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**I KEPT MY EYES
OPEN FOR
127 HOURS**

December 21, 2010

A Scientist, His Work and a Climate Reckoning

By **JUSTIN GILLIS**

MAUNA LOA OBSERVATORY, Hawaii — Two gray machines sit inside a pair of utilitarian buildings here, sniffing the fresh breezes that blow across thousands of miles of ocean.

They make no noise. But once an hour, they spit out a number, and for decades, it has been rising relentlessly.

The first machine of this type was installed on Mauna Loa in the 1950s at the behest of **Charles David Keeling**, a scientist from San Diego. His resulting discovery, of the increasing level of carbon dioxide in the atmosphere, transformed the scientific understanding of humanity's relationship with the earth. A graph of his findings is inscribed on a wall in Washington as one of the great achievements of modern science.

Yet, five years after **Dr. Keeling's death**, his discovery is a focus not of celebration but of conflict. It has become the touchstone of a

worldwide political debate over **global warming**.

When Dr. Keeling, as a young researcher, became the first person in the world to develop an accurate technique for measuring carbon dioxide in the air, the amount he discovered was 310 parts per million. That means every million pints of air, for example, contained 310 pints of carbon dioxide.

By 2005, the year he died, the number had risen to 380 parts per million. Sometime in the next few years it is expected to pass 400. Without stronger action to limit emissions, the number could pass 560 before the end of the century, double what it was before the Industrial Revolution.

The greatest question in climate science is: What will that do to the temperature of the earth?

Scientists have long known that carbon dioxide traps heat at the surface of the planet. They cite growing evidence that the inexorable rise of the gas is altering the climate in ways that threaten human welfare.

Fossil fuel emissions, they say, are like a runaway train, hurtling the world's citizens toward a stone wall — a carbon dioxide level that, over time, will cause profound changes.

The risks include melting ice sheets, rising seas, more droughts and heat waves, more flash floods, worse storms, extinction of many plants and animals, depletion of sea life and — perhaps most important — difficulty in producing an adequate supply of food.

Many of these changes are taking place at a modest level already, the scientists say, but are expected to intensify.

Reacting to such warnings, President George Bush committed the United States in 1992 to limiting its emissions of greenhouse gases, especially carbon dioxide. Scores of other nations made the same pledge, in a treaty that was long on promises and short on specifics.

But in 1998, when it came time to commit to details in a document known as the Kyoto Protocol, Congress balked. Many countries did ratify the protocol, but it had only a limited effect, and the past decade has seen little additional progress in controlling emissions.

Many countries are reluctant to commit themselves to tough emission limits, fearing that doing so will hurt economic growth. International climate talks in Cancún, Mexico, this month ended with only modest progress. The Obama administration, which came into office pledging to limit emissions in the United States, scaled back its ambitions after climate and energy legislation died in the Senate this year.

Challengers have mounted a vigorous assault on the science of climate change. Polls indicate that the public has grown more doubtful about that science. Some of the Republicans who will take control of the House of Representatives in January have promised to subject climate researchers to a season of new scrutiny.

One of them is Representative [Dana Rohrabacher](#), Republican of California. In a recent Congressional hearing on global warming, he said, “The CO₂ levels in the atmosphere are rather undramatic.”

But most scientists trained in the physics of the atmosphere have a different reaction to the increase.

“I find it shocking,” said Pieter P. Tans, who runs the government monitoring program of which the Mauna Loa Observatory is a part. “We really are in a predicament here, and it’s getting worse every year.”

As the political debate drags on, the mute gray boxes atop Mauna Loa keep spitting out their numbers, providing a reality check: not only is the carbon dioxide level rising relentlessly, but the pace of that rise is accelerating over time.

“Nature doesn’t care how hard we tried,” [Jeffrey D. Sachs](#), the Columbia University economist, said at a recent seminar. “Nature cares how high the parts per million mount. This is running away.”

A Passion for Precision

Perhaps the biggest reason the world learned of the risk of global warming was the unusual personality of a single American scientist.

Charles David Keeling’s son Ralph remembers that when he was a child, his family bought a new home in Del Mar, Calif., north of San Diego. His father assigned him the task of edging the lawn. Dr. Keeling insisted that Ralph copy the habits of the previous owner, an Englishman who had taken pride in his garden, cutting a precise two-inch strip between the sidewalk and the grass.

“It took a lot of work to maintain this attractive gap,” Ralph Keeling

recalled, but he said his father believed “that was just the right way to do it, and if you didn’t do that, you were cutting corners. It was a moral breach.”

