Save Ourselves?
Yes, We Can

This review of what can be done to reverse global warming and the rampant air pollution choking the world is intended to be a cursory, rather than exhaustive, overview of measures and technologies. By adopting these humanity could not only reverse global warming, but in the process save tens of millions of lives and avoid tens of billions of illnesses.

Much has been said and written of the need to invest heavily in research and development to improve ways of reducing emissions. It is simply untrue that further research is necessary.

Solutions exist, and they have for decades. They have not been deployed because to do so would sharply reduce consumption of coal and oil, and with that, profits of corporations that exist to exploit, move, consumer or otherwise use these resources. The world today generates its electricity and moves its people and goods in fundamentally the same way it has for a century. Change creates risk and, with it, the possibility that an innovator will develop an an alternative that is better, faster or cheaper. The status quo offers the best hope for continued corporate survival and profits. It also presents a grave risk to the survival of huamnity.

Those opposed to actions to curb global warming and save lives ane motivated principally by greed—a base desire to not merely make a profit, but one that is as large as possible. Coal and oil, as well as the cars and trucks, factories and power plants that burn them, are immense profit generators, and any threat to them is also a threat to those who own the companies. As a result, America's fleet of power plants and its cars and trucks are the dirtiest and least efficient in the developed world.

What follows, then is merely a sampling of what can be done—indeed, what is already being done in many places throughout the world.

GENERATING ELECTRICITY

Air Pollution from making electricity can be cut by up to 90 percent using technologies that now exist—and have for up to 20 years. In Stockholm, the Värtan power plant has been generating electricity and, by supplying heat to surrounding homes, factories and stores extracted from the still hot exhaust gases of the coal, squeezing out about 90 percent of the fuel's energy content. The plant is super-efficient for two reasons: first, it employs a technology called

Figure 1 The boiler installed at the Karita Power Station of Kyushu Electric Power Co. in Japan. Burning coal with pressurized fluidized bed combustion (PFBC), the plant operates at 42.8 efficiency, compared to an average of about 34 percent in the U.S. An older PFBC in Stockholm has run since 1991 at about 90 percent efficiency, because it uses heat from the exhaust to warm offices, homes and stores. (Source: IHI Industries.)

pressurized fluidized bed combustion (PFBC) that is intrinsically cleaner and more efficient than that used most commonly; second, instead of venting the remaining heat to the air as most plants do, it puts it to use.

Figure 2 At Walt Disney World, waste heat from electricity generation is used to provide air conditioning.

Some would no doubt contend that while using waste heat might be practical in the frigid temperatures of Sweden, it is impractical in hot weather areas like much of the southern United States. But not so—at Walt Disney World in Orlando, Florida, for example, waste heat is used for the resort's air conditioning. Other places use it for processing vegetables, making chemicals or paper or even hothouses to grow fruits and vegetables.

Even without combined heat and power, the Värtan system of extracting energy from smokestack gases, PFBC offers tremendous advantages. A plant in Karita, Japan, for example, that started running in July, 2001 operates at 42.8 percent efficiency,[1] compared to roughly 34 percent for plants in the United States. Another technology, integrated gasification-combined cycle, offers comparable increases in efficiency and with them, reductions in emissions of air pollution.[2] There are hundreds of IGCC facilities throughout the world generating electricity, though most are fueled with petroleum coke, not coal.

Pollution Reductions from Switching to IGCC/PFBC

Pollutant	Emissions (lbs/mWhr)	IGCC Emissions (lbs/mWhr)	Percent Reduction w/ CHP	Percent Reduction w/o CHP
SO_2	40.38	0.5	98.76 %	98.76 %
NO_x	9.66	1.0	89.64 %	89.64 %
CO_2	2,797	251.73	92 %	25 %

Sources: An Environmental Assessment of IGCC Power Systems, Nineteenth Annual Pittsburgh Coal Conference, September 23–27, 2002 and Saito, I. Current Status and Perspective of Research and Development on Coal Utilization Technology in Japan. 20th Annual International Pittsburgh Coal Conference Sep. 15—19, 2003.

There are more than 1,400 power plants—that is, facilities that generate electricity—in the United States.[3] Collectively, they emit:

- 10.2 billion tons of carbon dioxide, the principal cause of future global warming;

- 9.4 million tons of sulfur dioxide, the principal cause of acid rain and extremely fine particles, especially east of the Mississippi River, which account for thousands of unnecessary deaths;

- 3.4 million tons of oxides of nitrogen, a source of acid rain and fine particles, but also smog, or ozone, all of which cause thousands of deaths and untold numbers of illnesses; and,

- 48.3 tons of mercury, a potent neurotoxin that is of no nutritional value and poisonous in every known form.

