

Press Release

Contact: C. G. Steiner
Phone: 913.897.2727

For Immediate Release
Date: May 10, 2007

PROCESS: Jet Engine Emissions Control Technology Press Release

WaterSmart Environmental, Inc. announces the development of technology to neutralize the global warming harmful impact of jet engine exhaust emissions. The technology can be applied at altitude by adding sodium hydroxide (NaOH) chemical to the jet engine exhaust. This chemical causes the formation of Sodium Carbonate (Na_2CO_3) that achieves sequestration of the carbon dioxide formed during jet engine combustion. The technology also works at ground level as well by managing the earth's common atmosphere that recognizes the earth's atmosphere as a common sink. In doing so, the environmental results are nearly identical but significantly less costly. Attached WSE Publication No. 1597 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 treat-

ment 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

Product: Jet Engine Emissions Control Technology

Jet Engine History:

Before World War II, in 1939, jet engines existed only as laboratory items for test. By the end of the war, in 1945, it was clear that the future of aviation lay with jets. The new engines gave great power and thrust but were compact in size. They were also simple in their overall design giving rise to high levels of mechanical reliability.

A jet engine, down to the present day, pulls in air by using a *compressor*. It looks like a short length of an ear of corn, but instead of corn kernels, the compressor is studded with numerous small blades. The compressor rotates rapidly thereby compressing the air. The compressed air flows into a *combustor*. Here fuel is injected, mixed with this air, and burned. The combustion heats up the air to a high temperature. The hot, high-pressure air then passes through a *turbine*, forcing it to spin rapidly. The turbine draws power from this hot airflow. A long shaft connects the turbine and compressor. The spinning turbine uses its power to turn the compressor.

The jet-engine principle was known early in the twentieth century. Jet engines work well, however, only at speeds of at least several hundred miles per hour. Racing planes were the first to reach such speeds, with a British seaplane setting a record of 407 miles per hour (655 kilometers per hour) in 1934. A young German physicist, Hans von Ohain, was in the forefront. He started by working on his own at Göttingen University. He then went to work for Ernst Heinkel, a plane builder who had a strong interest in advanced engines. Together they crafted the world's first jet plane, the experimental Heinkel **He 178**, which first flew on August 27, 1939. Building on this work, the German engine designer Anselm Franz developed a successful engine for another early jet fighter. This airplane, the **Me 262**, was built by the firm of Messerschmitt. It was the only jet fighter to fly in combat during World War II. But the Me 262 spent most of its time on the ground because it used too much fuel. It was a sitting duck for the Allied attacks. In England, Frank Whittle had no knowledge of Ohain's ideas but invented a jet engine completely on his own. The British drew on his work and developed a successful engine for another early jet fighter—the Gloster Meteor. Britain used it for homeland defense but it did not see combat over Germany because it lacked high speed. The British shared Whittle's technology with the United States, enabling the engine-builder General Electric (GE) to build jet engines for America's first jet fighter, the **Bell XP-59**. The aircraft company Lockheed then used a British engine in the initial version of its Lockheed P-80, America's first operational jet fighter, which entered service soon after the war's end. The British continued to develop new jet engines that used Whittle's designs, with Rolls-Royce initiating work on the Nene engine dur-

ing 1944. Rolls sold Nenes to the Soviets, and a Soviet-built version of the engine subsequently powered the MiG-15 jet fighter that fought U.S. fighters and bombers during the Korean War.

The surrender of Germany in 1945 unlocked a treasure trove of wartime discoveries and inventions. General Electric and Pratt & Whitney, another American engine-builder, added German lessons to those of Whittle and other British designers. Early jet engines, such as those of the Me 262, gulped fuel rapidly. Thus, an initial challenge involved building an engine that could give high thrust with less fuel consumption. Pratt & Whitney solved this problem in 1948 with its “**dual spool**” concept. This combined two engines into one. The engine had two compressors—each rotated independently, with the inner one giving high compression for good performance. Each compressor drew power from its own turbine; hence there were two turbines, one behind the other. This approach led to the **J-57** engine, that entered service with the U.S. Air Force in 1953. This was one of the outstanding postwar engines. It powered U.S. Air Force fighters, including the **F-100**, the first to break the sound barrier without going into a dive. Eight such engines powered the **B-52** bomber. Commercial airlines—the **Boeing 707** and the **Douglas DC-8**, flew with it. This engine also saw use in the **U-2** spy plane, which flew over the Soviet Union and photographed its military secrets. The dual-spool engine represented an important step forward, but engine designers soon wanted more. As they reached for increasing performance, they ran into the problems of “**compressor stall**.” This meant that at certain speeds while in flight, the compressor would pull in more air than the rest of the engine could swallow. Compressor stall produced a sudden blast of air that rushed forward within the engine. The engine lost all its thrust, while the associated air blast sometimes caused severe damage by breaking off compressor blades.

During the early 1950s, Pratt & Whitney rode merrily along with its J-57. Its competitor, GE, had a good engine of its own: the **J-47**, which powered the **F-86** fighter and **B-47** bomber. Still, GE's managers wanted something better. They got it from the engineer Gerhard Neumann, who found a way to eliminate compressor stall. Neumann introduced the “**variable stator**.” This was a set of small vanes that protruded into the airflow within the compressor. Each such vane was like your hand that you stick into the outside air when you ride in a car. Like your hand, each vane could turn as if mounted to a wrist. When the vanes faced the airflow with their edges forward, they allowed the flow to pass them freely. But when the vanes were turned to present their broad faces to the flow, they partially blocked it. These vanes then reduced the amount of flow that was passing

