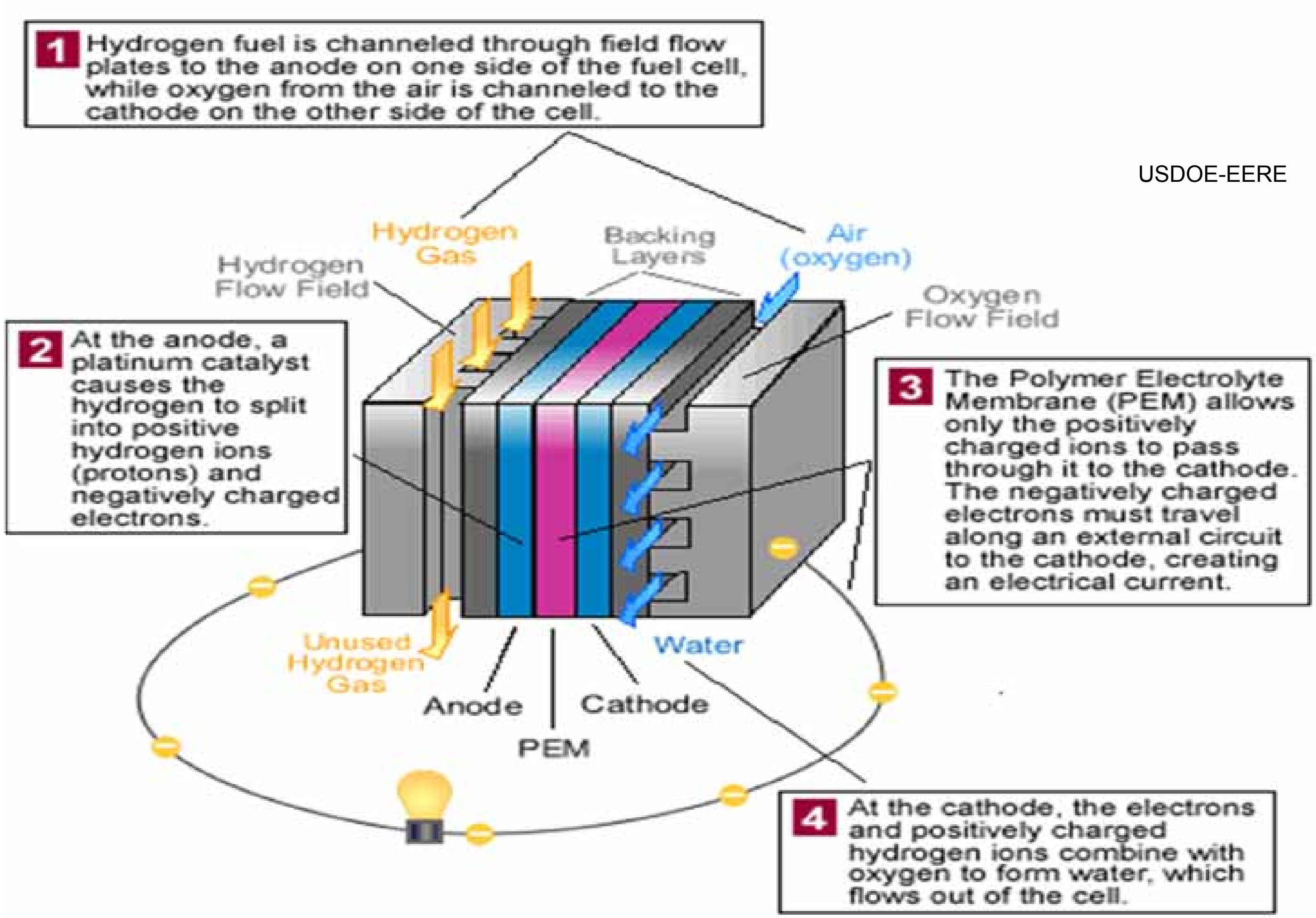
On the anode side:
hydrogen diffuses to the anode catalyst to dissociate into protons and electrons. Protons move through a membrane to the cathode, and electrons are released.

$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

On the cathode side:
oxygen molecules react with electrons (which have traveled through the external circuit) and with protons to form water vapor and/or liquid water**.**



Fuel Cell Energy Conversion Principle



Typical Fuel Cell Stack

Staxon

Standard proton electrolyte fuel cells must be constantly hydrated with water evaporation that occurs as a precise rate.

A proper temperature must be maintained throughout the cell to prevent heat damage.

Automotive fuel cells require about a 5,000 hour lifespan (approximately 150,000 miles) under extreme temperatures.

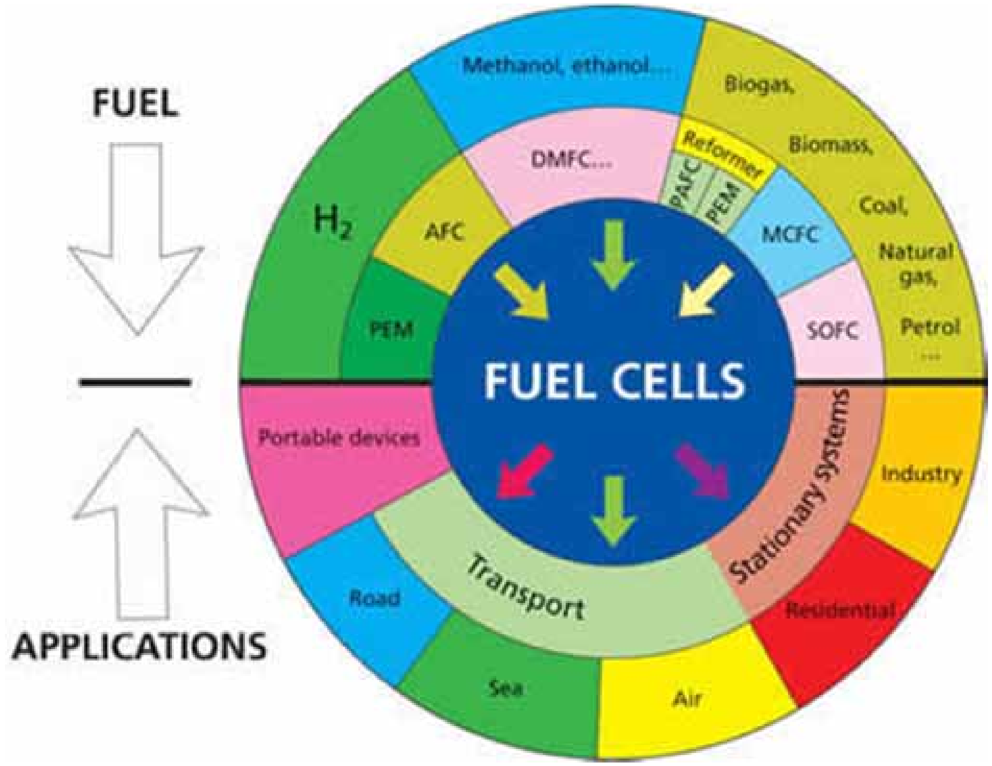
360 W/24 V PEM Unit

Fuel Cell with Water Cooling

Fuel cells are available in a variety of types for diverse uses:

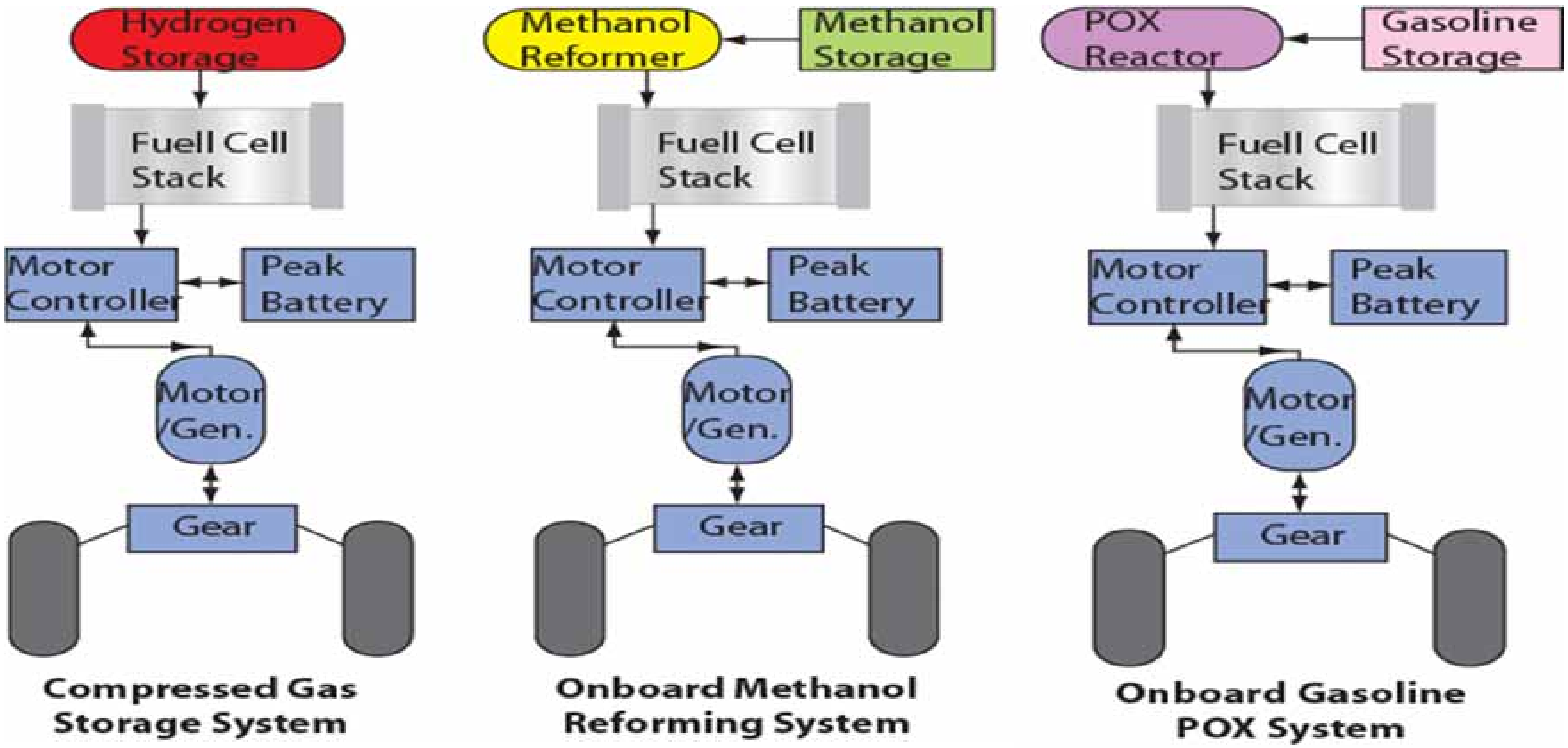
- **AFC: Alkaline (Space Applications)**
- **PEMFC: Polymer Electrolyte Membrane Carbonate**
- **DMFC: Direct Membrane**
- **PAFC: Phosphoric Acid**
- **MCFC: Molten**
- **SOFC: Solid Oxide**

European Commission



Fuel Cell Types and Applications

JM Ogden et.al., Journal of Power Sources



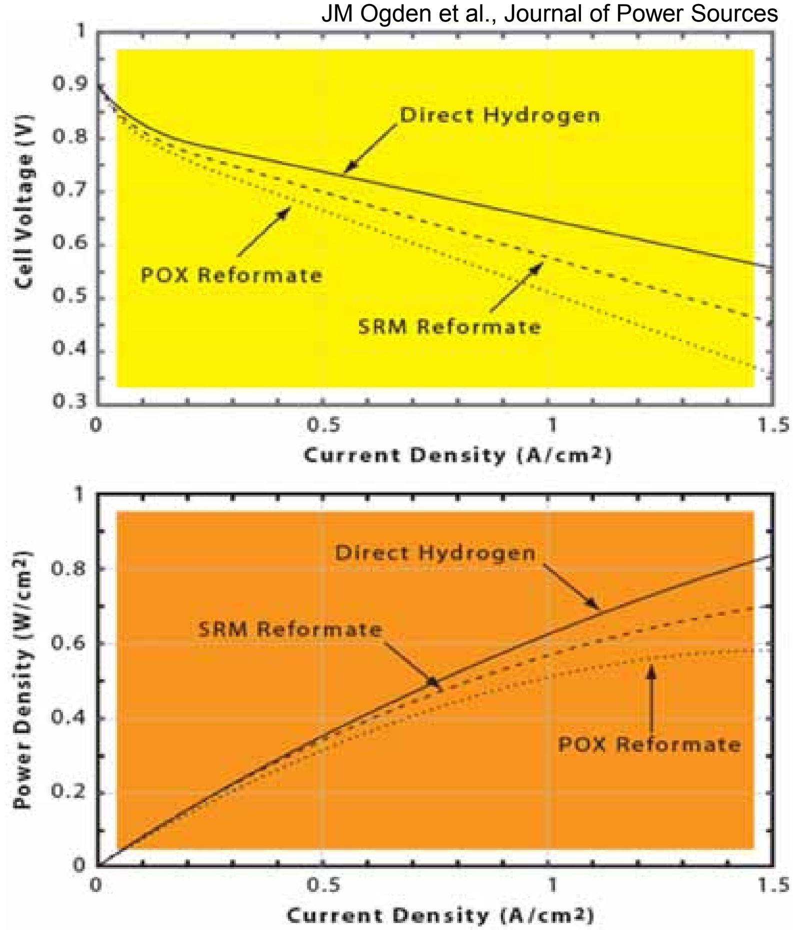
Various automotive fuel cell systems store hydrogen in the form of compressed gas, or convert methanol or petroleum fuels to hydrogen onboard the vehicles.

Types of Automotive Fuel Cell Systems

The output of a PEM fuel cell depends upon the hydrogen concentration in the feed gas:

- **Compressed hydrogen gas storage systems provide the highest peak power output per volume.**
- **The hydrogen content for onboard methanol steam reforming is about 75% by volume, compared with about 35% for a gasoline partial oxidation (POX) system.**
- **Large storage requirements add substantial weight for fuel and vehicle structure, and methanol type fuels may weigh about 10% more than compressed gas, and gasoline POX may weigh about 19% more.**

JM Ogden et al., Journal of Power Sources

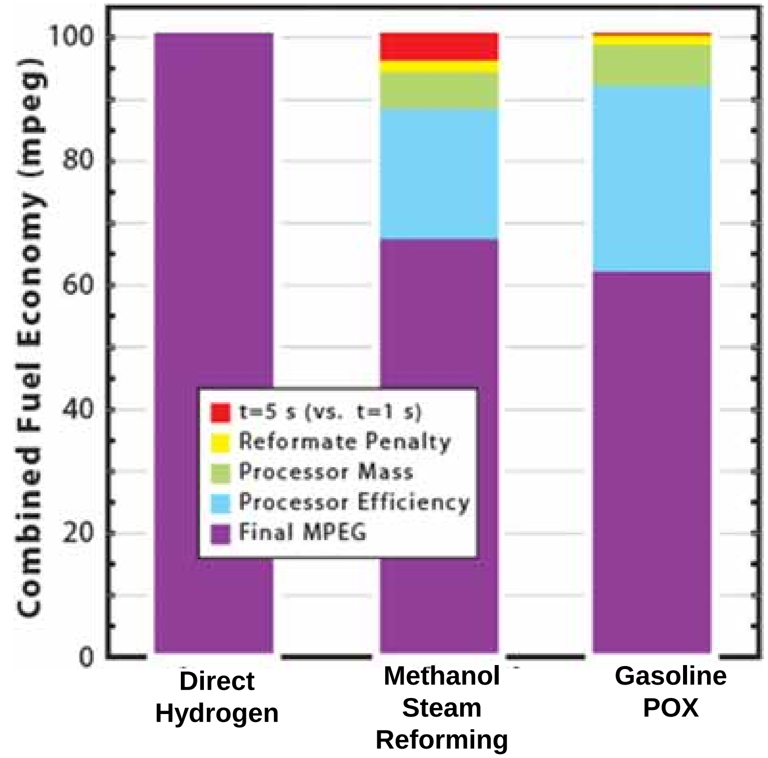


Comparison of Fuel Cell Performances

JM Ogden et al., Journal of Power Sources

Fuel cell economies are impacted by system energy conversion characteristics:

- **Compressed hydrogen systems are about one-third more efficient than those that convert hydrogen onboard a vehicle.**
- **About 15-25% of energy can be lost converting methanol or gasoline/diesel to hydrogen.**
- **While methanol and gasoline fuel cell cars have similar economy, about twice as much methanol is needed due to lower energy density, requiring larger storage tanks and weight.**
- **Onboard steam reforming response times are 40%-50% slower than onboard POX systems, requiring more backup energy to be routed through batteries.**