These power plants also emit a wide range of other poisons, including black carbon, but records of these are not maintained.

Figure 3 America's second-dirtiest power plant in terms of carbon dioxide, Sherco in Minnesota. Owned by Xcel, it emits 2,797 pounds of CO_2 for every megawatt hour generated and dates to 1976–77.

Figure 4 America's dirtiest power plant in terms of oxides of nitrogen. Bailly, owned by Northern Indiana Public Service and built in 1962, emits 9.66 pounds of NO_X for every megawatt generated.

Figure 5 America's dirtiest power plant in terms of sulfur dioxide. Gallagher, owned by Public Service of Indiana and built in 1961, emits 40 pounds of SO_2 for every megawatt hour of electricity generated.

Just What Is PFBC?

PFBC has been under development for more than two decades and American tax dollars have paid for much of it. In the process, coal is crushed and injected into a closed and pressurized boiler—really not too much different than a pressure cooker. The steam turns the blades of a turbine, generating electricity, then it is condensed for reuse. Some gas is left after burning the coal, so it is also used to make electricity. Because air pollution is sharply reduced, a plant can be built in residential neighborhoods—Värtan is about five minutes from downtown Stockholm, and surrounded by apartments—which then allows the rest of the heat to be put to use.

IGCC - The Prime Rival for Burning Coal

In integrated gasification-combined cycle, or IGCC, coal is first turned into a gas. The technology to do this has existed since the 1930s. Gasifying the coal leaves the pollutants in the coal, such as sulfur, mercury and carbon, behind to be dealt with separately, which is much cheaper and easier that burning them and then trying to cleanse the exhaust.

The gas is then burned in a “gas” turbine. It’s called a “gas” turbine not because it burns natural gas, though the vast majority of them do, but because combustion produces an exhaust gas used to spin the blades of the turbine that makes electricity. The gases existing the turbine–it is essentially the same as the engine of a jet plane–retain enough heat to make steam, which can then be used to spin the blades of another turbine to make electricity. Thus, IGCC “integrates” the process of fuel “gasification”of fuel, which is then used in two ways, or “cycles” of generating electricity, gas and steam. Hard as it is to believe, “pet coke,” as it is usually called, is nastier than even coal, but even it can be burned with greater efficiency and less pollution than in the powerplants that dot America’s cities and countryside.

Figure 6 The IGCC plant at the Saras Oil Refinery in Sarroch, Italy is the second largest European refinery. It makes 551 megawatts of electricity, enough for about 120,000 U.S. homes, as well as 285 metric tons of process steam for the refinery, as well as 20 million standard cubic feet a day of hydrogen feedstock.

Both PFBC and IGCC have the very significant advantage of eliminating pollutants from the fuel before it is burned by turning it into a gas thus leaving virtually all of the most poisonous materials behind. In virtually all power plants in the United States and elsewhere in the world, toxins are still in the fuel when it is burned, causing devasting environmental and health damages. PFBC and IGCC do not, so the challenging–indeed, in some cases, virtually impossible–job of stripping the noxious chemicals from the exhaust gases is avoided. Another of the greatest advantages of these technologies is that, like the time travel machine in the *Back to the Future* movies that could be fueled with anything from banana peels to stale beer, it sometimes seems they are the same.

We Gasify Anything

In Spreewitz, Germany, north of Dresden, Sekundarrohstoff-Verwertungszentrum Schwarze Pumpe GmbH operates an IGCC facility that converts an eclectic mix of 450,000 metric tons of solid waste, and 50,000 metric tons of liquid wastes, into electricity, steam, and methanol feedstock. The Spreewitz plant was originally designed in the 1960s to gasify brown coal. But more than $250 million in modernization allow it to gasify a wider variety of solid and liquid wastes.[4]

The solid materials treated at Spreewitz include plastic wastes, wood from junked

Figure 7 The Schwarze Pumpe IGCC plant in Spreewitz, Germany, gasifies a variety of wastes, ranging from scrap plastic to junked railroad ties, to produce electricity, steam, and chemical feedstock.

railroad ties and telephone poles, sewage sludge, old tires, and household garbage. These materials are ground up, pelletized, mixed with coal, and sent into four solid-bed gasifiers made by a variety of manufacturers. Another 200 tons per day of liquid wastes, primarily spent oils, tars, slurries, and oil-water emulsions, are also gasified.[5]