through the compressor, and kept it from gulping too much air. This invention led to an important GE engine, the **J-79**. It became the first true engine for supersonic flight. With it, the **Lockheed F-104** fighter flew at twice the speed of sound. In May, 1958, U.S. Air Force pilots used this airplane to set a world speed record of 1,404 miles per hour (2,260 kilometers per hour) and an altitude record of 91,249 feet (27,813 meters). With supersonic flight in hand, the next frontier in jet-engine progress called for engines of very great power, suitable for aircraft of the largest possible size. The key concept proved to be the “**turbofan**,” also called the “**fanjet**.” The “jet” of a jet engine is the hot stream of exhaust that blasts out of the back to produce thrust. However, that exhaust carries power as well as thrust, which the turbines use to run the compressor. By using a larger set of turbines, it is possible to tap off still more of this power. The big turbine then turns a fan, which somewhat resembles an airplane propeller but has many long blades set closely together. The fan adds its thrust to that of the jet. This arrangement yielded the turbofan. It more than doubled the thrust of earlier engines. It also further improved fuel economy. In addition, turbofan engines were relatively quiet, in contrast to earlier jets that produced loud shrieks and screams. GE and Pratt & Whitney both build turbofans after 1965, with Rolls-Royce, offering versions of its own. All truly large airliners have used them, starting with the **Boeing 747**. These engines have also powered very large U.S. Air Force cargo planes, including the **C-5A** and **C-17**. The first aircraft to use these very large engines was the **Lockheed C-5**, which entered development in 1965 and first flew in 1968. A key to its design was the engine—the **GE TF-39 turbofan**. It had a dual-spool layout as well as a variable stator, with its big fan providing 85% of the thrust. The dual-spool arrangement gave the fan its own turbine for power, separate from the rest of the engine. The compressor had 16 stages, or rows of blades.

These three design principles—*dual-spool layout*, *variable stators*, and the *turbofan*—remain in use to this day. All three can even appear in the same engine, as with the TF-39. The dual-spool design gives high thrust with good fuel economy. Variable stators allow efficient operation at all flight speeds. The big forward fan reduces noise, further improves fuel economy, and produces much of the thrust. In turn, the thrust of engines continues to increase. Germany’s engines for the wartime Me 262, the **Jumo 004**, delivered 2,000 pounds (8,900 newtons) of thrust. The J-57 was rated at 13,500 pounds (60,000 newtons) of thrust. The J-57 was similar in thrust but weighted considerably less, which made it much speedier. Early turbofans, around 1970, came in around 40,000 pounds (180,000 newtons) of thrust. But GE’s new **GE 90 turbofan** is rated at close to 90,000 pounds (400,000 newtons) of thrust! That is why today’s planes fly fast and are very large.

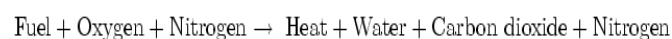
Jet Engine Exhaust Factors:

In the normal and routine combustion of jet engine fuel the two principal exhaust products of carbon dioxide and water vapor are produced. Both gases are hot from the

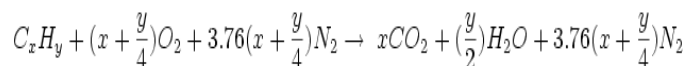
combustion process itself. The heat of combustion directly increases global warming due to the elevated temperature itself. The carbon dioxide is added to atmospheric carbon dioxide thus increasing its concentration in the environment. The associated water vapor is also added to the environment as moisture. At high altitudes the water vapor first appears as “**contrails**”, or condensation trails, that disappear over time thereby adding their moisture content to the environment. There is a general worldwide consensus that carbon dioxide gas increases global warming because of its “**greenhouse effect**.” It is listed as a greenhouse gas (GHG) about 1/20th as harmful as Methane Gas. Water vapor itself also adds to the global warming landscape but its adverse impact isn’t considered as severe as carbon dioxide.

Jet Engine Combustion Products Equations:

The simple word equation for the combustion of a hydrocarbon in air is:



If the combustion takes place using air as the oxygen source, the corresponding equation is:



Water vapor is the most abundant greenhouse gas and therefore significantly affects climate. It is involved in the global hydrological cycle, affecting both evaporation and precipitation. It participates in chemical reactions both in the troposphere, or lower atmosphere, where it is the major source of the hydroxyl (OH) radical, and in the stratosphere, which begins 6-10 miles (10-16 kilometers) altitude, where it affects the quantity of ozone (O₃). But, despite water vapor’s importance, its distribution and variability has not been as well studied as scientists would wish.

A new report indicates that the vast majority of the rapid temperature increase recently observed in Europe is likely due to an unexpected greenhouse gas: water vapor. Elevated surface temperatures due to other greenhouse gases have enhanced water evaporation and contributed to a cycle that stimulates further surface temperature increases, according to a report in *Geophysical Research Letters*. The research could help to answer a long-debated Earth science question about whether the water cycle could strongly enhance greenhouse warming.

Swiss researchers examined surface radiation measurements from 1995 to 2002 over the Alps in Central Europe and show strongly increasing total surface absorbed radiation, concurrent with rapidly increasing temperature. The authors, led by Rolf Philipona of the World Radiation Center in Davos, show experimentally that 70 percent of the rapid temperature increase is very likely caused by water vapor feedback. They indicate that remaining 30 percent is likely due to increasing

manmade greenhouse gases. The researchers analyzed temperature and humidity changes over Europe, which jumped nearly three times above the levels predicted by general circulation models in the past two decades. They provide observational evidence that large-scale weather patterns in Europe influence annual average temperatures uniformly, but weakly. They suggest that their combined observations indicate that the region is experiencing an increasing greenhouse effect and that the dominant part of the rising heat emitted from the Earth's atmosphere (longwave radiation) is due to water vapor increase.

After examining increased cloud cover to the north of the Alps and decreased cover to the south, the authors report that both sides of the mountain range experienced clear warming over the 1995-2002 period. While clouds are not entirely responsible for the warming, such findings correspond with previous cloud investigations showing that for midlatitudes, annual mean cloud cooling from the Sun (shortwave radiation) is roughly canceled by cloud warming caused by heat emitted by longwave radiation from the surface.

The strong increase of longwave radiation is shown in the study to be due to increasing cloudiness, rising temperature, rising water vapor, and above all to long-lived manmade greenhouse gases. The scientists' radiation measurements in the Alps show that the various inputs, or forcings, can be separated and that manmade greenhouse forcing is measurable at Earth's surface. Above all, their measurements demonstrate strong water vapor feedback that rapidly warms Central and Northeastern Europe, where sufficient water is available from plants and the surface, known as evapotranspiration.

A NASA-funded study found some climate models might be overestimating the amount of water vapor entering the atmosphere as the Earth warms. Since water vapor is the most important heat-trapping greenhouse gas in our atmosphere, some climate forecasts may be overestimating future temperature increases. In response to human emissions of greenhouse gases, like carbon dioxide, the Earth warms, more water evaporates from the ocean, and the amount of water vapor in the atmosphere increases. Since water vapor is also a greenhouse gas, this leads to a further increase in the surface temperature. This effect is known as "positive water vapor feedback." Its existence and size have been contentiously argued for several years.

