

Press Release

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PROCESS: Zero Greenhouse Gas (GHG) Emissions from Buses, Cars, Trucks, & Vans.

WaterSmart Environmental, Inc. announces the development of technology to simultaneously sequester carbon dioxide gas while capturing other combustion products from buses, cars, trucks, and vans. The technology applies equally to ground transportation equipment that use compressed natural gas (CNG), Biodiesel, Petroleum Diesel, Ethanol, Gasoline, and Gasoline-Ethanol blends. Attached WSE Publication No. 1599-2 discusses the technology in greater detail.

WaterSmart Environmental, Inc. is marketing its Kyoto Protocol compliant wastes-to-energy technology on an economic development platform to concentrated animal feeding operators and to municipalities. Animal farmers benefit by purchasing biodiesel, electricity, and natural gas (methane) at a 20% discount from retail. Municipalities also benefit by making biodiesel, electricity, natural gas, and potable water available to its citizens and businesses at a 20% discount from existing prices. The technology is marketed on a build-own-operate basis thereby eliminating the necessity for local sales and property tax increases since project financing is entirely secured from the financial marketplace. Municipalities that embrace the waste-to-energy technology automatically become zero waste-to-landfill communities. The waste-to-renewable energy technology has been slowly developed over the last 10 years. It is just now being introduced to the international marketplace. The technology has the clear potential for making every single city throughout the world energy and fuels independent while reducing oil and natural gas imports. The technology will also permit every single city throughout the world to improve water and wastewater treatment infrastructure while creating jobs and investment opportunities. The waste-to-energy technology can also be applied to Sugar Cane Mills as well as Pulp & Paper Mills with equal success. Both types of mills become energy, food, fuels, and water independent while significantly increasing profits from routine operations. In the case of Sugar Cane Mills temporary and seasonal jobs turn into full time better paying jobs.

WaterSmart Environmental, Inc. is a provider of waste-to-energy, food independence, water independence, and energy independence technologies and a manufacturer of highly engineered water purification components and systems. The company designs and builds a wide variety of water treatment equipment including packaged water and wastewater treatment plants, UltraPac™ aerobic package plants, OAT™ Process anaerobic digesters with associated energy production, aerators, filters, PuriSep™ and SmartWater™ oil/water and solids/liquids separators, RainDrain™ perimeter trench sand filters for stormwater runoff, dissolved air flotation separators, air strippers, complete skid assembled aqueous waste treatment plants, FilterFresh™ skid mounted potable water production plants, skid mounted wastewater treatment systems for laundromats, commercial laundries, and car/truck wash facilities

with water reclamation and reuse, softeners, demineralizers, activated carbon treatment equipment, and water purifiers for domestic and international markets.

*Specialists in Water and Wastewater Treatment Featuring
Next Generation Wastes-To-**Renewable Energy** Technologies*



Engineering Data Sheet

6255

Process: Zero Greenhouse Gas Emissions Cars, Trucks, Vans, and Buses

Emissions Control History

A **catalytic converter** (colloquially, "cat" or "catcon") is a device used to reduce the toxicity of emissions from an internal combustion engine. First widely introduced on series-production automobiles in the US market for the 1975 model year to comply with tightening EPA regulations on auto exhaust, catalytic converters are still most commonly used in motor vehicle exhaust systems. Catalytic converters are also used on generator sets, forklifts, mining equipment, trucks, buses, trains, and other engine-equipped machines. A catalytic converter provides an environment for a chemical reaction wherein toxic combustion byproducts are converted to less-toxic gases. The catalytic converter was invented at Trinity College (Connecticut).

Three-way Catalytic Converters

A three-way catalytic converter has three simultaneous tasks:

1. Reduction of nitrogen oxides to nitrogen and oxygen: $2\text{NO}_x \rightarrow x\text{O}_2 + \text{N}_2$.
2. Oxidation of carbon monoxide to carbon dioxide: $2\text{CO} + \text{O}_2 \rightarrow 2\text{CO}_2$.
3. Oxidation of unburnt hydrocarbons (HC) to carbon dioxide and water: $\text{C}_x\text{H}_y + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O}$ (generic equation).

These three reactions occur most efficiently when the catalytic converter receives exhaust from an engine running at the stoichiometric point. This is 14.7 parts oxygen to 1 part fuel, by weight, for gasoline (the ratio for propane, LPG, natural gas and ethanol fuels is slightly different, requiring modified fuel system settings when using those fuels). When there is more oxygen than required, then the system is said to be running lean, and the system is in oxidizing condition. In that case, the converter's two oxidizing reactions (oxidation of CO and hydrocarbons) are favored, at the expense of the reducing reaction. When there is excessive fuel, then the engine is running rich. The reduction of NO_x is favored, at the expense of CO and HC oxidation. If an engine could be held at the strict stoichiometric point for the fuel used, it is theoretically possible to reach 100% conversion efficiencies.

Since 1981, three-way catalytic converters have been at the heart of vehicle emission control systems in North American road going vehicles and are also used on "Large Spark Ignition" engines. LSI engines are used in

forklifts, aerial boom lifts, ice resurfacing machines and construction equipment. The converters used in these are three-way types designed to reduce combined NO_x + HC emissions from 12 gram/BHP-hour to 3 gram/BHP-hour or less, per the Environmental Protection Agency (EPA) 2004 regulations. A further drop to 2 gram/BHP-hour of NO_x + HC emissions is mandated in 2007 [note: NO_x is the industry standard short form for nitric oxide (NO) and nitrogen dioxide (NO_2) both of which are smog precursors. HC is the industry short form for hydrocarbons]. The EPA intends to introduce emissions rules for stationary Spark Ignition engines, to take effect in January 2008.

Two-Way Catalytic Converters

A two-way catalytic converter has two simultaneous tasks:

1. Oxidation of carbon monoxide to carbon dioxide: $2\text{CO} + \text{O}_2 \rightarrow 2\text{CO}_2$.
2. Oxidation of unburnt hydrocarbons (unburnt and partially-burnt fuel) to carbon dioxide and water: $\text{C}_x\text{H}_y + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O}$ (generic equation).

This type of catalytic converter is commonly used on diesel engines to reduce hydrocarbon and carbon monoxide emissions. They also were used on spark ignition (gasoline) engines in automobiles up until 1981, when they were replaced by three-way converters due to regulatory changes requiring reductions on NO_x emissions.

Curiously the regulations regarding hydrocarbons vary according to the engine regulated, as well as the specific jurisdiction. In some cases what is regulated is "non-methane hydrocarbons" and in other cases the regulated substance is "total hydrocarbons". Technology for one application (to meet a non-methane hydrocarbon standard) may not be suitable for use in an application that has to meet a total hydrocarbon standard. Methane is more difficult to break down in a catalytic converter, so in effect a "non-methane hydrocarbon" standard can be considered to be looser (more environmentally generous to the regulated industry). However since methane is a greenhouse gas, more interest is now rising in how to eliminate its emissions as well.

Catalyst poisoning and deactivation

Catalytic converters become ineffective in the presence of lead due to catalyst poisoning. The widespread use of catalytic converters caused the end of leaded gasoline. Catalyst poisoning occurs when a substance in the

engine exhaust coats the surface of the catalyst, preventing further exhaust access to the catalytic materials. Poisoning can sometimes be reversed by running the engine under a very heavy load for an extended period of time to raise exhaust gas temperature, which may cause liquefaction or sublimation of the catalyst poison. Common catalyst poisons are lead, sulfur, zinc, manganese, silicone and phosphorus.

Zinc, phosphorus and sulfur originate from lubricant antiwear additives such as ZDDP; sulfur and manganese primarily originate from fuel impurities or from additives such as Methylcyclopentadienyl Manganese Tricarbonyl (MMT), respectively. Silicone poisoning in automotive applications is the result of engine damage, such as a faulty cylinder head gasket or cracked casting, admitting silicate-containing coolant into the combustion chamber, in stationary engines silicon (siloxane) poisoning is more often caused by the use of "Landfill" gas as a fuel.

Removal of sulfur from a catalyst surface by running heated exhaust gasses over the catalyst surface is often successful; however removal of lead deposits is often not possible because of its high boiling point. In particularly bad cases of catalyst poisoning by lead, the catalytic converter can actually become completely plugged with lead residue.

A variety of conditions may cause the catalyst to overheat (heat deactivation) and potentially to melt down. A non-comprehensive list of conditions that can cause this is:

1. lube oil in the exhaust system (damaged rings or valves),
2. engine misfires (partially burnt fuel/air mix in the exhaust),
3. cracked exhaust valve (unburnt fuel/air mix in the exhaust), and
4. lack of spark (electrical failure - unburnt fuel/air mix in the exhaust).

Contrary to popular belief overly rich fuel mixtures are not an issue - there is too little unused oxygen for the exotherm to be large enough to cause damage, and many engine manufacturers design "rich excursions" as a catalyst protection measure in the engine control software. A slightly lean of stoichiometric mix is far more dangerous, as the oxygen level is elevated, allowing a very large exotherm.

