Curtis Moore
16-5-4

Criticisms of the Draft SCLP Strategy

• *The Air Resources Board* is not required to adopt a strategy of holding the planetary temperature increase to 2 degrees, but *is to "determine what the statewide greenhouse gas emissions level was in 1990, and approve in a public hearing, a statewide greenhouse gas emissions limit that is equivalent to that level, to be achieved by 2020."*

• The strategy proposed by the ARB completely ignores or understates considerably emissions of black carbon. The Air Resources Board regulates black carbon only as a constituent of diesel exhaust.

• The largest single source of BC is wildland fires, accounting for 66 percent of emissions. Humans cause 61,913 wildland fires each year, yet the strategy proposes no change whatsoever in the treatment of wildland fires or those caused by humans.

• Acres burned and the average size of wildland fires has tripled since 1990. The strategy proposes nothing to deals with these increases, which will only grow in the future;

• A proper baseline date for black carbon would arguably be 1950, pre-dating Boeing 707s, heavy duty diesel use and oceanic shipping, especially from the Far East.

• Black carbon emissions from takeoff and landings from LAX compare to the contribution from the region's freeway system. LAX is one of California's 13 major commercial airports. There is no discussion whatsoever of these, nor of ships at sea.

• HFC-134a is such an intrinsically "leaky" chemical that a parked car with its engine off will emit it, causing global warming. A consumer warranty would stop this and shift the cost.

• Analyses of methane leaks are confused and confusing. The Board's best strategy for reducing emissions and saving money would be adoption of best available control technology for all sources, including mandates for utilities to pay retail for electricity from manure.

• We are dangerously close to, and may have exceeded, the methane-carbon dioxide crossover point. All sources must be accounted for, and BACT adopted immediately. This includes leaks like Aliso Canyon and repealing the methane exclusion, so it is a "pollutant".

• California is expressly allowed under the U.S. Clean Air Act to adopt more stringent standards, and should, as follows:

(a) a standard for protection of human health should be expressed as a limit on, and require measurement of, black carbon particles;

(b) a secondary black carbon standard should be adopted to protect against global warming, especially its impacts in snowy and icy areas and role in wildland fires; and,

(c) even though the U.S Clean Air Act provides for preemption of more stringent fuel standards, there is no record of the Administrator having triggered such preemption by adopting a standard for jet fuel. California should act.

Criticisms of the Draft SCLP Strategy

CURTIS A. MOORE
ATTORNEY, AUTHOR AND CONSULTANT

The draft strategy embraces the concept that the world must limit the increase in global temperatures to 2 degrees Celsius (3.6 degrees Fahrenheit) to protect the future.

This concept of holding the global temperature increase above pre-Industrial levels, dates to 1975. That was when economist–an *economist*, mind you, not a biologist or atmospheric chemist or some other specialist intimately familiar with global change driven by human activity–William Nordhaus of Yale University, who believes that goal warming will produce both "winners" and "losers," concluded that warming past this point would "take the climate outside of the range of observations which have been made over the last several hundred thousand years."[a]

Since 1975, the 2 degrees C number proposed by Nordhaus has gained traction, but it was not until 2010 that countries finally committed to "hold the increase in global average temperatures below" 3.6 degrees.

Retired NASA climate scientist James Hansen and a group of colleagues wrote that the 2°C target was not stringent enough, and "so dangerous" as to be "foolhardy."

So, who is right? Hansen or the global community?

That is not the proper question.

The purpose of AB32 was not to adopt an arbitrary number, but to minimize global

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[a] Nordhaus wrote that "According to most sources the range of variation between between distinct climatic regimes is on the order of ±5°C, and at present time the global climate is at the high end of this range. If there were global temperatures more than 2° of 3° above the current average temperature, this would take the climate outside of the range of observations which have been made over the last several hundred thousand years."

warming and its impacts on California. It is, and remains today, the best law ever adopted to control global warming. It entrusts the future of California to a handful of bureaucrats and their bosses, the Air Resources Board.

Instead of adopting its own analysis of what is best for California and the planet, the draft strategy embraces wholly a number that has no basis in science.

Under AB32, the Air Resources Board is not required to adopt a strategy of holding the planetary temperature increase to 2 degrees, but to "determine what the statewide greenhouse gas emissions level was in 1990, and approve in a public hearing, a statewide greenhouse gas emissions limit that is equivalent to that level, to be achieved by 2020."[b] That limit was set at 431 million metric tonnes of carbon dioxide equivalent (MMTCO2e).[c] The Board is required to achieve these reductions by adopting "regulations to achieve the maximum technologically feasible and cost-effective GHG emission reductions."[d]

Black carbon (See Appendix A)

Black carbon was specifically excluded from the AB32 list of greenhouse gases at the request of the Air Resources Board, which feared that explicitly including it might imply that the Board did not have, until the adoption of AB32, the authority to regulate diesel exhaust, thus jeopardizing regulations that had already been issued.[e]

The drafters of AB32 complied with this request by stating that "'Greenhouse gas' or 'greenhouse gases' includes all of the following gases: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexaflouride."[f]

Exclusion from inventory.

Notwithstanding the ARB request that black carbon be covered by AB32 but not be specifically mentioned, the Board omitted it entirely from the list of causes of warming. The list of substances covered includes:

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[b] http://www.arb.ca.gov/cc/ab32/ab32.htm

[c] http://www.arb.ca.gov/cc/inventory/1990level/1990level.htm

[d] http://www.arb.ca.gov/cc/ab32/ab32.htm

[e] Personal communication, circa, August, 2006, from Catherine Witherspoon, Executive Officer of ARB.

[f] http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=200520060AB32

1. Carbon dioxide (CO2)
2. Methane (CH4)
3. Nitrous oxide (N2O)
4. Hydrofluorocarbons (HFCs)
5. Perfluorocarbons (PFCs)
6. Sulfur hexafluoride (SF6)
7. Nitrogen trifluoride* (NF3)

http://www.arb.ca.gov/cc/inventory/data/data.htm

Changed Attitude by ARB

More recently, the Board's attitude toward black carbon has changed. In its draft strategy, ARB said, "black carbon plays a far greater role in global warming than previously believed," boasting that "California has made tremendous progress in reducing black carbon emissions," adding that–

> California has already cut anthropogenic black carbon emissions by over 90 percent since the 1960s, and existing measures are projected to cut mobile source emissions by 75 percent and total anthropogenic emissions by nearly 60 percent between 2000 and 2020. http://www.arb.ca.gov/cc/shortlived/meetings/04112016/proposedstrategy.pdf

Not so. The strategy proposed by the ARB ignores completely or understates considerably emissions of black carbon.

Black carbon is not only a cause of global warming, but kills and injures humans.[g] That is true in California as well.[h] Yet the Air Resources Board does not regulate black carbon, only as a constituent of diesel exhaust, which accounts for 17 percent of the state's emissions.

Wildland fires

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[g] "We estimated approximately 14,000 deaths to result from the 2010 BC levels, and hundreds of thousands of illness cases"Ling Yi, et. al. Assessing public health burden associated with exposure to ambient black carbon in the United States, *Science of The Total Environment* 539 (2016): 515-525.)

[h] "We observed statistically significant ($p < 0.05$) associations of IHD (ischemic heart disease) with ... elemental carbon (EC)" Ostro, et. al., Associations of Mortality with Long-Term Exposures to Fine and Ultrafine Particles, Species and Sources: Results from the California Teachers Study Cohort, *Environ. Health Perspect.* 2015 Jun; 123(6): 549–556.

The largest single source of BC is wildland fires.[i] They account for 66 percent of the state's BC emissions.[j] They are consistently referred to by ARB as "wildfires." They are not "wild," because a majority are caused by humans.[k] According to the National Interagency Fire Center, humans cause 61,913 wildland fires each year.[l] Yet the strategy proposes no change whatsoever in the treatment of wildland fires caused by humans.

Even though about 65 percent of California's black carbon is emitted by fires in wildlands, "Forest-related sources include prescribed fire and wildfire and are separated to account for the unique challenges associated with inventorying and mitigating these sources."[m] They are, in other words, essentially untouched by the strategy.

The draft strategy says that the "extent and severity of wildfire varies significantly from one year to the next." Although statistics are not available for California specifically, but nationally this is simply untrue.[n] The number of acres burned has grown from about 1.8 million in 1990 to about 6.3 million in 2013. Similarly, the average size of wildland fires has grown from about 30 acres in 1990 to nearly 90 in the 2010's.[o] In short, nationally wildland fires have become larger and more destructive.

Ignores human-caused fires

The draft strategy essentially ignores fires caused by humans, even though the National Park Service has said "As many as 90 percent of wildland fires in the United States are caused by humans." https://www.nps.gov/fire/wildland-fire/learning

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[i] "Wildfires constitute the largest single source of BC emissions in the 2013 California BC emission inventory," p. 8, California's Black Carbon Emission Inventory, Air Resources Board, http://www.arb.ca.gov/cc/inventory/slcp/doc/bc_inventory_tsd_20160411.pdf.

[j] P. 50, short-lived pollutants strategy, http://www.arb.ca.gov/cc/shortlived/meetings/04112016/proposedstrategy.pdf

[k] "A hunter accidentally started the Rim fire which has scorched 370 square miles of California's Sierra Nevada, the US forest service said on Thursday." ("California Rim fire cause identified as 80% of blaze contained," *The Guardian*, Sep. 5, 2013.

[l] http://www.nifc.gov/fireInfo/fireInfo_stats_human.html

[m] http://www.arb.ca.gov/cc/shortlived/meetings/04112016/proposedstrategy.pdf

[n] The numbers are for the lower 49 states, which excludes Alaska, a state that in 2013 to date has had 609 fires that blackened 1,319,234 acres, about half the number of acres that burned in the other 49 states.

[o] http://wildfiretoday.com/2013/11/25/measuring-the-severity-of-a-fire-season/

-center/fire-in-depth/wildfire-causes.cfm

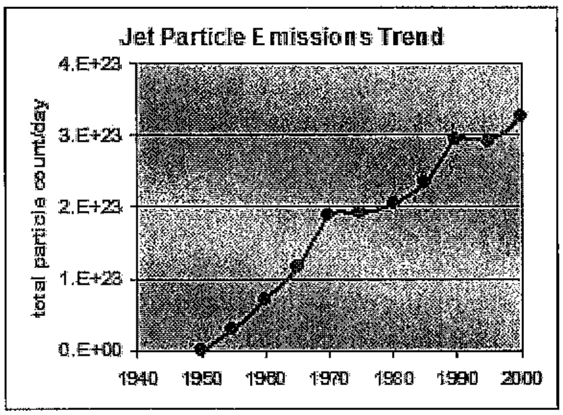
Baseline date

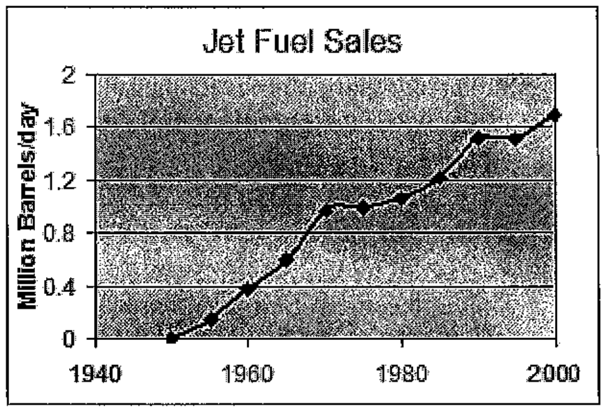
Setting aside emissions of black carbon from wildland fires, for other emissions the strategy uses a baseline date of either the 1960s or none. A proper baseline date for calculation of black carbon would arguably be 1950, which would pre-date Boeing 707s, heavy duty diesel use and oceanic shipping, especially from the Far East. These are all major sources of black carbon.

Aircraft Takeoffs and Landings

Commercial jet liners, which emit prodigious numbers of black carbon particles, simply did not exist until the late 1950s. Pan American World Airways began regular Boeing 707 service on Oct. 26, 1958.

Emissions of black carbon from the landings and take offs of aircraft have risen astronomically. Consider the following:





Takeoffs and landings at Los Angeles International Airport (LAX) account for ultrafine black carbon particles comparable in magnitude to the contribution from the region's freeway system.[p] One group of researchers has concluded that aviation-related health impacts from take

[p] LAX emissions adversely impacted air quality much farther than reported in previous airport studies. We measured at least a 2-fold increase in PN concentrations over unimpacted baseline PN concentrations during most hours of the day in an area of about 60 km2 that extended to 16 km (10 miles) downwind and a 4- to 5-fold increase to 8–10 km (5–6 miles) downwind....These results suggest that airport emissions are a major source of PN in Los Angeles that are of the same general magnitude as the entire urban freeway network. They also indicate that the air quality impact areas of major airports may have been seriously underestimated." Neelakshi Hudda, et. al., Emissions from an International Airport Increase

off and landings would increase by a factor of 6.1 from 2005 to 2025, with a factor of 2.1 attributable to emissions.[q]

There are at least 13 major civilian airports in California. Yet the draft strategy fails to even mention the contribution of black carbon from airport takeoffs and landings. When the draft strategy is searched for the words"airport", "takeoff" and "landing," there are no results.

Shipping

Simply comparing black carbon emissions from vessels to all black carbon emissions it assumes that all black carbon emissions are equivalent, but in reality, they aren't. Because of their purity, diesel emissions are the sources of black carbon most strongly linked with warming and with adverse human health effects. Exactly what the proportions of "black" and "brown" carbon are from forest fires and other sources is not well understood. However, there is little doubt that diesel sources black carbon are powerful warming agents, with heightened impacts in snowy and icy regions such as the Arctic and snowpack because they warm by darkening.

Virtually all ship engines are diesels. Their black carbon emissions should be compared to those of other diesel sources.

Such a comparison reveals that in the year 2000 shipping contributed between 7 to 9 percent of black carbon emissions from diesel sources.[r] By 2010 emissions from shipping accounted for 8 to 13 percent.[1]

HFC-134a and other "F-gases" (See Appendix B)

The replacement for many manmade chemicals destroying ozone in the stratosphere, HFC-134a, did not exist outside the laboratory until 1991. That's when it was mandated as a replacement for CFCs.[s,t]. It is an intrinsically "leaky" chemical, so a variety of technical

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Particle Number Concentrations 4-fold at 10 km Downwind, *Environ. Sci. Technol.*, 2014, 48 (12), pp 6628–6635.

[q] J. Levy, et. al., "Current and Future Particulate-Matter-Related Mortality Risks in the United States from Aviation Emissions During Landing and Takeoff," *Risk Analysis* 32.2 (2012): 237-249.

[r] Alyson Azzara, "Black carbon emissions from shipping: Fact-checking conventional wisdom" April 17, 2015, http://www.theicct.org/blogs/staff/black-carbon-emissions-shipping-fact-checking-conventional-wisdom.

[s] J.W. Linton, The Potential of HFC-134a and HFC-152a to Replace CFC-12 in Medium Temperature Heat Pump Applications, http://docs.lib.purdue.edu/cgi/

measures have been evaluated to stop leaks.[u] Indeed, the internet is filled with advertisements of products to stop leaks of HFC-134a emitted by the vehicle.[v]

HFC-134a will leak even when a car is parked with the engine off. Over the car's lifetime, the HFC-134a leakage from an AC equipped vehicle is approximately 4–5 percent of that of the CO2.[w]

The car's pollution control system is covered by a multi-year, high mileage warranty.[x] The emission control system may include parts such as the fuel injection system, ignition system, catalytic converter, and engine computer. Also included are hoses, belts, connectors, and other emission-related assemblies.[y]

Residential air conditioning can be covered by a warranty[z], but the air conditioning system of a car is limited, typically to 3 years/36,000 miles.[aa] The draft strategy counsels a wait-and-see approach. A better action would be to require that new motor vehicles equipped with mobile air conditioners be warranted for ten years/100,000 miles or more.

Methane Releases (See Appendix C)

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viewcontent.cgi?article=1156&context=iracc.

[t]NRDC Letter to EPA Administrator Lisa P. Jackson, https://www.nrdc.org/sites/default/files/air_10050701a.pdf.

[u] K. Schwaab, et. al. Fluorinated Greenhouse Gases in Products and Processes: An Evaluation of Technical Measures to Reduce Greenhouse Gas Emissions, German Federal Environmental Agency, http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.117.1965 &rep=rep1&type=pdf)

[v] http://www.amazon.com/s?ie=UTF8&page=1&rh=i%3Aaps%2Ck%3A134A% 20Leak%20Sealer).

[w] W. O. Siegl, et. al.,R-134a Emissions from Vehicles, *Environ. Sci. Technol.*, 2002, 36 (4), pp 561–566, http://pubs.acs.org/doi/abs/10.1021/es011108x.

[x] Partial Zero Emissions Vehicle, https://en.wikipedia.org/wiki/Partial_ zero-emissions_vehicle.

[y] http://ww2.justanswer.com/uploads/mcvgreg/2008-04-20_165903_2004-Trailblazer-Emission-Control-Warranty.pdf.

[z] http://blog.choicehomewarranty.com/home-warranty-cover-air-conditioning/.

[aa] http://www.cbsnews.com/news/what-new-car-warranties-cover-and-dont/.

This one of the most troubling of the draft strategy's sections. It presents a methane emissions inventory, and therefore control measures, with much greater certainty than actually exists. The total emissions for all of California is about 5.30 gigagrams per day, with the three aggregate sources–waste both (solid and waste water), gas and oil and livestock–accounting for over 90 percent of emissions, according to European Environmental Emissions Database for Global Atmospheric Research (EDGAR). Roughly 30 percent is from the San Francisco Bay/northern San Joaquin Valley (SFB and SJV).[bb]

This seems more concrete than it actually is

In the California's South Coast Air Basin, for example, (the larger Los Angeles metropolitan region), data is consistent with most methane being from the losses from the natural gas system. However, there are other possible sources, including natural gas seeps and leaks associated with petroleum production, "both of which are poorly known," according to one study. These could reduce the inferred contribution of the natural gas infrastructure to the total methane emissions, potentially significantly.[cc]

The picture in southern California is confused

In one recent study, for example, estimates of emissions from the petroleum and natural gas production sectors were 3 to 7 times higher than official California bottom-up inventories, and indicated that estimates from transmission and distribution were low by a factor of approximately 2.[dd]

The same confusion appears elsewhere

For example, emissions from natural gas were found in Boston to be two to three times larger than predicted by existing inventory methodologies and industry reports. That suggests that natural-gas–consuming regions may be larger sources of methane to the atmosphere than is

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[bb] Johnson, Matthew S., Emma L. Yates, Laura T. Iraci, Max Loewenstein, Jovan M. Tadić, Kevin J. Wecht, Seongeun Jeong, and Marc L. Fischer. "Analyzing source apportioned methane in northern California during Discover-AQ-CA using airborne measurements and model simulations." *Atmospheric Environment* 99 (2014): 248-256.

[cc] Wennberg, Paul O., Wilton Mui, Debra Wunch, Eric A. Kort, Donald R. Blake, Elliot L. Atlas, Gregory W. Santoni et al. "On the sources of methane to the Los Angeles atmosphere." *Environ. Sci. & Tech.* 46, no. 17 (2012): 9282-9289.

[dd] Jeong, Seongeun, Dev Millstein, and Marc L. Fischer. "Spatially explicit methane emissions from petroleum production and the natural gas system in California." *Env. Sci. & Tech.* 48, no. 10 (2014): 5982-5990.

currently estimated and represent areas of significant resource loss.[ee]

Boston data show that current inventory methods consistently underestimate methane emissions, that fossil fuels are likely responsible for a large portion of the underestimate, and that significant fugitive emissions may be occurring from all segments of the gas system.[ff]

In Boston, the inferred mean annual natural loss rate was 2.7 ± 0.6 percent of the total delivered gas in 2012–2013.[gg] Under even the most optimistic conditions–a loss of only 2.1 percent–the climate will be warmer, not cooler. According to the calculations of Tom M.L. Wigley, unless leakage rates for new methane can be kept below 2 percent, substituting gas for coal is not an effective means for reducing the magnitude of future climate change.[hh]

The Crossover

Scientists at the Environmental Defense Fund have reached a different conclusion. According to their calculations, the methane leakage rate must be at or less than 3.1 percent to overwhelm the cooling benefit from switching from coal to natural gas.[ii] The point is not whether who is correct, Wigley or the EDF scientists. Rather, it is that there is very little room for error, whether the tradeoff point is 2 percent or 3.1 percent, and the field is rife with room for error.

[ee] McKain, Kathryn, Adrian Down, Steve M. Raciti, John Budney, Lucy R. Hutyra, Cody Floerchinger, Scott C. Herndon et al. "Methane emissions from natural gas infrastructure and use in the urban region of Boston, Massachusetts." *Proceedings of the National Academy of Sciences* 112, no. 7 (2015): 1941-1946.

[ff] McKain, Kathryn, Adrian Down, Steve M. Raciti, John Budney, Lucy R. Hutyra, Cody Floerchinger, Scott C. Herndon et al. "Methane emissions from natural gas infrastructure and use in the urban region of Boston, Massachusetts." *Proceedings of the National Academy of Sciences* 112, no. 7 (2015): 1941-1946.

[gg] McKain, Kathryn, Adrian Down, Steve M. Raciti, John Budney, Lucy R. Hutyra, Cody Floerchinger, Scott C. Herndon et al. "Methane emissions from natural gas infrastructure and use in the urban region of Boston, Massachusetts." *Proceedings of the National Academy of Sciences* 112, no. 7 (2015): 1941-1946.

[hh] Wigley, Tom ML. "Coal to gas: the influence of methane leakage." *Climatic change* 108, no. 3 (2011): 601-608.

[ii] Alvarez, Ramón A., Stephen W. Pacala, James J. Winebrake, William L. Chameides, and Steven P. Hamburg. "Greater focus needed on methane leakage from natural gas infrastructure." *Proceedings of the National Academy of Sciences* 109, no. 17 (2012): 6435-6440.

Room for Error

A variety of attempts have been made to reconcile emissions estimates with measurements. In one, the authors analyzed samples of ambient air at a wide range of locations across the United States — 4,984 samples from tall towers and 7,710 from aircraft. Samples were taken in 2007 and 2008.[jj] The conclusions were as follows:

- U.S. methane emissions appeared to be significantly higher than previous estimates — 1.5 times greater than those by the U.S. Environmental Protection Agency and 1.7 times greater than data from the European Environmental Agency's Emission Database for Global Atmospheric Research (EDGAR).

- Emissions related to livestock operations were more than twice current estimates.

- Discrepancies were greatest in the south-central states of Texas, Oklahoma and Louisiana, a region that accounted for 24 percent of U.S. methane emissions.

- In the south-central United States, fossil-fuel extraction and refining contributed 45 percent of the emissions. Aircraft observations indicated that the natural gas and/or oil industries played a significant role in regional methane emissions.

- Concentrations of methane were about 1,800 parts per billion, which is nearly triple the preindustrial range of 680 to 715 parts per billion.

- Human activity accounted for 50 percent to 65 percent of global methane emissions.

The study also concluded that a small number of leaks contributed a significant portion of escaped natural gas, presenting the opportunity for large mitigation benefits, if scientists and engineers could develop reliable, and possibly remote, methods of rapidly identify and halting leaks from high-emitting sources.

Aliso Canyon/Porter Ranch

In 2016, the Aliso Canyon blowout in Los Angeles (sometimes referred to by the development's name, Porter Canyon), doubled the rate of methane emissions from the entire Los Angeles Basin and temporarily created the largest known human-caused source of methane in the

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[jj] Miller, Scot M., Steven C. Wofsy, Anna M. Michalak, Eric A. Kort, Arlyn E. Andrews, Sebastien C. Biraud, Edward J. Dlugokencky et al. "Anthropogenic emissions of methane in the United States." *Proceedings of the National Academy of Sciences* 110, no. 50 (2013): 20018-20022.

U.S.[kk]

The draft strategy devotes several pages to discussing the Aliso Canyon blowout, saying "Much of the equipment in the oil and gas industry has been regulated for decades by the local air districts. The districts have rules and regulations to limit VOC and NOx emissions because they are precursors of ground-level ozone."[ll] What the draft strategy fails to say is that methane is explicitly exempt from regulation at the local, state and national levels, even though it also causes ozone, though at some distances from cities where emission occur.

For reasons that are unclear, U.S. oil and gas methane emissions are 27 percent higher than earlier estimates.[mm] Previous estimates were 7.3 million metric tons, which means it was thought that 1.4 percent of harvested methane was slipping into the atmosphere. "Now it's 9.3 million metric tons, or closer to a 1.8 percent leak rate" said David Lyons, a scientist with the Environmental Defense Fund. He insists that it's not that there's more methane being leaked into the air than before, but that the EPA's accounting techniques have become more accurate.

Despite better accounting, one shocking setback reveals little safety in those numbers. Lyons cites a recent study that showed oil and gas methane emissions could be 90 percent higher than estimates based on the EPA Greenhouse Gas Inventory, in part because inventories often don't count super emitters, like the Aliso Canyon leak.[nn]

Coping With Uncertainity

All of this argues for rapid deployment of multiple systems that have been demonstrated to work. Leaks from oil and gas active and abandoned wells can be and should be found and plugged using commonly available detection devices. Financial incentives should be adopted and deployed to overcome utility resistance to buying electricity or gas from manure management facilities. Fuel cells should be used at landfills and sewage treatment plants, using captured methane. Flares should be forbidden, with financial incentives to convert islanded methane into methanol.

[kk] S. Conley, G. Franco, I. Faloona, D. R. Blake, J. Peischl, and T. B. Ryerson, "Methane emissions from the 2015 Aliso Canyon blowout in Los Angeles, CA," *Science,* Feb. 25, 2016.

[ll] Draft Strategy at p. 77.

[mm] Christina Procopiou, " First Study of Aliso Canyon Leak Confirms It Was Largest Methane Leak in U.S. History," *Newsweek*, Feb. 25, 2016. http://www.newsweek.com/aliso-canyon-largest-methane-leak-us-history-430462.

[nn] Christina Procopiou, " First Study of Aliso Canyon Leak Confirms It Was Largest Methane Leak in U.S. History," *Newsweek*, Feb. 25, 2016, http://www.newsweek.com/aliso-canyon-largest-methane-leak-us-history-430462.

Final Recommendations

1. Available evidence indicates that (a) the particulate standard for protection of human health should be expressed as a limit on and require measurement of black carbon particles and (b) a secondary black carbon standard should be established to minimize the contribution of particles in general, and black carbon in particular, to global warming, especially the impact in snowy and icy areas.

2. The U.S. Clean Air Act is non-preemptive, allowing any state that so wishes to adopt its own, more stringent primary, or health-based, or secondary, or welfare-based, standards. California should do this for black carbon.

3. In addition, although the U.S Clean Air Act provides for preemption of more stringent fuel standards, if the Administrator adopts such standards for non-road engines. I can find no reference to the EPA Administrator having adopted such a standard for jet fuel. California should develop and adopt such a standard.

4. Several years ago, as Editor and Co-Publisher of the *Health and Clean Air Newsletter*, which was supported by the Board, together with Co-publisher Dr. David Bates, wrote of the impact of black carbon on children. Dr. Bates was founding dean of the University of British Columbia School of Medicine and a member of the National Academy of Sciences. I was counsel to the U.S. Senate Committee on Environment and Public Works from 1978 to 1989, and have since written extensively on global warming and other environmental challenges.

In the *Newsletter*, Dr. Bates and I wrote the following:

"At a time when California has decided to regulate air pollutants for climate as well as health reasons, a recent study reinforces the health threats posed by one of the contaminants that causes global warming, black carbon, produced when wood, gasoline, diesel, coal or other carbon-rich fuels are burned.

"In one, a team at the University of Leicester in the United Kingdom examined the sputum of 114 healthy children to determine whether macrophages66, small blood cells that engulf bacteria, viruses and other foreign material, contained black carbon.67 They were able to assess the carbon content in 64 of the children, or 56 percent. They also administered lung tests.

"As levels of air pollution rose, so did the black carbon in macrophages; and, as macrophage carbon content increased, measures of lung function dropped sharply, between 12.9 and 34 percent.68

"Reduced lung function later in life has been described as second only to the exposure to tobacco smoke as a risk factor for death,69 and a deficit in growth during childhood will most likely translate into a deficit in baseline function carried throughout life.70 In the view of the

Newsletter's co-editor, Dr. David V. Bates, the study's findings suggest that exposure to fine particles is "associated with chronic respiratory subclinical bronchiolitis."71

"The reader is encouraged to consider the moment of these findings. First, black carbon is a ubiquitous pollutant. It simply cannot be avoided. Second, children who inhale black carbon are permanently, and almost certainly, irrevocably injured.

"In an editorial accompanying this study, the writer concluded that 'The best control strategy from the standpoint of human health, supported by the scientific evidence to date, is to reduce the levels of all types of air pollutants. Our children's health depends on it.' 72 We agree."

Notes as follows:

66. Macrophages in the lung's small air airways are the first line of host defense against inhaled organisms and soluble and particulate molecules. Fels AO & Cohn ZA. The alveolar macrophage. J Appl Physiol. 1986 Feb;60(2):353–69.

67. [12189]
KULKARNI, N., PIERSE, N., RUSHTON, L., & GRIGG, J.
Carbon in airway macrophages and lung function in children
N Engl J Med 2006; 355; 21–30 (6b)
Airway macrophages in 64 of 114 healthy children. General PM10 exposure at home site evaluated by study of residence location and data from local monitors. Ambient exposure to PM10 evaluated and an increase in primary PM10 of 1.0 micrograms/ m3 was associated with an increase of 0.10 microns per square meter in the carbon content of airway macrophages. Also, each increase of 1.0 micron/square meter in carbon content was associated with a reduction of 17 percent in FEV1, 12.9 percent in FVC, and 34.7 percent in FEF25-75. A few children with asthma also studied, and the carbon content of their macrophages was lower than in the normal children. All children were cotinine negative to exclude passive exposure to tobacco smoke, and none had any respiratory symptoms. All PFTs were within normal limits. Sputum induction methodology described. Lung function measured 20 minutes before sputum induction. Visual evaluation of area in macrophages occupied by black material using 100 randomly selected cells per child. Convincing association (with an r2 of 0.13) between FEV1 and median carbon area of the macrophages. Authors discuss the significance of the findings and believe that their data provide a link between environmental exposure and long term consequences in the children.
The abstract prepared by the research team described the study as follows: Epidemiologic studies indirectly suggest that the inhalation of carbonaceous particulate matter impairs lung function in children. Using the carbon content of airway macrophages as a marker of individual exposure to particulate matter derived from fossil fuel, we sought direct evidence of this association. METHODS: Airway macrophages were obtained from healthy children through sputum induction, and the area of airway macrophages occupied by carbon was measured. Lung function was measured with the use of spirometry. We modeled the exposure to primary particulate matter (PM) that is less than 10 mum in aerodynamic diameter (PM10) at or near each child's home

address. Linear regression was used to evaluate associations between carbon content of alveolar macrophages and variables that may affect individual exposure. To determine whether lung function that is reduced for other reasons is associated with an increase in the carbon content of airway macrophages, we also studied children with severe asthma. RESULTS: We were able to assess the carbon content of airway macrophages in 64 of 114 healthy children (56 percent). Each increase in primary PM10 of 1.0 microg per cubic meter was associated with an increase of 0.10 microm2 (95 percent confidence interval, 0.01 to 0.18) in the carbon content of airway macrophages, and each increase of 1.0 microm2 in carbon content was associated with a reduction of 17 percent (95 percent confidence interval, 5.6 to 28.4 percent) in forced expiratory volume in one second, of 12.9 percent (95 percent confidence interval, 0.9 to 24.8 percent) in forced vital capacity, and of 34.7 percent (95 percent confidence interval, 11.3 to 58.1 percent) in the forced expiratory flow between 25 and 75 percent of the forced vital capacity. The carbon content of airway macrophages was lower in children with asthma than in healthy children. CONCLUSIONS: There is a dose-dependent inverse association between the carbon content of airway macrophages and lung function in children. We found no evidence that reduced lung function itself causes an increase in carbon content. Copyright 2006 Massachusetts Medical Society.
http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&list_uids=16822993&dopt=Abstract

68. For each increase in primary PM10 of 1.0 micrograms per cubic meter was associated with an increase of 0.10 square micrometers in the carbon content of airway macrophages, and each increase of 1.0 microm2 in carbon content was associated with a reduction of—

— 17 percent in forced expiratory volume in one second;
— 12.9 percent in forced vital capacity; and,
— 34 percent in forced expiratory flow between 25 and 75 percent of the forced vital capacity.

69. Hole DJ, Watt GC, Davey-Smith G, Hart CL, Gillis CR, Hawthorne VM. Impaired lung function and mortality risk in men and women: findings from the Renfrew and Paisley prospective population study. BMJ 1996;313:711–715.
To assess the relation between forced expiratory volume in one second (FEV1) and subsequent mortality, 7058 men and 8353 women aged 45-64 years at baseline screening in 1972–76 were followed to determine mortality from all causes, ischaemic heart disease, cancer, lung and other cancers, stroke, respiratory disease, and other causes of death after 15 years of follow up. During the follow up period 2545 men and 1894 women died. Significant trends of increasing risk with diminishing FEV1 apparent for both sexes for all the causes of death examined after adjustment for age, cigarette smoking, diastolic blood pressure, cholesterol concentration, body mass index, and social class. The relative hazard ratios for all cause mortality for subjects in the lowest fifth of the FEV1 distribution were 1.92 (95% confidence interval 1.68 to 2.20) for men and 1.89 (1.63 to 2.20) for women. Corresponding relative hazard ratios were 1.56 (1.26 to 1.92) and 1.88 (1.44 to 2.47) for ischaemic heart disease, 2.53 (1.69 to 3.79) and 4.37 (1.84 to 10.42) for lung cancer, and 1.66 (1.07 to 2.59) and 1.65 (1.09 to 2.49) for stroke. Reduced FEV1 was also

associated with an increased risk for each cause of death examined except cancer for lifelong nonsmokers.
Impaired lung function is a major clinical indicator of mortality risk in men and women for a wide range of diseases. The use of FEV1 as part of any health assessment of middle aged patients should be considered. Smokers with reduced FEV1 should form a priority group for targeted advice to stop smoking.

70. [12190]
GAUDERMAN, W.J.
Editorial: Air Pollution and children – an unhealthy mix
New Engl J Med 2006; 355; 78–79
^(6b)
The lungs develop steadily throughout childhood, with peak function occurring between 20 and 25 years of age. Lung function then remains stable for as long as 10 years before beginning to decline with increasing age.
Comments on mounting evidence that exposure to urban air pollution induces long term effects in children. Assesses significance of previous paper [12189]and considers that it provides the first evidence of the mechanism whereby long term pollution exposure may induce chronic effects in the lung during childhood.

71. Bates D. V., Hogg J. C., Bruce N. G., Dherani M. K., Smith K. R., Gohil J. R., Grigg J.
Inhaled Carbon and Lung Function in Children.
N Engl J Med 2006; 355:1496–1497, Oct 5, 2006.
Kulkarni and colleagues (July 6 issue)1 found that the level of carbon in airway macrophages in children was strongly associated with expiratory flow rates, although in the 64 healthy children with sufficient numbers of airway macrophages for analysis, all these values were within generally acceptable normal limits. Why should this be? We suggest that this finding indicates that an accumulation of particles was a strong indicator of exposure to urban particulate air pollution and that exposure, in turn, is associated with chronic respiratory subclinical bronchiolitis. If so, we suggest that current exposures to urban pollution have to be taken very seriously."

72. Gauderman W. J. Air Pollution and Children—An Unhealthy Mix. N Engl J Med 2006; 355:78–79, Jul 6, 2006.

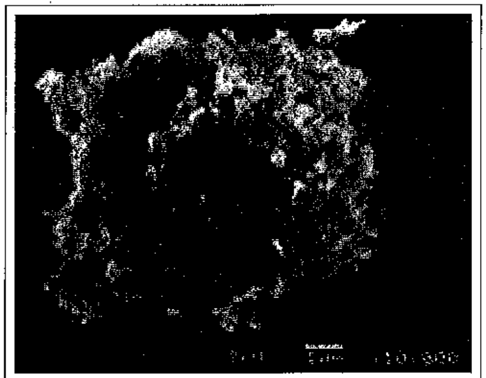
* * *

Appendix A: Black Carbon: The Mother of All Warmers and Killers

It is unlikely that any single action could produce benefits as immense or as quickly as those from eliminating black carbon. The lifetime of black carbon in the air–soot, to most of us–is four to twelve days,[2] and it is the second most potent contributor to global warming.[3] It causes widespread human death and illness. Reducing emissions would yield nearly immediate and very substantial benefits, saving up to 4.4 million lives per year,[4]and starting planetary cooling with 4 to 12 days.[5] In contrast, the biggest cause of global warming, carbon dioxide, has a lifetime in the air of 100 years, in the environment of 1,000 years and causes no direct human health damage.

Despite the unique and potent damage done to human health and the global climate, nowhere in the world is there a program to directly address emissions of black carbon by gasoline or diesel engines, open burning or the other sources. What is desperately needed to protect human health and prevent global warming is a program squarely aimed at black carbon. This could best be achieved by establishing ambient standards and specific emission limits for black carbon as a pollutant. This would trigger national, state and local programs to reduce emissions, attract global attention and force attention on a pollutant that is now almost completely ignored in its own right.

Dr. Susan Solomon, who proved that the Antarctic ozone hole was caused by CFCs,[6] wrote in a later paper that "the climate change that takes place due to increases in carbon dioxide concentration is largely irreversible for 1,000 years after emissions stop."[7]



Black carbon particle.