According to NASA, there is no more important greenhouse gas than water vapor. As one of the fundamental parts of Earth's atmosphere, water vapor affects global warming in both positive and negative terms, and offers a trail for scientists to follow towards a better understanding about how the planet functions as a whole. NASA's Aqua satellite is dedicated to tracking Earth's water, and plans are underway to launch Aura this June, another satellite for better understanding Earth's atmosphere. By applying integrated analytic tools to the study

of climate and climate change, experts hope to learn more specifically how water vapor and other greenhouse gasses move and function throughout the atmosphere.

Aerosol:

Aerosol are present throughout the boundary layer, at number concentrations depending upon factors such as location, atmospheric conditions, annual and diurnal cycles and presence of local sources. The highest concentrations are usually found in urban areas, reaching up to 10^8 and 10^9 particles per cc (Seinfeld and Pandis, 1998). The study of aerosol is interesting for a number of reasons. It is thought that aerosol may be involved in a feedback to global warming. It is certainly important in the Earth's radiation budget. There are also concerns about the effects of aerosol on human health. Finally it is, in some cases, an important part of the chemical deposition budget for certain chemical species to ecosystems.

The feedback to global warming would tend to cool down the Earth in the event of a rise in temperature, and acts in two ways. With increased temperature would come stronger average winds, suspending more crustal material, thus increasing average aerosol concentrations. The first mechanism is called the direct effect. This is simply aerosol reflecting back incident solar radiation into space. The magnitude of the direct effect is simpler to estimate than that of the indirect effect. The indirect effect again involves increased average aerosol number concentration. An increased aerosol population means that there are more cloud condensation nuclei, which would lead to more clouds forming. This situation is slightly more complicated, as the effect of the clouds on the Earth's radiation budget depends upon the cloud height, but increased tropospheric aerosol would also have a cooling effect on the atmosphere.

The smallest aerosol are small enough to get into the human respiratory system. British standards define the respirable fraction as those aerosol smaller than $5\ \mu\text{m}$, which as we will see, is a significant proportion of the total. Even aerosol composed of benign materials can be irritants (e.g. glass calibration microspheres used in the lab), and some aerosol are partly made of toxic materials (heavy metals, organic chemicals etc.).

The rate at which aerosol can act as a deposition pathway is an important part of total deposition rates for a number of species. Clearly this is more so for species with few other deposition pathways (e.g. heavy metals). The size of these particles ranges from around $100\ \mu\text{m}$ to a few nm. These are the largest particles which can be suspended in air for a significant amount of time and the smallest clusters of molecules which can be classified as particles respectively. Aerosol has a number of properties such as size, chemical composition, hygroscopicity, density and shape. Size is normally used to classify aerosol because it is the most easily measured property and because inferences about the other proper-

ties can be drawn from size information. The primary interest in this work is urban aerosol and urban airshed aerosol. These two situations normally yield much higher number concentrations than any other circumstances. For the purposes of this report, we will first look at sources and sinks of aerosol in general, before looking at typical sources and ambient concentrations for three well studied cases (marine, remote continental and urban).

Sources of Aerosol:

Aerosol can either be produced by ejection into the atmosphere, or by physical and chemical processes within the atmosphere (called primary and secondary aerosol production respectively). Examples of primary aerosol are sea spray and wind blown dust. Secondary aerosol are often produced by atmospheric gases reacting and condensing, or by cooling vapor condensation (gas to particle conversion). Figure 1 shows some of these processes, along with the three size ranges (modes) where high aerosol concentrations are often observed.

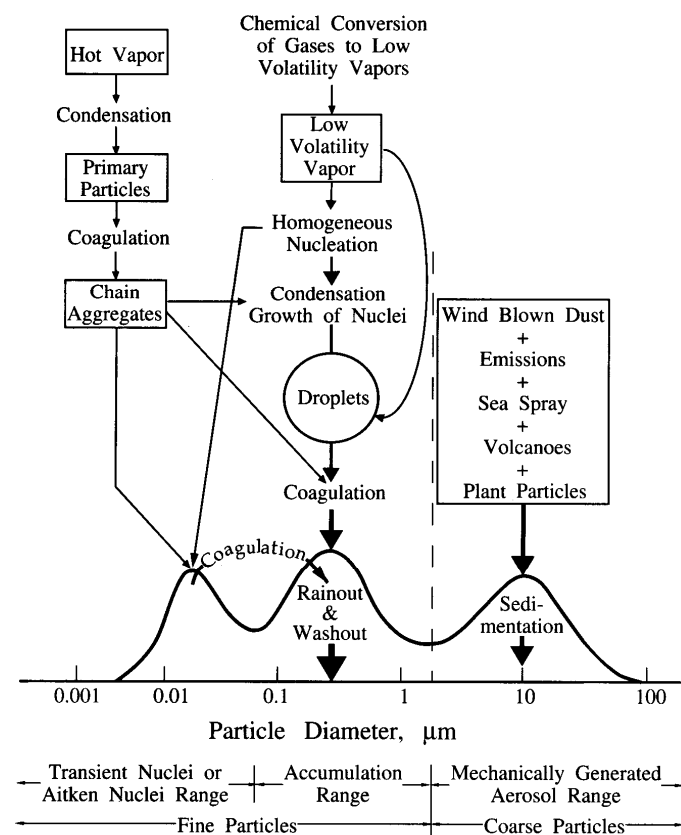


Figure 1

Although Figure 1 is a plot of surface area against particle diameter, rather than of number concentration (the parameter used in this work), it shows some of the important sources and sinks of aerosol without reference to location. Seinfeld and Pandis (1998) make a strong distinction between fine and coarse particles (the distinction is shown in figure 1). They note that the sources, chemical and optical properties, transformation mechanisms,

effects and deposition pathways are generally very different for the two classes of particles. It is worth noting that there are no sources shown in Figure 1 in the accumulation mode. This is an important property of many aerosol size distributions. Table 1 shows estimates of total global aerosol emission. A number of classes of aerosol are shown, and the size of the particles comprising the flux is also estimated.