Engine misfires can overheat and destroy the converter as the excessive amounts of unburned fuel are broken down within it, especially when the engine is under heavy loads. Vehicles equipped with OBD-II diagnostic systems are designed to alert the driver of a misfire condition, along with other malfunctions, using the Malfunction Indicator Lamp or "Check Engine" light. If the misfire and engine load can produce heating severe enough

to cause catalyst damage, the MIL will flash until the misfire or engine load is reduced.

Technical Details

The catalytic converter consists of several components:

1. **The core**, or substrate. In modern catalytic converters, this is most often a ceramic honeycomb, however stainless steel foil honeycombs are also used. The purpose of the core is to "support the catalyst" and therefore it is often called a "catalyst support". The ceramic substrate was invented by Rodney Bagley, Irwin Lachman and Ronald Lewis at Corning Glass for which they were inducted into the National Inventors Hall of Fame in 2002.
2. **The washcoat**. In an effort to make converters more efficient, a washcoat is utilized, most often a mixture of silicon and aluminum. The washcoat, when added to the core, forms a rough, irregular surface which has a far greater surface area than the flat core surfaces, which is desirable to give the converter core a larger surface area, and therefore more places for active precious metal sites. The catalyst is added to the washcoat (in suspension) before application to the core.
3. **The catalyst itself**, most often a precious metal. Platinum is the most active catalyst and is widely used. However, it is not suitable for all applications because of unwanted additional reactions and/or cost. Palladium and Rhodium are two other precious metals that are used. Rhodium is the material that enables a three-way reaction possible, while palladium is very popular as a substitute for platinum in three-way catalytic converters. While Cerium, Iron, Manganese, and Nickel catalysts are used, each has its own limitations. Nickel is not legal for use in the European Union (due to nickel hydrate formation). While copper can be used, its use is illegal in North America due to the formation of dioxin.

Rich Burn Gasoline (Spark Ignition) Engines

Catalytic converters are used on spark ignition (gasoline; liquefied petroleum gas (LPG); flexible fuel vehicles burning varying blends of E85 and gasoline; compressed natural gas (CNG)) engines; and compression ignition (diesel) engines.

For spark ignition engines the most commonly used catalytic converter is the three-way converter, which works best used on engines equipped with closed-loop feedback fuel mixture control employing an oxygen (lambda) sensor. While a 3-way catalyst can be used in a closed loop system (and has been for years in the non-

road engine market), NO_x conversions tend to be less than stellar - and since World emissions regulations are primarily aimed at NO_x reduction open loop fuel systems are now obsolete. Closed loop fuel system mean either fuel injection or a carburetor equipped for feedback mixture control to keep the Air fuel ratio at stoichiometric, 14.7:1 for gasoline. Within that band, conversions are very high, sometimes approaching 100%. However, outside of that band, conversions tend to fall off very rapidly. Two-way converters have been abandoned as a technology used on Spark Ignition engines, due to an inability to control NO_x.

A three-way catalyst reduces emissions of CO (carbon monoxide), HC (hydrocarbons), and NO_x (nitrogen oxides) simultaneously when the oxygen level of the exhaust gas stream is below 1.0%, though performance is best at below 0.5% O₂. Unwanted reactions can occur in the three-way catalyst such as the formation of H₂S (hydrogen sulfide) and NH₃ (ammonia). Formation of each can be limited by modifications to the washcoat/precious metals used. It is, however, difficult to eliminate these side products entirely.

For example, when control of H₂S (hydrogen sulfide) emissions are desired, nickel or manganese is added to the washcoat - both substances act to block the adsorption of sulfur by the washcoat. H₂S is formed when the washcoat has adsorbed sulfur during a low temperature part of the operating cycle, which is then released during the high temperature part of the cycle and the sulfur combines with HC). For "lean burn" spark ignition engines (e.g. compressed natural gas, or compressed natural gas with diesel fuel pilot injection), an oxidation catalyst is used in the same manner as in a compression ignition engine.

Recently, systems have used a separate early catalytic converter in the system to reduce startup emissions and burn off the hydrocarbons from the extra-rich mixture used in a cold engine. Also, the other parts are now often separated in the system to provide optimum temperature and provide space for extra oxygen sensors.

Early three-way catalytic converters utilized an air tube between the first part of the converter (the NO_x part) and the second part, which is virtually unchanged from earlier two-way catalytic converters. This tube was fed by either an air pump (derived from the earlier A.I.R. systems) or by a Pulse Air system. The extra oxygen was used to offset the less precise control of earlier systems by providing the oxygen for the catalyst's oxidizing reaction. The first section was still prone to difficulties on lean conditions with too much oxygen for the NO_x reduction to be complete, but the second section always had oxygen available. These systems also commonly included an upstream air injector, either a modified A.I.R. system or another opening in the manifold, to add oxygen into the system to burn the extra-rich mixture used in a cold engine and to allow the additional burning to

happen as close to the converter as possible to heat it up to operating temperature quickly.

Newer systems use several techniques to avoid the air tubes. They provide a constantly varying mixture that quickly cycles lean and rich mixtures to keep the first catalyst (NO_x) from becoming oxygen loaded and the second catalyst sufficiently oxidized, which is less of a concern due to the oxygen created in the first section. They also utilize several oxygen sensors to monitor the exhaust, at least one before the catalytic converter for each bank of cylinders, and one after the converter. Newer systems also often have several units mounted along the pipe to provide different functions rather than one monolithic system.

Diesel (Compression Ignition) Engines

For compression ignition (i.e., Diesel) engines, the most commonly used catalytic converter is the diesel oxidation catalyst. The catalyst uses excess O₂ (oxygen) in the exhaust gas stream to oxidize CO (Carbon Monoxide) to CO₂ (Carbon Dioxide) and HC (hydrocarbons) to H₂O (water) and CO₂. These converters often reach 90% effectiveness, virtually eliminating diesel odor and helping to reduce visible particulates (soot), however they are incapable of reducing NO_x as chemical reactions always occur in the simplest possible way, and the existing O₂ in the exhaust gas stream would react first.

To reduce NO_x on a compression ignition engine it is necessary to change the exhaust gas - two main technologies are used for this - selective catalytic reduction (SCR) and NO_x traps (or NO_x Adsorbers).

Another issue for diesel engines is particulate (soot). This can be controlled by a soot trap or diesel particulate filter (DPF), as catalytic converters are unable to affect elemental carbon (but they will remove up to 90% of the soluble organic fraction). However, DPFs can clog and lose their effectiveness with time and use.

Oxygen Storage

In order to oxidize CO and HC, the catalytic converter also has the capability of storing the oxygen from the exhaust gas stream, usually when the air fuel ratio goes lean. When insufficient oxygen is available from the exhaust stream the stored oxygen is released and consumed. This happens either when oxygen derived from NO_x reduction is unavailable or certain maneuvers such as hard acceleration enrich the mixture beyond the ability of the converter to compensate.

Regulations

Emissions regulations vary considerably from jurisdiction to jurisdiction, as do what engines are regulated. In North America any spark ignition engine of over 19 kW (25 hp) power output built later than January 1, 2004

probably has a three-way catalytic converter installed. In Japan a similar set of regulations will come into effect January 1, 2007, while the European Union has not yet enacted analogous regulations. Most automobile spark ignition engines in North America have been fitted with catalytic converters since the mid-1970s and the technology used in non-automotive applications is generally based on automotive technology.

Diesel engine regulations are similarly varied, with some jurisdictions focusing on NO_x (Nitric Oxide and Nitrogen Dioxide) emissions and others focusing on particulate (soot) emissions. This can cause problems for the engine manufacturers as it may not be economical to design an engine to meet two sets of regulations.

Note that no jurisdiction has specific legislation mandating the use of catalytic converters; however with spark ignition engines a catalytic converter is usually the only practical way to meet regulatory requirements.

An important issue is that fuel quality varies widely from place to place, even within jurisdictions, as do the regulations covering fuel quality. In North America, Europe, Japan, and Hong Kong both gasoline and diesel fuel are highly regulated and there are campaigns under way to regulate CNG and LPG as well. In most of Asia and Africa this is not true - in some places sulfur content of the fuel can reach 20,000 parts per million (2 %). Any sulfur in the fuel may be oxidized to SO₂ (sulfur dioxide) or even SO₃ (sulfur trioxide) in the combustion chamber. If sulfur passes over a catalyst it may be further oxidized in the catalyst, i.e. (SO₂ may be further oxidized to SO₃). Sulfur oxides are precursors to sulfuric acid, a major component of acid rain. While it is possible to add substances like Vanadium to the catalyst wash coat to combat sulfur oxide formation, this will reduce the effectiveness of the catalyst—the best solution is further refinement of the fuel at the refinery to remove the sulfur. Regulations in Japan, Europe and, by 2007, North America tightly restrict the amount of sulfur permitted in motor fuels. However, the expense is such that this is not practical in many developing countries. As a result cities in these countries with high levels of vehicular traffic suffer damage to buildings due to acid rain eating away the stone/woodwork, and acid rain has deleterious effects on the local ecosystem.