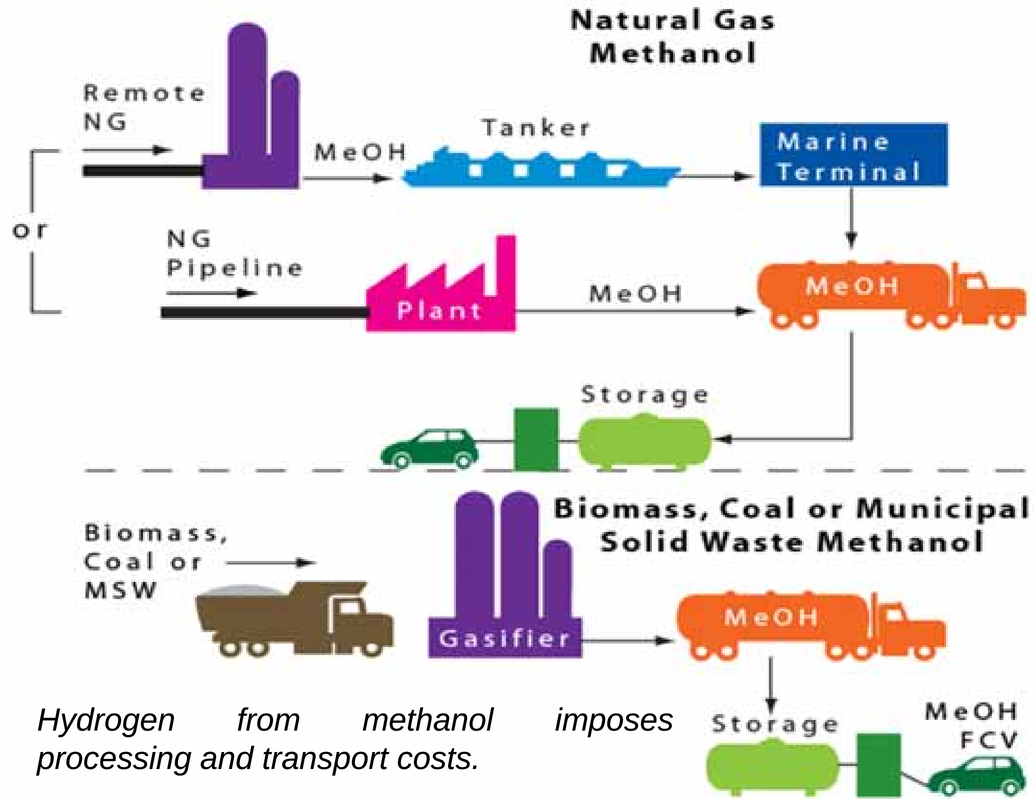
- ***T=5 s*** *(time=5 seconds) factors a delay time allowed for fuel processing by steam reformers and POX systems to meet peak demands, requiring batteries to fill energy gaps. This adds recharge penalties.*

Cumulative Fuel Economy Losses for Different Fuel Cell Types

JM Ogden et al., Journal of Power Sources

Other fuel cell considerations:

- **Use of compressed or liquefied hydrogen from natural gas reforming depletes fossil resources.**
- **Hydrogen obtained from water electrolysis competes with other electricity uses.**
- **Hydrogen derived from methanol or gasoline/diesel consumes energy for processing and transportation.**



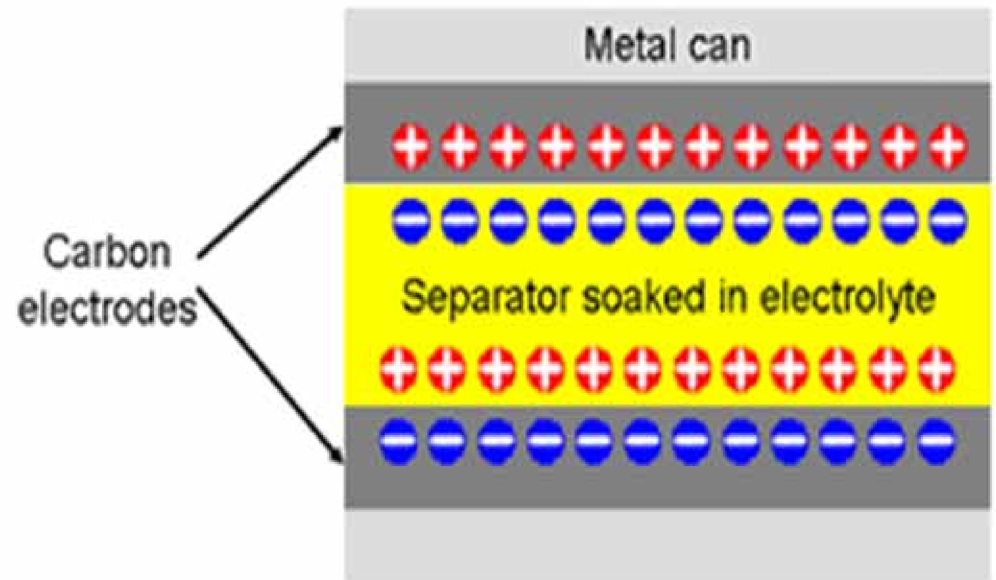
Hydrogen from methanol imposes processing and transport costs.

Fuel Cell Hydrogen from Methanol

Supercapacitors (or "ultra-capacitors") store energy in an electrostatic field rather than in a chemical state as batteries do.

They look much like batteries, and consist of two electrode plates of opposite polarity separated by an electrolyte. The capacitor is charged by applying voltage across terminals, causing current to migrate to the surface of the electrode of opposite polarity.

Axeon Power



Capacitor / Battery Comparison

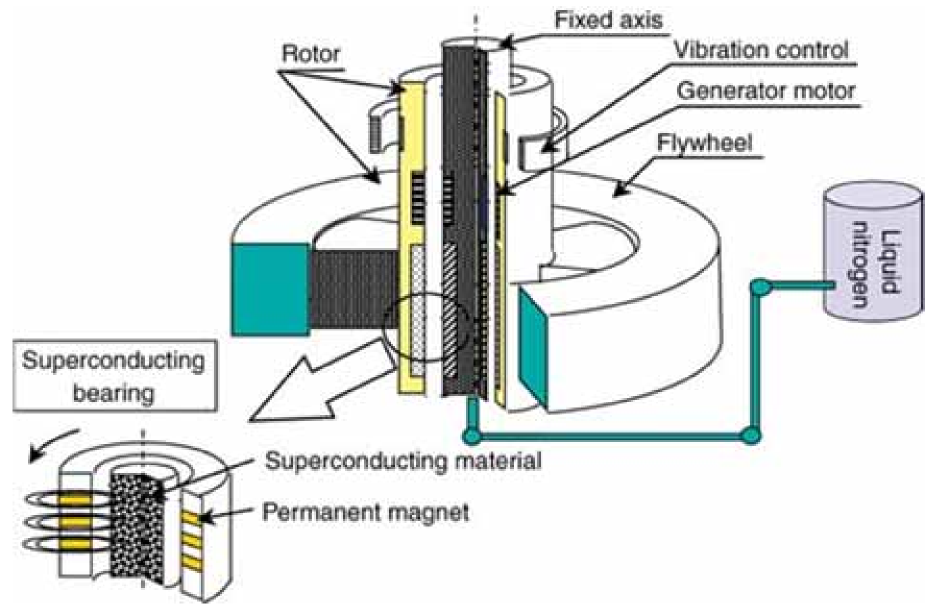
Device	Energy density Wh/L	Power density W/L	Cycle life Cycles	Discharge time Seconds
Batteries	50-250	150	1 - 10^3	> 1000
Capacitors	0.05 - 5	10^5 - 10^8	10^5 - 10^6	<1

Supercapacitor Electricity Storage

Super flywheels store kinetic energy in high-speed rotating drums that form rotors of electrical generators.

They must be very strong to avoid being torn apart by rotational forces at speeds of 100,000 rpm or more. A 1-foot diameter flywheel rotating at that speed would attain a rim surface speed of about 3,570 mph (4.8 times the speed of sound), with a centrifugal force on rim particles equal to 1.7 million Gs. Very strong materials such as fused silica are used along with extremely low-friction bearings.