No known pollutant can equal, much less exceed, the harm done by black carbon. It occurs naturally only from the occasional forest fire,[8] so neither the Earth itself nor the creatures that live on it have an evolved immunity.[9] Because it results from the incomplete burning of carbon-based fuels—everything from cow dung to coal, oil and wood—black carbon is virtually everywhere, save the center of a stone.

Black carbon is at street corners,[10] in the snow of the high reaches of the Himalayas,[11] on the ocean floors,[12] in the ice of the Arctic[13] and the sands of barren Saharan desert.[14] Yet it needn't be so.

Black carbon is exquisitely simple to eliminate: give poor people improved cooking stoves, equip gasoline and diesel engines with devices–add-on controls that have been used successfully for over 30 years–that trap and destroy black carbon, stop wildfires sooner and prohibit open burning. Those and other actions could save the lives of 1.6 million children a year under the age of six, which black carbon now kills. Within 12 days—***12 days***—of eliminating a source of black carbon, global cooling would begin.

Would this require change on the part of the world? Absolutely. But change is not sacrifice, merely a different way of acting, often accompanied by adopting measures that are better, faster or cheaper.

SUMMARY

Finding ways to reduce black carbon is no great technological challenge. Nor is the task of identifying sources difficult.

If a nation is developed, like the United States and western Europe, diesels will be the dominant source. Reduce diesel emissions 90 percent or more by installing "trap oxidizers," which are add-on pollution controls that catch and destroy diesel soot, used in trucks, buses and cars for over 30 years.[15]

If a nation is developing, like China and India, indoor cooking and, in some cities, the mosquito fleets of two-cycle motor cycles and diesel engines, dominate emissions. Provide low-cost, low-polluting cooking stoves, and require motorcycles to be powered by cleaner burning four-stroke engines, and emissions will be cut 90 percent or more. Ditto if conventional diesel fuel is replaced with natural gas or lanterns are fueled by sunlight instead of kerosene.

Yet despite these and many other ready solutions, almost nothing is actually being done, so the planet is warming, the poles and glaciers are melting and people are being sickened and killed, all needlessly. What this chapter suggests is an approach to reducing black and organic carbon emissions analogous to the U.S. strategy of "island hopping" in World War II in which Allied forces bypassed heavily fortified Japanese positions and instead concentrated on strategically important islands.[16] Just as taking those islands was the key to victory then, so, too, is virtually eliminating black carbon from certain sources the key to saving lives and the future today.

Black carbon is toxic to both the planet and its inhabitants because it occurs either not at all in nature, or only in vanishingly small amounts. While the burning of wood, coal, oil and other carbon-rich fuels is now commonplace, the rise in their use occurred so recently that neither the planet nor humans have had enough time to evolve resistance. Ozone, or smog, occurs naturally, as do hydrocarbons and larger particles, such as windblown dust. So, not surprisingly, humans and the planet can, while not necessarily be thriving, tolerate them.

The lifetime of black carbon in the air is so short that benefits of reductions would be virtually immediate. The impacts of black carbon on icy and snowy regions such as the poles, glaciers and snowpacks, are so disproportionate that eliminating it would vastly reduce the danger of reaching a "tipping point" at which a tiny change triggers a potentially catastrophic alteration, such as water to steam, static electricity to lightening or common energy to a thermonuclear explosion.

Enough is known about the dominant sources of black carbon, ways to reduce emissions and the immense benefits that would accrue to act immediately and comprehensively. By every measure, black carbon is dangerous as a cause of warming, highly disproportionate melting in glaciers, snowpacks and the poles and as a source of grave illness and death. Maximum reductions in minimum time should be the objective, with a goal of virtual elimination wherever possible.

GLOBAL EMISSION ESTIMATES FOR BLACK AND ORGANIC CARBONS

Transport	**Black Carbon**	**Organic Carbon**
Diesel on-road	1200	380
Diesel off-road	310	100
Gasoline	92	1000
Marine	120	225
Aviation	22	6
Subtotal	***1700***	***1700***
Industry & Power		
Industrial coal	740	1100
Other	190	990
Subtotal	***930***	***2100***
Residential		
Coal	330	28
Wood	1200	5800
Agricultural waste	260	1700
Animal waste	37	140
Subtotal	***1800***	***7900***
Open Burning		
Crop	330	1600
Waste	45	59
Other (forest/savanna)	3000	23000
Subtotal	***3400***	***25000***

Based on Bond, T.C. "A technology-based global inventory of black and organic carbon emissions from combustion." *Journal of Geophysical Research*, Vol. 109, D14203, 43 pp., 2004.

BLACK CARBON: THE POLLUTANT THAT'S IGNORED

Black absorbs heat. Touch a black car in the sun or toss a handful of cool ashes from the fireplace on fresh snow, if you doubt it. The car is hot, like black carbon, or soot, in the air; and the snow will melt, just as it does in the Arctic and on mountain ranges.

Carbon that is black, like the soot from diesels or fires, is the second largest contributor to global warming. Cutting emissions of black carbon would cool the world within a few days and avoid millions of deaths and billions of illnesses.[17]

But is humanity reducing black carbon pollution? No.

To demonstrate the truth of this, look no further than the many replacements available for one of humanity's most polluting and dangerous goods, the kerosene lantern.

THE KEROSENE LANTERN:
A LITTLE LIGHT, LOTS OF POLLUTION.

The Solar Muscle made by Flexiway is one of many versions that eliminate the kerosene lantern by substituting electricity made from sunlight coupled with high efficiency light emitting diodes (LEDs) and outlets for recharging cell phones or other devices. Approved by the International Federation of Red Cross and Red Crescent Societies (IFRC), the Solar Muscle was named the 'Best Eco Product' at the Australian Business Awards 2013.[18]

Flexiway says the Solar Muscle is a lightweight, pocket-sized solar light that can be carried or hung around the neck. It has 12 LED lights, three power settings, an integrated solar panel and battery unit, charges even on cloudy days, provide one hour of light for every hour of sunshine, runs eight hours on full power and 16 hours at half power, providing 48-60 lumens (a candle produces 13)[19], with a life of three years or 1,000 charges.[20]

Price: 400 for $5,000 ($12.50 each) or 1,000 for $10,000 ($10 each).[21]

Don't care for the Solar Muscle? Try the Sun King Solar Pro, which boasts that it is the "world's longest-lasting solar light with mobile phone charger." It is "10 times brighter than kerosene," provides 30 hours of light on one day's charge, making it "the industry's gold standard in affordable solar-powered lanterns."[22]

Price: $31.19 in Lagos, Nigeria, for one.[23] In fairness, probably much less in bulk.

Care for neither Solar Muscle nor Sun King Solar Pro? Then what about the version atop my bookcase, the Solar D.Light. Or the laptop sized photovoltaic in my shed, bought from Wal-Mart. Or one of SolarFine's products.[24] Or one of the 52 lanterns listed by the International

Finance Corporation, all meeting the Lighting Global Quality Standards.[25]

Nearly 1.3 billion people worldwide–almost one quarter of the world's population–live without access to electricity. More than half live in Asia, where "they face severe challenges to basic lighting access." in the words of the International Finance Corporation. In seven Asia nations–India, Cambodia, Philippines, Nepal, Pakistan, Bangladesh and Indonesia–subsidies for buying kerosene amounted to $3.7 billion in 2012.[26]

The *Christian Science Monitor* tells the hopeful story of what it calls "Africa's quiet solar revolution," in which a relatively prosperous family with mosquito screens on the windows and doors, a gas cookstove, and, most important, a faucet with running water in the back of the yard, next to a stall with a working toilet, but no electricity, was able to sign up in 2013 for "a fully functioning solar home system in their house – enough to power several LED lights and a radio." The payoff was immediate, the Monitor reports: while the family Noah used to spend $18 a month on kerosene, it now pays a monthly average of $11 for solar lighting, and no longer must go into town to charge a cellphone.[27]

The new off-grid solar system, wrote the *Monitor*, was "emblematic of a quiet revolution sweeping across much of rural Africa and the developing world." Yet this was one house. To truly eliminate kerosene lanterns requires not thousands, even millions or hundreds of millions of such systems, but billions.

Replacing kerosene lanterns is the lowest of the low hanging fruit. Laboratory and field measurements show that 7 to 9 percent of the kerosene consumed by widely used wick lamps is converted to nearly pure black carbon. Roughly 7 percent of the total warming caused by black carbon is due to kerosene lanterns.[28] Replacing them with solar lamps or other lighting options always– *always*– saves money, and quickly, usually within months.

There are no other affordable replacements, there are very few barriers to replacing kerosene with solar lights, and doing so would provide immediate benefits: children will live who otherwise would die, and global warming would be slowed within days.

But it is not happening.

Just as there are half-hearted attempts to give improved stoves to poor nations and adding devices that trap and destroy soot to diesels, a few kerosene lanterns are being replaced in a few places. The sunlight lanterns work, as do the improved stoves.[29] *So do the traps for diesels.*[30] *But these are fainted hearted gestures, trivial compared to what could and should be done.*

The United Nations Foundation oversees the Global Alliance for Clean Cookstoves, saying that household air pollution is the 4th biggest health risk in the world, that it kills 4.3 million people a year from exposure to cookstove smoke, with almost 3 billion people using polluting and inefficient stoves, or open fires, to cook their food each day, adding that "every 8 seconds cookstove smoke claims a life."[31]

The Alliance's plan? To sell 100 million cookstoves by 2010. That's 1/30 of the need, according to the Alliance's own estimates.[32]

BURN, IN KENYA

BURN, a U.S.-Kenya company, sells its Jikokoa charcoal stove in East Africa for $42, saving saves households about $250 a year, with a three to four month payback period, according to the firm. In 2014, Kenyan consumers collectively spent over $1.4 million to purchase BURN cookstoves.
Source: https://www.linkedin.com/pub/peter-scott/29/884/1a7.

In developed nations like the United States, western Europe and Japan, the most potent source of black carbon is the diesel engine.[33] We know how to reduce the emissions of black carbon by 95 percent, and have been doing that on a few sources for 30 years.[34]

Diesels–school buses, 18 wheeler trucks, farm tractors– can all be cleaned up using devices that trap and destroy diesel soot. In the test of a bus in Europe, the diesel trap destroyed more than 99.8 percent of the soot, doing as well as a brand new bus.[35]

BLACK CARBON: HOW IT WARMS GENERALLY

Black carbon is often transported over long distances, mixing with other pollutants at 3 to 5 kilometers (1 to 3 miles) and forming transcontinental plumes. Emissions of black carbon are the second strongest cause of global warming, after only carbon dioxide.[36]

Because black carbon often mixes with other pollutants that cause global cooling, its contribution to warming was underestimated until 2001. That's when Mark Z. Jacobson of Stanford University concluded the exact contribution of black carbon to global warming was determined by *how* black carbon is mixed with other pollutants emitted at the same time. The black carbon could be distinct from other pollution (externally mixed) or incorporated within them (internally mixed).

Until Jacobson's results, it was almost universally assumed that it and other pollutants existed as an external mixture.[37] Jacobson showed that black carbon in the air was mixed internally not externally. That switch almost doubled the calculated contribution of black carbon to global warming.[38] "Black carbon," Jacobson wrote "may be the second most important component of global warming after CO2."[39]

Almost overnight, scientists concluded that instead of having a net cooling effect, black carbon was the second most potent cause of global warming.

Then, scientists realized that while black carbon causes warming globally, it is especially damaging in regions with snow and ice, like mountain ranges and the Arctic. Ice cores taken in the Arctic show that starting about 1850, industrial emissions caused a sevenfold increase deposition of black carbon, with most in the winters, peaking from 1906 to 1910, when snow absorbed 3 watts per square meter in early summer, which is eight times the normal, or pre-industrial, value. Starting after 1951there were still increases, but they slowed.[40]

In addition, the Little Ice Age in the European Alps was most likely ended by black carbon.

The end has long been a paradox to glaciology and climatology. Glaciers in the Alps began to retreat abruptly in the mid-19th century, even though glaciers should have instead advanced into the 20th century.

TAKAMOTO BIOGAS

Takamoto, based in Kenya, replaces traditional cooking fuels with biogas, made from the manure of pigs, cattle or other animals. Almost 90 percent of rural Kenyans have no electricity, forcing them to use firewood, charcoal, kerosene and other fuels for cooking. Takamoto's customers save 45 minutes per day otherwise spent collecting, splitting and lighting firewood, saving about 2.7 trees per year and 12 percent of monthly cooking fuel expense, while avoiding fires that cause an estimated 4 million deaths per year in Kenya. The systems also produce an organic fertilizer that increases crop yields. Source: Kiva, http://www.kiva.org/partners/436.

Black carbon in snow, however, began to increase markedly in the mid-19th century. Simulations conclude that increased sunlight absorbed by black carbon were large enough to cause the glacier retreat.[41]

BLACK CARBON: HOW ITS WARMS GLOBALLY

Because they are black–remember how hot a black car in the sunlight is–carbon particles absorb heat from the sun. Those particles, whether in the air being blown from one continent to the next, or on the ground, absorb the heat of sunlight and thus cause warming.[42]

Also because they are black, the particles of carbon reduce heat that would otherwise be reflected back into space, decreasing reflectivity, or albedo.[43] Bright white sea ice reflects almost all of the incoming solar radiation back to space, whereas the dark ocean surface absorbs nearly all of it.

The albedo of snow-covered sea ice is 0.90, meaning it reflects 90 percent of the Sun's radiation. The ocean surface, however, is almost black, and it only reflects 10 percent, meaning it absorbs 90 percent. After something absorbs sunlight, it emits heat. Less sea ice and more ocean surface will lead to a warmer Arctic, and a warmer planet.[44]

These add the warming of the entire planet.[45] But black carbon is especially aggressive in snowy and icy regions, like mountain ranges and the Arctic.

BLACK CARBON: HOW IT MELTS SNOW AND ICE

Wherever there is snow or ice, black carbon accelerates melting. It does this by gathering heat, which causes the snow or ice to melt, replacing its with darker surfaces like water or soil that absorb still more heat. Black carbon contamination also sems the change the size of snow grain, which reduces their ability or reflect radiation even more.[46,oo]

For many years, it has been predicted that a darkening of the Arctic associated with disappearing ice would trigger a retreat of sea ice there, but its reality has been dramatic. The area of summer sea ice lost since the 1980s would cover over 40 percent of the of the continental United States. The consequences have been graphic. It has been almost impossible to avoid stories and photograph of some consequences, such as the endangerment of polar bears.

In the words of Polar Bears International, an advocacy group for the animals, "we have seen declines in physical stature and condition, declines in reproduction and survival, and declining population size due to sea ice losses induced by global warming."[47]

Scientists estimate the population of polar bears in the area north of Alaska and northern Canada declined by about 40 percent from 2001 to 2010.[48] But polar bears are not the only Arctic species at risk. Ice-loving seals, such as harp, hooded and ringed seals, are among the many species threatened by global warming.

Harp seals give birth to pure white pups on Arctic ice floes. During their first six weeks of life, before they grow large enough to spend most of their time in the water, the pups use the ice as platforms for nursing and resting. But as ice melts more quickly because of warming, pups are forced into the water before they are ready to fend for themselves. These young pups are especially at risk for hypothermia, starvation, and being crushed by moving ice in the Arctic.

Scientists from the Duke University Marine Lab found not only that over 3,000 sick or dead harp seals had stranded on U.S. beaches. Most of them were yearlings, which are particularly susceptible to stranding because they tend to be smaller, weaker, and have less experience fending for themselves.[49]

[oo] Of course, the reduction of surface albedo caused by black-carbon contamination of snow contributes to *global* warming and *near-worldwide* melting of ice, but this summary is focusing on the immediate effects within the regions of snow or ice.

Warming and melting of the Arctic has been confirmed by satellite measurements, which show that the decline has been caused by a warming of about 6.4 Watts per square meter. This is, wrote researchers, "considerably larger than expectations from models and recent less direct estimates," a change roughly equivalent to 25 percent of the warming due to carbon dioxide during the previous 30 years.[50]

Everywhere, it seems, the Arctic is warming. Off Barrow, the most northerly community in Alaska, open water increased by 44 percent and 46 percent for the Beaufort and Chukchi Seas, respectively, from 1979 to 2012, and temperature rose 2.7 degrees Celsius (about 5 degrees F).[51]

Of course, black carbon causes only a fraction of Arctic warming and melting, but the fraction is large. It is having the same warming and melting effect in the world's "third pole," the Himalayan Mountains, so-called because of the immense amounts of snow and ice there.

Black carbon aerosols exert relatively large surface heating (about 45 percent higher), compared to composite aerosols and contribute about 70 percent to the total atmospheric forcing at Manora Peak. Such a large warming effect of BC may affect the strength of Himalayan glaciers, monsoon circulation and precipitation over the Indian region.[52]

Black carbon deposited on snow and ice on the Himalayas and Tibetan Plateau is principally from India and south Asia, as well as China and east Asia, accounting for 67 percent and 17 percent, respectively. That same study concluded that black carbon deposited in the region increased 41 percent from 1996 to 2010, "implying that the BC problem is accelerating in the HTP region." wrote the researchers. They are followed by the former USSR (8 percent), Middle East (4 percent), Europe (2 percent), and Northern Africa (1 percent), but the relative contributions of different source regions varies with seasons.[53]

THE HUMAN EFFECT

It is simply not possible to separate the warming and melting in the Arctic caused by black carbon from that caused by ozone or that caused by carbon dioxide. There can be no question whatsoever, however, that the region is now warmer than it was, and there are human consequences, especially on hunting and gathering, the way in which native have survived.

Hunting and gathering serves a practical as well as cultural purpose: The median household income in the Alaskan Arctic is $66,908, according to 2010 Census data, but the cost of living is high. With exorbitant local grocery prices — ribeye steak is $18.98 per pound, a large bunch of bananas costs $11 — nearly every freezer in town contains a bucket of seal sitting in its own oil along with frozen berries from the hillside.[54]

But the sea ice on which bearded and ring seals, as well as walruses, depend is retreating farther to the north. It now freezes at least a month later than it did three decades ago, according to University of Alaska at Fairbanks professor Hajo Eicken, and the ice is unstable in June —

when it used to be solid. This poses a threat to the animals, who are more vulnerable to predation and have a harder time feeding, and to villagers who can no longer hunt and travel safely across the ice.[55]

Larry Westlake, a local elder who lives in Kiana, 80 miles east of Kotzebue, and serves as the Northwest Borough Assembly president, noted that this summer seal hunting not only came early — in late June — but also lasted "just a couple of days" because the ice moved out so quickly.[56]

"Every bit of our cultural life and our cultural gathering is in jeopardy," Westlake said. "It threatens our cultural hunting and fishing so bad it makes the elders wonder, 'How can we survive this?' "[57]

It is clear beyond dispute that black carbon contributes to warming and melting in the Arctic. The influence of weather in the Arctic, however, extends thousands of miles south, influencing temperatures and rainfall as far as Miami and even Jamaica.[58]

GLOBAL INFLUENCE OF A WARMING, MELTING ARCTIC

As the Arctic begins to freeze in September and October each year, a vast amount of energy absorbed during the previous during summer due to black carbon, ozone and carbon dioxide is released to the atmosphere as heat. It then becomes a question of not whether the entire northern hemisphere will be affected, but how?

The chances of seasons being warm or cold has become more and more likely sinmce about 1980 has increased, and the Earth has warmed. Temperatures have risen, boosting both the number and temperatures of heat waves. In 2011, for example, Texas and Oklahoma endured their warmest months on record as persistent heat scorched central and eastern states from May to July.

Temperatures averaged 88.9 degrees in Oklahoma -- the warmest monthly statewide average temperature ever recorded -- and 87.1 degrees in Texas, according to the National Oceanic and Atmospheric Administration, resulting in the fourth-warmest July on record for the United States. In Dallas, temperatures exceed 100 degrees for 30 of July's 31 days.[59]

One year earlier, nearly 11,000 died in Moscow during July and August, 2010 heat wave, than at the same time one year earlier. The head of Russia's weather service, Alexander Frolov, said that "Our ancestors haven't observed or registered a heat like that within 1,000 years. This phenomenon is absolutely unique."[60]

When a team of seven U.S. meterologists reviewed these events and the science associated with a warming Arctic, they concluded that these events "a consequence of global warming because their likelihood in the absence of global warming was exceedingly small."

They added that for some types of extreme — notably heat waves, but also precipitation extremes — there is now strong evidence linking specific events or an increase in their numbers to the human influence on climate. For other types of extreme, such as storms, the available evidence is less conclusive, but based on observed trends and basic physical concepts it is nevertheless plausible to expect an increase.[61]

In their conclusion, the asked whether "the persistent weather conditions associated with recent severe events such as the snowy winters of 2009/2010 and 2010/2011 in the eastern U.S. and Europe, the historic drought and heat-wave in Texas during summer 2011, or record-breaking rains in the northeast U.S. of summer 2011 be attributed to enhanced high-latitude warming?" The answer, they said, was that "Gradual warming of the globe may not be noticed by most, but everyone – either directly or indirectly – will be affected to some degree by changes in the frequency and intensity of extreme weather events as greenhouse gases continue to accumulate in the atmosphere."

That having been said–

- there are so many sources of black carbon, ranging from diesel engines to open cooking, and

- fuels, from refined and petroleum based liquids to dried cow dung, and

- so many geographic regions, and

- it is mixed with so many other pollutants, ranging from other forms of carbon to sulfate (from coal or diesel fuel containing sulfur) and nitrates (mostly from the high temperatures of some combustion)

that calculating what to control, where and how much is challenging. That said, there are some obvious targets. One of these is clearly diesels, everywhere.

The ratio of black carbon to other pollutants that might have a cooling effect is very low. In addition, because of the threat that diesels pose to human health

Black Carbon: How It Kills and Injures

It is well established that particulate matter generally and fine particles in particular are major causes of illness and death throughout the world.[62] Scores of studies have conclusively established this.[63] What research is now bearing down on are specific causes and mechanisms, including black carbon.

A growing body of evidence suggests that what is driving cardiotoxic effects observed in response to these air pollution exposures is black carbon.[64]

A landmark study in Boston conducted by some of the world's premier researchers on the health effects of air pollution using state-of-the-art technology and new techniques established a virtual causal relationship between death and black carbon exposures. *The evidence is so compelling that when researchers completed an examination of the links between vehicle pollutants, black carbon, and cardiovascular deaths and illness, they concluded that serious consideration should be given to establishing a health-based standard under the Clean Air Act, adding to those already in effect for smog, fine particles, carbon monoxide and lead.*[pp] The finding in Boston is consistent with other studies suggesting that black carbon and traffic pollution are associated with heart attack (myocardial infarctions),[65] arrhythmias,[66] and alterations in heart rate variability.[67]

BLACK CARBON: DEATH, INJURY AND ILLNESS

It is quite clear that particulate matter pollution kills.[68] Increasingly, in developed nations human sickness and death has been associated with one specific source of particulate matter—motor vehicles. That, in turn, is focusing on a specific constituent of vehicular emissions, which is black carbon.

Blood Pressure

Indeed, one study aimed at determining whether the pollutant causing increases in blood pressure, a risk factor for heart disease, was fine particles generally or black carbon specifically.

[pp] They concluded that "Abundant epidemiological studies now link exposure to vehicular emissions, characterized in many different ways, with CV health endpoints such as cardiopulmonary and ischemic heart disease and circulatory-disease-associated mortality; incidence of coronary artery disease; acute myocardial infarction; survival after heart failure; emergency CV hospital admissions; and markers of atherosclerosis. We identify numerous in vitro, in vivo, and human panel studies elucidating mechanisms which could explain many of these cardiovascular morbidity and mortality associations. These include: oxidative stress, inflammation, lipoperoxidation and atherosclerosis, change in heart rate variability (HRV), arrhythmias, ST-segment depression, and changes in vascular function (such as brachial arterial caliber and blood pressure). Panel studies with accurate exposure information, examining effects of ambient components of vehicular emissions on susceptible human subjects, appear to confirm these mechanisms. Together, this body of evidence supports biological mechanisms which can explain the various CV epidemiological findings. Based upon these studies, the research base suggests that vehicular emissions are a major environmental cause of cardiovascular mortality and morbidity in the United States. ***As a means to reduce the public health consequences of such emissions, it may be desirable to promulgate a black carbon (BC) $PM_{2.5}$ standard.***" (emphasis added).Thomas J. Grahame, T.J. & Schlesinger, R.B. Cardiovascular health and particulate vehicular emissions: a critical evaluation of the evidence. *Air Qual Atmos Health.* 2010 March; 3(1): 3–27. Published online 2009 June 30. doi: 10.1007/s11869-009-0047-x

They hypothesized that black carbon would be more strongly associated with blood pressure than would fine particles (2.5 microns or less, or $PM_{2.5}$), and it was. When levels of black carbon increased, so did both systolic and diastolic blood pressures, but there was no corresponding connection to increased $PM_{2.5}$. The researchers also found that the increased blood pressure was not linked to gene variants that reduce the body's ability to combat pollutants.[69]

Airway Inflammation

A Seattle study of asthmatics produced comparable results. Exhaled nitric oxide FENO is a measure of airway inflammation. Increases of FENO means there has been a rise in airway inflammation.

In the Seattle study, outdoor levels of PM_{10} and $PM_{2.5}$ were measured, then compared to measurements of exhaled FENO. Researchers found that when outdoor levels of PM_{10} and $PM_{2.5}$ rose 10 micrograms per cubic meter, the levels of exhaled FENO also rose, by 5.9 and 4.2 parts per billion, respectively. To determine whether black carbon, as a discrete fraction of the particle mix, might be responsible for increased inflammation, researchers measured outdoor, indoor and personal BC. When those rose by 1 microgram per cubic meter, FENO levels increased 2.3, 4.0 and 1.2 parts per billion, respectively. Thus, although increased PM_{10} and $PM_{2.5}$ are linked to rises in inflammation, so, too, is black carbon, and it was much more potent, with levels of FENO jumping much more sharply.[70]

Cardiovascular Damages

A variety of studies link exposure to black carbon not only to increased blood pressure,[71] but also cardiac and ventricular arrhythmias,[72] ST-segment depression,[73] decreased flow-mediated vascular reactivity,[74] lowered heart rate variability,[75] and, perhaps most importantly, increased cardiovascular mortality.[76]

Death

The Boston study linking black carbon to death is particularly compelling, partly because it was conducted by some of the world's most highly regarded researchers, but also because of its large size and, hence, persuasiveness. To determine the connection between two specific components of particulate matter—black carbon and sulfate—and mortality, they analyzed 107,925 deaths from cardiovascular, respiratory and all causes for the years 1995–2002.

To determine concentrations of sulfates, produced principally from coal burning, researchers used data from a central monitor at the Harvard School of Public Health. To estimate concentrations of black carbon, they used a model that began its calculations with daily data from another monitor at the school. The model then estimated black carbon concentrations at more than 80 representative sites in the Boston area, incorporating variables such as weather, season, day of week, traffic volume, proximity to major roadways, population density, and percent urbanization.

They also accounted for gender, education, income, and residence location for each death.[77]

When black carbon concentrations rose on the day before death, mortality for all causes rose 2.3 percent, while those from stroke jumped 4.4 percent. (A similar, though smaller, relationship existed for sulfate particles.) There were increases of similar magnitude for deaths from cardiovascular disease, respiratory diseases, and diabetes.[78]

While the final end point of exposure to black carbon may be death, it also causes a variety of serious, irreversible injuries and illnesses.

Inability to breathe normally

For example, in another Boston study, researchers probed the relationship between black carbon and lung function among women in the Maternal-Infant Smoking Study of East Boston. They found that when BC levels climbed, there were sharp decreases in several measures of the ability to breathe normally: 1.1 percent decrease in forced expiratory volume in 1 sec; 0.6 percent decrease in forced vital capacity, and 3.0 percent decrease in forced mid-expiratory flow rate.[79]

Declines in intelligence, vocabulary and abstract reasoning

When some of the same researchers examined the relationship between black carbon and cognition among 202 Boston children averaging 9.7 years of age, the findings were alarming: after accounting for sociodemographic factors, birth weight, blood lead level, tobacco smoke exposure, and other potential confounding factors, higher levels of black carbon were linked to decreases in—

- vocabulary (-2.2 percent);
- "matrices," a measure of abstract reasoning ability (-4.0 percent); and,
- composite intelligence quotient (-3.4 percent).

"Higher levels of black carbon," they wrote, "predicted decreased cognitive function across assessments of verbal and nonverbal intelligence and memory constructs."[80] However, even in developed nations there are other sources of black carbon, and their emissions are also dangerous.

Not all studies seeking to isolate one specific constituent of vehicular pollution as the cause of illness and death have found black carbon to be the sole cause. One study aimed at establishing associations between daily mortality and specific components of $PM_{2.5}$ measured in downtown Santiago, Chile between 1998 and 2006. The strongest individual effect was seen for elemental carbon. When its levels increased, so did death rates. However, soil-sourced particles had a weaker but nevertheless statistically significant mortality effect.[81]

CARS, TRUCKS, DEATHS AND ILLNESS

It makes sense that air pollution would be worse near busy streets and highways, and studies show that it is. For example, studies in Stockholm, Munich and various areas in the Netherlands have all found that at sites with heavy traffic, levels of particles 2.5 microns (millionths of a meter) were roughly 18 percent higher than in the urban areas generally. The "reflectance" of filters, which is a measure of black carbon, was 31 to 59 percent higher at traffic sites.

If pollution is worse, shouldn't the same be true of the injuries it causes? Yes, and scores of studies demonstrate this.

Munich researchers randomly selected 7,509 school children and compared the presence of various ailments with traffic counts. They found that where traffic levels were higher, so were cough, wheeze and, most alarmingly, asthma. This, commented one prominent scientist, suggested "an important role for primary combustion products from traffic." A study of 16,663 junior high school students in Jakarta also found a link between traffic levels and a variety of illnesses—cough, phlegm, persistent cough and, again, asthma.

From these beginnings, researchers have accumulated a remarkable and damning body of evidence, demonstrating that proximity to traffic causes death, serious illness, and a wide variety of other ailments.

In a study of residents of England and Wales aged 45 years and older, researchers compared 189,966 deaths from stroke with distance from a main road. They found that among men who lived within 200 meters of such a road, stroke mortality was 7 percent higher compared with men living 1,000 or more meters away. For women, the increase was 4 percent. The scientists concluded that about 990 stroke deaths per year could be attributed to traffic pollution.

In Amsterdam, adults living within 100 meters of a freeway or 50 meters of a busy road were almost twice as likely to die from lung or heart disease, causing researchers to conclude that "long-term exposure to traffic-related air pollution may shorten life expectancy." In another Amsterdam study, scientists concluded that increases two specific vehicular pollutants—"black smoke," which is a measure of particle concentrations, and oxides of nitrogen—which were both linked to death the following day. This effect, they also concluded, was higher "in the summer and in the population living along busy roads."

Researchers in Denmark, relying on data from the nation's Cancer Registry, concluded that a doubling of vehicle pollution increased the risk of lymphomas in children by 25 percent. A Swedish study of 6,364 truck drivers found they were at increased risk of both lung and prostate cancer. The records are replete with such findings: cough, respiratory disease, shortness of breath, use of respiratory medicines, wheeze. runny nose, doctor-diagnosed asthma, declines in lung function, and many, many more illnesses and injuries have been linked to cars and trucks by hundreds of studies.

Black Carbon from Burning Gasoline or Diesel Fuel

Beginning about two decades ago, researchers established linkages between exposure to fine particles and a variety of illnesses and death.[82] Initial attention focused on fine particles emitted from stationary sources, such as steel mills. Then, starting in 2002, the first of many studies emerged finding significantly higher risks of cardiovascular morbidity and mortality for people living in close proximity to major roadways, versus those living further away, leading one pair of researchers to conclude in 2009 that—

> Abundant epidemiological studies now link exposure to vehicular emissions, characterized in many different ways, with CV health endpoints such as cardiopulmonary and ischemic heart disease and circulatory-disease-associated

mortality; incidence of coronary artery disease; acute myocardial infarction; survival after heart failure; emergency CV hospital admissions; and markers of atherosclerosis.[83]

The link of tailpipe pollution to a variety of cardiovascular illness and death became more clearly established as researchers found it associated with a variety of adverse health endpoints: oxidative stress, inflammation, lipoperoxidation and atherosclerosis, change in heart rate variability (HRV), arrhythmias, ST-segment depression, and changes in vascular function (such as brachial arterial caliber and blood pressure). Panel studies with accurate exposure information, examining effects of ambient components of vehicular emissions on susceptible human subjects, confirmed these mechanisms. Together, this evidence demonstrates the existence of biological mechanisms that explain how vehicular pollution kills and injures. It also makes it clear that vehicle emissions are a major environmental cause of cardiovascular mortality and morbidity in the United States and other developed nations.

Diesel Engines

The adverse health effects of one specific vehicular source of black carbon, diesel engines, are well established. The hazards range from lightheadedness, cough and nausea to lung cancer.[84] In one study, 20 men with a history of heart attack were exposed while exercising to either filtered air or diluted diesel exhaust at a level comparable to one that would be routinely encountered in traffic. Breathing diesel exhaust triggered myocardial ischemia, or reduced blood supply to the heart, as well as declines in endogenous fibrinolytic capacity,[85] a symptom of chronic, low-grade inflamation thought to be an important contributor to heart attacks.[86] One investigator concluded that the study showed that the relationship between diesel fumes and heart troubles "is indeed a causal relationship."[87]

Adverse Effects of Black Carbon from Burning of Wood, Crop Residues, or Forests

Wood smoke is a common outdoor pollutant throughout much of Canada and the northern United States. Animal toxicological studies show that wood smoke exposure can disrupt cellular membranes, depress macrophage activity, destroy ciliated and secretory respiratory epithelial cells, and cause aberrations in biochemical enzyme levels. With respect to the human epidemiological data, the literature shows a coherence of the data from young children, with seven of eight studies, especially in children with asthma, reporting increased respiratory symptoms, lower respiratory infection, and decreased pulmonary function as a result of exposure to wood smoke.[88]

Several studies of wildfires have confirmed these results. For example, in late October, 2003, wildfires blanketed southern California with smoke, including several that were already participated in Southern California Children's Health Study (CHS), one of the world's most famous on-going examinations of air pollution health effects. Researchers exploited this additional research opportunity, sending questionnaires to 6,424 enrolled children. They found that based on the degree of smoke exposure, there were increases in nose, eyes, and throat irritations, cough, bronchitis, cold, wheezing, asthma attacks, medication usage, and doctors' visits.[89]

Similarly, in June–July 1998, forest fires raged in parched areas of Florida, burning 499,477 acres. Researchers pooled data from eight area hospitals, finding that emergency visits increased 91 percent for asthma, 132 percent for acute bronchitis and 37 percent for chest pain.[90] After lightning strikes touched off fires that eventually burned over 600,000 acres of woodland in California during August 1987, researchers compared hospital data during that time with two other relatively fire-free periods. They found a 40 percent increase in emergency room visits for asthma, as well as increases for sinusitis, upper respiratory infections, and laryngitis.[91]

These surges in smoke can pose a special threat to those already suffering from respiratory illness, as a study in Winnipeg, Canada demonstrates. When smoke levels there increased sharply from September 25 to October 12, 1992 due to the burning of agricultural residue, 428 people with mild-to-moderate airway obstruction were already enrolled in an ongoing study. Researchers were able to closely monitor lung health. They found that virtually all of the 163 women reported difficulty in breathing, though only 16 percent of the 265 men did so. Their symptoms included cough, wheezing, chest tightness, and shortness of breath.[92]

The Horrific Toll of Indoor Black Carbon in Developing Nations

The dominant source of black carbon in urban areas of developed nations is combustion in engines, especially diesels. Elsewhere, however, the burning of biomass is the culprit. In some developing nations, the biomass being burned may be wood or even dried dung, for the purpose of cooking and heating. In other developing nations, forests may be torched for "slash and burn" agriculture, in which areas cleared by fire are fertilized for a few years by the ashes of trees, and used to grow food. Abandoned when the nutrients in the ash are exhausted, farmers move on to burn still more forest. In Africa, the grassland savannas are burned to stimulate regrowth that can be harvested.

The cooking fires take a horrific toll in human health. Children, their lungs and respiratory systems weakened by smoke, die from upper respiratory infections, illnesses that are virtually unknown in developed nations.

Throughout much of the developing world, cooking is done on primitive stoves in small rooms that frequently lack adequate ventilation. In one survey, 60 percent of households used a three-stone hearth or a U-shaped mud-plastered hearth known as a chulha. Only 28 percent of kitchens had chimneys, and only 32 percent had windows for ventilation.

Under these circumstances, exposure to indoor air pollutants is unavoidable.[93] The pollution burden falls most heavily on women, who do most of the cooking, and on infants and children, who spend a great deal of time near their mothers and are highly susceptible to its damages. Acute respiratory infections (ARI) are the single most important cause of mortality in children under age 5,[94] and as indoor burning of biomass increases, so do ARIs. This has been documented generally,[95] as well as in the specific nations of South Africa, Zimbabwe, Nigeria, Tanzania, Gambia, Brazil, Argentina, and Nepal, to name but a few.[96]

Indoor wood smoke is also associated with low birth weight[97] as well as infant mortality.[98]

By one estimate, the number of deaths because of indoor air pollution in India alone is as much as 400,000 per year.[99] Globally, it is estimated to account for two million deaths in developing countries and 4 percent of the world's disease burden.[100]

Evidence also exists of associations with increased infant and perinatal mortality, pulmonary tuberculosis, nasopharyngeal and laryngeal cancer, cataract, and, specifically in respect to the use of coal, with lung cancer.[101]

CONCLUSIONS

It is clear beyond any credible dispute that black carbon in all of its forms and from all sources should be regulated to the point of virtual elimination. Without question black carbon causes widespread death and illness throughout the world, whether the emission sources are motor vehicles, indoor cooking or outdoor burning. Ways of eliminating these emissions exist, and should be deployed.