Source	Estimated Flux (Tg yr^{-1})			Particle Size Category ^a
	Low	High	Best	
NATURAL				
Primary				
Soil dust (mineral aerosol)	1000	3000	1500	Mainly coarse
Sea salt	1000	10000	1300	Coarse
Volcanic dust	4	10000	30	Coarse
Biological debris	26	80	50	Coarse
Secondary				
Sulfates from biogenic gases	80	150	130	Fine
Sulfates from volcanic SO_2	5	60	20	Fine
Organic matter from biogenic VOC	40	200	60	Fine
Nitrates from NO_x	15	50	30	Fine and coarse
Total natural	2200	23500	3100	
ANTHROPOGENIC				
Primary				
Industrial dust, etc. (except soot)	40	130	100	Fine and coarse
Soot	5	20	10	Mainly fine
Secondary				
Sulfates from SO_2	170	250	190	Fine
Biomass burning	60	150	90	Fine
Nitrates from NO_x	25	65	50	Mainly coarse
Organics from anthropogenic VOC	5	25	10	Fine
Total anthropogenic	300	650	450	
Total	2500	24000	3600	

^aCoarse and fine size categories refer to mean particle diameter above and below $1 \mu\text{m}$, respectively.

Note: Sulfates and nitrates are assumed to occur as ammonium salts. Flux unit: Tg yr^{-1} (dry mass).

Source: Kiehl and Rodhe (1995).

Table 1

Global emission estimates for major aerosol types in the 1980s.

(Reproduced from "Atmospheric Physics and Chemistry", Seinfeld and Pandis, 1998)

It can be seen from Table 1 that it is not thought that anthropogenic aerosol sources produce a large proportion of the total aerosol by mass (best estimate gives about 14.5%). However, this is on a global scale, and in the vicinity of major towns and cities the figures would be quite different. In the vicinity of large scale biomass burning (either fossil fuels or vegetation for land clearance) the proportion of anthropogenic aerosol would also be much higher.

Table 1 also shows that the sources of coarse particles tend to be physical. These include volcanic activity, production of sea spray and suspension of surface dust. However, chemical reactions and changes of state of gases produce the majority of fine particles (by mass).

Sinks of Aerosol:

Once aerosol is suspended in the atmosphere, it is altered, removed or destroyed. It cannot stay in the atmosphere indefinitely, and average lifetimes are of the

order of a few days to a week. Clearly the lifetime of any particular particle depends on its size and location. Larger aerosol settle out of the atmosphere very quickly under gravity, and some surfaces are more efficient at capturing aerosol than others. We will first examine some removal pathways before looking at how aerosol may be expected to change during the course of its atmospheric residence. Note that the mechanisms described below bring the particle to the surface. Precise details of how the particle adheres to the surface are not discussed here.

Wet Deposition:

Wet deposition is the name given to deposition pathways involving water. They include rainout, washout, sweepout and occult deposition. Brief qualitative explanations of these will be given, as the primary focus of the work referred to in this report is dry deposition.

Rainout:

Rainout describes the removal of a cloud condensation nucleus. Aerosol act as nuclei for the condensation of cloud droplets. In clouds producing rain, some of these drops grow to such a large size that they fall (gravitationally settle) to the surface as rain drops. The aerosol (condensation nuclei) deposited in this way are said to have been rained out.

Washout:

Washout describes the removal of aerosol by cloud droplets. If an aerosol is incorporated into an already existing cloud drop, and that drop grows large enough to fall as rain, the particle is said to have been washed out. Note that the difference between washout and rainout is the required pre-existence of a collecting drop for washout.

Sweepout:

Another fairly closely related wet deposition process is sweepout. Aerosol remaining below the cloudbase of a raining cloud can impact into falling raindrops. If the impact leads to incorporation of the aerosol into the drop, the aerosol is deposited with the raindrop, the condensation nucleus, and any other washed or swept out particles. Although the final fate of rained, washed and swept out particles is the same, the three processes are distinct because the efficiency of each, and the size and amount of aerosol swept out by each process is calculated differently. The distinction is therefore mainly useful in modelling work where the total deposition due to all three processes is of interest.

Occult Deposition:

Occult deposition is a slightly more complicated concept than the other three wet processes examined. Impaction efficiency is the likelihood that a particle will strike a surface feature encountered in a flow, rather than be de-

flected around the object. It is a strong function of size, with larger aerosol being more likely to impact on a surface feature than smaller particles. Aerosol can be incorporated into droplets in clouds making contact with the surface of the ground (e.g. fog, orographic clouds). The impaction efficiency of droplets is higher than that of the aerosol they nucleate on. This produces an enhanced probability of impaction for such aerosol incorporated into drops. Sticking efficiency is the probability that an impacted object will not bounce off and be instantly resuspended. Providing the sticking efficiency of cloud drops is not significantly lower than that of the nucleating aerosol, (it is not) clouds contacting the ground can give rise to an enhanced deposition rate for small aerosol.

Dry Deposition:

Dry deposition pathways are the group of deposition mechanisms that transport pollutants (in this case particles) directly to the surface without the aid of precipitation. Through the boundary layer there are two dry deposition mechanisms. Each will be described briefly here.

Gravitational Settling:

This process is possibly the simplest of all the deposition processes to describe. It simply means a particle falling under gravity. Very large particles fall, reaching a terminal velocity, which can be found by equating the force due to gravity by the drag force (from Stokes' law) and solving for velocity. It falls through the boundary layer at this rate until it strikes the surface. Gravitational settling is of only secondary interest here, as in this work we are interested in particles too small to be effectively deposited by gravitational settling (settling velocity is directly proportional to particle mass).

Turbulent Deposition:

Turbulence is the most effective dry vertical transport mechanism in the boundary layer. It is also the major focus of measurements presented in this work.

Transformation Mechanisms:

The removal mechanisms described previously are all very efficient at depositing coarse particles. Very fine particles, however, are often not removed as such, but are transformed into larger particles before being deposited. Figure 1 shows some transformation mechanisms schematically, but for the purposes of this discussion an aerosol size distribution taken during the SASUA I project is presented in Figure 2.

Figure 2 shows an aerosol number distribution covering most of the "fine" particle range defined in Figure 1. The range covers diameter $3.5 \text{ nm} > D_p > 450 \text{ nm}$. Aerosol in the very small part of the range ($10 \text{ nm} > D_p$) are probably new secondary particles. Aerosol at the larger end of the spectrum are either old particles, or are primary

aerosol. The possible dynamics of this spectrum will be discussed in the following sections.