NEDO Japan



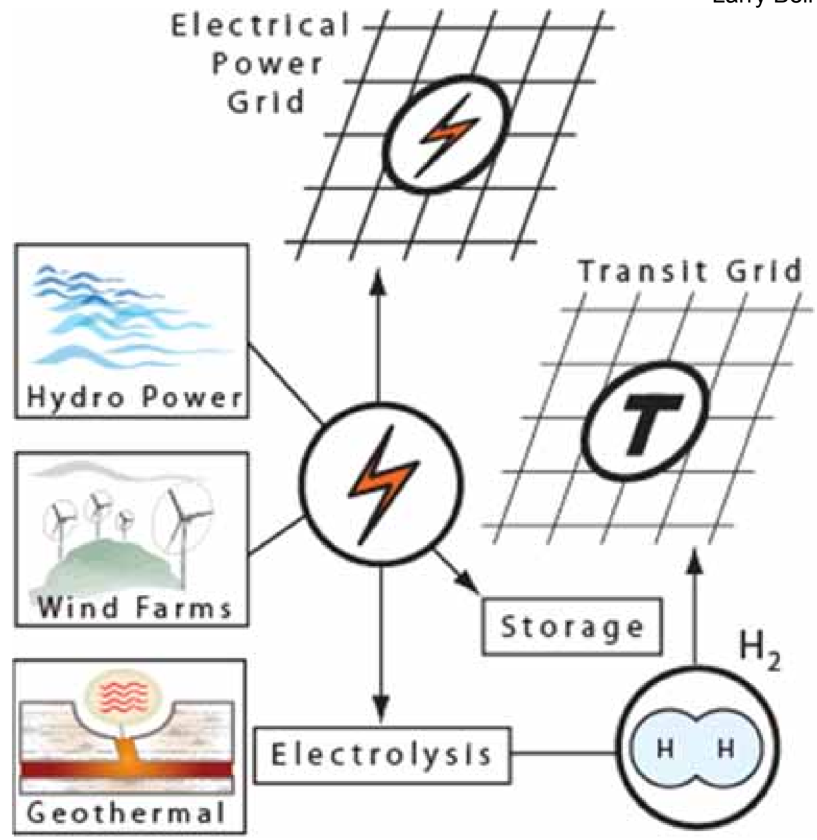
Super Flywheel Kinetic Energy Storage

Energy costs for various options are fundamentally influenced by the transportation, conversion, and storage systems used.

Electrical power economies from renewal sources are particularly sensitive to conversion and storage methods:

- Wind/hydro efficiencies depend upon how kinetic energy is captured and transformed, and if electricity is used directly or stored.
- Geothermal efficiency depends upon whether heat is used directly or converted to electricity.
- Hydrogen efficiency depends upon the source and conversion method.

Larry Bell

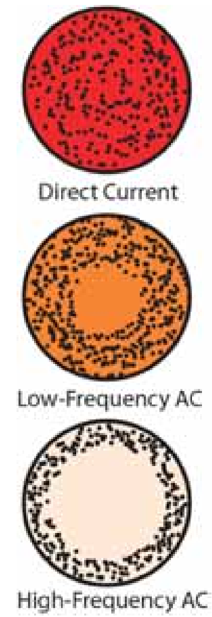


Energy Transfer Grids

Heat losses in electrical power transmission can impose large efficiency penalties through lower line resistance.

This resistance can be reduced by converting DC to AC using an inverter to redistribute current density near the surface of the conductor.

When heat is a desired product, conductors are selected to maximize electric resistance.



Larry Bell

DC Conductor

DC currents distribute electron flow throughout a conductor, causing more collisions with atoms (more heat).

AC Conductors

AC currents distribute electron flow towards the outer surfaces of conductors, producing less resistance (heat). Higher frequencies increase this benefit.

Heat Reduction Through AC

Both AC and DC transmission lines can produce coronas that cause significant power losses as their electric fields tear electrons from surrounding un-ionized air and positive ions, or electrons are attracted to the conductor while charged particles drift away. High-voltage direct current (HVDC) systems can experience about half the loss of AC lines of the same power.

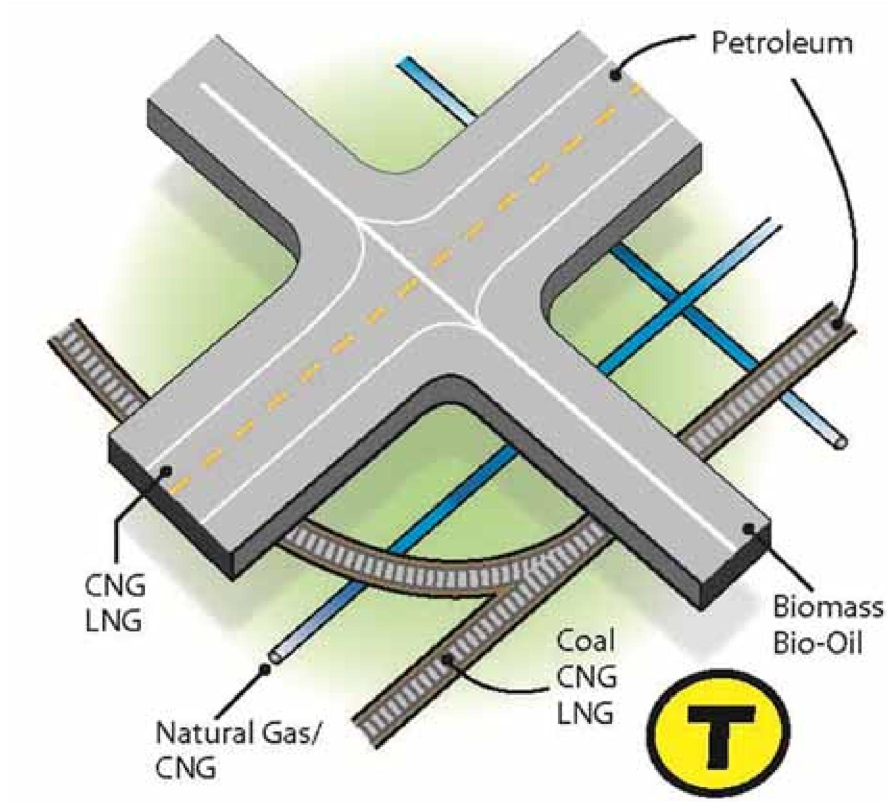
AC Systems	HVDC Systems
• Almost universally used by US commercial power distributors.	• Useful for long-haul bulk power transmission in remote areas.
• Lower costs / transmission losses for shorter applications than HVDC.	• Enable power transmission between unsynchronized AC distribution systems.
• Can change voltage to respond to particular power needs.	• Reduce line costs due to use of 2 rather than 3 conductors.
• Transformers are currently cheaper and more reliable than solid-state devices.	• Minimize power losses associated with corona discharge of ions/electrons.

Applications and Advantages of AC and HVDC Power Transmission Systems

Larry Bell

Transport economies for fuel distribution can be realized in three basic ways:

- **Reduce consumption using more energy-efficient vehicles and living/travel practices.**
- **Select the most energy-efficient transportation mode for fuels and materials (pipelines, rail, or trucks).**
- **Convert fuels to electricity at or near supply sites to enable power transmission by wire.**



Natural gas storage and transportation add substantial costs:

- **Pipelines are more economical over land, but not for ocean transport, and many are operating near full capacity.**
- **CNG tanker ships require deepwater pouts, and CNG trucks consume energy for fuel.**
- **Liquefication and compression also consume energy, and gasification or decompression expand requirements and costs.**

Pacific Summit Energy
Enter Stage Right

Peker Construction, Inc.
Kleenheat Gas Australia

Natural gas is flammable and explosive, and must be handled carefully.

End-use sites must provide good ventilation to prevent hazardous concentrations that prevent explosion and human suffocation risks.

While it can be transported by pipeline over relatively short distances (about 9 miles), broader distribution usually converts it to a compressed (CNG) form.

Compressed gas requires strong, high-pressure tanks and is dehydrated to avoid water corrosion of metal parts.

Michel Halbwachs

Steel Tanks

Composite Tanks

Natural Gas Containment

As petroleum supplies continue to be depleted, advancements in ethanol and coal-to-liquid fuel processing are becoming increasingly vital.

Cellulosic ethanol avoids large cropland and cultivation requirements but is currently difficult to process economically.