Because some sources are "natural," such as wildfires, complete elimination is beyond current capabilities. Still, emissions can be reduced from even natural sources. Certainly, anthropogenic emissions can be reduced to virtual zero, and should be based on the health evidence. Maximum technologically achievable reductions should not be a goal, but the standard.

BLACK CARBON'S SOURCES

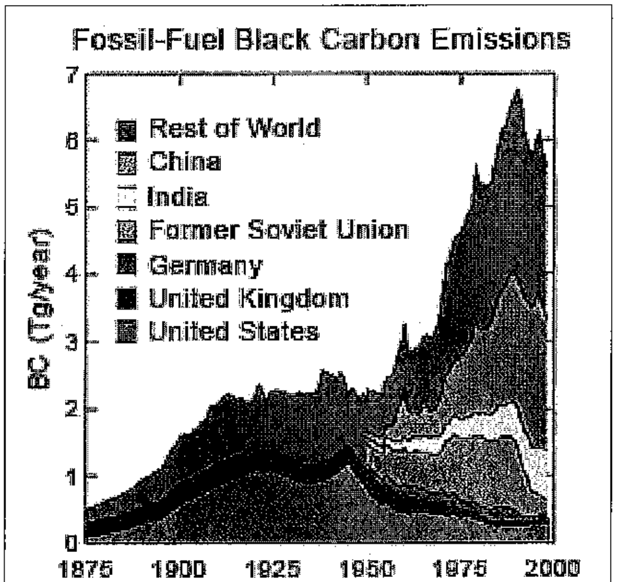
Black carbon, most often referred to as "soot" from diesels, fireplaces and the like, is almost literally everywhere on the planet.[102] It is a product of the incomplete combustion of carbon-containing fuels. These include not only fossil fuels of ancient origin, such as coal and oil, but renewables, such as ethanol and wood. It is burning, specifically a flame, that creates black carbon.[103] If the fuel is burned completely, carbon dioxide, with a lifetime of 100 to 1,000 years is produced. If the fuel is burned incompletely, black carbon, with a lifetime of 4 to 12 days is produced. They are the first and second most potent causes of global warming–but black carbon's life is only one 30,416th of carbon dioxide's.

Visible solar radiation—sunlight to most of us—is absorbed in the atmosphere by particles of black carbon, then re-emitted as infrared energy, resulting in increased heat. It also changes the nature and formation of clouds. When it falls to Earth, black carbon reduces the brightness of snow and ice.

To curb the warming caused by black carbon, two questions must be answered: for any given point, where did the black carbon come from and what created it. If those questions can be answered, it is simple enough to determine how to reduce black carbon in the air or on the snow, and hence, its warming effect.

Thus, for purposes of this review, "sources" of black carbon include both (a) activities or technologies that emit black carbon and (b) geographic areas or regions from which black carbon is transported elsewhere. Neither of these is susceptible to easy analysis, mostly because black carbon is an air pollutant that is regulated indirectly, if at all. For example, some nations and states (e.g., the United States and California) regulate emissions from specific sources, such as diesels and open burning. Others regulate particulate matter, which includes black carbon, but other constituents as well. Still more protect visibility, which can be diminished by black carbon and other fractions of particulate matter. No nation, however, has yet adopted a requirement that directly and explicitly regulates black carbon, whether for the purpose of protecting human health or curbing global warming.

The source of 99.99 percent of all black carbon is incomplete combustion. Although there is considerable public support for switching from fossil fuels to biofuels (e.g., running a car on oil from french fries), that does not *per se* reduce emissions of black carbon. What creates soot is the incomplete combustion of any fuel containing carbon. If a fuel, whether french fry oil or commercial diesel refined from crude pumped from Saudi Arabia, contains carbon and it is burned incompletely, the product will be black carbon.[104] And, because individual particles of black carbon are so fine, they are transported long distances. In one study of black carbon deposited in the snow pack of the Sierra Mountains of California, for example, researchers concluded from the mixture of metals that one-third to one-half probably originated in Asia.[105]



Major contributors to black carbon emissions. Source: Lawrence Berkeley National Laboratory, http://eetdnews.lbl.gov/nl18/eetd-nl18-5-aerosol.html

Developing Nations

In developing nations, most black carbon is emitted from burning coal, wood, dung and other carbon-rich fuels for indoor cooking and heating. In developed nations, most black carbon is emitted by diesel engines. In ships and aircraft, the sources are, respectively, diesels burning bunker fuel[qq] and jets combusting kerosene-like jet fuel.

GLOBAL TRANSPORT TO OTHER REGIONS

Intercontinental transport of air pollution, whether from Asia to North America, North America to Europe or from some other source region to some other target, is a fact of life. How fast clouds of pollution are blown and what they contain depends on a variety of factors, including the pollutant in question (e.g., ozone vs. black carbon), time of year, height, local chemistry, and others. It is beyond question that pollution, and a lot of it, moves from one continent to another. In one case, for example, scientists using three different aircraft were able to track and analyze in detail transport of a plume from Alaska to Europe, sampling it over North America, the North Atlantic and Europe.[106]

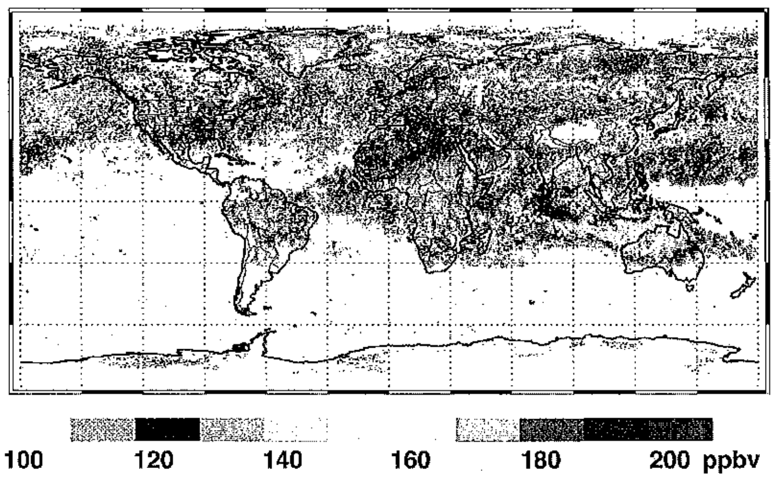


Figure 5 Carbon monoxide is a good surrogate for a number of other pollutants, including black carbon. This November, 2006 shows global levels of carbon monoxide at an altitude of about 3 km, as measured by NASA's Terra satellite. High levels of CO pollution are shown in red. A large plume of pollution from Indonesian fires is clearly visible, as well as CO from fires in northwestern Australia and the South American Amazon and southern Africa. Note the persistent plumes of industrial pollution leaving China and out over the Pacific Ocean. Source: University Corporation for Atmospheric Research, data courtesy of the NCAR and University of Toronto MOPITT teams.

Emissions of black carbon generated by human activity, although distributed globally, are most concentrated in the tropics where solar irradiance is highest. The aerosol mix can form transcontinental plumes of atmospheric brown clouds, with heights of 3 to 5 kilometers (km).

Most of the black carbon transported at high altitudes over the West Coast of the United States in spring comes from Asia. It equals 77 percent of the black carbon emitted into the troposphere, or upper atmosphere, from North America during that season.[rr] Although this may be a small component of air pollution at

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[qq]Bunker fuel is so-named because it is stored in a ship's bunkers. It is the last part of a barrel of oil, so laden with residual contaminants that at room temperature is a solid, and must be heated to become thin enough to burn in an engine.

[rr]Another study found that Southeast Asia produces 15 percent and 10 percent of the world's black carbon and sulfate, and exports over two-thirds of it over the Northern Hemisphere. Koch, D. et. al. Global impacts of aerosols from particular source regions and

land surface levels, at altitudes above two kilometers (7,000 feet) it heats the atmosphere significantly, warming the Pacific Ocean region, which drives much of Earth's climate.[107] Generally, black carbon stays in the air about 5 days, but at higher altitudes, this can be longer.[108]

How and where black carbon is transported is a function of the time of the year and the height of the transport, as well as other factors.

GLOBAL AND NATIONAL INVENTORIES

Several "top-down" and "bottom-up" global emission inventories have been constructed for black carbon. While probably accurate, they are imprecise. Recent estimates of global emissions of black carbon (BC) and organic carbon (OC) range from 8 to 24 terragrams (Tg) and 33 to 62 Tg per year, respectively. Thus, uncertainty is the hallmark of these studies, with emission estimates varying by a factor of 2 or more.[109]

At the national level, the U.S. National Emissions Inventory is well documented, but major source categories of the pollutants reported do not conform to emitters of BC and OC. Similarly, although California's bottom-up emission inventory appears to be easily manipulated to reveal sources of black and organic carbon (for example, by using a proportion of fine particulate matter as a surrogate for carbon), in the final analysis that fails.[110]

Initially, regrouping produces a California BC inventory of 38,731 tg/year, which is comparable to a bottom-up global BC inventory. But closer comparison reveals substantial differences in the amounts of pollution attributed to pollution subcategories. For example, the global inventory estimate of emissions in California from biomass burning (e.g., of wheat or rice straw, slash from lumbering) was more than twice that of the California inventory.[111]

Thus, although inventories of black carbon exist, they tend to be relatively recent and lacking in detail. Perhaps the world's premier expert on sources of black carbon is Dr. Tami Bond of the University of Illinois, Urbana Champaign. In Congressional testimony, she estimated the sources of black carbon emissions as follows:

- 42 percent open biomass burning (e.g., forests in Brazil and savannas in Africa);
- 24 percent residential:18 percent biofuel burned with traditional technologies; 6 percent residential coal burned with traditional technologies.
- 24 percent diesel engines:14 percent for transportation; 10 percent diesels for non-transportation (e.g., industrial applications, construction).
- 10 percent industrial processes and power generation, usually from smaller boilers.

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sectors. J. Geo. Res., VOL. 112, D02205, 24 PP., 2007 doi:10.1029/2005JD007024

Reducing emissions from open burning requires changes in behaviors and attitudes—for example, collecting and utilizing field, crop, lumber and other wastes rather than burning it in place. For the remaining 58 percent of emissions, there are technologies and practices that can cost-effectively cut emissions by 90 or more percent. Some of these, such as vessel efficiency improvements, actually save money. Others require expenditures, but the benefits vastly outweigh costs.[ss]

Thus, whether the sources of black carbon are on-road or off-road diesels, opening burning, or cooking, ways of sharply reducing, or even eliminating emissions altogether, exist. Most of these options have other benefits: they save money, for example. Or, in the case of stoves that allow cooking with vastly less pollution, they reduce fuel consumption by, say, 70 percent. This means that women—on whom the burden of collecting twigs, branches, or even dried dung, falls—do so less often, which in turn decreases their exposure to rape and murder.

Black carbon, most often referred to as "soot" from diesels, fireplaces and the like, is almost literally everywhere on the planet,[112] even though it is not a naturally occurring pollutant. It did not exist in the oceans where life began, and it existed on land only when natural fires, e.g., from lightening strikes, happened.[tt]

When anthropogenic control of fire started is unclear, and may have varied from region to region. One reconstruction of the grassland fire record in Manitoba, Canada dates its beginning at 5,000 years before present (bp), with an apparent peak about 2,500 years bp. This was most likely deliberate burning of grassland by hunter-gatherers.[113] Another study places the onset of slash-and-burn agriculture at roughly 7,000 years ago.[114] In other environments, the beginning of controlled burning by humans is placed at about 40,000 years ago.[115]

Whenever humans began to engage in controlled burning, the elapsed time has been too little for evolved resistance to develop.[116] Circumstantial evidence of the absence of an evolved

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[ss]The U.S. Environmental Protection Agency estimates that the benefits of its new regulations for the largest ship engines (class C3) and fuel will outweigh the costs by at least 30 to 1. The benefits include annually preventing between 12,000 and 31,000 premature deaths, 1,500,000 work days lost, and 9,600,000 minor restricted activity days, which the agency values at between $99 billion and $270 billion annually. U.S. EPA, "Regulatory Announcement: EPA Proposal for Control of Emissions from New Marine Compression-Ignition Engines at or Above 30 Liters Per Cylinder," June 2009, at http://www.epa.gov/otaq/regs/ nonroad/marine/ci/420f09029.htm#4.

[tt] It is thought that there would have been 3 lightening strikes per square kilometer per year in temperate environments. A.J. Parker, Fire in the Sierra Nevada forests: evaluating the ecological impact of burning by native Americans, in: T.R. Vale (Ed.), *Fire, native peoples and the natural landscape*, Island Press, Washington, Colvelo, London, 2002, pp. 233–267.

defense is the complete absence of a mechanism for protecting against black carbon and other ultrafine particles. They easily penetrate the usual defenses against airborne threats, reach the blood-air barrier, and pass through it to enter the circulatory and nervous systems.[117]

If there were an evolved resistance to black carbon in humans, their respiratory system should differ from those of non-human primates, who do not cook over fire or use it as a tool. Yet the system of humans and non-human primates are so alike that monkeys, chimpanzees are their brethren are said to be "the ideal system for answering questions in lung development."[118] Even though the respiratory systems of non-human primates would have evolved in the absence of exposure to black carbon, they also lack defense mechanisms, suggesting that the lungs of today's humans are essentially unchanged from those of pre-history. That is, they continue to possess no evolved resistance to black carbon.[119]

Similarly, just as specific life forms evolved on a planet largely free of black carbon, so, too, did life generally. The conditions of an Earth in which black carbon is ubiquitous and another in which it is essentially absent, are dramatically different. Temperatures differ, as do the presence or absence of snowy and icy conditions. Clouds form and dissipate differently, rain and snowfalls change and, with them, global, regional and other climates. Life on Earth, in short, evolved in the absence of black carbon, but must today survive in its presence.

These extraordinary circumstances set black carbon apart from virtually all of the other common pollutants. Ozone, for example, occurs naturally[120] and, not surprisingly, there appears to be a threshold at or near to this natural background below which there seem to be no adverse health effects.[121] The uniqueness of black carbon makes extreme caution essential in determining how to regulate emissions.

Adverse Health Effects of Black Carbon

To assess the health effects of black carbon as a discrete air pollutant requires that several bodies of literature be critically examined, as follows:

As a particle. Because black carbon is a particle, the literature on health effects of particles must be reviewed.

As a fine or ultrafine particle. Because the particles of black carbon are most often found in the fine or ultrafine modes, the literature of the health effects of these must be examined.

As a tailpipe pollutant. Because the major source of black carbon particles in developed nations is from vehicular emissions, literature on these, as well as that associating morbidity or mortality with proximity to traffic, must be reviewed.

As a product of burning either gasoline or diesel fuels. Because both gasoline spark-ignited engines and diesel compression-ignited engines emit black carbon, the health effects of one from the other must be disentangled and associated with specific adverse impacts, if any.

As a product of house burning of biomass. Because major sources of black carbon, especially in the developing world, are from combustion of wood, dried dung and other biomass that is not of fossil origin for heating and cooking, impacts—especially on children and women, the two most highly exposed populations—must be examined.

As a product of burning of wood, crop residues, or forests. Because the other major sources of black carbon are wildfires, fireplaces and prescribed burning, the nature of these particles must be distinguished from those of burning fossil fuels, and the adverse effects identified.

As a function of black carbon in its own right. Finally, an attempt must be made to ascribe adverse health effects of black carbon in its own right, as opposed those that might be due to its size or other characteristics.

SAVING LIVES BY REDUCING BLACK CARBON FROM INDOOR BURNING

According to the World Health Organization, more than half of the world's population rely on wood, crop waste, dried dung or coal to cook or heat, often on open fires or stoves without chimneys, producing prodigious amounts of soot, or black carbon. This kills roughly 1.6 million persons a year, a death every 20 seconds.[122]

This rocket kisasa, or cook stove, was made from local mud, sawdust and red clay in Kenya. GTZ, the German government's foreign aid agency, gave 300 away free, because local residents could not afford the cost of about $14 USD. Source: United Nations Development Program.

In sub-Saharan Africa, 94 percent of the rural population and 73 percent of the urban population, use wood, charcoal, crop residues, animal dung and coal as their main source of energy for cooking and heating. In the year 2000, researchers estimated that 350,000 sub-Saharan African children died of lower respiratory infections, and 34,000 adult women died of chronic obstructive pulmonary disease attributable to indoor air pollution caused by burning biomass.[123]

In India, research has linked indoor burning of solid fuels use to increased death in children aged 1 to 4 and non-fatal pneumonia. The use of solid fuel was very common: 87 percent in households with child deaths and 77 percent in households with living children. It was the cause of 6 percent of all deaths at ages 0–4 and 20 percent of deaths at ages 1–4, or about 128,000.[124] Earlier estimates had placed the number of deaths in India due to indoor black carbon at 400,000 to 550,000, or 4 to 6 percent of India's total annual mortality.[125]

In China, indoor burning is estimated to account for 20 percent of total mortality.[126] **In Africa**, more than a half-billion people, about 78 percent of the total population, cook with solid fuels, killing about 391,000 per year. **In the Americas**, 20 percent of the population, more than 170 million people rely on wood, dung and other solid fuels, accounting for about 21,000 deaths in 2000. **In the eastern Mediterranean**, about 42 percent of the population, or about 200 million people cook or heat with solid fuel, resulting in 118,000 deaths in 2000. In Europe, 160 million rely on solid fuels, which is about 19 percent of the population. This results in about 21,000 deaths a year, but the disease burden is low there compared to other regions of the world, mostly because most stoves have stove pipes. **In Southeast Asia**, about 1.2 billion, 78 percent of the people, rely on solid fuels. Deaths in 2000 were estimated as 374,000 children under the age of 5, as well as another 185,000 adults. **In the western Pacific**, 1.2 billion people, about 71 percent of the population, use solid fuels. This killed about 441,000 people, 62,000 of them children.[127]

There are a variety of ways to reduce either the emissions from indoor use of solid fuels or exposures to them. The simplest alternative in many places (e.g., China) would be to simply eliminate the use of certain kinds of coal. Substituting anthracite for medium volatility bituminous coal, for example, reduced emissions of black and organic carbon by 50 and 30 percent, respectively.[128, uu] Emissions from burning of crop residues can also vary, depending on factors such as fuel moisture and combustion efficiency.[129]

BLACK CARBON CONTROLS

Pre-Treating Biofuel

One option is to either switch fuels or "pre-treat" them by, for example, converting wood to charcoal for cooking or heating. Because charcoal burns more cleanly and produces less indoor pollution than wood, between 1 and 2.8 million deaths might be avoided by burning it. Researchers who advocate this approach concede that current production methods in Africa are heavily polluting and potentially destructive of the continent's forests and that other fuels would be even less polluting than charcoal. However, they argue, disseminating

IN NEED OF PROTECTION

Mtabila, Tanzania: "When the afternoon sun begins to sink in Mtabila, the women get ready for their daily trip to the forest. They go to collect firewood to fuel their small cooking pits. They go at night when the 15-kilometer trek is cooler. They go in groups, in the hope it may keep them safer: At least seven women from the camps in this area have been raped while collecting wood in the past three months."

Carinne Meyer, "In Need of Protection: Addressing Sexual Assault against Women and Girls Associated with the Collection of Firewood in Refugee Camps in Sub Sahara Africa," Oct. 2005, Columbia University, Mailman School of Public Health, Program on Forced Migration and Health.

[uu] By strict definition the difference between anthracite and bituminous coal is determined by fixed carbon content. Bituminous coal contains less than 86 percent fixed carbon and an appreciable percentage of volatile hydrocarbons. Anthracite contains 86 percent or more fixed carbon and a very low percentage of volatile hydrocarbons. They have a very similar average heat value of about 14,500 to 15,750 BTUs-per-pound. Pennsylvania Topographic & Geologic Survey, http://www.dcnr.state.pa.us/info/dcnrfaq/topogeofaq.aspx#top, accessed Nov. 3, 2010.

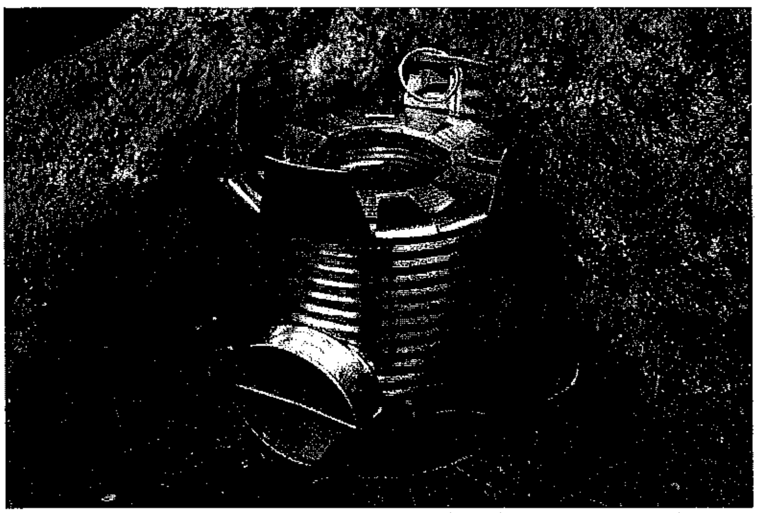
charcoal in large scale is more appropriate, because there is a well developed market and no need for an expensive infrastructure of refineries and pipelines.[130]

Ideally, households could switch to cleaner fuels such as electricity, kerosene or gas. In the real world, however, this is not a realistic option because of the high costs of equipment. In Kenya, for example, a gas stove and tank costs $30 to $50, while a charcoal stove costs one-tenth as much, $3 to $5.

Improved Stoves and Ventilation

Of course, reducing exposure by venting smoke to the outside will save lives and avoid sickness, but do little for minimizing global and other warming and melting caused by black carbon. However, if the chimney is part of an improved stove, fuel consumption—and hence black carbon emissions—can drop sharply. In a pilot study that was a collaboration between the World Bank and the University of California, Berkeley, improved stoves were distributed to homes in Mongolia and China. The stoves reduced coal use by 21 to 42 percent and wood/biomass by 12 to 51 percent.[131]

There is widespread agreement that the best solution would be global distribution and use of new versions of cookstoves, which use less fuel while reducing pollution by one half or more. There are a wide variety of such stoves, but an astonishingly small number have been distributed considering the magnitude of the health and environmental damages that open burning causes. A recently announced program aimed at distributing 100 million stoves by 2020 would be the largest in history, but even it falls far short of the need.



The "rocketstove," a portable twig powered cooking stove, is made from 100 percent reused tin cans and is "perfect for hiking and camping!" according to its seller. The stove is 7 inches high, by 6 inches wide and weighs 14oz. Source: http://rocketstoves.org/

Public-Private effort

The United States- and United Nations-backed effort would use $50 million from the U.S. and $10 million from each of the other partners to provide seed money to a new Global Alliance for Clean Cookstoves. The public-private initiative intends to provide 100 million homes "clean and efficient stoves and fuels by 2020."[132]

Stoves compared

The potential of stoves to reduce emissions was demonstrated in side-by-side comparisons of various ways of burning fuel.[133] Six cooking stoves were analyzed: a three-stone fire, a rocket stove, a fan stove, a gasifier stove, a charcoal stove, and a rice-hull burning stove. (Because of a shortage of rice hulls, particle emissions from this stove were not measured, though 5,000 of them are in use in the Phillipines.)

The fan stove was clearly superior, followed in most cases by the rocket stove. "When fuel was harvested sustainably the rocket stove produced 41 percent of the warming potential of the three stone fire, the gasifier 29 percent, and the fan stove a remarkable 4 percent." The burning of charcoal produced 61 percent more warming emissions than the three stone fire, not counting the energy loss or emissions made when making the charcoal.[134]

Clearly, there are many options available for reducing emissions from the open burning of solid fuel, ranging from switching coal types to using newer, more efficient stoves. All are cost effective, with stoves costing on the order of $10–$15 and many other alternatives costing zero. The question is not whether options to reduce pollution, save lives and slow warming exist, but why they are not being aggressively deployed.

TORCHING FORESTS AND SAVANNAS ("OPEN BIOMASS BURNING")

Burning creates smoke, some of which warms and some of which cools. Beyond that, it becomes difficult to predict precisely what happens when forests and savannas burn.

Smoke properties vary between fires depending on fuel type and moisture, combustion phase, wind conditions, and several other variables. Also, the physical, chemical, and optical properties of biomass-burning aerosols can change rapidly as they disperse, so it is difficult to relate the properties of individual fires to the ensemble smoky hazes that affect the atmosphere's radiative balance.[135]

Types of Open Burning

There is a tendency to place all intentional burning into a single basket, thus confusing a variety of different practices, including the following:

- Throughout much of the United States and other regions where crops, including trees, are harvested, burning is a convenient form of ***waste disposal.***
- In some parts of the world, especially Africa, fire is used extensively as a ***land management tool*** by indigenous people.[136]
- In still other regions, especially in the Amazon of South America, ***"slash and burn"*** consists of clearing plots in the forest (slashing), allowing vegetation to dry, then burning

so the ash fertilizes the soil enough for a few years of crops. The land is then abandoned. According to some estimates, slash and burn is practiced by 240 to 500 million people on nearly one-half of the land area of the tropics.[137]

- Finally, in still other regions, forest burning can be either ***accidental or intentional*** and illegal, for the purpose of facilitating the harvesting of trees. In Indonesia, as much as 50 million cubic meters of timber are estimated to be illegally cut, while at least one-fifth of Russia's annual timber harvest is taken illegally, and illegal harvesting may account for as much as 50 percent of the total in east Asia. In Cambodia in 1997, the volume of illegally harvested logs was ten times that of the legal harvest.[138]

REDUCING OPEN BURNING

While it is unlikely that open burning could be eliminated as a source of black carbon, it can be substantially reduced with a variety of practices and technologies, including the following:

- ***Substitute waste collection for burning***, followed by, for example, gasification. Major field crop waste streams include corn stover (leaves and stalks), grain sorghum residues and wheat straw, to name but a few. The technologies for burning, gasifying or otherwise generating useful heat and electricity are all commercially available: anaerobic digesters, fluidized bed boilers, fixed bed boilers, co-firing, modular direct combustion technology and pyrolysis. By one estimate, Texas alone could generate 418.9 megawatts of electricity from agricultural wastes.[139]

- Nearly all wildfires are extinguished when they are still small. The 3 to 5 percent that get out of control cause 95 percent of all wildfire-related costs and damages. Monetary losses can be immense: during the record-breaking heatwave of 2010, Russia lost forests with an economic value of at least $300 billion in the ensuing wildfires.[140] ***Prescribed burning*** can decrease the probability of large, severe wildfires. Prescribed burning has reduced the average size of wildfires in ponderosa pine in Arizona, and effectively reduced the number, size, and intensity of wildfires in the southeast.[141]

DIESEL ENGINES

SUMMARY

Diesel engines—strong and relatively fuel efficient, flexible in applications, easy to maintain—are usually the power plant of choice for heavy-duty applications. Diesels are so rugged that it is not uncommon for an engine to last 15–20 years and achieve a one million-mile life.[142] They are thus both a curse and blessing of current technology.

A DeutscheBahn locomotive equipped with a diesel particulate trap.

However, whether used on the road or off, in trucks, locomotives, ships or anything else, diesels are major sources of air pollution, especially black carbon, or soot, as well as oxides of nitrogen (NO_X), hydrocarbons (HC), and carbon monoxide (CO). The International Agency for Research on Cancer classifies diesel soot as a "probable" cause of cancer in humans;[143] the National Toxicology Programs, which evaluates substances that cause cancer, in 2005 classified diesel soot as a "reasonably anticipated" cause of human cancer;[144] and, the California Air Resources Board has listed diesel soot as a toxic air contaminant based on its potential to cause cancer, premature death, and other health damage.[145]

Parsing the regulations applicable to diesel engines is complicated. Engines can be sorted on the basis of age (new, existing and existing rebuilt); use (on-road, off-road, locomotive, marine), size (3,000 to 100,000 horsepower, smaller than 3,000). For purposes of this review, however, what is most important is which diesels remain essentially unregulated, because they contribute the most to pollution, specifically black carbon.

Emission standards for diesel engines have long lacked the stringency of those for gasoline engines. As a practical matter, while limits for over-the-road trucks are emerging, there are no controls on cargo and other ships, very limited controls on locomotives, and barely emerging controls for off-road diesels, such as tractors, bulldozers and other heavy equipment. This lack of regulation prevails despite the fact that emissions from diesels could be sharply and quickly reduced through a combination of add-on controls and efficiency measures. Adopting controls for these engines is arguably the largest piece of low-hanging fruit in air pollution history.

That said, there are major barriers to adopting controls. The number of jurisdictions involved is dizzying. Ships, for example, are potentially subject to international, national, state and multiple local controls. Not surprisingly, the result is not conflicting, overlapping or a duplicative requirement, but instead virtually no regulation whatsoever. Ships burn the dirtiest of all fuels with no pollution controls. Locomotives are essentially uncontrolled and so are older trucks and most non-road farm, industrial and commercial engines. True, there are supposedly regulations for most of the engines on the book, but close examination reveals that these are illusory.

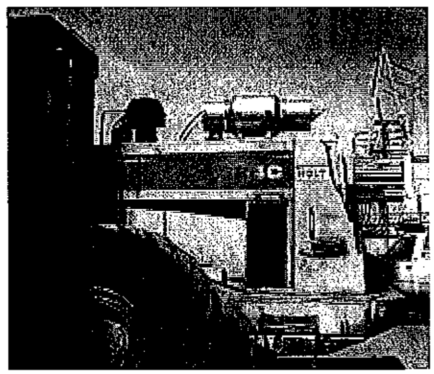
The sources of diesel soot emissions generally fall into two camps: on-road and off-road.

ON-ROAD DIESELS

On-road sources include automobiles, motorcycles, trucks, and buses. Of these, the largest emitters of black carbon, or soot, are diesels, especially in developed nations; and, small two-stroke engines of the sort found on motorcycles, especially in developing nations. In developed and developing nations alike, so-called "super emitters,"[vv] vehicles that are badly out of tune or otherwise operating improperly, are also major sources of soot. Fortunately, emissions can be reduced substantially from each of these categories.

OFF-ROAD DIESELS

Off-road sources include diesel engines in farm tractors, locomotives, cargo and other ships, generators and construction equipment. Non-road sources of black carbon also include stoves and open fires, wildfires, and prescribed burns.



According to CleanAIR, a subsidiary of Caterpillar, its diesel particulate filters reduce black carbon by greater than 85 percent and hydrocarbons and carbon monoxide up to 95 percent. Source: CleanAIR.

MARINE DIESEL ENGINES

Marine engines—extremely large two-stroke or four stroke engines that burn "bunker" fuel, which is so viscous that it is solid at room temperature—are sometimes said to be a special case. In fact, their engines, some of them large enough to produce electricity for a small town, largely operate at a constant speed, making them inherently easier to control than, say, 18-wheel trucks. They operate virtually free of

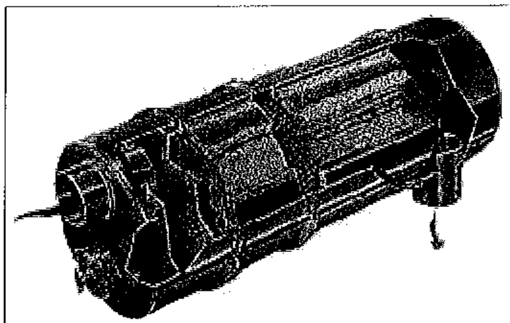
[vv]"Super emitting" passenger vehicles in California, for example, constitute only about 10 percent of the fleet but represent almost half of the emissions of carbon monoxide and VOC's and about 90 percent of the particulate emissions from passenger cars. Winer, A. Air Quality in Southern California—Time for a Paradigm Shift. *The State of the Region*, Southern California Council of Governments, 2004, http://www.scag.ca.gov/publications/pdf/2004/SOTR04_WinerEssay.pdf, accessed Nov. 1, 2010.

emission controls, while on-shore power plants are subject to permit, monitoring, record keeping and enforcement penalties. Marine vessel engines are remarkably well designed, remain in service for decades and burn the cheapest, lowest quality fuel available. While these are great advantages from the perspective of a ship owner or operator, an uncontrolled engine burning low quality fuel for decades is an air pollution nightmare locally, regionally and globally. Limits on air pollution are miserably inadequate, and for no good reason since the technologies and practices to easily halve emissions are, and have been, widely available.

Because of the complex regulatory regimes that apply to diesels, the international, national, state and local controls adopted are described and discussed in Appendix A.

THE DISCREPANCY BETWEEN NEW AND EXISTING DIESEL ENGINES

Trap Oxidizers



A "continuously regenerating trap," or CRT, of the sort made by several companies. Source: kankyo.metro.tokyo.jp

Emissions of soot and other constituents of diesel exhaust can be reduced by 90 percent or more by the installation of add-on pollution control devices that trap the soot, then destroy it, usually by burning. Diesel trucks are large polluters, which virtually every driver knows from personal experience. But the pollution from locomotives, ships, bulldozers, farm tractors and many other sources is immense. Their emissions are largely out-of-sight so for most people they are also out-of-mind. But they shouldn't be: the U.S. Environmental Protection Agency estimates that by 2030, without new emission controls, locomotive and marine diesel engines will contribute about 27 percent of the national mobile source of NO_X and 45 percent of the national mobile source of fine diesel particulate matter ($PM_{2.5}$).

Importance of Low-Sulfur Fuel

The prerequisite to requiring stringent emission controls on diesel engines is low-sulfur fuel. This is already available for over-the-road trucks and diesels used in non-road applications (e.g., bulldozers). Starting in mid-2012, the sulfur limit of diesel fuel used by locomotives and marine diesel engines will be limited to 15 ppm.[146] This requirement was adopted in May, 2004 for the specific purpose of facilitating the installation of pollution controls, which EPA estimated prevents 12,000 premature deaths, 8,900 hospitalizations, and one million work days lost each year, starting in 2030.[147]

Reducing Emissions from Existing Diesel Engines

Reducing emissions from new engines, however, is of limited effect because diesels are so rugged that they can last for decades. To reduce emissions from older diesels requires engine modifications, retrofit pollution control systems or other measures. To encourage these, the U.S. Environmental Protection Agency has launched the National Clean Diesel Campaign (NCDC), which reviews and tests emission reductions from various technologies.[148]

An estimated 85 percent of ship traffic occurs in the northern hemisphere and 70 percent of that is within 400 kilometers from land. The number, size and power of cargo ships is increasing. Their cargo is projected to double or triple in some areas by 2020. The international marine transport of goods is about 90 percent of global trade.[149]

The United States has about 133 ports that are capable of handling vessels of 10,000 dead weight tons (DWT) or greater. The ports of Los Angeles and Long Beach combine to form the world's third largest port complex in the world, behind only Hong Kong and Singapore. Their 2003 container volumes were 6.61 million and 4.66 million tons, respectively. The rest of the top five U.S. ports, by both vessel calls and capacity, are the ports of Houston, New York, New Orleans, and San Francisco.[150]

While at sea, cargo ships are most often beyond the jurisdiction of U.S. authorities. At the beginning of 2005, some 14,480 merchant vessels representing approximately 65 percent of the world's total shipping tonnage were flagged, not by the home nation of the vessel owner but under foreign flag. This share of the world shipping tonnage is up from about 62 percent in 2001 and for each major vessel type the general trend is increasing towards foreign flagged vessels.[151]

Even ships owned by U.S. entities are typically beyond the reach of local or national authorities. In 2005, the United States ship owners had 31 percent of their foreign flagged tonnage registered with the Marshall Islands and 35 percent with the Bahamas.[152]

Of the particles emitted by diesels, virtually all is 10 microns or less in diameter (PM_{10}), and about 94 percent of the mass of these particles from marine engines are less than 2.5 microns ($PM_{2.5}$) in diameter. In 1996, diesel marine engines accounted for 6 percent of the total mobile source particulate matter, and were expected to grow to 25 percent by 2030.

Whether the source of soot emissions in and around ports is ships, trucks or trains, it is virtually certain that far less is being done to reduce them than is feasible. Ships essentially have no controls, locomotives have none either, as a practical matter, and trucks, while in theory subject to regulation, are in all likelihood exempted from some or all controls because of their age.

Containers at the Port of Los Angeles. About 40 percent of U.S. imports pass through it and the adjacent Port of Long Beach. Source: LADWP.

Ports

In ports, ships together with the trains and over-the-road trucks that service them are usually the largest aggregate sources of air pollution. At the Ports of Long Beach and Los Angeles, there were 22,466 truck trips per day in one study. Roughly 56 percent of the trips were by trucks in model years 1993 through 1998.[153] The two ports handle more than 40 percent of the nation's total import traffic and 24 percent of its total exports.

A new and substantially more stringent emission standard for emissions of soot from "18-wheelers"[ww] of 0.01 grams per brake-horsepower hour (g/bhp-hr), a 90 percent reduction compared to the previous 1994 standard of 0.10 g/bhp-hr.[154]

Most of the goods that leave Southern California are transported by rail. In the last four years, the Alameda Corridor saw a 106 percent increase in cargo; double the ports' growth during that time. In 2007, the Alameda Corridor carried 19,924 trains, an average of 55 trains per day; a 15 percent increase over the number of trains that used the corridor in 2005.[155] Although locomotives[xx] are subject to emissions standards, they are much less stringent.[156]

In 2008, an engineering team from the University of Delaware reviewed the technologies and measures available for reducing vessel emissions from the fleet in service.[157] The "opportunities" identified could apply equally well to locomotives, farm tractors, bulldozers and other non-road diesel engines, and fell into five principal categories.

