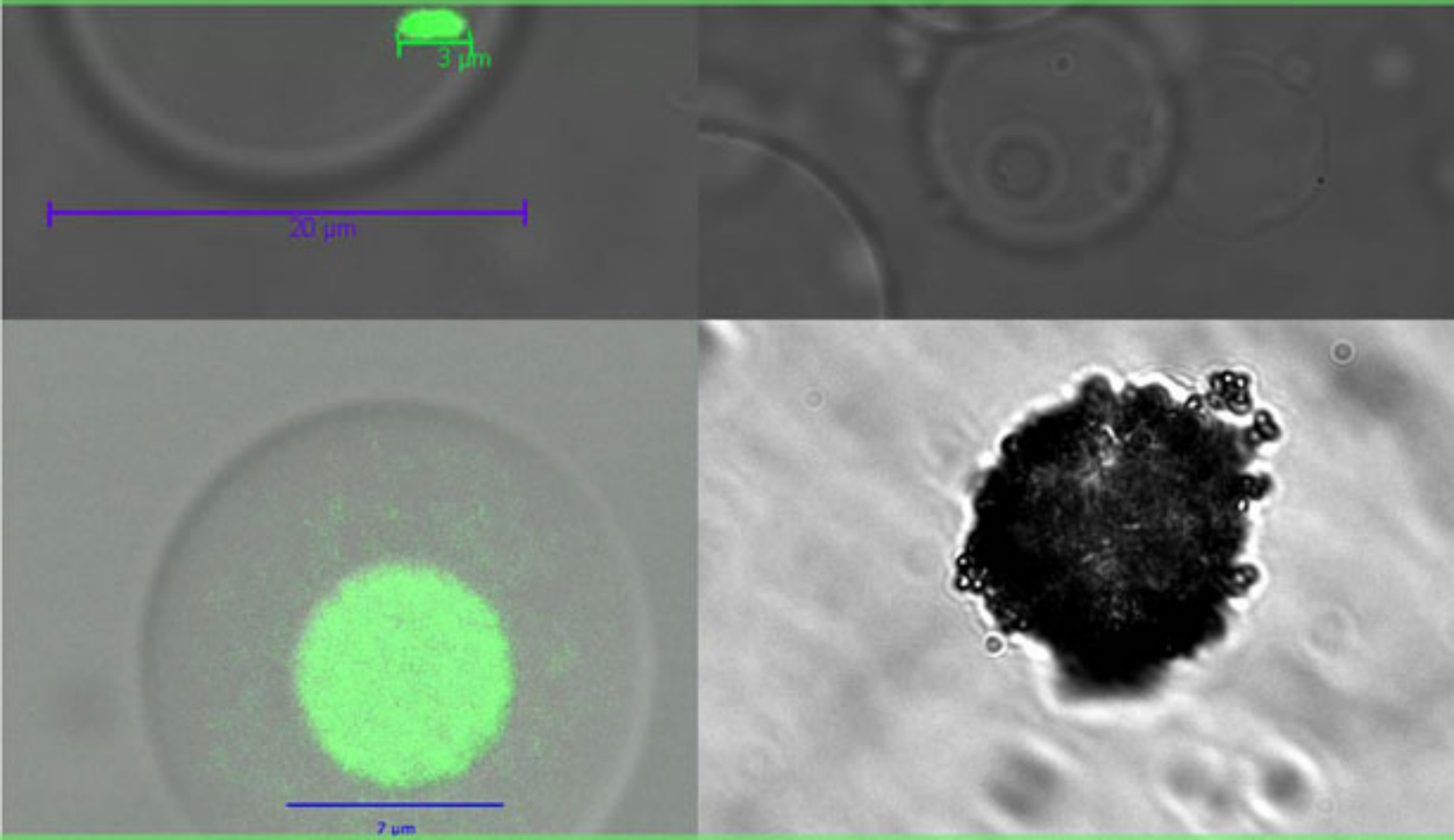
Essence of Environmental Biotechnology



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Introduction

Environmental biotechnology is when biotechnology is applied to and used to study the natural environment. Environmental biotechnology could also imply that one try to harness biological process for commercial uses and exploitation. The International Society for Environmental Biotechnology defines environmental biotechnology as "the development, use and regulation of biological systems for remediation of contaminated environments (land, air, water), and for environment-friendly processes (green manufacturing technologies and sustainable development)".

Environmental biotechnology can simply be described as "the optimal use of nature, in the form of plants, animals, bacteria, fungi and algae, to produce renewable energy, food and nutrients in a synergistic integrated cycle of profit making processes where the waste of each process becomes the feedstock for another process".

Significance towards agriculture, food security, climate change mitigation and adaptation and the MDGs

Science through the IAASTD has called for the advancement of small-scale agro-ecological farming systems and technology in order to achieve food security, climate change mitigation, climate change adaptation and the realisation of the Millennium Development Goals. Environmental biotechnology has been shown to play a significant roll in agroecology in the form of zero waste agriculture and most significantly through the operation of over 15 million biogas digesters worldwide.

Significance towards industrial biotechnology

Consider an environment in which pollution of a particular type is maximum. Let us consider the effluents of a starch industry (aka Sago industry) which has mixed up with a local water body like a lake or pond. We find huge deposits of starch which are not so easily taken up for degradation by micro-organisms except for a few exemptions. We isolate a few micro-organisms from the polluted site and scan for any significant changes in their genome like mutations or evolutions. The modified genes are then identified. This is done because, the isolate would have adapted itself to degrade/utilize the starch better than other microbes of the same genus. Thus, the resultant genes are cloned onto industrially significant micro-organisms and are used for more economically significant processess like in pharmaceutical industry, fermentations...etc.

Similar situations can be elucitated like in the case of oil spills in the oceans which require cleanup, microbes isolated from oil rich environments like oil wells, oil transfer

pipelines...etc have been found having the potential to degrade oil or use it as an energy source. Thus they serve as a remedy to oil spills.

Still another elucidation would be in the case of microbes isolated from pesticide rich soils These would be capable of utilizing the pesticides as energy source and hence when mixed along with bio-fertilizers, would serve as excellent insurance against increased pesticide-toxicity levels in agricultural platform.

But the counter argument would be that whether these newly introduced microorganisms would create an imbalance in the environment concerned.The mutual harmony in which the organisms in that particular environment existed may have to face alteration and we should be extremely careful so as to not disturb the mutual relationships already existing in the environment to which we are introducing the newly discovered and cloned microorganisms. Analysis of both the benefits and the disadvantages would pave way for an improvised version of environmental biotechnology. After all it is the environment that we strive to protect.

Chapter- 1

Biofuel

Information on pump regarding ethanol fuel blend up to 10%, California.

Bus run on biodiesel.

Biofuels are a wide range of fuels which are in some way derived from biomass. The term covers solid biomass, liquid fuels and various biogases. Biofuels are gaining increased public and scientific attention, driven by factors such as oil price spikes, the need for increased energy security, and concern over greenhouse gas emissions from fossil fuels.

Bioethanol is an alcohol made by fermenting the sugar components of plant materials and it is made mostly from sugar and starch crops. With advanced technology being developed, cellulosic biomass, such as trees and grasses, are also used as feedstocks for ethanol production. Ethanol can be used as a fuel for vehicles in its pure form, but it is usually used as a gasoline additive to increase octane and improve vehicle emissions. Bioethanol is widely used in the USA and in Brazil.

Biodiesel is made from vegetable oils, animal fats or recycled greases. Biodiesel can be used as a fuel for vehicles in its pure form, but it is usually used as a diesel additive to reduce levels of particulates, carbon monoxide, and hydrocarbons from diesel-powered vehicles. Biodiesel is produced from oils or fats using transesterification and is the most common biofuel in Europe.

Biofuels provided 1.8% of the world's transport fuel in 2008. Investment into biofuels production capacity exceeded $4 billion worldwide in 2007 and is growing.

Liquid fuels for transportation

Most transportation fuels are liquids, because vehicles usually require high energy density, as occurs in liquids and solids. High power density can be provided most inexpensively by an internal combustion engine; these engines require clean burning fuels, to keep the engine clean and minimize air pollution.

The fuels that are easiest to burn cleanly are typically liquids and gases. Thus liquids (and gases that can be stored in liquid form) meet the requirements of being both portable and clean burning. Also, liquids and gases can be pumped, which means handling is easily mechanized, and thus less laborious.

First generation biofuels

'First-generation biofuels' are biofuels made from sugar, starch, and vegetable oil.

Bioalcohols

Neat ethanol on the left (A), gasoline on the right (G) at a filling station in Brazil.

Biologically produced alcohols, most commonly ethanol, and less commonly propanol and butanol, are produced by the action of microorganisms and enzymes through the fermentation of sugars or starches (easiest), or cellulose (which is more difficult). Biobutanol (also called biogasoline) is often claimed to provide a direct replacement for gasoline, because it can be used directly in a gasoline engine (in a similar way to biodiesel in diesel engines).

Ethanol fuel is the most common biofuel worldwide, particularly in Brazil. Alcohol fuels are produced by fermentation of sugars derived from wheat, corn, sugar beets, sugar cane, molasses and any sugar or starch that alcoholic beverages can be made from (like potato and fruit waste, etc.). The ethanol production methods used are enzyme digestion (to release sugars from stored starches), fermentation of the sugars, distillation and drying. The distillation process requires significant energy input for heat (often unsustainable natural gas fossil fuel, but cellulosic biomass such as bagasse, the waste left after sugar cane is pressed to extract its juice, can also be used more sustainably).

The Koenigsegg CCXR Edition at the 2008 Geneva Motor Show. This is an "environmentally friendly" version of the CCX, which can use E85 and E100.

Ethanol can be used in petrol engines as a replacement for gasoline; it can be mixed with gasoline to any percentage. Most existing car petrol engines can run on blends of up to 15% bioethanol with petroleum/gasoline. Ethanol has a smaller energy density than gasoline, which means it takes more fuel (volume and mass) to produce the same amount of work. An advantage of ethanol (CH3CH2OH) is that it has a higher octane rating than ethanol-free gasoline available at roadside gas stations which allows an increase of an engine's compression ratio for increased thermal efficiency. In high altitude (thin air) locations, some states mandate a mix of gasoline and ethanol as a winter oxidizer to reduce atmospheric pollution emissions.

Ethanol is also used to fuel bioethanol fireplaces. As they do not require a chimney and are "flueless", bio ethanol fires are extremely useful for new build homes and apartments

without a flue. The downside to these fireplaces, is that the heat output is slightly less than electric and gas fires.

In the current alcohol-from-corn production model in the United States, considering the total energy consumed by farm equipment, cultivation, planting, fertilizers, pesticides, herbicides, and fungicides made from petroleum, irrigation systems, harvesting, transport of feedstock to processing plants, fermentation, distillation, drying, transport to fuel terminals and retail pumps, and lower ethanol fuel energy content, the net energy content value added and delivered to consumers is very small. And, the net benefit (all things considered) does little to reduce un-sustainable imported oil and fossil fuels required to produce the ethanol.

Although ethanol-from-corn and other food stocks has implications both in terms of world food prices and limited, yet positive energy yield (in terms of energy delivered to customer/fossil fuels used), the technology has led to the development of cellulosic ethanol. According to a joint research agenda conducted through the U.S. Department of Energy, the fossil energy ratios (FER) for cellulosic ethanol, corn ethanol, and gasoline are 10.3, 1.36, and 0.81, respectively.

Many car manufacturers are now producing flexible-fuel vehicles (FFV's), which can safely run on any combination of bioethanol and petrol, up to 100% bioethanol. They dynamically sense exhaust oxygen content, and adjust the engine's computer systems, spark, and fuel injection accordingly. This adds initial cost and ongoing increased vehicle maintenance. As with all vehicles, efficiency falls and pollution emissions increase when FFV system maintenance is needed (regardless of the fuel mix being used), but is not performed. FFV internal combustion engines are becoming increasingly complex, as are multiple-propulsion-system FFV hybrid vehicles, which impacts cost, maintenance, reliability, and useful lifetime longevity.

Even dry ethanol has roughly one-third lower energy content per unit of volume compared to gasoline, so larger / heavier fuel tanks are required to travel the same distance, or more fuel stops are required. With large current unsustainable, non-scalable subsidies, ethanol fuel still costs much more per distance traveled than current high gasoline prices in the United States.

Methanol is currently produced from natural gas, a non-renewable fossil fuel. It can also be produced from biomass as biomethanol. The methanol economy is an interesting alternative to get to the hydrogen economy, compared to today's hydrogen production from natural gas. But this process is not the state-of-the-art clean solar thermal energy process, where hydrogen production is directly produced from water.

Butanol is formed by ABE fermentation (acetone, butanol, ethanol) and experimental modifications of the process show potentially high net energy gains with butanol as the only liquid product. Butanol will produce more energy and allegedly can be burned "straight" in existing gasoline engines (without modification to the engine or car), and is less corrosive and less water soluble than ethanol, and could be distributed via existing

infrastructures. DuPont and BP are working together to help develop Butanol. E. coli have also been successfully engineered to produce Butanol by hijacking their amino acid metabolism.

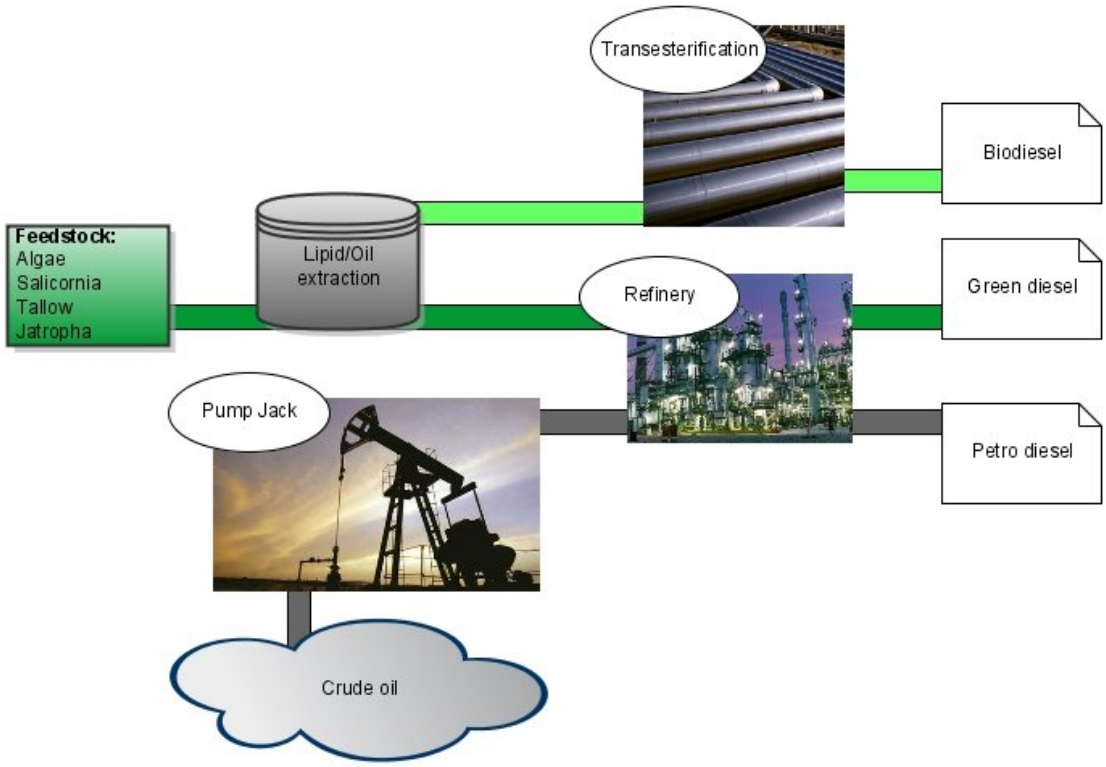
Fermentation is not the only route to forming biofuels or bioalcohols. One can obtain methanol, ethanol, butanol or mixed alcohol fuels through pyrolysis of biomass including agricultural waste or algal biomass. The most exciting of these pyrolysis alcoholic fuels is the pyrolysis biobutanol. The product can be made with limited water use and most places in the world.

Green diesel

Green diesel, also known as renewable diesel, is a form of diesel fuel which is derived from renewable feedstock rather than the fossil feedstock used in most diesel fuels. Green diesel feedstock can be sourced from a variety of oils including canola, algae, jatropha and salicornia in addition to tallow.

“Green Diesel” as commonly known in Ireland should not be confused with dyed green diesel sold at a lower tax rate for agriculture purposes, using the dye allows custom officers to determine if a person is using the cheaper diesel in higher taxed applications such as commercial haulage or cars.

Green diesel, also known as **renewable diesel**, is a form of diesel fuel which is derived from renewable feedstock by using biomass to liquid or vegetable oil refining technologies. Based on its feedstock it could be classified as biodiesel; however, based on the processing technology and chemical formula green diesel and biodiesel are different products. While biodiesel is processed using transesterification, green diesel is processed by the traditional fractional distillation like fossil origin diesel fuel (petrodiesel).



Inputs and outputs of diesel and diesel-like fuels

Feedstock

Green diesel feedstock can be sourced from a variety oils including canola, algae, jatropha and salicornia in addition to tallow.

Green diesel was used to power at least one vehicle during a transportation showcase at the 2009 United Nations Climate Change Conference in Copenhagen, Denmark in December 2009.

Also in December 2009, the South Dakota School of Mines and Technology received a $1M US grant from the United States government, in part to do research on green diesel, along with biodiesel and other bio fuel research for the United States Air Force.

“Green Diesel” as commonly known in Ireland should not be confused with dyed green diesel sold at a lower tax rate for off-road use, using the dye allows custom officers to determine if a person is using the cheaper diesel in higher taxed applications such as commercial haulage or cars.

Technology

At this stage the only commercial scale green diesel refinery process is the UOP/Eni "Ecofining" process.

Smaller scale refining can be carried out using technology from Renewable Fuel Products, Inc.

Biodiesel

In some countries biodiesel is less expensive than conventional diesel.

Biodiesel is the most common biofuel in Europe. It is produced from oils or fats using transesterification and is a liquid similar in composition to fossil/mineral diesel. Chemically, it consists mostly of fatty acid methyl (or ethyl) esters (FAMEs). Feedstocks

for biodiesel include animal fats, vegetable oils, soy, rapeseed, jatropha, mahua, mustard, flax, sunflower, palm oil, hemp, field pennycress, pongamia pinnata and algae. Pure biodiesel (B100) is the lowest emission diesel fuel. Although liquefied petroleum gas and hydrogen have cleaner combustion, they are used to fuel much less efficient petrol engines and are not as widely available.

Biodiesel can be used in any diesel engine when mixed with mineral diesel. In some countries manufacturers cover their diesel engines under warranty for B100 use, although Volkswagen of Germany, for example, asks drivers to check by telephone with the VW environmental services department before switching to B100. B100 may become more viscous at lower temperatures, depending on the feedstock used. In most cases, biodiesel is compatible with diesel engines from 1994 onwards, which use 'Viton' (by DuPont) synthetic rubber in their mechanical fuel injection systems.

Electronically controlled 'common rail' and 'unit injector' type systems from the late 1990s onwards may only use biodiesel blended with conventional diesel fuel. These engines have finely metered and atomized multi-stage injection systems that are very sensitive to the viscosity of the fuel. Many current generation diesel engines are made so that they can run on B100 without altering the engine itself, although this depends on the fuel rail design. Since biodiesel is an effective solvent and cleans residues deposited by mineral diesel, engine filters may need to be replaced more often, as the biofuel dissolves old deposits in the fuel tank and pipes. It also effectively cleans the engine combustion chamber of carbon deposits, helping to maintain efficiency. In many European countries, a 5% biodiesel blend is widely used and is available at thousands of gas stations. Biodiesel is also an oxygenated fuel, meaning that it contains a reduced amount of carbon and higher hydrogen and oxygen content than fossil diesel. This improves the combustion of fossil diesel and reduces the particulate emissions from un-burnt carbon.

Biodiesel is also safe to handle and transport because it is as biodegradable as sugar, 10 times less toxic than table salt, and has a high flash point of about 300 F (148 C) compared to petroleum diesel fuel, which has a flash point of 125 F (52 C).