Conversion of coal into diesel fuel, petroleum, and aviation fuel is possible, but is presently in experimental stages and not yet commercially viable.

Nat. Sustain. Agri. Info. Svc.
GE Dolbear & Assoc.

Plant biowaste ethanol can offer a more land- and energy-efficient alternative to grain sources.

Coal-derived liquid fuels can be substituted for petroleum vehicles and aviation fuels.

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Energy Sources	Long-Term Supply	Utility Capacity	Energy Efficiency	Environment Issues
Fossil Fuels: ▪ Natural Gas ▪ Petroleum ▪ Coal	Dwindling natural gas & petroleum reserves. Longer coal reserves.	Primary sources of electricity, heat, vehicle fuels and chemicals.	Relatively high compared with other fuel options (use-dependent).	CO_2 & other combustion emissions are greenhouse & health liabilities.
Biofuels: ▪ Biomass burning ▪ Bioenergy crops	Renewable energy sources, but may consume energy for production and transport.	Depends upon croplands & energy for acquisition, processing & distribution.	Depends upon biomass source, yields and process/ distribution costs.	May reduce greenhouse emissions, depending on production/ processing.
Nuclear Electric Plants	Can offer long-term potential using breeder reactors to process fuels.	Currently provides19% of US electricity with large growth possible.	Comparable to fossil fuels in production and plant costs.	Clean emissions but requires storage/ protection of spent fuels.

Primary Sources

Energy Sources	Long-Term Supply	Utility Capacity	Energy Efficiency	Environment Issues
Mechanical Energy ▪ Wind Turbines ▪ Hydropower	Renewable sources with limited site applications for substantial benefits	Depends upon local site features & seasonal/ daily weather conditions	Can be very efficient, primarily for power grid balancing.	Wind is clean. Hydro can impact marine ecosystems.
Geothermal Power Plants	Renewable energy source, but very limited growth possibility	Depends upon limited sites with suitably high/ accessible temperatures.	Depends upon size/ temperature of heat reservoirs for power plants.	Clean, but can have potential adverse subterranean impacts.
Solar Power: ▪ PV systems ▪ Utility-scale concentrators	Renewable, but primarily a back-up or power-balancing supplement.	Depends upon geographic climate & daily site weather.	Influenced by atmosphere, weather & size/type of system used.	Clean energy with excellent conservation benefits.

Secondary Sources

Important Source Considerations

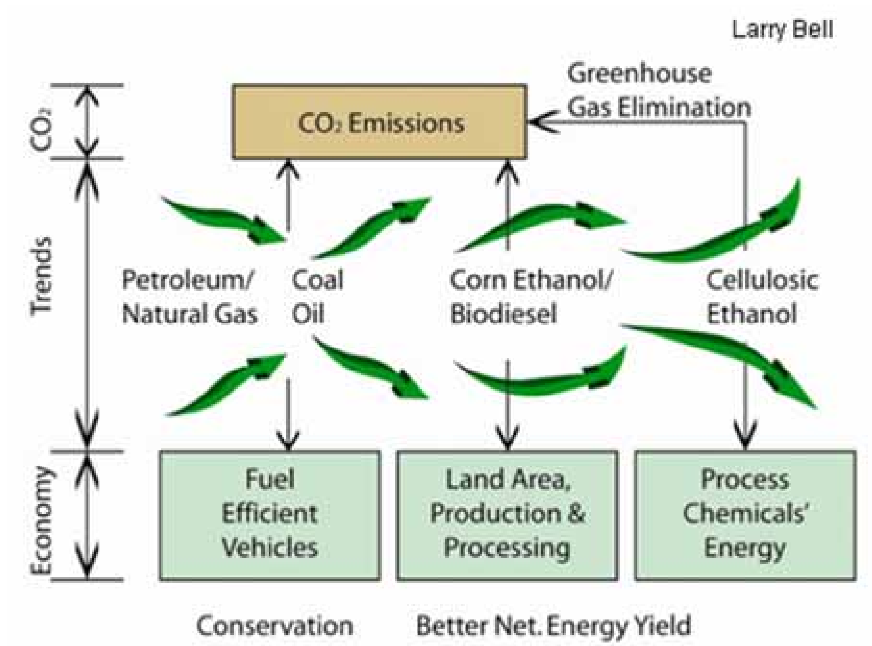
Transitioning to organic and coal-derived fuels appears to be a useful but somewhat limited and long-term solution.

All hydrocarbon combustion processes release CO_2 and other pollutant emissions and require large amounts of production energy.

Developments are needed to improve energy crop yields, and to reduce farming and processing energy.

Cellulosic bioethanol can gain advantages if difficult chemical digestion problems can be solved.

Coal-derived liquid fuels will become more attractive as oil costs continue to rise if experimental technologies prove practical.



Fuel Transition Challenges

Larry Bell / Candy Feuer

Growing interest in renewable energy alternatives is spurring technical advancements which can be expected to drive costs down and expand markets.

Although initial up-front investments for these technologies can be high, life cycle costs may compensate, particularly through government incentive programs.

The Road to Renewables

Renewable types of electrical power options can offer important ways to reduce fossil consumption and pollution, but are most applicable to local and off-grid services.

All of these secondary options are governed by geographic and site-specific conditions that constrain expansion and use.

Wind and solar energy are intermittent and influenced by weather.

Hydroelectric and geothermal sites are scarce and subject to environmental restrictions.

SKF Group
How Stuff Works

EV World
ACRE

Mechanical and solar power is limited to sites with favorable weather conditions.

Hydroelectric and geothermal expansion is constrained by a scarcity of sites and environmental restrictions.

Expansion Limitations

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A variety of methods are being developed and used to convert fossil and biomass materials into gaseous and liquid fuels, fertilizers, and chemical product feedstocks.

All have special applications, advantages and disadvantages, and none can be ignored.

Systems	Applications	Advantages	Disadvantages
Biochemical: ▪ Anaerobic Digestion ▪ Alcoholic Fermentation	Produces methane, liquid fuels, & chemical feedstocks through natural bacterial & chemical processes.	Can be applied using organic, municipal & agricultural wastes for resource recovery & bio-remediation.	Must be applied on a practical scale to realize practical development & operation benefits.
Chemical	Reacts bio-chemical, thermo-chemical & other materials to produce fuels and derivatives.	Can convert alcohols & sugars from organic sources into biodiesel and other energy products.	May require expensive catalysts that impose costs that reduce advantages.
Thermochemical: ▪ Pyrolysis ▪ Gasification	Use conventional industry processes to produce bio-oil, hydrogen, sugars & liquid fuels.	Extensively used to create "clean coal" (gasification) & may be a source of diesel and jet fuel.	Use of a natural gas as the heat source consumes a dwindling natural resource.
Steam Methane Reforming (SMR)	Is the most widely used process to produce hydrogen from natural gas/ methane	Is also used to produce methanol & syngas for local plant & commercial applications	Use of natural gas as a feedstock consumes a valuable & dwindling natural resource.

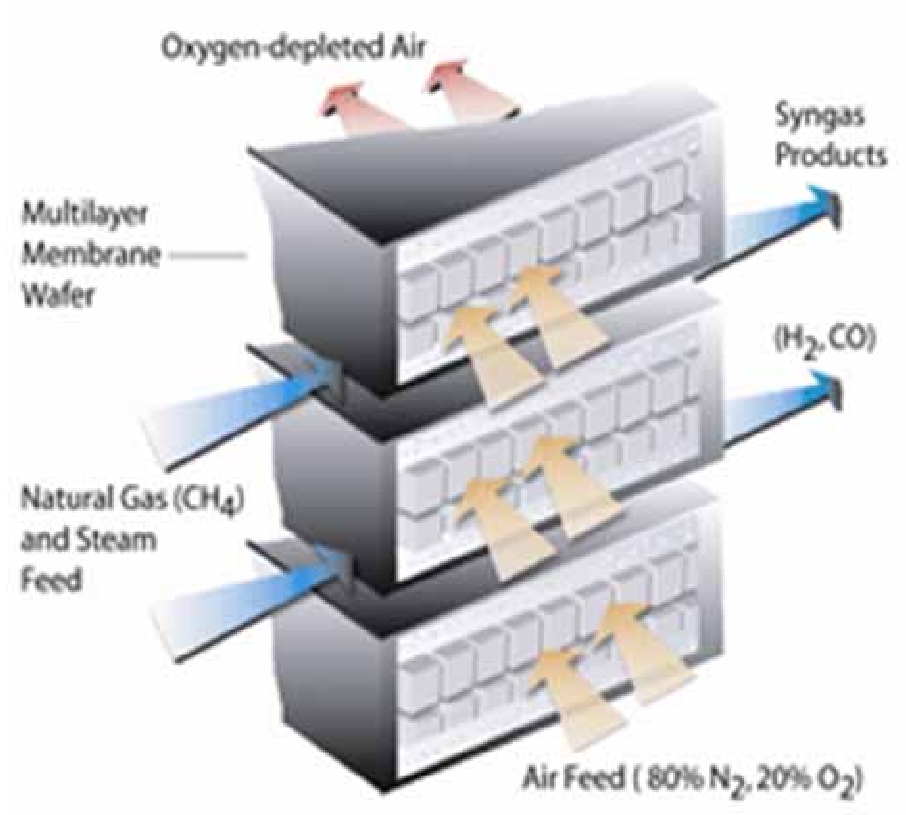
Biomass and Fossil Processing Methods

Hydrogen for fuel cells is currently an economically-limited transportation option because more energy is required to produce it than can be extracted.