• **Technological:** engine optimization, process modification, and after-treatment technologies (e.g., particulate traps).[yy]

[ww]In the jargon of air pollution control, these are referred to as Heavy Heavy Duty Trucks.

[xx] **LOCOMOTIVE EMISSION STANDARDS**

TIER	DATE	STANDARD
0	2010	.22 g/bhp-hr
1	2010	.22 g/bhp-hr
2	2010	.10 g/bhp-hr
3	2012	.10 g/bhp-hr
4	2015	.03 g/bhp-hr

Source: U.S.E.P.A.

[yy]Engine optimization involves in-engine control (e.g., combustion time, compression ratio, valve timing) to optimize fuel economy. Engine modifications include exhaust gas recirculation; injection of water, urea or ammonia, and, electronic valve control. After-treatment technologies reduce emissions in exhaust gases. A wide variety of these is available, but far and

• **Operational:** changes in vessel design, propellers, maintenance, or propulsion can boost fuel economy, reducing emissions.[zz] "Cold-ironing," or the use of shore-based electricity in port allows on board engines to be turned off [thus leaving them as "cold iron]." Another operational measure is to simply reduce speed: for example, a 10 percent reduction in speed can cut emissions by ~23 percent.

• **Fuel switching:** substituting alternative fuels, ranging from other petroleum-based options to wind, to replace "bunker fuel" can reduce emissions considerably.

• **Intermodal shifting:** Shipping transportation is comparable to rail on a pollution-per ton-kilometer (t/km) basis and is typically less polluting than air and truck transportation. However, not all ships are created equally, nor are their routes. In specific cases, one of the competing types of transport might be better.

• **Demand management:** the current trade system emphasizing "just-in-time" delivery of cargo, which places a premium on speed from shipper to receiver, increasing the frequency of trips. Although, there is a tendency to view decreasing emissions as constraining trade growth. However, Japan and Germany, both large exporting economies, have focused on this connection and may have successfully decoupled transport emissions and economic activity.[aaa]

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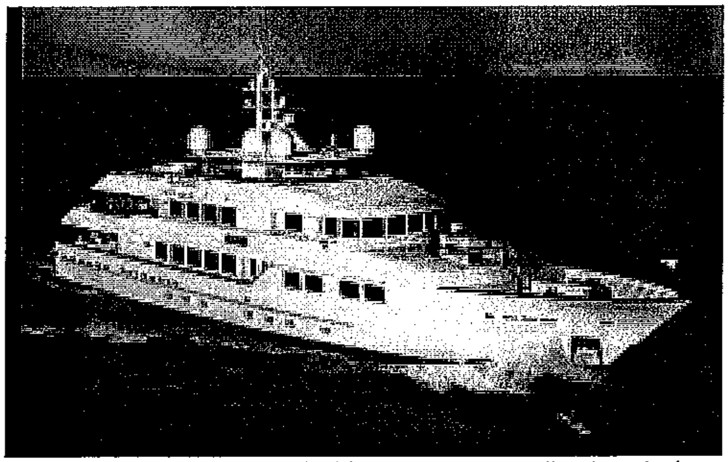
away the most effective at reducing black carbon emissions are diesel particulate filters, either coated with a catalyst or not, cutting emissions by 95 to 99.9 percent by mass and 70–95 percent by number.

[zz] Modifications to vessel and propeller design can reduce fuel consumption and, hence, emissions. These could include: hull optimization (e.g., use of a stern flap which lengthens the bottom surface of a hull; replacement of flat bottom hull surface with air cavity system), propeller system improvements, propeller coatings, and a bulbous bow. Hull and propeller maintenance also increases fuel efficiency.

[aaa]In Japan, Transport emissions have been decreasing since 2001 despite sustained economic growth due to increased load factors, reduced congestion and other changes. In Germany, Japan and France, transport emissions of carbon dioxide have declined 1.7, 7.9 and 3.2 percent, respectively, between 2002 and 2005. OECD-International Transport Forum Greenhouse Gas Reduction Strategies in the Transport Sector: Preliminary Report; 2008.

Diesel particle filters are exceptionally effective devices for eliminating black carbon emissions. Particle loading decreases by more than two orders of magnitude when after-treatment is deployed.[158] Because diesel particulate filters (sometimes called traps) are long-lasting and reliable, they are the control option of choice for many. However, they are by no means the only way of reducing emissions of soot (see above).



Diesel-engined boat equipped with a MARINE-X® diesel particulate filter. According to the company, it will "operate for thousands of hours with only minimal maintenance." http://www.dcl-inc.com/marine-new-

Whatever means is chosen, however, reducing the amount of sulfur in diesel fuel is often the gateway action. Indeed, for older engines, simply reducing fuel sulfur from 3000 ppm to 500 ppm gives large reductions in PM emissions, though not enough to satisfy current standards.[159]

Partially in anticipation of tightening the soot emission standard for diesels in the future, in January 2001 and in June 2004, EPA issued final regulations requiring the use of ultralow sulfur diesel fuels to be used in newer on- and off-road diesel vehicles.[160,bbb]

TWO-CYCLE ENGINES

In the cities of the developing world, from Ahmedabad to Zanzibar, motorbikes, tuk-tuks and other forms of transport powered by the peppy, fuel efficient two-stroke engines fill the air with their high pitched buzz—and air pollution. The reason:

> The most easily affordable motorized mode in India is two-wheeled motor (M2W) vehicles—scooters, motorcycles and mopeds. M2W vehicles are accessible round-

[bbb]At the time the rule was issued, diesel fuel contains about 3,000 parts per million (ppm) sulfur. The new rule cut that to 500 ppm in 2007 and 15 ppm by 2010. Diesel fuel intended for locomotive, marine and non-road engines and equipment is required to meet a maximum specification of 500 ppm sulfur in 2007. Beginning in 2012, locomotive and marine diesel fuel must meet the ULSD fuel standard of 15 ppm sulfur. In June 2010, the ULSD fuel standard of 15 ppm sulfur was applied to non-road diesel fuel production. The new low sulfur standards allow for effective use of particulate filters in diesel vehicles. Particulate matter limits for on-road diesel vehicles went into effect by the 2007 model year.

the-clock, offer reliable door-to-door service, require little parking space, can be parked securely inside the home, and can carry passengers as well as luggage.[ccc]

Despite these advantages, many nations are quickly moving away from the historic engine for two- and three-wheelers, the two-stroke, and toward more modern, fuel efficient and less polluting four-stroke motors. In China and India, for example, technology has largely shifted from the highly emitting 2-stroke engines to cleaner 4-stroke engines.[161] The reason for this is air pollution. In head-to-head testing of a motorcycle with a conventional two-stroke engine equipped with a carburetor compared to four-stroke engines, the two-cycle emissions were up 8 times those of the four-cycle.[162] In another test, a two-cycle motorcycle's particle emissions (both mass and particle number) were greater than those of a diesel car.[163]

> **The Loud and Dirty Mosquito Fleets**
>
> In areas where two-cycle engines are widely used, they account for much of the air pollution. For example, levels of particulate pollution, including black carbon, in West Africa are comparable to those measured in European and Asian megacities. The pollution is mostly from road traffic, with a substantial contribution from two-wheeled, two-stroke engines. In Dhaka, the capital of Bangladesh, two-cycle engines were banned and particle concentration immediately dropped.

Two-stroke engine vehicles constitute a major share of the motor vehicle fleet in Asian countries. In South Asia, for example, the vehicles account for about 60 percent of the motor vehicle fleet and contribute significantly to air pollution. Particle emissions from a typical 2-stroke engine used in South Asia are an order of magnitude higher compared to a 4-stroke engine of equivalent size.[164] There are a number of reasons for this—poor vehicle maintenance, misuse of lubricants, and adulteration of gasoline, for example—but the core problem is simply that as they have historically been manufactured and fueled, two-stroke engines produce clouds of pollution.

In areas where two-cycle engines are widely used, they account for much of the air pollution. For example, levels of particulate pollution, including black carbon, in West Africa are comparable to those measured in European and Asian megacities. The pollution is mostly from road traffic, with a substantial contribution from two-wheeled, two-stroke engines,[165] which are widely used. Two-wheel taxis, locally termed "zemidjans", first appeared in Benin during the late 1980's and have since been largely adopted in neighboring countries Nigeria, Togo and Niger. These"zemidjans" emit large amounts of carbonaceous particles, partly due to the very poor quality fuel used.[166]

[ccc]Narayan V. Iyer, N.V. &, Madhav G. Badami, M.G. Two-wheeled motor vehicle technology in India: Evolution, prospects and issues. *Energy Policy* 35 (2007) 4319–4331.

Two-cycle "tuk-tuks" and motorcycles are are so polluting that in some areas they have been banned in favor of four-stroke engines.

In some areas, governments have taken decisive action. In Dhaka, the capital of Bangladesh, two-cycle engines were banned and particle concentration immediately dropped.[167] Sri Lanka also banned two-cycle engines,[168] as did Shanghai in 1996.[169]

Motorcycle production has also grown rapidly, especially in Asia. China has now become the worlds largest producer by far, building over 10 million motorcycles per year, more than half the world's annual total.[170]

SHIPS AND GLOBAL WARMING

Most ocean-going ships operate without any pollution controls at all. New and re-manufactured engines on tug boats, ferries, and other smaller ships are subject to emission controls beginning in 2008 and 2009, but most existing engines in vessels of these types remain uncontrolled.

The average fuel used by oceangoing ships contains 27,000 parts per million (ppm) sulfur, for example—*roughly 2,000 times as much as would be allowed in trucks operating on U.S. roads.*

The world's governments have arguably done a half-decent job of protect human health from the near-shore emissions from ships and from ports. What is, and has been, lacking is much attention to pollution that causes global warming.

For example, emissions of the second greatest cause of global warming, black carbon, increases 3 to 6 times at very low engine loads, while absolute BC emissions (per nautical mile of travel) also increase up to 100 percent depending on engine load, which are the two most effective ways to reduce carbon dioxide from ships.[171]

Oceangoing vessels are also among the largest sources of nitrogen oxides (NO_X) in the area, emitting more of this smog-forming pollutant than, for example, all power plants and refineries in the South Coast air basin combined (which includes Los Angeles).

Seventy percent of the area's emissions of sulfur dioxide (SO_2) come from ships. These emissions need to be cut by over 90 percent to attain the national air quality standard for particulate matter. Particulates from marine vessels also create significant cancer risks; more than 700 premature deaths are caused in the Los Angeles area annually by these emissions, according to the air pollution officials.

Oceangoing ships may be the largest source of port emissions, but they are by no means the only source. Tug boats guide ships entering and leaving the harbor, and ports connect to land-based transportation networks, such as railroads, and they generally operate large truck terminals. Ships resting in the port need a source of power, and often this requires auxiliary engines. Because a harbor is served by substantial local boat or barge traffic, sometimes including ferry service, addressing pollution in a port may requires a multi-faceted approach.

Pollution from ships (not only air pollution, but pollution of all kinds) is governed by the International Convention for the Prevention of Pollution from Ships, first negotiated through the International Maritime Organization (IMO) in 1973. The Convention, known as MARPOL (for "MARine POLlution") 73/78 (the dates referring to the 1973 Convention and its 1978 amendments), applies to all ships of the flag states that have ratified it.

About 150 countries, representing over 98.7 percent of world shipping tonnage, have done so. The Convention also applies to ships of non-signatory nations operating in waters under the jurisdiction of parties to MARPOL. Six annexes to MARPOL 73/78 cover various sources of pollution from ships (oil, noxious liquids, sewage, garbage, etc.) and provide an overarching framework for implementation.

Annex VI of the Convention, which was adopted in 1997 but did not enter into force until 2005, addresses the Prevention of Air Pollution from Ships. It –

- limits the sulfur content of the fuel used in oceangoing ships, almost always bunker fuel, to 4.5 percent (45,000 parts per million (ppm)). By comparison, highway diesel fuel in the United States is limited to 15 ppm;.

- limits emissions of oxide of nitrogen from new engines and engines that have undergone major conversions to a range of 9.8–17.0 grams per kilowatt-hour (g/kwh), depending on the rated engine speed. This is roughly, at a minimum, thirteen times the limit for power plants in the eastern United States of 0.45–0.73 g/kwh. Although, the United States is a party to MARPOL 73/78 and most of its annexes, it did not enact legislation to implement Annex VI until the summer of 2008.[ddd]

[ddd] The Annex VI standards apply to any oceangoing vessel that is registered in the United States; ships of any registry in ports, shipyards, terminals, or the internal waters of the United States; ships of any registry bound for or departing from the United States, while they are located in the navigable waters of the United States or designated emission control areas; and ships bearing the flag of any country that has ratified Annex VI traveling through U.S. waters or designated emission control areas, even if they are not bound for or departing from a U.S.

AMENDMENTS TO ANNEX VI

More stringent limits on both fuels and emissions were approved by the IMO on October 10, 2008, cutting the sulfur content of bunker fuel to 3.5 percent (35,000 ppm) Jan. 1, 2012 and to 0.5 percent (5,000 ppm) on Jan. 1, 2020. (This provision will have little effect prior to 2020, since bunker fuel currently averages 27,000 ppm sulfur, substantially cleaner than the 2012 requirements.)

IMO phased in reduced emissions of oxides of nitrogen with those on ships constructed after Jan. 1, 2011, but before 2016,cut about 20 percent to a range of 7.7 to 14.4 grams per kilowatt-hour. For ships built after Jan. 1, 2016, emissions are cut about 80 percent, to a range of 2.0 to 3.4 g/kWh while operating in designated emission control areas (e.g. near large cities). Outside these areas–which is the vast majority of both time and distance–the weaker old limit (7.7 to 14.4 g/kWh) would apply.[172]

The U.S. Environmental Protection Agency breaks engines into three categories: "Category 3" or "C3" engines (with a per-cylinder displacement at or above 30 liters), which are the main ones on oceangoing ships. Category 1 and 2 engines, smaller than 7 liters per cylinder, and 7 to 30 liters per cylinder, respectively), are used in boats or smaller ships, such as tugs, Great Lakes freighters and fishing boats.

CATEGORY 3 ENGINES AND FUELS

EPA began requiring U.S. flag carriers to meet more stringent limits, but these carry only 1.2 percent of cargo. Moreover, the limits apply only to new and re-manufactured engines.

In addition, EPA has proposed that the entire U.S. coastline, except portions of Alaska, be designated an Emission Control Area (ECA), subject to the lower sulfur limits in bunker fuel. In 2016, ships must reduce emissions of oxides of nitrogen from new engines 80 percent below current standards through the application of after treatment technology such as selective catalytic reduction (SCR), a technology now widely used at electric power plants.

Great Lakes Ships

As originally proposed, the emission restraints would have applied to large ships plying the Great Lakes, about 100 U.S.- and Canadian-flagged vessels generally carry bulk cargoes, such as iron ore, coal, limestone, agricultural products and rock salt. However, Congress intervened.

CATEGORY 1 AND 2 ENGINES

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destination. To the extent consistent with international law, the Annex also applies to any other ship in the U.S. exclusive economic zone.

Starting in 2014, the smaller engines were required to burn fuel with a sulfur content of 15 parts per million or less and reduce particulate matter emissions by 90 percent and oxides of nitrogen by 80 percent, as well as "sizeable reductions" of hydrocarbon, carbon monoxide, and air toxics.[173]

CALIFORNIA EMISSION REDUCTION MEASURES

Because California is more at risk than most states it has focused on port activities, in addition to fuel and emission standards for marine vessels. California's measures fall into four categories: (1) requiring the use of lower sulfur fuel; (2) requiring emission controls on harbor vessels and shore-side equipment; (3) providing alternative (electric) power to ships while they are docked at marine terminals; and (4) providing grants for the re-powering of harbor craft and short-haul trucks with cleaner engines.

Greenhouse Gases

The International Maritime Organization's estimates that international shipping emitted 843 million metric tons of carbon dioxide, of about 2.7 percent of global emissions in 2007. If domestic shipping and fishing vessels larger than 100 gross tons, are included the total mounts to 1.019 billion tons, or 3.3 percent. Only five nations– the United States, China, Russia, India, and Japan–account for a higher percentage of the world total of CO_2 emissions.

This ignores the massive contribution of ships to emissions of black carbon, F-gases and other causes of global warming.

MEASURES TO REDUCE SHIPS' GHG EMISSIONS

A number of measures could reduce the shipping's emissions. One of the more common suggestions is that ships operate at lower speeds. The IMO's 2000 study of GHG emissions from ships concluded that a 10 percent reduction in speed would result in a 23.3 percent cut in emissions.[174] Slowing speeds is not without problems, according to the 2000 IMO report.[175]

Nevertheless, without changes in technology or fuels it is possible to significantly reduce air pollution. Some shipping companies have begun to implement slow steaming policies to reduce their emissions.

For example, A.P. Moller - Maersk Group, the world's largest container shipper, for example, reports that it reduced fuel consumption in its transport group 6 percent in 2008 compared to the fuel used for the same level of business activity in 2007. In addition to slow steaming, the company has implemented waste heat recovery systems on 32 ships, has installed software in containers to reduce energy consumption for cooling, and has developed a voyage planning program to identify the most fuel-efficient routes, and a "just in time" steady running strategy that minimizes engine loads.[176]

Cleaner fuels and emission controls could also lower emissions, particularly of black carbon and nitrogen oxides. Like slow steaming, these could be implemented without the need to replace ship engines or the ships themselves. The use of alternative power in ports may also reduce emissions, if the shore power is derived from low-carbon sources such as natural gas, or no-carbon sources (hydropower, wind, solar, or nuclear).

New ships can reduce emissions further through improved hull design, more efficient propulsion, and propeller coatings and other options.[ccc]

[ccc] A detailed discussion of options (in the context of Navy ships) is provided in CRS Report RL33360, *Navy Ship Propulsion Technologies: Options for Reducing Oil Use—Background for Congress*, by Ronald O'Rourke.

Appendix B
CFCs, HCFCs, HFCs
And Related Chemicals

In their quest to profit from cooling food, bodies, space and other things, corporations have wrought devastating environmental damage, and there may be no end in sight. Even the thinnest pancake has two sides, however, and the positive news from the success of these chemical, auto, appliance and other companies is this: their success at unnecessarily prolonging the production and use of old chemicals, while expanding distribution of new ones, provides an immense supply of low hanging fruit that can be harvested to quickly slow global warming. Collectively, these chemicals are referred to as "F-gases" because they all contain the element fluorine.

- ***Ban HFC-134a.*** The synthetic chemical now used in the air conditioners of cars and trucks, HFC-134a, causes global warming and has a lifetime of about 14 years.[177] If it were banned immediately, which Europe started doing on January 1, 2011 for new cars, the cooling benefits would be realized when children born today were in their teens.

- ***Capture banked CFCs.*** The synthetic chemicals that HFC-134a replaced, the chlorofluorocarbons (CFCs), also cause global warming. Their lifetimes are longer than HFC-134a, but many of them are "banked"—that is, trapped inside in foams, air conditioners and refrigerators, for example. Capturing these banked CFCs before they can be released chokes off what would otherwise be a powerful source of warming.

- ***Ban HCFC-22.*** One specific synthetic chemical, HCFC-22, has a lifetime of nine to thirteen years.[178] It is in widespread production and use and this is growing because China, India and other developing nations have been accorded special treatment under the Montreal Protocol, the international agreement for protection of stratospheric ozone. In addition, when HCFC-22 is made, another powerful warming agent, HFC-23, is released. If the Montreal Protocol were re-opened, HCFC-22 banned and banked supplies captured and destroyed, cooling could start in nine to thirteen years, and other powerful contributor warming, HCFC-23, eliminated.

There are a variety of existing legal authorities that could be invoked to reduce emissions of F-gases. One of the clearest, and less well known, basis for action would Title VI of the Clean Air Act, Stratospheric Ozone Protection. Although principally occupied by the details of controlling and phasing out chemicals that destroy stratospheric ozone, the over-arching purpose of the law is to protect the stratosphere from an "effect" that "may reasonably be anticipated to endanger public health or welfare," to wit:

> **SEC. 615. AUTHORITY OF ADMINISTRATOR.**
> If, in the Administrator's judgment, any substance, practice, process, or activity may reasonably be anticipated to affect the stratosphere, especially ozone in the stratosphere, and such effect may reasonably be anticipated to endanger public health or welfare, the Administrator shall promptly promulgate regulations respecting the control of such substance, practice, process, or activity, and shall submit notice of the proposal and promulgation of such regulation to the Congress.[fff]

The interaction between global warming and changes in the stratosphere is well established.[ggg] As one of the more prominent researchers, V. Ramanathan, explained, "According to the greenhouse theory of climate change, the climate system will be restored to equilibrium by a warming of the surface troposphere system and a cooling of the stratosphere."[hhh]

Thus, whether or not an "endangerment finding" is made, or overturned by Congress, the authority—indeed the mandate—already exists in federal law. This section reviews one major source of warming by a collection of pollutants known as "F-gases," many of which have already been banned or subjected to controls because they destroy stratospheric ozone, as well as others that have entered the market place as substitutes for the ozone-destroyers.

A Brief History of the "F-Gases"

For other causes of global warming, a history of this sort would be not only unnecessary, but inappropriate. In the case of the F-gases, however, a brief history is essential because, for practical purposes, these chemicals do not exist in nature. They are developed, manufactured, sold, used and released by humans, or more accurately, corporations created by humans. Those who burn coal or drive cars are not purposefully causing global warming, but those who make F-gases must be assumed to have intended the natural consequences of their actions. For these substances, what is past is prologue. Past actions are likely to be repeated in the future. If there were harmful consequences in the past and we wish to avoid them in the future, it is essential to

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[fff] 42 U.S.C. 7671n.

[ggg] See, e.g., C. Schnadt et al. Interaction of atmospheric chemistry and climate and its impact on stratospheric ozone, *Climate Dynamics*, V. 18, Nr. 6, pp. 501–17, DOI: 10.1007/s00382-001-0190-z.

[hhh] V. Ramanathan, The Greenhouse Theory of Climate Change: A Test by an Inadvertent Global Experiment, *Science,* Vol. 240 no. 4850, pp. 293–99, DOI: 10.1126/science.240.4850.293, 15 April 1988.

know what was done and by whom.

The simple truth is that companies develop these synthetic chemicals and market them at will, while others buy, use and release them at will, all in virtually complete disregard of their effects. This happened initially with CFCs, and while the fact that they destroy ozone was not initially known, that eventually came to light. DuPont and other manufacturers ignored the damage. When the ozone destruction could no longer be credibly denied because CFCs had destroyed so much ozone that a "hole" the size of North America and the height of Mt. Everest was opened in the Antarctic, the manufacturers relented. But they forced onto the market another synthetic chemical, HCFC-134a, that they knew full well caused global warming. There was much ado about HFC-134a being a "new" refrigerant, but in fact it was synthesized in 1936 by Albert Henne, a co-developer of CFCs.[179] He worked with Thomas Midgely of General Motors who is credited with developing R-12 in 1931. They kept it on the market and expanded the production and use of yet another F-gas, HCFC-22, which also causes global warming, in addition to stratospheric ozone destruction.

Now, HFC-134a is being banned and the same companies that gave the world ozone destruction and global warming are preparing to populate the planet with tens of millions of machines that can generate hydrofluoric acid, a chemical warfare agent, which can catch fire in, say, a minor auto accident. In addition, the new synthetic replacement for HFC-134a is less efficient than alternatives to F-gases (e.g., carbon dioxide) and will therefore increase energy consumption and, with it, emissions of air pollutants and greenhouse gases.

The first synthetic refrigerants, chlorofluorocarbons (CFCs), or "Freons," were developed and marketed by the giant U.S. chemical company, E. I. du Pont de Nemours and Company.[iii, jjj] The great advantage of CFCs was the stability of the molecules, which made them nonflammable and somewhat non-toxic. Thomas Midgley, their co-developer, was fond of demonstrating these qualities by inhaling CFCs, then blowing out a candle flame, as he did in 1930 at a meeting of the American Chemical Society.[180, kkk]

[iii]The same DuPont engineer that developed CFCs, Thomas Midgley, also developed tetraethyl lead, a gasoline additive that destroys intelligence in children and is linked to 50,000 U.S. deaths per year from high blood pressure.

[jjj]At the time, the DuPont family controlled not only General Motors, but its subsidiary, Frigidaire. This provided an immense competitive advantage for DuPont in the markets for mobile and stationary refrigeration equipment alike, and it quickly became the dominant maker of not only CFCs, but much of the equipment that used them.

[kkk]He was equally fond of demonstrating the supposed safety of the tetraethyl lead gasoline additive by washing his hands in the fuel, which may explain why in February, 1923 Midgley took leave for lead poisoning. Mark Bernstein, "Thomas Midgley and the Law of Unintended Consequences," *American Heritage*, Spring 2002,

In time, however, the molecular strength of which Midgley was so proud ultimately proved to be the Achilles heel of CFCs, because it allowed them to survive long enough to rise into the stratosphere, where incoming ultraviolet radiation sent speeding to Earth by the Sun's nuclear explosions, struck and shattered the bonds, freeing chlorine atoms to destroy stratospheric ozone with ferocity.[181] Each molecule of a CFC can destroy 100,000 molecules of ozone.[182]

The first scientists to publish their finding that CFCs destroy stratospheric ozone, Mario Molina and F. Sherwood Rowland, calculated that if industry were to continue releasing a million tons of CFCs each year, atmospheric ozone would eventually drop by 7 to 13 percent.[183] In reaction, in 1978 the United States banned the non-essential use of CFCs in aerosol spray cans, almost immediately reducing global releases by nearly one-half.[lll]

That ban was perhaps the most effective single action ever taken to slow global warming until the making of some CFCs was halted altogether by the Montreal Proocol. The cooling benefits from banning CFC use in spray cans in the 1970s, followed by adoption of limited other global bans in 1987 are far greater than what would have been achieved under the Kyoto Protocol, the international agreement to curb global warming.[184] Not surprisingly, some have suggested that the Montreal Protocol be re-crafted so that it can be used to address global warming in addition to stratospheric ozone depletion.[185]

Only Canada, Norway and Sweden followed the U.S. ban,[186] however, and by 1988 global production had rebounded to an estimated at 12 million tons[187]. Despite arguments by scientists, including the National Academy of Sciences in the United States and the Royal Academy of Sciences in the United Kingdom, the chemicals remained not only on the market, but thrived, being used to make new products ranging egg cartons, "silly string" and foam "clamshells" for McDonald's fast food hamburgers.

> "There was, you know, a world before Styrofoam egg cartons."
>
> Sen. John Chafee (R.-RI), circa 1987

Then in May 1985 the British Antarctic Survey stunned the world, announcing that it had discovered a massive hole in the ozone layer over the Antarctic the size of North America and the height of Mt. Everest. The fears triggered by Rowland and Molina's conclusions were neither trivial nor speculative. Numerous studies soon confirmed that CFCs

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http://www.americanheritage.com/articles/magazine/it/2002/4/2002_4_38_print.shtml, accessed Feb. 11, 2011. Also, Jamie Lincoln Kitman, "The Secret History of Lead," *The Nation*, March 2, 2000.

[lll]The 1978 ban reduced aerosol use of CFCs in the United States by approximately 95 percent, eliminating nearly half of the total U.S consumption of these chemicals. U.S. Environmental Protection Agency, "Protection of Stratospheric Ozone," 40 CFR Part 82, Sep. 27, 1993, http://www.epa.gov/ozone/fedregstr/58fr50464.html, accessed March 15, 2011.

were not only responsible for the Antarctic hole, but for global ozone destruction as well.[4]

Remarkably, despite discovery of both global ozone destruction and "holes" at both poles, the chemical industry, particularly DuPont continued to fight a ban on CFC production.[188] The company had pledged to Congress in 1974, and in full-page newspaper advertisements to the public, that "should reputable evidence show that some fluorocarbons cause a health hazard through destruction of the ozone layer, we are prepared to stop production of these compounds."[189] But on March 4, 1988, DuPont President Richard Heckert angrily refused to stop making CFCs, saying there was no reason for Du Pont to stop. But 20 days later, on March 24, 1988, Heckert reversed course and said DuPont would get out of the chlorofluorocarbon business entirely.[190] Heckert's initial refusal, followed by his apparent concession, came six months after the world had already agreed in the Montreal Protocol to regulate production and use of CFCs.[191]

Although the Protocol has been widely lauded as one of history's most effective actions to protect the environment,[mmm] in truth, the result has been a second global environmental catastrophe—acceleration of global warming—and one that was obvious from the outset.[192] When officials decided to approve HFC-134a as a replacement for CFCs, they knew full well that it was a powerful cause of global warming, but cleared the chemical for use despite this.[193] Between 1990 and 2002, emissions of HFC-134a increased 59-fold, more than any other greenhouse gas.[194] That was just the beginning of the Montreal Protocol's failings, however, which include the following:

- **First,** although the new synthetic chemical selected to replace the CFCs, HFC-134a, does not destroy ozone, it is a powerful cause of global warming, roughly 3,400 times as powerful as carbon dioxide over a 20-year period.[195] Less harmful refrigerants were, and are, available. Even if using HFC-134a for some products might be justified, there was absolutely no need to increase global warming by using it as the substitute for ozone-destroying CFCs in all cases. In Europe, for example, the public demanded hydrocarbon replacements, which now account for 36 percent of all refrigerator production globally, principally with isobutene (HC-600a).[196]

[mmm]"The Montreal Protocol, the foundation for this process, thus stands as an extraordinary and even spectacular success story. Its success owes a great deal to the actions not only of the United States government, which played an exceedingly aggressive role in producing the Protocol, but to American companies as well, which stood at the forefront of technical innovation leading to substitutes for ozone-depleting chemi cals."Cass R. Sunstein, "Of Montreal and Kyoto: A Tale of Two Protocols," *Harv. Envtl. L. Rev.* 2007.

- **Second,** systems that use HFC-134a are intrinsically leaky,[nnn,ooo] in part because the molecule is smaller than the CFC-12 which it replaces.[197] Leaking just one pound of HFC-134a from a car's air conditioning system has the same global warming impact as physically driving the car for a month.[198] When it approved HCFC-134a in 1995, the U.S. Environmental Protection Agency candidly admitted that "HFC-134a's contribution to global warming could be significant in leaky end-uses such as motor vehicle air conditioning systems."[199] Today, after roughly 20 years of production, about 59 percent of HFC-134a ever made has entered the atmosphere.[200]

- **Third,** apparently because HFC-134a would not have been a suitable substitute for some CFCs uses, or perhaps not profitable enough, DuPont, environmental groups, and the U.S. Environmental Protection Agency met secretly and, for the first and only time in history, singled out a specific member of the Freon family and renamed it: CFC-22 ceased to exist and instead became HCFC-22. Voila! Governments and industry could, and did, boast that they were no longer using CFCs.[201] There were two calamitous results:

  - It boosted production and release of HCFC-22, rising sharply from 490,000 metric tons in 2000 to a projected level of 710,000 in 2015,[202] further exacerbating global warming and unnecessarily prolonging ozone depletion.[ppp]

  - It increased emissions of HFC-23, an unavoidable by-product of HCFC-22 production which, over 100 years, is 11,700 times as powerful a warming agent as carbon dioxide.[203] HFC-23 historically had been considered a waste to be vented to the atmosphere.[204] It is

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[nnn]About 60 percent of -134a emissions are from routine leaks from refrigeration and air conditioning. In one test of the permeability of hoses typically used for auto air conditioners, DuPont found that one square meter would leak 1.07 kilograms of -134a per year.

[ooo]Based on data supplied to the State of Minnesota, every 2009 car leaked HFC-134a. The best lost 0.6 percent per year, while the worst leaked 4.3 percent. Minnesota Pollution Control Agency, "Climate Change: Mobile Air Conditioners," http://www.pca.state.mn.us/index.php/topics/climate-change/regulatory-initiatives-programs-and-policies/climate-change-mobile-air-conditioners.html, accessed Feb. 16, 2011.

[ppp]In the 15 years prior to 2004, steady or declining rates of HCFCs were observed in the global background atmosphere. But, since 2005, the accumulation rates of these gases have increased substantially; the growth rates of HCFC-22, HCFC-142b, and HCFC-141b were 50 to 100 percent larger in 2007 than measured in 2004. Increased outputs of these gases from developing countries are believed to be the cause. Russell C. Schnell, "Updates on radiatively important atmospheric trace gas concentrations and trends in other parameters from the NOAA ESRL global network," http://ams.confex.com/ams/89annual/techprogram/paper_144854.htm, Jan. 15, 2009, accessed Feb. 17, 2011.

emitted at a rate of between 2 and 4 percent of HCFC-22 production.[qqq]

- **Fourth,** the negotiators focused phasing out on production and consumption of CFCs, not releases. As a result, untold amounts of CFCs remain "banked," or stored in refrigerators, foams and other products. There is no requirement in the Montreal Protocol that the CFCs be captured and destroyed when these products are discarded, so in most cases they aren't.[rrr] The United Nations projects that emissions of banked F-gases in 2015 will be equivalent to about 1.15 gigatons of carbon dioxide, which is slightly less that the 2007 emissions of Japan.[205]

- **Fifth,** in addition to causing global warming directly, chemicals can also cause it indirectly—for example, by reducing a car's gas mileage, thus boosting the amount of CO_2 it emits—and HFC-134a does exactly that.

- **Sixth,** the Protocol created two categories of nations: Article 5, or developing nations; and, Non-Article 5, or developed nations. Article 5 nations are treated much more leniently, with slower reductions in production, exemption from reporting requirements, etc., even though some of them—China and India, for example—are major sources of pollution. While this divergent treatment reflects a principle agreed to in 1992 at the United Nations Conference on Environment and Development—all countries have a common but differentiated responsibility to protect and manage the global commons—it nevertheless stretches a process that arguably could have been completed within two decades to scores of years, loading the air unnecessarily with immense amounts of air pollution, including greenhouse gases. Not knowing what emissions actually are, scientists are forced to "deduce" them or otherwise engage in awkward and potentially misleading calculations.[206]

These are by no means the only failings of the Montreal Protocol, just the worst of them. Production and use of a chemical that can and has killed humans,[sss] methyl bromide, continues because the United States has adamantly insisted on a "critical" use exception to a ban—an

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[qqq]Between 1978 and 1995, HFC-23 concentrations increased from 3 to 10 parts per trillion (ppt), and continued to rise.

[rrr]The Montreal Protocol controls only substances that deplete ozone and even then it applies only to production and consumption. Thus, it does not take into the global warming caused by F-gases, nor does it affect them once they enter commerce. This leaves emissions of CFCs and HCFCs present in products, or "banked," and not subject to controls internationally. The banked CFCs and HCFCs contained in existing refrigerators, foams and other products will eventually be released, even though they could be captured and destroyed rather easily. The build up of banks will, in the absence of management measures, significantly determine future emissions.

[sss]Horowitz, BZ et al., "An unusual exposure to methyl bromide leading to fatality," *J Toxicol Clin Toxicol.* 1998;36(4):353–7.

exception that makes it possible to grow winter strawberries and tomatoes.

Cooling the Earth by Eliminating "F-gases"

It would have been vastly preferable to simply rid the world of CFCs a quarter-century ago, but that did not happen. The replacement, HFC-134a, should never have entered the marketplace, nor should production of HCFC-22 have been allowed to grow exponentially. Programs to capture and destroy banked F-gases should have been started, but they were not. That means all of these actions can be taken now, with immense benefits. Because HFC-134a and HCFC-22 both have short atmospheric lifetimes—fourteen years, and nine to thirteen years, respectively—the cooling benefits of actions will be quickly realized.

Banning HFC-134a

Direct versus Indirect Emissions. Air conditioners in cars and trucks cause global warming both directly—that is, from leaks of a refrigerant that is a greenhouse gas—and indirectly, as a result of emissions from the energy consumed to manufacture, operate, and dispose of them.

Direct emissions. Leaks of a chemical refrigerant fall into the following categories:

- **Regular emissions** are leaks from the air conditioning system in operation through, for example, hoses, valves, and compressors. Whether there are regular emissions and, if so, how much depends both on the refrigerant itself—whether it can pass through hoses, for example—and the equipment. Metal hoses leak less than nylon, for instance.

- **Irregular emissions** occur due to accidents, stone hits, product defects, etc. Ordinary "fender bender" accidents can rupture hoses, for example.

- **Service emissions** can occur from garages during maintenance and repair and others from home mechanics refilling their system with disposable canisters of refrigerant. At a garage, whether there are leaks and of how much, depends very much on the skills and practices of the mechanic.

- **End-of-life emissions** occur when a vehicle is taken to a recycling yard.

In addition, refrigerants can leak during production and transport.

Indirect emissions. Indirect emissions are largely due to energy consumed when air conditioners are made, operated and disposed. Operating emissions are a function of the energy used to run the system and transport it. Again, some refrigerants are more efficient than others, and some systems weigh more or less, again depending on the chemical.

Direct Emissions from HFC-134a Systems

Systems using HFC-134a leak badly. Those leaks cost consumers, principally people who own cars, money, and lots of it. They also cause global warming, because HFC-134a is a powerful greenhouse gas, about 3,400 times as powerful as carbon dioxide compared over a 20-year period.[207] The leaks may also cause other damage, because HFC-134a degrades rapidly in the air into trifluoroacetic acid (TFA), which then washes into lakes, rivers, streams, oceans and other bodies of water, where it appears to remain inert. However, so little study has been undertaken that it is impossible to say one way or the other.