In the USA, more than 80% of commercial trucks and city buses run on diesel. The emerging US biodiesel market is estimated to have grown 200% from 2004 to 2005. "By the end of 2006 biodiesel production was estimated to increase fourfold [from 2004] to more than 1 billion gallons".

Vegetable oil

Filtered waste vegetable oil.

Straight unmodified edible vegetable oil is generally not used as fuel, but lower quality oil can be used for this purpose. Used vegetable oil is increasingly being processed into biodiesel, or (more rarely) cleaned of water and particulates and used as a fuel.

Also here, as with 100% biodiesel (B100), to ensure that the fuel injectors atomize the vegetable oil in the correct pattern for efficient combustion, vegetable oil fuel must be heated to reduce its viscosity to that of diesel, either by electric coils or heat exchangers. This is easier in warm or temperate climates. Big corporations like MAN B&W Diesel, Wärtsilä and Deutz AG as well as a number of smaller companies such as Elsbett offer engines that are compatible with straight vegetable oil, without the need for after-market modifications.

Vegetable oil can also be used in many older diesel engines that do not use common rail or unit injection electronic diesel injection systems. Due to the design of the combustion chambers in indirect injection engines, these are the best engines for use with vegetable oil. This system allows the relatively larger oil molecules more time to burn. Some older engines, especially Mercedes are driven experimentally by enthusiasts without any conversion, a handful of drivers have experienced limited success with earlier pre-"Pumpe Duse" VW TDI engines and other similar engines with direct injection. Several

companies like Elsbett or Wolf have developed professional conversion kits and successfully installed hundreds of them over the last decades.

Oils and fats can be hydrogenated to give a diesel substitute. The resulting product is a straight chain hydrocarbon, high in cetane, low in aromatics and sulfur and does not contain oxygen. Hydrogenated oils can be blended with diesel in all proportions Hydrogenated oils have several advantages over biodiesel, including good performance at low temperatures, no storage stability problems and no susceptibility to microbial attack.

Bioethers

Bio ethers (also referred to as fuel ethers or oxygenated fuels) are cost-effective compounds that act as octane rating enhancers. They also enhance engine performance, whilst significantly reducing engine wear and toxic exhaust emissions. Greatly reducing the amount of ground-level ozone, they contribute to the quality of the air we breathe.

Biogas

Pipes carrying biogas

Biogas is methane produced by the process of anaerobic digestion of organic material by anaerobes. It can be produced either from biodegradable waste materials or by the use of energy crops fed into anaerobic digesters to supplement gas yields. The solid byproduct, digestate, can be used as a biofuel or a fertilizer.

- Biogas can be recovered from mechanical biological treatment waste processing systems.

Note:Landfill gas is a less clean form of biogas which is produced in landfills through naturally occurring anaerobic digestion. If it escapes into the atmosphere it is a potential greenhouse gas.

- Farmers can produce biogas from manure from their cows by getting a anaerobic digester (AD).

Syngas

Syngas, a mixture of carbon monoxide and hydrogen, is produced by partial combustion of biomass, that is, combustion with an amount of oxygen that is not sufficient to convert the biomass completely to carbon dioxide and water. Before partial combustion the biomass is dried, and sometimes pyrolysed. The resulting gas mixture, syngas, is more efficient than direct combustion of the original biofuel; more of the energy contained in the fuel is extracted.

- Syngas may be burned directly in internal combustion engines or turbines. The wood gas generator is a wood-fueled gasification reactor mounted on an internal combustion engine.
- Syngas can be used to produce methanol, DME and hydrogen, or converted via the Fischer-Tropsch process to produce a diesel substitute, or a mixture of alcohols that can be blended into gasoline. Gasification normally relies on temperatures >700°C.
- Lower temperature gasification is desirable when co-producing biochar but results in a Syngas polluted with tar.

Solid biofuels

Examples include wood, sawdust, grass cuttings, domestic refuse, charcoal, agricultural waste, non-food energy crops (see picture), and dried manure.

When raw biomass is already in a suitable form (such as firewood), it can burn directly in a stove or furnace to provide heat or raise steam. When raw biomass is in an inconvenient form (such as sawdust, wood chips, grass, urban waste wood, agricultural residues), the typical process is to densify the biomass. This process includes grinding the raw biomass to an appropriate particulate size (known as hogfuel), which depending on the densification type can be from 1 to 3 cm (1 in), which is then concentrated into a fuel product. The current types of processes are wood pellet, cube, or puck. The pellet process is most common in Europe and is typically a pure wood product. The other types of densification are larger in size compared to a pellet and are compatible with a broad range of input feedstocks. The resulting densified fuel is easier to transport and feed into thermal generation systems such as boilers.

A problem with the combustion of raw biomass is that it emits considerable amounts of pollutants such as particulates and PAHs (polycyclic aromatic hydrocarbons). Even modern pellet boilers generate much more pollutants than oil or natural gas boilers.

Pellets made from agricultural residues are usually worse than wood pellets, producing much larger emissions of dioxins and chlorophenols.

Notwithstanding the above noted study, numerous studies have shown that biomass fuels have significantly less impact on the environment than fossil based fuels. Of note is the U.S. Department of Energy Laboratory, Operated by Midwest Research Institute Biomass Power and Conventional Fossil Systems with and without CO2 Sequestration – Comparing the Energy Balance, Greenhouse Gas Emissions and Economics Study. Power generation emits significant amounts of greenhouse gases (GHGs), mainly carbon dioxide (CO_2). Sequestering CO_2 from the power plant flue gas can significantly reduce the GHGs from the power plant itself, but this is not the total picture. CO_2 capture and sequestration consumes additional energy, thus lowering the plant's fuel-to-electricity efficiency. To compensate for this, more fossil fuel must be procured and consumed to make up for lost capacity.

Taking this into consideration, the global warming potential (GWP), which is a combination of CO_2, methane (CH_4), and nitrous oxide (N_2O) emissions, and energy balance of the system need to be examined using a life cycle assessment. This takes into account the upstream processes which remain constant after CO_2 sequestration as well as the steps required for additional power generation. firing biomass instead of coal led to a 148% reduction in GWP.

A derivative of solid biofuel is biochar, which is produced by biomass pyrolysis. Bio-char made from agricultural waste can substitute for wood charcoal. As wood stock becomes scarce this alternative is gaining ground. In eastern Democratic Republic of Congo, for example, biomass briquettes are being marketed as an alternative to charcoal in order to protect Virunga National Park from deforestation associated with charcoal production.

Second generation biofuels

Supporters of biofuels claim that a more viable solution is to increase political and industrial support for, and rapidity of, second-generation biofuel implementation from non-food crops. These include waste biomass, the stalks of wheat, corn, wood, and special-energy-or-biomass crops (e.g. Miscanthus). Second generation (2G) biofuels use biomass to liquid technology, including cellulosic biofuels. Many second generation biofuels are under development such as biohydrogen, biomethanol, DMF, BioDME, Fischer-Tropsch diesel, biohydrogen diesel, mixed alcohols and wood diesel.

Cellulosic ethanol production uses non-food crops or inedible waste products and does not divert food away from the animal or human food chain. Lignocellulose is the "woody" structural material of plants. This feedstock is abundant and diverse, and in some cases (like citrus peels or sawdust) it is in itself a significant disposal problem.

Producing ethanol from cellulose is a difficult technical problem to solve. In nature, ruminant livestock (like cattle) eat grass and then use slow enzymatic digestive processes

to break it into glucose (sugar). In cellulosic ethanol laboratories, various experimental processes are being developed to do the same thing, and then the sugars released can be fermented to make ethanol fuel. In 2009 scientists reported developing, using "synthetic biology", "15 new highly stable fungal enzyme catalysts that efficiently break down cellulose into sugars at high temperatures", adding to the 10 previously known. The use of high temperatures, has been identified as an important factor in improving the overall economic feasibility of the biofuel industry and the identification of enzymes that are stable and can operate efficiently at extreme temperatures is an area of active research. In addition, research conducted at TU Delft by Jack Pronk has shown that elephant yeast, when slightly modified can also create ethanol from non-edible ground sources (e.g. straw).

The recent discovery of the fungus Gliocladium roseum points toward the production of so-called myco-diesel from cellulose. This organism was recently discovered in the rainforests of northern Patagonia and has the unique capability of converting cellulose into medium length hydrocarbons typically found in diesel fuel. Scientists also work on experimental recombinant DNA genetic engineering organisms that could increase biofuel potential.

Scientists working in New Zealand have developed a technology to use industrial waste gases from steel mills as a feedstock for a microbial fermentation process to produce ethanol.

Second, third, and fourth generation biofuels are also called advanced biofuels.

Third generation biofuels

Algae fuel, also called oilgae or third generation biofuel, is a biofuel from algae. Algae are low-input, high-yield feedstocks to produce biofuels. Based on laboratory experiments, it is claimed that algae can produce up to 30 times more energy per acre than land crops such as soybeans, but these yields have yet to be produced commercially. With the higher prices of fossil fuels (petroleum), there is much interest in algaculture (farming algae). One advantage of many biofuels over most other fuel types is that they are biodegradable, and so relatively harmless to the environment if spilled. Algae fuel still has its difficulties though, for instance to produce algae fuels it must be mixed uniformly, which, if done by agitation, could affect biomass growth.

The United States Department of Energy estimates that if algae fuel replaced all the petroleum fuel in the United States, it would require only 15,000 square miles (38,849 square kilometers), which is roughly the size of Maryland, or less than one seventh the amount of land devoted to corn in 2000.

Algae, such as Botryococcus braunii and Chlorella vulgaris are relatively easy to grow, but the algal oil is hard to extract. There are several approaches, some of which work better than others. Macroalgae (seaweed) also have a great potential for bioethanol and biogas production.

Ethanol from living algae

Most biofuel production comes from harvesting organic matter and then converting it to fuel but an alternative approach relies on the fact that some algae naturally produce ethanol and this can be collected without killing the algae. The ethanol evaporates and then can be condensed and collected. The company Algenol is trying to commercialize this process.

Fourth generation biofuels

A number of companies are pursuing advanced "bio-chemical" and "thermo-chemical" processes that produce "drop in" fuels like "green gasoline," "green diesel," and "green aviation fuel." While there is no one established definition of "fourth-generation biofuels," some have referred to it as the biofuels created from processes other than first generation ethanol and biodiesel, second generation cellulosic ethanol, and third generation algae biofuel. Some fourth generation technology pathways include: pyrolysis, gasification, upgrading, solar-to-fuel, and genetic manipulation of organisms to secrete hydrocarbons.

- GreenFuel Technologies Corporation developed a patented bioreactor system that uses nontoxic photosynthetic algae to take in smokestacks flue gases and produce biofuels such as biodiesel, biogas and a dry fuel comparable to coal.
- With thermal depolymerization of biological waste one can extract methane and other oils similar to petroleum.

Hydrocarbon plants or petroleum plants are plants which produce terpenoids as secondary metabolites that can be converted to gasoline-like fuels. Latex producing members of the Euphorbiaceae such as Euphorbia lathyris and E. tirucalli and members of Apocynaceae have been studied for their potential energy uses.

Green fuels

However, if biocatalytic cracking and traditional fractional distillation are used to process properly prepared algal biomass i.e. biocrude, then as a result we receive the following distillates: jet fuel, gasoline, diesel, etc.. Hence, we may call them third generation or green fuels.

Biofuels by region

There are international organizations such as IEA Bioenergy, established in 1978 by the OECD International Energy Agency (IEA), with the aim of improving cooperation and information exchange between countries that have national programs in bioenergy research, development and deployment. The U.N. International Biofuels Forum is formed by Brazil, China, India, South Africa, the United States and the European Commission.

The world leaders in biofuel development and use are Brazil, United States, France, Sweden and Germany.

Issues with biofuel production and use

There are various social, economic, environmental and technical issues with biofuel production and use, which have been discussed in the popular media and scientific journals. These include: the effect of moderating oil prices, the "food vs fuel" debate, poverty reduction potential, carbon emissions levels, sustainable biofuel production, deforestation and soil erosion, loss of biodiversity, impact on water resources, as well as energy balance and efficiency.

Chapter- 2

Second Generation Biofuels

Second generation biofuels are derived from lignocellulosic crops. Plants are made from lignin and cellulose, second generation technology allows these two components of a plant to be split. Then the cellulose can be fermented into alcohol in much the same way as a first generation biofuel.

These biofuels can be manufactured from various types of biomass. Biomass is a wide-ranging term meaning any source of organic carbon that is renewed rapidly as part of the carbon cycle. Biomass is all derived from plant materials but can also include animal materials.

Second Generation Technology

Second generation biofuel technologies have been developed because first generation biofuels manufacture has important limitations. First generation biofuel processes are useful, but limited in most cases: there is a threshold above which they cannot produce enough biofuel without threatening food supplies and biodiversity. Many first generation biofuels are dependent of subsidies and are not cost competitive with existing fossil fuels such as oil, and some of them produce only limited greenhouse gas emissions savings. When taking emissions from production and transport into account, life cycle assessment from first-generation biofuels frequently exceed those of traditional fossil fuels.

Second generation biofuels can help solve these problems and can supply a larger proportion of our fuel supply sustainably, affordably, and with greater environmental benefits.

First generation bioethanol is produced by fermenting plant-derived sugars to ethanol, using a similar process to that used in beer and wine-making. This requires the use of 'food' crops such as sugar cane, corn, wheat, and sugar beet. These crops are required for food, so if too much biofuel is made from them, food prices could rise and shortages might be experienced in some countries. Corn, wheat and sugar beet also require high agricultural inputs in the form of fertilizers, which limit the greenhouse gas reductions that can be achieved.

The goal of second generation biofuel processes is to extend the amount of biofuel that can be produced sustainably by using biomass consisting of the residual non-food parts of

current crops, such as stems, leaves and husks that are left behind once the food crop has been extracted, as well as other crops that are not used for food purposes (non food crops), such as switchgrass, jatropha, miscanthus and cereals that bear little grain, and also industry waste such as woodchips, skins and pulp from fruit pressing, etc.

The problem that second generation biofuel processes are addressing is to extract useful feedstocks from this woody or fibrous biomass, where the useful sugars are locked in by lignin and cellulose. All plants contain cellulose and lignin. These are complex carbohydrates (molecules based on sugar). Lignocellulosic ethanol is made by freeing the sugar molecules from cellulose using enzymes, steam heating, or other pre-treatments. These sugars can then be fermented to produce ethanol in the same way as first generation bioethanol production. The by-product of this process is lignin. Lignin can be burned as a carbon neutral fuel to produce heat and power for the processing plant and possibly for surrounding homes and businesses.

Types of biofuel

The following second generation biofuels are under development:

- Bio-synthetic liquid fuel might be available; such a fuel can be produced by the Fischer-Tropsch process a Gas-to-Liquid (GtL) process. When biomass is the source of the gas production the process is also referred to as Biomass-To-Liquids (BTL).
- Biohydrogen. Biohydrogen is the same as hydrogen except it is produced from a biomass feedstock. This is done using gasification of the biomass and then reforming the methane produced, or alternatively, this might be accomplished with some organisms that produce hydrogen directly under certain conditions. BioHydrogen can be used in fuel cells to produce electricity.
- BioDME. BioDME, Fischer-Tropsch, BioHydrogen diesel, Biomethanol and Mixed Alcohols all use syngas for production. This syngas is produced by gasification of biomass. HTU (High Temperature Upgrading) diesel is produced from particularly wet biomass stocks using high temperature and pressure to produce an oil. It is the same as DME but is produced from bio-sources. BioDME can be produced from Biomethanol using catalytic dehydration or it can be produced from syngas using DME synthesis. DME can be used in the compression ignition engine.
- Biomethanol. Biomethanol is the same as methanol but it is produced from biomass. Biomethanol can be blended with petrol up to 10-20% without any infrastructure changes.
- Butanol and Isobutanol. Via recombinant pathways expressed in hosts such as E. coli and yeast, butanol and isobutanol may be significant products of fermentation using glucose as a carbon and energy source.
- DMF. Recent advances in producing DMF from fructose and glucose using catalytic biomass-to-liquid process have increased its attractiveness.
- HTU diesel. HTU diesel is produced from wet biomass. It can be mixed with fossil diesel in any percentage without need for infrastructure.

- Fischer-Tropsch (FT) fuels. FT diesel is produced using the Fischer-Tropsch gas-to-liquids technology. In case biomass is used to produce hydrogen and CO, the reactants in the FT process, the carbon stays in a closed cycle. Disadvantage of this process is the high energy investment for the FT synthesis and consequently, the process is not yet economic. FT diesel can be mixed with fossil diesel at any percentage without need for infrastructure change and moreover, synthetic kerosene can be produced
- Mixed Alcohols (i.e., mixture of mostly ethanol, propanol and butanol, with some pentanol, hexanol, heptanol and octanol). Mixed alcohols are produced from syngas with catalysts similar to those used for methanol. Most R&D in this area is concentrated in producing mostly ethanol. However, some fuels are marketed as mixed alcohols Mixed alcohols are superior to pure methanol or ethanol, in that the higher alcohols have higher energy content. Also, when blending, the higher alcohols increase compatibility of gasoline and ethanol, which increases water tolerance and decreases evaporative emissions. In addition, higher alcohols have also lower heat of vaporization than ethanol, which is important for cold starts.
- Wood diesel. A new biofuel was developed by the University of Georgia from woodchips. The oil is extracted and then added to unmodified diesel engines. Either new plants are used or planted to replace the old plants. The charcoal byproduct is put back into the soil as a fertilizer. According to the director Tom Adams since carbon is put back into the soil, this biofuel can actually be carbon negative not just carbon neutral. Carbon negative decreases carbon dioxide in the air reversing the greenhouse effect not just reducing it.

Feedstocks

In theory, any lignocellulosic crop can be used for second generation biofuel production. Common lignocellulosic energy crops include wheat straw, Miscanthus, short rotation coppice poplar and willow. However, each offers different opportunities and no one crop can be considered 'best' or 'worst'.

Greenhouse gas emissions

Producing lignocellulosic ethanol offers greater greenhouse gas emissions savings than those obtained by first generation biofuels. Lignocellulosic ethanol can reduce greenhouse gas emissions by around 90% when compared with fossil petroleum, in contrast first generation biofuels offer savings of only 20-70%

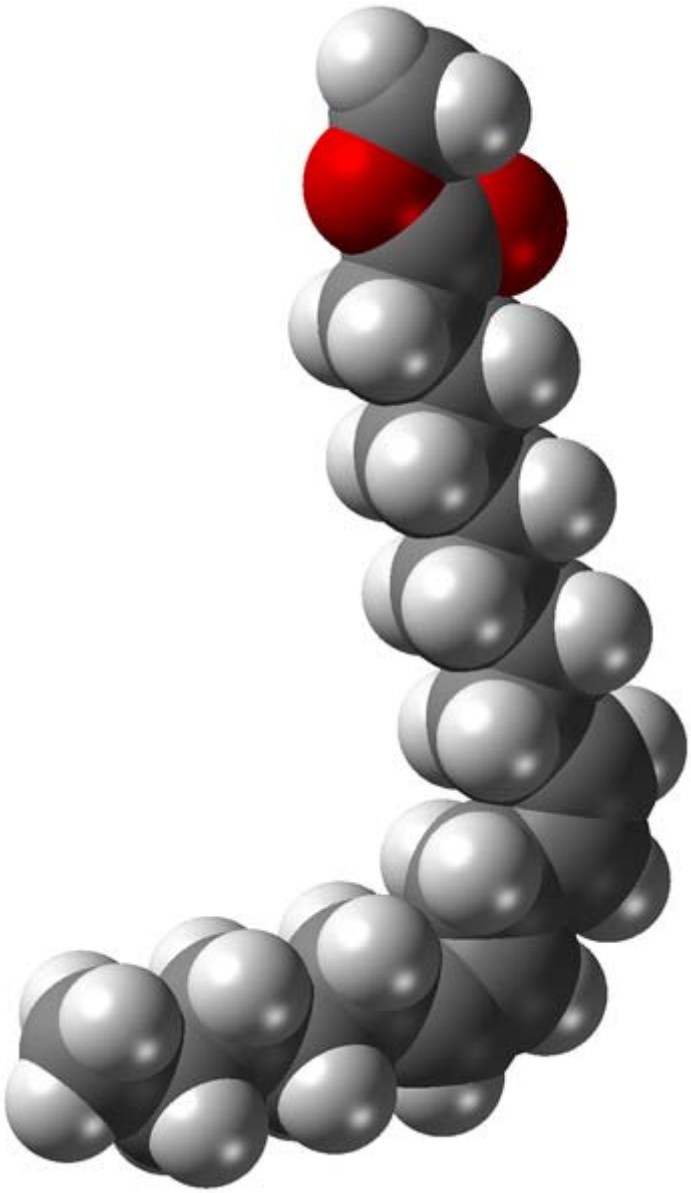
Examples

An operating lignocellulosic ethanol production plant is located in Canada, run by IOGEN Corporation. The demonstration-scale plant produces around 700,000 litres of bioethanol each year. A commercial plant is under construction. Many further lignocellulosic ethanol plants have been proposed in North America and around the world.