Regulatory agencies

The agencies charged with regulating engine emissions vary from jurisdiction to jurisdiction, even in the same country. For example in the United States overall responsibility belongs to the United States Environmental Protection Agency (EPA), however due to the special requirements of the State of California emissions in California are regulated by the Air Resources Board, and in Texas the Texas Railroad Commission is responsible for regulating emissions from LPG fueled rich burn engines (but not gasoline fueled rich burn engines).

1. California Air Resources Board - California, United States (most sources)
2. Environment Canada - Canada (most sources)
3. Environmental Protection Agency - United States (most sources)
4. Texas Railroad Commission - Texas, United States (LPG fueled engines only)
5. Transport Canada - Canada (trains and ships)

Criticisms Of Catalytic Converters

Catalytic converters have proven to be reliable devices and have been successful in reducing noxious tailpipe emissions. However, they have two adverse environmental impacts in use (ignoring the pollution caused in their manufacture, which would not exist were they not mandated):

1. The requirement for the engine to run at the stoichiometric point means fuel economy is not as good as that of a "lean burn" engine running at a mixture of 20:1 or weaker. This increases the rate at which fossil fuel resources (aka poor mileage) are consumed and the carbon dioxide emissions of the vehicle.
2. Catalytic converters are estimated to account for 50% of total nitrous oxide (dinitrogen oxide, 'laughing gas') emissions to atmosphere. While N₂O emissions in these concentrations are not harmful to human health, it is a potent greenhouse gas, accounting for around 7% of the overall greenhouse effect despite its small concentration in the atmosphere.

Therefore one conclusion is that **catalysts have reduced toxic emissions and the incidence of smog at the expense of increased global warming.**

Diagnostics

Various jurisdictions now legislate on-board diagnostics to monitor the effectiveness of the emissions control system, including the catalytic converter and such diagnostics are often included in aftermarket retrofit kits as a matter of course, even if legislation does not directly require them.

On-board diagnostics take several forms, depending upon the legislation and the type of emissions control product being monitored, the three main types are

1. Temperature,
2. Oxygen, and
3. NO_x.

Temperature Sensors

Temperature sensors are used for two purposes. The first is as a warning system, typically on obsolete 2-Way catalytic converters such as are still sometimes used on LPG forklifts. The function of the sensor is to warn of temperature excursions above the safe operating temperature of the 2-Way catalytic converter of 750°Celsius. Note that modern catalytic converters are not as susceptible to temperature damage, many modern 3-Way platinum based converters can handle temperatures of 900°C sustained, while many modern 3-way palladium based converters can handle temperatures of 925°C sustained. Temperature sensors are also used to monitor catalyst functioning - usually two sensors will be fitted, one before the catalyst and one after to monitor the temperature rise over the catalytic converter core. For every 1% of CO in the exhaust gas stream the exhaust gas temperature will rise by 100°C.

Oxygen Sensors

The Oxygen sensor or "lambda sensor" is the basis of the closed loop control system on a spark ignited rich burn engine, however it is also used for diagnostics. Oxygen sensors only work when at operating temperature, when they output a voltage based on the O₂ level in the exhaust gas to the computer. Typically a single wire oxygen sensor will take 3-5 minutes to reach operating temperature. The more expensive heated sensors (3 to 5 wires) can reach operating temperature in 1 minute.

The simplest sort of diagnostic an oxygen sensor can perform is related to the closed loop control system. If the system makes a change to the air-fuel ratio based on oxygen sensor readings, and the readings do not change the sensor will light an indicator on the instrument panel warning the operator that there is a problem with the vehicle. There is always a delay before this happens, usually 5 minutes of engine operation. Most systems do not store the state, so turning off the engine and turning it back on will reset the system. If the error is transient (i.e. fuel filter is partially blocked), the light will not come back on, however if the problem is recurring the light will come on as soon as the sensor reaches operating temperature and a manufacturer-defined driving pattern known as a drive-trace is completed. Until this procedure has finished, the diagnostic computer will set a parameter called a readiness monitor to unready. The readiness monitor system was implemented in order to ensure that diagnostic computers would not falsely report working emissions systems in vehicles whose computer's error memory had recently been cleared. Such diagnostics have been factory fitted to automobiles since 1985 in North America and factory fitted to off-road Spark Ignition engines since 2004 (however such systems have been available as retrofit kits for off-road SI engines since 1997).

The second sort of diagnostic is more complex and is a result of the California OBD 2 rule (though temperature

sensors are sometimes used for this). For OBD 2 a second oxygen sensor is fitted after the catalytic converter, and this sensor monitors the O₂ levels, and the on-board computer makes comparisons to the readings of the two sensors. If both sensors give the same output, the catalytic converter is non-functioning, and must be replaced. It will also spot less serious damage to a catalytic converter, such as the use of racing fuel in an on-road vehicle. Lead is still legal in racing fuel, and use of as little as half a tank of leaded fuel will cause enough damage for the computer to notice, and warn the operator that the converter is not functioning properly.

NOx Sensors

NOx sensors are extremely expensive and are generally only used when a compression ignition engine is fitted with a Selective Catalytic Reduction Converter, or a NOx Adsorber Catalyst in a feedback system (though many SCR systems do not use a NOx sensor, but instead rely on the engine map being programmed into the Engine Control Unit or computer). When fitted to an SCR system there may be one or two sensors. When one sensor is fitted it will be pre-catalyst, when two are fitted the second one is post catalyst. They are utilized for the same reasons, and in the same manner as an Oxygen Sensor - the only difference is the substance being monitored.

Cars, Trucks, Vans, & Buses and Global Warming

Motor vehicles are responsible for almost a quarter of annual US emissions of carbon dioxide (CO₂), the primary global-warming gas. The US transportation sector emits more CO₂ than all but three other countries' emissions from all sources combined. And motor vehicle emissions will continue to increase as more vehicles hit America's roads and as the number of miles driven continues to grow.

Three factors contribute to CO₂ emissions from cars, trucks, vans, and buses:

1. Amount of fuel used,
2. Amount of CO₂ released when a particular fuel is consumed, and
3. Number of vehicle miles traveled.

Combating global warming requires reducing all of these factors. This necessitates increased fuel efficiency, switching to renewable fuels, and possibly less driving.

Increased Fuel Efficiency

The amount of fuel consumed by motor vehicles governs how much CO₂ pollution enters the atmosphere: the more gasoline burned, the more CO₂ released. Automobiles need to become more fuel efficient. For the last decade, however, the fuel-economy standards for motor

vehicles have stagnated. In addition, low gas prices have helped create a market for gas-guzzling light trucks such as sport-utility vehicles (SUVs) and minivans that have actually led to an increase in CO₂ emissions.

Increasing fuel efficiency is a cost-effective and technologically feasible method to address the threat of global warming, benefit our economy, and protect public health. To do this, government policies should consider:

1. Strengthening fuel-efficiency standards (CAFE) for all passenger vehicles and eliminate the light-truck (SUV) loophole while
2. Supporting the development and marketing of advanced vehicles, like battery electrics, hybrid electrics, and fuel cells.

Switch to Renewable Fuels

Using conventional, gasoline-combustion technology can only decrease CO₂ pollution so much. The large-scale CO₂ savings that are necessary require a shift to renewable fuels. These fuels, because they are not produced from high-carbon fossil fuels, have lower carbon emissions. To encourage this shift, government policies should:

1. Provide incentives for research and development of renewable fuels
2. Encourage investment in renewable fuels and the necessary infrastructure through methods like tax incentives

Reduce Driving

With the number of cars on the road expected to double over time, gains in fuel efficiency alone will not reduce CO₂ pollution. Measures that reduce vehicle miles (VMT) traveled also improve the quality of life and protect natural resources. To reduce VMT, government policies might consider:

1. Promoting transit-oriented, compact development,
2. Providing transportation alternatives to cars, including mass transit, bicycle, and pedestrian routes, and
3. Adopting "fix-it first" policies to improve existing infrastructure and roads.

Cars, trucks, vans, buses, and other internal combustion vehicles (mostly SUVs) are a major cause of global warming pollution. Approximately 40% of carbon dioxide (CO₂) emissions in California derive from the combustion of gasoline in cars, SUVs and other passenger vehicles. These vehicles are also responsible for about 25% of nitrous oxide emissions (N₂O) and about 10% of

methane (CH₄) emissions, both potent greenhouse gases. In addition, vehicle air conditioners leak hydrofluorocarbon-134a (HFC-134a), a greenhouse gas (GHG) that is 1300 times as potent as CO₂. The buildup of heat-trapping gases plays a significant role in global warming.

However, many vehicle technologies are commercially available today to reduce greenhouse gas (GHG) emissions. Most of the technologies discussed below are already in use on some mass-market vehicles, or are proven technologies ready to be utilized in new car models, often at little or no additional cost.

Engine Modifications

Engine modifications can reduce GHG emissions through three effects: reduction of pumping losses, reduction in engine friction, and/or improved combustion.

Variable Valve Timing (VVT) or Variable Valve Lift and Timing (VVLVT). By providing a better fuel/air mix and improved combustion, these technologies reduce CO₂ emissions.

