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Published on *Solutions* (http://www.thesolutionsjournal.com)

The Economics of 350

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Worldwide, there is a growing consensus that strong action is needed to reduce carbon emissions. European Union (EU) governments have begun large-scale policy initiatives to do so; the United States lags behind but has finally begun a serious debate about proposals for climate legislation. Yet at their best, both EU and proposed U.S. policies would contain CO2 concentrations at about 450 parts per million (ppm), which until recently was considered a “safe” level but which many scientists now believe would still result in substantial, costly climate changes. Even a target of 450 ppm is viewed by many economists as too ambitious and potentially damaging to the economy.

Economists for Equity and Environment, a group dedicated to applying and developing economic principles to protect human health and the environment, conducted a study last year titled *The Economics of 350*.[1] None of the scenarios from credible research that were examined found that moving toward a goal of 350 ppm would cost, at its peak, more than 5 percent of global GDP, and the long-term average cost of achieving 350 ppm is more likely to be between 1 and 3 percent per year.

Let’s examine, for example, spending the equivalent of 2.5 percent of GDP, roughly the rate at which developed countries’ economies grow each year, on climate protection. That would be equivalent to skipping one year’s growth and then resuming. Average incomes in the United States would take 29 years to double from today’s level, compared to 28 years in the absence of climate protection costs. In an economy experiencing 10 percent annual growth, as China has in many recent years, imposing a cost of 2.5 percent per year is equivalent to skipping three months of growth; if 10 percent growth is sustained, average incomes would reach double the current level in 86 months, compared to 83 months in the absence of climate protection costs.

Or consider this: In 68 countries, military spending is greater than 2.5 percent of GDP. In both the United States and China, military expenditures exceed 4 percent of GDP. Military spending in France and India, among many other countries, is at or above 2.5 percent of GDP. Around the world, people willingly spend very large sums to protect themselves against perceived threats to their way of life. Catastrophic climate change is just such a threat.

Inaction is the most expensive scenario. Scientific research continues to yield evidence that climate change is occurring faster, and its consequences could be more severe, than previously expected. We need a big initiative, a comprehensive global deal on protecting the Earth's climate by rapidly reducing emissions of greenhouse gases.

Reaching 350 ppm: Challenges and Possibilities

How do we arrive at 350 ppm? The first step is to decide how soon to get there. James Hansen, NASA's top climate scientist, has argued that paleoclimatic evidence shows that 450 ppm is the threshold for transition to an ice-free Earth, with catastrophic sea-level rise and extensive flooding. Since the world is already at 390 ppm and rising, Hansen believes aggressive action is needed to get down to 350 ppm by 2100.[2]

In Hansen's scenario, coal burning would be phased out by 2030, or else technology would have to be developed to capture and store 100 percent of emissions from it. Oil and gas use would fade out on their own, presuming the Intergovernmental Panel on Climate Change's estimates of reserves are correct; these fuels can be used as their market prices allow (assuming, as economic theory suggests, that prices will increase as reserves shrink, until and unless nonfossil energy sources are developed).

But Hansen doesn't want to just control emissions; he wants to aim for negative net carbon emissions by midcentury (i.e., removing more carbon from the atmosphere than is emitted). To do that, he has proposed large-scale reforestation and biochar initiatives, with land-use emissions hitting zero as soon as 2015 and massive sequestration of carbon in forests and soils outweighing global emissions within a few decades. Because that ambitious approach might be deemed too demanding, we considered an alternative: aiming to reach 350 ppm by 2200. In that scenario, the world would not have to achieve negative net emissions, although it would have to quickly approach zero. The different trajectories could have important, though highly uncertain, implications for peak temperature changes: the peak temperature change from 1990 is 1 °C in 2050 in Hansen's scenario, compared to a peak change of 1.5 °C in the 350 ppm by 2200 scenario.

Gary Braasch
Mt. Hood in September 2006

Note that both scenarios assume success, within this century, in the vast undertaking of converting the world energy system to carbon-free or low-carbon sources such as wind, solar, geothermal, hydro, nuclear, and biomass-fueled power. This is the first and foremost challenge for climate policy, the essential hurdle that must be overcome. But it is not all that is needed, especially if we set out to reach 350 ppm of CO2 by the end of this century.

Both scenarios have very similar emissions through 2020. Then, within a few decades, Hansen's assumptions of complete carbon capture from coal and large CO2 withdrawals from land-use changes make yearly emissions in that scenario negative, and the stock of atmospheric CO2 begins to decrease over time.

Our scenario, which represents the most ambitious schedule we can imagine without assuming the technical, political, and institutional changes necessary for achieving negative emissions, would reduce emissions to 54 percent of the 1990 level by 2020 and to 3 percent by 2050. The conversion to renewable energy systems would have to be complete and the world economy would have to be virtually free of carbon emissions by midcentury, a more demanding goal than any of the leading policy proposals under discussion today. To achieve 350 ppm before 2200 without net negative emissions in any year, global emissions would have to be reduced even faster.

