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TECHNOLOGY UPDATE

CLIMATE CHANGE AND CO_2 HAVE BEEN MUCH IN THE NEWS OF LATE, AND I THOUGHT IT WOULD BE interesting to collect information, chat with specialists and share my findings with fellow auto enthusiasts. ❖ I gained insights from Scott Samuelsen, Professor of Mechanical, Aerospace and Environmental Engineering, and Director, National Fuel Cell Research Center, University of California Irvine; from Richard S. Lindzen, Alfred P. Sloan Professor of Atmospheric Sciences, M.I.T.; from Robert Socolow, Professor of Mechanical and Aerospace Engineering, Princeton University; from Marlo Lewis Jr., Senior Fellow, Competitive Enterprise Institute; and also from specialists at Honda, GM, Volkswagen and Toyota. I read Executive Summaries of the Intergovernmental Panel on Climate Change (hereinafter, the IPCC) and the Stern Review: The Economics of Climate Change, as well as commentaries in *Science,* published by the American Association for the Advancement of Science, *Scientific American,* M.I.T.'s *Technology Review* and *Weatherwise* magazine. I accumulated items from sources as varied as *Automotive News,* the Internet, *The New York Times* and our local *Orange County Register* (on this particular topic, these two respected newspapers couldn't have been more contrasting). I compared popularizations such as Al Gore's *An Inconvenient Truth* with contrasting viewpoints, some scientific, others decidedly less so. ❖ Here's what I gleaned from all this.

Climate Change, CO_2 and the Automobile

Are we arrogant in changing the climate? Or arrogant in thinking we can?

BY DENNIS SIMANAITIS » ILLUSTRATIONS BY GUY BILLOUT

CLIMATE CHANGE

There's nothing profound—nor particularly contentious—in observing that the climate of our earth changes. Over geologic time we've had major ice ages. The Wisconsin Glaciation, which formed our Great Lakes, lasted about 80,000 years until around 12,000 years ago during which time the temperatures were perhaps 15 degrees Fahrenheit colder than today's. There have also been Interglacial warm spells. In the Mesozoic Age, dinosaurs thrived in a climate that was some 18 deg F warmer than the Interglacial we're now experiencing.

A lot more recently (in the geologic sense), there was a Medieval Warm Period about 1000 to 1300 A.D. Temperatures were some 1–3 deg F warmer than today's and, for example, coastal regions of Greenland were farmed by Vikings, though its central ice cap remained.

And then, roughly 1300–1850 A.D., the climate shifted by about the same degree into a Little Ice Age. Growing seasons were shorter and less reliable. It's said that the colder climate's dense wood contributed to the special tone of Antonio Stradivari's violins. London's River Thames regularly froze over and, in the winter of 1780, people walked across New York Harbor from Manhattan to Staten Island.

Some say these were merely regional and can be discounted. Others say we're still emerging from this Little Ice Age as we enter a period they call Modern Warming.