In addition to electricity, the Schwarze Pump plant produces 240 metric tons per hour of process steam for a waste treatment plant, as well as 100,000 tons of methanol, which it sells to processors of gasoline, paint, refrigerants, and wood preservatives.[6]

Like PFBC, the efficiency of IGCC is much higher than existing power plants: from 40 to 42 percent efficiency, compared to about 34 percent. Improved IGCC systems are projected to reach 48 to 52 percent by the end of the decade and 60 percent by 2020.[7]

OPPORTUNITY KNOCKING

It bears repeating that pollution is waste, something that is being thrown into the air or water or on the land that can be used. Pollution can, in other words "reduced, reused and recycled," as the mantra of solid waste says. Just as a carpenter will sometimes dump nails on the ground or in a trash can after finishing one job and before starting another because it's too much trouble to return them to the box, so, too, do many others discard perfectly good materials or energy.

Throughout the world, but especially in the United States, vast amounts of material are simply thrown out. But virtually all of it can be exploited in some fashion. Even household food and dairy scraps, as well as other garbage, can be collected and turned into an energy rich gas to generate electricity, as it is in Bluemel, Germany, for example.

The Stuff That's Thrown Out
("Opportunity Wastes")

Biomass	Industrial Byproducts	Commercial/ Industrial Waste
Stalks, leaves and other crop residue	*"Black Liquor" waste from pulp and paper making*	*Landfill gas from city and other dumps*
Cattle, hog and other animal waste	*Gas from "coking," or heating coal in airless ovens*	*City garbage, wastepaper, etc.*
Peels, husks and other food processing waste	*Industrial solvents*	*Construction waste*
Bark, slash and other wood waste	*"Petroleum coke," the bottom of the crude oil barrel*	*Combustible Production Waste*
Sewage sludge	*Heated vented the air use in makings, processing foods, etc.*	*Used tires*

Three wastes that are loaded with energy, but can be burned cleanly with the right technology

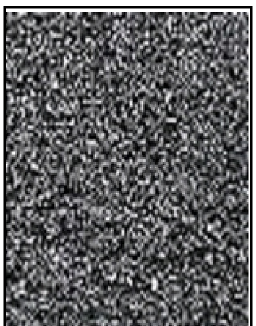

Figure 8 Petroleum coke: bottom of the barrel and loaded with energy can be burned cleanly.

Petroleum coke

"Pet coke" is a carbon-rich black solid byproduct of "coking," or separating light and heavy crude oil products. There is a lot of petroleum coke so it's usually cheaper than its chief competition, coal. Coal is dirty, but pet coke is even worse. Just as coal can be burned cleanly in an integrated gasification-combined cycle plant, so can pet coke.

An IGCC plant in Puertollano, Spain, considered the world's biggest IGCC power plant with a net output of 300 megawatts, enough electricity for about 75,000 homes, has been running since March, 1998[8] with no problems and has since been generating extremely environment-friendly power and valuable by-products. Globally, in 2004 there were 117 IGCC plants operating with 384 gasifiers, and almost all were burning petroleum coke.[9]

Figure 9 Black Liquor.

Black liquor

A tar-like substance, black liquor is a byproduct of making paper. Because the pulp and paper mills need steam and other heat for their own processes, much of the black liquor never goes off site. Virtually all of it, however, is burned in so-called Tomlinson boilers.[10] Replacing these with systems to convert the liquor into gas, then burning it in an integrated gasification combined cycle set of turbines would substantially increase efficiency, allow chemical contaminants to be removed and reduce air pollution.

Used tires

In the United States, between 250 and 350 million tires are thrown away each year. Now banned from most landfills, tires are increasingly ground up and burned as a substitute for coal. Like pet coke and black liquor, however, the cement kilns, pulp and paper mills, and other users often burn them in boilers designed to burn coal, because coal-fired boilers already exist and tires can be easily co-fired with no modifications. Again, if the tires were gasified, then burned to generate both electricity and steam, pollution would drop dramatically.[11]

Figure 10 Used tires.