HFC-134a is on the market in the United States, because it was approved by the U.S. Environmental Protection Agency as an acceptable CFC substitute under the Significant New Alternatives Policy (SNAP) program.[ttt] The first step toward rescinding that approval in the United States has recently been taken,[uuu] with a phaseout of the chemical that started in the European Union for use in new cars, which was effective January 1, 2011.[208]

That mobile air conditioners using HFC-134a leak badly is beyond question. According to manufacturers of HCFC-134a, between the time it was placed on the market in 1990 through 2005, about 19.7 billion pounds, or about 59 percent of the HFC-134a ever made, had leaked out of air conditioners and entered the atmosphere.[209] At the 2007 street price for HFC-134a in Europe, the leaked refrigerant was worth $229.9 billion,[210] and the price of HFC-134a continues to rise.[211]

This leakage estimate is consistent with studies that found about 60 percent of HFC-134a emissions were from routine leaks. In a test of the permeability of hoses typically used for auto air conditioners, DuPont found that one square meter would leak 1.07 kilograms of -134a per

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[ttt]The Significant New Alternatives Policy (SNAP) program, which implements section 612 of the Clean Air Act, was created to assure the health and environmental safety of alternatives for ozone-depleting substances that were being phased out under the 1990 Clean Air Act Amendments. The purpose of the SNAP program is "to allow a safe, smooth transition away from ozone-depleting compounds by identifying substitutes that offer lower overall risks to human health and the environment." Environmental Protection Agency, Significant New Alternatives Policy (SNAP) Program, http://www.epa.gov/ozone/snap/index.html, accessed March 22, 2011.

[uuu]Institute for Governance & Sustainable Development, "EPA Set to Ban Powerful GHGs From Auto Air Conditioning," March 23, 2011, http://www.enn.com/press_releases/3675, accessed March 23, 2011.

Freon is very hard to contain in an automotive system. The reason is your air conditioning compressor operates at all different speeds due to engine RPM. The rest of the system is comprised of many dissimilar materials that expand and contract and, along with the movement of the engine, this allows a minute amount of freon to escape. This is normal and that's why the system should be checked for a low charge. ...We at Professional Fleet Services are certified by ASC and MACS in the proper handling and have the equipment to handle both R12 and R134A refrigerant along with some of the most sophisticated leak detection equipment now available. For $59.95 we will service your air conditioning. ... Due to the constantly changing price of R12 and R134A, the refrigerant needed to fully charged the A/C system would be in addition to the above service.

Lansing Auto Air Conditioning Repair
http://www.professionalfleet.com/lansing_auto_repair_services/lansing_auto_air_conditioning_repair,
accessed March 15, 2011

year.[212] A more recent analysis conducted by the French research institute École de Mines found that the average leak flow rate from new HFC-134a automobile air conditioning systems was about 10 grams per year, with the compressor accounting for 50 to 60 percent of the losses.[213]

In still another test—this one with stationary vehicles located within an enclosed space and with both the motor and air conditioning systems turned off—"all vehicles exhibited measurable R-134a leakage over the 2-day diurnal test. Leak rates of R-134a ranged from 0.01 to 0.36 g/day with an average of 0.07+/-0.07 g/day." The 28 light-duty vehicles were from five manufacturers (Ford, Toyota, Daimler Chrysler, General Motors, and Honda).

The researchers estimated that the global warming impact of the leaked HFC-134a was 4 to 5 percent of that from the carbon dioxide emitted, assuming 10,000 miles were driven a year.[214] Nearly 54 percent of the 1,178 metric tons transportation-related emissions of carbon dioxide in the United States in 2009 resulted from gasoline consumption for personal vehicle use, or about 636 metric tons.[215] Put another way, eliminating HFC-134a in the United States alone would be the global warming equivalent of reducing all carbon dioxide emissions from the world's 63 smallest emitting nations.[216]

Some companies attribute this high leakage rate to the smaller molecule size of HFC-134a compared to CFC-12, the refrigerant it replaced.[217] However, tests have also confirmed that the tightness of mobile air conditioners drops over time, increasing leakage.[218]

As is the case in reducing methane emissions, controls do not necessarily translate into additional costs. Just as the use of another DuPont chemical, tetraethyl lead, increased consumer costs because it damaged engines and their components, so, too, does HFC-134a. The price of HFC-134a sold in 30-pound tanks is currently about $350, or $11.67 per pound.[219] Prices have been rising so rapidly that Honeywell imposed two 10 percent hikes in Europe, one in April 2007 and another in July 2007.[220] The average amount of HFC-134s in an auto air conditioning system is about two pounds,[221] so the HFC-134a alone costs roughly $23.

The cost of losing a charge of HFC-134a, however, only begins with replacing the refrigerant. According to the commercial web site costhelper, the following costs for auto air conditioning repair are typical :

- Between \$250 and \$650 to test for leaks, replace a few minor parts and then top-off or completely recharge the refrigerant in a vehicle's system. The work takes an average of four hours labor, at roughly \$50 –\$100 an hour, plus parts; for luxury vehicles both parts and labor may cost more.

- For more extensive repairs the costs can range from \$800–\$1,200 for replacing or upgrading most of the major parts. Vehicles with easy access to the A/C system and plentiful low-cost parts could be less; high-end luxury vehicles will often cost more.[222]

Money, however, is only one way of measuring cost, and the costs of HFC-134a leaks in terms of damage to health and the environment are unknown. That's largely because, as was the case with CFCs, it is almost impossible to predict the future. In fact, there are some eerie similarities between HFC-134a, its likely replacement, HFO-1234yf, and the CFCs.

The chemical bonds of CFCs are so strong that they survive until they reach the stratosphere, where ultraviolet radiation shatters them, freeing chlorine to destroy the ozone layer. Similarly, when other F-gases, including HFC-134a, leak into the air, they are quickly attacked and degraded to form trifluoroacetate (TFA), whose chemical bonds are even stronger than those of the CFCs.[223]

Highly soluble in water, TFA is transported rapidly by rain, snow and fog back to the Earth's surface, where it enters streams, rivers, lakes and ponds. In China, when researchers tested for the presence of TFA, it was found in rainfall, snowfall, inland surface water, ground water, and waste water from nine provinces and autonomous regions in concentrations ranging from 4.7 to 221 nanograms per liter (ng/l). Surprisingly, TFA was found even in Beijing groundwater at 10 ng/l.[224] In a Canadian study, the source of TFA appeared to be urban centers.[225] In Switzerland when more than 1,000 water samples were analyzed for TFA it was found to be "quite persistent in the aquatic and terrestrial environment and may thus accumulate in soils and groundwater."[226]

DuPont and other HFC-134a manufacturers claim that there is no significant long-term accumulation in forests, bogs and other soils.[227] But when researchers tested the claim that TFA would not accumulate by examining the Hubbard Brook research forest in New Hampshire, they found it wrong: TFA was retained within the forest's vegetation and soil compartments, especially in wetlands.[228]

TFA concentrations continue to increase, especially in bodies of water lacking outflows, like many wetlands. In California, for example, TFA accumulated in seasonal wetlands to the point that aquatic plants growing in the water had 279 ng/g dry weight of TFA in their tissues as compared to 33 ng/g for species growing outside the pools. The TFA was retained from year to year, thus increasing further with time.[229]

What damage trifluoricacetic acid might be doing is fundamentally unknown. The Alternative Fluorocarbons Environmental Acceptability Study (AFEAS), is an undertaking of seven major producers and users of F-gases.[vvv] It has funded most of the research and, consequently, has provided the primary source of information on the potential environmental effects of the HCFCs and HFCs.[230, www] In an environmental risk assessment published in 1999, about 10 years after HFC-134a entered the market place and funded by AFEAS, the authors concluded that "Based on available data, one can conclude that environmental levels of TFA resulting from the breakdown of alternative fluorocarbons do not pose a threat to the environment."[231]

The presence of fluorine in compounds can have a profound effect on potency, which helps explain the dramatic increase of its content in drugs, pesticides and other chemicals. In 1978, roughly 600 pesticides were known, but only about 25, or 4 percent contained fluorine. By 2004, fluorine-containing compounds accounted for more than 17 percent of all commercially available crop protection agents and others under development. In the pharmaceutical arena, around 220 fluorinated drugs were on the market in 1990, and about 8 percent of all were synthetic drugs. Six years later more than 1,500 fluorine-containing drugs were under development.[232]

TFA is one of a family of chemicals known as perfluorinated organic acids (PFOAs). They are the breakdown products of HFCs, and are now found in all of the world's oceans, and many organisms. One team of researchers collected seawater samples during several international research cruises undertaken during 2002–2004 in the central to eastern Pacific Ocean (19 locations), South China Sea and Sulu Seas (5), north and mid-Atlantic Ocean (12), and the Labrador Sea (20). An additional 50 samples of coastal seawater from several Asian countries (Japan, China, Korea) were analyzed. PFOA was found at levels ranging from several thousands of picograms per liter (pg/L) in water samples collected from coastal areas in Japan to a few tons of pg/L in the central Pacific Ocean. Where these chemicals go and what injury they might cause remains largely undefined and, frankly, under-investigated.[233]

There have been relatively few studies of the environmental impacts of fluorinated compounds such as TFA. In one, decomposition of cellulose and nitrification in the soil were inhibited, and respiratory intensity was also reduced.[234]

TFA and other PFOAs are almost literally everywhere. One study found them even in

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[vvv]Arkema, Asahi Glass Co., Daikin Industries, DuPont, Honeywell, INEOS Fluor Ltd., and Solvay S.A.

[www]Some manufacturers have also funded studies. For example, a study of the fate and effects of TFA in soils from throughout the world was supported by the DuPont Educational Program. Richey, D. et al., "Soil Retention of Trifluoroacetate," *Environ. Sci. Technol.*, 1997, 31, 1723–27.

newborn babies,[xxx] raising concerns about the chemical's use as a protective coating on some food packaging.

Indirect Increases in Emissions. There also are indirect impacts on global warming caused by air conditioners in cars and trucks. They consume more energy than any other auxiliary vehicle equipment. In the United States alone, these air conditioners consume over 7 billion gallons of gasoline every year, emitting over 58 million metric tons of carbon dioxide.[235]

One example of the impact that air conditioning can have on fuel economy, and hence indirect emissions, is provided by a vehicle simulation of a Hyundai Santro. On the Indian combined drive cycle, the Santro averaged 46.9 mpg. (This compares to the United States average of 21.4 mpg for cars and 17.1 mpg for light trucks and the European Union average for cars of 30.4 mpg.) When the load of an air conditioner was added to the Santro simulation, fuel economy dropped 22 percent to 36.6 mpg.[236]

FUEL ECONOMY DROP WITH AIR CONDITIONING

U.S. Car	U.S. Truck	E.U. Car
-18 percent	-14 percent	-10 percent

Source: J ohn Rugh, "Significant Fuel Savings and Emission Reductions by Improving Vehicle Air Conditioning," 15th Annual Earth Technologies Forum and Mobile Air Conditioning Summit April 15, 2004, National Renewable Energy Laboratory, http://www.nrel.gov/vehiclesandfuels/ancillary_loads/pdfs/fuel_savings_ac.pdf.

In the United States the average on time for A/C is 32.6 percent; in the European Union it is 21.1 percent.

Reducing the engine load from an air conditioner by using more efficient variable displacement compressors (VDC), condensers and evaporators with improved heat transfer, and better control systems, can cut indirect emissions by 30 to 50 percent.

VDCs are more common in Europe than the United States. They reduce engine load by varying refrigerant according to the cooling demand. In contrast, fixed displacement compressors (FDCs) provide a constant flow of refrigerant with on/off cycling. As cooling demands increase, which they do in much of the south and west of the United States, the benefits of VDCs decrease compared to FDCs. Indeed, when maximum compressor displacement is required, the benefit of VDCs over FDCs approaches zero.[237]

[xxx] A study of about 300 umbilical cord blood samples by researchers at the Johns Hopkins Bloomberg School of Public Health found that newborn babies are exposed to perfluorooctane sulfonate (PFOS) and PFOA while in the womb. Ahmed ElAmin, "Packaging PFOAs found in newborns," Food Production Daily.com, Apr. 26, 2007.

In the United States the average "on" time for air conditioners is 32.6 percent, while in the European Union it is 21.1 percent.[238] For cars with smaller engines, FDCs can significantly reduce performance. In the EU and other areas of the world where engine displacement is less than two liters, variable speed compressors improve driving performance, while maintaining fuel economy.[239]

Another way to increase the efficiency of car air conditioning, thus reducing emissions by boosting fuel economy, is to control the mixture of outside versus inside air, either automatically or manually. This reduces the amount of outside air that needs to be cooled. Air conditioner performance can also be improved by eliminating "air reheat." This is common in fixed displacement air compressors, which overcool, then reheat the air to moderate chill. Because VDCs modulate refrigerant flow, they can eliminate air reheat. However, eliminating air reheat requires automatic climate controls, and manual controls are most prevalent in the United States.[240]

Accelerating Bans and Phaseouts

The Montreal Protocol is by no means the unalloyed success that its admirers would have the public believe. In the view of some, the phase out schedules are leisurely and the coverage incomplete. The interplay between it and the Kyoto Protocol not only allows manufacturers to capture billions in windfall profits, but in a perverse, almost Kafkaesque way, had led to actual increases in production of some powerful greenhouse gases at a time when they could be, and should be, falling. It has been and continues to be manipulated in the most cynical way as an engine to increase profits for London, Chicago and other traders, while diverting immense sums of money away from the development of wind, solar and other forms of renewable energy.

At the insistence of the United States, the Kyoto Protocol allows polluters and their customers to trade their pollution like so many shares of stock or head of cattle. First, the warming impact of, say, one ton of a substance is converted to common value, its "carbon dioxide equivalent" or CO_2e. Consider the case of HCFC-22.

Seek out information on uses of HCFC-22 on the web, and you will quickly be told by, for example, DuPont that HCFC-22 is the "most commonly used as a refrigerant in residential and commercial air conditioning."[241] Yet 40 percent of global production is not for refrigeration or chilling, but what some might consider a rather trivial purpose: production of polytetrafluoroethylene (PTFE), more commonly known as Teflon, DuPont's brandname.[242] Because HCFC-22 produced as a feedstock is exempt, its production will be unabated under the Montreal Protocol.

HCFC-22 is 1,810 times more powerful than carbon dioxide as a greenhouse gas. Its global warming potential, or GWP, is therefore 1,810. Eliminating one ton is the warming equivalent of cutting CO_2 emissions by 1,810 tons. If carbon dioxide is "trading"—that is, is being bought and sold on stock exchanges—for $10 per ton, a factory owner that reduces HCFC emissions by one ton can sell that reduction for $18,100.

Another greenhouse gas, HFC-23, is an unwanted byproduct of producing HCFC-22. Its lifetime is about 270 years and its GWP is 11,700. Typically, the ratio of HFC-23/HCFC-22 is three to four percent.[243]

> (H)arshest critics say outright fraud is at work and suggest that up to half of all the Certified Emission Reductions (CERs) ever issued are bogus. CERs are the offset credits earned from CDM projects, sold primarily into the European Union's cap-and-trade scheme.
>
> Nathanial Gronewold, "U.N. Body Probes Cases of Paying Greenhouse Gas Emitters, Which Then Produce More," *New York Times*, July 26, 2010

HFC-23 is an unwanted by product that can be destroyed at a cost of about $.50 per ton for a carbon dioxide equivalent.[244] If a newly built plant to produce HCFC-22 is constructed without destruction capability, then is retrofitted later, the HFC-23 reductions can be sold in a trading program. On March 16, 2011, the prices for carbon allowances in the European Union was 17.75 euros, or $24.82 per metric ton.[245] Thus, one ton of CO_2e destroyed at a cost of $.50 could be sold for $49.64 on March 16, 2011.

Not surprisingly, sales of destroyed HFC-23 are robust. For example, in 2009 the Swedish government's power company, Vattenfall, bought 6.7 million emission reductions, and about 56 percent, or 3.6 million, came from HFC-23 destruction projects in China and India.[246]

There are 19 manufacturers of HCFC-22, mainly located in China and India, with others in South Korea, Argentina and Mexico. In 2010, greenhouse gas trading projects utterly dominate the Kyoto Protocols Clean Development Mechanism (CDM), which was initially designed to funnel money from industrialized nations into the construction of solar, wind and other forms of renewable energy. Research by Sandbag, a U.K.-based nonprofit monitoring emissions trading, says just ten of the HCFC-22 projects accounted for 66 percent of all reductions sold in the E.U. carbon market in 2009.[247]

There are several possible ways for the profit from these trades to be used: as dividends for brokers in London and elsewhere; as increased profits for HCFC-22 manufacturers; or, to reduce the price of HCFC-22 by 30 to 40 percent, leading one commentator to warn that—

> ... the profits from HFC-23 decomposition sales will pull down HCFC-22 prices. This will pass on the wrong signal to HCFC22 producers. They should gradually phase out production capacity along with the Montreal Protocol control regime for HCFC-22. ... Low priced HCFC-22 will increase the GHG load of the atmosphere (which) is currently not reported under the UNFCCC GHG inventories. Lower HCFC-22 production costs do further establish a barrier to early phase out of HCFC-22 as developing country markets do become more

addicted to lôw priced HCFC-22. ... Back of envelope projections suggest that HCFC22 emissions will account for 6% of the Chinese total GHG emissions by 2010 ...[248]

HCFC-22 is by no means the only one of this family of chemicals with soaring production rates. The total quantity of HCFCs made globally increased globally from about 2.5 million metric tons in 1990 to nearly 5 million metric tons in 2004, and is projected to reach 8 billion by 2015.[249] Generally, production and consumption are declining in developed nations, but rising in developing countries.

Chemicals Covered by the Montreal Protocol

Ninety-six (96) chemicals are presently controlled by the Montreal Protocol, including:

- ***Halocarbons, notably chlorofluorocarbons (CFCs) and halons.*** CFCs were discovered in 1928 and were considered wonder gases because they are long-lived, non-toxic, non-corrosive, and non-flammable. They are also versatile and from the 1960s were increasingly used in refrigerators, air conditioners, spray cans, solvents, foams, and other applications. CFC-11 remains in the atmosphere for 50 years, CFC-12 for 102 years, and CFC-115 for 1,700. Halon 1301 is used primarily in fire extinguishers and has an atmospheric lifetime of 65 years.
- ***Carbon tetrachloride*** is used as a solvent and takes about 42 years to break down in the atmosphere. ***Methyl chloroform (1,1,1-trichloroethane)*** is also used as a solvent and takes about 5.4 years to break down.
- ***Hydrobromofluorocarbons (HBFCs)*** are not widely used, but they have been included under the Protocol to prevent any new uses.
- ***Hydrochlorofluorocarbons (HCFCs)*** were developed with the other CFCs, but were renamed, thus allowing their continued, and expended use. They cause global warming and destroy stratospheric ozone. They have an atmospheric lifetime ranging from 1.4 to 19.5 years.
- ***Methyl bromide (CH3Br)***, highly toxic, is lethal to virtually all animals, including humans. Injected into soil, it kills nematodes, thus shielding winter strawberries and tomatoes, as well as nut trees. It is also used to fumigate warehouses and logs awaiting export. Total world annual consumption is about 70,000 metric tons, most of it in the industrialized countries. It takes about 0.7 years to break down.
- ***Bromochloromethane (BCM)***, a new ozone-depleting substance that some companies sought to introduce into the market in 1998, has since been targeted for immediate phase-out.

Source: United Nations Environment Program

One way of effectively dealing with the contributions of HCFC-22 and HFC-23 would be to accelerate bans and phaseouts that are already scheduled under the Montreal Protocol.

Both the Protocol and the 1990 Clean Air Act Amendments[yyy] implementing its provisions

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[yyy] 47USC § 7416. Retention of State authority

Except as otherwise provided in sections 1857c–10 (c), (e), and (f) (as in effect before August 7, 1977), 7543, 7545(c)(4), and 7573 of this title (preempting certain State regulation of moving sources) nothing in this chapter shall preclude or deny the right of any State or political subdivision thereof to adopt or enforce (1) any standard or limitation respecting emissions of air in the United States are non-preemptive. This reflects a conscious decision by negotiators to leave the door open to programs at the local, state and national levels to move more quickly or aggressively against ozone-destroying CFCs.[250]

MONTREAL PROTOCOL CONTROLS

Chemical	Action	Developed Nations	Developing Nations
Halons	Phase out production and consumption	1994	July 1, 1999 - freeze at average 1995–97 levels 2005 - reduce 50 % 2007 - reduce 85 % 2010 - Phase out production and consumption
CFCs	Phase out production and consumption	1996	July 1, 1999 - freeze at average 1995–97 levels 2005 - reduce 50 % 2007 - reduce 85 % 2010 - Phase out production and consumption
carbon tetrachloride	Phase out production and consumption	1996	July 1, 1999 - freeze at average 1995–97 levels 2005 - reduce 50 % 2007 - reduce 85 % 2010 - Phase out production and consumption
methyl chloroform	Phase out production and consumption	1996	2003 - freeze at average 1998–2000 levels 2005 - reduce 30 % 2010 - reduce 70% 2015 - Phase out production and consumption
HBFCs	Phase out production and consumption	1996	1996
methyl bromide	Reduce by 25 % Reduce by 50% Reduce by 70% Phase out production and consumption	1999 2001 2003 2005	2002 - freeze at average 1995-98 levels 2005 - reduce 20% 2015 - Phase out production and consumption

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pollutants or (2) any requirement respecting control or abatement of air pollution; except that if an emission standard or limitation is in effect under an applicable implementation plan or under section 7411 or section 7412 of this title, such State or political subdivision may not adopt or enforce any emission standard or limitation which is less stringent than the standard or limitation under such plan or section.

Chemical	Action	Developed Nations	Developing Nations
HCFCs	Reduce by 35% Reduce by 65% Reduce by 90% Reduce by 99.5% For maintenance purposes only	2004 2010 2015 2020 0.5% permitted until 2030	2016 - freeze at 2015 levels 2040 - phase out
HBFCs	Phase out production and consumption	1996	1996
BCM	Phase out production and consumption	immediately	immediately

Production is total production minus amounts destroyed or used as chemical feedstock. Consumption is production plus imports minus exports. Trade in recycled and used chemicals is not included in consumption.

CAPTURING AND DESTROYING OZONE-DEPLETING SUBSTANCES

Throughout the world, ozone-destroying chlofluorocarbons (CFCs), all of which are powerful greenhouse gases, are "banked," or contained in hundreds of different sorts of goods, ranging from systems to put out fires to foams for insulating buildings and appliances. The chemicals can be captured and destroyed, but one of the great failings of the Montreal Protocol is that it creates no requirement for the world's governments to do this, so it is happening in an *ad hoc*, haphazard manner if at all. Similarly, the Protocol provides no financing or other incentives for developing nations to establish capture and destruction programs. There is nevertheless widespread agreement that global capture and destruction programs would not only slow the projected rise in global warming, but accelerate recovery of the stratospheric ozone layer. Indeed, a United Nations panel has estimated that destroying the banked chemicals could be equivalent to a reduction in emissions of carbon dioxide of more than 18 billion metric tons.[251]

Banks in refrigeration, stationary and mobile air conditioners are the easiest and most cost-efficient to recover and destroy. They are, in the terms of the Technology and Assessment Panel (TEAP) of the United Nations Environment Program, "reachable." However, the window of opportunity is closing rapidly, with TEAP estimating that by 2015, about 90 percent of the reachable CFCs and 50 percent of the HCFCs in developed nations and over 75 percent of the CFCs in these banks in developing nations, will have been emitted.

REACHABLE ODS BANKS WITH DIFFERENT LEVELS OF EFFORTS REFLECTING THE EASE OF ACCESS

Region (all in ktonnes)	ODS type	Low Effort	Medium Effort	High Effort
Developed Countries	CFCs	123.82	239.76	1009.08
	HCFCs	631.86	308.23	838.73

	Halons	44.32	15.00	--
Developing Countries	CFCs	160.79	225.80	154.27
	HCFCs	563.49	645.72	347.22
	Halons	22.24	28.95	--
Global		1546.52	1463.46	2349.3

Source: Workshop on management and destruction of ozone-depleting substance banks and implications for climate change Geneva, Technology and Economic Assessment Panel report on the environmentally sound management of banks of ozone-depleting substances: executive summary, July 13, 2009.

The Montreal Protocol has approved twelve technologies to date for the destruction of CFCs and halons. Developed countries use many different technologies for CFC destruction on a commercial basis. For instance, in Japan, more than ten technologies were being used in approximately eighty-two operational ODS destruction plants in 2006.[252]

One reason these programs have not spread widely is that they're not cheap: costs for capture and destruction range from $3.75 to $11 per kilogram, depending on the chemical and use.[253] Partially because of the cost, the few programs that have started have been funded through the so-called Clean Development Program of the Kyoto Protocol or other trading programs. These allow a polluter to continue emitting a greenhouse gas—say, carbon dioxide—if it reduces emissions of another—in this case, a CFC.

In California, for example, where a trading program was established under the 2006 Global Warming Solutions Act, one of the state's electric utilities, Pacific Gas & Electric (PG&E), paid to collect and destroy more than 38,000 pounds of CFCs. In exchange, PG&E is allowed by the state to continue emitting other pollutants that cause global warming. The CFCs will be from junked refrigerators, freezers and air conditioners.[254]

Aside from a very limited number of state or local programs, there is virtually no capture and destruction of CFCs in the United States. In a 2008 draft report, a contractor for the U.S. Environmental Protection Agency identified fewer than 10 facilities employing six different technologies that had commercially destroyed CFCs or burned waste-derived fuel containing them in the United States.[255]

In their quest to profit from cooling food, bodies, space and other things, corporations have wrought devastating environmental damage, and there may be no end in sight. Even the thinnest pancake has two sides, however, and the positive news from the success of these chemical, auto, appliance and other companies is this: their success at unnecessarily prolonging the production and use of old chemicals, while expanding distribution of new ones, provides an immense supply of low hanging fruit that can be harvested to quickly slow global warming. Collectively, these chemicals are referred to as "F-gases" because they all contain the element fluorine.

- ***Ban HFC-134a.*** The synthetic chemical now used in the air conditioners of cars and trucks, HFC-134a, causes global warming and has a lifetime of about 14 years.[256] If it were banned immediately, which Europe started doing on January 1, 2011 for new cars, the cooling benefits would be realized when children born today were in their teens.

- ***Capture banked CFCs.*** The synthetic chemicals that HFC-134a replaced, the chlorofluorocarbons (CFCs), also cause global warming. Their lifetimes are longer than HFC-134a, but many of them are "banked"—that is, trapped inside in foams, air conditioners and refrigerators, for example. Capturing these banked CFCs before they can be released chokes off what would otherwise be a powerful source of warming.

- ***Ban HCFC-22.*** One specific synthetic chemical, HCFC-22, has a lifetime of nine to thirteen years.[257] It is in widespread production and use and this is growing because China, India and other developing nations have been accorded special treatment under the Montreal Protocol, the international agreement for protection of stratospheric ozone. In addition, when HCFC-22 is made, another powerful warming agent, HFC-23, is released. If the Montreal Protocol were re-opened, HCFC-22 banned and banked supplies captured and destroyed, cooling could start in nine to thirteen years, and other powerful contributor warming, HCFC-23, eliminated.

There are a variety of existing legal authorities that could be invoked to reduce emissions of F-gases. One of the clearest, and less well known, basis for action would Title VI of the Clean Air Act, Stratospheric Ozone Protection. Although principally occupied by the details of controlling and phasing out chemicals that destroy stratospheric ozone, the over-arching purpose of the law is to protect the stratosphere from an "effect" that "may reasonably be anticipated to endanger public health or welfare," to wit:

> **SEC. 615. AUTHORITY OF ADMINISTRATOR.**
> If, in the Administrator's judgment, any substance, practice, process, or activity may reasonably be anticipated to affect the stratosphere, especially ozone in the stratosphere, and such effect may reasonably be anticipated to endanger public health or welfare, the Administrator shall promptly promulgate regulations respecting the control of such substance, practice, process, or activity, and shall submit notice of the proposal and promulgation of such regulation to the Congress.[zzz]

The interaction between global warming and changes in the stratosphere is well established.[aaaa] As one of the more prominent researchers, V. Ramanathan, explained, "According to the greenhouse theory of climate change, the climate system will be restored to equilibrium by a

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[zzz] 42 U.S.C. 7671n.

[aaaa] See, e.g., C. Schnadt et al. Interaction of atmospheric chemistry and climate and its impact on stratospheric ozone, *Climate Dynamics*,V. 18, Nr. 6, pp. 501–17, DOI: 10.1007/s00382-001-0190-z.

warming of the surface troposphere system and a cooling of the stratosphere."[bbbb]

Thus, whether or not an "endangerment finding" is made, or overturned by Congress, the authority—indeed the mandate—already exists in federal law. This section reviews one major source of warming by a collection of pollutants known as "F-gases," many of which have already been banned or subjected to controls because they destroy stratospheric ozone, as well as others that have entered the market place as substitutes for the ozone-destroyers.

A Brief History of the "F-Gases"

For other causes of global warming, a history of this sort would be not only unnecessary, but inappropriate. In the case of the F-gases, however, a brief history is essential because, for practical purposes, these chemicals do not exist in nature. They are developed, manufactured, sold, used and released by humans, or more accurately, corporations created by humans. Those who burn coal or drive cars are not purposefully causing global warming, but those who make F-gases must be assumed to have intended the natural consequences of their actions. For these substances, what is past is prologue. Past actions are likely to be repeated in the future. If there were harmful consequences in the past and we wish to avoid them in the future, it is essential to know what was done and by whom.

The simple truth is that companies develop these synthetic chemicals and market them at will, while others buy, use and release them at will, all in virtually complete disregard of their effects. This happened initially with CFCs, and while the fact that they destroy ozone was not initially known, that eventually came to light. DuPont and other manufacturers ignored the damage. When the ozone destruction could no longer be credibly denied because CFCs had destroyed so much ozone that a "hole" the size of North America and the height of Mt. Everest was opened in the Antarctic, the manufacturers relented. But they forced onto the market another synthetic chemical, HCFC-134a, that they knew full well caused global warming. There was much ado about HFC-134a being a "new" refrigerant, but in fact it was synthesized in 1936 by Albert Henne, a co-developer of CFCs.[258] He worked with Thomas Midgely of General Motors who is credited with developing R-12 in 1931. They kept it on the market and expanded the production and use of yet another F-gas, HCFC-22, which also causes global warming, in addition to stratospheric ozone destruction.

Now, HFC-134a is being banned and the same companies that gave the world ozone destruction and global warming are preparing to populate the planet with tens of millions of machines that can generate hydrofluoric acid, a chemical warfare agent, which can catch fire in, say, a minor auto accident. In addition, the new synthetic replacement for HFC-134a is less

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[bbbb] V. Ramanathan, The Greenhouse Theory of Climate Change: A Test by an Inadvertent Global Experiment, *Science,* Vol. 240 no. 4850, pp. 293–99, DOI: 10.1126/science.240.4850.293, 15 April 1988.

efficient than alternatives to F-gases (e.g., carbon dioxide) and will therefore increase energy consumption and, with it, emissions of air pollutants and greenhouse gases.

The first synthetic refrigerants, chlorofluorocarbons (CFCs), or "Freons," were developed and marketed by the giant U.S. chemical company, E. I. du Pont de Nemours and Company.[cccc, dddd] The great advantage of CFCs was the stability of the molecules, which made them nonflammable and somewhat non-toxic. Thomas Midgley, their co-developer, was fond of demonstrating these qualities by inhaling CFCs, then blowing out a candle flame, as he did in 1930 at a meeting of the American Chemical Society.[259, eeee]

In time, however, the molecular strength of which Midgley was so proud ultimately proved to be the Achilles heel of CFCs, because it allowed them to survive long enough to rise into the stratosphere, where incoming ultraviolet radiation sent speeding to Earth by the Sun's nuclear explosions, struck and shattered the bonds, freeing chlorine atoms to destroy stratospheric ozone with ferocity.[260] Each molecule of a CFC can destroy 100,000 molecules of ozone.[261]

The first scientists to publish their finding that CFCs destroy stratospheric ozone, Mario Molina and F. Sherwood Rowland, calculated that if industry were to continue releasing a million tons of CFCs each year, atmospheric ozone would eventually drop by 7 to 13 percent.[262] In reaction, in 1978 the United States banned the non-essential use of CFCs in aerosol spray cans, almost immediately reducing global releases by nearly one-half.[ffff]

[cccc]The same DuPont engineer that developed CFCs, Thomas Midgley, also developed tetraethyl lead, a gasoline additive that destroys intelligence in children and is linked to 50,000 U.S. deaths per year from high blood pressure.

[dddd]At the time, the DuPont family controlled not only General Motors, but its subsidiary, Frigidaire. This provided an immense competitive advantage for DuPont in the markets for mobile and stationary refrigeration equipment alike, and it quickly became the dominant maker of not only CFCs, but much of the equipment that used them.

[eeee]He was equally fond of demonstrating the supposed safety of the tetraethyl lead gasoline additive by washing his hands in the fuel, which may explain why in February, 1923 Midgley took leave for lead poisoning. Mark Bernstein, "Thomas Midgley and the Law of Unintended Consequences," *American Heritage*, Spring 2002, http://www.americanheritage.com/articles/ magazine/it/2002/4/2002_4_38_print.shtml, accessed Feb. 11, 2011. Also, Jamie Lincoln Kitman, "The Secret History of Lead," *The Nation*, March 2, 2000.

[ffff]The 1978 ban reduced aerosol use of CFCs in the United States by approximately 95 percent, eliminating nearly half of the total U.S consumption of these chemicals. U.S. Environmental Protection Agency, "Protection of Stratospheric Ozone," 40 CFR Part 82, Sep. 27, 1993, http://www.epa.gov/ozone/fedregstr/58fr50464.html, accessed March 15, 2011.

That ban was perhaps the most effective single action ever taken to slow global warming until the making of some CFCs was halted altogether by the Montreal Proocol. The cooling benefits from banning CFC use in spray cans in the 1970s, followed by adoption of limited other global bans in 1987 are far greater than what would have been achieved under the Kyoto Protocol, the international agreement to curb global warming.[263] Not surprisingly, some have suggested that the Montreal Protocol be re-crafted so that it can be used to address global warming in addition to stratospheric ozone depletion.[264]

Only Canada, Norway and Sweden followed the U.S. ban,[265] however, and by 1988 global production had rebounded to an estimated at 12 million tons[266]. Despite arguments by scientists, including the National Academy of Sciences in the United States and the Royal Academy of Sciences in the United Kingdom, the chemicals remained not only on the market, but thrived, being used to make new products ranging egg cartons, "silly string" and foam "clamshells" for McDonald's fast food hamburgers.

> "There was, you know, a world before Styrofoam egg cartons."
>
> Sen. John Chafee (R.-RI), circa 1987

Then in May 1985 the British Antarctic Survey stunned the world, announcing that it had discovered a massive hole in the ozone layer over the Antarctic the size of North America and the height of Mt. Everest. The fears triggered by Rowland and Molina's conclusions were neither trivial nor speculative. Numerous studies soon confirmed that CFCs were not only responsible for the Antarctic hole, but for global ozone destruction as well.[4]

Remarkably, despite discovery of both global ozone destruction and "holes" at both poles, the chemical industry, particularly DuPont continued to fight a ban on CFC production.[267] The company had pledged to Congress in 1974, and in full-page newspaper advertisements to the public, that "should reputable evidence show that some fluorocarbons cause a health hazard through destruction of the ozone layer, we are prepared to stop production of these compounds."[268] But on March 4, 1988, DuPont President Richard Heckert angrily refused to stop making CFCs, saying there was no reason for Du Pont to stop. But 20 days later, on March 24, 1988, Heckert reversed course and said DuPont would get out of the chlorofluorocarbon business entirely.[269] Heckert's initial refusal, followed by his apparent concession, came six months after the world had already agreed in the Montreal Protocol to regulate production and use of CFCs.[270]

Although the Protocol has been widely lauded as one of history's most effective actions to protect the environment,[gggg] in truth, the result has been a second global environmental

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[gggg]"The Montreal Protocol, the foundation for this process, thus stands as an extraordinary and even spectacular success story. Its success owes a great deal to the actions not only of the United States government, which played an exceedingly aggressive role in producing the Protocol, but to American companies as well, which stood at the forefront of technical innovation leading to substitutes for ozone-depleting chemi cals."Cass R. Sunstein, "Of Montreal

catastrophe—acceleration of global warming—and one that was obvious from the outset.[271] When officials decided to approve HFC-134a as a replacement for CFCs, they knew full well that it was a powerful cause of global warming, but cleared the chemical for use despite this.[272] Between 1990 and 2002, emissions of HFC-134a increased 59-fold, more than any other greenhouse gas.[273] That was just the beginning of the Montreal Protocol's failings, however, which include the following:

- **First,** although the new synthetic chemical selected to replace the CFCs, HFC-134a, does not destroy ozone, it is a powerful cause of global warming, roughly 3,400 times as powerful as carbon dioxide over a 20-year period.[274] Less harmful refrigerants were, and are, available. Even if using HFC-134a for some products might be justified, there was absolutely no need to increase global warming by using it as the substitute for ozone-destroying CFCs in all cases. In Europe, for example, the public demanded hydrocarbon replacements, which now account for 36 percent of all refrigerator production globally, principally with isobutene (HC-600a).[275]

- **Second,** systems that use HFC-134a are intrinsically leaky,[hhhh,iiii] in part because the molecule is smaller than the CFC-12 which it replaces.[276] Leaking just one pound of HFC-134a from a car's air conditioning system has the same global warming impact as physically driving the car for a month.[277] When it approved HCFC-134a in 1995, the U.S. Environmental Protection Agency candidly admitted that "HFC-134a's contribution to global warming could be significant in leaky end-uses such as motor vehicle air conditioning systems."[278] Today, after roughly 20 years of production, about 59 percent of HFC-134a ever made has entered the atmosphere.[279]

- **Third,** apparently because HFC-134a would not have been a suitable substitute for some CFCs uses, or perhaps not profitable enough, DuPont, environmental groups, and the U.S. Environmental Protection Agency met secretly and, for the first and only time in history, singled out a specific member of the Freon family and renamed it: CFC-22 ceased to exist and instead became HCFC-22. Voila! Governments and industry could, and did, boast that they were no longer using CFCs.[280] There were two calamitous results:

  - It boosted production and release of HCFC-22, rising sharply from 490,000 metric tons in

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and Kyoto: A Tale of Two Protocols," *Harv. Envtl. L. Rev.* 2007.