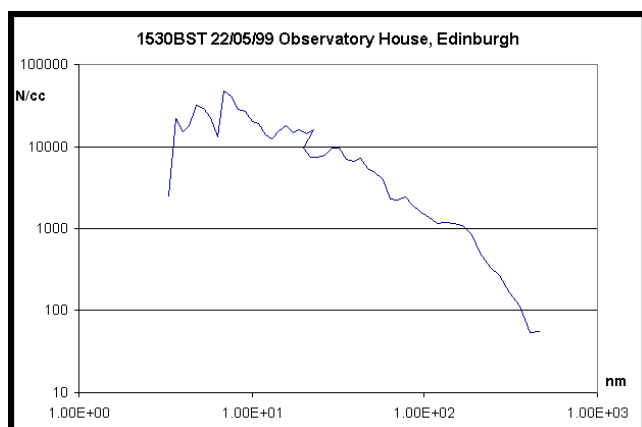


Figure 2

Aerosol size spectrum taken during SASUA I. Observatory House, Calton Hill, Edinburgh

Coagulation:

As previously stated, there are no effective deposition pathways for very small particles. Such particles must therefore leave the Aitken Range (< 100nm as shown in Figure 1) by growing before being deposited at larger sizes. One manner in which small particles can rapidly leave the Aitken mode is by coagulation.

Coagulation is the sticking together of two particles. It is the result of particles coming into contact due to Brownian diffusion or some force (electrostatic, phoretic effects *etc.*). Note that contact does not necessarily lead to coagulation, but must happen as a pre-requisite. This happens more quickly for Aitken mode (also known as nucleation mode) particles with large aerosol than for coagulation of two Aitken mode particles (Seinfeld and Pandis, 1998). Coagulation is also enhanced in shearing or turbulent flows, as these induce fast relative particle motion.

Condensation:

As long as the partial pressure of a compound in the gas phase is higher than the vapor pressure of that compound in aerosol, growth will occur. Of course, the opposite situation is possible, where particles outgas certain compounds, but in the urban environment growth tends to be the dominant process. Condensational growth is another mechanism by which aerosol can leave the nucleation mode.

Seinfeld and Pandis (1998) derive an expression for particle diameter with respect to time for cases of condensation of outgassing:

$$D_y^2 = D_{y_0}^2 + 2 At$$

Where D_y = Particle Diameter, and

D_{y_0} = Initial Particle Diameter, and

A = Constant

The term “A” is, in fact, related to the driving force for the condensation, and is only constant in situations like persistent supersaturation of the gas phase species. The interesting point about the equation is that it predicts smaller particles will grow proportionally faster than large particles. In fact, Seinfeld and Pandis comment that it tends to produce monodisperse (one size) aerosol as “T” approaches infinity.

Cloud Processing:

Cloud drops undergo aqueous chemical reactions. Because of their larger surface area, reaction rate per drop is usually higher than reaction rate per condensation nucleus. If a drop that has been involved in such reactions is subsequently evaporates, the condensation nucleus is left behind and may be considerably larger than it was before entering cloud. This process is called cloud processing, and can considerably increase the rate at which accumulation mode aerosol grow. Cloud processing generally affects accumulation mode rather than coarse mode aerosol, as the former tends to be more hygroscopic.

Marine Aerosol:

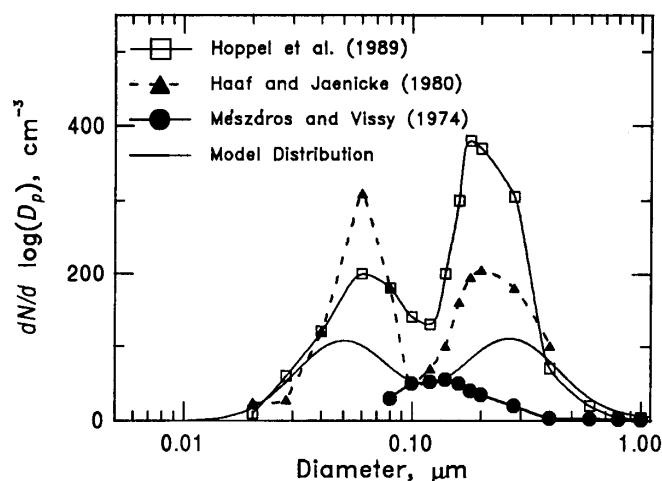


Figure 3

Figure 3: Measured marine aerosol number distributions and a model distribution used to represent average conditions.

(Reproduced from "Atmospheric Physics and Chemistry", Seinfeld and Pandis, 1998)

Particles in remote ocean environments are found at concentrations around 100 – 300 per cc. They occupy the three modes described previously, with the coarse fraction containing most of the total particulate mass, but low number concentration. Coarse marine aerosol are mainly composed of salt from evaporated spray droplets (Seinfeld and Pandis, 1998). The finer aerosol too, are

produced in the ocean environment, but from processes such as DMS reaction product condensation (DMS, or Dimethyl Sulphate is produced at sea by plankton (M. Flynn, *pers. comm.*).

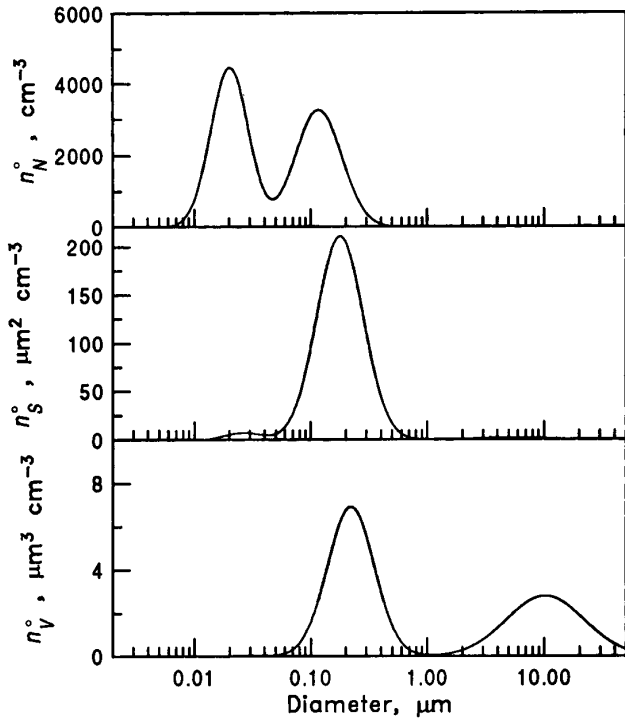


Figure 4

Figure 4: Typical remote continental aerosol number, surface and volume distributions.