Cylinder Deactivation. Also known as "displacement on demand," this technology shuts down one or more cylinders when the extra power is not needed. This is particularly applicable to larger vehicles with V-6 and V-8 engines.

Engine Downsizing Combined with Turbocharger or Supercharger. This approach can lead to reduced CO₂ emissions with no loss of engine power or performance.

Some engine technologies on the horizon that could result in GHG emission reductions include: stoichiometric burn direct injection, variable compression ratio engines, and homogeneous charge compression ignition engines.

Improved Transmissions

New transmission technologies can reduce greenhouse gas emissions by enabling the engine to operate close to (or near) its optimal speed more frequently.

Five or six-speed automatic transmissions accomplish this goal when used instead of the four-speed automatic transmission standard on most new cars today.

Continuously variable transmissions (CVT) take this goal to its full realization by allowing an infinite number of speeds within an automatic transmission.

Automatic shift manual transmissions can reduce GHG emission by reducing the mechanical losses associated with transmission operation.

Additional Vehicle Technologies are being developed such as:

Aerodynamic drag can be reduced through sleeker design.



Integrated Starter Generators or Belt-driven Starter Generators allow a vehicle to turn off at idle and then quickly restart, thereby eliminating emissions while stopped.

The use of a 42 Volt Electrical System can reduce the engine load created by vehicle systems or accessories such

as power-steering pumps, air conditioners, or lubrication systems.

Improvements in catalyst technology can reduce N_2O and CH_4 emissions.

The use of alternative refrigerants. Leaks of HFC-134a, a refrigerant, from vehicle air conditioners, while small in magnitude, accounts for approximately 2% of the CO_2 -equivalent GHG emissions released each mile. In part this is because HFC-134a is 1300 times more potent as a GHG than CO_2 . Research is ongoing into the use of alternative refrigerants. In the meantime, HFC-134a leakage could be greatly reduced by improving air conditioning system seals and hoses, and by recovering HFC-134a from air conditioner units when vehicles are scrapped.

Low Rolling Resistance Tires. The use of low rolling resistance tires reduces friction between the vehicle and the road, and can result in a 3% reduction in greenhouse gas emissions.

At some point or another, we've all gotten caught behind an 18-wheeler, a garbage truck, a tractor, or a bulldozer and seen, smelled, and even felt the clouds of soot coming from their tailpipes. But how and why does diesel fuel produce this haze of soot, or particulate matter (PM), and how does it affect the bodies of those who breathe it in? In this backgrounder we take a look at the lifecycle of soot and explore its implications for your family's health.

The Birth of Soot

Soot, or particulate matter (PM), begins its life in the belly of both gasoline and diesel-powered engines. These engines create chemical and organic compounds from the combustion of hydrocarbon-based fuels (fossil fuels). These compounds then cluster together in particle form to create soot, which is released into the air as exhaust. Soot may also come to life as the indirect by-product of nitrogen oxides (NO_x) and sulfur dioxides (SO_x) reacting in the atmosphere. Soot's composition

often includes hundreds of different chemical elements, including sulfates, ammonium, nitrates, elemental carbon, condensed organic compounds, and even carcinogenic compounds and heavy metals such as arsenic, selenium, cadmium and zinc.

One of reasons conventional diesel engines release more soot than their conventional gasoline counterparts has to do with the way fuel is injected and ignited: on gas engines, fuel is injected during the intake stroke and ignited with a spark; on diesels, fuel is injected during the compression stroke, and the fuel ignites spontaneously from the pressure. As a result, gas engines have two emissions advantages: The ignition process is more carefully controlled and the air and fuel are more thoroughly mixed before ignition occurs, thereby reducing the amount of unburned fuel. In a conventional diesel, fuel is injected late in the cycle and the air is injected late in the cycle and the air is not as well mixed as in a gasoline engine. As a result of this less homogeneously mixed fuel and air, there are fuel-dense pockets in the combustion chamber. The consequence is that diesel engine exhaust contains incompletely burned fuel (soot) known as particulate matter.

But it's not "engine-out" pollution that really matters—it's what comes out of the tailpipe. Gasoline engines have gotten a lot cleaner over time through the use of add-on pollution controls, like catalytic converters. The environmental Protection Agency (EPA) has passed increasingly stricter standards for gasoline engines, and as a result, catalytic converters are now standard on every new gas car.



A Diesel Engine Particulate Filter System.

The real reason diesels pollute more soot is that EPA has not forced them to meet the stricter standards facing gasoline engines. The soot standard for diesel cars under EPA's Tier 1 regulation is at least ten times the average emission from a gasoline car. But under the new Tier 2

regulations, which will phase in between 2004 and 2009, diesels will finally have to meet the same strict standard as gasoline cars. Diesel cleanup technology has come a long way. From diesel particulate traps to oxidation catalysts, there are now various methods of catching or converting much of diesel pollution before it escapes the tailpipe. Starting in 2009, all diesel light trucks and cars will have to meet the same tailpipe standards as gasoline vehicles.

But new engine standards alone are not enough to protect the public from diesel pollution. New standards for diesel engines will be slowly phased in over the next 10

years. Plus, the durability of diesel engines means that older, high-polluting vehicles can continue to operate for decades. Diesel soot emissions are furthered by the fuel itself, as today's conventional diesel fuel contains significantly more sulfur than does gasoline.

Soot's exact composition is difficult to characterize because different engine technologies and conditions produce different types of soot. Indeed, the smoke clouds coming from diesel engines can even have different colors. For example, blue smoke (mainly oil and unburnt fuel) can indicate a poorly serviced and/or tuned engine; black smoke (soot, oil and unburnt fuel) can indicate a mechanical fault with the engine; and white smoke (water droplets and unburnt fuel) is produced when the engine is started from cold and may disappear when the engine warms up.

The soot in your neighborhood may be different than the soot in someone else's hometown, but no matter the source and type, soot can present a grave health threat.



Soot's Journey Across the Land

As previously mentioned, soot particles either come directly from the tailpipe, or can be formed when tailpipe emissions of NO_x and SO_x react with several atmospheric agents. Once formed, soot comes in very many sizes, though all just a fraction of the width of a human hair, from coarse PM (less than 10 microns in diameter) to fine PM (less than 2.5 microns) to ultrafine PM (less than 0.1 microns). Most soot is in the fine and ultrafine categories, with ultrafine particles making up 80-95% of soot. Ultrafine particles are the most dangerous, however, as they are small enough to penetrate the cells of the lungs. Soot particles can have an environmental lifetime of one to three weeks, and they can travel long distances, journeying to communities in far regions. Soot particles have even been found at the South Pole, where no major emission source exists for thousands of miles.

But in general, soot tends to fall out of the atmosphere close to the source of the pollution. The further you are away from diesel exhaust sources, the better for your health, and vice-versa. In California, the home of the nation's largest fleet of diesel vehicles, roughly 80 percent of the state's diesel pollution sources are found in 5 of the 15 air basins. Showing that the effects of diesel soot are, mostly close to the source, about 87% of California's over \$21.5 billion yearly diesel exhaust-related health care costs come from the same 5 air basins.

Estimated Premature Deaths by Diesel Exposure in the California Air Basin



NOTE: Premature deaths are a result of exposure to diesel particulate matter, both direct from the tailpipe and from the conversion of NO_x emissions to particulates in the atmosphere. Estimates for indirect particulate exposure for each air basin are based on a conversion of NO_x emissions to particulates. SOURCE: Image courtesy of CARB.

Soot's Trip Through Your Body

As soot travels through the air in your community, you breathe it in, and so it starts the next phase of its journey: a trip through your body's respiratory system. Large soot particles (>10 microns) deposit in your nose, throat, and lungs, causing coughing and sore throat, and are ejected from your body through sneezing, coughing, and nose blowing. Coarse particles (10 microns) are inhaled into your windpipe and settle there, causing irritation and more coughing. Fine and ultrafine particles (less than 2.5 microns) are the most successful in invading your body, small enough to travel all the way down deep into your lungs.

Once there, these soot particles can irritate and mutate the most sensitive tissues in your lungs: your alveoli. These air sacs line your lung's alveolar ducts and are the primary gas exchange units of the lungs. Surrounded by networks of blood capillaries, alveoli exchange oxygen and carbon dioxide from the air you breathe in with blood in your capillaries, thus allowing your circulatory system to carry oxygen to the rest of your body. Soot particles, however, make this task more difficult as they cause inflammation and scarring of these alveoli. Scar tissue builds up and slows oxygen flow to your capillaries, straining your heart because it must work harder to compensate for oxygen loss.

Soot also finds other ways to harm your body, including causing chronic bronchitis and asthma. These conditions occur when the linings of your lung's bronchioles (air passageways) become irritated and swollen, in turn causing your lungs to create mucus to soothe the irritation. These conditions prevent your bronchioles from

moving oxygen to the rest of your body. Symptoms can range from coughing and shortness of breath to severe and fatal attacks of oxygen loss. In addition, soot particles also reduce your respiratory system's ability to fight infections and remove other foreign particles.