Dr. Keeling was a punctilious man. It was by no means his defining trait — relatives and colleagues described a man who played a brilliant piano, loved hiking mountains and might settle a friendly argument at dinner by pulling an etymological dictionary off the shelf.

But the essence of his scientific legacy was his passion for doing things in a meticulous way. It explains why, even as challengers try to pick apart every other aspect of climate science, his half-century record of carbon dioxide measurements stands unchallenged.

By the 1950s, when Dr. Keeling was completing his scientific training, scientists had been observing the increasing use of fossil fuels and wondering whether carbon dioxide in the air was rising as a result. But nobody had been able to take accurate measurements of the gas.

As a young researcher, Dr. Keeling built instruments and developed techniques that allowed him to achieve great precision in making such measurements. Then he spent the rest of his life applying his approach.

In his earliest measurements of the air, taken in California and other parts of the West in the mid-1950s, he found that the background level for carbon dioxide was about 310 parts per million.

That discovery drew attention in Washington, and Dr. Keeling soon found himself enjoying government backing for his research. He joined the staff of the [Scripps Institution of Oceanography](#), in the La Jolla section of San Diego, under the guidance of an esteemed scientist named [Roger Revelle](#), and began laying plans to measure carbon dioxide around the world.

Some of the most important data came from an analyzer he placed in a government geophysical observatory that had been set up a few years earlier in a remote location: near the top of Mauna Loa, one of the volcanoes that loom over the Big Island of Hawaii.

He quickly made profound discoveries. One was that [carbon dioxide](#) oscillated slightly according to the seasons. Dr. Keeling realized the reason: most of the world's land is in the Northern Hemisphere, and plants there were taking up carbon dioxide as they sprouted leaves and grew over the summer, then shedding it as the leaves died and decayed in the winter.

He had discovered that the earth itself was breathing.

A more ominous finding was that each year, the peak level was a little higher than the year before. Carbon dioxide was indeed rising, and quickly. That finding electrified the small community of scientists who understood its implications. Later chemical tests, by Dr. Keeling and others, proved that the increase was due to the combustion of fossil fuels.

The graph showing rising carbon dioxide levels came to be known as the [Keeling Curve](#). Many Americans have never heard of it, but to

climatologists, it is the most recognizable emblem of their science, engraved in bronze on a building at Mauna Loa and carved into a wall at the National Academy of Sciences in Washington.

By the late 1960s, a decade after Dr. Keeling began his measurements, the trend of rising carbon dioxide was undeniable, and scientists began to warn of the potential for a big increase in the temperature of the earth.

Dr. Keeling's mentor, Dr. Revelle, moved to Harvard, where he lectured about the problem. Among the students in the 1960s who first saw the Keeling Curve displayed in Dr. Revelle's classroom was a senator's son from Tennessee named Albert Arnold Gore Jr., who marveled at what it could mean for the future of the planet.

Throughout much of his career, Dr. Keeling was cautious about interpreting his own measurements. He left that to other people while he concentrated on creating a record that would withstand scrutiny.

John Chin, a retired technician in Hawaii who worked closely with Dr. Keeling, recently described the painstaking steps he took, at Dr. Keeling's behest, to ensure accuracy. Many hours were required every week just to be certain that the instruments atop Mauna Loa had not drifted out of kilter.

The golden rule was "no hanky-panky," Mr. Chin recalled in an interview in Hilo, Hawaii. Dr. Keeling and his aides scrutinized the records closely, and if workers in Hawaii fell down on the job, Mr. Chin said, they were likely to get a call or letter: "What did you do?"

What happened that day?”

In later years, as the scientific evidence about climate change grew, Dr. Keeling’s interpretations became bolder, and he began to issue warnings. In [an essay](#) in 1998, he replied to claims that global warming was a myth, declaring that the real myth was that “natural resources and the ability of the earth’s habitable regions to absorb the impacts of human activities are limitless.”

Still, by the time he died, global warming had not become a major political issue. That changed in 2006, when Mr. Gore’s movie and book, both titled “[An Inconvenient Truth](#),” brought the issue to wider public attention. The Keeling Curve was featured in both.

In 2007, [a body](#) appointed by the [United Nations](#) declared that the scientific evidence that the earth was warming had become unequivocal, and it added that humans were almost certainly the main cause. Mr. Gore and the panel [jointly won](#) the Nobel Peace Prize.

But as action began to seem more likely, the political debate intensified, with fossil-fuel industries mobilizing to fight emission-curbing measures. Climate-change contrarians increased their attack on the science, taking advantage of the Internet to distribute their views outside the usual scientific channels.

In an interview in La Jolla, Dr. Keeling’s widow, Louise, said that if her husband had lived to see the hardening of the political battle lines over climate change, he would have been dismayed.