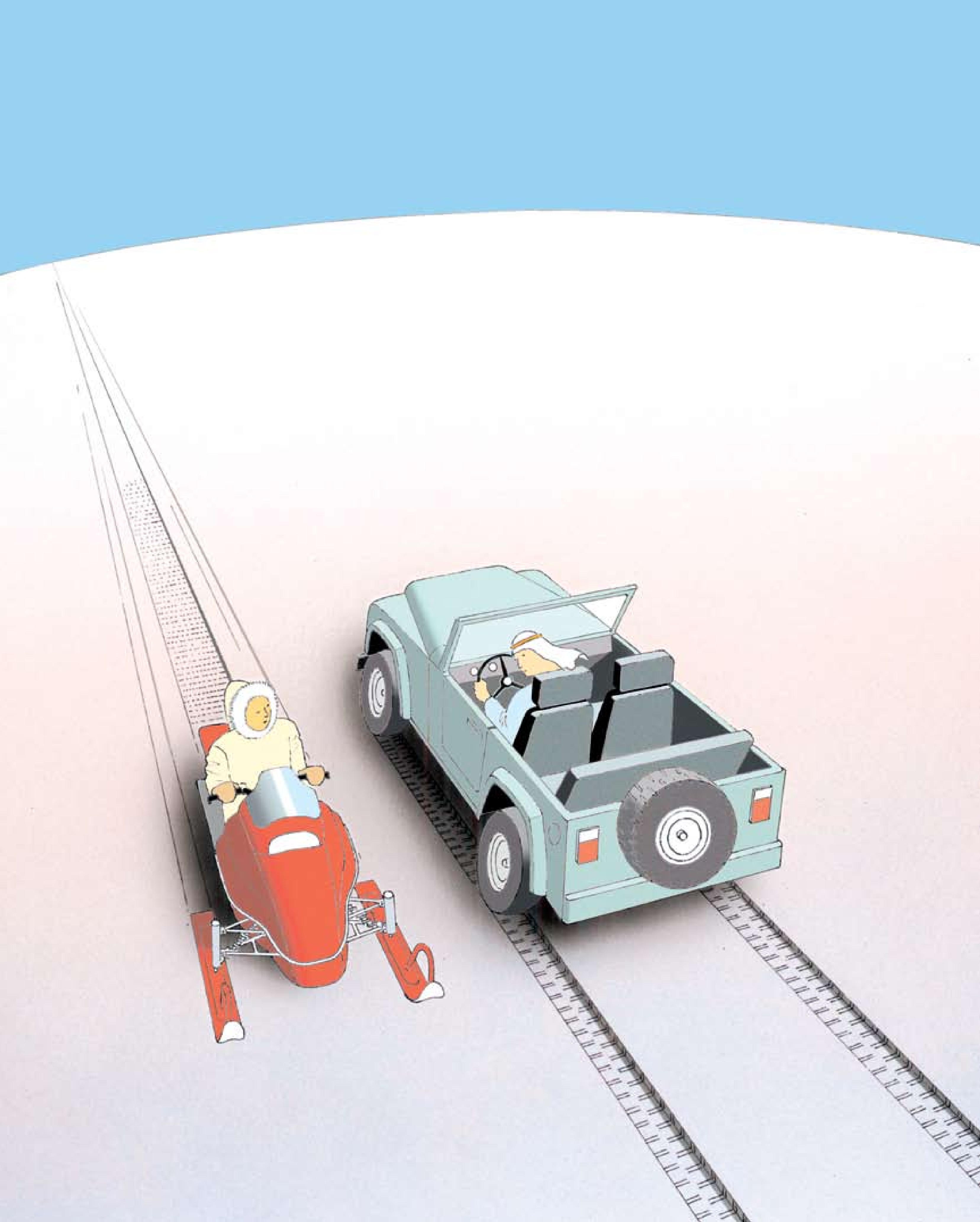
Formed by the United Nations Environment Programme and the World Meteorological Organization, the IPCC has published four reports, the most recent this year. According to IPCC data, between 1900 and 2000 the global average surface temperature rose by about 1.2 deg F, with uncertainty of perhaps ± 0.2 deg F.

Note: IPCC values are reported in SI (metric) units; the conversions to English units are mine. Also, a word on wiggle room: Whenever a single value is offered in these matters, you can suspect it's chosen with appropriate stacking to fit an agenda. Forgive me the pedantry of bringing these uncertainties to your attention, but I believe they're part of the story.

Even knowledgeable skeptics of the IPCC report concur that there was an increase in global temperature over the 20th century, albeit at the lower end of IPCC values. What's more, says the IPCC, "11 of the last 12 years rank among the 12 warmest years in the instrumental record of global surface temperature (since 1850)."

Maybe someone says the year 1936 beats them all, or, depending on where and how you measure, maybe it's 1934, which brings up a crucial point of distinguishing "climate" from "weather."

Weather is local, chaotic and short-term. Mathematically, it's a non-linear potentially unstable dynamical system. "Nonlinear"—don't assume proportional responses; "unstable"—a tiny nudge here and now may cause huge differences later and elsewhere. By contrast, climate is pre-



"Be it climate or weather, most specialists agree—for one reason or another—**the earth is warming.**"

vailing or average weather of broad regions as recorded over years, decades, centuries or more.

Hurricanes, tornadoes, hailstorms, regions of low or high pressure; all of these are matters of weather. Persistent or recurring phenomena (el Niño/la Niña ocean-atmosphere cycles, for instance) are matters of climate. So are rather less predictable events such as volcanic eruptions and major dust storms, the aerosols—ash, soot and the like—of which can have long-term influence. Climatic effects help define weather. But only long-term accumulations of weather events characterize climate.

Nonetheless, be it climate or weather, most specialists agree—for one reason or another—the earth is warming.