Soot particles can also act as carriers of carcinogenic compounds into your body. Compounds in soot such as polycyclic aromatic hydrocarbons (PAHs) are carcinogenic, and diesel soot itself is classified by many government agencies as either a probable or known cancer-causing agent. For example, the California Air Resources Board has concluded that diesel soot is responsible for 70 percent of the state's risk of cancer from airborne toxics.

Lastly, diesel pollution can be deadly, causing premature mortality through cancer or heart and respiratory illnesses. In the population as a whole, studies have shown a 26% increase in mortality in people living in soot-polluted cities.

Soot's Harms Vulnerable Populations Most

Although all human beings are susceptible to soot's journey through their body, individuals with preexisting respiratory conditions, children, and the elderly are the most vulnerable to soot's lasting and deadly effects. People with heart disease, emphysema, asthma, and chronic bronchitis suffer from increased hospital admissions and emergency room visits as a result of exposure to soot.

Children—and their developing lungs—may also suffer more acutely from breathing in diesel soot. Outdoors more often and breathing in more air per body weight than adults do, children suffer disproportionately from asthma and other respiratory conditions. Asthma is the most common chronic disease of childhood and a leading cause of disability among children; today about one in thirteen children have asthma. Elderly persons also bear a large burden when coming in contact with soot. Studies estimate that tens of thousands of elderly people die prematurely each year from exposure to ambient levels of fine PM.



A Costly Journey

In the end, soot travels far and wide to affect thousands of communities and millions of people, including you and your family. It begins in the combustion of an engine and ends up in the innermost reaches of individuals' lungs.

Society pays a heavy price for soot's journey. Billions of dollars in health care costs, the loss of work and school days, and the loss of human lives create an enormous burden for society to shoulder. This burden is not a necessary one, however, as it can be lifted from off our backs with the help of stricter air regulations and cleaner engine technology.

According to reporter Cat Lazaroff, California Law Will Limit CO₂ Emissions From Cars

SACRAMENTO, California, July 22, 2002 (ENS) - California today became the first state in the nation to regulate emissions of the greenhouse gas carbon dioxide from motor vehicles. Governor Gray Davis signed legislation ordering the state's air quality board to develop statewide standards for tailpipe emissions of carbon dioxide, beginning in model year 2009.

The new law is aimed at reducing the global warming impacts of carbon emissions from cars, light trucks and sport utility vehicles (SUVs), and could prompt similar legislation in other states across the nation.

"This is the first law in America to substantively address the greatest environmental challenge of the 21st century," Governor Davis said. "In time, every state - and hopefully every country - will act to protect future generations from the threat of global warming. For California, that time is now."

Assembly Bill 1493, authored by state assembly member Fran Pavley, a Democrat, requires the California Air Resources Board to develop carbon dioxide (CO₂) standards for vehicles in model year 2009 and beyond. The standards will apply to automakers' fleet averages, rather than each individual vehicle, and carmakers will be able to partially achieve the standards by reducing pollution from non-vehicle sources, including automobile factories.

"Today is another giant step toward cleaner air for all Californians and serves as a model for our country to follow," said Pavley.

Automakers have warned that the law could force them to produce smaller, less safe cars, or could force a statewide ban on large, gas guzzling vehicles such as SUVs. But Davis said Californians will

continue to be able to choose from the same wide variety of vehicles.

"The technology is available. It's affordable. And it's widely utilized in other countries," Davis explained. "We're merely asking business to do what business does best: innovate, compete, find solutions to problems and do it in a way that strengthens the economy."

"Opponents of this bill say the sky is falling," Davis explained. "But they said it about unleaded gasoline. They said it about catalytic converters. They said it about seat belts and air bags. But the sky is not falling. It's just getting a whole lot cleaner."

Vehicle emissions account for about 40 percent of the greenhouse gas pollution emitted in California. California ranks second in the nation - behind Texas - in overall emissions of CO₂, the most common greenhouse gas. Most of California's emissions of CO₂ comes from transportation and almost 40 percent is from passenger vehicles. In June, researchers from several California universities released a new study documenting that global warming could reduce the state's supplies of fresh drinking water, and make remaining supplies less predictable. Other experts warn of increased wildfire risk, added strain on the electric grid, and deterioration in air quality from the changing climate.

"You don't have to look far to see where California could be affected by global warming," Davis said. "From our seaside communities to our low lying agricultural land to the Tracy pumps that send fresh water south, we could be affected by a relatively small rise in sea level. The Department of Water Resources tells me that California's snowpack, our state's greatest natural reservoir, is already less reliable than it was just a few decades ago. We know the costs if we don't act."

*"This legislation is based four-square on sound science," he added. "Global warming is no longer a theory. **It's an urgent reality.**"*

The bill won wide support from conservation groups and many of the state's business leaders. In June, a poll conducted by the non-partisan Public Policy Institute of California found that more than 80 percent of state residents support setting limits on CO₂ pollution from vehicles.

"California business is happy to see AB 1493 signed," said Bob Epstein, co-founder of Sybase and the business group Environmental Entrepreneurs. "We believe that a healthy environment and a stable climate is in the best interest of all California businesses."

"Today California is leading the nation and the world and showing that we can address our environmental problems and keep our economy strong," added Sierra Club president Carl Pope. "We can and we must do this."

The bill had an uphill battle to overcome a well funded campaign by automakers who warned that enforcing the new law could require new vehicle or gasoline taxes, slower speed limits or restrictions on the number of miles consumers would be allowed to drive. The bill passed the state legislature by a single vote earlier this month after supporters presented evidence that most of those steps are beyond the power of the Air Resources Board (ARB) to enact, and none of the steps would be necessary to reduce CO₂ emissions.

Governor Davis echoed those arguments today when signing the bill.

"Some of the technology to reduce carbon pollution is already in use today on vehicles you can buy from your local dealership," Davis said. "These technologies are as simple as smoother rolling tires and wheels, some as innovative as advanced transmissions or hybrid drives. The bill I've signed directs the ARB to consider the overall costs of these technologies. In any case, the ARB will be setting the standards, but the carmakers will decide what specific technologies to use."

Because California set its own limits on air pollution before the enactment of the federal Clean Air Act, the state is the only one in the nation to be allowed to set pollution rules overriding the federal law. California has the strictest air quality standards in the nation, and requires cleaner fuel than any other state.

Under a special provision of the Clean Air Act, any state is free to adopt California's strict emissions standards in place of weaker federal rules, and a number of states, including New York, Massachusetts, Maine and Vermont, have followed in California's footsteps. These added states, representing some of the nation's largest automobile markets, could force the auto industry to make nationwide changes in tailpipe emissions standards.

Even other nations took note of California's new law.

"This is a dramatic breakthrough," said Gerry Scott, director of the climate change campaign at Canada's Davis Suzuki Foundation. "This is the single biggest initiative on global warming ever taken in North America. And if California can do it, so can Canada."

Ford, General Motors and DaimlerChrysler have already announced plans to produce low CO₂ emissions, fuel efficient hybrid SUVs within the next few years. But a number of automakers have threatened to sue to block new mandatory CO₂ emissions standards in California.

Speaking to the automakers who opposed California's newest emissions law, Davis said, "We Californians love our cars. "Don't change our cars. Just change the amount of harmful emissions that come from our cars."

Automakers Say They Will Sue To Block California Bill Restricting Carbon Dioxide Emissions

July 23, 2002

LOS ANGELES (AP) _ U.S. automakers say they will sue California to block an anti-global warming law that restricts carbon dioxide emissions from cars.

California Gov. Gray Davis signed the measure Monday after it squeaked by the state Legislature despite a multimillion-dollar opposition campaign by carmakers and auto workers.

California already has the United States' most stringent standards for other vehicle pollutants. The new law sets emission standards for carbon dioxide and other greenhouse gases that would apply to new passenger cars and light trucks beginning in 2009.

Before signing the measure on a hot, smoggy day along a park trail, Davis said the bill is the first in the United States designed to combat global warming. He said he believed other states and the federal government eventually would follow.

"We are going to set an example for the country," he said.

More than 2 million cars were sold in California last year, making it the United States' biggest auto market, so the law's effect on the auto industry was expected to be enormous. The legislation does not affect large polluters like big tractor trailers or other commercial vehicles.

Opponents said the measure would increase the price of vehicles and reduce greenhouse gases globally by less than 1 percent.

The bill "will reduce the freedom of choice" by pricing sport utility vehicles, minivans and other models out of some consumers' range, said a statement from the American Highway Users Alliance, a Washington-based nonprofit group.

The Alliance of Automobile Manufacturers said it would challenge the law in federal court.

Supporters of the bill maintain that passenger cars and light trucks are responsible for 40 percent of California's carbon dioxide emissions. The gases form a heat-trapping blanket in the atmosphere that scientists fear could cause disruptions in farming and the snowpack that provides much of Southern California's water.

"This bill is an earthshaking event. This is going to start us on the fight against global warming," said David G. Hawkins of the Natural Resources Defense Council.