KILOWATTS FROM MANURE

Since humans were not around several million years ago when the plants and animals that are thought to have, over millions of years, turned into natural gas it is unclear what, exactly, happened. There is general agreement, however, that microscopic plants and animals living in the oceans died, were buried in silt and over the ages were folded into various layers, eventually turning into oil and gas.[12]

The essential ingredient in this process is not time, but biological matter. With modern technologies, all sorts of materials—animal and human sewage, wood chips, rice husks and other crop residues, for example—can be turned into gas in a matter of hours or days. Doing this prevents them from rotting, thus adding methane—a powerful cause of greenhouse gas in its own right, as well as a source of ozone, or smog—to the air.

Whatever and wherever it comes from, gas is a fabulous fuel. It is inherently clean, with almost none of the poisons of coal and oil, which emits immense amounts of air pollution when burned. In addition, because natural gas is so clean, it can be used with technologies that are much more efficient and clean burning from massive furnaces, to the millions of car and truck engines. As a result, demand for gas is rising sharply, especially for generating electricity.[13]

Figure 11 A power plant in Alberta, Canada harnesses the power of solid cow manure. The $8-million system starts with manure, adds water and heat, and then lets the mixture stew without oxygen, producing methane, or natural gas, that is burned to generate electricity. (Source: Canadian Broadcasting Corporation)

Throughout the world, biological wastes are being dealt with as they have been for centuries. Corn stalks, rice husks and the like are burned where they stand and manure is spread on fields as fertilizer. In entire counties, the stench of cow or pig manure makes breathing not only difficult but painful. The gases react in the air with the products of burning gasoline or coal to form extremely fine particles that cause widespread death and illness. But if these wastes are collected, they can be turned into gas to generate electricity, fuel for cars and trucks and provide heat for homes, offices and factories.

Cow, pig and poultry power

Take an $8 million anaerobic,[14] or airless, cooker, manure from lots of cows, pigs, or poultry, add water, heat and Voila! You have—

- natural gas, that can be used to generate electricity;
- fertilizer in which all the bacteria and other dangerous bugs have been killed; and,
- water.[15]

At Highmark Renewables in Alberta, Canada the manure from 36,000 cows, about 36 million kilograms (almost 80 million pounds), generates enough electricity to run the feedlot and about 700 homes. When it reaches full capacity, the plant will power more than 2,000 homes, while producing fertilizer as well as water for irrigation. The next step will be to build more plants—20 in five years.[16]

People Power

In Portland, Oregon, the Columbia Boulevard sewage plant uses essentially the same process as Highmark, but uses waste from humans, not cattle. About 82 million gallons of "wastewater" per day generate methane, but instead of being burned it is fed in to a fuel cell, a device that generates enough electricity for about 40 homes.[17] Sold to Portland General Electric, the electricity saves the city about $60,000 per year.

Figure 12 The Portland, Oregon, Columbia Boulevard sewage plant makes methane, or natural gas, from human waste. It is fed in to a fuel cell, a device that generates chemically, making enough electricity for about 40 homes, saving the city about $60,000 a year. (Source: Oregon Chapter, American Society of Landscape Architects)

In 2003, four microturbines were added to the system to generate additional electricity.[18] Solids are converted to fertilizer, while the water is treated and returned to the nearby Columbia River.[19]

According to the U.S. Environmental Protection Agency, there are more than 500 sewage treatment plants in the U.S. that could, in the aggregate, generate about 340 megawatts, eliminating as much carbon dioxide and other pollution as taking 430,000 cars off the road.[20]

Crop Residues

When corn, rice, seeds and other crops are harvested, stalks, leaves, husks and other wastes are left in the field to rot or, in areas that will still allow it, burned in place. The technology to gasify other sources of plant matter is well established, but only recently has interest been sparked in doing the same with wastes like crop residues.

MAKE MY KILOWATT ZERO POLLUTING, PLEASE

For nearly a quarter-century, a phalanx of several hundred giant mirrored troughs each 12 feet long and tall as a small ranch house, have shimmered in the almost blinding sunlight of the Mojave Desert in California, silently generating what, until recently, was the world's cleanest electricity.

As the sun moves, the computer controlled mirrors pivot as well, focusing intently on the sun's brilliance. Running down each trough's center is a black steel tube. Sunlight reflected from the silvered Mylar skin of each trough is focused on the tubes, superheating the synthetic oil within it to 735 degrees Fahrenheit. The oil flows to a low block building where it is converted to steam that drives a turbine that turns a generator that makes electricity—all with zero pollution.[21]

Figure 13 The largest 'solar thermal-electric' installation in the world, the Luz project in California's Mojave Desert, has a peak output of some 350 MW, or about 350,000 homes. It has been making zero and near-zero polluting electricity since the 1980s.