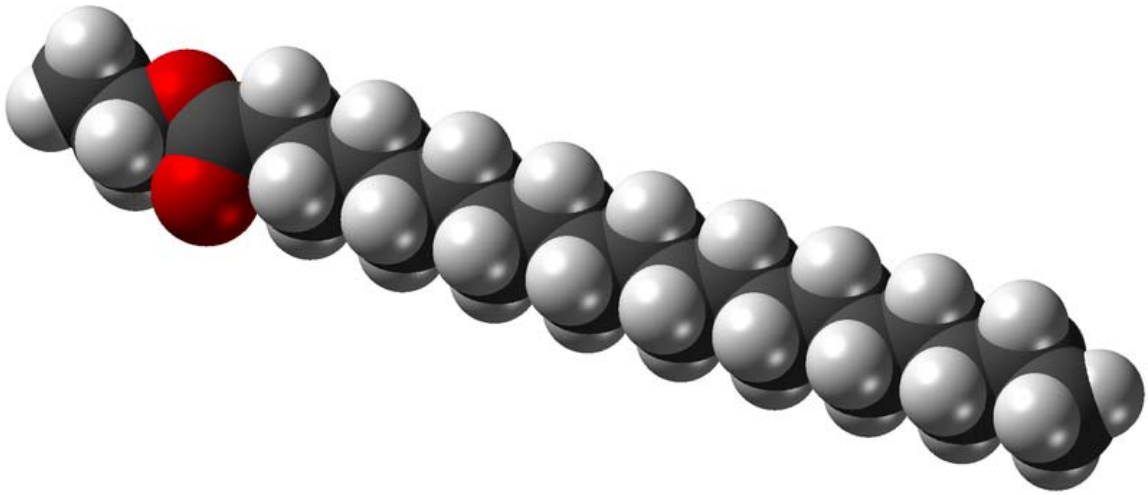
Chapter- 3

Biodiesel

Bus run by biodiesel



Space-filling model of methyl linoleate, or linoleic acid methyl ester, a common methyl ester produced from soybean or canola oil and methanol



Space-filling model of ethyl stearate, or stearic acid ethyl ester, an ethyl ester produced from soybean or canola oil and ethanol

Biodiesel refers to a vegetable oil- or animal fat-based diesel fuel consisting of long-chain alkyl (methyl, propyl or ethyl) esters. Biodiesel is typically made by chemically reacting lipids (e.g., vegetable oil, animal fat (tallow)) with an alcohol.

Biodiesel is meant to be used in standard diesel engines and is thus distinct from the vegetable and waste oils used to fuel converted diesel engines. Biodiesel can be used alone, or blended with petrodiesel.

The National Biodiesel Board (USA) also has a technical definition of "biodiesel" as a mono-alkyl ester.

Blends

Biodiesel sample

Blends of biodiesel and conventional hydrocarbon-based diesel are products most commonly distributed for use in the retail diesel fuel marketplace. Much of the world uses a system known as the "B" factor to state the amount of biodiesel in any fuel mix:

- 100% biodiesel is referred to as **B100**, while
- 20% biodiesel is labeled **B20**
- 5% biodiesel is labeled **B5**
- 2% biodiesel is labeled **B2**

Obviously, the higher the percentage of biodiesel, the more ecology-friendly the fuel is. It is common in the USA to see **B99.9** because a federal tax credit is awarded to the first

entity which blends petroleum diesel with pure biodiesel. Blends of 20 percent biodiesel with 80 percent petroleum diesel (B20) can generally be used in unmodified diesel engines. Biodiesel can also be used in its pure form (B100), but may require certain engine modifications to avoid maintenance and performance problems. Blending B100 with petroleum diesel may be accomplished by:

- Mixing in tanks at manufacturing point prior to delivery to tanker truck
- Splash mixing in the tanker truck (adding specific percentages of Biodiesel and petroleum diesel)
- In-line mixing, two components arrive at tanker truck simultaneously.
- Metered pump mixing, petroleum diesel and Biodiesel meters are set to X total volume, transfer pump pulls from two points and mix is complete on leaving pump.

Applications

Biodiesel can be used in pure form (B100) or may be blended with petroleum diesel at any concentration in most injection pump diesel engines. New extreme high pressure (29,000 psi) common rail engines have strict factory limits of B5 or B20 depending on manufacturer. Biodiesel has different solvent properties than petrodiesel, and will degrade natural rubber gaskets and hoses in vehicles (mostly vehicles manufactured before 1992), although these tend to wear out naturally and most likely will have already been replaced with FKM, which is nonreactive to biodiesel. Biodiesel has been known to break down deposits of residue in the fuel lines where petrodiesel has been used. As a result, fuel filters may become clogged with particulates if a quick transition to pure biodiesel is made. Therefore, it is recommended to change the fuel filters on engines and heaters shortly after first switching to a biodiesel blend.

Distribution

Since the passage of the Energy Policy Act of 2005 biodiesel use has been increasing in the United States. In the UK, the Renewable Transport Fuel Obligation obliges suppliers to include 5% renewable fuel in all transport fuel sold in the UK by 2010. For road diesel, this effectively means 5% biodiesel.

Vehicular use and manufacturer acceptance

In 2005, Chrysler (then part of DaimlerChrysler) released the Jeep Liberty CRD diesels from the factory into the American market with 5% biodiesel blends, indicating at least partial acceptance of biodiesel as an acceptable diesel fuel additive. In 2007, DaimlerChrysler indicated intention to increase warranty coverage to 20% biodiesel blends if biofuel quality in the United States can be standardized.

Starting in 2004, the city of Halifax, Nova Scotia decided to update its bus system to allow the fleet of city buses to run entirely on a fish-oil based biodiesel. This caused the

city some initial mechanical issues but after several years of refining, the entire fleet had successfully been converted.

In 2007, McDonalds of UK announced that it would start producing biodiesel from the waste oil byproduct of its restaurants. This fuel would be used to run its fleet.

Railway usage

British Train Operating Company Virgin Trains claimed to have run the world's first "biodiesel train", which was converted to run on 80% petrodiesel and only 20% biodiesel, and it is claimed it will save 14% on direct emissions.

The Royal Train on 15 September 2007 completed its first ever journey run on 100% biodiesel fuel supplied by Green Fuels Ltd. His Royal Highness, The Prince of Wales, and Green Fuels managing director, James Hygate, were the first passengers on a train fueled entirely by biodiesel fuel. Since 2007 the Royal Train has operated successfully on B100 (100% biodiesel).

Similarly, a state-owned short-line railroad in Eastern Washington ran a test of a 25% biodiesel / 75% petrodiesel blend during the summer of 2008, purchasing fuel from a biodiesel producer seated along the railroad tracks. The train will be powered by biodiesel made in part from canola grown in agricultural regions through which the short line runs.

Also in 2007 Disneyland began running the park trains on B98 biodiesel blends (98% biodiesel). The program was discontinued in 2008 due to storage issues, but in January 2009 it was announced that the park would then be running all trains on biodiesel manufactured from its own used cooking oils. This is a change from running the trains on soy-based biodiesel.

Aircraft use

A test flight has been performed by a Czech jet aircraft completely powered on biodiesel. Other recent jet flights using biofuel, however, have been using other types of renewable fuels.

As a heating oil

Biodiesel can also be used as a heating fuel in domestic and commercial boilers, a mix of heating oil and biofuel which is standardized and taxed slightly differently than diesel fuel used for transportation. It is sometimes known as "bioheat" (which is a registered trademark of the National Biodiesel Board [NBB] and the National Oilheat Research Alliance [NORA] in the U.S., and Columbia Fuels in Canada). Heating biodiesel is available in various blends; up to 20% biofuel is considered acceptable for use in existing furnaces without modification.

Older furnaces may contain rubber parts that would be affected by biodiesel's solvent properties, but can otherwise burn biodiesel without any conversion required. Care must be taken, however, given that varnishes left behind by petrodiesel will be released and can clog pipes- fuel filtering and prompt filter replacement is required. Another approach is to start using biodiesel as blend, and decreasing the petroleum proportion over time can allow the varnishes to come off more gradually and be less likely to clog. Thanks to its strong solvent properties, however, the furnace is cleaned out and generally becomes more efficient. A technical research paper describes laboratory research and field trials project using pure biodiesel and biodiesel blends as a heating fuel in oil fired boilers. During the Biodiesel Expo 2006 in the UK, Andrew J. Robertson presented his biodiesel heating oil research from his technical paper and suggested that B20 biodiesel could reduce UK household CO_2 emissions by 1.5 million tons per year.

A law passed under Massachusetts Governor Deval Patrick requires all home heating diesel in that state to be 2% biofuel by July 1, 2010, and 5% biofuel by 2013.

Historical background

Transesterification of a vegetable oil was conducted as early as 1853 by scientists E. Duffy and J. Patrick, many years before the first diesel engine became functional. Rudolf Diesel's prime model, a single 10 ft (3 m) iron cylinder with a flywheel at its base, ran on its own power for the first time in Augsburg, Germany, on 10 August 1893 running on nothing but peanut oil. In remembrance of this event, 10 August has been declared "International Biodiesel Day".

It is often reported that Diesel designed his engine to run on peanut oil, but this is not the case. Diesel stated in his published papers, "at the Paris Exhibition in 1900 (Exposition Universelle) there was shown by the Otto Company a small Diesel engine, which, at the request of the French government ran on arachide (earth-nut or pea-nut) oil, and worked so smoothly that only a few people were aware of it. The engine was constructed for using mineral oil, and was then worked on vegetable oil without any alterations being made. The French Government at the time thought of testing the applicability to power production of the Arachide, or earth-nut, which grows in considerable quantities in their African colonies, and can easily be cultivated there." Diesel himself later conducted related tests and appeared supportive of the idea. In a 1912 speech Diesel said, "the use of vegetable oils for engine fuels may seem insignificant today but such oils may become, in the course of time, as important as petroleum and the coal-tar products of the present time."

Despite the widespread use of fossil petroleum-derived diesel fuels, interest in vegetable oils as fuels for internal combustion engines was reported in several countries during the 1920s and 1930s and later during World War II. Belgium, France, Italy, the United Kingdom, Portugal, Germany, Brazil, Argentina, Japan and China were reported to have tested and used vegetable oils as diesel fuels during this time. Some operational problems were reported due to the high viscosity of vegetable oils compared to petroleum diesel fuel, which results in poor atomization of the fuel in the fuel spray and often leads to

deposits and coking of the injectors, combustion chamber and valves. Attempts to overcome these problems included heating of the vegetable oil, blending it with petroleum-derived diesel fuel or ethanol, pyrolysis and cracking of the oils.

On 31 August 1937, G. Chavanne of the University of Brussels (Belgium) was granted a patent for a "Procedure for the transformation of vegetable oils for their uses as fuels" (fr. "Procédé de Transformation d'Huiles Végétales en Vue de Leur Utilisation comme Carburants") Belgian Patent 422,877. This patent described the alcoholysis (often referred to as transesterification) of vegetable oils using ethanol (and mentions methanol) in order to separate the fatty acids from the glycerol by replacing the glycerol with short linear alcohols. This appears to be the first account of the production of what is known as "biodiesel" today.

More recently, in 1977, Brazilian scientist Expedito Parente invented and submitted for patent, the first industrial process for the production of biodiesel. This process is classified as biodiesel by international norms, conferring a "standardized identity and quality. No other proposed biofuel has been validated by the motor industry." Currently, Parente's company Tecbio is working with Boeing and NASA to certify bioquerosene (bio-kerosene), another product produced and patented by the Brazilian scientist.

Research into the use of transesterified sunflower oil, and refining it to diesel fuel standards, was initiated in South Africa in 1979. By 1983, the process for producing fuel-quality, engine-tested biodiesel was completed and published internationally. An Austrian company, Gaskoks, obtained the technology from the South African Agricultural Engineers; the company erected the first biodiesel pilot plant in November 1987, and the first industrial-scale plant in April 1989 (with a capacity of 30,000 tons of rapeseed per annum).

Throughout the 1990s, plants were opened in many European countries, including the Czech Republic, Germany and Sweden. France launched local production of biodiesel fuel (referred to as diester) from rapeseed oil, which is mixed into regular diesel fuel at a level of 5%, and into the diesel fuel used by some captive fleets (e.g. public transportation) at a level of 30%. Renault, Peugeot and other manufacturers have certified truck engines for use with up to that level of partial biodiesel; experiments with 50% biodiesel are underway. During the same period, nations in other parts of the world also saw local production of biodiesel starting up: by 1998, the Austrian Biofuels Institute had identified 21 countries with commercial biodiesel projects. 100% Biodiesel is now available at many normal service stations across Europe.

In September 2005 Minnesota became the first U.S. state to mandate that all diesel fuel sold in the state contain part biodiesel, requiring a content of at least 2% biodiesel.

In 2008, ASTM published new Biodiesel Blend Specifications Standards.

Properties

Biodiesel has better lubricating properties and much higher cetane ratings than today's lower sulfur diesel fuels. Biodiesel addition reduces fuel system wear, and in low levels in high pressure systems increases the life of the fuel injection equipment that relies on the fuel for its lubrication. Depending on the engine, this might include high pressure injection pumps, pump injectors (also called unit injectors) and fuel injectors.

Older diesel Mercedes are popular for running on biodiesel.

The calorific value of biodiesel is about 37.27 MJ/L. This is 9% lower than regular Number 2 petrodiesel. Variations in biodiesel energy density is more dependent on the feedstock used than the production process. Still these variations are less than for petrodiesel. It has been claimed biodiesel gives better lubricity and more complete combustion thus increasing the engine energy output and partially compensating for the higher energy density of petrodiesel.

Biodiesel is a liquid which varies in color — between golden and dark brown — depending on the production feedstock. It is immiscible with water, has a high boiling point and low vapor pressure. *The flash point of biodiesel (>130 °C, >266 °F) is significantly higher than that of petroleum diesel (64 °C, 147 °F) or gasoline (−45 °C, -52 °F). Biodiesel has a density of ~ 0.88 g/cm³, higher than petrodiesel (~ 0.85 g/cm³).

Biodiesel has virtually no sulfur content, and it is often used as an additive to Ultra-Low Sulphur Diesel (ULSD) fuel to aid with lubrication, as the sulfur compounds in petrodiesel provide much of the lubricity.

Material compatibility

- Plastics: High density polyethylene (HDPE) is compatible but polyvinyl chloride (PVC) is slowly degraded. Polystyrenes are dissolved on contact with biodiesel.

- Metals: Biodiesel has an effect on copper-based materials (e.g. brass), and it also affects zinc, tin, lead, and cast iron. Stainless steels (316 and 304) and aluminum are unaffected.

- Rubber: Biodiesel also affects types of natural rubbers found in some older engine components. Studies have also found that fluorinated elastomers (FKM) cured with peroxide and base-metal oxides can be degraded when biodiesel loses its stability caused by oxidation. Commonly used synthetic rubbers FKM- GBL-S and FKM- GF-S found in modern vehicles were found to handle biodiesel in all conditions.

Technical standards

Biodiesel has a number of standards for its quality including European standard EN 14214, ASTM International D6751, and others.

Low Temperature Gelling

When biodiesel is cooled below a certain point, some of the molecules aggregate and form crystals. The fuel starts to appear cloudy once the crystals become larger than one quarter of the wavelengths of visible light - this is the cloud point (CP). As the fuel is cooled further these crystals become larger. The lowest temperature at which fuel can pass through a 45 micrometre filter is the cold filter plugging point (CFPP). As biodiesel is cooled further it will gel and then solidify. Within Europe, there are differences in the CFPP requirements between countries. This is reflected in the different national standards of those countries. The temperature at which pure (B100) biodiesel starts to gel, varies significantly and depends upon the mix of esters and therefore the feedstock oil used to produce the biodiesel. For example, biodiesel produced from low erucic acid varieties of canola seed (RME) starts to gel at approximately −10 °C (14 °F). Biodiesel produced from tallow tends to gel at around +16 °C (61 °F). There are a number of commercially available additives that will significantly lower the pour point and cold filter plugging point of pure biodiesel. Winter operation is also possible by blending biodiesel with other fuel oils including #2 low sulfur diesel fuel and #1 diesel / kerosene.

Another approach to facilitate the use of biodiesel in cold conditions is by employing a second fuel tank for biodiesel in addition to the standard diesel fuel tank. The second fuel

tank can be insulated and a heating coil using engine coolant is run through the tank. The fuel tanks can be switched over when the fuel is sufficiently warm. A similar method can be used to operate diesel vehicles using straight vegetable oil.

Contamination by water

Biodiesel may contain small but problematic quantities of water. Although it is not miscible with water, it is, like ethanol, hygroscopic (absorbs water from atmospheric moisture). One of the reasons biodiesel can absorb water is the persistence of mono and diglycerides left over from an incomplete reaction. These molecules can act as an emulsifier, allowing water to mix with the biodiesel. In addition, there may be water that is residual to processing or resulting from storage tank condensation. The presence of water is a problem because:

- Water reduces the heat of combustion of the bulk fuel. This means more smoke, harder starting, less power.
- Water causes corrosion of vital fuel system components: fuel pumps, injector pumps, fuel lines, etc.
- Water & microbes cause the paper element filters in the system to fail (rot), which in turn results in premature failure of the fuel pump due to ingestion of large particles.
- Water freezes to form ice crystals near 0 °C (32 °F). These crystals provide sites for nucleation and accelerate the gelling of the residual fuel.
- Water accelerates the growth of microbe colonies, which can plug up a fuel system. Biodiesel users who have heated fuel tanks therefore face a year-round microbe problem.
- Additionally, water can cause pitting in the pistons on a diesel engine.

Previously, the amount of water contaminating biodiesel has been difficult to measure by taking samples, since water and oil separate. However, it is now possible to measure the water content using water-in-oil sensors.

Water contamination is also a potential problem when using certain chemical catalysts involved in the production process, substantially reducing catalytic efficiency of base (high pH) catalysts such as potassium hydroxide. However, the super-critical methanol production methodology, whereby the transesterification process of oil feedstock and methanol is effectuated under high temperature and pressure, has been shown to be largely unaffected by the presence of water contamination during the production phase.

Availability and prices

In some countries biodiesel is less expensive than conventional diesel

Global biodiesel production reached 3.8 million tons in 2005. Approximately 85% of biodiesel production came from the European Union.

In 2007, in the United States, average retail (at the pump) prices, including federal and state fuel taxes, of B2/B5 were lower than petroleum diesel by about 12 cents, and B20 blends were the same as petrodiesel. However, as part as a dramatic shift in diesel pricing over the last year, by July 2009, the US DOE was reporting average costs of B20 15 cents per gallon higher than petroleum diesel ($2.69/gal vs. $2.54/gal). B99 and B100 generally cost more than petrodiesel except where local governments provide a tax incentive or subsidy.

Production

Biodiesel is commonly produced by the transesterification of the vegetable oil or animal fat feedstock. There are several methods for carrying out this transesterification reaction including the common batch process, supercritical processes, ultrasonic methods, and even microwave methods.

Chemically, transesterified biodiesel comprises a mix of mono-alkyl esters of long chain fatty acids. The most common form uses methanol (converted to sodium methoxide) to produce methyl esters (commonly referred to as Fatty Acid Methyl Ester - FAME) as it is the cheapest alcohol available, though ethanol can be used to produce an ethyl ester (commonly referred to as Fatty Acid Ethyl Ester - FAEE) biodiesel and higher alcohols such as isopropanol and butanol have also been used. Using alcohols of higher molecular weights improves the cold flow properties of the resulting ester, at the cost of a less efficient transesterification reaction. A lipid transesterification production process is used to convert the base oil to the desired esters. Any free fatty acids (FFAs) in the base oil are either converted to soap and removed from the process, or they are esterified (yielding more biodiesel) using an acidic catalyst. After this processing, unlike straight vegetable oil, biodiesel has combustion properties very similar to those of petroleum diesel, and can replace it in most current uses.