California Sues Again

According to Nick Bunkley of The New York Times

California sues 6 car companies – September 21, 2006

California, which has battled the automotive industry over new global warming regulations for years, is suing the world's six largest automakers, demanding that they pay for environmental damage caused by emissions from their vehicles.

The suit is the first such attempt to hold automakers accountable for the greenhouse gases that vehicles produce. It accuses General Motors, Toyota, Ford, Honda, Chrysler and Nissan of creating a public nuisance by building millions of vehicles that collectively discharge 289 million metric tons of carbon dioxide into the atmosphere annually.

"Global warming is causing significant harm to California's environment, economy, agriculture and public health," the state attorney general, Bill Lockyer, said Wednesday.

"Vehicle emissions are the single most rapidly growing source of the carbon emissions contributing to global warming, yet the federal government and automakers have refused to act."

Lockyer contends that the products of the six companies are responsible for a fifth of carbon dioxide emissions in the United States and nearly a third of the emissions in California, which has more vehicles than any other U.S. state.

He said he would seek at least "tens of millions" of dollars in damages for past, current and future contributions to air pollution, beach erosion and reduced water supplies.

The automakers named in the suit declined to comment on it directly, but a trade group representing them labeled the accusations a "nuisance suit" similar to an unsuccessful attempt by several states in the northeastern United States to hold utilities liable for environmental damages.

"Automakers are already building cleaner, more fuel-efficient vehicles," the Alliance of Automobile Manufacturers, based in Washington, said in a statement. "Today's autos are 99 percent cleaner than a generation ago, and every model of auto is now available with some type of fuel-efficient technology."

Dave Barthmuss, a GM spokesman in Los Angeles, said the company was working toward the eventual goal of selling clean hydrogen-powered vehicles and, as an interim step, had invested in technology like flexible-fuel engines.

"We are spending significant financial and human resources to commercialize alternatives," Barthmuss said.

James Marston, director of the energy program at Environmental Defense, a nonprofit organization, said GM, Ford and Chrysler could improve their profit by reducing emissions. He cited a study released this week by transportation researchers at the University of Michigan. The study suggested that the three companies would sell more cars, adding \$2 billion in annual profit, by raising the fuel

economy of their vehicles by only a few miles per gallon.

The industry is "wasting a lot of money paying lawyers to fight, and we ought to be spending that money on engineering," Marston said. Carmakers "need to get the message that they've got to do something different," he said.

Lockyer said the suit was not an attempt to persuade automakers to back down from their legal challenges to rules enacted by the state aimed at cutting greenhouse-gas emissions.

In 2004, the state enacted similar requirements for auto emissions, which the automakers sought to throw out in federal court. That law was aimed at reducing pollution created by cars and light trucks by 25 percent and from sport utility vehicles by 18 percent.

Last month, the California Legislature passed a measure to regulate industrial output of greenhouse gases. Governor Arnold Schwarzenegger is expected to sign the bill into law soon.

Marc Ross, a professor of physics at the University of Michigan who has studied automobile emissions, said automakers had set themselves up to become targets of environmentalists as they worked to maximize sales of sport utility vehicles.

"Regardless of the negative social aspects of those vehicles, they proceeded to develop that market as much as they could," he said.

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Ground Transportation Emissions Background

The emission rates for hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NOx) shown in the following tables are from U.S. Environmental Protection Agency (EPA) highway vehicle emission factor models. They assume an average, properly maintained vehicle on the road in July 2000, operating on typical gasoline on a warm summer day (72-96°F). Emissions may be higher in very hot (especially HC) or very cold (especially CO) weather.

The calculations for Total Annual Pollution Emitted and Fuel Consumed are based on an average annual passenger car mileage of 12,500 miles and an average annual light truck mileage of 14,000 miles. Fuel consumption is based on fleetwide average in-use fuel economy of 21.5 miles per gallon (mpg) for passenger cars and 17.2 mpg for light trucks, as reported in the 19th edition of the "Transportation Energy Data Book," prepared for the U.S. Department of Energy.

Passenger Car

Component	Emission Rate and Fuel Consumption per mile (mi) per year ¹	Calculation	Total Annual Pollution Emitted and Fuel Consumed
Hydrocarbons	2.8 grams (g)	2.8g/mi x (12,500 mi) x 1 lb/454 g	77.1 lbs of hydrocarbons
Carbon Monoxide	20.9 grams (g)	20.9g/mi x (12,500 mi) x 1lb/454 g	575 lbs of carbon monoxide
Oxides of Nitrogen	1.39 grams (g)	1.39g/mi x (12,500 mi) x 1lb/454 g	38.2 lbs of oxides of nitrogen
Carbon Dioxide ²	0.916 pound (lb)	(0.916 lb/mi x (12,500 mi) x	11,450 lbs of carbon dioxide
Gasoline	0.0465 gallon	(0.0465 gallon/mi x (12,500 mi)	581 gallons of gasoline

Light Truck

Component	Emission Rate and Fuel Consumption per mile (mi) per year ¹	Calculation	Total Annual Pollution Emitted and Fuel Consumed ³
Hydrocarbons	3.51 grams (g)	3.51g/mi x (14,000 mi) x 1 lb/454 g	108 lbs of hydrocarbons
Carbon Monoxide	27.7 grams (g)	27.7g/mi x (14,000 mi) x 1lb/454 g	854lbs of carbon monoxide
Oxides of Nitrogen	1.81 grams (g)	1.81g/mi x (14,000 mi) x 1lb/454 g	55.8 lbs of oxides of nitrogen
Carbon Dioxide ²	1.15 pound (lb)	(1.15 lb/mi x (14,000 mi) x	16,035 lbs of carbon dioxide
Gasoline	0.0581 gallon	(0.0581 gallon/mi x (14,000 mi)	813 gallons of gasoline

Notes:

1. These emission factors and fuel consumption rates are averages for the entire in-use fleet. Newer cars and trucks will emit less pollution and use less gasoline; older cars and trucks may emit more pollution and use more gasoline.
2. Carbon dioxide, while not regulated as an emission, is the transportation sector's primary contribution to climate change. Carbon dioxide emissions are directly proportional to fuel economy--each 1% increase (decrease) in fuel consumption results in a corresponding 1% increase (decrease) in carbon dioxide emissions.
3. The total annual emissions and fuel consumption are greater for light trucks than was presented in the April 1998 version of this fact sheet. This reflects the increasing trend toward the largest, heaviest light trucks, which currently and in the past have had less stringent emission standards and lower fuel economy than do the lighter light trucks and cars. The new "Tier 2" emission standards taking effect starting with the 2004 model year will bring all light trucks into compliance with the same emission standards as cars (for HC, CO, and NOx).

Generally Speaking

1. **Catalytic converters have performed OK at best** (environmentally) but at lesser mileage and increased carbon dioxide and nitrous oxide (dinitrogen oxide, 'laughing gas') emissions to the

environment. Catalytic converters are estimated to account for 50% of total nitrous oxide emissions to the atmosphere. While N₂O emissions in these concentrations are not harmful to human health, it is a potent greenhouse gas, accounting for around 7% of the overall greenhouse effect despite its small concentrations in the atmosphere. Thus, while reducing toxic emissions and the incidence of smog **global warming has been increased due to additional carbon dioxide emissions while also increasing fuel costs.**

2. **Next Generation Technology has been developed to eliminate the need for expensive and sometimes problematic catalytic converters while eliminating carbon dioxide, carbon monoxide, NOx, smoke, soot, sulfur dioxide, and unburnt hydrocarbons discharges to the environment. The technology also decreases total fuel costs due to significantly increased fuel mileage from both gasoline and diesel powered transportation equipment.**
3. Since the technology removes both NOx and Carbon Dioxide the engine may be tuned to operate at its **stoichiometric point** thereby maximizing both engine power and fuel economy. Due to the significant increase in fuel mileage the next generation technology accomplishes both global cooling and decreased driving costs simultaneously at very little, if any, increase in its capital cost. The technology is shown on attached WSE Drawing No. 1599-2 replete with automotive, chemical, environmental, and mechanical engineering considerations.

Next Generation Technology Further Explained

1. A stainless steel finned tube heat exchanger is added to the transportation equipment immediately after the engine exhaust header(s). The engine exhaust contains NOx (N₂O₃ and N₂O₅), sulfur dioxide, carbon monoxide (due to incomplete combustion) gases; unburnt hydrocarbons (HC); polynuclear and polycyclic aromatic hydrocarbons (PAH); soot and smoke (mostly from diesels); and lastly water vapor at a temperature ranges of up to 500°C (932°F) for diesel fueled transportation equipment and up to 700°C (1292°F) for gasoline fueled transportation equipment.

A stainless steel finned tube heat exchanger is shown below.