“He was a registered Republican,” she said. “He just didn’t think of it as a political issue at all.”

The Numbers

Not long ago, standing on a black volcanic plain two miles above the Pacific Ocean, the director of the Mauna Loa Observatory, John E. Barnes, pointed toward a high metal tower.

Samples are taken by hoses that snake to the top of the tower to ensure that only clean air is analyzed, he explained. He described other measures intended to guarantee an accurate record. Then Dr. Barnes, who works for the National Oceanic and Atmospheric Administration, displayed the hourly calculation from one of the analyzers.

It showed the amount of carbon dioxide that morning as 388 parts per million.

After Dr. Keeling had established the importance of carbon dioxide measurements, the government began making its own, in the early 1970s. Today, a NOAA monitoring program and the Scripps Institution of Oceanography program operate in parallel at Mauna Loa and other sites, with each record of measurements serving as a quality check on the other.

The Scripps program is now run by Ralph Keeling, who grew up to become a renowned atmospheric scientist in his own right and then joined the Scripps faculty. He took control of the measurement program after his father’s sudden death from a heart attack.

In an interview on the Scripps campus in La Jolla, Ralph Keeling calculated that the carbon dioxide level at Mauna Loa was likely to surpass 400 by May 2014, a sort of odometer moment in mankind's alteration of the atmosphere.

“We're going to race through 400 like we didn't see it go by,” Dr. Keeling said.

What do these numbers mean?

The basic physics of the atmosphere, worked out more than a century ago, show that carbon dioxide plays a powerful role in maintaining the earth's climate. Even though the amount in the air is tiny, the gas is so potent at trapping the sun's heat that it effectively works as a one-way blanket, letting visible light in but stopping much of the resulting heat from escaping back to space.

Without any of the gas, the earth would most likely be a frozen wasteland — according to a recent study, its average temperature would be colder by roughly 60 degrees Fahrenheit. But scientists say humanity is now polluting the atmosphere with too much of a good thing.

In recent years, researchers have been able to put the Keeling measurements into a broader context. Bubbles of ancient air trapped by glaciers and ice sheets have been tested, and they show that over the past 800,000 years, the amount of carbon dioxide in the air oscillated between roughly 200 and 300 parts per million. Just before the Industrial Revolution, the level was about 280 parts per million and had been there for several thousand years.

That amount of the gas, in other words, produced the equable climate in which human civilization flourished.

Other studies, covering many millions of years, show a close association between carbon dioxide and the temperature of the earth. The gas seemingly played a major role in amplifying the effects of the ice ages, which were caused by wobbles in the earth's orbit.

The geologic record suggests that as the earth began cooling, the amount of carbon dioxide fell, probably because much of it got locked up in the ocean, and that fall amplified the initial cooling. Conversely, when the orbital wobble caused the earth to begin warming, a great deal of carbon dioxide escaped from the ocean, amplifying the warming.

Richard B. Alley, a climate scientist at Pennsylvania State University, refers to carbon dioxide as the master control knob of the earth's climate. He said that because the wobbles in the earth's orbit were not, by themselves, big enough to cause the large changes of the ice ages, the situation made sense only when the amplification from carbon dioxide was factored in.

“What the ice ages tell us is that our physical understanding of CO₂ explains what happened and nothing else does,” Dr. Alley said. “The ice ages are a very strong test of whether we've got it right.”

When people began burning substantial amounts of coal and oil in the 19th century, the carbon dioxide level began to rise. It is now about 40 percent higher than before the Industrial Revolution, and

humans have put half the extra gas into the air since just the late 1970s. Emissions are rising so rapidly that some experts fear that the amount of the gas could double or triple before emissions are brought under control.

The earth's history offers no exact parallel to the human combustion of fossil fuels, so scientists have struggled to calculate the effect.

Their best estimate is that if the amount of carbon dioxide doubles, the temperature of the earth will rise about five or six degrees Fahrenheit. While that may sound small given the daily and seasonal variations in the weather, the number represents an annual global average, and therefore an immense addition of heat to the planet.

The warming would be higher over land, and it would be greatly amplified at the poles, where a considerable amount of ice might melt, raising sea levels. The deep ocean would also absorb a tremendous amount of heat.

Moreover, scientists say that an increase of five or six degrees is a mildly optimistic outlook. They cannot rule out an increase as high as 18 degrees Fahrenheit, which would transform the planet.

Climate-change contrarians do not accept these numbers.

The Internet has given rise to a vocal cadre of challengers who question every aspect of the science — even the physics, worked out in the 19th century, that shows that carbon dioxide traps heat. That is a point so elementary and well-established that demonstrations of

it are routinely carried out by high school students.