A by-product of the transesterification process is the production of glycerol. For every 1 tonne of biodiesel that is manufactured, 100 kg of glycerol are produced. Originally, there was a valuable market for the glycerol, which assisted the economics of the process as a whole. However, with the increase in global biodiesel production, the market price for this crude glycerol (containing 20% water and catalyst residues) has crashed. Research is being conducted globally to use this glycerol as a chemical building block. One initiative in the UK is The Glycerol Challenge.

Usually this crude glycerol has to be purified, typically by performing vacuum distillation. This is rather energy intensive. The refined glycerol (98%+ purity) can then be utilised directly, or converted into other products. The following announcements were made in 2007: A joint venture of Ashland Inc. and Cargill announced plans to make propylene glycol in Europe from glycerol and Dow Chemical announced similar plans for North America. Dow also plans to build a plant in China to make epichlorhydrin from glycerol. Epichlorhydrin is a raw material for epoxy resins.

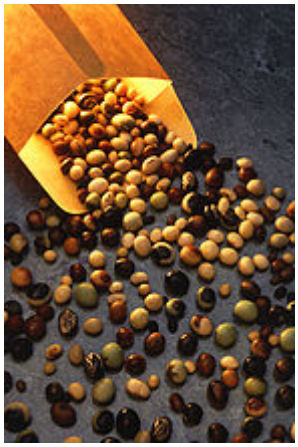
Production levels

In 2007, biodiesel production capacity was growing rapidly, with an average annual growth rate from 2002-06 of over 40%. For the year 2006, the latest for which actual production figures could be obtained, total world biodiesel production was about 5-6 million tonnes, with 4.9 million tonnes processed in Europe (of which 2.7 million tonnes was from Germany) and most of the rest from the USA. In 2008 production in Europe alone had risen to 7.8 million tonnes. In July 2009, a duty was added to American imported biodiesel in the European Union in order to balance the competition from

European, especially German producers. The capacity for 2008 in Europe totalled 16 million tonnes. This compares with a total demand for diesel in the US and Europe of approximately 490 million tonnes (147 billion gallons). Total world production of vegetable oil for all purposes in 2005/06 was about 110 million tonnes, with about 34 million tonnes each of palm oil and soybean oil.

Biodiesel feedstocks

Plant oils



Soybeans are used as a source of biodiesel

Types

Vegetable fats (list)

Macerated (list)

Uses

Drying oil - Oil paint

Cooking oil

Fuel - **Biodiesel**

Components

Saturated fat

Monounsaturated fat

Polyunsaturated fat

Trans fat

A variety of oils can be used to produce biodiesel. These include:

- Virgin oil feedstock; rapeseed and soybean oils are most commonly used, soybean oil alone accounting for about ninety percent of all fuel stocks in the US. It also can be obtained from field pennycress and jatropha and other crops such as mustard, flax, sunflower, palm oil, coconut, hemp
- Waste vegetable oil (WVO);

- Animal fats including tallow, lard, yellow grease, chicken fat, and the by-products of the production of Omega-3 fatty acids from fish oil.
- Algae, which can be grown using waste materials such as sewage and without displacing land currently used for food production.
- Oil from halophytes such as salicornia bigelovii, which can be grown using saltwater in coastal areas where conventional crops cannot be grown, with yields equal to the yields of soybeans and other oilseeds grown using freshwater irrigation

Many advocates suggest that waste vegetable oil is the best source of oil to produce biodiesel, but since the available supply is drastically less than the amount of petroleum-based fuel that is burned for transportation and home heating in the world, this local solution does not scale well.

Animal fats are a by-product of meat production. Although it would not be efficient to raise animals (or catch fish) simply for their fat, use of the by-product adds value to the livestock industry (hogs, cattle, poultry). However, producing biodiesel with animal fat that would have otherwise been discarded could replace a small percentage of petroleum diesel usage. Today, multi-feedstock biodiesel facilities are producing high quality animal-fat based biodiesel. Currently, a 5-million dollar plant is being built in the USA, with the intent of producing 11.4 million litres (3 million gallons) biodiesel from some of the estimated 1 billion kg (2.2 billion pounds) of chicken fat produced annually at the local Tyson poultry plant. Similarly, some small-scale biodiesel factories use waste fish oil as feedstock. An EU-funded project (ENERFISH) suggests that at a Vietnamese plant to produce biodiesel from catfish (basa, also known as pangasius), an output of 13 tons/day of biodiesel can be produced from 81 tons of fish waste (in turn resulting from 130 tons of fish). This project utilises the biodiesel to fuel a CHP unit in the fish processing plant, mainly to power the fish freezing plant.

Quantity of feedstocks required

Current worldwide production of vegetable oil and animal fat is not sufficient to replace liquid fossil fuel use. Furthermore, some object to the vast amount of farming and the resulting fertilization, pesticide use, and land use conversion that would be needed to produce the additional vegetable oil. The estimated transportation diesel fuel and home heating oil used in the United States is about 160 million tons (350 billion pounds) according to the Energy Information Administration, US Department of Energy -. In the United States, estimated production of vegetable oil for all uses is about 11 million tons (24 billion pounds) and estimated production of animal fat is 5.3 million tonnes (12 billion pounds).

If the entire arable land area of the USA (470 million acres, or 1.9 million square kilometers) were devoted to biodiesel production from soy, this would just about provide the 160 million tonnes required (assuming an optimistic 98 US gal/acre of biodiesel). This land area could in principle be reduced significantly using algae, if the obstacles can be overcome. The US DOE estimates that if algae fuel replaced all the petroleum fuel in

the United States, it would require 15,000 square miles (38,849 square kilometers), which is a few thousand square miles larger than Maryland, or 1.3 Belgiums, assuming a yield of 140 tonnes/hectare (15,000 US gal/acre). Given a more realistic yield of 36 tonnes/hectare (3834 US gal/acre) the area required is about 152,000 square kilometers, or roughly equal to that of the state of Georgia or England and Wales. The advantages of algae are that it can be grown on non-arable land such as deserts or in marine environments, and the potential oil yields are much higher than from plants.

Yield

Feedstock yield efficiency per unit area affects the feasibility of ramping up production to the huge industrial levels required to power a significant percentage of vehicles.

Some typical yields

Crop	Yield	
	L/ha	US gal/acre
Algae[n 1]	~3,000	~300, 1500-3000
Chinese tallow[n 2][n 3]	907	97
Palm oil[n 4]	4752	508
Coconut	2151	230
Rapeseed[n 4]	954	102
Soy (Indiana)	554-922	59.2-98.6
Peanut[n 4]	842	90
Sunflower[n 4]	767	82
Hemp	242	26

Algae fuel yields have not yet been accurately determined, but DOE is reported as saying that algae yield 30 times more energy per acre than land crops such as soybeans. Yields of 36 tonnes/hectare are considered practical by Ami Ben-Amotz of the Institute of Oceanography in Haifa, who has been farming Algae commercially for over 20 years.

Jatropha has been cited as a high-yield source of biodiesel but yields are highly dependent on climatic and soil conditions. The estimates at the low end put the yield at about 200 US gal/acre (1.5-2 tonnes per hectare) per crop; in more favorable climates two or more crops per year have been achieved. It is grown in the Philippines, Mali and India, is drought-resistant, and can share space with other cash crops such as coffee, sugar, fruits and vegetables. It is well-suited to semi-arid lands and can contribute to slow down desertification, according to its advocates.

Efficiency and economic arguments

Pure biodiesel (B-100) from soybeans

According to a study by Drs. Van Dyne and Raymer for the Tennessee Valley Authority, the average US farm consumes fuel at the rate of 82 litres per hectare (8.75 US gal/acre) of land to produce one crop. However, average crops of rapeseed produce oil at an average rate of 1,029 L/ha (110 US gal/acre), and high-yield rapeseed fields produce

about 1,356 L/ha (145 US gal/acre). The ratio of input to output in these cases is roughly 1:12.5 and 1:16.5. Photosynthesis is known to have an efficiency rate of about 3-6% of total solar radiation and if the entire mass of a crop is utilized for energy production, the overall efficiency of this chain is currently about 1% While this may compare unfavorably to solar cells combined with an electric drive train, biodiesel is less costly to deploy (solar cells cost approximately US$1,000 per square meter) and transport (electric vehicles require batteries which currently have a much lower energy density than liquid fuels).

However, these statistics by themselves are not enough to show whether such a change makes economic sense. Additional factors must be taken into account, such as: the fuel equivalent of the energy required for processing, the yield of fuel from raw oil, the return on cultivating food, the effect biodiesel will have on food prices and the relative cost of biodiesel versus petrodiesel.

The debate over the energy balance of biodiesel is ongoing. Transitioning fully to biofuels could require immense tracts of land if traditional food crops are used (although non food crops can be utilized). The problem would be especially severe for nations with large economies, since energy consumption scales with economic output.

If using only traditional food plants, most such nations do not have sufficient arable land to produce biofuel for the nation's vehicles. Nations with smaller economies (hence less energy consumption) and more arable land may be in better situations, although many regions cannot afford to divert land away from food production.

For third world countries, biodiesel sources that use marginal land could make more sense; e.g., honge oil nuts grown along roads or jatropha grown along rail lines.

In tropical regions, such as Malaysia and Indonesia, oil palm is being planted at a rapid pace to supply growing biodiesel demand in Europe and other markets. It has been estimated in Germany that palm oil biodiesel has less than one third of the production costs of rapeseed biodiesel. The direct source of the energy content of biodiesel is solar energy captured by plants during photosynthesis. Regarding the positive energy balance of biodiesel:

> When straw was left in the field, biodiesel production was strongly energy positive, yielding 1 GJ biodiesel for every 0.561 GJ of energy input (a yield/cost ratio of 1.78).
> When straw was burned as fuel and oilseed rapemeal was used as a fertilizer, the yield/cost ratio for biodiesel production was even better (3.71). In other words, for every unit of energy input to produce biodiesel, the output was 3.71 units (the difference of 2.71 units would be from solar energy).

Energy security

One of the main drivers for adoption of biodiesel is energy security. This means that a nation's dependence on oil is reduced, and substituted with use of locally available sources, such as coal, gas, or renewable sources. Thus a country can benefit from adoption of biofuels, without a reduction in greenhouse gas emissions. While the total energy balance is debated, it is clear that the dependence on oil is reduced. One example is the energy used to manufacture fertilizers, which could come from a variety of sources other than petroleum. The US National Renewable Energy Laboratory (NREL) states that energy security is the number one driving force behind the US biofuels programme, and a White House "Energy Security for the 21st Century" paper makes it clear that energy security is a major reason for promoting biodiesel. The EU commission president, Jose Manuel Barroso, speaking at a recent EU biofuels conference, stressed that properly managed biofuels have the potential to reinforce the EU's security of supply through diversification of energy sources.

Environmental effects

The surge of interest in biodiesels has highlighted a number of environmental effects associated with its use. These potentially include reductions in greenhouse gas emissions, deforestation, pollution and the rate of biodegradation.

According to the EPA's Renewable Fuel Standards Program Regulatory Impact Analysis, released in February 2010, biodiesel from soy oil results, on average, in a 57% reduction in greenhouse gases compared to fossil diesel, and biodiesel produced from waste grease results in an 86% reduction.

Food, land and water vs. fuel

In some poor countries the rising price of vegetable oil is causing problems. Some propose that fuel only be made from non-edible vegetable oils such as camelina, jatropha or seashore mallow which can thrive on marginal agricultural land where many trees and crops will not grow, or would produce only low yields.

Others argue that the problem is more fundamental. Farmers may switch from producing food crops to producing biofuel crops to make more money, even if the new crops are not edible. The law of supply and demand predicts that if fewer farmers are producing food the price of food will rise. It may take some time, as farmers can take some time to change which things they are growing, but increasing demand for first generation biofuels is likely to result in price increases for many kinds of food. Some have pointed out that there are poor farmers and poor countries who are making more money because of the higher price of vegetable oil.

Biodiesel from sea algae would not necessarily displace terrestrial land currently used for food production and new algaculture jobs could be created.

Current research

There is ongoing research into finding more suitable crops and improving oil yield. Using the current yields, vast amounts of land and fresh water would be needed to produce enough oil to completely replace fossil fuel usage. It would require twice the land area of the US to be devoted to soybean production, or two-thirds to be devoted to rapeseed production, to meet current US heating and transportation needs.

Specially bred mustard varieties can produce reasonably high oil yields and are very useful in crop rotation with cereals, and have the added benefit that the meal leftover after the oil has been pressed out can act as an effective and biodegradable pesticide.

The NFESC, with Santa Barbara-based Biodiesel Industries is working to develop biodiesel technologies for the US navy and military, one of the largest diesel fuel users in the world.

A group of Spanish developers working for a company called Ecofasa announced a new biofuel made from trash. The fuel is created from general urban waste which is treated by bacteria to produce fatty acids, which can be used to make biodiesel.

Algal biodiesel

From 1978 to 1996, the U.S. NREL experimented with using algae as a biodiesel source in the "Aquatic Species Program". A self-published article by Michael Briggs, at the UNH Biodiesel Group, offers estimates for the realistic replacement of all vehicular fuel with biodiesel by utilizing algae that have a natural oil content greater than 50%, which Briggs suggests can be grown on algae ponds at wastewater treatment plants. This oil-rich algae can then be extracted from the system and processed into biodiesel, with the dried remainder further reprocessed to create ethanol.

The production of algae to harvest oil for biodiesel has not yet been undertaken on a commercial scale, but feasibility studies have been conducted to arrive at the above yield estimate. In addition to its projected high yield, algaculture — unlike crop-based biofuels — does not entail a decrease in food production, since it requires neither farmland nor fresh water. Many companies are pursuing algae bio-reactors for various purposes, including scaling up biodiesel production to commercial levels.

Fungi

A group at the Russian Academy of Sciences in Moscow published a paper in September 2008, stating that they had isolated large amounts of lipids from single-celled fungi and turned it into biodiesel in an economically efficient manner. More research on this fungal species; Cunninghamella japonica, and others, is likely to appear in the near future.

The recent discovery of a variant of the fungus Gliocladium roseum points toward the production of so-called myco-diesel from cellulose. This organism was recently discovered in the rainforests of northern Patagonia and has the unique capability of converting cellulose into medium length hydrocarbons typically found in diesel fuel.

Biodiesel from used coffee grounds

Researchers at the University of Nevada, Reno, have successfully produced biodiesel from oil derived from used coffee grounds. Their analysis of the used grounds showed a 10% to 15% oil content (by weight). Once the oil was extracted, it underwent conventional processing into biodiesel. It is estimated that finished biodiesel could be produced for about one US dollar per gallon. Further, it was reported that "the technique is not difficult" and that "there is so much coffee around that several hundred million gallons of biodiesel could potentially be made annually." However, even if all the coffee grounds in the world were used to make fuel, the amount produced would be less than 1 percent of the diesel used in the United States annually. “It won’t solve the world’s energy problem,” Dr. Misra said of his work.

Chapter- 4

Biogas

Pipes carrying biogas (foreground), natural gas and condensate

Biogas typically refers to a gas produced by the biological breakdown of organic matter in the absence of oxygen. Biogas originates from biogenic material and is a type of

biofuel. Biogas is produced by anaerobic digestion or fermentation of biodegradable materials such as biomass, manure, sewage, municipal waste, green waste, plant material and energy crops. This type of biogas comprises primarily methane and carbon dioxide. Other types of gas generated by use of biomass is wood gas, which is created by gasification of wood or other biomass. This type of gas consist primarily of nitrogen, hydrogen, and carbon monoxide, with trace amounts of methane.

The gases methane, hydrogen and carbon monoxide can be combusted or oxidized with oxygen. Air contains 21% oxygen. This energy release allows biogas to be used as a fuel. Biogas can be used as a low-cost fuel in any country for any heating purpose, such as cooking. It can also be used in modern waste management facilities where it can be used to run any type of heat engine, to generate either mechanical or electrical power. Biogas can be compressed, much like natural gas, and used to power motor vehicles and in the UK for example is estimated to have the potential to replace around 17% of vehicle fuel. Biogas is a renewable fuel, so it qualifies for renewable energy subsidies in some parts of the world.

History

Ancient Persians observed that rotting vegetables produce flammable gas. In the 13th century, the traveller Marco Polo noted the Chinese used covered sewage tanks to generate power, while biogas technologies were also referred to by 17th century author Daniel Defoe.

In 1859, an anaerobic digestion plant was built to process sewage at a Bombay leper colony. Biogas has been used in the UK since 1895, when gas from sewage was used in street lamps across the city of Exeter.

Production

Biogas is practically produced as landfill gas (LFG) or digester gas.

A biogas plant is the name often given to an anaerobic digester that treats farm wastes or energy crops.

Biogas can be produced utilizing anaerobic digesters. These plants can be fed with energy crops such as maize silage or biodegradable wastes including sewage sludge and food waste. During the process, an air-tight tank transforms biomass waste into methane producing renewable energy that can be used for heating, electricity, and many other operations that use any variation of an internal combustion engine, such as GE Jenbacher gas engines. There are two key processes: Mesophilic and Thermophilic digestion.

Landfill gas is produced by wet organic waste decomposing under anaerobic conditions in a landfill. The waste is covered and mechanically compressed by the weight of the material that is deposited from above. This material prevents oxygen exposure thus

allowing anaerobic microbes to thrive. This gas builds up and is slowly released into the atmosphere if the landfill site has not been engineered to capture the gas. Landfill gas is hazardous for three key reasons. Landfill gas becomes explosive when it escapes from the landfill and mixes with oxygen. The lower explosive limit is 5% methane and the upper explosive limit is 15% methane. The methane contained within biogas is 20 times more potent as a greenhouse gas than carbon dioxide. Therefore uncontained landfill gas which escapes into the atmosphere may significantly contribute to the effects of global warming. In addition landfill gas' impact in global warming, volatile organic compounds (VOCs) contained within landfill gas contribute to the formation of photochemical smog.

Composition

Typical composition of biogas

Compound	Chem	%
Methane	**CH_4**	50–75
Carbon dioxide	**CO_2**	25–50
Nitrogen	**N_2**	0–10
Hydrogen	**H_2**	0–1
Hydrogen sulfide	**H_2S**	0–3
Oxygen	**O_0**	0–0

The composition of biogas varies depending upon the origin of the anaerobic digestion process. Landfill gas typically has methane concentrations around 50%. Advanced waste treatment technologies can produce biogas with 55–75% CH_4 or higher using in situ purification techniques As-produced, biogas also contains water vapor, with the fractional water vapor volume a function of biogas temperature; correction of measured volume for water vapor content and thermal expansion is easily done via algorithm.

In some cases biogas contains siloxanes. These siloxanes are formed from the anaerobic decomposition of materials commonly found in soaps and detergents. During combustion of biogas containing siloxanes, silicon is released and can combine with free oxygen or various other elements in the combustion gas. Deposits are formed containing mostly silica (SiO_2) or silicates (Si_xO_y) and can also contain calcium, sulfur, zinc, phosphorus. Such white mineral deposits accumulate to a surface thickness of several millimeters and must be removed by chemical or mechanical means.

Practical and cost-effective technologies to remove siloxanes and other biogas contaminants are currently available.

Applications

A biogas bus in Linköping, Sweden

Biogas can be utilized for electricity production on sewage works, in a CHP gas engine, where the waste heat from the engine is conveniently used for heating the digester; cooking; space heating; water heating; and process heating. If compressed, it can replace compressed natural gas for use in vehicles, where it can fuel an internal combustion engine or fuel cells and is a much more effective displacer of carbon dioxide than the normal use in on-site CHP plants.