2. The several gaseous reactions with Ozone are chemically identified on WSE Drawing No. S-1599-2. Because of the high temperatures and reactivity of Ozone these reactions proceed quite rapidly and completely even though the reaction temperature is quickly decreasing. The next chemical sodium hydroxide (NaOH) is then added to achieve additional reactions all of which also proceed rapidly and completely because of the favorable reactivity of the reactants. As the sodium hydroxide liquid chemical is added the rate of vapor condensing increases due to both latent and sensible heat transfers similar to the operation of a traditional cooling tower. The resulting condensate contains solutions of Sodium Carbonate (NaCO_3), Sodium Nitrate (NaNO_3), and Sodium Sulfate (Na_2SO_4). Throughout the entire condensing period soot particles become scrubbed out of the gaseous stream thereby becoming occluded within the condensate in the same manner as microscopic dust is occluded in a normal rainfall event with its deposition on a car or truck windshield. The condensate automatically overflows the Float & Thermostatic Steam Trap onto to the highway. The technology will be designed to routinely achieve at least a 3-Log (99.9%) efficiency for both gaseous and solids condensate capture under all driving conditions. The technology eliminates the necessity for any and all catalytic converters and, in the case of diesel transportation equipment the necessity for a particulate filter system and its associated maintenance requirements. Additionally, if the Float & Thermostatic Steam Trap is properly designed, this device will eliminate the necessity for the muffler as well.
3. The acetone additive can increase fuel mileage (both gasoline and diesel) by about 25% at an addition rate of about 2 ounces/10 gallons of fuel. Acetone, a ketone, can be purchased at Wal-Mart for about 10 pennies/oz

or in bulk at 1/5th that amount. Acetone is a byproduct of the phenol industry. Other ketones also work as well, i.e., methyl ethyl ketone (MEK) commonly used to clean PVC piping prior to gluing. MEK costs about 10 times more than acetone. If one pays \$2.50/gallon of fuel, 2 oz of Acetone will cost another 20¢ for a total of \$25.20. The acetone addition translates into a mileage increase of at least 5 miles/gallon. If the initial mileage were 20 mpg, the new mileage becomes 25 mpg at an investment of less than 1 penny/mpg. The scientific reason for this significant increase in mileage has to do with the surface tension properties of both gasoline (and its many formulations and blends) and diesel (and its many formulations and blends). At a nominal 2,500 engine revolutions per minute (RPM) complete combustion must occur in less than 1/25,000th of a second. Gasoline and diesel fuels are both liquid fuels. All liquids are scientifically incapable of combustion. Liquids must first become vapor in order for combustion to occur. Liquid fuels do indeed vaporize rapidly, but not fast enough to burn all of the fuel in the time period allowed due to the inherent surface tension of all liquid fuels. Incomplete combustion results in the familiar smell of raw gasoline in the tailpipe discharge of gasoline engines and the formation of soot and smoke particles in diesel engines. The unburnt gasoline is scientifically referred to as unburnt hydrocarbons. The soot particles are scientifically referred as diesel particulate matter. The increased fuel mileage is scientifically referred to as better fuel economy.

4. Another investment worthy improvement in fuel economy is the use of synthetic lubricants that exhibit the ability to increase mileage by at least another 10%. Synthetic lubricants are available from many sources and at long last are getting more competitive in the marketplace as their usage continues to increase.
5. Another potential improvement in mileage has to do with a vehicle's tire pressure. The current marketplace trend is to use Nitrogen rather than Air even though its cost is quite high. The promoters of Nitrogen claim that this particular gas does not leak out of a tire as fast as air and additionally, does not permit any harmful oxidation of the tire to occur. The routine zinger sales pitch is the statement that NASCAR (see nascar.com) racers have used nitrogen gas for many years to achieve better performance on the racetrack. Science says that Nitrogen are

smaller molecule than air (a 21:79% mixture of both Oxygen and Nitrogen) molecules thus refuting the first claim. Oxidation of rubber tires used to be a factor some 25 years ago but because of significant improvements in tire manufacturing oxidation is no longer a problem thus refuting the second claim. The actual science behind the improved performance experienced by NASCAR drivers is attributable to the fact that nitrogen is lighter in weight than air. In racetrack events every fraction of an ounce counts against both mileage and acceleration. This applies to both motorcycle and automotive racing events. For car owners using nitrogen under normal driving-to-work conditions won't be noticed at the pump. However, if one increases the air pressure (either expensive Nitrogen or inexpensive and sometimes free Air) to the maximum listed on the tire could easily increase mileage by another 3% or so. Increased tire pressure reduces the rolling resistance of a tire thereby improving fuel mileage. This is the basic reason why Tour de France and other bike event competitors use tire pressures of 80 pounds per square inch (PSI) or more. Better automotive and truck tires permit higher maximum pressure limits. Higher tire pressures have long been used in the trucking industry but are mostly unknown in the passenger car automotive industry. Higher tire pressures (while keeping drag racing to a minimum) will therefore further improve fuel mileage on a continuing (sustainable) basis.

6. Because outside combustion air contains about 350 parts per million of carbon dioxide, the technology has the potential for reducing global warming (climate change) by simultaneously sequestering both combustion air intake carbon dioxide as well as fuel combustion produced carbon dioxide at a combined 99.9% efficiency.

Condensate Discharge Considerations

1. Condensate discharge rate will vary from about ¼ gallon per minute from a gasoline passenger vehicle to about ½ gallon per minute from a heavy duty diesel truck. It will contain mostly Sodium Carbonate (Na_2CO_3) with far lesser amounts of particulate matter (PM), Sodium Sulfate (Na_2SO_4), and Sodium Nitrate (NaNO_3). If waste caustics are used for the Sodium Hydroxide chemical source the condensate will then contain very minor amounts of inorganic metal constituents like iron, zinc,

magnesium, copper, silica, and others. All of these inorganic constituents represent beneficial micronutrients to agricultural activities. There will be little and likely no organics in the condensate that constitute a Biochemical Oxygen Demand (BOD) or a Chemical Oxygen Demand (COD) because of the occurrence of Ozone (O_3) oxidation throughout the condensation process.

2. The condensate will fall on the highway where it will either evaporate to dryness under dry weather conditions or drain off with stormwater. The stormwater will run to ditches in the countryside and into storm sewers in urban and suburban areas. Condensate that reaches a stream will be carried to the ultimate destination of that stream whether another stream, river, lake, or the ocean itself.

Ozone Addition Considerations

1. Ozone gas may be produced (generated) within the transportation equipment as an add-on or original equipment component. Ozone generation equipment can be adequately powered by the transportation equipment's OEM supplied electricity generator (alternator).
2. Ozone Generating Equipment is becoming less expensive and more reliable as its marketplace use continues to increase. For example, within the last year its use for water disinfection was approved in an eastern United States jurisdiction (Massachusetts) in place of traditional chlorine. Ozone is now being used to sterilize bottled water and a plethora of other marketplace applications.

Sodium Hydroxide (NaOH) Addition Considerations

1. An additional chemical storage tank will have to be added to the transportation equipment to supply this (NaOH) required chemical. There will also have to be provision made to heat the tank to prevent crystallization of NaOH crystals under colder climate conditions. When all of the chemical equations identified on the engineering drawing are fully analyzed the size of the NaOH (CAS# 1310-73-2) chemical storage tank will have to be 6-7 times (6 for gasoline and 7 for diesel) times the size of the transportation equipment fuel tank to achieve process effective (99.9%) CO_2 capture (carbon sequestration). The substantially larger chemical storage tank relative to the fuel tank should pose no problem

for truck transportation equipment but will require a redesign of passenger sized cars—perhaps using some of the space available in the truck coupled with the space behind and underneath the rear seats. There might also be some additional space adjacent to the existing fuel tank in some car models.

2. Sodium Hydroxide is one of the most economical chemical in the marketplace because of its massive use throughout. It is used at crude oil refineries, for barge cleaning activities, and a host of other applications. The refinery industry alone generates well over 1 millions pounds/day of caustic wastes (waste code C100). The proposed next generation technology can accommodate the use of **waste caustics** rather than using virgin NaOH chemical thus enabling inexpensive waste management of this sometimes troublesome waste chemical. The EPA knows where all the waste caustics are located through its reporting requirements program. There are likely ample caustic wastes generated throughout the United States to obviate the need to use virgin NaOH. An EPA exclusion rule exists for spent caustic generated by petroleum refineries when used as a feedstock in the manufacture of certain commercial chemical products. This rule applies to owners or operators of facilities that generate, transport, store, treat, or dispose of wastes listed as RCRA codes K169, K170, K171, and/or K172. Treatment, storage, and disposal operations involving these wastes are also subject to the permitting and land disposal restriction requirements of RCRA. In addition, these wastes are deemed hazardous substances under the authority of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Emergency Planning and Community Right to Know Act (EPCRA). Therefore, any parties participating in CERCLA or EPCRA activities involving the newly listed wastes must comply accordingly. For example, responsible parties must report releases of 10 pounds or greater for waste code K169 and 1 pound or greater for waste codes K170, K171, and K172. These requirements would apply to and be imposed on Petroleum Industry Fueling Stations. 50% strength sodium hydroxide had been used for some 30 years for unplugging household kitchen sinks (i.e., Brand Name **Drano**). The 50% form (there are several others) has been withdrawn in recent years—likely for safety reasons. The proposed two-nozzle designed delivery pump fueling system is intended to minimize user contact with caustic liquids thereby minimizing exposure to the fueling operator.
3. The NaOH chemical (virgin or waste) will have to be added to the transportation equipment simultaneously with the addition of the fuel (gasoline or diesel)

with a two-nozzle designed delivery pump so that both liquids (fuel and chemical) are automatically added to the transportation equipment in the proper ratio. These delivery pumps may be located at existing service stations by increasing the infrastructure to include an additional NaOH storage tank utilizing carbon steel constructed with exterior only epoxy paint corrosion protection. This tank should be located below grade with provisions for heating to prevent chemical crystallization to occur since the freezing point of 50% NaOH occurs at 52-54°F (11°C). The refinery industry can easily deliver its waste sulfidic, naphthenic, and cresylic caustics to their service stations in the same manner as their fuel is delivered. Perhaps the EPA can find ways to achieve the delivery of other caustic wastes to the petroleum industry's service stations since both entities are friends rather than foes.