CO_2

Carbon dioxide, CO_2, is part of every breath we exhale. It's what plants inspire through their stomata. And, alas, it's a product of just about every combustion of anything carbonaceous. Together with water vapor, methane and nitrous oxide, CO_2 is also one of the principal greenhouse gases enhancing life on earth.

Enhancing life on earth? Aren't greenhouse gases bad?

Without the greenhouse effect, the earth would be perhaps 50 deg F colder—and there'd be an Ice Age to end all ice ages.

Its mechanism is a complex one, rather more involved than our-planet-in-a-blanket usually pictured. (One specialist warned me, "If it's simple enough, people will be happier than if it's correct.") But let's try for a more accurate description.

In particular, the process involves both radiation (the absorption and emission of energy, in this case, heat) and convection (the transfer of heat by circulation or movement). By contrast, our-planet-in-a-blanket comes closer to a model of conduction (the transfer of heat between elements of different temperature in a stationary system).

We spend our lives in the troposphere, an atmospheric skin surrounding the earth. And, even at 10 miles thick, the troposphere is the thinnest of skins; think a coat of paint on an extremely smooth basketball.

The troposphere maintains the earth's delicate balance of incoming solar radiation and its outgoing infrared/heat resultant. Three-atom molecules like CO_2 (or, for that matter, H_2O, water vapor) don't absorb in the incoming visible range, but they do absorb and emit in the infrared.

Now comes the subtle part: According to specialists, adding CO_2 moves the emitting level higher in the troposphere where it is colder. Thus the emitted radiation no longer balances the net incoming solar radiation and, to reestablish balance, this emitting level has to warm. How this warming is communicated to the surface involves convection, and this is complicated by turbulent activity in the troposphere.

CO_2 is a relatively small proportion of the troposphere, typically measured in parts per million. According to ice-core data from the IPCC, these CO_2 levels have risen from a pre-industrial value of about 280 ppm to around 380 ppm today. What's more, says the IPCC, it's "highly likely" that these changes are anthropogenic—i.e., man-made.

Others say CO_2 levels have varied considerably over geologic time and, indeed, have been as much as 16 times today's level. The IPCC says today's level "exceeds by far the natural range over the last 650,000 years (180–300 ppm)"—though I must confess its "by far" assessment got my confidence needle quivering just a tad. In particular, an IPCC graph (one of the popularly known "hockey sticks") shows CO_2 levels greater than 250 ppm for the past 10,000 years and greater than 275 for the past 2500.

Also, remember that CO_2 isn't the only greenhouse gas. Methane, its presence largely traceable to agriculture, is some 24 times more reactive in its greenhouse contribution. Fortunately, its concentration is typically measured in parts per *billion* (i.e., 1000 million).

Water vapor and clouds are also part of it. In fact some specialists say the H_2O greenhouse-effect contribution is the dominant one.

Nevertheless, as one of my sources put it, "Any time you put energy-absorbing molecules into the atmosphere, you're potentially disrupting the system."

WHO'S THE CULPRIT: US OR MOTHER NATURE?

In seeking a culprit, let's distinguish between "correlation" (a mutual relationship) and "causality" (the interrelation of cause leading to effect). Left over from my teaching days: There's a strong positive correlation between teacher salaries in a community and that community's alcoholic consumption.

Points off if you automatically assume it's the teachers doing all the drinking, or inebriates signing all the teacher checks.

That is, though these two may be highly correlated, there's no reason to assume that one is causing the other. For instance, maybe they're both effects, the common cause being community average income.

As in any science, climate specialists seek causality by collecting real-world data, building mathematical models, assessing how well the models fit reality and then using the models for prediction.

A nearby table collects IPCC predictions on temperature change and sea-level rise to be expected by 2090–2099, the results assembled from several models and based on different scenarios of world activity. I've included CO_2 data from other parts of its report to help gauge these scenarios.

The first one assumes a hypothetically constant CO_2 level of 375 ppm throughout the next 90 years. Its best estimate of temperature rise, +1.1 deg F, albeit with a rather wide range of likelihood, is comparable to that experienced over 1900–2000. Feedback mechanisms in the climate system, things like warming tundra, contribute to this.

The B1 storyline has a world population "that peaks in mid-century and declines thereafter." It's characterized by "global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives." Its CO_2 level is about 600 ppm, rather more than the 550-ppm threshold considered by many to be critical. Its best estimate of temperature change for 2090–2099 is +3.2 deg F, its likely values ranging from +2.0 to +5.2 deg F. A predicted rise in sea level by 2090–2099 ranges between 7.1 and 15.0 in.