Methane within biogas can be concentrated via a biogas upgrader to the same standards as fossil natural gas(which itself has had to go through a cleaning process), and becomes **biomethane**. If the local gas network allows for this, the producer of the biogas may utilize the local gas distribution networks. Gas must be very clean to reach pipeline quality, and must be of the correct composition for the local distribution network to accept. Carbon dioxide, water, hydrogen sulfide and particulates must be removed if present. If concentrated and compressed it can also be used in vehicle transportation. Compressed biogas is becoming widely used in Sweden, Switzerland, and Germany. A biogas-powered train has been in service in Sweden since 2005.

Biogas has also powered automobiles. In 1974, a British documentary film entitled Sweet as a Nut detailed the biogas production process from pig manure, and how the biogas fueled a custom-adapted combustion engine.

Benefits

By using biogas, many advantages arise. In North America, utilization of biogas would generate enough electricity to meet up to three percent of the continent's electricity expenditure. In addition, biogas could potentially help reduce global climate change. Normally, manure that is left to decompose releases two main gases that cause global climate change: nitrous dioxide and methane. Nitrous dioxide warms the atmosphere 310 times more than carbon dioxide and methane 21 times more than carbon dioxide. By converting cow manure into methane biogas via anaerobic digestion, the millions of cows in the United States would be able to produce one hundred billion kilowatt hours of electricity, enough to power millions of homes across the United States. In fact, one cow can produce enough manure in one day to generate three kilowatt hours of electricity; only 2.4 kilowatt hours of electricity are needed to power a single one hundred watt light bulb for one day. Furthermore, by converting cow manure into methane biogas instead of letting it decompose, we would be able to reduce global warming gases by ninety-nine million metric tons or four percent.

The 30 million rural households in China that have biogas digesters enjoy 12 benefits: saving fossil fuels, saving time collecting firewood, protecting forests, using crop residues for animal fodder instead of fuel, saving money, saving cooking time, improving hygienic conditions, producing high-quality fertilizer, enabling local mechanization and electricity production, improving the rural standard of living, and reducing air and water pollution.

Biogas upgrading

Raw biogas produced from digestion is roughly 60% methane and 29% CO_2 with trace elements of H_2S, and is not high quality enough if the owner was planning on selling this gas or using it as fuel gas for machinery. The corrosive nature of H_2S alone is enough to destroy the internals of an expensive plant. The solution is the use of a biogas upgrading or purification process whereby contaminants in the raw biogas stream are absorbed or scrubbed, leaving 98% methane per unit volume of gas. There are four main methods of biogas upgrading, these include water washing, pressure swing absorption, selexol absorption and chemical treatment. The most prevalent method is water washing where high pressure gas flows into a column where the carbon dioxide and other trace elements are scrubbed by cascading water running counter-flow to the gas. This arrangement can deliver 98% methane with manufacturers guaranteeing maximum 2% methane loss in the system. It takes roughly between 3-6% of the total energy output in gas to run a biogas upgrading system.

Biogas gas-grid injection

Gas-grid injection is the injection of biogas into the methane grid (natural gas grid). Injections includes biogas: until the breakthrough of micro combined heat and power two-thirds of all the energy produced by biogas power plants was lost (the heat), using the grid to transport the gas to customers, the electricity and the heat can be used for on-site generation resulting in a reduction of losses in the transportation of energy. Typical

energy losses in natural gas transmission systems range from 1–2%. The current energy losses on a large electrical system range from 5–8%.

Legislation

The European Union presently has some of the strictest legislation regarding waste management and landfill sites called the Landfill Directive. The United States legislates against landfill gas as it contains VOCs. The United States Clean Air Act and Title 40 of the Code of Federal Regulations (CFR) requires landfill owners to estimate the quantity of non-methane organic compounds (NMOCs) emitted. If the estimated NMOC emissions exceeds 50 tonnes per year the landfill owner is required to collect the landfill gas and treat it to remove the entrained NMOCs. Treatment of the landfill gas is usually by combustion. Because of the remoteness of landfill sites it is sometimes not economically feasible to produce electricity from the gas. However, countries such as the United Kingdom and Germany now has legislation in force that provide farmers with long term revenue and energy security.

Development around the world

In 2007 an estimated 12,000 vehicles were being fueled with upgraded biogas worldwide, mostly in Europe.

In the United States

With the many benefits of biogas, it is starting to become a popular source of energy and is starting to be utilized in the United States more. In 2003 the United States consumed 147 trillion BTU of energy from "landfill gas", about 0.6% of the total U.S. natural gas consumption. Methane biogas derived from cow manure is also being tested in the U.S. According to a 2008 study, collected by the Science and Children magazine, methane biogas from cow manure would be sufficient to produce 100 billion kilowatt hours enough to power millions of homes across America. Furthermore, methane biogas has been tested to prove that it can reduce 99 million metric tons of greenhouse gas emissions or about 4% of the greenhouse gases produced by the United States.

In Vermont, for example, biogas generated on dairy farms around the state is included in the CVPS Cow Power program. The Cow Power program is offered by Central Vermont Public Service Corporation as a voluntary tariff. Customers can elect to pay a premium on their electric bill, and that premium is passed directly to the farms in the program. In Sheldon, Vermont Green Mountain Dairy has provides renewable energy as part of the Cow Power program. It all started when the brothers who own the farm, Bill and Brian Rowell, wanted to address some of the manure management challenges faced by dairy farms, including manure odor, and nutrient availability for the crops they need to grow to feed the animals. They installed an anaerobic digester to process the cow and milking center waste from their nine hundred and fifty cows to produce renewable energy, a bedding to replace sawdust, and a plant friendly fertilizer. The energy and environmental

attributes are sold. On average the system run by the Rowell brothers produces enough electricity to power three hundred to three hundred fifty other homes. The generator capacity is about three hundred kiloWatts.

In Hereford, Texas cow manure is being used to power an ethanol power plant. By switching to methane bio-gas, the ethanol power plant has saved one thousand barrels of oil a day. Overall, the power plant has reduced transportation costs and will be opening many more jobs for future power plants that will be relying on biogas.

In the United Kingdom

In the UK, sewage gas electricity production is tiny compared to overall power consumption - a mere 80 MW of generation, compared to 70 GW on the grid.. There are currently less than 50 non-sewage landfill plants in the UK.

In the Indian subcontinent

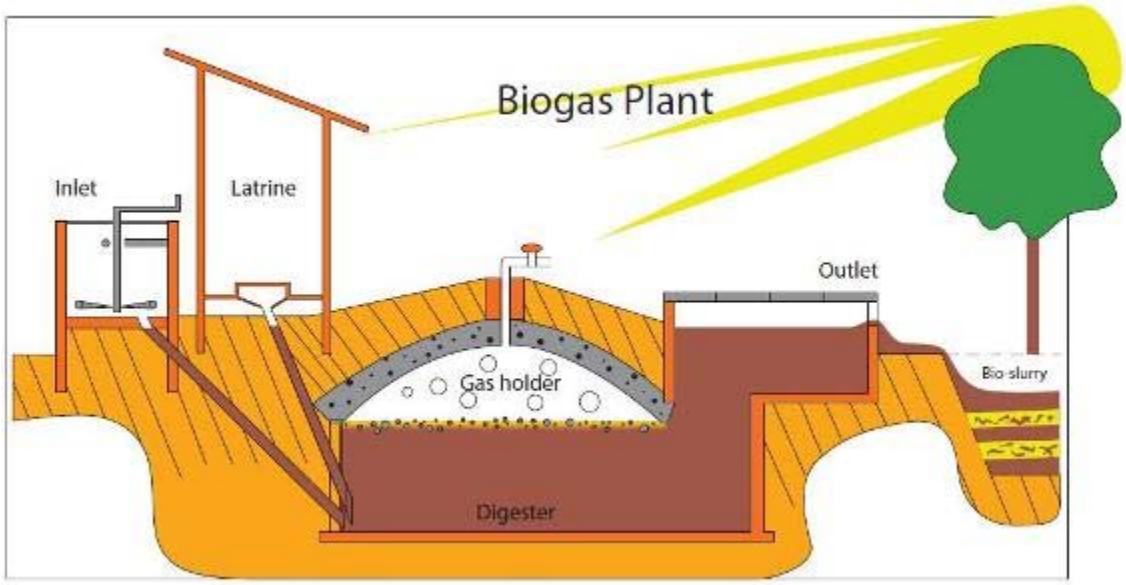
In Pakistan and India biogas produced from the anaerobic digestion of manure in small-scale digestion facilities is called gobar gas; it is estimated that such facilities exist in over two million households in India and in hundreds of thousands in Pakistan, particularly North Punjab, due to the thriving population of lifestock . The digester is an airtight circular pit made of concrete with a pipe connection. The manure is directed to the pit, usually directly from the cattle shed. The pit is then filled with a required quantity of wastewater. The gas pipe is connected to the kitchen fireplace through control valves. The combustion of this biogas has very little odour or smoke. Owing to simplicity in implementation and use of cheap raw materials in villages, it is one of the most environmentally sound energy sources for rural needs. One type of these system is the Sintex Digester. Some designs use vermiculture to further enhance the slurry produced by the biogas plant for use as compost.

The Deenabandhu Model is a new biogas-production model popular in India. (Deenabandhu means "friend of the helpless.") The unit usually has a capacity of 2 to 3 cubic metres. It is constructed using bricks or by a ferrocement mixture. The brick model costs approximately 18,000 rupees and the ferrocment model 14,000 rupees, however India's Ministry of Non-conventional Energy Sources offers a subsidy of up to 3,500 rupees per model constructed.

In developing nations

Domestic biogas plants convert livestock manure and night soil into biogas and slurry, the fermented manure. This technology is feasible for small holders with livestock producing 50 kg manure per day, an equivalent of about 6 pigs or 3 cows. This manure has to be collectable to mix it with water and feed it into the plant. Toilets can be connected. Another precondition is the temperature that affects the fermentation process. With an optimum at 36 C° the technology especially applies for those living in a (sub)

tropical climate. This makes the technology for small holders in developing countries often suitable.



Simple sketch of household biogas plant

Depending on size and location, a typical brick made fixed dome biogas plant can be installed at the yard of a rural household with the investment between 300 to 500 US $ in Asian countries and up to 1400 US $ in the African context. A high quality biogas plant needs minimum maintenance costs and can produce gas for at least 15–20 years without major problems and re-investments. For the user, biogas provides clean cooking energy, reduces indoor air pollution and reduces the time needed for traditional biomass collection, especially for women and children. The slurry is a clean organic fertilizer that potentially increases agricultural productivity.

Domestic biogas technology is a proven and established technology in many parts of the world, especially Asia. Several countries in this region have embarked on large-scale programmes on domestic biogas, such as China and India. The Netherlands Development Organisation, SNV, supports national programmes on domestic biogas that aim to establish commercial-viable domestic biogas sectors in which local companies market, install and service biogas plants for households. In Asia, SNV is working in Nepal, Vietnam, Bangladesh, Cambodia, Lao PDR, Pakistan and Indonesia, and in Africa in Rwanda, Senegal, Burkina Faso, Ethiopia, Tanzania, Uganda and Kenya.

Chapter- 5

Compost

Compost

Compost is plant matter that has been decomposed and recycled as a fertilizer and soil amendment. Compost is a key ingredient in organic farming. At its most essential, the process of **composting** requires simply piling up waste outdoors and waiting a year or more. Modern, methodical composting is a multi-step, closely monitored process with measured inputs of water, air and carbon- and nitrogen-rich materials. The decomposition process is aided by shredding the plant matter, adding water and ensuring proper aeration by regularly turning the mixture. Worms and fungi further break up the material. Aerobic bacteria manage the chemical process by converting the inputs into heat, carbon dioxide

and ammonium. The ammonium is further refined by bacteria into plant-nourishing nitrites and nitrates.

Due to increase in environmental awareness, many people are composting their own garbage and table scraps. Composting normally takes a large amount of outdoor space and require labor to turn and maintain a compost pile, but with the advent of vermicompost it can now be done on a small scale and even indoors by apartment dwellers.

Compost can be rich in nutrients. It is used in gardens, landscaping, horticulture, and agriculture. The compost itself is beneficial for the land in many ways, including as a soil conditioner, a fertilizer, addition of vital humus or humic acids, and as a natural pesticide for soil. In ecosystems, compost is useful for erosion control, land and stream reclamation, wetland construction, and as landfill cover.

History

Composting as a recognized practice dates to at least the early Roman era since Pliny the Elder (AD 23-79) who refers to compost in his writings. Traditionally, composting was to pile organic materials until the next planting season, at which time the materials would be ready for soil application. The main advantage of this method is that little working time or effort is required from the composter and it fits in naturally with agricultural practices in temperate climates. Disadvantages (from the modern perspective) are that space is used for a whole year, some nutrients might be leached due to exposure to rainfall, and disease producing organisms, some weed, weed seeds and insects may not be adequately controlled.

Composting was somewhat modernized beginning in the 1920s in Europe as a tool for organic farming. The first industrial station for the transformation of urban organic materials into compost was set up in Wels/Austria in the year 1921. The early personages most cited for propounding composting within farming are for the German-speaking world Rudolf Steiner, founder of a farming method called biodynamics, and Annie Francé-Harrar, who was appointed on behalf of the government in Mexico and supported the country 1950–1958 to set up a large humus organization in the fight against erosion and soil degradation. In the English-speaking world it was Sir Albert Howard who worked extensively in India on sustainable practices and Lady Eve Balfour who was a huge proponent of composting. Composting was imported to America by various followers of these early European movements in the form of persons such as J.I. Rodale (founder of Rodale Organic Gardening), E.E. Pfeiffer (who developed scientific practices in biodynamic farming), Paul Keene (founder of Walnut Acres in Pennsylvania), and Scott and Helen Nearing (who inspired the back-to-land movement of the 1960s). Coincidentally, some of these personages met briefly in India - all were quite influential in the U.S. from the 1960s into the 1980s.

There are many modern proponents of rapid composting which attempt to correct some of the perceived problems associated with traditional, slow composting. Many advocate

that compost can be made in 2 to 3 weeks. Many such short processes involve a few changes to traditional methods, including smaller, more homogenized pieces in the compost, controlling carbon to nitrogen (CN) ratio at 30 to 1 or less, and monitoring the moisture level more carefully. However, none of these parameters differ significantly from early writings of Howard and Balfour, suggesting that in fact modern composting has not made significant advances over the traditional methods which take a few months to work. For this reason and others, many modern scientists who deal with carbon transformations are sceptical that there is a "super-charged" way to get nature to make compost rapidly. They also point to the fact that it is the structure of the natural molecules - such as carbohydrates, proteins, and cellulose - that really dictate the rate at which microbial-mediated transformations are possible.

Some cities such as San Francisco and Seattle require food and yard waste to be sorted for composting.

Ingredients

Home compost barrel in the Escuela Barreales, Chile.

Composting organisms require four equally important things to work effectively:

- Carbon — for energy; the microbial oxidation of carbon produces the heat.
    - High carbon materials tend to be brown and dry.
- Nitrogen — to grow and reproduce more organisms to oxidize the carbon.
    - High nitrogen materials tend to be green (or colorful, such as fruits and vegetables) and wet.
- Oxygen — for oxidizing the carbon, the decomposition process.
- Water — in the right amounts to maintain activity without causing anaerobic conditions.

Materials in a compost pile.

Certain ratios of these materials will provide beneficial bacteria with the nutrients to work at a rate that will heat up the pile. In that process much water will be released as [evaporation|vapor] ("steam"), and the oxygen will be quickly depleted, explaining the need to actively manage the pile. The hotter the pile gets, the more often added air and water is necessary; the air/water balance is critical to maintaining high temperatures until the materials are broken down. At the same time, too much air or water also slows the process, as does too much carbon (or too little nitrogen).

The most efficient composting occurs with a carbon:nitrogen mix of about 30 to 1. Nearly all plant and animal materials have both carbon and nitrogen, but amounts vary widely, with characteristics noted above (dry/wet, brown/green). Fresh grass clippings

have an average ratio of about 15 to 1 and dry autumn leaves about 50 to 1 depending on species. Mixing equal parts by volume approximates the ideal C:N range. Few individual situations will provide the ideal mix of materials at any point in time - in this respect, home composting is like horseshoes, perfect is great, but close still works. Observation of amounts, and consideration of different materials as a pile is built over time, can quickly achieve a workable technique for the individual situation.

Urine

People excrete far more of certain water-soluble plant nutrients (nitrogen, phosphorus, potassium) in urine than in feces. Human urine can be used directly as fertilizer or it can be put onto compost. Adding a healthy person's urine to compost usually will increase temperatures and therefore increase its ability to destroy pathogens and unwanted seeds. Urine from a person with no obvious symptoms of infection, is generally much more sanitary than fresh feces. Unlike feces, urine doesn't attract disease-spreading flies (such as house flies or blow flies), and it doesn't harbor the most hardy of pathogens, such as parasitic worm eggs. Urine usually does not stink for long, particularly when it is fresh, diluted, or put on sorbents.

Urine is primarily composed of water and urea. Although metabolites of urea are nitrogen fertilizers, it is easy to over-fertilize with urine creating too much ammonia for plants to absorb, acidic conditions, or other phytotoxicity.

Micro-organisms

With the proper mixture of water, oxygen, carbon, and nitrogen, micro-organisms are allowed to break down organic matter to produce compost. The composting process is dependant on micro-organisms to break down organic matter into compost. There are many types of microorganisms found in active compost of which the most common are:

- Bacteria- The most numerous of all the microorganisms found in compost.
- Actinomycetes- Necessary for breaking down paper products such as newspaper, bark, etc.
- Fungi- Molds and yeast help break down materials that bacteria cannot, especially lignin in woody material.
- Protozoa- Help consume bacteria, fungi and micro organic particulates.
- Rotifers- Rotifers help control populations of bacteria and small protozoans.

In addition, earthworms not only ingest partly composted material, but also continually re-create aeration and drainage tunnels as they move through the compost.

A lack of a healthy micro-organisms community is the main reason why composting processes are slow in landfills with environmental factors such as lack of oxygen, nutrients or water being the cause of the depleted biological community.

Uses

Compost is generally recommended as an additive to soil, or other matrices such as coir and peat, as a tilth improver, supplying humus and nutrients. It provides a rich growing medium, or a porous, absorbent material that holds moisture and soluble minerals, providing the support and nutrients in which plants can flourish, although it is rarely used alone, being primarily mixed with soil, sand, grit, bark chips, vermiculite, perlite, or clay granules to produce loam.

Generally, direct seeding into a compost is not recommended due to the speed with which it may dry and the possible presence of phytotoxins which may inhibit germination, and the possible tie up of nitrogen by incompletely decomposed lignin. It is very common to see blends of 20–30% compost used for transplanting seedlings at cotyledon stage or later.

Compost is a versatile product resulting from composting - the biodegradation of organic waste, industrially, commercially or domestically produced. The basic use is conditioning and fertilizing soil by the addition of humus, nutrients and beneficial soil bacteria, with a wide range of specific applications.

Agriculture

Open ground For growing wheat, corn, soybeans, and similar crops, compost theoretically can be broadcast across the top of the soil using spreader trucks or spreaders pulled behind a tractor. It is expected that the spread layer is very thin (approximately 6 mm (0.25 in.)) and worked into the soil prior to planting. However, application rates of 25 mm (one in.) or more are not unusual when trying to rebuild poor soils or control erosion. Due to the extremely high cost of compost per unit of nutrients in the western world (such as USA) on-farm use is relatively rare since rates over 4 tons/acre can not be afforded. This is unfortunate and results from over-emphasis on "recycling organic matter" than on "sustainable nutrients". In other countries such as Germany, where compost distribution and spreading are partially subsidized in the original waste fees, compost is used more frequently on open ground, but only on the premise of nutrient "sustainability"

Plasticulture Strawberries, tomatoes, peppers, melons, and other fruits and vegetables are often grown under plastic to control temperature, retain moisture and control weeds. Compost may be banded (applied in strips along rows) and worked into the soil prior to bedding and planting, be applied at the same time the beds are constructed and plastic laid down, or used as a "top dressing".

Transplant mix Many crops are not seeded directly in the field but are started in seed trays in a greenhouse. When the seedlings reach a certain stage of growth, they are transplanted in the field. Compost can be used as an ingredient in the mix used to grow the seedlings, but is not normally used as the only planting substrate. The crop to be grown and the seeds' sensitivity to nutrients, salts, etc. dictates the ratio of the blend, and maturity is important to insure that oxygen deprivation will not occur or that no lingering phyto-toxins remain.