[hhhh] About 60 percent of -134a emissions are from routine leaks from refrigeration and air conditioning. In one test of the permeability of hoses typically used for auto air conditioners, DuPont found that one square meter would leak 1.07 kilograms of -134a per year.

[iiii] Based on data supplied to the State of Minnesota, every 2009 car leaked HFC-134a. The best lost 0.6 percent per year, while the worst leaked 4.3 percent. Minnesota Pollution Control Agency, "Climate Change: Mobile Air Conditioners," http://www.pca.state.mn.us/index.php/topics/climate-change/regulatory-initiatives-programs-and-policies/climate-change-mobile-air-conditioners.html, accessed Feb. 16, 2011.

2000 to a projected level of 710,000 in 2015,[281] further exacerbating global warming and unnecessarily prolonging ozone depletion.[jjjj]

- It increased emissions of HFC-23, an unavoidable by-product of HCFC-22 production which, over 100 years, is 11,700 times as powerful a warming agent as carbon dioxide.[282] HFC-23 historically had been considered a waste to be vented to the atmosphere.[283] It is emitted at a rate of between 2 and 4 percent of HCFC-22 production.[kkkk]

- **Fourth,** the negotiators focused phasing out on production and consumption of CFCs, not releases. As a result, untold amounts of CFCs remain "banked," or stored in refrigerators, foams and other products. There is no requirement in the Montreal Protocol that the CFCs be captured and destroyed when these products are discarded, so in most cases they aren't.[llll] The United Nations projects that emissions of banked F-gases in 2015 will be equivalent to about 1.15 gigatons of carbon dioxide, which is slightly less that the 2007 emissions of Japan.[284]

- **Fifth,** in addition to causing global warming directly, chemicals can also cause it indirectly—for example, by reducing a car's gas mileage, thus boosting the amount of CO_2 it emits—and HFC-134a does exactly that.

- **Sixth**, the Protocol created two categories of nations: Article 5, or developing nations; and, Non-Article 5, or developed nations. Article 5 nations are treated much more leniently, with slower reductions in production, exemption from reporting requirements, etc., even though

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[jjjj]In the 15 years prior to 2004, steady or declining rates of HCFCs were observed in the global background atmosphere. But, since 2005, the accumulation rates of these gases have increased substantially; the growth rates of HCFC-22, HCFC-142b, and HCFC-141b were 50 to 100 percent larger in 2007 than measured in 2004. Increased outputs of these gases from developing countries are believed to be the cause. Russell C. Schnell, "Updates on radiatively important atmospheric trace gas concentrations and trends in other parameters from the NOAA ESRL global network," http://ams.confex.com/ams/89annual/techprogram/paper_144854.htm, Jan. 15, 2009, accessed Feb. 17, 2011.

[kkkk]Between 1978 and 1995, HFC-23 concentrations increased from 3 to 10 parts per trillion (ppt), and continued to rise.

[llll]The Montreal Protocol controls only substances that deplete ozone and even then it applies only to production and consumption. Thus, it does not take into the global warming caused by F-gases, nor does it affect them once they enter commerce. This leaves emissions of CFCs and HCFCs present in products, or "banked," and not subject to controls internationally. The banked CFCs and HCFCs contained in existing refrigerators, foams and other products will eventually be released, even though they could be captured and destroyed rather easily. The build up of banks will, in the absence of management measures, significantly determine future emissions.

some of them—China and India, for example—are major sources of pollution. While this divergent treatment reflects a principle agreed to in 1992 at the United Nations Conference on Environment and Development—all countries have a common but differentiated responsibility to protect and manage the global commons—it nevertheless stretches a process that arguably could have been completed within two decades to scores of years, loading the air unnecessarily with immense amounts of air pollution, including greenhouse gases. Not knowing what emissions actually are, scientists are forced to "deduce" them or otherwise engage in awkward and potentially misleading calculations.[285]

These are by no means the only failings of the Montreal Protocol, just the worst of them. Production and use of a chemical that can and has killed humans,[mmmm] methyl bromide, continues because the United States has adamantly insisted on a "critical" use exception to a ban—an exception that makes it possible to grow winter strawberries and tomatoes.

Cooling the Earth by Eliminating "F-gases"

It would have been vastly preferable to simply rid the world of CFCs a quarter-century ago, but that did not happen. The replacement, HFC-134a, should never have entered the marketplace, nor should production of HCFC-22 have been allowed to grow exponentially. Programs to capture and destroy banked F-gases should have been started, but they were not. That means all of these actions can be taken now, with immense benefits. Because HFC-134a and HCFC-22 both have short atmospheric lifetimes—fourteen years, and nine to thirteen years, respectively—the cooling benefits of actions will be quickly realized.

Banning HFC-134a

Direct versus Indirect Emissions. Air conditioners in cars and trucks cause global warming both directly—that is, from leaks of a refrigerant that is a greenhouse gas—and indirectly, as a result of emissions from the energy consumed to manufacture, operate, and dispose of them.

Direct emissions. Leaks of a chemical refrigerant fall into the following categories:

- **Regular emissions** are leaks from the air conditioning system in operation through, for example, hoses, valves, and compressors. Whether there are regular emissions and, if so, how much depends both on the refrigerant itself—whether it can pass through hoses, for example—and the equipment. Metal hoses leak less than nylon, for instance.

[mmmm] Horowitz, BZ et al., "An unusual exposure to methyl bromide leading to fatality," *J Toxicol Clin Toxicol.* 1998;36(4):353–7.

- **Irregular emissions** occur due to accidents, stone hits, product defects, etc. Ordinary "fender bender" accidents can rupture hoses, for example.

- **Service emissions** can occur from garages during maintenance and repair and others from home mechanics refilling their system with disposable canisters of refrigerant. At a garage, whether there are leaks and of how much, depends very much on the skills and practices of the mechanic.

- **End-of-life emissions** occur when a vehicle is taken to a recycling yard.

In addition, refrigerants can leak during production and transport.

Indirect emissions. Indirect emissions are largely due to energy consumed when air conditioners are made, operated and disposed. Operating emissions are a function of the energy used to run the system and transport it. Again, some refrigerants are more efficient than others, and some systems weigh more or less, again depending on the chemical.

Direct Emissions from HFC-134a Systems

Systems using HFC-134a leak badly. Those leaks cost consumers, principally people who own cars, money, and lots of it. They also cause global warming, because HFC-134a is a powerful greenhouse gas, about 3,400 times as powerful as carbon dioxide compared over a 20-year period.[286] The leaks may also cause other damage, because HFC-134a degrades rapidly in the air into trifluoroacetic acid (TFA), which then washes into lakes, rivers, streams, oceans and other bodies of water, where it appears to remain inert. However, so little study has been undertaken that it is impossible to say one way or the other.

HFC-134a is on the market in the United States, because it was approved by the U.S. Environmental Protection Agency as an acceptable CFC substitute under the Significant New Alternatives Policy (SNAP) program.[nnnn] The first step toward rescinding that approval in the

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[nnnn]The Significant New Alternatives Policy (SNAP) program, which implements section 612 of the Clean Air Act, was created to assure the health and environmental safety of alternatives for ozone-depleting substances that were being phased out under the 1990 Clean Air Act Amendments. The purpose of the SNAP program is "to allow a safe, smooth transition away from ozone-depleting compounds by identifying substitutes that offer lower overall risks to human health and the environment." Environmental Protection Agency, Significant New Alternatives Policy (SNAP) Program, http://www.epa.gov/ozone/snap/index.html, accessed March 22, 2011.

United States has recently been taken,[oooo] with a phaseout of the chemical that started in the European Union for use in new cars, which was effective January 1, 2011.[287]

That mobile air conditioners using HFC-134a leak badly is beyond question. According to manufacturers of HCFC-134a, between the time it was placed on the market in 1990 through 2005, about 19.7 billion pounds, or about 59 percent of the HFC-134a ever made, had leaked out of air conditioners and entered the atmosphere.[288] At the 2007 street price for HFC-134a in Europe, the leaked refrigerant was worth $229.9 billion,[289] and the price of HFC-134a continues to rise.[290]

> Freon is very hard to contain in an automotive system. The reason is your air conditioning compressor operates at all different speeds due to engine RPM. The rest of the system is comprised of many dissimilar materials that expand and contract and, along with the movement of the engine, this allows a minute amount of freon to escape. This is normal and that's why the system should be checked for a low charge. ...We at Professional Fleet Services are certified by ASC and MACS in the proper handling and have the equipment to handle both R12 and R134A refrigerant along with some of the most sophisticated leak detection equipment now available. For $59.95 we will service your air conditioning. ... Due to the constantly changing price of R12 and R134A, the refrigerant needed to fully charged the A/C system would be in addition to the above service.
>
> Lansing Auto Air Conditioning Repair
> http://www.professionalfleet.com/lansing_auto_repair_services/lansing_auto_air_conditioning_repair, accessed March 15, 2011

This leakage estimate is consistent with studies that found about 60 percent of HFC-134a emissions were from routine leaks. In a test of the permeability of hoses typically used for auto air conditioners, DuPont found that one square meter would leak 1.07 kilograms of -134a per year.[291] A more recent analysis conducted by the French research institute École de Mines found that the average leak flow rate from new HFC-134a automobile air conditioning systems was about 10 grams per year, with the compressor accounting for 50 to 60 percent of the losses.[292]

In still another test—this one with stationary vehicles located within an enclosed space and with both the motor and air conditioning systems turned off—"all vehicles exhibited measurable R-134a leakage over the 2-day diurnal test. Leak rates of R-134a ranged from 0.01 to 0.36 g/day with an average of 0.07+/-0.07 g/day." The 28 light-duty vehicles were from five manufacturers (Ford, Toyota, Daimler Chrysler, General Motors, and Honda).

The researchers estimated that the global warming impact of the leaked HFC-134a was 4 to 5 percent of that from the carbon dioxide emitted, assuming 10,000 miles were driven a year.[293] Nearly 54 percent of the 1,178 metric tons transportation-related emissions of carbon dioxide in the United States in 2009 resulted from gasoline consumption for personal vehicle use, or about 636 metric tons.[294] Put another way, eliminating HFC-134a in the United States alone would be

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[oooo] Institute for Governance & Sustainable Development, "EPA Set to Ban Powerful GHGs From Auto Air Conditioning," March 23, 2011, http://www.enn.com/press_releases/3675, accessed March 23, 2011.

the global warming equivalent of reducing all carbon dioxide emissions from the world's 63 smallest emitting nations.[295]

Some companies attribute this high leakage rate to the smaller molecule size of HFC-134a compared to CFC-12, the refrigerant it replaced.[296] However, tests have also confirmed that the tightness of mobile air conditioners drops over time, increasing leakage.[297]

As is the case in reducing methane emissions, controls do not necessarily translate into additional costs. Just as the use of another DuPont chemical, tetraethyl lead, increased consumer costs because it damaged engines and their components, so, too, does HFC-134a. The price of HFC-134a sold in 30-pound tanks is currently about $350, or $11.67 per pound.[298] Prices have been rising so rapidly that Honeywell imposed two 10 percent hikes in Europe, one in April 2007 and another in July 2007.[299] The average amount of HFC-134s in an auto air conditioning system is about two pounds,[300] so the HFC-134a alone costs roughly $23.

The cost of losing a charge of HFC-134a, however, only begins with replacing the refrigerant. According to the commercial web site costhelper, the following costs for auto air conditioning repair are typical :

- Between $250 and $650 to test for leaks, replace a few minor parts and then top-off or completely recharge the refrigerant in a vehicle's system. The work takes an average of four hours labor, at roughly $50 –$100 an hour, plus parts; for luxury vehicles both parts and labor may cost more.

- For more extensive repairs the costs can range from $800–$1,200 for replacing or upgrading most of the major parts. Vehicles with easy access to the A/C system and plentiful low-cost parts could be less; high-end luxury vehicles will often cost more.[301]

Money, however, is only one way of measuring cost, and the costs of HFC-134a leaks in terms of damage to health and the environment are unknown. That's largely because, as was the case with CFCs, it is almost impossible to predict the future. In fact, there are some eerie similarities between HFC-134a, its likely replacement, HFO-1234yf, and the CFCs.

The chemical bonds of CFCs are so strong that they survive until they reach the stratosphere, where ultraviolet radiation shatters them, freeing chlorine to destroy the ozone layer. Similarly, when other F-gases, including HFC-134a, leak into the air, they are quickly attacked and degraded to form trifluoroacetate (TFA), whose chemical bonds are even stronger than those of the CFCs.[302]

Highly soluble in water, TFA is transported rapidly by rain, snow and fog back to the Earth's surface, where it enters streams, rivers, lakes and ponds. In China, when researchers tested for the presence of TFA, it was found in rainfall, snowfall, inland surface water, ground water, and waste water from nine provinces and autonomous regions in concentrations ranging from 4.7 to 221 nanograms per liter (ng/l). Surprisingly, TFA was found even in Beijing groundwater at 10 ng/l.[303] In a Canadian study, the source of TFA appeared to be urban centers.[304] In Switzerland when more than 1,000 water samples were analyzed for TFA it was found to be "quite persistent in the aquatic and terrestrial environment and may thus accumulate in soils and groundwater."[305]

DuPont and other HFC-134a manufacturers claim that there is no significant long-term accumulation in forests, bogs and other soils.[306] But when researchers tested the claim that TFA would not accumulate by examining the Hubbard Brook research forest in New Hampshire, they found it wrong: TFA was retained within the forest's vegetation and soil compartments, especially in wetlands.[307]

TFA concentrations continue to increase, especially in bodies of water lacking outflows, like many wetlands. In California, for example, TFA accumulated in seasonal wetlands to the point that aquatic plants growing in the water had 279 ng/g dry weight of TFA in their tissues as compared to 33 ng/g for species growing outside the pools. The TFA was retained from year to year, thus increasing further with time.[308]

What damage trifluoricacetic acid might be doing is fundamentally unknown. The Alternative Fluorocarbons Environmental Acceptability Study (AFEAS), is an undertaking of seven major producers and users of F-gases.[pppp] It has funded most of the research and, consequently, has provided the primary source of information on the potential environmental effects of the HCFCs and HFCs.[309, qqqq] In an environmental risk assessment published in 1999, about 10 years after HFC-134a entered the market place and funded by AFEAS, the authors concluded that "Based on available data, one can conclude that environmental levels of TFA resulting from the breakdown of alternative fluorocarbons do not pose a threat to the environment."[310]

The presence of fluorine in compounds can have a profound effect on potency, which helps explain the dramatic increase of its content in drugs, pesticides and other chemicals. In 1978, roughly 600 pesticides were known, but only about 25, or 4 percent contained fluorine. By 2004, fluorine-containing compounds accounted for more than 17 percent of all commercially available crop protection agents and others under development. In the pharmaceutical arena, around 220 fluorinated drugs were on the market in 1990, and about 8 percent of all were synthetic drugs. Six years later more than 1,500 fluorine-containing drugs were under

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[pppp]Arkema, Asahi Glass Co., Daikin Industries, DuPont, Honeywell, INEOS Fluor Ltd., and Solvay S.A.

[qqqq]Some manufacturers have also funded studies. For example, a study of the fate and effects of TFA in soils from throughout the world was supported by the DuPont Educational Program. Richey, D. et al., "Soil Retention of Trifluoroacetate," *Environ. Sci. Technol.*, 1997, 31, 1723–27.

development.[311]

TFA is one of a family of chemicals known as perfluorinated organic acids (PFOAs). They are the breakdown products of HFCs, and are now found in all of the world's oceans, and many organisms. One team of researchers collected seawater samples during several international research cruises undertaken during 2002–2004 in the central to eastern Pacific Ocean (19 locations), South China Sea and Sulu Seas (5), north and mid-Atlantic Ocean (12), and the Labrador Sea (20). An additional 50 samples of coastal seawater from several Asian countries (Japan, China, Korea) were analyzed. PFOA was found at levels ranging from several thousands of picograms per liter (pg/L) in water samples collected from coastal areas in Japan to a few tons of pg/L in the central Pacific Ocean. Where these chemicals go and what injury they might cause remains largely undefined and, frankly, under-investigated.[312]

There have been relatively few studies of the environmental impacts of fluorinated compounds such as TFA. In one, decomposition of cellulose and nitrification in the soil were inhibited, and respiratory intensity was also reduced.[313]

TFA and other PFOAs are almost literally everywhere. One study found them even in newborn babies,[rrr] raising concerns about the chemical's use as a protective coating on some food packaging.

Indirect Increases in Emissions. There also are indirect impacts on global warming caused by air conditioners in cars and trucks. They consume more energy than any other auxiliary vehicle equipment. In the United States alone, these air conditioners consume over 7 billion gallons of gasoline every year, emitting over 58 million metric tons of carbon dioxide.[314]

One example of the impact that air conditioning can have on fuel economy, and hence indirect emissions, is provided by a vehicle simulation of a Hyundai Santro. On the Indian combined drive cycle, the Santro averaged 46.9 mpg. (This compares to the United States average of 21.4 mpg for cars and 17.1 mpg for light trucks and the European Union average for cars of 30.4 mpg.) When the load of an air conditioner was added to the Santro simulation, fuel economy dropped 22 percent to 36.6 mpg.[315]

FUEL ECONOMY DROP WITH AIR CONDITIONING

U.S. Car	U.S. Truck	E.U. Car
-18 percent	-14 percent	-10 percent

[rrr]A study of about 300 umbilical cord blood samples by researchers at the Johns Hopkins Bloomberg School of Public Health found that newborn babies are exposed to perfluorooctane sulfonate (PFOS) and PFOA while in the womb. Ahmed ElAmin, "Packaging PFOAs found in newborns," Food Production Daily.com, Apr. 26, 2007.

Source: J ohn Rugh, "Significant Fuel Savings and Emission Reductions by Improving Vehicle Air Conditioning," 15th Annual Earth Technologies Forum and Mobile Air Conditioning Summit April 15, 2004, National Renewable Energy Laboratory, http://www.nrel.gov/vehiclesandfuels/ancillary_loads/pdfs/fuel_savings_ac.pdf.

In the United States the average on time for A/C is 32.6 percent; in the European Union it is 21.1 percent.

Reducing the engine load from an air conditioner by using more efficient variable displacement compressors (VDC), condensers and evaporators with improved heat transfer, and better control systems, can cut indirect emissions by 30 to 50 percent.

VDCs are more common in Europe than the United States. They reduce engine load by varying refrigerant according to the cooling demand. In contrast, fixed displacement compressors (FDCs) provide a constant flow of refrigerant with on/off cycling. As cooling demands increase, which they do in much of the south and west of the United States, the benefits of VDCs decrease compared to FDCs. Indeed, when maximum compressor displacement is required, the benefit of VDCs over FDCs approaches zero.[316]

In the United States the average "on" time for air conditioners is 32.6 percent, while in the European Union it is 21.1 percent.[317] For cars with smaller engines, FDCs can significantly reduce performance. In the EU and other areas of the world where engine displacement is less than two liters, variable speed compressors improve driving performance, while maintaining fuel economy.[318]

Another way to increase the efficiency of car air conditioning, thus reducing emissions by boosting fuel economy, is to control the mixture of outside versus inside air, either automatically or manually. This reduces the amount of outside air that needs to be cooled. Air conditioner performance can also be improved by eliminating "air reheat." This is common in fixed displacement air compressors, which overcool, then reheat the air to moderate chill. Because VDCs modulate refrigerant flow, they can eliminate air reheat. However, eliminating air reheat requires automatic climate controls, and manual controls are most prevalent in the United States.[319]

Accelerating Bans and Phaseouts

The Montreal Protocol is by no means the unalloyed success that its admirers would have the public believe. In the view of some, the phase out schedules are leisurely and the coverage incomplete. The interplay between it and the Kyoto Protocol not only allows manufacturers to capture billions in windfall profits, but in a perverse, almost Kafkaesque way, had led to actual increases in production of some powerful greenhouse gases at a time when they could be, and should be, falling. It has been and continues to be manipulated in the most cynical way as an engine to increase profits for London, Chicago and other traders, while diverting immense sums of money away from the development of wind, solar and other forms of renewable energy.

At the insistence of the United States, the Kyoto Protocol allows polluters and their customers to trade their pollution like so many shares of stock or head of cattle. First, the warming impact of, say, one ton of a substance is converted to common value, its "carbon dioxide equivalent" or CO_2e. Consider the case of HCFC-22.

Seek out information on uses of HCFC-22 on the web, and you will quickly be told by, for example, DuPont that HCFC-22 is the "most commonly used as a refrigerant in residential and commercial air conditioning."[320] Yet 40 percent of global production is not for refrigeration or chilling, but what some might consider a rather trivial purpose: production of polytetrafluoroethylene (PTFE), more commonly known as Teflon, DuPont's brandname.[321] Because HCFC-22 produced as a feedstock is exempt, its production will be unabated under the Montreal Protocol.

HCFC-22 is 1,810 times more powerful than carbon dioxide as a greenhouse gas. Its global warming potential, or GWP, is therefore 1,810. Eliminating one ton is the warming equivalent of cutting CO_2 emissions by 1,810 tons. If carbon dioxide is "trading"—that is, is being bought and sold on stock exchanges—for $10 per ton, a factory owner that reduces HCFC emissions by one ton can sell that reduction for $18,100.

Another greenhouse gas, HFC-23, is an unwanted byproduct of producing HCFC-22. Its lifetime is about 270 years and its GWP is 11,700. Typically, the ratio of HFC-23/HCFC-22 is three to four percent.[322]

HFC-23 is an unwanted by product that can be destroyed at a cost of about $.50 per ton for a carbon dioxide equivalent.[323] If a newly built plant to produce HCFC-22 is constructed without destruction capability, then is retrofitted later, the HFC-23 reductions can be sold in a trading program. On March 16, 2011, the prices for carbon allowances in the European Union was 17.75 euros, or $24.82 per metric ton.[324] Thus, one ton of CO_2e destroyed at a cost of $.50 could be sold for $49.64 on March 16, 2011.

> (H)arshest critics say outright fraud is at work and suggest that up to half of all the Certified Emission Reductions (CERs) ever issued are bogus. CERs are the offset credits earned from CDM projects, sold primarily into the European Union's cap-and-trade scheme.
>
> Nathanial Gronewold,
> "U.N. Body Probes Cases of Paying Greenhouse Gas Emitters, Which Then Produce More,"
> *New York Times*, July 26, 2010

Not surprisingly, sales of destroyed HFC-23 are robust. For example, in 2009 the Swedish government's power company, Vattenfall, bought 6.7 million emission reductions, and about 56 percent, or 3.6 million, came from HFC-23 destruction projects in China and India.[325]

There are 19 manufacturers of HCFC-22, mainly located in China and India, with others in South Korea, Argentina and Mexico. In 2010, greenhouse gas trading projects utterly dominate the Kyoto Protocols Clean Development Mechanism (CDM), which was initially designed to funnel money from industrialized nations into the construction of solar, wind and other forms of renewable energy. Research by Sandbag, a U.K.-based nonprofit monitoring emissions trading, says just ten of the HCFC-22 projects accounted for 66 percent of all reductions sold in the E.U. carbon market in 2009.[326]

There are several possible ways for the profit from these trades to be used: as dividends for brokers in London and elsewhere; as increased profits for HCFC-22 manufacturers; or, to reduce the price of HCFC-22 by 30 to 40 percent, leading one commentator to warn that—

> ... the profits from HFC-23 decomposition sales will pull down HCFC-22 prices. This will pass on the wrong signal to HCFC22 producers. They should gradually phase out production capacity along with the Montreal Protocol control regime for HCFC-22. ... Low priced HCFC-22 will increase the GHG load of the atmosphere (which) is currently not reported under the UNFCCC GHG inventories. Lower HCFC-22 production costs do further establish a barrier to early phase out of HCFC-22 as developing country markets do become more addicted to low priced HCFC-22. ... Back of envelope projections suggest that HCFC22 emissions will account for 6% of the Chinese total GHG emissions by 2010 ...[327]

HCFC-22 is by no means the only one of this family of chemicals with soaring production rates. The total quantity of HCFCs made globally increased globally from about 2.5 million metric tons in 1990 to nearly 5 million metric tons in 2004, and is projected to reach 8 billion by 2015.[328] Generally, production and consumption are declining in developed nations, but rising in developing countries.

Chemicals Covered by the Montreal Protocol

Ninety-six (96) chemicals are presently controlled by the Montreal Protocol, including:

- ***Halocarbons, notably chlorofluorocarbons (CFCs) and halons.*** CFCs were discovered in 1928 and were considered wonder gases because they are long-lived, non-toxic, non-corrosive, and non-flammable. They are also versatile and from the 1960s were increasingly used in refrigerators, air conditioners, spray cans, solvents, foams, and other applications. CFC-11 remains in the atmosphere for 50 years, CFC-12 for 102 years, and CFC-115 for 1,700. Halon 1301 is used primarily in fire extinguishers and has an atmospheric lifetime of 65 years.
- ***Carbon tetrachloride*** is used as a solvent and takes about 42 years to break down in the atmosphere. ***Methyl chloroform (1,1,1-trichloroethane)*** is also used as a solvent and takes about 5.4 years to break down.
- ***Hydrobromofluorocarbons (HBFCs)*** are not widely used, but they have been included under the Protocol to prevent any new uses.
- ***Hydrochlorofluorocarbons (HCFCs)*** were developed with the other CFCs, but were renamed, thus allowing their continued, and expended use. They cause global warming and destroy stratospheric ozone. They have an atmospheric lifetime ranging from 1.4 to 19.5 years.
- ***Methyl bromide (CH3Br)***, highly toxic, is lethal to virtually all animals, including humans. Injected into soil, it kills nematodes, thus shielding winter strawberries and tomatoes, as well as nut trees. It is also used to fumigate warehouses and logs awaiting export. Total world annual consumption is about 70,000 metric tons, most of it in the industrialized countries. It takes about 0.7 years to break down.
- ***Bromochloromethane (BCM)***, a new ozone-depleting substance that some companies sought to introduce into the market in 1998, has since been targeted for immediate phase-out.

Source: United Nations Environment Program

One way of effectively dealing with the contributions of HCFC-22 and HFC-23 would be to accelerate bans and phaseouts that are already scheduled under the Montreal Protocol.

Both the Protocol and the 1990 Clean Air Act Amendments[ssss] implementing its provisions in the United States are non-preemptive. This reflects a conscious decision by negotiators to leave the door open to programs at the local, state and national levels to move more quickly or aggressively against ozone-destroying CFCs.[329]

[ssss]47USC § 7416. Retention of State authority
Except as otherwise provided in sections 1857c–10 (c), (e), and (f) (as in effect before August 7, 1977), 7543, 7545(c)(4), and 7573 of this title (preempting certain State regulation of moving sources) nothing in this chapter shall preclude or deny the right of any State or political subdivision thereof to adopt or enforce (1) any standard or limitation respecting emissions of air pollutants or (2) any requirement respecting control or abatement of air pollution; except that if an emission standard or limitation is in effect under an applicable implementation plan or under section 7411 or section 7412 of this title, such State or political subdivision may not adopt or enforce any emission standard or limitation which is less stringent than the standard or limitation under such plan or section.

MONTREAL PROTOCOL CONTROLS

Chemical	Action	Developed Nations	Developing Nations
Halons	Phase out production and consumption	1994	July 1, 1999 - freeze at average 1995–97 levels 2005 - reduce 50 % 2007 - reduce 85 % 2010 - Phase out production and consumption
CFCs	Phase out production and consumption	1996	July 1, 1999 - freeze at average 1995–97 levels 2005 - reduce 50 % 2007 - reduce 85 % 2010 - Phase out production and consumption
carbon tetrachloride	Phase out production and consumption	1996	July 1, 1999 - freeze at average 1995–97 levels 2005 - reduce 50 % 2007 - reduce 85 % 2010 - Phase out production and consumption
methyl chloroform	Phase out production and consumption	1996	2003 - freeze at average 1998–2000 levels 2005 - reduce 30 % 2010 - reduce 70% 2015 - Phase out production and consumption
HBFCs	Phase out production and consumption	1996	1996
methyl bromide	Reduce by 25 % Reduce by 50% Reduce by 70% Phase out production and consumption	1999 2001 2003 2005	2002 - freeze at average 1995-98 levels 2005 - reduce 20% 2015 - Phase out production and consumption
HCFCs	Reduce by 35% Reduce by 65% Reduce by 90% Reduce by 99.5% For maintenance purposes only	2004 2010 2015 2020 0.5% permitted until 2030	2016 - freeze at 2015 levels 2040 - phase out
HBFCs	Phase out production and consumption	1996	1996
BCM	Phase out production and consumption	immediately	immediately

Production is total production minus amounts destroyed or used as chemical feedstock. Consumption is production plus imports minus exports. Trade in recycled and used chemicals is not included in consumption.

Capturing and Destroying Ozone-Depleting Substances

Throughout the world, ozone-destroying chlofluorocarbons (CFCs), all of which are powerful greenhouse gases, are "banked," or contained in hundreds of different sorts of goods, ranging from systems to put out fires to foams for insulating buildings and appliances. The chemicals can be captured and destroyed, but one of the great failings of the Montreal Protocol is that it creates no requirement for the world's governments to do this, so it is happening in an *ad hoc*, haphazard manner if at all. Similarly, the Protocol provides no financing or other incentives for developing nations to establish capture and destruction programs. There is nevertheless widespread agreement that global capture and destruction programs would not only slow the projected rise in global warming, but accelerate recovery of the stratospheric ozone layer. Indeed, a United Nations panel has estimated that destroying the banked chemicals could be equivalent to a reduction in emissions of carbon dioxide of more than 18 billion metric tons.[330]

Banks in refrigeration, stationary and mobile air conditioners are the easiest and most cost-efficient to recover and destroy. They are, in the terms of the Technology and Assessment Panel (TEAP) of the United Nations Environment Program, "reachable." However, the window of opportunity is closing rapidly, with TEAP estimating that by 2015, about 90 percent of the reachable CFCs and 50 percent of the HCFCs in developed nations and over 75 percent of the CFCs in these banks in developing nations, will have been emitted.

Reachable ODS Banks with Different Levels of Efforts Reflecting the Ease of Access

Region (all in ktonnes)	ODS type	Low Effort	Medium Effort	High Effort
Developed Countries	CFCs	123.82	239.76	1009.08
	HCFCs	631.86	308.23	838.73
	Halons	44.32	15.00	--
Developing Countries	CFCs	160.79	225.80	154.27
	HCFCs	563.49	645.72	347.22
	Halons	22.24	28.95	--
Global		1546.52	1463.46	2349.3

Source: Workshop on management and destruction of ozone-depleting substance banks and implications for climate change Geneva, Technology and Economic Assessment Panel report on the environmentally sound management of banks of ozone-depleting substances: executive summary, July 13, 2009.

The Montreal Protocol has approved twelve technologies to date for the destruction of CFCs and halons. Developed countries use many different technologies for CFC destruction on a commercial basis. For instance, in Japan, more than ten technologies were being used in approximately eighty-two operational ODS destruction plants in 2006.[331]

One reason these programs have not spread widely is that they're not cheap: costs for capture and destruction range from $3.75 to $11 per kilogram, depending on the chemical and use.[332] Partially because of the cost, the few programs that have started have been funded through the so-called Clean Development Program of the Kyoto Protocol or other trading programs. These allow a polluter to continue emitting a greenhouse gas—say, carbon dioxide—if it reduces emissions of another—in this case, a CFC.

In California, for example, where a trading program was established under the 2006 Global Warming Solutions Act, one of the state's electric utilities, Pacific Gas & Electric (PG&E), paid to collect and destroy more than 38,000 pounds of CFCs. In exchange, PG&E is allowed by the state to continue emitting other pollutants that cause global warming. The CFCs will be from junked refrigerators, freezers and air conditioners.[333]

Aside from a very limited number of state or local programs, there is virtually no capture and destruction of CFCs in the United States. In a 2008 draft report, a contractor for the U.S. Environmental Protection Agency identified fewer than 10 facilities employing six different technologies that had commercially destroyed CFCs or burned waste-derived fuel containing them in the United States.[334]

Other jurisdictions have taken a decidedly less leisurely approach to capture and destruction programs, however. Australia and Canada have started programs to have industry collect and destroy bulk ozone-destroyers, funded by levies placed on the production/import of virgin/reclaimed CFCs and other depleters. These have been "immensely successful" in the words of the TEAP program.[tttt]

In Japan, end-of-life vehicles must be sent to registered recovery operators, who recover chemicals and are paid based on the number of air conditioning systems and quantity of refrigerant recovered. Although the number of air conditioners filled by CFCs is declining, recovery of HFC-134a will continue, utilizing the existing system and infrastructure.

Banks of ozone-destroyers or greenhouse gases are of two sorts:

- Those where the chemical is inside a container or other device, such as refrigerator compressors, chillers and the like; and,
- Those where the chemical is encapsulated in foams that were created for insulating or

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[tttt]Australia's program is mandated by law, provides a rebate on the return of used refrigerant (as opposed to permitting them to be returned free of charge), and applies to all F-gases, including HFCs. This broad coverage assures that the program will be able to handle all refrigerants as industry moves away from HFCs and HCFCs. However, Australia does not mandate collection of CFC-containing foams. TEAP, Supplement to the IPCC/TEAP Report, http://ozone.unep.org/Assessment_Panels/TEAP/Reports/TEAP_Reports/teap-supplement-ippc-teap-report-nov2005.pdf, accessed March 15, 2011.

other purposes.

California has recently completed an inventory and analysis of the feasibility of capturing foams.[335] Sources of foam insulation containing gases that are powerful global warming agents include building insulation, appliances (e.g., refrigerator-freezers, water heaters, transport refrigerated units, often called "reefers" in the trade), and miscellaneous uses such as for marine buoyancy. Typically, the gases within the foam are released at the end of a product's useful life or when it is discarded as waste. Insulating foams typically have been made with fully halogenated CFCs or, later, HCFCs or HFCs.

The chemicals used to blow foams and encapsulated inside them often have global warming potentials thousands of times greater than carbon dioxide. Some, especially CFCs and HCFCs, also destroy stratospheric ozone. Neither the Montreal nor Kyoto Protocols, requires capture and destruction of the banks of these chemicals, but if that is not done, they will be set free to cause global warming and destroy ozone, injuries that can be avoided.

Appendix C
Methane: The Smell of Money

Methane not only traps heat, but controversy—and a lot of each.

There is widespread agreement that methane is either the second or third most powerful cause of global warming, either followed or preceded by soot, or black carbon.

Estimates of methane leaks are bound up in controversy. The oil and gas industry is anxious to smooth the way of so called fracturing, or "fracking," operations, in which underground rock is turned into rubble to free natural gas. They had pushed the U.S. Environmental Protection Agency to lower its leak estimates, and the Agency did just that, dramatically reducing its estimate of how much leaks during natural gas production.

The change was described by one industry observer as "kind of an earthquake."[336] EPA's revision was vast, saying that average annual emissions fell 41.6 million metric tons from 1990 through 2010, or more than 850 million metric tons overall, about a 20 percent reduction from previous estimates.[uuuu] But there's the rub: EPA figures are based on estimates, not measurements.[vvvv]

[uuuu]For more information, see the "Inventory of U.S. Greenhouse Gas Emissions and Sinks sections on Natural Gas Systems and Petroleum Systems," http://www.epa.gov/climatechange/Downloads/ghgemissions/2013Workshop/natural-gas-systems-in-draft-GHGInventory.pdf.

[vvvv]EPA's estimates take no account of the warming effects of soot, or black carbon, which darkens snow and clouds, increasing the amount of heat absorbed from sunlight. Soot could very well be the second leading cause of warming. In addition, EPA's calculation is an aggregate of estimates, ranging from some that are downright wrong in perhaps many areas—the amount of methane emitted by oil and gas operations, for example—to others that are doubtful. Finally, EPA ignores the dozens to hundreds of other pollutants consciously excluded from the Kyoto Protocol, which is the international agreement to combat global warming.

Thus, methane is either the second or third most powerful warming agent, we don't know which, and its likely to stay that way for quite some time.

But what difference should that make? Methane caused by humans is clearly a major cause of warming, and just as clearly, one that can be reduced sharply, or even eliminated altogether using technologies that exist today.

The World Resources Institute, a research and education non-profit organization based in Washington, D.C. concluded that, as the *Washington Post* summarized it—

> The bad news: We have no idea how much methane is actually seeping out of our natural-gas wells and pipelines. The good news: The technologies to plug those leaks are readily available, but new regulations may be necessary to make sure they're widely adopted.[337]

During the same month that EPA concluded that emissions of methane had fallen from 1990 to 2010, the World Resources Institute reviewed the same information and reached a diametrically opposite conclusion: "the weight of evidence suggests that significant leakage occurs during every life cycle state of U.S. natural gas systems."[338]

With that caveat, EPA's estimates are as good a place to start as any. In 2011, methane, or CH_4, accounted for about 9 percent of all U.S. greenhouse gas emissions from human activities.[339]

Globally, over 60 percent of total CH_4 emissions come from human activities, as follows:

INDUSTRY

Methane is the major constituent of so-called natural gas, but not the only one. Most of these other constituents are eliminated when the gas is cleaned up and a skunk-smelling odorizer, butyl mercaptan, is added to make leaks so stinky they can be detected by the human nose at 10 parts per billion.[wwww]

Typical Composition of Natural Gas

Methane	CH_4	70–90%
Ethane	C_2H_6	0–20%

[wwww]M. Devos, F. Patte (Ed), J. Roualt,, Paul Laffort (Ed), & L. J. Van Gemert, *Standardized Human Olfactory Thresholds*, Publisher: Oxford University Press, USA, July 1, 1990, ISBN-13: 9780199631469.