Figure 14 Located in Seville, Spain, this 40-story "power tower" will eventually provide electricity for the city's 600,000 residents, producing no air pollution whatsoever. (Source: BBC)

This is the heart of LUZ International, the world's largest solar thermal plant and long the envy of the world. Here, on sunny days, a torrent of zero-polluting electricity cascades through the power lines into the homes and offices of Los Angeles, enough to meet the residential needs of a city the size of Atlanta. On cloudy days, turbines fired with natural gas are turned on, but that's not often.

Like all facilities that make electricity from so-called "renewable" sources such as sunlight and wind, the Luz segments are costly to build, but cheap to operate—after all, the sun and wind are free. Most of the costs are for maintenance and to pay off the banks that made the construction loans. With the advent of global warming and high-cost oil, more and more solar, wind and other renewable energy plants are being built and, as that happens, costs of construction are falling.

Indeed, one solar thermal facility started operating in 2007 in Seville, Spain making enough electricity for 6,000 homes, but designed to ultimately provide power to all of its city's 600,000 people. The company that built the 40-story solar thermal plant has also been awarded the contract to construct a system in Arizona to generate enough electricity for 70,000 homes.[22]

These facilities, especially those that use sunlight, are utterly reliable. There are at the most only a few moving parts and in some, none whatsoever, so there's little or nothing to break.

Two kinds of technologies use sunlight to make electricity:

1. Solar thermal, which uses the heat of the sunlight to generate electricity; and,
2. Solar photovoltaic, which is made from materials whose electrons are dislodged by sunlight, thus generating electricity directly.

The other major technology for making electricity with zero air pollution extracts energy from the wind. This is, in a sense, also solar, because wind is created when surfaces are warmed differently by sunlight (e.g., land versus water). Hot air rises and, as it does, cooler air moves in to replace it, causing the wind to blow.

After nearly 20 years of stagnation, solar thermal applications for generating electricity—as opposed to heating water for residential or commercial use—has begun to surge.

In June, 2007 the largest solar power plant built in 17 years kicked off its operation in Boulder City, Nevada, about 40 miles southeast of Las Vegas. The Nevada Solar One plant is the third largest plant in the world, and like Luz, makes electricity with zero and near-zero emissions. Much smaller than Luz, it generates about 64 megawatts, or enough for about 14,000 homes.[23]

Both the Luz and Solar One plants suffer from one major drawback: when night falls, electricity production drops to zero. Of course, there's no problem with this if the plant's purpose is to provide electricity when demands suddenly jump—when families come home after work or school and switch on air conditioning, for example.

Figure 15 Nevada Solar One started operating in June, 2007, the largest such plant to be built in 17 years. Much smaller than Luz, it generates about 64 megawatts, or enough power for about 14,000 homes. (Source: ACCONIA)

mirrors to track the sun and focus its rays onto a salt-filled container about 20 feet high and 15 feet in diameter atop a 300 foot tower. With so much heat focused on a single object, the salt's temperature rose to about 565 degrees Centigrade (1,045 Fahrenheit), melting so it could be stored in a nearby tank to generate steam at night to make electricity. The plant made 10 megawatts, enough for about 2,500 homes.[24]

ZERO-POLLUTING ELECTRICITY FOR 600,000

As with the Luz-like technologies, technological and commercial leadership has passed from the United States to other nations, principally Spain. In Seville, energy giant Abengoa has constructed a 40-story concrete tower intended to eventually provide electricity for all of the city's 600,000 residents.[25]

It is an absolutely extraordinary sight, like something from a science fiction film. The immense tower is bathed in intense white light focused on it by 600 massive mirrors, each thin but about the size of a small house. Unlike Solar Two, the Seville plant uses steam to store energy instead of salt.

Abengoa Solar also won a contract with Arizona Public Service (APS), the state's largest electric company, to build and operate the first concentrating solar power plant for producing electric power in the United States. To be located near Gila Bend, about 65 miles southwest of Phoenix, the plant will generate 280 megawatts of electricity. It will use the Luz-like parabolic trough technology, coupled with the Solar Two heat storage system of molten salt. It will generate enough power for 70,000—without emitting a speck of air pollution whatsoever.