Steam methane reforming, the most widely used source of H_2 today, requires substantial energy to create the steam and depletes natural gas.

A more efficient way to obtain H_2 from natural gas in the future may be through a partial combustion process that passes methane through non-porous ceramic membrane wafers under high temperature and pressure.

105. US DOE, Office of Fossil Energy



Hydrogen Extraction Through Partial Combustion of Natural Gas

The economics of producing hydrogen for fuel cells from "free" renewable sources vs. SMR of fossil or biodigested methane for other purposes must be addressed on a regional/ongoing basis.

In addition to H_2, SMR can also produce syngas for direct use or as a feedstock for methanol.

Methanol can be used to produce biodiesel fuel, or can be converted into valuable fertilizer.

Syngas can be burned for space heating, or can be used to drive turbines for electrical power.

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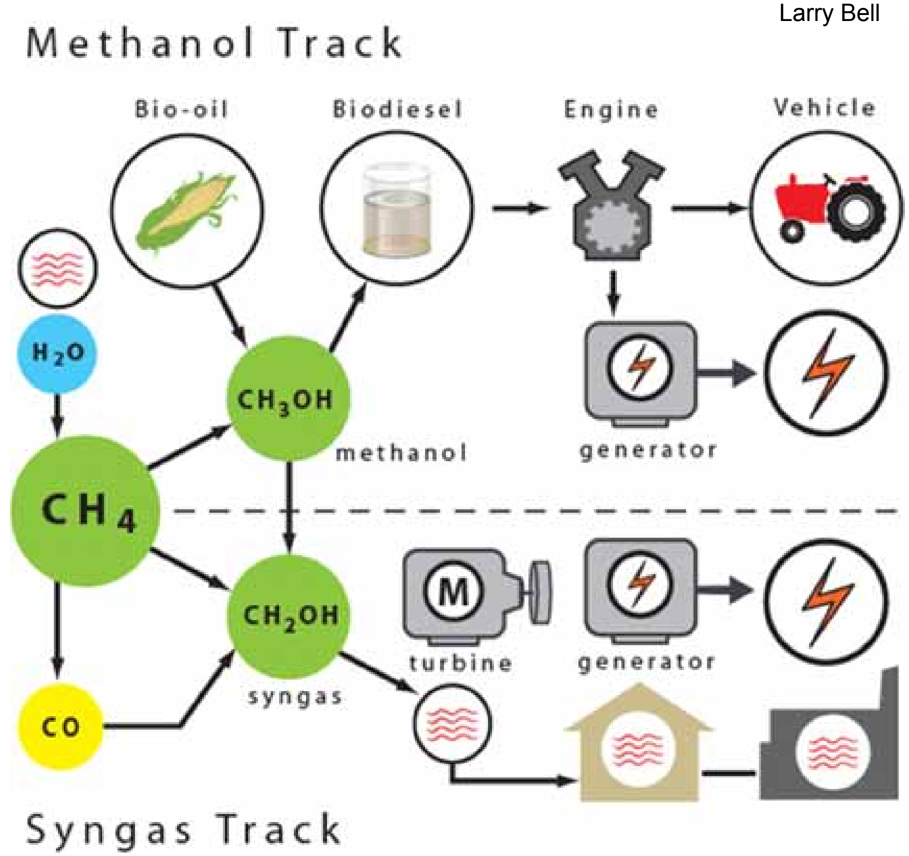
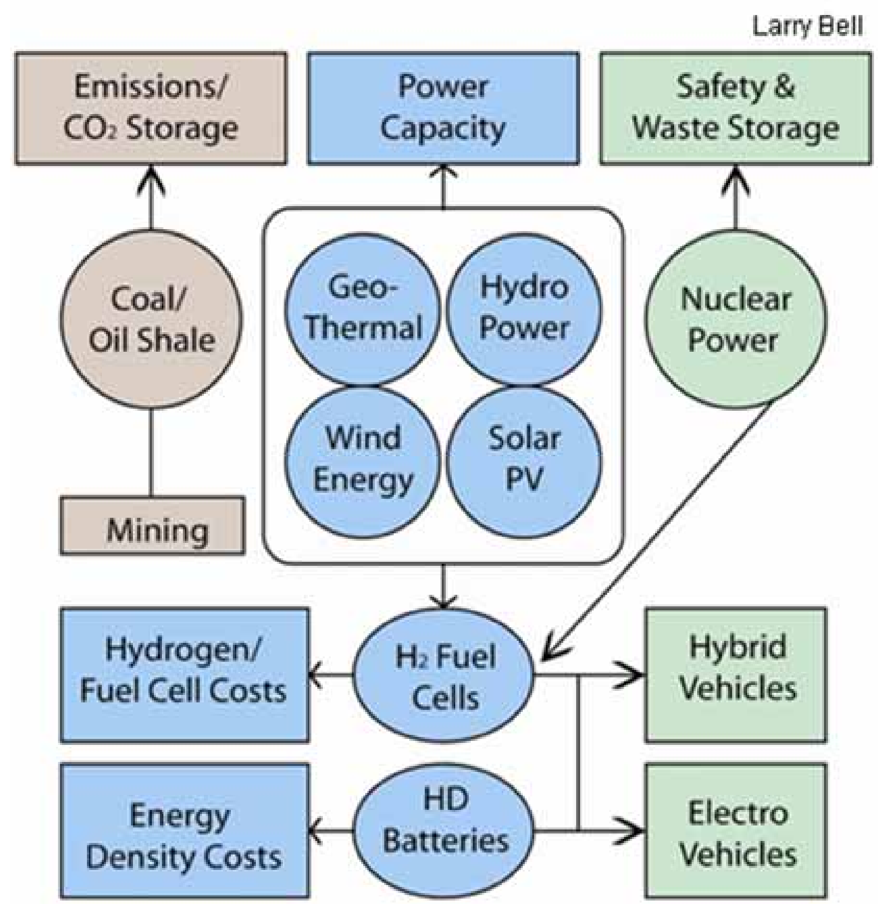


Methane Reduction for Methanol and Syngas

No recent or emerging energy technology offers a perfect or complete solution:

- **More efficient and effective clean coal and CO_2 sequestration methods are needed.**
- **Nuclear energy can be greatly expanded, but safety and waste storage concerns must be addressed.**
- **Geothermal, hydropower, wind and solar approaches can provide clean hydrogen for fuel cells, but fuel cell cost must be greatly reduced.**
- **More power batteries are needed to improve performance and expand use of clean electric vehicles.**