Propane	C_3H_8	
Butane	C_4H_{10}	
Carbon Dioxide	CO_2	0–8%
Oxygen	O_2	0–0.2%
Nitrogen	N_2	0–5%
Hydrogen sulphide	H_2S	0–5%
Rare gases	A, He, Ne, Xe	trace

Source: http://www.naturalgas.org/overview/background.asp.

Natural gas and petroleum systems are the largest source of CH_4 emissions from industry in the United States. Methane is the primary component of natural gas. Some CH_4 is emitted to the atmosphere during the production, processing, storage, transmission, and distribution of natural gas. Because gas is often found alongside petroleum, the production, refinement, transportation, and storage of crude oil is also a source of CH_4 emissions.[xxxx]

AGRICULTURE

Methane is emitted at many stages of food production:

- From paddies where rice is grown;
- By cattle, buffalo, sheep, goats, camels and other "ruminants" with chambered stomachs, allowing them to regurgitate and re-chew grass, grains and other food; and,
- From poultry litter or cattle, hog and other manure that's stored in lagoons or holding tanks, when it decomposes, producing chest-tightening odors as well as methane.

WASTE FROM HOMES AND BUSINESSES

When waste rots in landfills or human manure decomposes at sewage treatment plants, methane is the result.

[xxxx]For more information, see the "Inventory of U.S. Greenhouse Gas Emissions and Sinks sections on Natural Gas Systems and Petroleum Systems," http://www.epa.gov/climatechange/Downloads/ghgemissions/2013Workshop/natural-gas-systems-in-draft-GHGInventory.pdf.

When wetlands break down peat moss, grass or other organic matter in the absence of oxygen, or termites eat wood, volcanoes erupt and fires started—either accidentally by, for example, lightning strikes or on purpose, so the trees can be harvested—methane is the result.

In 1990, when the United States and its government still seemed to view global warming as a serious threat and were determined to reduce emissions, the U.S. Environmental Protection Agency and the Environment Agency of Japan convened two workshops to look at ways to cut methane. They concluded that because of methane's short lifetime, reductions "could quickly produce benefits" and "would be substantially more effective than carbon dioxide emission reductions in slowing global warming."[yyyy]

In 2010, twenty years later and counting, EPA has identified 8,241 cattle and pig farms—not including the chicken and turkey lots, buffalo and lamb lots and many other possible sites that have the potential to operate digesters—that have the means to make a profit. How many are actually up and running? A grand total of 145, or less than 0.018 percent.[340]

The workshops produced a laundry list of way to cut methane emissions with "control options that are profitable or low cost."[zzzz]

This snail's pace, hear-see-speak no evil approach to making money by eliminating waste is absurd. Thus, in that spirit, allow the author to suggest what could be done if the King or Queen of the World were in charge and decided to actually take action.

Reducing Methane: The Easy and Fast Way to Cool Off

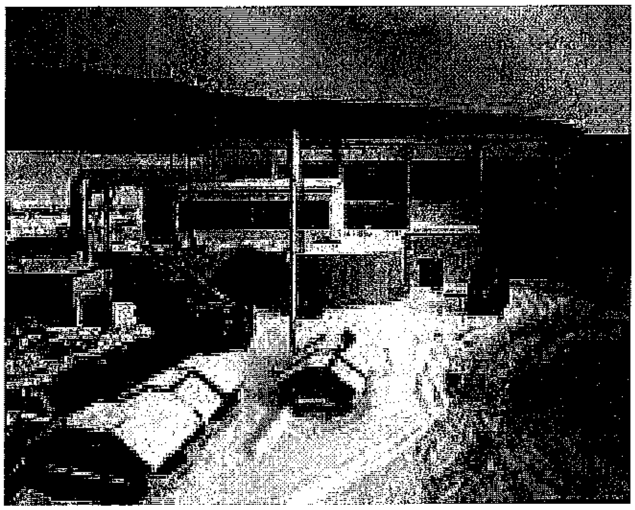
Pound for pound, eliminating methane—natural gas to most of us—could arguably cool the globe and deliver more health benefits faster than any other action humanity could take. Methane is itself the second (or third) most powerful cause of global warming, but it also reacts in

[yyyy]U.S. Environmental Protection Agency, *Methane Emissions and Opportunities for Control*, EPA/400/9-90/007, Septmber 1990, http://nepis.epa.gov/Exe/ZyNET.exe/600009GP.txt?ZyActionD=ZyDocument&Client=EPA&Index=1986 Thru 1990&Docs=&Query=(fire) OR FNAME%3D"600009GP.txt" AND FNAME%3D"600009GP.txt"&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&, accessed May 29, 2013.

[zzzz]U.S. Environmental Protection Agency, *Methane Emissions and Opportunities for Control*, EPA/400/9-90/007, September 1990, http://nepis.epa.gov/Exe/ZyNET.exe/600009GP.txt?ZyActionD=ZyDocument&Client=EPA&Index=1986 Thru 1990&Docs=&Query=(fire) OR FNAME%3D"600009GP.txt" AND FNAME%3D"600009GP.txt"&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&, accessed May 29, 2013.

the air to form smog, or ozone, which is both the third most powerful warming agent and a cause of grievous injury to the health of humans, crops, and forests.

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



Since 1995, Bluemel, Germany has collected 13,000 tons a year of biowaste—table scraps and garden trimmings—in special bins from each household, then gasified it to generate 320 kilowatts of electricity. Source: Krieg and Fischer.

Throughout the world, but especially in the United States, vast amounts of material are simply thrown out, producing methane and carbon dioxide as they rot. But virtually all of it can be exploited in some fashion. Even household table scraps, yard clippings, as well as other garbage can be collected and turned into an energy-rich gas to generate electricity, as it is in Bluemel, Germany, for example (figure).[341]

Vast amounts of methane escape from landfills, livestock, coal mines and oil and gas wells, pipelines and storage tanks. The people who own those places might just as well open a window and throw out bushel baskets of money, because that's essentially what's happening when methane is allowed to escape.

Fortunately, change is underway. Methane is being captured at landfills and coal-mines. New feed additives and breeds of livestock cut methane emissions, while boosting milk production. The oil and gas industry, at least in a few places, is finally admitting that the loss of methane from standard practices at gas wells is immense, up to 12 times higher than longstanding estimates.

If it weren't for human activity, methane's lifetime would be relatively short—8.3 years, compared to 3,000 for carbon dioxide. But other pollutants, such as carbon monoxide from cars and trucks, have upset the chemistry of the atmosphere, increasing methane's lifetime to about 12.3 years. As a result, methane can be controlled directly—by reducing emissions of methane itself, for example—or indirectly, by eliminating the pollutants that have skewed the atmosphere's natural chemistry.

U.S. METHANE EMISSIONS BY SOURCE[1]

($TgCO_2$ Equivalents)

Source Category	1990	1995	2000	2005	2006	2007	2008
Enteric Fermentation	132.5	143.7	136.8	136.7	139.0	141.2	140.8
Landfills	149.3	144.1	120.7	125.6	127.1	126.5	126.3
Natural Gas Systems	129.5	132.6	130.7	103.6	103.1	99.5	96.4
Active and Abandoned Coal Mines	90.1	75.3	67.8	65.5	63.8	63.8	73.8
Manure Management	29.3	33.9	38.6	42.2	42.3	45.9	45
Petroleum Systems	33.9	32.0	30.2	28.2	28.2	28.8	29.1
Wastewater Treatment	23.5	24.8	25.2	24.3	24.5	24.4	24.3
Stationary and Mobile Combustion	12.1	11.1	10.0	9.1	8.6	8.7	8.7
Total, All U.S. Sources	613.4	613.2	586.0	553.2	568.2	569.2	567.6

1. Source: U.S. Environmental Protection Agency, Methane: Sources and Emissions, http://epa.gov/methane/sources.html, accessed Aug. 23, 2010.

Compared to most other causes of warming, the payoff from eliminating methane is fast, measured in a few years, not a few centuries. As methane emissions drop, so, too, will levels of ozone, which methane creates through chemical reactions with still other air pollutants, such as those from cars and powerplants.

Emissions of methane have risen inexorably over the past several decades, yielding a comparable rise in the concentrations of smog. According to the U.S. National Academy of Sciences, arguably the world's most prestigious scientific body, methane and other pollutants have increased smog concentrations by 40 to 100 percent since pre-industrial times.[342] The other side of this coin is that with humanity what has increased, can also decrease. And as with methane, reductions in ozone have a quick payback, cooling the air and eliminating illnesses within days to months.[343]

Whether methane is leaking from oil and gas operations or landfills, it is relatively easy to control and provides a quick and certain payback. The elimination of methane, the second largest cause of global warming, could substantially and quickly reduce the threats posed by near-term warming.

Methane can be reduced from virtually every major group of sources, using a variety of technologies and policies. In the worst cases, the costs of cleaning up are low; in most cases, polluters make money because methane is such a valuable resource.

The U.S. Environmental Protection Agency identifies potential waste-based sources of methane as follows:

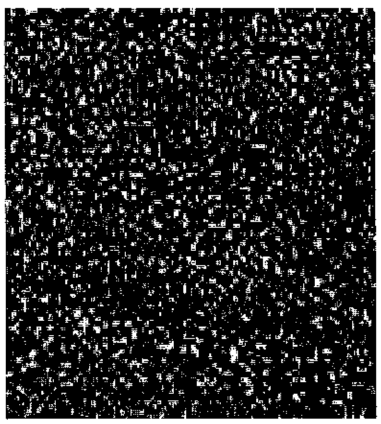
RURAL RESOURCES

- Forest residue and wood waste
- Crop residues
- Biogas

URBAN RESOURCES

- Urban wood waste
- Landfill gas
- Energy crops
- Food processing residue

"Black liquor" from pulp and paper operations should be called black gold because of its immense energy value.



Petroleum coke: bottom of the barrel and loaded with energy, can be burned cleanly. Rather, it's exported from the U.S. instead of being exploited.

California is rich in all of these sources, and in virtually every incidence they are being under-exploited. For example, according to the Food and Water Watch, California is home to 1,434,748 dairy cattle on 1,075 farms. Another 519,074 cattle at 27 ranches are raised for meat at each site, as are 126,594 hogs found at 10 sites. The number of chickens held for egg production are 21,236,253, located at 44 sites, while broilers number 45,969,637 at 36 facilities.[344]

In each case, converting these wastes to energy would reduce emissions of methane while providing valuable heat or electricity or both. However, despite these large numbers of feeding operations, averaging roughly 1,335 head of dairy cattle and 19,225 of beef cows, only a very small number of digesters are found in the state. According to the AgStar program at the U.S. Environmental Protection Agency, there currently are only 15 methane digesters in California, of the 151 nationally.[345]

Amazingly, the pace of construction and deployment of it is slower today than 30 years ago. For example, according to the California Energy Commission, during and before the 1980s, some 53 biomass solid fuel facilities were constructed, generating 759 megawatts of electricity. Currently 22 of these remain in operation, producing 474 megawatts.[346]

Yet after Gov. Jerry Brown and his aggressive pursuit of renewable energy faded from the California scene, only 14 new projects were built in the decades of the 1990s and 2000s, adding 235 megawatts to the state's electricity supply. Currently, only 8 of those are still operating, providing 193 megawatts. For all of the castigation of Brown as "Governor Moonbeam," his attitudes and policies did, and continue to do, more to advance these forms of energy than that of all of his successors combined.

The potential for further reducing methane emissions in California is immense. According to Environmental Entrepreneurs, a group that describes itself as an "advocate for good environmental policy while building economic prosperity," if biogas to electricity systems were installed at every California dairy, the systems would provide approximately 188 MW (or 188,320 kW) of generating capacity and over 1.6 billion kilowatt-hours per year of delivered, renewable electricity (assuming operation at 100 percent capacity).[347]

THE STUFF THAT'S THROWN OUT ("OPPORTUNITY WASTES")

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

WASTES CAN BE TURNED INTO ENERGY WITH RIGHT TECHNOLOGY

There are three wastes that are loaded with energy, but can be gasified and burned cleanly with the right technology.

Petroleum Coke

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

An IGCC plant in Puertollano, Spain, considered the world's biggest IGCC power plant with a net output of 300 megawatts, enough electricity for about 75,000 homes, has been running since March 1998[348] with no problems and has since been generating extremely environment-friendly power and valuable by-products. Globally, in 2004 there were 117 IGCC plants operating with 384 gasifiers, and almost all were burning pet coke.[349], [aaaaa]

Black Liquor

Used tires, a resource that is wasted, wasted, wasted.

A tar-like substance, black liquor, is a byproduct of making paper. Because the pulp and paper mills need steam and other heat for their own processes, much of the black liquor never goes off site. Virtually all of it, however, is burned in so-called Tomlinson boilers.[350] Replacing these with systems to convert the liquor into gas, then burning it in an integrated gasification combined cycle set of turbines would substantially increase efficiency, allow chemical contaminants to be removed and reduce air pollution.[351]

Used Tires

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

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[aaaaa]For an excellent review of the competing gasification technologies, see Breault, Ronald W., 2010, "Gasification Processes Old and New: A Basic Review of the Major Technologies," Energies 3, no. 2: 216–240.

the tires were gasified, then burned to generate both electricity and steam, pollution would drop dramatically.[352]

KILOWATTS FROM MANURE

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

Since humans were not around several million years ago when the plants and animals that are thought to have, over millions of years, turned into natural gas it is unclear what, exactly, happened. There is general agreement, however, that microscopic plants and animals living in the oceans died, were buried in silt and over the ages were folded into various layers, eventually turning into oil and gas.[353]

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

Whatever and wherever it comes from, gas is a fabulous fuel. It is inherently clean, with almost none of the poisons of coal and oil, which emits immense amounts of air pollution when burned. In addition, because natural gas is so clean, it can be used with technologies that are much more efficient and clean burning from massive furnaces, as well as millions of car and truck engines. As a result, demand for gas is rising sharply, especially for generating electricity.[354]

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


Kitchen showing wood or straw stove at left, biogas stove fueled by anaerobic digestion at right and pressure gauge at right.

Cow, Pig and Poultry Power

Take an $8 million anaerobic,[355] or airless, cooker, manure from lots of cows, pigs, or poultry, add water and heat and Voila! You have—

- natural gas, that can be used to generate electricity;
- fertilizer in which all the bacteria and other dangerous bugs have been killed; and,
- water.[356]

At Highmark Renewables in Alberta, Canada the manure from 36,000 cows, about 36 million kilograms (which is almost 80 million pounds), generates enough electricity to run the feedlot and about 700 homes. When it reaches full capacity, the plant will power more than 2,000 homes, while producing fertilizer, as well as water for irrigation. The next step will be to build more plants—20 in five years.[357]

SAVING THE WORLD, ONE SEWAGE PLANT AT A TIME

For centuries, humans have exploited the energy contained in their own sewage. After all, it's fairly basic chemistry: throw organic matter into a pot, add a handful of bacteria, shut the lid and come back after a while. The products will be gas that can be burned, these days to generate electricity, and a sterile but nutrient rich fertilizer.

Of course, the process can be made to sound much more complicated, but really it isn't.

It has been said that—

> Humans have been using anaerobic digestion for centuries. Over 3,000 years ago, biogas was used to heat bath water in Assyria. In the late 19th century, biogas recovered from a sewage treatment facility fueled street lamps in Exeter, Devon in the United Kingdom. Biogas from sewage sludge was converted and used for fuel in automobiles in Germany in the 1950s. Today, biogas is being used worldwide, particularly in developing countries such as India, China, and Costa Rica.[358]

Whether or not humans have actually been using digesters for centuries, they certainly could have. The waste from 4 to 5 pigs will provide enough gas for a family of 4 to 5. Presumably, the same is true of the waste from the humans themselves.[359]

Since the 1970s, China has been promoting the use of underground, individual household scale, anaerobic digesters to process rural organic wastes. There are approximately 5,000,000 households using anaerobic digesters in China. The digesters produce biogas that is used as an energy source by the households, and produce fertilizer that is used in agricultural production.[360]

Methane can be produced through anaerobic digestion of a wide variety of materials other than animal wastes. When corn, rice, seeds and other crops are harvested, stalks, leaves, husks and other wastes are left in the field to rot or, in areas that will still allow it, burned in place. The technology to gasify other sources of plant matter is well established, but only recently has interest been sparked in doing the same with wastes.

ELIMINATING LEAKS FROM OIL AND GAS OPERATIONS

Methane—natural gas to most people—is invisible to the naked eye, so a stroll around a gas well or refinery will reveal nothing out of the ordinary. Looking through the lens of an infrared camera, however, discloses a torrential outpouring of gas, massive plumes of darkness that cloud the sky and, eventually, directly and indirectly cause human illness and death, injuries to crops and forests and, most alarmingly, global warming.

Gas leaks can be halted through relatively simple means, yielding increased profits. But as easy as that would be, it isn't happening. It may not be cheaper to waste the gas, but it's easier, and most owners and operators follow that path of least resistance, and do nothing to even detect the leaks, much less shut them.

There are exceptions, of course. When a reporter for the *New York Times* accompanied Terry Gosney, an environmental field coordinator Canadian gas producer on a tour of Texas wells, the reaction was immediate: "Holy smoke, it's blowing like mad," said Gosney. "It does look nasty."

Because methane is invisible to the naked eye, there is no hint in the left image of the immense amount escaping from a storage tank. An infrared camera, however, reveals the immensity of the polluting and dangerous leaks of methane. Source: U.S. E.P.A.

Within a few days the leaks revealed by the infrared images had been sealed by workers. But such quick and effective response is the exception, not the rule.

According to the Environmental Protection Agency's official estimate, roughly three trillion cubic feet of methane leak into the air every year, the warming equivalent of the emissions from over half the coal plants in the United States. Most government scientists and industry officials believe the actual amount is much higher—methane is, after all, invisible so there are no complaining neighbors or pesky environmentalists.

There is extensive confirmation that existing inventories of leaks from oil and gas industries are unreliable and understate actual emissions of methane, perhaps vastly.

Internationally, the amount of methane escaping from gas and oil operations can be only "crudely gauged," in the words of the *New York Times*. In 2006 the E.P.A. estimated that Russia, the world's largest gas producer, had the highest methane emissions annually at 427 billion cubic feet, followed by the United States at 346 billion, Ukraine at 225 billion and Mexico at 191 billion. But Gazprom, Russia's giant state gas monopoly, estimated its annual emissions at half that figure last year.[361]

E.P.A. concluded that the amount emitted by routine operations at gas wells is 12 times the agency's longtime estimate of nine billion cubic feet. In heat-trapping potential, that new estimate equals the carbon dioxide emitted—and the fuel consumed—annually by eight million cars.[362]

In California, in a study in the Los Angeles basin, measurements taken at the Mt. Wilson observatory starting in the spring of 2007 were used to construct a "top down" inventory of methane. When compared to the "bottom up" inventory prepared by the California Air Resources Board, the "top-down" results were about one-third greater.[363] The modelers concluded that given the large uncertainties, the two inventories were "in good agreement," which demonstrates the unreliability of government and industry estimates. A different analysis of methane emissions in central California reached similar results.[364]

Globally, Russia and the United States are the leading emitters of methane. The amounts gushing into the air are bound to increase as companies worldwide increase gas production through the controversial technique called "fracking," in which water is pumped underground under immense pressure to shatter gas-bearing shale into rubble, releasing trapped methane. U.S. Department of Energy projects that gas production could rise nearly 50 percent over the next 20 years as companies race to discover and tap new sources. In the United States, 4,000 miles of new pipeline was laid last year alone.

Officially, oil and gas systems are the second largest human-made source of methane emissions, trailing only enteric emissions from livestock. It seems likely, however, that the rankings should be reversed, and methane leaks from oil and gas operations moved into the top spot. At the very least, leaks and intentional venting account for 23 percent of methane emissions in the United States, which represents 2 percent of the total greenhouse gas emissions in the United States.[365] Put more plainly, the United States could reduce its emissions of greenhouse gases by at least 2 percent, and very likely much more, by simply taking infrared photographs of leaks, then stopping them.

"Fracking" is slang for hydraulic fracturing of underground shale by injecting water at immense pressure, which shatters the rock. That releases trapped gas and, as shown here in a photo by the *Toronto Globe and Mail*, waste water. The water may be reinjected or, often, pumped into nearby streams.

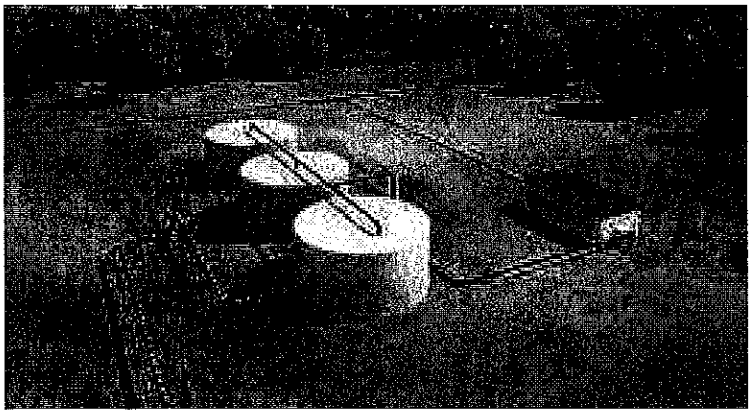
According to the U.S. Environmental Protection Agency, methane is released in all sectors of the natural gas industry, from drilling and production, through processing and transmission, to distribution. Some of this is intentional venting from normal operations and routine maintenance. Leaks like the one shown in the figure, usually referred to as fugitive emissions, happen throughout the system, from connections between pipes and vessels, to valves and equipment.

The oil industry is also a major source of methane emissions, principally from field production operations, such as natural gas released when oil wells are drilled or crude is stored and refined.[366] Indeed, the most prominent recent demonstration of this was the explosion of methane that preceded and triggered BP's Macando blowout in the Gulf of Mexico.

In California, emissions from oil and gas operations follow a similar pattern. Expressed in terms of carbon dioxide equivalent, methane emissions were 17 million tons in 2008.[367]

In some respects, the failure of the oil and gas industry to either stop or collect methane emissions is perplexing. Methane is a valuable resource, and by one estimate the value of the fuel lost through leaks equates to a loss of about $20 billion in revenue.[368]

In addition to the fugitive emissions of methane from venting or leakage, an enormous amount is flared, or burned. A recent global survey by the U.S. National Oceanic and Atmospheric Administration using satellite data—funded by the World Bank's Global Gas Flaring Reduction partnership—showed that oil-producing companies and countries burned close to 170 billion cubic meters (Bcm) of natural gas in 2006. According to the study, 170 Bcm of natural gas equates to 27 percent of total U.S. natural gas consumption and 5.5 percent of total global production of natural gas for the year. The study found that if the gas had been sold in the United States instead of being flared, its market value would have been about $40 billion.


A vapor recovery system that can reduce methane emissions from a storage tank by 95 percent.

The ease with which these leaks can be halted is illustrated by what could be done with storage tanks, which account for 4 percent of methane emissions in the natural gas and oil production sector. Some storage tanks have vapor recovery systems, not unlike those found on cars and at gasoline stations. But many tanks do not have vapor recovery, and they account for 96 percent of tank losses.[369] Thus, retrofitting tanks with vapor recovery would reduce leaks, and the system would pay for itself in short order.

Similarly, reducing or totally eliminating emissions at oil and gas facilities, is fairly straightforward. Fugitive equipment leaks are a major source of methane emissions at oil and gas facilities, and most are from a few large leaks rather than many of small to medium ones. Even with a payback period of only six months, the costs of fixing leaks are recovered in 75 to 85 percent of the cases.[370]

Appendix 1 Cost-Effective Opportunities to Recover Methane At Oil and Gas Operations

In conjunction with the oil and natural gas industry, the U.S. Environmental Protection Agency's Natural Gas STAR Program has identified technologies and practices that could reduce methane emissions from oil and gas operations. The following summarizes these technologies and practices for each sector.

GAS PRODUCTION AND PROCESSING

- Perform reduced emissions completions
- Install plunger lifts
- Aerial leak detection using laser and/or infrared technology
- Eliminate unnecessary equipment and/or systems

OIL PRODUCTION

- Install vapor recovery units (VRUs) on crude oil storage tanks
- Route casinghead gas to VRU or compressor for recovery & use or sale

GAS STORAGE

- Convert gas pneumatic controls to instrument air
- Replace bi-directional orifice metering with ultrasonic meters
- Reduce methane emissions from compressor rod packing systems

GAS TRANSMISSION

- Directed Inspection and Maintenance (DI&M) at compressor stations
- Use fixed/portable compressors for pipeline pumpdown
- Install vapor recovery units on pipeline liquid/condensate tanks

GAS DISTRIBUTION

- DI&M at surface facilities
- Identify and replace high-bleed pneumatic devices
- Survey and repair leaks

"ENTERIC FERMENTATION": METHANE EMISSIONS FROM CATTLE

Global warming skeptics, not to mention quite a number of folks who like to think of themselves as comedians, get off on trivializing "enteric fermentation" as "farts" or "burps" from cows.[bbbbb] That's true enough. But just as humans can deal with this problem through pre-washing beans or a dose of Beano, so too can the diets of cattle, sheep and other ruminants—animals that eat plants—be manipulated. And, indeed, just as not every human who eats beans passes gas, so, too, do some cattle burp less methane.

Most methane emitted on a farm originates in the fore-stomach, also called the rumen, of cattle, sheep, deer and other such livestock, collectively called ruminants. Methane is not the inevitable byproduct of digestion, but quite the opposite. Called enteric methane, it results from the incomplete digestion of feed and is released into the atmosphere as the animal breathes. Just as other air pollutants are emitted from factories because they are inefficient, ruminants emit pollution because they, too, are inefficient.

The options for reducing emissions of enteric methane abound, everything from improved

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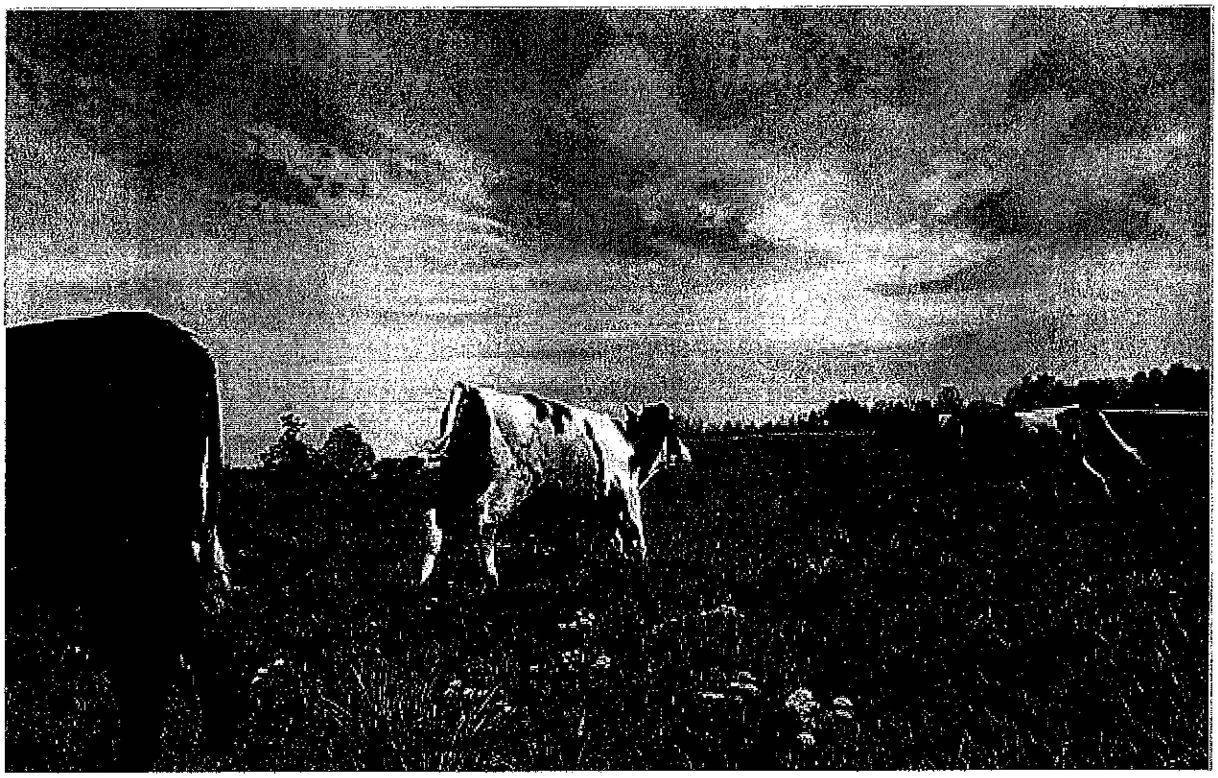
[bbbbb]See, for example, Meredith Niles "New climate legislation overlooks a major GHG source: industrial ag," asking "Who really cares about cow farts anyway...." *Grist*, http://www.grist.org/article/2009-04-02-cut-crap-markey-and-waxman, accessed Aug. 23, 2010.

food additives to better livestock. Nor are the changes extraordinarily burdensome. On the contrary, after a cradle-to-grave review of emissions from dairy farms, the United Nations Food and Agriculture Organization (FAO) concluded that "marginal improvements of feed digestibility would achieve significant reductions in methane emissions per kilogram of milk, through a direct reduction of emissions and through the improvement of milk yields."[371]

In Vermont, since January 2009, 15 farms across the state have adjusted grain feeds for cows to include more plants like alfalfa and flaxseed—substances that, unlike corn or soy, mimic the spring grasses that the animals evolved long ago to eat.

At one of these farms, owned by Guy Choiniere the methane output of the herd had dropped 18 percent. Meanwhile, milk production held its own.



Some of the 75 dairy cows at Guy Choiniere's farm in Highgate, VT, where feed has been changed to plants like alfalfa and flaxseed to reduce the methane emitted when they belch. Source: The New York Times, June 4, 2009.

Choiniere participated in the program because it had been started by Stoneyfield Farms, a yogurt manufacturer that specializes in organic and environmentally responsible products. Choiniere, a third-generation dairy herder who went organic in 2003, said he had sensed that the outcome would be good even before he got the results.

"They are healthier," he said of his cows. "Their coats are shinier, and the breath is sweet."[372]

But Choiniere is the exception, not the rule. In the absence of a customer like Stoneyfield Farms, there are no compelling reasons for a farmer or a rancher to adopt these changes. The challenge, therefore, is not necessarily to identify solutions, but rather incentives to adopt them.

Increasing the efficiency of digestion reduces both feed consumption and methane production, while boosting milk output. Globally, cattle and other livestock collectively release about 80 million metric tons of methane per year, or about 28 percent of the total methane emitted from human activity. In the U.S., cattle produce about 5.5 metric tons per year, about 20 percent of total national methane emissions due to human activity.

In the aggregate, beef and dairy cattle account for up to 95 percent of the methane from enteric fermentation. The biggest emitters of methane from enteric fermentation are, logically, states that have large numbers of cattle. Texas and California, with their immense dairy and beef cattle operations, are the greatest contributors. Many agricultural states in the Midwest are also a significant source of enteric fermentation emissions.

Unlike humans and other meat-eaters, cattle and other ruminants can survive by eating grass, hay and other plant material because methanogens, bacteria found in their digestive tracts, break down the feed. However, the conversion of plant matter to food falls up to 10 percent short of 100 percent efficiency. The unused food energy is emitted, principally through burps, as the animals swallow, chew, regurgitate and re-chew their food. However, feed additives can increase the efficiency of digestion, eliminating or reducing this wasted-food-to-methane. This reduces both methane emissions and food costs—because less feed is needed—while increasing growth or milk production.

For example, in a study comparing methane emissions, milk production and feed consumption of Holstein dairy cattle with monensin added to their diet and others without the additive, those eating monensin-enhanced feeds ate less food and emitted less methane, but produced more milk.[373] In another study, this one of the methane inhibitor amicloral, the efficiency of feed utilization increased by 12 percent.[374]

Adding oil to feed can also curb enteric fermentation. One 2008 study found that a 1 percent increase in dietary oils cut methane emissions by 6 percent. Adding whole cottonseed reduced methane emissions by around 12 percent and increased milk yield by about 15 percent.[375] Sunflower oil cut methane emissions by 22 percent.[376] Studies with coconut and palm oils have yielded similar results.

Sacks of Monensin, a food additive for reducing methane emissions from cattle.

There are a number of other options for reducing methane from enteric fermentation, ranging from a switch in human eating from beef to other meats, or none at all, to engineering or moving to new breeds of cattle. Existing breeds already differ markedly in the efficiency with which they utilize food. In one Australian study, researchers found that the lowest emitter of methane in the study group of cattle produced on average 25 percent less gas than the highest emitters. This apparently was because low emitters could utilize food with much higher efficiency.[377]

Appendix 2
Options for Reducing Methane on Dairy Farms

Dairy Australia, the website (http://www.dairyaustralia.com.au/Home.aspx) of the Australian dairy industry, very nicely summarized the options available for reducing methane emissions from dairy farms, as follows:

HERD BASED STRATEGIES

Reduce Herd Size

Reducing cow numbers would reduce emissions. A smaller number of high producing cows will produce less methane for a given amount of milk production than a larger number of lower producing cows.

Reduce the Number of Unproductive Animals

- Reducing the number of replacement heifers and dry cows (either between lactations, or those carried over due to a failure to get back in calf) can increase profitability and reduce emissions.
- Retaining cows longer in the herd can reduce the number of replacement heifers needed. Strategies like extended lactation (for example, cows might be milked for 15 months and calve every 18 instead of annually) can theoretically reduce emissions by up to 10 percent, but this has not been proven.

- Each farm must weigh up the pros and cons of these strategies. For example, retaining older cows to reduce the number of heifers can slow genetic gain, and older cows are likely to have more health problems.

Animal Breeding

- Some studies show heritable differences in rumen methane production between dairy cows, so theoretically, a breeding program could reduce methane emissions. However there is currently no attempt to include reduced methane in dairy breeding programs and bulls are not assessed for methane production. While not a viable option now, it may be in the future.

- Dairy Australia is exploring the possibility of breeding cattle to improve feed conversion efficiency (FCE), the efficiency with which feed is converted to milk. It is likely that any increase in FCE would have an associated reduction in the amount of methane produced per litre of milk.

Rumen Manipulation

- Methanogens (microbes that produce methane) are a small proportion of the total rumen microbial population. Reducing the numbers of methanogens in the rumen can reduce methane production, apparently without detriment to the digestion process.

- A vaccine that acts against the methanogens reduces methane by up to 7.7 percent, however this Australian study has not been able to be repeated, perhaps because rumen populations are influenced by a range of location and diet factors.

- Biological control strategies where 'predators' of the methanogens are introduced or encouraged are possible, but this research is only in its very early stages.

- Antibiotics (such as rumensin) added to the diet of ruminants can reduce methane production. However the effect is not reliable, and there is low public acceptance for using antibiotics in animal production systems.

FEED BASED STRATEGIES

Maximise Diet Quality/Digestibility

- Digestion of 'roughage' causes methane production, and ruminants have an evolutionary advantage by being able to digest relatively fibrous plant material. This suggests that methane production is deeply embedded in the evolution of ruminants and therefore may be difficult to alter.

- Any strategy that improves diet quality will tend to reduce methane production per unit of milk, such as:
    - Improving pasture quality through grazing management;
    - Switching from C4 (subtropical) grasses such as paspalum or kikuyu to C3 (temperate) species such as ryegrass or fescue; and,
    - Adding grain to a forage diet.
- Although improvements in diet quality can reduce methane emissions per unit of milk produced, they often act to increase total farm methane emissions. This is because milk production per cow increases, but cow numbers often go up to take advantage of the higher quantity and quality of feed.

Pasture Breeding

Traditionally, pasture breeding has focused on increasing dry matter yields and the longevity of sown pastures. These are still vital traits, but now that the ability to manipulate plant genes has dramatically increased, plant breeders in Australia are working to significantly increase the digestibility of pasture species. Though several years away, highly digestible ryegrass is being developed, with fescue and C4 grasses to follow.

Feeding Fats and Oils

- This has long been common practice in some herds—usually through high protein meals that are by-products from oilseed crops, and direct feeding of whole cotton seed. A review of 17 feeding experiments showed that for each 1 percent increase in dietary fat, methane production was reduced by 5.6 percent. Inclusions of fats can boost production, and reduce emissions.
- The suppression of methane emissions seems most pronounced when pasture quality declines, such as summer and autumn in southern Australia, and this is likely to be the time when production responses to fats and oils are greatest. This strategy is limited by the fact that if total diet fat content (including the fat contained in the pasture and other forage supplements) exceeds 6–7 percent, then intake and milk production will be suppressed.

Feeding Condensed Tannins

- Condensed tannins (often extracted from tree bark) can reduce methane production because they have a directly toxic effect on methanogens. However, even at relatively low concentrations in the diet, condensed tannins suppress voluntary food intake, reduce diet digestibility and therefore reduce milk production.

- It is the condensed tannins in some legumes that make them 'bloat safe' and there have been breeding efforts in recent years (focused on lucerne and white clover) to increase the tannin content of these species to reduce their potential to cause bloat in grazing cattle. If these breeding programs are successful, then these bloat safe legumes might also act to reduce methane production.