Others concur, estimating sea-level rise at around 1 in./decade, mostly attributed

IPCC PREDICTIONS FOR 2090–2099

SCENARIO	CO_2 LEVEL	TEMPERATURE INCREASE**		SEA-LEVEL INCREASE
		Best Estimate	Likely Range	
Constant Year 2000	375 ppm*	1.1 deg F	0.5 deg F – 1.6 deg F	na
B1	600 ppm	3.2 deg F	2.0 deg F – 5.2 deg F	7.1 in. – 15.0 in.
A1FI	1550 ppm	7.2 deg F	4.3 deg F – 11.5 deg F	10.2 in. – 23. 2 in.

**Parts per million. **Changes relative to 1980–1999.*

Source: Climate Change 2007: The Physical Science Basis; Summary for Policymakers

> “We’d be foolish **not to adapt.**
> But we’d be almost as foolish **to overreact…”**

to thermal expansion of the oceans. Some contend glaciers are only minor contributors to this, as their outflow is seen offset by ice accumulation on inland ice caps. (When coastal Greenland was farmed, the Thames Estuary didn’t submerge London.)

The most dire case offered in the IPCC summary is its A1FI scenario. The storyline posits population dynamics similar to those of the B1 scenario, very rapid economic growth, but with a “substantial reduction in regional differences in per capita income.” And, in particular, “FI” stands for Fossil Intensive, continued extensive use of fossil fuels. The predicted CO_2 level of 1550 ppm is more than four times the current level. Best estimate of temperature is +7.2 deg F. Water levels could increase by as much as 23.2 in.

Many say the IPCC analyses are good science. And, as is the case with any good science, there is also critical review. In fact—and note well—when any “science” scoffs at disagreement, it’s no longer very good science.

Some specialists question the state of the art of today’s climate models. One, for example, said no model comes close to replicating clouds—and the most natural greenhouse effect is water vapor’s. Also, the modeling of aerosols, which have a cooling effect, is a particularly difficult art. Climate models are highly complex, requiring sensitive choices of parameters in fine-tuning. Last, storyline assumptions have been brought into question. As an example, one of my sources noted that the A1FI scenario implies an economic parity of the U.S. and Niger, one of the world’s most impoverished nations. Observed this specialist, “If A1FI occurs, we’ll have a lot more to complain about than climate.”

There’s also the fundamental assumption of cause and effect. All of the IPCC models assume that elevated CO_2 levels cause the temperature rise. However, other studies of geologic time offer a similar correlation of temperature and CO_2—but with the rise in temperature leading the increase in CO_2 by some 1900 years.

Are we arrogant in changing the climate? Or are we arrogant in thinking we can change it?

In either case, it is changing. And mankind is doing something that’s potentially disruptive. We’d be foolish not to adapt. But we’d be almost as foolish to overreact, based on the extremes of this complex issue.

Fortunately, research continues.

WHERE DO OUR CARS FIT IN?

Cars are part of this simply because the more hydrocarbon fuel they consume, the more CO_2 they produce. And note, this isn’t a matter of traditional emissions controls, as the latter treat the hard-core automotive pollutants of hydrocarbons, carbon monoxide and nitrogen oxides. The control of HC, CO and NO_X has been an automotive success story. Today’s SULEVs, as in Super Ultra Low Emissions Vehicles, literally cleanse the urban environment of these three pollutants. And AT-PZEVs, our latest Advanced Technology Partial Zero Emissions Vehicles, are even cleaner. But they still burn carbonaceous fuels and thus emit CO_2 (which, in any case, many find hard to classify as a “pollutant”).

Cars and trucks contribute perhaps 15 percent of the world’s anthropogenic CO_2. (Electrical power generation is the largest single contributor, with some 40 percent of the total.)

At first glance, this suggests that even a significant automotive improvement has only modest payoff in the overall picture. For instance, suppose the U.S. eliminated all gas-guzzling SUVs and, in doing so, suppose this halved our fleet consumption—and thus as well our vehicles’ CO_2 contribution.