(Reproduced from "Atmospheric Physics and Chemistry", Seinfeld and Pandis, 1998)

Urban Aerosol:

Urban aerosol is the subject of interest. Again, typical spectra have three peaks, visible in the three plots of number, area and volume distribution shown in figure 5. As before, fine and coarse mode particles have different sources. Coarse particles tend to be mechanically generated, but are composed of materials such as tire dust as well as sea salt and dust in urban areas. Fine particles (accumulation and nucleation mode) tend to be produced either directly from combustion sources, or by gas to particle conversion involving reaction products of sulfates, nitrates, ammonium, and organics.

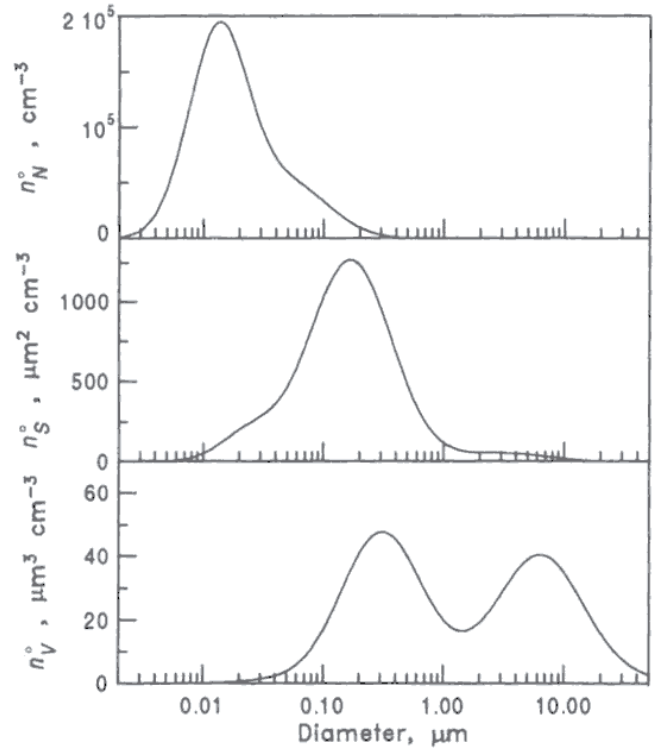


Figure 5

Figure 5: Typical urban aerosol number, surface and volume distributions

(Reproduced from "Atmospheric Physics and Chemistry", Seinfeld and Pandis, 1998)

The nucleation mode in urban areas often contains comparatively few particles. Very close to local sources, significant numbers may be found, but in urban areas, there is generally a good supply of species to rapidly condense onto small aerosol, moving them into the accumulation mode. Further, accumulation mode concentrations tend to be very high, so that available precursor gases will condense onto those particles without the need to nucleate fresh particles in most circumstances.

The main difference between the three categories of aerosol distribution examined here is the total number concentration. In urban areas, aerosol concentrations reach around 10^8 to 10^9 per cc. Figure 6 shows a comparison between urban, urban influenced and background conditions. Note that the background here is higher than in the remote continental spectra shown in figure 4, as it probably contains some anthropogenic particles (making it a rural continental distribution).

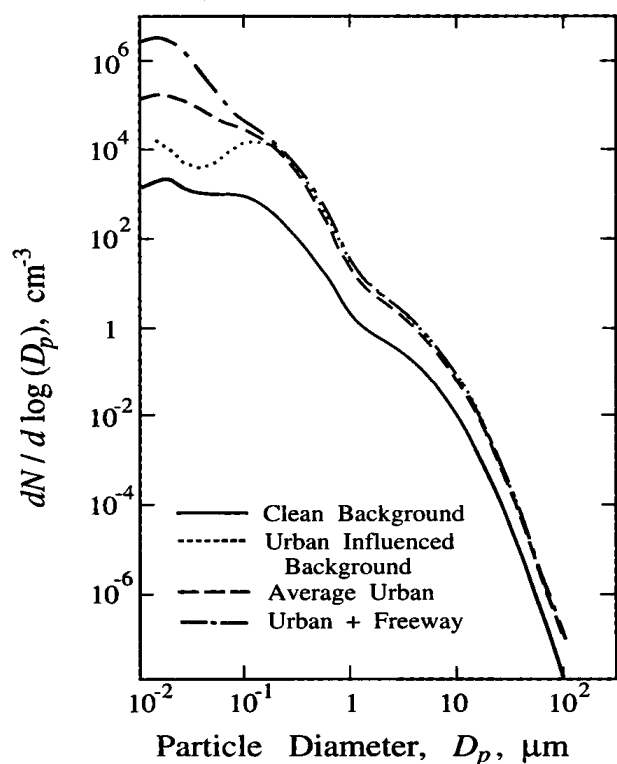


Figure 6

Figure 6: Aerosol number distributions next to a source (freeway), for average urban, for urban influenced background, and for background conditions.

(Reproduced from "Atmospheric Physics and Chemistry", Seinfeld and Pandis, 1998)

Although numerous trace elements are found in aerosol, Seinfeld and Pandis (1988) give the main constituents as sulfates, nitrates, ammonium, organics, crustal species, sea salt, hydrogen ions and water. Figure 7 shows the proportions of some of these ions as an equivalent number concentration.