4. **In capturing greenhouse gas carbon dioxide** carbon credits are produced—at least in California in that Prime Minister Tony Blair and Governor Arnold Schwarzenegger have formed a **Carbon Trading Coalition**. The carbon credits will be earned by the drivers/owners of the transportation equipment itself or to the State of California. Governor Schwarzenegger will figure it out.



On Monday July 31st, Prime Minister Tony Blair and Governor Arnold Schwarzenegger joined a select group of prominent CEOs and business leaders from leading California and international companies at a roundtable discussion, convened by The Climate Group, to share ideas on how business and government can work together to reduce greenhouse gas emissions.

“Because climate change is a global problem, it requires a global partnership between business, government and NGOs,” said Dr. Steve Howard, CEO, The Climate Group. “We have convened the roundtable so that Prime Minister Blair and Governor Schwarzenegger can discuss practical ideas with business leaders. Focusing on

how business and government can work together to bring about the technology revolution needed, the discussion will help accelerate the transition to a low carbon economy.”

CEOs and Senior Executives participating in the roundtable discussion included Lord John Browne, BP; Charles O. Holliday Jr., DuPont; Sir Richard Branson, Virgin Group; Sergey Brin, Google; John Bryson, Edison International; Jacques Dubois, Swiss Re; Dan Hendrix, Interface; Michael Morris, AEP; James Murdoch, British Sky Broadcasting; Anthony Pratt, Pratt Industries/Visy; Tom King, PG&E; Jeff Swartz, Timberland; Tracy Wolstencroft, Goldman Sachs; Rick Lazio, JPMorgan Chase and others.

“These companies represent one half trillion dollars in turnover, well more than 315,000 employees, and in excess of 207 million customers,” said Dr. Howard. “We expect the discussion will include specific examples of what’s already been rolled out in California and the UK – which are both leaders in reducing greenhouse emissions – so that we can build on best practices.”

Research by The Climate Group has highlighted the economic up-side of curbing climate change. Many Fortune 500 companies, like BP and others attending the event, have already taken significant steps to reduce emissions and, in doing so, have decreased operations costs and increased profitability.

Speaking at the event, Lord Browne, CEO of BP, said: “Addressing climate change will take bold leadership. It’s a global problem and will require a global solution. Meetings like the one held today between business and government leaders are an important step in building consensus on a way forward.”



Prime Minister Blair and Governor Schwarzenegger with Climate Group CEO, Steve Howard

Acetone Addition Considerations

1. The acetone extender storage tank can be mounted within the engine compartment by the automotive assembly plant or its dealership. It's size would be very small permitting refilling at normal oil changes. Normal oil changes occur at 3-4,000 miles for vehicles using standard grade lubrication oils and 7-8,000 miles for vehicles using high grade synthetic lubricating oils. The size of the extender storage tank would be 2 Liters, slightly more than 2 Quarts.
2. Vehicles advertised by the auto industry that achieve substantially better (more than a 25% increase) fuel economy will result in greater sales and thus drive new business in that direction. **The Auto Industry makes its money on the sales of new autos.** The Auto Industry's Dealerships can fill the 2 Quart acetone extender storage tank for about \$1.20 (acetone 2006 bulk cost is about \$2.29/gal for MMA Grade). The Dealerships can advertise that they will refill the **fuel extender** storage tank at no charge whenever the owner brings the transportation equipment in for normal servicing, i.e., oil-lube-filter servicing or abnormal servicing such as body work, changing tires, changing batteries, etc. thus driving business in that direction. Dealerships make substantial profits because of their service and very little money on the sale of new transportation equipment. The Dealerships will then have the associated ability to increase tire pressure to the maximum listed on the tires and to additionally recommend synthetic lubricants (with better profit margins than non-synthetics) as supportive of better fuel economy. Synthetics oils do indeed support better mileage because they provide better lubricating properties than non-synthetics and last longer. Synthetic oil manufacturers will gladly provide the test data if asked. By adopting the Dealership Service program the transportation equipment owner only needs to bring in vehicle. The Dealership takes care of the rest. The Dealership Service program will take much business away from Jiffy Lube, Midas, Joe's Always Happy Service Station, Pete's Transmission Specialists, and all other look-alikes.

The Proposed Next Generation Technology is not to be confused with Honda's Just Announced Next-Generation Clean Diesel Engine.

1. Honda's Next-Generation technology improves diesel exhausts to that of gasoline engines.
2. Honda's Next-Generation technology still emits carbon dioxide and uses catalytic converters.

Honda Develops Next-Generation Clean Diesel Engine

9/25/2006

Capable of Meeting Stringent Tier II Bin 5 Emissions Requirements in the U.S.

Tokyo, Japan — Honda Motor Co., Ltd. has announced it has developed a next-generation diesel engine that reduces exhaust gas emissions to a level equal to a gasoline engine. Honda's next-generation diesel engine employs a revolutionary NOx catalytic converter that enables a great reduction in NOx emissions sufficient to meet stringent U.S. Environmental Protection Agency (EPA) Tier II Bin 5 emissions requirements (based on Honda's internal calculations). This catalytic converter features the world's first innovative system using the reductive reaction of ammonia generated within the catalytic converter to "detoxify" nitrogen oxide (NOx) by turning it into harmless nitrogen (N₂).

The new catalytic converter utilizes a two-layer structure: one layer adsorbs NOx from the exhaust gas and converts a portion of it into ammonia, while the other layer adsorbs the resulting ammonia, and uses it later in a reaction that converts the remaining NOx in the exhaust into nitrogen (N₂). Ammonia is a highly effective reagent for reducing NOx into N₂ in an oxygen-rich, lean-burn atmosphere. This ability to generate and store ammonia within the catalytic converter has enabled Honda to create a compact, lightweight NOx reduction system for diesel engines. The system also features enhanced NOx reduction performance at 200 - 300C, the main temperature range of diesel engines.

Honda designed the catalytic converter for use with its 2.2 i-CTDi diesel engine, which has earned widespread praise for quiet, clean operation and dynamic performance since its introduction in 2003 on the European Accord model. By further advancing combustion control, the 2.2 i-CTDi delivers cleaner exhaust to the NOx catalytic converter. Honda achieved this by optimizing the combustion chamber configuration, reducing fuel injection time with a 2,000-bar common rail injection system and boosting the efficiency of the EGR (exhaust gas recirculation) system. Thanks to these improvements, Honda has reduced the amount of NOx and soot normally found in engine exhaust, while increasing power output.

Along with developing superior technology for cleaning exhaust gas, Honda plans to address other technical challenges in developing clean diesel engines, such as handling diesel fuels with different cetane numbers and meeting U.S. On-Board Diagnostic System requirements. Honda plans to introduce its next-generation diesel engine in the U.S. within three years.

Gasoline engines presently employ three-way catalytic converters that offer NOx reduction rates as high as 99%, but this performance is possible only at the stoichiometric air-fuel ratio. In the oxygen-rich environment of a lean-burn diesel engine, three-way catalytic converters only reduce NOx levels by approximately 10%. Honda's new catalytic converter efficiently reduces NOx in a lean-burn atmosphere, enabling diesel engines to rival gasoline engines in cleanliness. The compact system is also easy to install in passenger vehicles.

SOURCE: Honda Motor Co., Ltd.

The proprietary Next Generation Technology is now being proposed under license for timely implementation in the marketplace.

The eligible licensee list includes the State of California, The California Environmental Protection Agency, The Automotive Industry, The Petroleum Industry, The United States Environmental Protection Agency, The United States Department of Energy, The United States Department of Transportation, and The United States Department of Agriculture all of whom are prospective stakeholders each having an inherent interest in this important technology. The non-exclusive license being proposed prevents, as a practical matter, the ability, or perhaps willingness, on the part of some of the listed stakeholders to suppress the technology thereby preventing its implementation in the marketplace. Should that appear to be occurring our company would then be ready, willing, and able to develop other marketplace activities to implement the technology.

The engineers, scientists, and senior management at WaterSmart Environmental welcome your inquiries with enthusiasm.

From the Engineering Department of

**WaterSmart
Environmental, Inc.**