Another project is being built at Sanlúcar la Mayor, Spain that will generate 300 megawatts from a combination of—

- 50 megawatts from a solar tower;
- 250 megawatts from Luz-like parabolic troughs; and,
- 1.2 megawatts from solar photovoltaics.[26]

Scheduled to be finished in 2013, it will produce enough energy to supply 153,000 households.[2]

On a smaller scale, electricity can also be generated from the sun's heat using a "Stirling" engine. Invented in 1816 by Rev. Robert Stirling, a minister of the Church of Scotland, the engine is a closed chamber filled with ordinary air, hydrogen, helium or some other

Figure 18 To make small amounts of electricity—for villages, islands and other remote places, for example—a saucer-shaped mirror focuses sunlight onto a Stirling engine, which drives a small generator to make electricity. The engine is roughly the size of a 55-gallon barrel.

[1] Arizona Public Service Company, Bechtel Corporation, California Energy Commission, Electric Power Research Institute, Idaho Power Company, Los Angeles Department of Water and Power, Pacificorp, Sacramento Municipal Utility District, Salt River Project, and Southern California Edison Company.

[2] The amount of electricity consumed by an average homes varies by country, so the number of households that can be powered by the same size plant varies.

gas. Heat applied to the engine's outside causes the gas to move from one chamber to another. The movement can be harnessed to generate electricity (or, for that matter, run a car or truck or perform other work).[27]

The source of the external energy can just as easily be sunlight as a flame, and Abengoa Solar uses a saucer-shaped mirror to focus sunlight onto a Stirling engine, which drives a small generator to make electricity. The entire engine is roughly the size of a 55-gallon barrel and perfect for small villages, islands and other remote places.

THE HIGH PRICE OF CHEAP OIL

The collapse of solar thermal technology in California caused a shift in technological leadership—and, perhaps more importantly, jobs and income—from the United States to other nations. A victim of on again-off again federal and state policies and the plunge in oil and gas prices during the 1980s, driven by a cheap oil strategy adopted by the Reagan Administration, forced Luz into bankruptcy in 1991. Much the same happened to U.S.-based makers of wind turbines.

This created a vacuum now filled by Spain-based Acconia and other non-U.S. companies. Acconia built Nevada Solar One. It also is the first developer of windparks in the world, with more than 5,300 MW installed in twelve countries, and turbine manufacturing operations in Spain, China and the United States. It owns three biomass plants, 19 small hydro power stations, makes biodiesel from vegetable oil and bio-ethanol from wine-surplus alcohol. It employs 38,000 workers.

All of that could have belonged to America.

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The kraft process dominates pulp and paper production worldwide. Black liquor, a mixture of lignin and inorganic chemicals, is generated in this process as fiber is extracted from wood. At most kraft mills today, black liquor is burned in Tomlinson boilers to produce steam for on-site heat and power and to recover the inorganic chemicals for reuse in the process. Globally, the black liquor generation rate is about 85,000 MW{sub fuel} (or 0.5 million tonnes of dry solids per day), with nearly 50% of this in North America. The majority of presently installed Tomlinson boilers will reach the end of their useful lives during the next 5 to 20 years. As a replacement for Tomlinson-based cogeneration, black liquor-gasifier/gas turbine cogeneration promises higher electrical efficiency, with prospective environmental, safety, and capital cost benefits for kraft mills. Several companies are pursuing commercialization of black liquor gasification for gas turbine applications. This paper presents results of detailed performance modeling of gasifier/gas turbine cogeneration systems using different black liquor gasifiers modeled on proposed commercial designs.

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14. Organic matter is broken down by bacteria in the absence of air to produce a biogas and a residue. The biogas, normally methane, can then be used as a fuel in gas engine or boiler. The residue, called the digestate, can be returned to the land in the form of a fertilizer which is high in organic nutrients. The biomass, cattle, chicken and pig waste, is placed in a digester (a warm, sealed and airless container) for roughly 10–25 days. The bacterium produces a fermentation process that results in the biogas which is then drawn off and used as the fuel. This can be on an individual farm basis or on an industrial scale with slurry being brought to a central location for processing. Anaerobic digestion reduces the solid/liquid mass by 40 to 60 percent, and this could be increased by additional processing.

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Every Stirling engine has a sealed cylinder with one part hot and the other cold. The working gas inside the engine (which is often air, helium, or hydrogen) is moved by a mechanism from the hot side to the cold side. When the gas is on the hot side it expands and pushes up on a piston. When it moves back to the cold side it contracts. Properly designed Stirling engines have two power pulses per revolution, which can make them very smooth running. Two of the more common types are two piston Stirling engines and displacer-type Stirling engines. The two piston type Stirling engine has two power pistons. The displacer type Stirling engine has one power piston and a displacer piston.