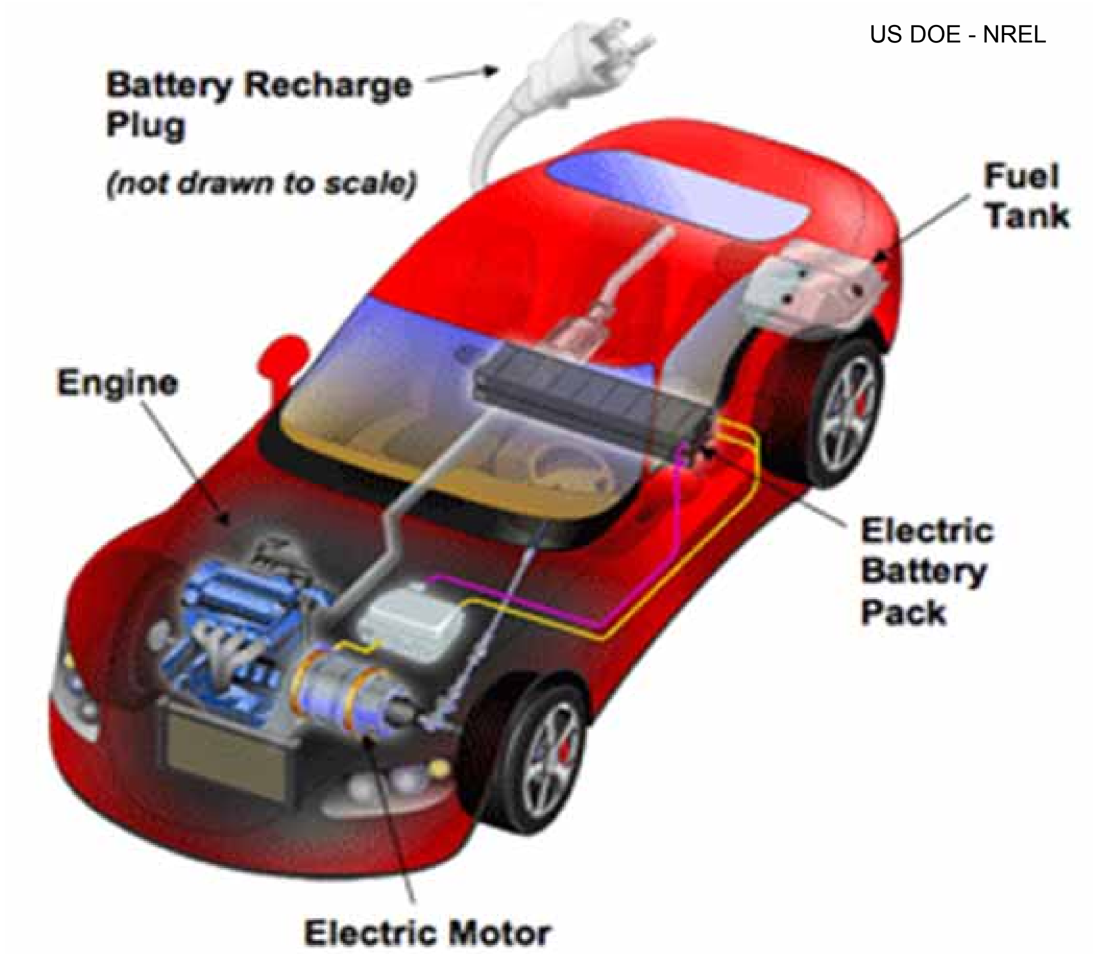


Power/Fuel Innovation Challenges

Plug-in hybrids are applicable to vehicles with gasoline or diesel engines using either fossil or biofuels.

Large batteries enable them to be powered totally by electricity over limited ranges.

Improved battery technologies are key to expand utility and market interest.



Plug-In Hybrids

Texas A&M University
US DOE-EERE

State of New York
US DOE OCRWM

Coal and natural gas now supply about 48% of all US energy used by industry, and about 67% of all electrical power.

Transitioning to nuclear power which already produces about 19% of all US electricity can stretch these resources and greatly reduce atmospheric pollutant emissions.

Industry and Electrical Sectors

Large investments will be needed to create new and expanded production and distribution infrastructures that support continuing technology innovations and market growth:

- **Improved nuclear safety through pebble bed reactors and other advancements including possible fusion can have major benefits.**
- **More affordable fuel cells and high energy-density super batteries can boost hybrid and electric vehicle performance.**
- **Cleaner, more efficient engines (such as HCCI) can help extend fossil fuels and improve biofuel performance.**

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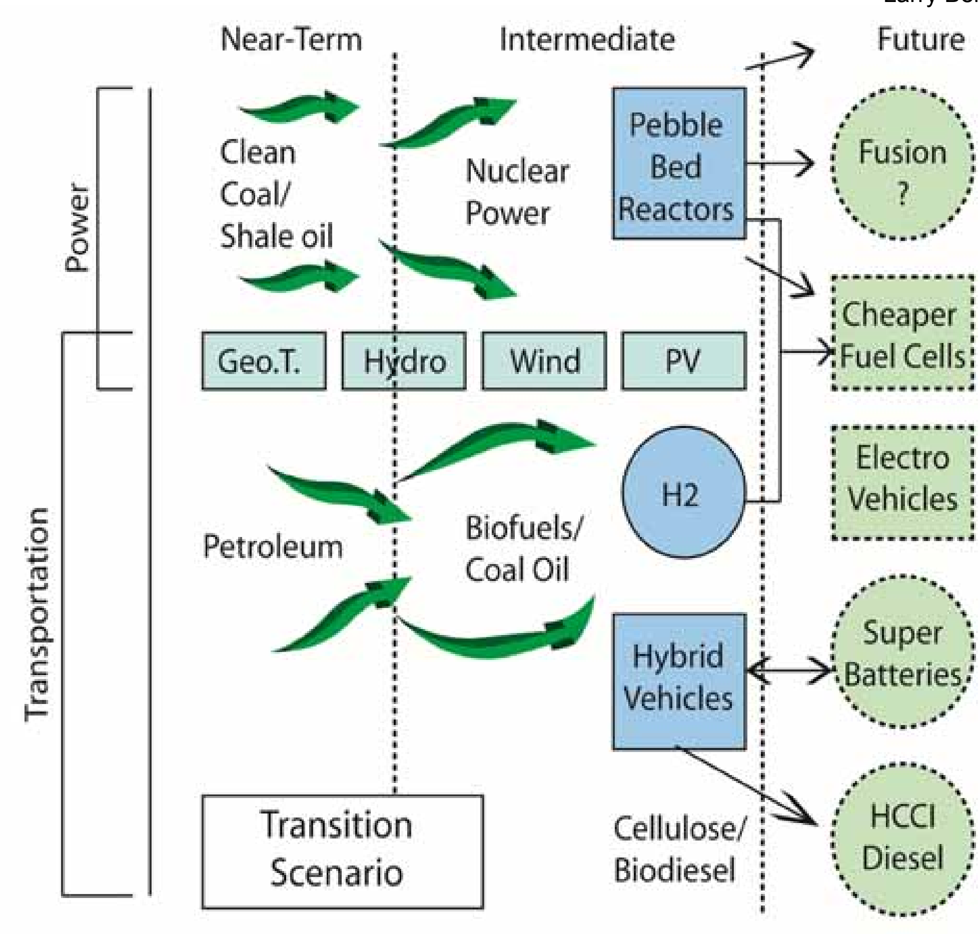


Applying Alternatives

All 4 Engineers

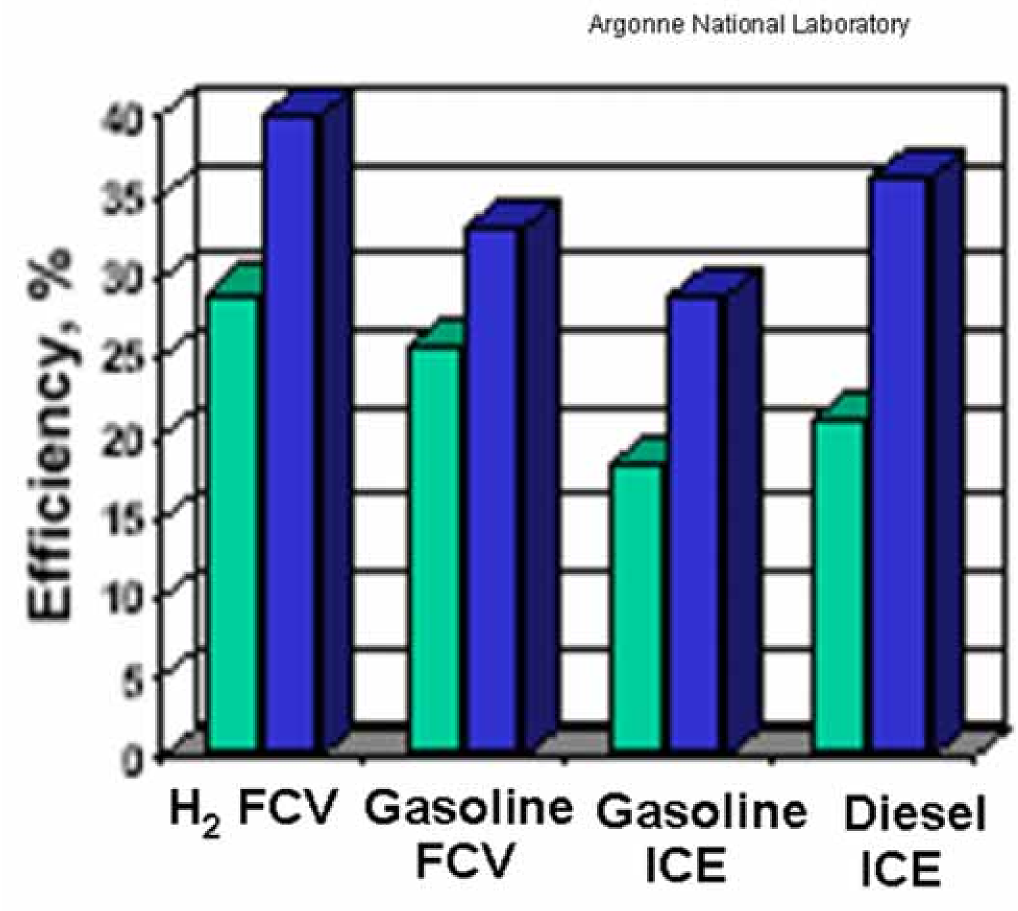
HCCI engines which combine features of diesel and gasoline systems may eventually be perfected to increase fuel efficiency and significantly reduce combustion pollutants.