WASTE—A WASTED RESOURCE

California could, if it chose to, save an immense amount of energy, eliminate a lot of pollution and make a lot of places smell better. But it chooses not to.

A biogas digester at a dairy farm in Cottonwood, California. Depending on the waste feedstock and the system design, biogas is typically 55 to 75 percent pure methane. State-of-the-art systems report producing biogas that is more than 95 percent pure methane. Source: California Energy Commission.

According to the Food and Water Watch, California is home to 1,434,748 dairy cattle on 1,075 farms. Another 519,074 cattle at 27 ranches are raised for meat, as are 126,594 hogs found at 10 sites. Chickens held for egg production are 21,236,253, located at 44 sites, while broilers number 45,969,637 at 36 facilities.[378]

The waste from all those farms is—well, wasted. Used readily available devices called anaerobic digesters poultry litter, as well as manure from cattle and hogs, can be turned into a high-energy gas that, in turn, can be burned for heat, used to generate electricity or both.[ccccc]

The benefits of widescale deployment of anaerobic, which means oxygen-free, digesters in California are immense. According to the state's Energy Commission, capturing and converting

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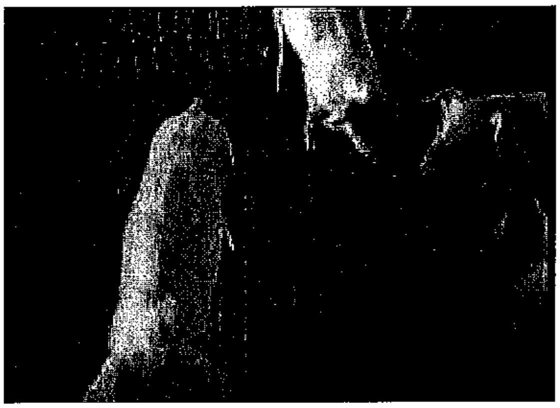
[ccccc]The process of anaerobic digestion consists of three steps: First, breakdown, or hydrolysis, of plant or animal matter into molecules such as sugar; second, conversion of decomposed matter into organic acids; third, conversion of acids to methane gas. Source: California Energy Commission.

waste to gas on dairy farms—just dairy farms—would be the global warming equivalent of taking 2 million cars off the road. It could provide electricity to 120,000 homes, produce a high quality sterile fertilizer, reduce pollution of groundwater, lakes and streams, and eliminate the need to ship waste on trucks.[379] That's not even to mention eliminating odors, nor does it take into account the benefits of installing even more digesters at pig and poultry production sites.

The environmental burden of these food factories is immense. According to one study—

> California's dairy industry is the largest in the nation. The industry produces more than $5 billion in annual sales. The state's 1.7 million dairy cows generate each year more than 67 billion pounds of manure. The manure emits 450,000 tons of methane, a greenhouse gas 20 times more potent than carbon dioxide. Insufficient collection and storage of manure results in surface water contamination from high concentrations of ammonia, organic matter, and phosphorous, and groundwater contamination from high concentrations of salts and nitrates.[380]



Waste from pigs can also be gasified.

None of this is inevitable, however. Ways of converting "bio-waste," whether its manure of discarded apricot pits, have been in use for tens of centuries. There is anecdotal evidence that biogas was used ten centuries before the birth of Christ to heat bath water in Assyria.[381] The preferred method of handling currently is anaerobic digestion, a process by which bacteria break down organic matter in, for example, animal sewage, turning it into methane, carbon dioxide, and other gases. It can then be used to provide heat or electricity or both.

California Resource and Market Potential for Combined Heat and Power From Wastewater and Co-Digestion From Other Bio-Wastes (in Megawatts)

Resource Type	Technical Resource Potential	Market Potential
Wastewater	125	95[a]

Restaurant fat, oil, and grease	10	8
Food Processing Waste	129	97
Dairy Waste Manure	334	250
Combined Total	598	450

[a]The 95 MW of market potential from the wastewater plants includes the existing CHP capacity of 35 MW in California. Source: California Energy Commission.

Designing, building and operating anaerobic, or oxygen free, digesters is not rocket science. According to the PennState Department of Agricultural and Biological Engineering:

> A well designed and operated digester will require modest daily attention and maintenance. The care and feeding of a digester is not unlike feeding a cow or a pig; it responds best to consistent feeding and the appropriate environmental (temperature and anaerobic-oxygen free) conditions.[382]

Nor are the number of makers and sellers of equipment small in number. When California established a Dairy Manure Technology Feasibility Assessment Panel in 2005, it called for companies to describe their technologies. Although the Panel accepted submissions for only 6 weeks, it received 44 submissions before the deadline, 25 afterwards and identified several dozen more companies marketing technologies to treat manure that did not submit information.

"It is apparent," reported the Panel, "that many companies are seeing entrepreneurial opportunities for industrial scale manure management and treatment, and that these technologies hold promising for potential use as best management practices at dairies."[383]

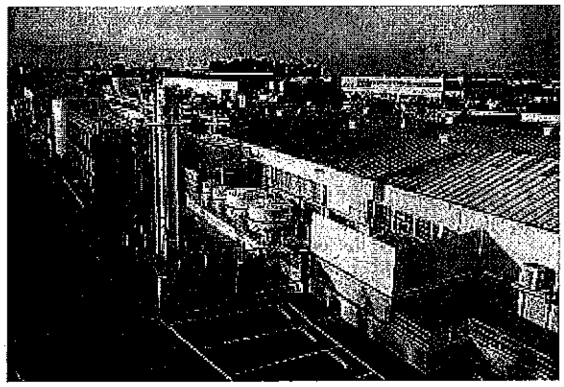
Some believe such calculations understate the benefits to be had. According to Environmental Entrepreneurs, a group that describes itself as an "advocate for good environmental policy while building economic prosperity," if biogas to electricity systems were installed at every California dairy, the systems would provide approximately 188 megawatts (or 188,320 kW) of generating capacity and over 1.6 billion kilowatt-hours per year of delivered, renewable electricity (assuming operation at 100 percent capacity).[384]

Yet despite ready availability of technological solutions, the money to be made by selling electricity or gas or both, and the multiple benefits ranging from cleaner water to safer air, anaerobic digesters are, for practical purposes, being largely ignored by the state and its industries. This, despite the fact that California would be ideally suited for application of the technology and creation of a manufacturing base that could export turn-key systems to other states and throughout the world.

Even though feeding operations are of more than adequate size to support anerobic digestion, each averaging roughly 1,335 head of dairy cattle or 19,225 beef cows, only a very small number of digesters are found in the state. According to the AgStar program at the U.S. Environmental Protection Agency, there are only 15 methane digesters in California, of the 151 nationally.[385]

Part of the responsibility for this must be laid at the feet of the state's energy and environmental bureaucracies, for California's landmark Global Warming Solutions Act, AB32, which requires the state—especially the Air Resources Board (ARB)—to reduce emissions of pollutants that cause global warming. And, indeed, ARB's December 2008 AB32 *Scoping Plan Document* identified methane capture from dairies as a recommended greenhouse gas reduction measure.

But short of identifying methane capture and use as a priority, it did little else—nothing to clear the way for aggressive deployment of digesters, for example. Instead it recommended near-term "encourage[ment of] investment in manure digesters," a five-year wait, for years, then a determination on whether "the program should be made mandatory by 2020."

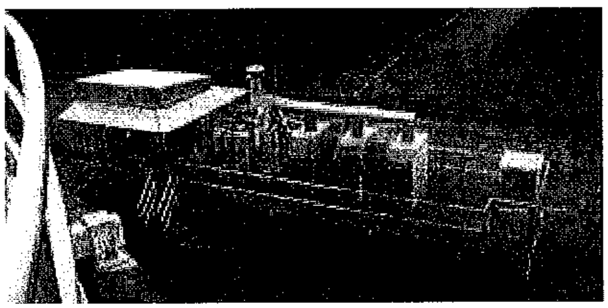


Gills Onions, the nation's largest processor of fresh onions, has built an anaerobic digester system at its Oxnard, California facility, which converts the hundreds of thousands of pounds of onion waste into electricity to power the plant.

The potential for reducing methane emissions from these operations is extraordinary.

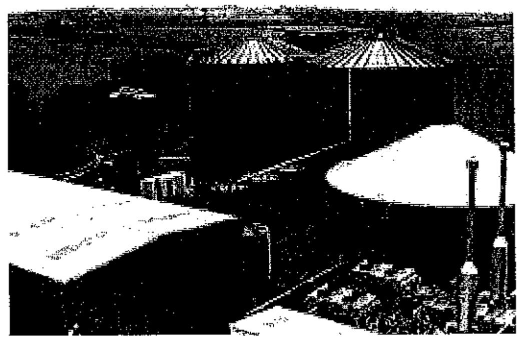
Methane can be reduced from virtually every major group of wastes, using a variety of technologies and policies. In the worst cases, the costs of cleaning up are low; in most cases, operators make money because methane is such a valuable resource.

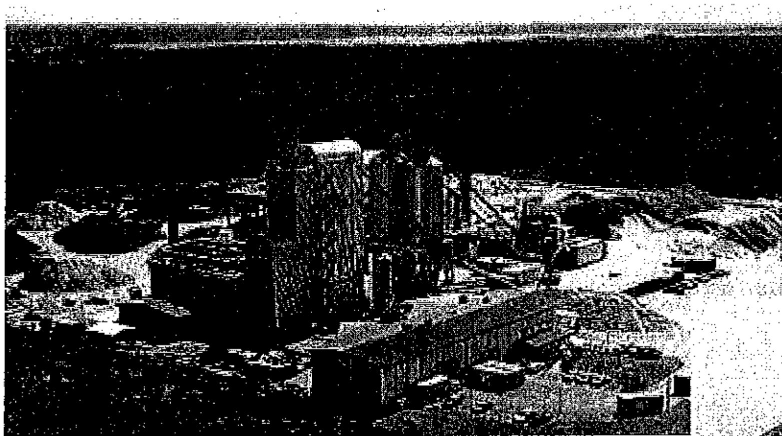
Appendix 3 - Biomass Examples of Biogas Generators Using a Variety of Inputs



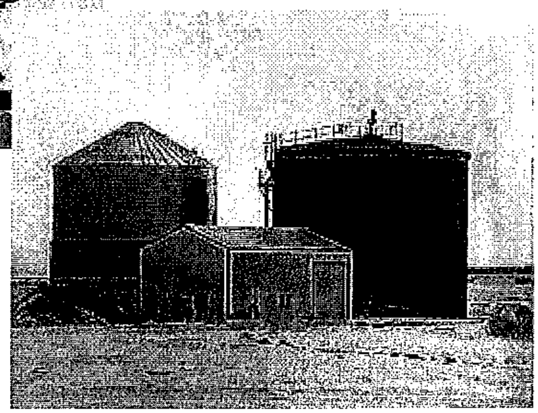
Location: Shafter, Calif.
Project: 90 kW Digester Gas-Fired
Co-generator: Micro turbine (3 x 30 kW)
Year: 2004
Input: sewage
Co-generator: Micro turbine, 4 x 30kW
Designer: Calpwr

Location: Devon, England
Project: 90 kW Digester Gas-Fired
Co-generator: Micro turbine (3 x 30 kW)
Year: 2005
Input: cattle manure, abattoir and food processing waste
Designer: Rutherford Renewables

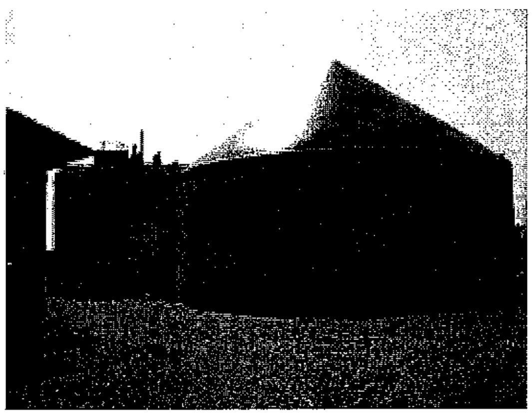




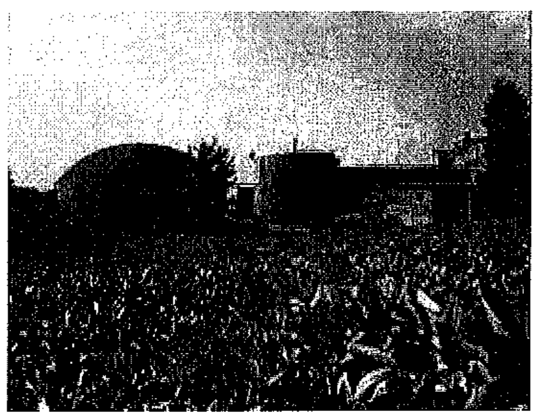
Gasification plant in Växjö, Sweden for the production of bio-hydrogen and dimethyl-ether (DME), a cleaner-burning synthetic vehicle fuel, from biomass. More than 50 percent of Växjö's energy is from renewables, making it what many consider to be the world's cleanest city.



Location: Saskatoon, Canada
Year: 2003
Input: Manure, potatoes
Digester: Steel tank, 2 000 m³
Co-generator: Micro turbine, 4 x 30kW
Designer: Krieg & Fischer
Source of this and following items: Electrigaz, http://www.electrigaz.com/company_en. htm



Location: Fakler, Germany
Year: 2005
Input: Corn, grass and wheat silage
Digester: Concrete tank, 1 045 m³
Co-generator: Gas engine 250 kW
Designer: Krieg & Fischer



Location: Hofgut Holland, Germany
Year: 2004
Input: Pig dung, turkey dung, grass and corn silage
Digester: Concrete tank, 350 m³
Co-generator: Gas engine 60 kW
Designer: Krieg & Fischer

Location: Brahm, Germany
Year: 2004
Input: Pig Manure, Kitchen Waste, Fats, Grain
Digester: Concrete tank, 1 205m³
Co-generator: Gas engine 2 x 190 kW
Designer: Krieg & Fischer

Location: Bluemel, Germany
Year: 1994/95
Input: Biowaste, separately collected in households
Digester: Concrete tanks, 2 x 800 m³
Co-generator: dual fuel co-generators, 2 x 160 kW
Designer: Krieg & Fischer

Location:
Barz, Germany
Year: 1996-1998
Input: Manure, kitchen waste
Digester: 2-stage-concrete tank, 200 m³ and 230 m³
Co-generator: Dual fuel co-generator, 45 kW
Designer: Krieg & Fischer

Appendix 4
People Power:
Waste That Should Be Used

Strangely, at a time when recycling, solid waste reduction, composting and other ways of conserving resources are burgeoning, most cities in the United States waste their most valuable waste: sewage. But then, cities have company, because industrial plants—pulp and paper mills, food processors, winemakers and others—are doing the same with their byproducts.

Sewage and the rest can be used to produce methane, which can generate electricity or provide heat. Of the 16,000 sewage, or wastewater, treatment plants in the United States, about 1,000 process enough gallons (five million daily) to make a profit from generating electricity, according to the U.S. Environmental Protection Agency (EPA). Yes, a bit more than one-half, 544, use anaerobic digestion, in which microbes break down sewage or other wastes in the absence of oxygen to produce methane. But only 106 take the next step and put the gas to use. The others simply flare, or burn, the gas.[386]

Used to generate electricity, the methane from those 544 sewage plants[ddddd] could power 340,000 homes with 340 megawatts of electricity, according to the EPA.[387] If the process were adopted at even more sewage treatment plants, as well as industrial facilities, the methane generated—and the global warming avoided—would be immense.

In California, of the roughly 268 wastewater treatment plants with a discharge capacity of one million gallons per day or more, only 117 have digesters, largely because of the conventional wisdom that at plants with less than 3 million or 4 million gallons per day of capacity, the return is not worth the investment. In fact, smaller plants using diverse feedstocks and mixing

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[ddddd]In the jargon of water pollution, these are often referred to as Publicly Owned Treatment Works or POTWs.

technologies are cost effective.[388]

Almost any organic material can be processed with anaerobic digestion. This includes biodegradable waste materials such as waste paper, grass clippings, leftover food, sewage and animal waste.[389] Mixing used oil, and grease from restaurants and other wastes together with sewage sludge, called co-digestion, can boost methane production up to 40 percent[390]

PEOPLE POWER

Needing to reduce pollutant emissions and reliance on the local power grid, the Regional Wastewater Treatment Facility in Tulare, California decided to turn to the fuel closest at hand: its own sewage sludge. It helped, of course, that there was $4 million in financial incentives available from California's Self-Generation Incentive Program, because it aids in paying for a 900 kilowatt (kW) system, the heart of which is three stationary fuel cell power plants from FuelCell Energy.

Heat from the fuel cells is used to increase sludge temperature, which speeds digestion. By combining heat and power, the system can deliver an overall efficiency of up to 90 percent.[391]

Tulare, population 50,000, is surrounded by Southern California's richest agricultural farm land. It treats nearly 9 million gallons per day of the region's wastewater. The region's air pollution is some of the nation's worst, partially because Tulare is growing at twice the California average.[392]


The city of Tulare digests sewage anaerobically, or in the absence of air, to produce methane that runs fuel cells to generate electricity.

In January 2010, Tulare announced that the system would expand by adding a fourth fuel cell.[393] Meanwhile, the Dublin San Ramon Services District has installed power plants from FuelCell Energy Inc. that are preparing to come online in the near future. Livermore, Riverside, Rialto, the Turlock Irrigation District, and the Eastern Municipal Water District are also proceeding with the installation of DFC power plants.[394]

Tulare is by no means alone in exploiting people power. The Dublin San Ramon Services District has installed a pair of 300 kilowatt fuel cells at its plant in Pleasanton, California, about 50 miles east of San Francisco, thanks to a grant from Pacific Gas & Electric, the local utility.[395]

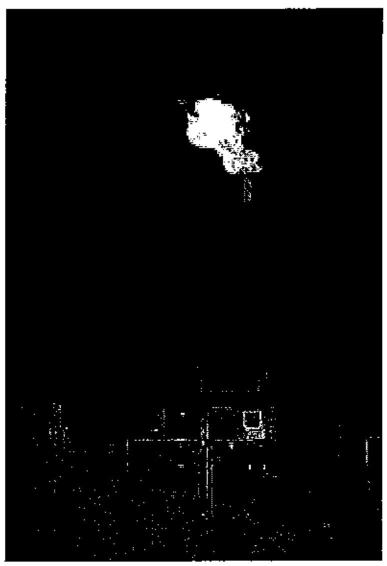
Another 2.8-megawatt fuel cell, this at the University of California-San Diego, will be paired with an additional 2.8-megawatt advanced energy-storage system to allow off-peak power to be stored, then used during peak-demand hours. The components, $7.65 million and $3.4 million, respectively, and funded by the California Self Generation Initiative, represent the largest project of its kind in the world.[396]

Not all fuel cell projects are as successful as those in California, however. Starting in July 1999, the Portland, Oregon, Columbia Boulevard sewage plant began using a 200 kilowatt fuel cell running on about 82 million gallons of wastewater per day generating methane. It generated enough electricity for about 40 homes which was sold to Portland General Electric. The electricity saved the city about $60,000 per year.[397]

In 2003, four microturbines were added to the system to generate additional electricity.[398] The fuel cell, however, began to experience problems and was shut down in 2005.[399]

Landfill Gas-to-Energy

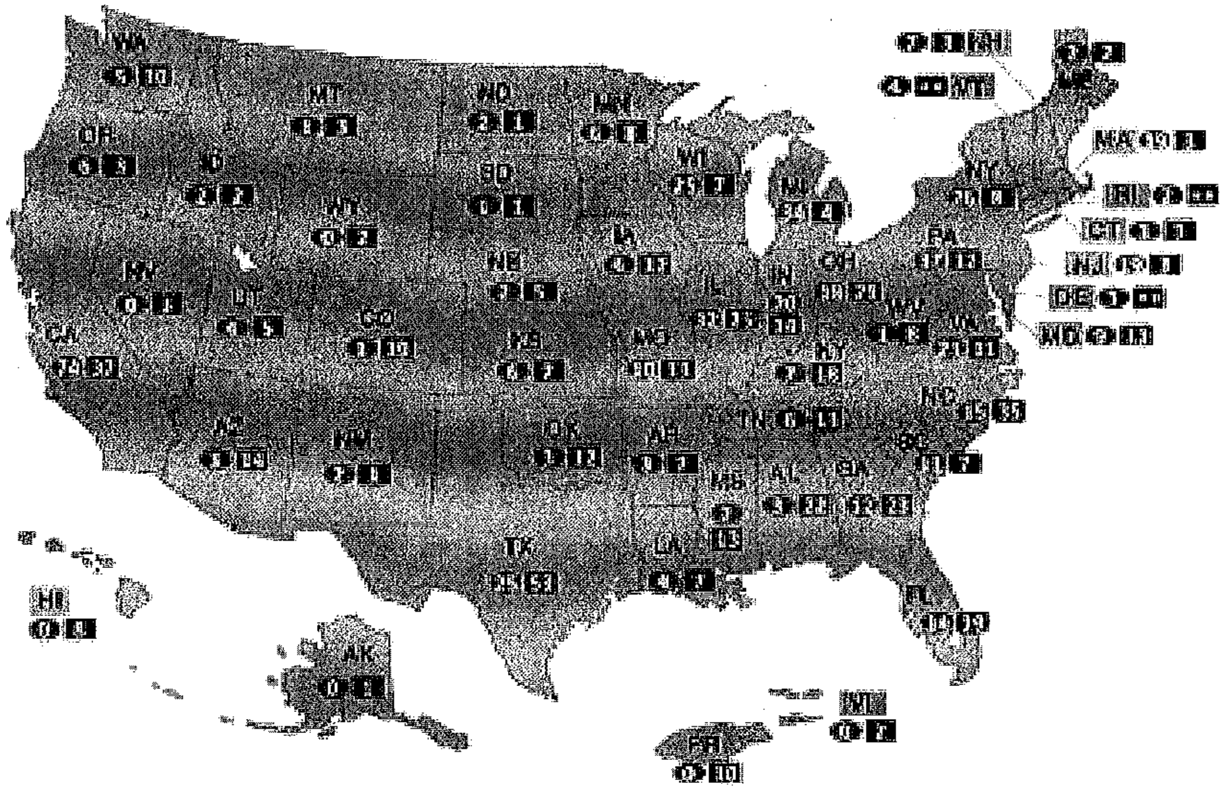
As food and other trash rots, it produces methane and carbon dioxide. Not surprisingly, therefore, where there's a lot of trash, such as a "Mt. Trashmore" city landfill, there is a lot of methane. The methane can be allowed to slowly escape to the air; collected and burned, or "flared,"or, for cities that want to make a modest profit, captured, converted to usable energy, such as electricity, and either sold or used. It is, in the words of *EnergyToday* magazine, "a renewable, practical, affordable energy resource that is quite possibly available in your area right now."[400]



Landfill gas being burned, or "flared."

At hundreds of landfills across the nation, cities, utilities or others have built networks for collecting, purifying, and converting methane into energy, using a series of wells and a blower or vacuum system which directs the gas to a central processing point. There, the gas is used to generate electricity and heat with internal combustion engines or turbines—or better still, fuel cells, which produce electricity chemically with virtually no air pollution whatsoever—or it can be upgraded to pipeline-quality gas and sold.

Landfill gas (LFG) is about 50 percent methane, with a heat content of about half that of natural gas. Unlike wind, solar and some other forms of renewable energy, landfill gas is generated 24 hours per day, seven days a week. Landfill gas-to-energy projects have on-line reliability of over 90 percent.



Landfill Gas Energy Projects and Candidate Landfills. Source: EPA.

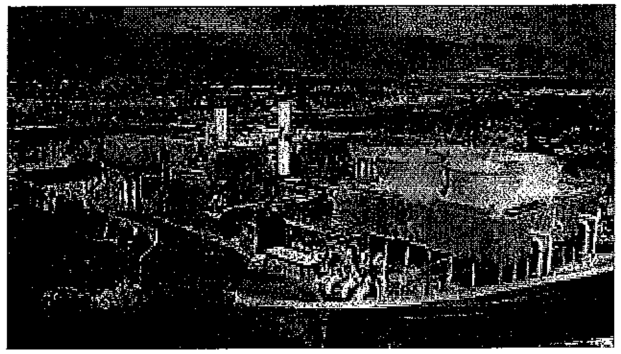
According to the U.S. Environmental Protection Agency, there are already more than 509 operational landfill gas projects nationally. Another 530 landfills are good candidates for projects.[401] These numbers may greatly understate the potential of exploiting methane from waste because they assume megawatt-sized generators—a megawatt can power 250 or more U.S.-size homes—at a time when tiny fuel cells the size of a stack of wedding invitations can generate just enough electricity for a single light bulb. Others of these "Bloom boxes," made by Silicon Valley start-up Bloom Energy, are as big as a parking space. eBay, the internet auction firm, bought a Bloom box for its headquarters and saved $100,000 in electricity costs in the first year alone.[402]

In many cases, landfill gas is wasted because it "flared," or burned. In others, it is used to generate electricity. But there is a third option, cogeneration, in which the heat that remains after making electricity is also used. Landfill gas-to-cogeneration projects present a win-win-win situation. Emissions of a particularly damaging pollutant, methane, are avoided; electricity is generated from a 'free' fuel; and, heat is available for use locally.

Examples of Landfill Gas-to-Energy Projects

Puente Hills Landfill Gas-to-Energy

13130 Crossroads Parkway South
City of Industry, CA 91746



Background

The largest gas-to-energy facility in California is the Puente Hills Landfill, which has been in full commercial operation since January 1987 and has remained on-line 95 percent of the time. The facility produces 50 megawatts (MW) (gross) electricity, equivalent to the energy requirements of approximately 70,000 homes.

Landfill

The Puente Hills Landfill serves homes and businesses in over 60 cities as well as unincorporated areas within Los Angeles County, managing approximately one-third of the countywide waste requiring disposal.

Power Generation

The Puente Hills Gas-to-Energy facility uses a conventional steam power plant to generate electric power, burning landfill gas with a steam turbine/generator. Currently, the Puente Hills Landfill facility produces approximately 46 MW net of electric power. The power is sold to the local utility company, Southern California Edison.

Benefits

The Puentes Hill plant is one of several operated by the Los Angeles County Sanitation Districts. By collecting the landfill gas and burning it in burners that emit low levels of oxides of nitrogen, one of the pollutants that forms smog, the Sanitation Districts reduce air pollution and make money by selling the electricity.[403]

Modern Landfill Inc, New York

The LFG-fired cogeneration facility at Modern Landfill in New York provides 100 percent of the electricity and heating requirements for H2Gro Hydroponic Greenhouses, with excess power sold to the grid. Innovative Energy Systems started the initial phase in 2001, when it designed and installed a 5.6 MW project to power and heat a 2,024 square meter greenhouse test plot. In its first year, the project yielded 82,000 kilograms (180,000 pounds) of tomatoes. After a successful test plot, this greenhouse was expanded to 30,352 square meters and 12 megawatts of generating capacity. The H2Gro facility produces over 1,600 tons of tomatoes per year.[404]

Creswell and Frey Farm Landfills, Pennsylvania

The Pennsylvania Lancaster County Solid Waste Management Authority, PPL Corporation and Turkey Hill Dairy formed a unique partnership to install a combined heat-and-power using gas from two landfills. The landfill gas is sold to PPL Energy Services, which operates two Caterpillar 3520 engines to produce 3.2 MW of electricity. The engine heat is captured to generate steam, which is sold to the nearby Turkey Hill Dairy through a closed-loop steam pipeline. Landfill methane is eliminated, electricity is generated and sold, and heat is put to use: win-win-win.[405]

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Air Pollution and Cardiovascular Disease: A Statement for Healthcare Professionals from the Expert Panel on Population and Prevention Science of the American Heart Association Circulation 2004: 109; 2655–2671

Summary (with 194 references) of the epidemiological data indicating that current levels of air pollution are having a detrimental effect on people with heart disease. Abstract notes: "Several plausible mechanistic pathways have been described, including enhanced coagulation/thrombosis, a propensity for arrhythmias, acute arterial vasoconstriction, systemic inflammatory responses, and the chronic promotion of atherosclerosis".

Summarise present data on PM_{10} as indicating that a 10 μg/m3 increase in 90 cities increases daily total and cardiopulmonary mortality in the short-term by 21 percent and totally by 31 percent. Reviews SO_2 and ozone as well as particles. ETS exposure also reviewed. Detailed review of possible mechanistic links.

Notes: "On the basis of these conclusions and the potential to improve the public health, the AHA writing group supports the promulgation and implementation of regulations to expedite the attainment of the existing NAAQS. Moreover, because a number of studies have demonstrated associations between particulate air pollution and adverse cardiovascular effects even when levels of ambient $PM_{2.5}$ were within current standards, even more stringent standards for $PM_{2.5}$ should be strongly considered by the EPA."

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Data on 22,905 Los Angeles subjects extracted from the ACS cohort for the period 1982–2005, for a total of 5,856 deaths. Total of 434 lung cancers, and 1462 cases of ischemic heart disease. Pollution exposures were interpolated from 23 $PM_{2.5}$ and 42 ozone monitors. Subjects with a P.O. Box address were excluded. The proximity of the individual to expressways was used as a measure of traffic pollution. Associations between variables was tested by standard and spatial multilevel Cox regression models. The data were controlled for 44 individual covariates, and the RR was 1.17 for an increase of 10 μg/m3 in $PM_{2.5}$, and if maximal control for both individual and contextual confounders was used, RR was 1.11. The RRs for both ischemic heart disease and lung cancer deaths were elevated in the range of 1.24 to 1.60 depending on the model used. Results were robust to adjustments for O_3 and expressway exposure. Map of Los Angeles basin with $PM_{2.5}$ data interpolated with a hybrid universal-multiquartic model, and values from zero up to a maximum of a mean $PM_{2.5}$ of 24.4 to 27.1 μg/m3 are shown. Table shows different models used, and it is clear from this that most of the adjustments make little difference to the RR values calculated.

The authors conclude: "Our results suggest the chronic health effects associated with within-city gradients in exposure to $PM_{2.5}$ may be even larger than previously reported across metropolitan areas. We observed effects nearly three times greater than in models relying on comparisons between communities. We also found specificity in cause of death, with $PM_{2.5}$ associated more strongly with ischemic heart disease than with cardiopulmonary or all-cause mortality."

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Time-series, cross-sectional, and prospective cohort studies have observed associations between mortality and particulate air pollution but have been limited by ecologic design or small number of subjects or study areas. The present study evaluates effects of particulate air pollution on mortality using data from a large cohort drawn from many study areas. We linked ambient air pollution data from 151 U.S. metropolitan areas in 1980 with individual risk factor on 552,138 adults who resided in these areas when enrolled in a prospective study in 1982. Deaths were ascertained through December, 1989. Exposure to sulfate and fine particulate air pollution, which is primarily from fossil fuel combustion, was estimated from national data bases. The relationships of air pollution to all-cause, lung cancer, and cardiopulmonary mortality was examined using multivariate analysis which controlled for smoking, education, and other risk factors. Although small compared with cigarette smoking, an association between mortality and particulate air pollution was observed. Adjusted relative risk ratios (and 95 percent confidence intervals) of all-cause mortality for the most polluted areas compared with the least polluted equaled 1.15 (1.09 to 1.22) and 1.17 (1.09 to 1.26) when using sulfate and fine particulate measures respectively. Particulate air pollution was associated with cardiopulmonary and lung cancer mortality but not with mortality due to other causes. Increased mortality is associated with sulfate and fine particulate air pollution at levels commonly found in U.S. cities. The increase in risk is not attributable to tobacco smoking, although other unmeasured correlates of pollution cannot be excluded with certainty.

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Investigators recruited 20 men who had had a prior MI but were asymptomatic with no exertional angina and who were on optimal secondary-prevention medication. In the double-blind, randomized, crossover study—conducted at Umea University in Sweden—the men were exposed for one hour to either filtered air or dilute diesel-exhaust fumes (300 μg/m3) while intermittently riding a bicycle ergometer for two 15-minute periods, separated by 15-minute rest periods. Mills said the levels of diesel fumes in the study were chosen to mimic the sorts of air pollution that would be encountered in everyday life. During exposure, myocardial ischemia was quantified by ST-segment analysis using continuous 12-lead ECG. Six hours after exposure, vasomotor and fibrinolytic functions were assessed by means of intra-arterial agonist infusions. Heart rate

increased similarly with exercise during both air and diesel exposures, but there was as much as a threefold increase in myocardial ischemia during exposure to diesel-exhaust fumes compared with filtered air (-22.4 vs -8 mV-sec; $p<0.001$). Exposure to diesel fumes did not aggravate preexisting vasomotor dysfunction, but it did dampen the acute release of endothelial tissue plasminogen activator by 35%.

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Mills told heartwire that while a wealth of large-scale and robust studies have been conducted in the past five to 10 years looking at the association between air pollution and adverse cardiac outcomes, "these have been challenged because it's been impossible to prove causality. What's been missing in this field is an understanding of what the mechanism is that links exposure to adverse outcomes. We're the first group to have conducted controlled exposures anywhere in the world, and our results are important because they provide strength to the observational studies, and they show that this is indeed a causal relationship we are talking about."

The study is—Mills, N.L. Ischemic and Thrombotic Effects of Dilute Diesel-Exhaust Inhalation in Men with Coronary Heart Disease. *N Engl J Med 2007*; 357:1075–1082.

Although exposure to air pollution from traffic is associated with adverse cardiovascular events, the mechanisms for this association are unknown. To identify ischemic and thrombotic mechanisms that may explain in part the observation that exposure to combustion-derived air pollution is associated with adverse cardiovascular events, investigators conducted a controlled exposure to dilute diesel exhaust in patients with stable coronary heart disease to determine the direct effect of air pollution on myocardial, vascular, and fibrinolytic function.

In a double-blind, randomized, crossover study, 20 men with prior myocardial infarction were exposed, in two separate sessions, to dilute diesel exhaust (300 μg per cubic meter) or filtered air for 1 hour during periods of rest and moderate exercise in a controlled-exposure facility. During the exposure, myocardial ischemia was quantified by ST-segment analysis using continuous 12-lead electrocardiography. Six hours after exposure, vasomotor and fibrinolytic function were assessed by means of intraarterial agonist infusions. During both exposure sessions, the heart rate increased with exercise ($P<0.001$); the increase was similar during exposure to diesel exhaust and exposure to filtered air ($P=0.67$). Exercise-induced ST-segment depression was present in all patients, but there was a greater increase in the ischemic burden during exposure to diesel exhaust (–22±4 vs. –8±6 millivolt seconds, $P<0.001$). Exposure to diesel exhaust did not aggravate preexisting vasomotor dysfunction, but it did reduce the acute release of endothelial tissue plasminogen activator ($P=0.009$; 35% decrease in the area under the curve).

The investigators concluded that brief exposure to dilute diesel exhaust promotes myocardial ischemia and inhibits endogenous fibrinolytic capacity in men with stable coronary heart disease. Our findings point to ischemic and thrombotic mechanisms that may explain in part the observation that exposure to combustion-derived air pollution is associated with adverse cardiovascular events. (ClinicalTrials.gov number, NCT00437138 [ClinicalTrials.gov] .)

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Biomass fuel used for cooking results in widespread exposure to indoor air pollution (IAP), affecting nearly 3 billion people throughout the world. Few studies, however, have tested for an exposure-response relationship between biomass fuel and health outcomes. To assess the relationship between biomass fuel, infant mortality, and children's respiratory symptoms. Eighty households in a rural community in Ecuador were selected based on their use of biomass fuel and questioned regarding a history of infant mortality and children's respiratory symptoms. Carbon monoxide (CO) and particulate matter (PM) were measured in a subset of these homes to confirm the relationship between biomass fuel use and IAP. Results showed a significant trend for higher infant mortality among households that cooked with a greater proportion of biomass fuel (P = 0.008). Similar trends were noted for history of cough (P = 0.02) and earache (P < 0.001) among children living in these households.

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desirable, with clearer recognition of the interrelationships between poverty and dependence on polluting fuels.

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

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Abstract: The prior goal for a pulp and paper mill is to achieve a chemical recovery system with high availability and good reliability. It is also important that the heat recovery system produces sufficient process heat for the heat-demanding processes in the mill. Black liquor gasification promises to be a future alternative or a complement to the conventional Tomlinson recovery boilers in the pulp industry. Black liquor gasification should offer several advantages from both a chemical recovery and an energy point of view. The gasification process produces a combustible gas which can be used for steam and power generation in many ways. Several studies have shown that the power output from a heat and power cycle integrated with black liquor gasification has potential to get a higher energy efficiency than today's heat recovery technology. Especially with pressurized gasification and a gas-turbine-based cogeneration system, the power output will be significantly improved. However, the gas turbine is very sensitive to corrosive elements. The gas cleaning equipment in the gasification system must therefore have a high removal efficiency and a high reliability. The ambition is to keep the gasification capacity constant during the year, but the fuel consumption for the gas turbine increases at low ambient temperatures. The seasonal variation will cause the gas turbine to operate at partial load and, consequently, there will be a decrease in the gas turbine efficiency. An alternative combined cycle with high power efficiency is given by a hybrid plant in which the gas turbine is fired with natural gas while the fuel gas from the pressurized gasifier is used as a supplementary fuel for the Rankine cycle. A major advantage of the hybrid system is the use of a high purity fuel gas in the gas turbine. The system also allows for variations in pulp capacity which is difficult in an integrated gasification combined cycle (IGCC). This study compares the effect of using an IGCC system and a hybrid combined plant instead of a conventional recovery system. The results indicate a potential to double the power output if the conventional system is replaced by an IGCC system. A hybrid combined cycle system has also a higher net power efficiency than the conventional recovery system. Furthermore, the hybrid system can make the mill self-supporting on power and allows an increase in the heat consumption.

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