Horticulture

Bedding mixes. Compost can be mixed with sand, clay, aged sawdust, and other materials to create an enriched mix for landscape beds or raised-bed gardens. Compost should be no more than 30 percent of the total mix. Use a high quality mature compost to avoid nutrient and oxygen competition with plants.

Container mixes Like bedding mixes, compost may be a beneficial ingredient in potting media, used up to 30 percent of the total mix, depending on salinity and maturity. It is considered a partial substitute for peat moss, but generally lacks the porosity and water-holding capacity of peat so must be used in limited percentages. The nutrient content of compost can also reduce the need for supplement chemical fertilizers, although this has to be determined in each situation.

Foundation plantings Excavated areas around the foundation of new buildings are backfilled when construction is complete, but these planting zones may contain rubble, residues of toxic chemicals, and other undesirable substances. Removing the backfill and replacing it with a soil/compost mix will improve soil structure and give foundation plantings a healthier start.

Mulch/weed control Two or more inches of compost can be used alone or in conjunction with conventional mulch products to keep root zones cool, conserve moisture, and act as a slow-release fertilizer, provided the product is course textured and mature. For a weed barrier, double or triple the depth of compost can be used, placed on top of a thick layer of newspapers, to replace geomembrane weed barriers. This is obviously only true if the compost is weed free; many are not.

Trees and shrubs Mix well aged compost with the native soil and use as backfill when planting trees and shrubs. Immature composts may cause settling and young root disturbance due to oxygen deprivation. Seasonally, top dress with compost to the drip line and rake into the soil.

Turf and pasture management To establish new turf areas (lawns, recreation fields, golf courses), apply compost prior to seeding or sodding and work into the soil. Seasonally, top dress with compost and rake into the soil. Some turf farms also use compost, growing grass in a couple of inches of the material to prevent topsoil loss.

Erosion control

Topsoil loss is a serious planetary issue. The use of compost to control sediment run-off and fight erosion is a relatively new technology, now being adopted by local authorities, developers, farmers, and other major disturbers of soil as another tool to reduce topsoil loss.

Compost blankets A layer of compost spread over a disturbed area of soil is called a compost blanket. With a high water-holding capacity, compost is not tilled into the soil but remains on the surface to temper the impact of rainfall. Even small amounts can help, but typical recommendations call for a 5 cm (2 in.) layer to insure adequate surface coverage. The blanket can also be directly planted into.

Compost berms and filter socks Compost berms and socks are used alone or in conjunction with compost blankets to mitigate the impact of high volume water discharges and flows. Compost berms are more aesthetically pleasing than silt fences and eliminate the need to remove the berm when the project is complete. Over time, a compost berm simply biodegrades and returns to the earth. As the name implies, a compost sock is a mesh tube stuffed with compost. Socks stand up better to heavy equipment, can be anchored in place, and are easily removed/reused. If a biodegradable fiber is used for the sock, it can also be left in place to biodegrade. This is rarely if ever practiced, however, since it defeats the idea of the sock.

Special uses

Constructed wetlands Compost is used as a planting media for constructed or artificial wetlands.

Landfill cover When a landfill cell is closed, compost can be added to the soil used to cap the cell to encourage vegetation and reduce erosion.

Streambank restoration Erosion along streambanks threatens trees and property, but the use of compost can not only restore functionality and beauty to riparian zones, but also mitigate future damage.

Regulation and Voluntary Standards

EPA Class A and B guidelines in the U.S.A. were developed solely to manage the processing and beneficial reuse of sludge, also now called biosolids, following the US EPA ban of ocean dumping. About 26 American states now require composts to be processed according to these federal protocols for pathogen and vector control, even though the application to non-sludge materials has not been scientifically tested (an example is that green waste composts are used at much higher rates than sludge composts were ever anticipated to be applied at. U.K guidelines also exist regarding compost quality, as well as Canadian, Australian, and the various European states.

In the USA some compost manufacturers participate in a testing program offered the U.S. Composting Council, a private lobbying organization for the industry. The USCC was originally established to promote composting of disposable diapers, but ultimately the idea was aboned. The current quality guidelines of the USCC called "Seal of Testing Assurance" ("STA") program, and for a fee, the applicant may display the USCC logo, agreeing to volunteer to customers a current laboratory analysis that includes parameters

established by the private consultant-run group on certain nutrients, respiration rate, salt content, pH, and other indicators . However, the STA program is not ISO approved, and is a financially beneficial activity for the USCC. By approving all products that pay the fee, and being monitored by consultants to the industry, it is not likely to be recognized as a bona-fide quality standard.

Destroying pathogens, seeds, or unwanted plants

Composting can destroy pathogens or unwanted seeds. Unwanted living plants (or weeds) can be destroyed by covering with mulch/compost.

The "microbial pesticides" in compost may include thermophiles and mesophiles, however certain composting detritivores such as black soldier fly larvae and redworms, also reduce many pathogens. Thermophilic (high-temperature) composting is well known to destroy many seeds and nearly all types of pathogens (exceptions may include prions). However, thermophilic composting requires a fair amount of material, around a cubic meter.

The sanitizing qualities of (thermophilic) composting are desirable where there is a high likelihood of pathogens, such as with manure. Applications include humanure composting or the deep litter technique.

Types

Compost tea

Compost tea is a liquid solution or suspension made by steeping compost in water. It is used as both a fertilizer and in attempts to prevent plant diseases. The liquid is applied as a spray to non-edible plant parts, or as a soil-drench (root dip), such as seedlings, or as a surface spray to reduce incidence of harmful phytopathogenic fungi in the phyllosphere.

Vermicompost

Rotary screen harvested worm castings

Vermicompost is the product of composting utilizing various species of worms, usually red wigglers, white worms, and earthworms to create a heterogeneous mixture of decomposing vegetable or food waste, bedding materials, and vermicast. Vermicast, also known as worm castings, worm humus or worm manure, is the end-product of the breakdown of organic matter by species of earthworm.

The earthworm species (or **composting worms**) most often used are Red Wigglers (Eisenia foetida or Eisenia andrei), though European nightcrawlers (Eisenia hortensis) could also be used. Users refer to European nightcrawlers by a variety of other names, including dendrobaenas, dendras, and Belgian nightcrawlers.

Containing water-soluble nutrients, vermicompost is a nutrient-rich organic fertilizer and soil conditioner.

Bokashi composting

Inside a recently started Bokashi bin. The aerated base is just visible through the food scraps and Bokashi bran.

Bokashi is a method of intensive composting. It can use an aerobic or anaerobic inoculation to produce the compost. Once a starter culture is made, it can be used to extend the culture indefinitely, like yogurt culture. Since the popular introduction of effective microorganisms (EM), Bokashi is commonly made with only molasses, water, EM, and wheat bran.

In home composting applications, kitchen waste is placed into a container which can be sealed with an air tight lid. These scraps are then inoculated with a Bokashi EM mix. This usually takes the form of a carrier, such as rice hulls, wheat bran or saw dust, that has been inoculated with composting micro-organisms. The EM are natural lactic acid bacteria, yeast, and phototrophic bacteria that act as a microbe community within the kitchen scraps, fermenting and accelerating breakdown of the organic matter. The user would place alternating layers of food scraps and Bokashi mix until the container is full.

Hugelkultur

The practice of making raised beds filled with rotting wood. It is in effect creating a Nurse log though covered with dirt. The buried decomposing wood will give off heat, as all compost does, for several years. This effect has been used by Sepp Holzer for one to allow fruit trees to survive at otherwise inhospitable temperatures and altitudes.

Alternative to landfilling

As concern about landfill space increases, worldwide interest in recycling by means of composting is growing, since composting is a process for converting decomposable organic materials into useful stable products. Industrial scale composting in the form of in-vessel composting, aerated static pile composting, and anaerobic digestion takes place in most Western countries now, and in many areas is mandated by law. There are process and product guidelines in Europe that date to the early 1980s (Germany, Holland, Switzerland) and only more recently in the UK and the US. In both these countries, private trade associations within the industry have established loose standards, some say as a stop-gap measure to discourage independent government agencies from establishing tougher consumer-friendly standards. The USA is the only Western country that does not distinguish sludge-source compost from green-composts, and by default in the USA 50% of states expect composts to comply in some manner with the federal EPA 503 rule promulgated in 1984 for sludge products. Compost is regulated in Canada and Australia as well.

Industrial systems

A large (and oversized) compost pile that is steaming with the heat generated by thermophilic microorganisms.

Industrial composting systems are increasingly being installed as a waste management alternative to landfills, along with other advanced waste processing systems. Mechanical sorting of mixed waste streams combined with anaerobic digestion or in-vessel composting, is called mechanical biological treatment, increasingly used in developed countries due to regulations controlling the amount of organic matter allowed in landfills. Treating biodegradable waste before it enters a landfill reduces global warming from fugitive methane; untreated waste breaks down anaerobically in a landfill, producing landfill gas that contains methane, a potent greenhouse gas.

Large-scale composting systems are used by many urban centers around the world. Co-composting is a technique which combines solid waste with de-watered biosolids, although difficulties controlling inert and plastic contamination from municipal solid waste makes this approach less attractive. The world's largest MSW co-composter is the Edmonton Composting Facility in Edmonton, Alberta, Canada, which turns 220,000 tonnes of residential solid waste and 22,500 dry tonnes of biosolids per year into 80,000 tonnes of compost. The facility is 38,690 meters^2 (416,500 ft^2), equivalent to 4½ Canadian football fields, and the operating structure is the largest stainless steel building in North America, the size of 14 NHL rinks. In 2006, the State of Qatar awarded Keppel Seghers, a subsidiary of Keppel Corporation to began construction on a 275,000 tonne/year Anaerobic Digestion and Composting Plant. This plant, with 15 independent anaerobic digestors will be the World's Largest Composting facility once fully operational in early 2011 and forms part of the Qatar Domestic Solid Waste Management Center, the largest integrated waste management complex in the Middle East.

Chapter- 6

Water Purification

Water purification is the process of removing undesirable chemicals, materials, and biological contaminants from contaminated water. The goal is to produce water fit for a specific purpose. Most water is purified for human consumption (drinking water) but water purification may also be designed for a variety of other purposes, including meeting the requirements of medical, pharmacology, chemical and industrial applications. In general the methods used include physical processes such as filtration and sedimentation, biological processes such as slow sand filters or activated sludge, chemical processes such as flocculation and chlorination and the use of electromagnetic radiation such as ultraviolet light.

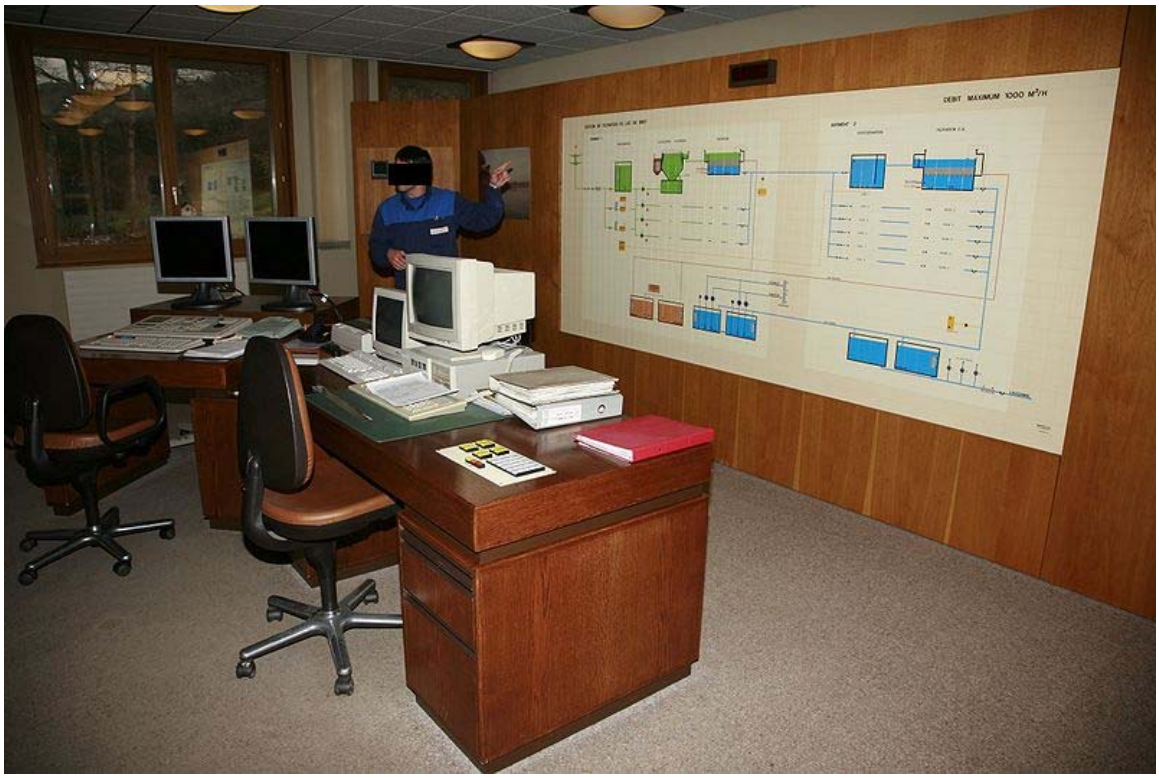
The purification process of water may reduce the concentration of particulate matter including suspended particles, parasites, bacteria, algae, viruses, fungi; and a range of dissolved and particulate material derived from the surfaces that water may have made contact with after falling as rain.

The standards for drinking water quality are typically set by governments or by international standards. These standards will typically set minimum and maximum concentrations of contaminants for the use that is to be made of the water.

It is not possible to tell whether water is of an appropriate quality by visual examination. Simple procedures such as boiling or the use of a household activated carbon filter are not sufficient for treating all the possible contaminants that may be present in water from an unknown source. Even natural spring water – considered safe for all practical purposes in the 1800s – must now be tested before determining what kind of treatment, if any, is needed. Chemical analysis, while expensive, is the only way to obtain the information necessary for deciding on the appropriate method of purification.

According to a 2007 World Health Organization report, 1.1 billion people lack access to an improved drinking water supply, 88% of the 4 billion annual cases of diarrheal disease are attributed to unsafe water and inadequate sanitation and hygiene, and 1.8 million people die from diarrheal diseases each year. The WHO estimates that 94% of these diarrheal cases are preventable through modifications to the environment, including access to safe water. Simple techniques for treating water at home, such as chlorination, filters, and solar disinfection, and storing it in safe containers could save a huge number

of lives each year. Reducing deaths from waterborne diseases is a major public health goal in developing countries.



Control room and schematics of the water purification plant to Lac de Bret, Switzerland.

Sources of water

1. Groundwater: The water emerging from some deep ground water may have fallen as rain many tens, hundreds, thousands of years ago. Soil and rock layers naturally filter the ground water to a high degree of clarity before the treatment plant. Such water may emerge as springs, artesian springs, or may be extracted from boreholes or wells. Deep ground water is generally of very high bacteriological quality (i.e., pathogenic bacteria or the pathogenic protozoa are typically absent), but the water typically is rich in dissolved solids, especially carbonates and sulfates of calcium and magnesium. Depending on the strata through which the water has flowed, other ions may also be present including chloride, and bicarbonate. There may be a requirement to reduce the iron or manganese content of this water to make it pleasant for drinking, cooking, and laundry use. Disinfection may also be required. Where groundwater recharge is practised; a process in which river water is injected into an aquifer to store the water in times of plenty so that it is available in times of drought; it is equivalent to lowland surface waters for treatment purposes.
2. Upland lakes and reservoirs: Typically located in the headwaters of river systems, upland reservoirs are usually sited above any human habitation and may be

surrounded by a protective zone to restrict the opportunities for contamination. Bacteria and pathogen levels are usually low, but some bacteria, protozoa or algae will be present. Where uplands are forested or peaty, humic acids can colour the water. Many upland sources have low pH which require adjustment.
3. Rivers, canals and low land reservoirs: Low land surface waters will have a significant bacterial load and may also contain algae, suspended solids and a variety of dissolved constituents.
4. Atmospheric water generation is a new technology that can provide high quality drinking water by extracting water from the air by cooling the air and thus condensing water vapor.
5. Rainwater harvesting or fog collection which collects water from the atmosphere can be used especially in areas with significant dry seasons and in areas which experience fog even when there is little rain.
6. Desalination of seawater by distillation or reverse osmosis.

Treatment

The processes below are the ones commonly used in water purification plants. Some or most may not be used depending on the scale of the plant and quality of the water.

Pre-treatment

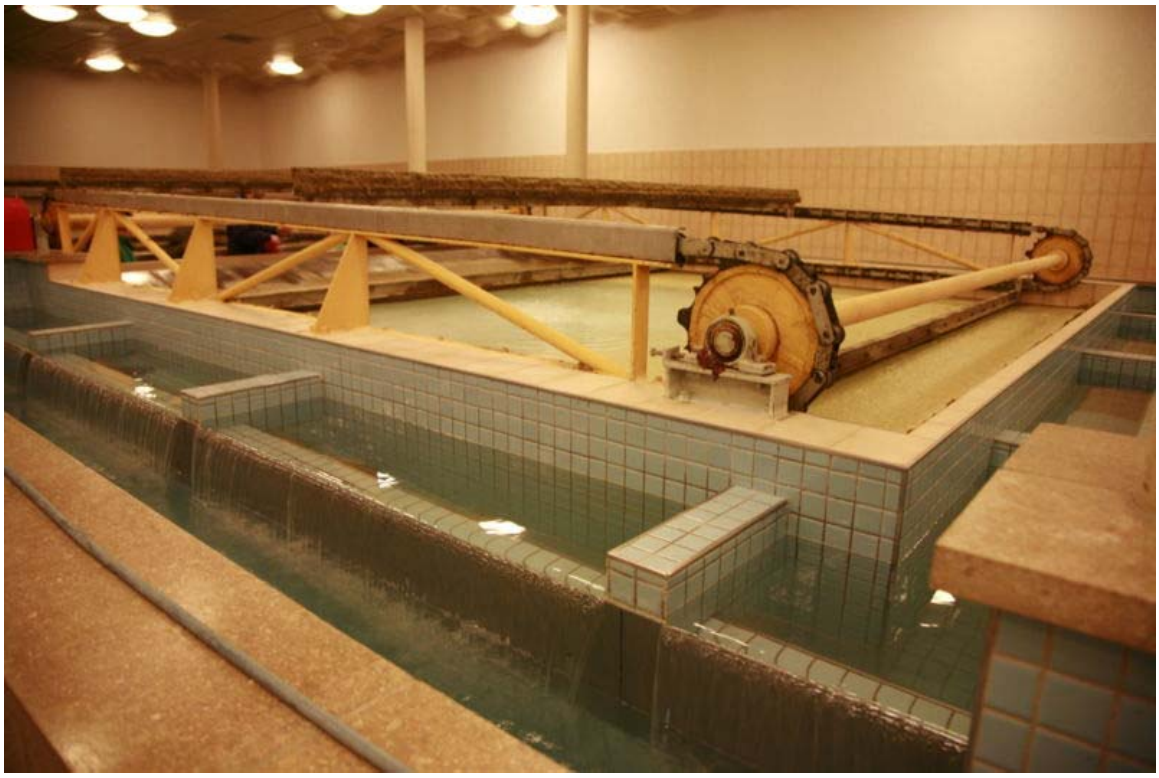
1. Pumping and containment - The majority of water must be pumped from its source or directed into pipes or holding tanks. To avoid adding contaminants to the water, this physical infrastructure must be made from appropriate materials and constructed so that accidental contamination does not occur.
2. Screening - The first step in purifying surface water is to remove large debris such as sticks, leaves, trash and other large particles which may interfere with subsequent purification steps. Most deep groundwater does not need screening before other purification steps.
3. Storage - Water from rivers may also be stored in bankside reservoirs for periods between a few days and many months to allow natural biological purification to take place. This is especially important if treatment is by slow sand filters. Storage reservoirs also provide a buffer against short periods of drought or to allow water supply to be maintained during transitory pollution incidents in the source river.
4. Pre-conditioning - Water rich in hardness salts is treated with soda-ash (sodium carbonate) to precipitate calcium carbonate out utilising the common-ion effect.
5. Pre-chlorination - In many plants the incoming water was chlorinated to minimise the growth of fouling organisms on the pipe-work and tanks. Because of the potential adverse quality effects, this has largely been discontinued.