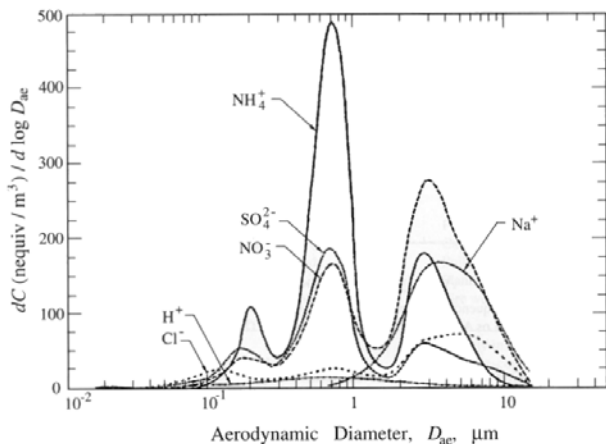


Figure 7

Figure 7: Measured size distributions of aerosol sulfate, nitrate, ammonium, chloride, sodium and hydrogen in Claremont, CA (Wall *et. al.*, 1988)

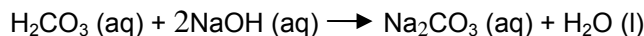
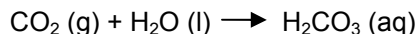
(Reproduced from "Atmospheric Physics and Chemistry", Seinfeld and Pandis, 1998)

Consistent Fate of Aerosol:

The extensive research by Seinfeld, Pandis, and others firmly establish that all solid and liquid aerosol reach the ground in the form of rain, dust, or both rain and dust within a week or two after initial formation. Thus water vapor discharged from commercial and military jets quickly reaches the ground when produced from 0 to 40,000 feet elevation range. This elevation range accounts for over 99% of all worldwide jet aircraft travel. Combustion exhaust greenhouse gas carbon dioxide is not an aerosol and therefore remains in the environment unless it can be induced to behave like one.

Carbon Dioxide Sequestration Concept:

Carbon dioxide reacts almost instantaneously with sodium hydroxide as follows:



Atmospheric levels of CO_2 have risen from preindustrial levels of 280 parts per million (ppm) to present levels of 375 ppm. Evidence suggests this observed rise in atmospheric CO_2 levels is due primarily to expanding use of fossil fuels for energy. Predictions of global energy use in the next century suggest a continued increase in carbon emissions and rising concentrations of CO_2 in the atmosphere unless major changes are made in the way we produce and use energy—in particular, how we manage carbon. One way to manage carbon is to use energy more efficiently to reduce our need for a major energy and carbon source—fossil fuel combustion. Another way is to increase our use of low-carbon and carbon-free fuels and technologies (renewable sources such as solar energy, wind power, and biomass fuels). These approaches are supported by the U.S. Department of Energy (DOE). The third and newest way to manage carbon is through carbon sequestration.

Carbon sequestration refers to the provision of long-term storage of carbon in the terrestrial biosphere, underground, or the oceans so that the buildup of carbon dioxide (the principal greenhouse gas) concentration in the atmosphere will reduce or slow. In some cases, this is accomplished by maintaining or enhancing natural processes; in other cases, novel techniques are developed to dispose of carbon. DOE's Office of Science is focusing its carbon sequestration efforts on:

- **Sequestering Carbon in Underground Geologic Repositories:** Geosciences research related to understanding the geophysics and geo-

chemistry of potential reservoirs appropriate for subsurface sequestration of carbon dioxide and

- **Enhancing the Natural Terrestrial Cycle:** Identifying ways to enhance carbon sequestration of the terrestrial biosphere through CO₂ removal from the atmosphere by vegetation and storage in biomass and soils.

Current Projects:

- **Carbon Sequestration in the Oceans:** Enhancing the net oceanic uptake from the atmosphere by fertilization of phytoplankton with nutrients, and injecting CO₂ to ocean depths greater than 1000 meters. See Figure 8 below.
- **Sequencing Genomes of Micro-organism for Carbon Management:** Sequencing the genomes of microbes that produce fuels such as methane and hydrogen or aid in carbon sequestration, to allow an evaluation of their potential use to produce, for example, methane or hydrogen from either fossil fuels or other carbonaceous sources, including biomass or even some waste products.

Understanding how carbon dioxide "sinks" perform so we can enhance the ongoing natural processes, and developing innovative new processes, may add powerful new measures to carbon management options.

An innovative new process to achieve permanent carbon dioxide sequestration of jet fuel combustion produced carbon dioxide consists of adding 50% Sodium Hydroxide (NaOH) to the exhaust discharge (see WSE Engineering Drawing No. S-1597). The Engineering Drawing lists all of the possible chemical reactions. The principal (99+%) reaction is that between carbonic acid (H₂CO₃) and Sodium Hydroxide (NaOH). Other bases would also work technically but NaOH is by far the most economical. This reactant would be added under turbulent flow conditions thereby assuring maximum sequestration as Sodium Carbonate (Na₂CO₃).



Figure 8

The stoichiometric efficiency of the given reaction is always 100%. Depending on the attending atmospheric conditions Na₂CO₃ would reach the ground either as a liquid or solid in conformance with the extensive discus-

sions on Aerosol including the **Consistent Fate of Aerosol** paragraph supra.

In order to prevent crystallization of 50% caustic its delivery container would have to be heated to maintain a minimum temperature of about 70°F (21°C). The weight of the 50% NaOH chemical storage container will accordingly decrease the maximum payload of the aircraft. The decrease in payload would be specific for each aircraft as well as the amount of jet fuel loaded for each specific flight. Other than payload considerations the addition of NaOH is not expected to exhibit any other adverse impact on aircraft performance itself. The payload considerations may be quite severe depending on the length of the flight. On a volumetric basis the size of the NaOH storage tank will have to be about seven (7) times larger than the aircraft's fuel tank in order to achieve stoichiometric chemical addition throughout the entire flight from take off to final landing. If a multiple stop flight both fuel and NaOH may have to be added at each stop location in order to maintain the availability of sufficient NaOH to match the fuel supply for chemical balance. On a weight basis the amount of NaOH required is about fourteen (14) times the weight of the jet fuel itself. In order to achieve effective carbon dioxide emission control the aircraft industry will have to consider shorter flights as well as both in-flight refueling and in-flight NaOH refilling consistent with total payload considerations. To be sure, the technology will be both extremely effective and very expensive under all such scenarios.

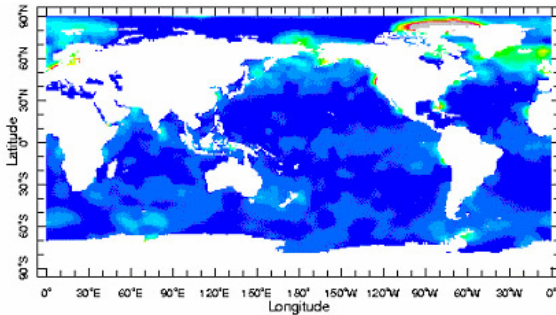
Both Boeing and Airbus are worried over the prospects of new air travel curbs to combat global warming—moves that could chill the long-term growth of **Boeing Company** and rival **Airbus SAS**. In July, 2006 the European Parliament voted in favor of a report calling for jet fuel taxes, a "rigorous" cap on aviation industry emissions and other measures to "lay down an example of how to tackle aviation's impact on the climate." While air travel accounts for less than 4 percent of the greenhouse gas effect, environmentalists fear that aviation's growth and contribution to high-altitude pollution will negate efforts to reduce global warming by other industries. The airline industry is already maxed out on fuel efficiency thereby requiring **something new** to achieve meaningful reductions in greenhouse gas emissions. For the time being, the airline industry might consider the practice of adding lesser than stoichiometric requirements of the chemical relative to the fuel in order to max out on its payload capacity with the knowledge that the chemical won't last the entire flight. This practice would reduce uncontrolled emissions of carbon dioxide and should mitigate somewhat against the taxation of jet fuel idea being proposed by the European Parliament.