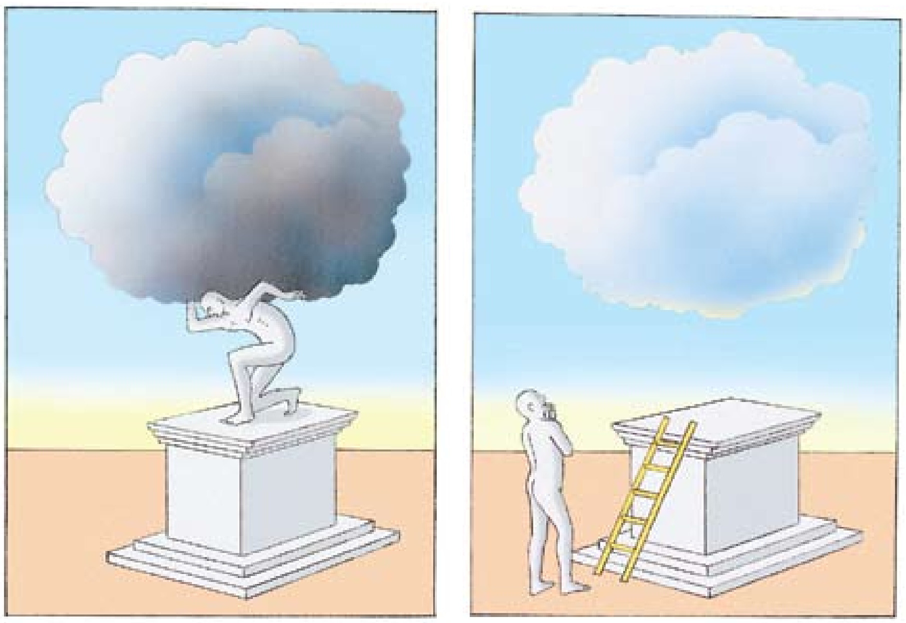
Our hardly frugal national fleet currently accounts for perhaps 45 percent of that global car-and-truck value. Thus, our driving can be associated with 6.75 percent (0.45 x 0.15) of the earth’s anthropogenic CO_2. So even if we improve fuel consumption by a staggering 50 percent, the payoff is a mere 3-percent reduction in global CO_2. (And, yes, I’ve rounded it low here for emphasis.)

Princeton’s Robert Socolow and Stephen Pacala, Professor of Ecology and Evolutionary Biology, Co-Directors of the university’s Carbon Mitigation Initiative, offer encouragement in what have come to be known as Pacala-Socolow Wedges. As shown in the nearby graph, the world’s present rate of emissions of carbon into the atmosphere is on track to double in 50 years, from about 7 to 14 gigatons per year (a gigaton, Gt for short, being 1 billon tons). To envision stabilizing this, they divide the resulting triangle into seven wedges, each worth a reduction in the emission rate by 1 Gt of carbon per year 50 years hence. Said another way, each wedge represents 25 Gt of emissions reductions over the intervening time.

Many combinations of technology might fill the seven wedges. For example, transportation experts figure that there’ll be about 2 billion cars on the road in 50 years. Altogether, if each is driven 15,000 miles and gets 30 mpg, they’ll emit 2.7 Gt carbon that year (equivalently, around 10 Gt of CO_2).

Suppose instead they’re replaced by cars averaging 47 mpg and driven the same average distance. This 2-billion-car world fleet would then produce 1.7 Gt carbon that year, thus saving 1 Gt—worth one Pacala-Socolow Wedge.

Other potential automotive wedges include things like increased development and use of carbon-neutral fuels, electric-hybrid or electric vehicles deriving their plug-ins from renewable-source power and, of course, technologies not yet envisioned.



ARE WE ARROGANT IN CHANGING THE CLIMATE ? OR ARROGANT IN THINKING WE CAN ?

Write Pacala and Socolow, "Our goal in developing the wedge framework was to be pragmatic and realistic—to propose engineering our way out of the problem and not waiting for the cavalry to come over the hill."

A good number of innovative engineers are already off to a good start. During the last decade, for instance, Honda has cut CO_2 by 10 percent, both in its cars and in their production. Volkswagen has aggressive programs with biodiesel and cellulosic ethanol. Nissan has an ambitious "Nissan Green Program 2010." GM's proposed E-Flex concept offers multiple variations on the hybrid theme. And not all that far off is the promise of carbon-free mobility based on hydrogen.

How far off?

A start is no more than 7.2 miles from our Newport Beach offices. (See "Tech Tidbits" elsewhere in this issue.)

Pacala-Socolow Wedges offer a means of envisioning the effects of potential engineering solutions. In their model of stabilized carbon emissions, each of the seven wedges represents a reduction of 1 Gt (a gigaton, 1 billion tons) of carbon per year 50 years hence.