Widely varied techniques are available to remove the fine solids, micro-organisms and some dissolved inorganic and organic materials. The choice of method will depend on the quality of the water being treated, the cost of the treatment process and the quality standards expected of the processed water.

pH adjustment

Distilled water has a pH of 7 (neither alkaline nor acidic) and sea water has an average pH of 8.3 (slightly alkaline). If the water is acidic (lower than 7), lime, soda ash, or sodium hydroxide is added to raise the pH. For somewhat acidic, alkaline waters (lower than 6.5), forced draft degasifiers are the cheapest way to raise the pH, as the process raises the pH by stripping dissolved carbon dioxide (carbonic acid) from the water. Lime is commonly used for pH adjustment for municipal water, or at the start of a treatment plant for process water, as it is cheap, but it also increases the ionic load by raising the water hardness. Making the water slightly alkaline ensures that coagulation and flocculation processes work effectively and also helps to minimize the risk of lead being dissolved from lead pipes and lead solder in pipe fittings. Acid (HCl or H_2SO_4) may be added to alkaline waters in some circumstances to lower the pH. Having alkaline water does not necessarily mean that lead or copper from the plumbing system will not be dissolved into the water but as a generality, water with a pH above 7 is much less likely to dissolve heavy metals than water with a pH below 7.

floc floating at the surface of a basin



Mechanical system to push floc out of the water basin

Flocculation

Flocculation is a process which clarifies the water. Clarifying means removing any turbidity or colour so that the water is clear and colourless. Clarification is done by causing a precipitate to form in the water which can be removed using simple physical methods. Initially the precipitate forms as very small particles but as, the water is gently stirred, these particles stick together to form bigger particles - this process is sometimes called flocculation. Many of the small particles that were originally present in the raw water adsorb onto the surface of these small precipitate particles and so get incorporated into the larger particles that coagulation produces. In this way the coagulated precipitate takes most of the suspended matter out of the water and is then filtered off, generally by passing the mixture through a coarse sand filter or sometimes through a mixture of sand and granulated anthracite (high carbon and low volatiles coal). Coagulants / flocculating agents that may be used include:

1. Iron (III) hydroxide. This is formed by adding a solution of an iron (III) compound such as iron(III) chloride to pre-treated water with a pH of 7 or greater. Iron (III) hydroxide is extremely insoluble and forms even at a pH as low as 7. Commercial formulations of iron salts were traditionally marketed in the UK under the name Cuprus.
2. Aluminium hydroxide is also widely used as the flocculating precipitate although there have been concerns about possible health impacts and mis-handling led to a

severe poisoning incident in 1988 at Camelford in south-west UK when the coagulant was introduced directly into the holding reservoir of final treated water.

3. PolyDADMAC is an artificially produced polymer and is one of a class of synthetic polymers that are now widely used. These polymers have a high molecular weight and form very stable and readily removed flocs, but tend to be more expensive in use compared to inorganic materials. The materials can also be biodegradable.

Sedimentation

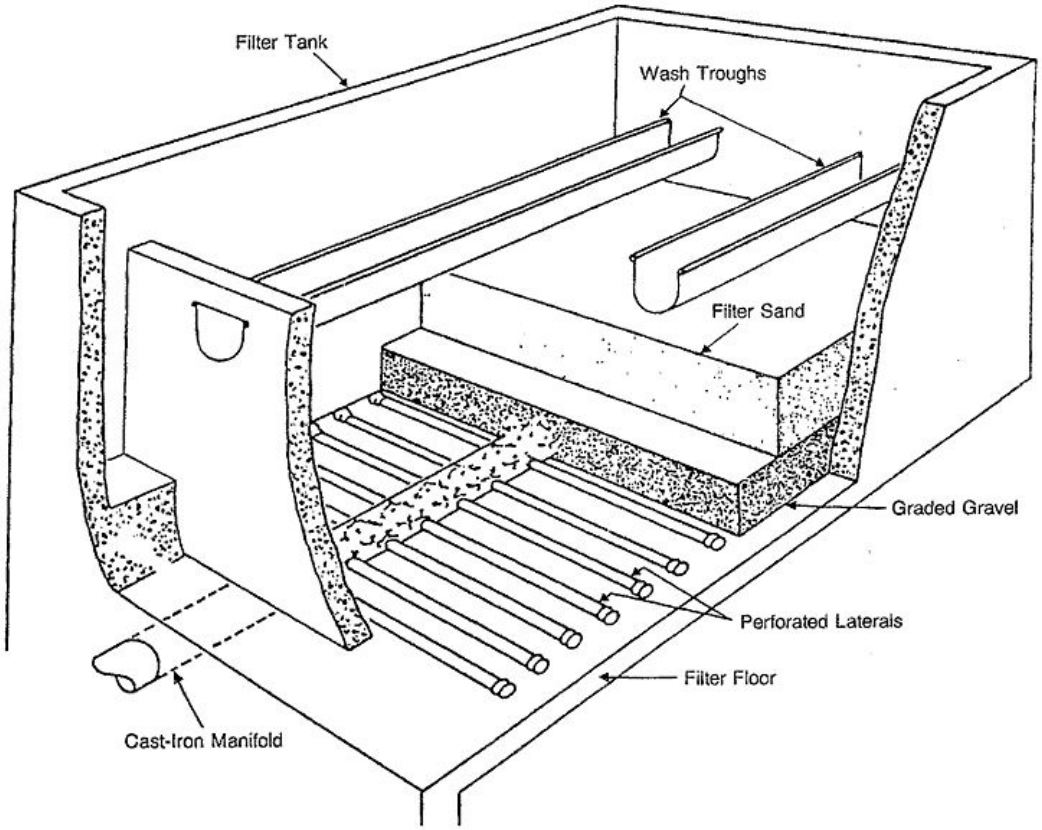
Waters exiting the flocculation basin may enter the sedimentation basin, also called a clarifier or settling basin. It is a large tank with slow flow, allowing floc to settle to the bottom. The sedimentation basin is best located close to the flocculation basin so the transit between does not permit settlement or floc break up. Sedimentation basins may be rectangular, where water flows from end to end, or circular where flow is from the centre outward. Sedimentation basin outflow is typically over a weir so only a thin top layer—that furthest from the sediment—exits. The amount of floc that settles out of the water is dependent on basin retention time and on basin depth. The retention time of the water must therefore be balanced against the cost of a larger basin. The minimum clarifier retention time is normally 4 hours. A deep basin will allow more floc to settle out than a shallow basin. This is because large particles settle faster than smaller ones, so large particles collide with and integrate smaller particles as they settle. In effect, large particles sweep vertically through the basin and clean out smaller particles on their way to the bottom.

As particles settle to the bottom of the basin, a layer of sludge is formed on the floor of the tank. This layer of sludge must be removed and treated. The amount of sludge that is generated is significant, often 3 to 5 percent of the total volume of water that is treated. The cost of treating and disposing of the sludge can be a significant part of the operating cost of a water treatment plant. The tank may be equipped with mechanical cleaning devices that continually clean the bottom of the tank or the tank can be taken out of service when the bottom needs to be cleaned.

Filtration

After separating most floc, the water is filtered as the final step to remove remaining suspended particles and unsettled floc.

Rapid sand filters



Cutaway view of a typical rapid sand filter

The most common type of filter is a rapid sand filter. Water moves vertically through sand which often has a layer of activated carbon or anthracite coal above the sand. The top layer removes organic compounds, which contribute to taste and odour. The space between sand particles is larger than the smallest suspended particles, so simple filtration is not enough. Most particles pass through surface layers but are trapped in pore spaces or adhere to sand particles. Effective filtration extends into the depth of the filter. This property of the filter is key to its operation: if the top layer of sand were to block all the particles, the filter would quickly clog.

To clean the filter, water is passed quickly upward through the filter, opposite the normal direction (called backflushing or backwashing) to remove embedded particles. Prior to this, compressed air may be blown up through the bottom of the filter to break up the compacted filter media to aid the backwashing process; this is known as air scouring. This contaminated water can be disposed of, along with the sludge from the sedimentation basin, or it can be recycled by mixing with the raw water entering the plant although this is often considered poor practice since it re-introduces an elevated concentration of bacteria into the raw water

Some water treatment plants employ pressure filters. These work on the same principle as rapid gravity filters, differing in that the filter medium is enclosed in a steel vessel and the water is forced through it under pressure.

Advantages:

- Filters out much smaller particles than paper and sand filters can.
- Filters out virtually all particles larger than their specified pore sizes.
- They are quite thin and so liquids flow through them fairly rapidly.
- They are reasonably strong and so can withstand pressure differences across them of typically 2-5 atmospheres.
- They can be cleaned (back flushed) and reused.

Membrane filtration

Membrane filters are widely used for filtering both drinking water and sewage. For drinking water, membrane filters can remove virtually all particles larger than 0.2 um—including giardia and cryptosporidium. Membrane filters are an effective form of tertiary treatment when it is desired to reuse the water for industry, for limited domestic purposes, or before discharging the water into a river that is used by towns further downstream. They are widely used in industry, particularly for beverage preparation (including bottled water). However no filtration can remove substances that are actually dissolved in the water such as phosphorus, nitrates and heavy metal ions.

Slow sand filters

Slow "artificial" filtration (a variation of bank filtration) to the ground, Water purification plant Káraný, Czech Republic

Slow sand filters may be used where there is sufficient land and space as the water must be passed very slowly through the filters. These filters rely on biological treatment processes for their action rather than physical filtration. The filters are carefully constructed using graded layers of sand with the coarsest sand, along with some gravel, at the bottom and finest sand at the top. Drains at the base convey treated water away for disinfection. Filtration depends on the development of a thin biological layer, called the zoogleal layer or Schmutzdecke, on the surface of the filter. An effective slow sand filter may remain in service for many weeks or even months if the pre-treatment is well designed and produces water with a very low available nutrient level which physical methods of treatment rarely achieve. Very low nutrient levels allow water to be safely sent through distribution system with very low disinfectant levels thereby reducing consumer irritation over offensive levels of chlorine and chlorine by-products. Slow sand filters are not backwashed; they are maintained by having the top layer of sand scraped off when flow is eventually obstructed by biological growth.

A specific 'large-scale' form of slow sand filter is the process of bank filtration, in which natural sediments in a riverbank are used to provide a first stage of contaminant filtration. While typically not sufficiently clean enough to be used directly for drinking water, the water gained from the associated extraction wells is much less problematic than river water taken directly from the major streams where bank filtration is often used.

Removal of ions and other dissolved substances

Ultrafiltration membranes use polymer membranes with chemically formed microscopic pores that can be used to filter out dissolved substances avoiding the use of coagulants. The type of membrane media determines how much pressure is needed to drive the water through and what sizes of micro-organisms can be filtered out.

Ion exchange: Ion exchange systems use ion exchange resin- or zeolite-packed columns to replace unwanted ions. The most common case is water softening consisting of removal of Ca^{2+} and Mg^{2+} ions replacing them with benign (soap friendly) Na^{+} or K^{+} ions. Ion exchange resins are also used to remove toxic ions such as nitrate, nitrite, lead, mercury, arsenic and many others.

Electrodeionization: Water is passed between a positive electrode and a negative electrode. Ion exchange membranes allow only positive ions to migrate from the treated water toward the negative electrode and only negative ions toward the positive electrode. High purity deionized water is produced with a little worse degree of purification in comparison with ion exchange treatment. Complete removal of ions from water is regarded as electrodialysis. The water is often pre-treated with a reverse osmosis unit to remove non-ionic organic contaminants.

Other mechanical and biological techniques

In addition to the many techniques used in large-scale water treatment, several small-scale, less (or non)-polluting techniques are also being used to treat polluted water. These techniques include those based on mechanical and biological processes. An overview:

- mechanical systems: sand filtration, lava filter systems and systems based on UV-radiation)
- biological systems:
    - plant systems as constructed wetlands and treatment ponds (sometimes incorrectly called reedbeds and living walls) and
    - compact systems as activated sludge systems, biorotors, aerobic biofilters and anaerobic biofilters, submerged aerated filters, and biorolls

In order to purify the water adequately, several of these systems are usually combined to work as a whole. Combination of the systems is done in two to three stages, namely primary and secondary purification. Sometimes tertiary purification is also added.

Disinfection

Disinfection is accomplished both by filtering out harmful microbes and also by adding disinfectant chemicals in the last step in purifying drinking water. Water is disinfected to kill any pathogens which pass through the filters. Possible pathogens include viruses, bacteria, including Escherichia coli, Campylobacter and Shigella, and protozoa, including Giardia lamblia and other cryptosporidia. In most developed countries, public water supplies are required to maintain a residual disinfecting agent throughout the distribution system, in which water may remain for days before reaching the consumer. Following the introduction of any chemical disinfecting agent, the water is usually held in temporary storage - often called a contact tank or clear well to allow the disinfecting action to complete.

Chlorine disinfection

The most common disinfection method involves some form of chlorine or its compounds such as chloramine or chlorine dioxide. Chlorine is a strong oxidant that rapidly kills many harmful micro-organisms. Because chlorine is a toxic gas, there is a danger of a release associated with its use. This problem is avoided by the use of sodium hypochlorite, which is a relatively inexpensive solution that releases free chlorine when dissolved in water. Chlorine solutions can be generated on site by electrolyzing common salt solutions. A solid form, calcium hypochlorite exists that releases chlorine on contact with water. Handling the solid, however, requires greater routine human contact through opening bags and pouring than the use of gas cylinders or bleach which are more easily automated. The generation of liquid sodium hypochlorite is both inexpensive and safer than the use of gas or solid chlorine. All forms of chlorine are widely used despite their respective drawbacks. One drawback is that chlorine from any source reacts with natural organic compounds in the water to form potentially harmful chemical by-products

trihalomethanes (THMs) and haloacetic acids (HAAs), both of which are carcinogenic in large quantities and regulated by the United States Environmental Protection Agency (EPA) and the Drinking Water Inspectorate in the UK. The formation of THMs and haloacetic acids may be minimized by effective removal of as many organics from the water as possible prior to chlorine addition. Although chlorine is effective in killing bacteria, it has limited effectiveness against protozoa that form cysts in water (Giardia lamblia and Cryptosporidium, both of which are pathogenic).

Chlorine Dioxide Disinfection

Chlorine dioxide is a faster-acting disinfectant than elemental chlorine, however it is relatively rarely used, because in some circumstances it may create excessive amounts of chlorite, which is a by-product regulated to low allowable levels in the United States. Chlorine dioxide is supplied as an aqueous solution and added to water to avoid gas handling problems; chlorine dioxide gas accumulations may spontaneously detonate.

Chloramine disinfection

The use of chloramine is becoming more common as a disinfectant. Although chloramine is not as strong an oxidant, it does provide a longer-lasting residual than free chlorine and it won't form THMs or haloacetic acids. It is possible to convert chlorine to chloramine by adding ammonia to the water after addition of chlorine. The chlorine and ammonia react to form chloramine. Water distribution systems disinfected with chloramines may experience nitrification, as ammonia is used a nutrient for bacterial growth, with nitrates being generated as a by-product.

Ozone disinfection

O_3 is an unstable molecule which readily gives up one atom of oxygen providing a powerful oxidizing agent which is toxic to most waterborne organisms. It is a very strong, broad spectrum disinfectant that is widely used in Europe. It is an effective method to inactivate harmful protozoa that form cysts. It also works well against almost all other pathogens. Ozone is made by passing oxygen through ultraviolet light or a "cold" electrical discharge. To use ozone as a disinfectant, it must be created on-site and added to the water by bubble contact. Some of the advantages of ozone include the production of fewer dangerous by-products (in comparison to chlorination) and the lack of taste and odour produced by ozonisation. Although fewer by-products are formed by ozonation, it has been discovered that the use of ozone produces a small amount of the suspected carcinogen bromate, although little bromine should be present in treated water. Another of the main disadvantages of ozone is that it leaves no disinfectant residual in the water. Ozone has been used in drinking water plants since 1906 where the first industrial ozonation plant was built in Nice, France. The U.S. Food and Drug Administration has accepted ozone as being safe; and it is applied as an anti-microbiological agent for the treatment, storage, and processing of foods.

Ultraviolet disinfection

Ultraviolet light is very effective at inactivating cysts, as long as the water has a low level of colour so the UV can pass through without being absorbed. The main disadvantage to the use of UV radiation is that, like ozone treatment, it leaves no residual disinfectant in the water. Because neither ozone nor UV radiation leaves a residual disinfectant in the water, it is sometimes necessary to add a residual disinfectant after they are used. This is often done through the addition of chloramines, discussed above as a primary disinfectant. When used in this manner, chloramines provide an effective residual disinfectant with very few of the negative aspects of chlorination.

Hydrogen peroxide disinfection

Works in a similar way to ozone. Activators such as formic acid are often added to increase the efficacy of disinfection. It has the disadvantages that it is slow-working, phytotoxic in high dosage, and decreases the pH of the water it purifies.

Various portable methods of disinfection

Available for disinfection in emergencies or in remote locations. Disinfection is the primary goal, since aesthetic considerations such as taste, odour, appearance, and trace chemical contamination do not affect the short-term safety of drinking water.

Solar water disinfection

One low-cost method of disinfecting water that can often be implemented with locally available materials is solar disinfection (SODIS). Unlike methods that rely on firewood, it has low impact on the environment.

One recent study has found that the wild Salmonella which would reproduce quickly during subsequent dark storage of solar-disinfected water could be controlled by the addition of just 10 parts per million of hydrogen peroxide.

Additional treatment options

1. Water fluoridation: in many areas fluoride is added to water with the goal of preventing tooth decay. Fluoride is usually added after the disinfection process. In the U.S., fluoridation is usually accomplished by the addition of hexafluorosilicic acid, which decomposes in water, yielding fluoride ions.
2. Water conditioning: This is a method of reducing the effects of hard water. Hardness salts are deposited in water systems subject to heating because the decomposition of bicarbonate ions creates carbonate ions that crystallise out of the saturated solution of calcium or magnesium carbonate. Water with high concentrations of hardness salts can be treated with soda ash (sodium carbonate) which precipitates out the excess salts, through the common-ion effect, producing calcium carbonate of very high purity. The precipitated calcium carbonate is

traditionally sold to the manufacturers of toothpaste. Several other methods of industrial and residential water treatment are claimed (without general scientific acceptance) to include the use of magnetic or/and electrical fields reducing the effects of hard water.

3. Plumbosolvency reduction: In areas with naturally acidic waters of low conductivity (i.e. surface rainfall in upland mountains of igneous rocks), the water may be capable of dissolving lead from any lead pipes that it is carried in. The addition of small quantities of phosphate ion and increasing the pH slightly both assist in greatly reducing plumbo-solvency by creating insoluble lead salts on the inner surfaces of the pipes.
4. Radium Removal: Some groundwater sources contain radium, a radioactive chemical element. Typical sources include many groundwater sources north of the Illinois River in Illinois. Radium can be removed by ion exchange, or by water conditioning. The back flush or sludge that is produced is, however, a low-level radioactive waste.
5. Fluoride Removal: Although fluoride is added to water in many areas, some areas of the world have excessive levels of natural fluoride in the source water. Excessive levels can be toxic or cause undesirable cosmetic effects such as staining of teeth. Methods of reducing fluoride levels is through treatment with activated alumina and bone char filter media.

Other water purification techniques

Other popular methods for purifying water, especially for local private supplies are listed below. In some countries some of these methods are also used for large scale municipal supplies. Particularly important are distillation (de-salination of seawater) and reverse osmosis.