While several technical obstacles remain to be overcome, several automobile manufactures are pursing development of this alternative.

Homogeneous Charge Compression Ignition Engine

Concerns about environmental impacts as well as efficiencies of various vehicle fuel options are beginning to influence public, industry and government technology preferences.

The Argonne National Laboratory Transportation Technology R&D Center estimates that fuel cell vehicles using hydrogen from natural gas (H2 FCV) and from gasoline (Gasoline FCV) will emit significantly less CO2 than conventional (reference) and future high performance gasoline and diesel internal combustion engine vehicles.



Engine Pollutant Emissions

Costs energy alternatives must be weighed against penalties of continued fossil fuel dependence.

- **Renewable source development can offer large economic, environmental and social rewards.**
- **Nuclear, wind, hydropower, geothermal and solar, along with clean coal, can reduce natural gas and oil consumption for electricity.**
- **Naturally-occurring organic processes can provide biofuels, fertilizers and chemical feedstocks.**
- **More efficient transportation and industry technologies can conserve energy and reduce environmental impacts.**

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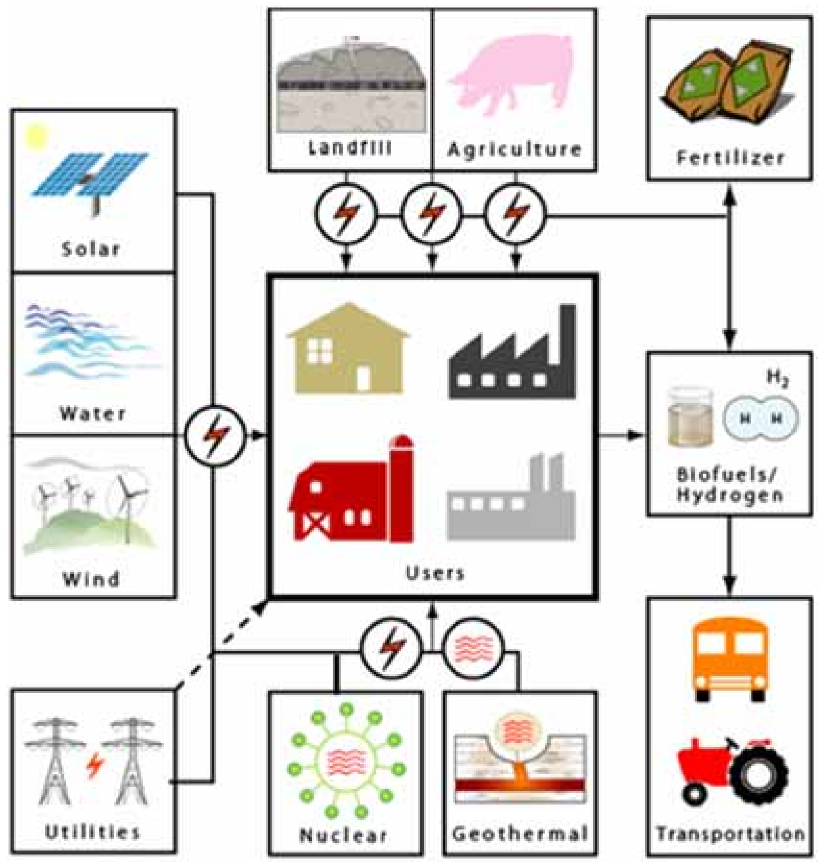
MSNBC

Real progress towards energy conservation and pollution reduction will require a combination of means:

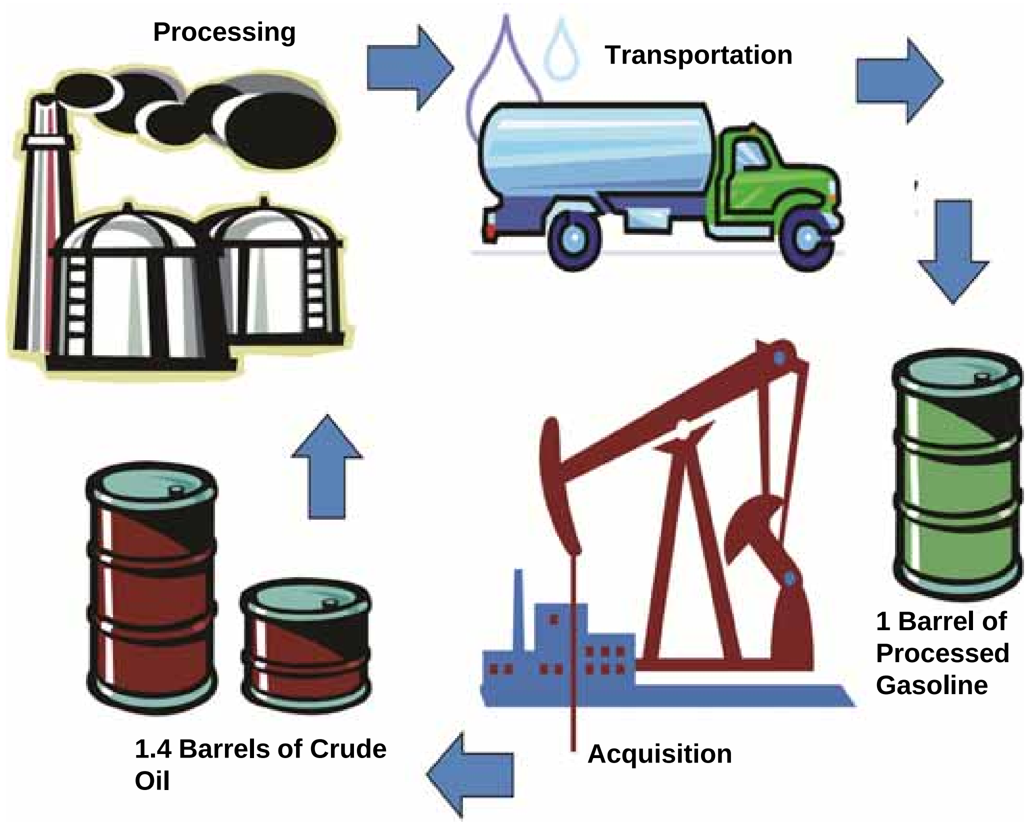
- **Nuclear and renewable energy use must be greatly expanded.**
- **Petroleum and natural gas must be shifted away from electricity and reserved for transportation and petrochemicals.**
- **Wind, water, solar and geothermal development must be accelerated.**
- **Biofuels and methane recovery must replace oil and natural gas for fuels and chemicals.**
- **All strategies require that we consume less and use resources more efficiently.**



Combined Resource Utilization

In the long run, every unit of energy saved pays large dividends by avoiding costs of production, conversion and distribution.

The EIA's Texas Energy Office estimates that every barrel of oil saved equals 1.4 barrels earned due to avoided costs of processing and transporting the energy.



Dividends of Conservation