However, the contrarians who have most influenced Congress are a handful of men trained in atmospheric physics. They generally accept the rising carbon dioxide numbers, they recognize that the increase is caused by human activity, and they acknowledge that the earth is warming in response.

But they doubt that it will warm nearly as much as mainstream scientists say, arguing that the increase is likely to be less than two degrees Fahrenheit, a change they characterize as manageable.

Among the most prominent of these contrarians is Richard Lindzen of the Massachusetts Institute of Technology, who contends that as the earth initially warms, cloud patterns will shift in a way that should help to limit the heat buildup. Most climate scientists contend that little evidence supports this view, but Dr. Lindzen is regularly consulted on Capitol Hill.

“I am quite willing to state,” Dr. Lindzen said in [a speech](#) this year, “that unprecedented climate catastrophes are not on the horizon, though in several thousand years we may return to an ice age.”

The Fuel of Civilization

While the world’s governments have largely accepted the science of climate change, their efforts to bring emissions under control are lagging.

The simple reason is that modern civilization is built on burning fossil fuels. Cars, trucks, power plants, steel mills, farms, planes,

cement factories, home furnaces — virtually all of them spew carbon dioxide or lesser heat-trapping gases into the atmosphere.

Developed countries, especially the United States, are largely responsible for the buildup that has taken place since the Industrial Revolution. They have begun to make some headway on the problem, reducing the energy they use to produce a given amount of economic output, with some countries even managing to lower their total emissions.

But these modest efforts are being swamped by rising energy use in developing countries like China, India and Brazil. In those lands, economic growth is not simply desirable — it is a moral imperative, to lift more than a third of the human race out of poverty. A recent scientific paper referred to China's surge as “the biggest transformation of human well-being the earth has ever seen.”

China's citizens, on average, still use less than a third of the energy per person as Americans. But with 1.3 billion people, four times as many as the United States, China is so large and is growing so quickly that it has surpassed the United States to become the world's largest overall user of energy.

Barring some big breakthrough in clean-energy technology, this rapid growth in developing countries threatens to make the emissions problem unsolvable.

Emissions dropped sharply in Western nations in 2009, during the [recession](#) that followed the financial crisis, but that decrease was largely offset by continued growth in the East. And for 2010, global

emissions are projected to return to the rapid growth of the past decade, rising more than 3 percent a year.

Many countries have, in principle, embraced the idea of trying to limit global warming to two degrees Celsius, or 3.6 degrees Fahrenheit, feeling that any greater warming would pose unacceptable risks. As best scientists can calculate, that means about one trillion tons of carbon can be burned and the gases released into the atmosphere before emissions need to fall to nearly zero.

“It took 250 years to burn the first half-trillion tons,” Myles R. Allen, a leading British climate scientist, said in a briefing. “On current trends, we’ll burn the next half-trillion in less than 40.”

Unless more serious efforts to convert to a new energy system begin soon, scientists argue, it will be impossible to hit the 3.6-degree target, and the risk will increase that global warming could spiral out of control by century’s end.

“We are quickly running out of time,” said Josep G. Canadell, an Australian scientist who tracks emissions

In many countries, the United States and China among them, a conversion of the energy system has begun, with [wind turbines](#) and solar panels sprouting across the landscape. But they generate only a tiny fraction of all power, with much of the world’s electricity still coming from the combustion of coal, the dirtiest fossil fuel.

With the exception of European countries, few nations have been willing to raise the cost of fossil fuels or set emissions caps as a way

to speed the transformation. In the United States, a particular fear has been that a carbon policy will hurt the country's industries as they compete with companies abroad whose governments have adopted no such policy.

As he watches these difficulties, Ralph Keeling contemplates the unbending math of carbon dioxide emissions first documented by his father more than a half-century ago and wonders about the future effects of that increase.

“When I go see things with my children, I let them know they might not be around when they're older,” he said. “ ‘Go enjoy these beautiful forests before they disappear. Go enjoy the glaciers in these parks because they won't be around.’ It's basically taking note of what we have, and appreciating it, and saying goodbye to it.”

On Dec. 11, another round of international climate negotiations, sponsored by the United Nations, concluded in Cancún. As they have for 18 years running, the gathered nations pledged renewed efforts. But they failed to agree on any binding emission targets.

Late at night, as the delegates were wrapping up in Mexico, the machines atop the volcano in the middle of the Pacific Ocean issued their own silent verdict on the world's efforts.

At midnight Mauna Loa time, the carbon dioxide level hit 390 — and rising.