1. Boiling: Water is heated hot enough and long enough to inactivate or kill micro-organisms that normally live in water at room temperature. Near sea level, a vigorous rolling boil for at least one minute is sufficient. At high altitudes (greater than two kilometres or 5000 feet) three minutes is recommended. In areas where the water is "hard" (that is, containing significant dissolved calcium salts), boiling decomposes the bicarbonate ions, resulting in partial precipitation as calcium carbonate. This is the "fur" that builds up on kettle elements, etc., in hard water areas. With the exception of calcium, boiling does not remove solutes of higher boiling point than water and in fact increases their concentration (due to some water being lost as vapour). Boiling does not leave a residual disinfectant in the water. Therefore, water that has been boiled and then stored for any length of time may have acquired new pathogens.
2. Granular Activated Carbon filtering: a form of activated carbon with a high surface area, adsorbs many compounds including many toxic compounds. Water passing through activated carbon is commonly used in municipal regions with organic contamination, taste or odors. Many household water filters and fish tanks use activated carbon filters to further purify the water. Household filters for drinking water sometimes contain silver as metallic silver nanoparticle. if water is

held in the carbon block for longer period, microorganisms can grow inside which results in fouling and contamination. Silver nanoparticles are excellent anti-bacterial material and they can decompose toxic halo-organic compounds such as pesticides into non-toxic organic products.

3. Distillation involves boiling the water to produce water vapour. The vapour contacts a cool surface where it condenses as a liquid. Because the solutes are not normally vaporised, they remain in the boiling solution. Even distillation does not completely purify water, because of contaminants with similar boiling points and droplets of unvapourised liquid carried with the steam. However, 99.9% pure water can be obtained by distillation.
4. Reverse osmosis: Mechanical pressure is applied to an impure solution to force pure water through a semi-permeable membrane. Reverse osmosis is theoretically the most thorough method of large scale water purification available, although perfect semi-permeable membranes are difficult to create. Unless membranes are well-maintained, algae and other life forms can colonize the membranes.
5. The use of iron in removing arsenic from water.
6. Direct contact membrane distillation (DCMD). Applicable to desalination. Heated seawater is passed along the surface of a hydrophobic polymer membrane. Evaporated water passes from the hot side through pores in the membrane into a stream of cold pure water on the other side. The difference in vapour pressure between the hot and cold side helps to push water molecules through.
7. Gas hydrate crystals centrifuge method. If carbon dioxide gas is mixed with contaminated water at high pressure and low temperature, gas hydrate crystals will contain only clean water. This is because the water molecules bind to the gas molecules at molecular level. The contaminated water is in liquid form. A centrifuge may be used to separate the crystals and the concentrated contaminated water.

Hydrogen production

For the small scale production of hydrogen, water purifiers are installed to prevent formation of minerals on the surface of the electrodes and to remove organics and chlorine from utility water. First, the water passes through a 20 micrometre interference (mesh or screen filter) filter to remove sand and dust particles, then a charcoal filter using activated carbon to remove organics and chlorine and finally a de-ionizing filter to remove metallic ions. Testing can be done before and after the filter to verify the proper removal of barium, calcium, potassium, magnesium, sodium and silica.

Another method that is used is reverse osmosis.

Safety and controversies

Drinking water pollution detector Rainbow trout (Oncorhynchus mykiss) is being used in water purification plants to detect acute water pollution

In April, 2007, the water supply of Spencer, Massachusetts became contaminated with excess sodium hydroxide (lye) when its treatment equipment malfunctioned.

Many municipalities have moved from free chlorine to chloramine as a disinfection agent. However, chloramine in some water systems, appears to be a corrosive agent. Chloramine can dissolve the "protective" film inside older service line, with the leaching of lead into residential spigots. This can result in harmful exposure to lead, with elevated blood levels of lead the outcome. Lead is a known neurotoxin.

Demineralized water

Distillation removes all minerals from water, and the membrane methods of reverse osmosis and nanofiltration remove most to all minerals. This results in demineralized water which is not considered ideal drinking water. The World Health Organization has investigated the health effects of demineralized water since 1980. Experiments in humans found that demineralized water increased diuresis and the elimination of electrolytes, with decreased blood serum potassium concentration. Magnesium, calcium, and other minerals in water can help to protect against nutritional deficiency. Demineralized water may also increase the risk from toxic metals because it more readily leaches materials from piping like lead and cadmium, which is prevented by dissolved minerals such as calcium and magnesium. Low-mineral water has been implicated in specific cases of lead

poisoning in infants, when lead from pipes leached at especially high rates into the water. Recommendations for magnesium have been put at a minimum of 10 mg/L with 20–30 mg/L optimum; for calcium a 20 mg/L minimum and a 40–80 mg/L optimum, and a total water hardness (adding magnesium and calcium) of 2 to 4 mmol/L. At water hardness above 5 mmol/L, higher incidence of gallstones, kidney stones, urinary stones, arthrosis, and arthropathies have been observed. Additionally, desalination processes can increase the risk of bacterial contamination.

Manufacturers of home water distillers, of course, claim the opposite—that minerals in water are the cause of many diseases, and that most beneficial minerals come from food, not water. They quote the American Medical Association as saying "The body's need for minerals is largely met through foods, not drinking water." The WHO report agrees that "drinking water, with some rare exceptions, is not the major source of essential elements for humans" and is "not the major source of our calcium and magnesium intake", yet states that demineralized water is harmful anyway. "Additional evidence comes from animal experiments and clinical observations in several countries. Animals given zinc or magnesium dosed in their drinking water had a significantly higher concentration of these elements in the serum than animals given the same elements in much higher amounts with food and provided with low-mineral water to drink."

Portable water purification

Portable water purification devices – also known as **point-of-use** (POU) **water treatment systems** and **field water disinfection** techniques – are self-contained units that can be used by recreational enthusiasts, military personnel, survivalists, and others who must obtain drinking water from untreated sources (e.g., rivers, lakes, etc.). The objective of these personal devices is to render unchlorinated water potable (that is, safe for drinking purposes).

Many commercial portable water purification systems or chemical additives are available for hiking, camping, and other travel in remote areas. These devices are not only used for remote or rural areas. They can also be used to treat safe municipal water for aesthetic purposes by removing chlorine, bad taste, heavy metals like lead and mercury, and odors.

Techniques

Boiling

Boiling water will kill bacteria as well as other disease-causing microorganisms like Giardia lamblia and Cryptosporidium parvum which are commonly found in rivers and lakes. At high elevations, though, the boiling point of water drops, so that extra boiling time is required. Water temperatures above 70 °C (158 °F) will kill all pathogens within 30 minutes, above 85 °C (185 °F) within a few minutes, and at boiling point (100 °C (212 °F)), most pathogens will be killed, excluding certain pathogens and their spores, which must be heated to 118 °C (244 °F)(e.g.: botulism – Clostridium botulinum. This

can be achieved by using a pressure cooker, as regular boiling will not heat water past 100 °C (212 °F) at sea level. It is worth noting that not all pollutants are removed from water by boiling, even in a pressure cooker. Boiling cannot remove chemicals having boiling points at or above 100 °C (212 °F), nor heavy metal contamination, e.g., colloidal metal pollutants. Activated charcoal, however, can remove many pollutants, but can't remove pathogens. A combination of rolling boiling for one minute at standard atmospheric pressure (i.e., not in a pressure cooker) plus filtering with activated charcoal can neutralize most pathogens and pollutants.

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Filtration

Portable pump filters are commercially available with ceramic filters that filter 5,000 to 50,000 litres per cartridge, removing pathogens down to the 0.2–0.3 micrometer (μm) range. Some also utilize activated charcoal filtering. Most filters of this kind remove most bacteria and protozoa, such as Cryptosporidium and Giardia lamblia, but not viruses except for the very largest of 0.3 micrometer and larger diameters, so disinfection by chemicals or ultraviolet light is still required after filtration. It is worth noting that not all bacteria are removed by 0.2 micron (micrometer) pump filters; for example, strands of thread-like Leptospira spp. bacteria, (that can cause leptospirosis), are thin enough to pass through a 0.2 micrometer filter. Effective chemical additives to address shortcomings in pump filters include chlorine, chlorine dioxide, iodine, and sodium hypochlorite (bleach). There have been polymer and ceramic filters on the market that incorporated iodine post-

treatment in their filter elements to kill viruses and the smaller bacteria that cannot be filtered out, but most have disappeared due to the unpleasant taste imparted to the water, as well as possible adverse health effects when iodine is ingested over protracted periods.

While the filtration elements may do an excellent job of removing most bacteria and fungi contaminants from drinking water when new, the elements themselves can become colonization sites. In recent years some filters have been enhanced by bonding silver metal nanoparticles to the ceramic element and/or to the activated charcoal to suppress growth of pathogens.

Small, hand-pumped reverse osmosis filters were originally developed for the military in the late 1980s for use as survival equipment, for example, to be included with inflatable rafts on aircraft. Civilian versions are available. Instead of using the static pressure of a water supply line to force the water through the filter, pressure is provided by a hand-operated pump, similar in function and appearance to a mechanic's grease gun. These devices can generate drinkable water from seawater.

A new portable pump filter, the LifeSaver bottle, filters with a combination of hand pump, filter membranes and a charcoal filter. This new system removes particles larger than 15 nm, and thus is able to filter-out viruses. A similar system, the LifeStraw , removes particles larger than 15 microns with a set of two membrane filters and a carbon filter. The polymer membrane filters are impregnated with antimicrobial halogens to kill pathogens, and the carbon filter is impregnated with silver to inactivate residual halogens from the membrane filters.

Activated charcoal adsorption

Granular activated carbon filtering utilizes a form of activated carbon with a high surface area, and adsorbs many compounds, including many toxic compounds. Water passing through activated carbon is commonly used in concert with hand pumped filters to address organic contamination, taste, or objectionable odors. Activated carbon filters aren't usually used as the primary purification techniques of portable water purification devices, but rather as secondary means to complement another purification technique. It is most commonly implemented for pre-filtering or post-filtering, in a separate step than ceramic filtering, in either case being implemented prior to the addition of chemical disinfectants used to control bacteria or viruses that filters cannot remove. Activated charcoal can remove chlorine from treated water, removing any residual protection remaining in the water protecting against pathogens, and should not, in general, be used without careful thought after chemical disinfection treatments in portable water purification processing.

Chemical disinfection

Iodine used for water purification is commonly added to water as a solution, in crystallized form, or in tablets containing tetraglycine hydroperiodide that release 8 mg of iodine per tablet adaptation to chronic tetraglycine hydroperiodide. The iodine kills

many — but not all — of the most common pathogens present in natural fresh water sources. Carrying iodine for water purification is an imperfect but lightweight solution for those in need of field purification of drinking water. Kits are available in camping stores that include an iodine pill and a second pill (vitamin C or ascorbic acid) that will remove the iodine taste from the water after it has been disinfected, such as those marketed under the Potable Aqua Plus name. The addition of vitamin C, in the form of a pill or in flavored drink powders, precipitates much of the iodine out of solution, so it should not be added until the iodine has had sufficient time to work. This time is 30 minutes in relatively clear, warm water, but is considerably longer if the water is turbid or cold. Consumption of iodine treated drinking water, treated with tablets containing tetraglycine hydroperiodide, also reduces the uptake of radioactive iodine in human subjects to only 2% of the value it would otherwise be, which could be an important factor worthy of consideration for treating water in a post nuclear event survival situation. Such iodine treated water is not suitable for the small percentage of the population allergic to iodine, a problem that also exists in using iodine-based dyes for medical test radiography imaging. Tetraglycine hydroperiodide maintains its effectiveness indefinitely before the container is opened; although some manufacturers suggest not using the tablets more than three months after they the container has initially been opened, the shelf life is in fact very long provided that the container is resealed immediately after each time it is opened.

A potentially lower cost alternative to using iodine based water purification tablets is the use of iodine crystals, commonly sold under the Polar Pure name. A small amount of water is poured into a small glass bottle containing the iodine crystals, one waits 30 minutes, and then pours off only the amount of liquid solution needed into a larger source of untreated water such as a canteen. After waiting a small amount of time, lengthened if treating cold water instead of warm water, potable water is then available from the treated water. An advantage of using iodine crystals is that only a small amount of iodine is dissolved from the iodine crystals at each use, giving this method of treating water a capability for treating very large amounts of water, typically over 2,000 gallons, with but a small bottle of crystals. Ingestion of the actual iodine crystals must be avoided when using this method. Unlike tetraglycine hydroperiodide tablets, iodine crystals have essentially an unlimited shelf life as long as they are not exposed to air for long periods of time and are kept under water. (Iodine crystals will sublimate if exposed to air for long periods of time.) The large quantity of water that can be purified with iodine crystals at low cost makes this technique especially cost effective for point of use or emergency water purification methods intended for use longer than the shelf life of tetraglycine hydroperiodide. Care must be taken to prevent the small glass bottle of iodine crystals covered with water from freezing in cold climates.

Chlorine-based halazone tablets were formerly popularly used for portable water purification. Chlorine in water is more than three times more effective as a disinfectant against Escherichia coli than an equivalent concentration of iodine. Halazone tablets were thus commonly used during World War II by U.S. soldiers for portable water purification, even being included in accessory packs for C-rations until 1945. The primary limitation of halazone tablets was the very short usable life of opened bottles of

halazone tablets, typically 3 days or less, unlike iodine based tablets which have a usable open bottle life of 3 months. Sodium dichloroisocyanurate has largely displaced halazone tablets for the few remaining chlorine based water purification tablets available today. Sodium dichloroisocyanurate is often abbreviated to NaDCC and is compressed with effervescent salts, usually adipic acid and sodium bicarbonate to form a rapidly dissolving tablets. Diluted to 10 parts per million available chlorine (ppm av.cl) when drinking water is mildly contaminated and 20ppm when visibly contaminated. Chlorine bleach tablets give a more stable platform for disinfecting the water than liquid bleach (sodium hypochlorite) as the liquid version tends to degrade with age and give unregulated results unless assays are carried out – not practical on the spot. Still, despite chlorine-based portable water purification falling from favor in tablet form such as in halazone tablets, chlorine-based bleach may nonetheless safely be used for short term emergency water disinfection. Two drops of unscented 5% bleach can be added per liter or quart of clear water, then allowed to stand covered for 30 to 60 minutes. After this treatment, the water may be left open to reduce the chlorine smell and taste. Guidelines are available online for effective emergency use of bleach to render unsafe water potable. The Centers for Disease Control & Prevention (CDC) and Population Services International (PSI) promote a similar product (a 0.5% - 1.5% sodium hypochlorite solution) as part of their Safe Water System (SWS) strategy. The product is sold in developing countries under local brand names specifically for the purpose of disinfecting drinking water (CDC: SWSPSI: SWS).

Neither chlorine (e.g., bleach) nor iodine alone is considered completely effective against Cryptosporidium, although they are partially effective against Giardia. Iodine should be allowed at least 30 minutes to kill Giardia. Chlorine is considered slightly better than iodine against Giardia. A more complete field solution that includes chemical disinfectants is to first filter the water, using a 0.2 micron ceramic cartridge pumped filter, followed by treatment with iodine or chlorine, thereby filtering out cryptosporidium, Giardia, and most bacteria, along with the larger viruses, while also using chemical disinfectant to address smaller viruses and bacteria that the filter cannot remove. This combination is also potentially more effective in some cases than even using portable electronic disinfection based on UV treatment, such as using a Steripen, that fails to work for other than very clear water.

An alternative to iodine based preparations in some usage scenarios are silver ion/chlorine dioxide based tablets or droplets. Sold under names like Micropur Forte, Aquamira, and Pristine, these solutions may disinfect water more effectively than iodine based techniques while leaving hardly any noticeable taste in the water in some usage scenarios. Silver ion/chlorine dioxide based disinfecting agents will kill Cryptosporidum and Giardia, if utilized correctly. The primary disadvantage of silver ion/chlorine dioxide based techniques is the long purification times (generally 30 minutes to 4 hours, depending on the formulation used). Another concern is the possible deposition and accumulation of silver compounds in various body tissues leading to a rare condition called argyria that results in a permanent, disfiguring, bluish-gray pigmentation of the skin, eyes, and mucous membranes. The cost of chlorine dioxide treatment is about four times higher than the cost of iodine treatment.

Ultraviolet purification

Ultraviolet (UV) light induces the formation of covalent linkages on DNA and thereby prevents microbes from reproducing. Without reproduction, the microbes become far less dangerous. Germicidal UV-C light in the short wavelength range of 100–280 nm acts on thymine, one of the four base nucleotides in DNA. When a germicidal UV photon is absorbed by a thymine molecule that is adjacent to another thymine within the DNA strand, a covalent bond or dimer between the molecules is created. This thymine dimer prevents enzymes from "reading" the DNA and copying it, thus neutering the microbe. Hydro-Photon introduced the portable UV water purifer, with the brand name SteriPEN. These UV water purifiers are lightweight and work very quickly. Still, there are limits to this technology. Water turbidity (i.e., the amount of suspended & colloidal solids contained in the water to be treated) must be low, such that the water is clear, for UV purification to work well. Also, water treated with UV still has the microbes present in the water, only with their means for reproduction turned "off". In the event that such UV-treated water containing neutered microbes is exposed to visible light (specifically, wavelengths of light over 330-500 nm) for any significant period of time, a process known as photoreactivation can take place, whereby there becomes a possibility for repairing the damage in the bacteria's reproduction DNA, potentially rendering them once more capable of reproducing and causing disease. UV-treated water must therefore not be exposed to visible light for any significant period of time after UV treatment, before consumption, to avoid ingesting reactivated and dangerous microbes. For long term usage, the issue of obtaining batteries to power portable water purification UV devices can be a concern.

Another concern with UV portable water purification is that some pathogens are hundreds of times less sensitive to UV light than others. Protozoan cysts were once believed to be among the least sensitive, however recent studies have proved otherwise, demonstrating that both Cryptosporidium and Giardia are deactivated by a UV dose of just 6 mJ/cm sq. However, EPA regulations and other studies show that it is viruses that are the limiting factor of UV treatment, requiring a 10-30 times greater dose of UV light than Giardia or Cryptosporidium . Furthermore, studies have shown that UV doses at the levels provided by common portable UV units are effective at killing Giardia and that there was no evidence of repair and reactivation of the cysts .

Fortunately, Giardia are among the easiest pathogens to filter out of water. A viable two-step portable water purification approach, providing greater protection than UV purification alone, is to first filter suspect water, thereby removing the larger pathogens, prior to using UV purification.

Solar water disinfection

In solar water disinfection (SODIS), microbes are destroyed by temperature and UVA radiation provided by the sun. Water is placed in a transparent plastic PET bottles, which is first oxygenated by shaking partially-filled capped bottles prior to filling the bottles all the way. The completely water-filled and capped bottles are exposed to sunlight,

preferably on a corrugated metal roof, slanted slightly to maximize the exposure to solar radiation. In practice, the water-filled bottles are placed for six hours in full sun, or for two days in partial sunlight for weather conditions involving partially overcast days, which raises the temperature of the water and gives an extended dose of solar radiation to the water in the bottles, killing almost all microbes that may be present. The combination of the two effects (UVA and heat) provides a simple method of disinfection for use in tropical developing countries, or in survival situations. The use of glass bottles may or may not provide the same degree of SODIS disinfection as using PET bottles. This is because most glass bottles are non-transparent or opaque over the wavelengths of sunlight required for successful UV disinfection from the solar spectrum required for SODIS to work, and glass bottles are usually thicker than PET bottles, which further reduces the dose of UVA to the water inside glass bottles versus PET bottles. For cases where the UVA is blocked, or reduced, only the heating effects without adequate UVA exposure are typically at work if glass bottles are used, potentially leaving dangerous amounts of bacterial and viral loads within the water.

Solar distillation

Solar distillation may use a pre-manufactured and easily portable still, commonly referred to as a solar still, but it has its roots in a makeshift still that can be constructed simply from readily available components, typically being placed over a small pit that is dug into the ground. The solar still relies on sunlight to warm and evaporate the water to be purified. The water vapour condenses, usually on a plastic sheet suspended as an inverted cone, dripping into a collection cup placed beneath its center. For more continuous use, thin tubing or a hose is sometimes routed into the collection cup beneath the inverted cone, permitting repeated removal of water without disturbing the inverted cone upon which water condenses. This is potentially an important method to prevent losing moisture to atmospheric air, such as can occur in the desert, if the inverted cone is removed each time distilled water is removed from the cup. An alternative method based on the same technique is to tie a plastic bag over a branch of vegetation, to capture water released by the vegetation during photosynthesis. Note that while the solar still shares exposure to UV and infra-red radiation with SODIS, along with the use of plastic materials (sheeting in place of a PET bottle), a solar still relies on a completely different mechanism for operation and the two methods should not be confused. In an extreme survival situation, a solar still can be used to prepare safe drinking water from usually unsuitable water sources, such as one's own urine, or even sea water.