There is another idea that would have virtually no impact on routine airline operations, other than cost.

1. Atmospheric air already contains about 375 parts per million (PPM) of carbon dioxide (CO₂)

due to natural causes as well as human activities. The human activities include carbon dioxide discharges from both surface and air transportation equipment. Surface equipment includes cars, buses, trains, barges, ships, coal fired power plants, refineries, and building heating systems. Air transportation equipment includes airplanes, both gasoline and jet powered.

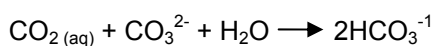
- Nearly half of the US utility-owned steam electric generating capacity is cooled by once-through cooling systems. Coastal located oil refineries also use one-through cooling systems. Cooling is achieved by both sensible (cooling due to direct contact) and latent heat transfer (cooling due to evaporation). There is always intimate contact between the air and the cooling liquid itself. If one were to artificially add NaOH to the cooling liquid prior to the cooling tower the chemical would react with the CO₂ in the air forming sodium carbonate (Na₂CO₃) in the same manner and efficiency that would occur by jet airliners at altitude. In coastal regions the Na₂CO₃ ends up in the ocean.



0.0 in Aug

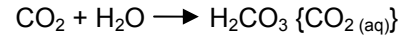
Productivity map of the surface ocean waters from satellite surveys for August, 2006.

The dark blue color that represents most of the ocean area indicates low productivity (i.e. low plankton). The lighter blue color in the equatorial upwelling and coastal upwelling areas indicate higher productivity (i.e., higher plankton). Greens, yellows-to-red color zones indicate even higher productivity (the colors in the high arctic are an artifact of the measurement technique, and do not indicate high productivity in the arctic region.) Over time scales of millennia, the ocean can be considered to be the most important carbon reservoir, in terms of its potential to influence CO₂ changes. Dissolved inorganic carbon in the ocean, or "total CO₂" (SCO₂) includes HCO₃⁻ (carbonate ion) (90%), CO₃²⁻ (bicarbonate ion) (9%) and dissolved CO₂ gas (CO_{2(aq)}) (1%). These agents exist in equilibrium, according to Equation A.



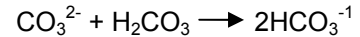
[Equation A]

Atmospheric CO₂ is directly regulated by the chemical composition of the surface sea water, according to Equation B.



[Equation B]

Equations A and B combine to form Equation C, the governing equation for carbonate chemistry in the ocean system.



[Equation C]

Equation C can be simplified to:

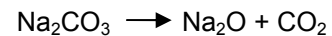
$$C_w = sC_a$$

[Equation D]

where C_w is the CO₂ concentration (or partial pressure) in water, C_a is the CO₂ concentration (or partial pressure) in air and s is the solubility (equilibrium) constant for Equation B.

There are two ways in which the concentration of atmospheric CO₂ (C_a) can be altered: varying s or varying C_w. The solubility of CO₂ increases with decreasing temperature, thus decreasing C_a for constant C_w.

The discharge of Na₂CO₃ into the coastal water of the ocean will therefore increase the concentration of HCO₃⁻¹. The auxiliary chemical reaction is:



[Equation E]

The discharge of Na₂CO₃ into coastal waters will beneficially increase the dissolved CO₂ content of the ocean waters accordingly. Dissolved CO₂ participates in the photosynthesis of both macro and micro algae. An example of macro algae is Kelp. An example of micro algae is Phytoplankton. Phytoplankton, a plant, is consumed by Zooplankton, an animal. Zooplankton are consumed by small minnows and one species of whale. Small minnows are consumed by larger minnows, and so forth. Photosynthesis occurs only in coastal waters because of the limited ability of light to penetrate to greater depths. The photosynthesis of phytoplankton represents the start of the food chain in the oceans of the world for millions, and perhaps billions of years. It is quite well known that the oceans of the world no longer support ocean fishing at the rate that occurred from 1950 to 2000 except for the

lighter blue locations shown on the Productivity Map above. Therefore the discharge of Na_2CO_3 is economically beneficial to coastal fisheries and to the extent that coastal fisheries represent food sources for the rest of the ocean, to ocean fisheries as well (rather than harmful to the ocean).

This idea can be implemented by the airlines by contracting with coastal utility-owned steam electric power generation plants and coastal oil refineries by contractually adding 50% NaOH to their once-through cooling towers thereby forming Na_2CO_3 . As previously disclosed, 1 lb of jet fuel is the stoichiometric equivalent of 14 lbs of 50% NaOH in terms of CO_2 sequestration. By keeping track of the NaOH usage, the airlines can scientifically claim credit for sequestering the carbon dioxide equivalent to its aircraft emissions from aircraft by sequestering an equal amount of carbon dioxide from the atmosphere itself. The effect on total climate change would be identical. By sending Na_2CO_3 to coastal waters the production of coastal fisheries would be increased as discussed above. If sequestered from the jet engine discharge as shown on the referenced drawing, most of the Na_2CO_3 would fall over land rather than the oceans since airline flight maps reflect the vast majority of flights occur over land rather than water. This idea

would totally displace the rather onerous method of adding NaOH to jet exhaust at altitude while benefiting fish populations in the oceans of the world.

Not So Green	
Carbon Dioxide Emissions From Aviation (Percent of World Total)	
United States	37.2%
European Union	20.3%
Japan	5.0%
Russia	4.5%
China	2.8%
Canada	2.4%
Source: World Resources Institute	

The Chemists, Engineers, Environmentalists, and Scientists, at **WaterSmart Environmental, Inc.** welcome your inquiries with enthusiasm.