Carbon Removal

The ability to remove CO2 from the atmosphere at this point is fairly limited. There are, however, three widely discussed methods of carbon removal, of which the first two (reforestation and biochar) are currently available and the third (biomass burning with carbon capture and storage) is still under development.

Reforestation (and the prevention of deforestation) is a key, low-cost component of any strategy for removing carbon from the atmosphere. Forests play a critical role in the global carbon cycle, absorbing CO2 emissions from the atmosphere and storing carbon long term in woody biomass and soil. Hansen's plan assumes that the world can sequester 5.9 gigatons (Gt) of CO2 annually through reforestation starting in 2030, an amount roughly equivalent to annual

U.S. energy-related CO2 emissions in 2008. Other estimates of the technical potential for sequestering carbon emissions range from 20 to 110 Gt of CO2 annually.[1]

Much of the potential for emissions reduction through forestry is found in the developing world, where forest conservation and reforestation initiatives would compete against alternative land uses, including logging and commercial and subsistence agriculture. Bottom-up estimates of forestry mitigation potential in developing countries suggest that much of these reductions are available for less than $15 per ton of CO2.[1]

The search for low-cost global opportunities for mitigation repeatedly leads to a focus on tropical forest management. Nicholas Stern, the economist who wrote the influential *Stern Review on the Economics of Climate Change* for the British government, released in 2009 a “blueprint” for a new global deal on climate change, calling for spending $15 billion per year to combat deforestation in tropical countries; he estimates that this would buy 3 Gt per year of reduction at an average cost of $5 per ton of CO2 equivalents (CO2-e). (Concentrations of all gases are typically expressed in CO2-e—the amount of CO2 alone that would have the same warming potential as the full range of greenhouse gases in the atmosphere. Because of the importance of methane and other gases, 350 ppm of CO2 alone roughly corresponds to 450 ppm of CO2-e, that is, of all greenhouse gases combined.)

Heavily forested developing countries should not bear the financial burden of these reductions. New international agreements, institutional structures, and financing arrangements are necessary to facilitate payment to developing countries and to ensure the legitimacy of these reductions.

A second effort to remove carbon is biochar, a relatively obscure technology that is getting more and more attention. The technology involves slowly burning plant material into a form of charcoal and then burying it in the soil; that process sequesters carbon and may have beneficial effects on soil productivity and water retention. However, while appealing, biochar is unlikely to play a major role in reducing emissions in the coming decades. Hansen estimates that 0.6 Gt of CO2 can be sequestered annually via biochar.

Biomass and Carbon Capture and Storage

A related prospect is using biomass—including sugar cane, switchgrass, corn (maize), palm oil, and carbon-rich waste products from the paper and agricultural industries—as a fuel, burning it to generate electricity or heat. The use of biomass as a fuel is typically described as carbon neutral: the CO2 emissions released in combustion are balanced by the CO2 removed from the atmosphere by the growth of the plant material.

For biomass crops, especially those grown in an industrial agricultural setting, this equation is more complex—emissions removed in plant growth still equal emissions released in combustion, but biomass farming is also responsible for emissions caused by tractors and other farm equipment, by the production of pesticides and fertilizers, and in some cases by land-use changes, as when forest is converted to agricultural land for the purpose of biomass farming.

To use biomass energy as a tool to reduce net greenhouse gas emissions, a second step is necessary: biomass power plants must be combined with carbon capture and storage. The full life cycle of biomass energy production with carbon capture and storage would absorb carbon in plant material, burn that material to make energy (thereby avoiding greenhouse gas emissions from fossil fuels), and then capture the resulting CO2 emissions and store them underground.

Carbon capture and storage stops greenhouse gas emissions by trapping CO2 from power plants and storing it indefinitely. If the process could be developed on a commercial scale, it could be used for more than biomass plants; it could also allow continuing use of coal-fired generation while still reducing emissions. Without carbon capture and storage, it is difficult to fit large-scale use of coal into scenarios for rapid emissions reduction. This potential for “redeeming” coal may account for some of the current interest in the strategy. Full-scale industrial carbon capture and storage, however, may not be commercially viable for some time to come.

In the meantime, experimental programs are testing a few carbon capture and storage technologies: pre-combustion carbon capture and storage removes carbon from fossil fuels before combustion, often through coal gasification. Post-combustion carbon capture and storage removes carbon from power plant smokestacks before it can enter the atmosphere. And oxyfuel carbon capture and storage burns fuels in a pure oxygen atmosphere, which limits smokestack effluent to just water vapor and CO2; cooling the smokestack gas is sufficient to separate the two into liquid water and gaseous CO2.

CO2 storage options are the same for all three capture processes. CO2 must be transported to the site of storage and injected 800 meters or more into the ground. Beneath the soil, CO2 may mix with groundwater to form a fizzy seltzer or may become trapped underneath rock formations. Potential storage sites include former oil and gas fields and deep aquifers.

Returning to 350 ppm CO2: The Total Costs are Manageable, but Can We Share Them Fairly?
By: Paul Baer

Advocates of stringent climate policy face somewhat of a strategic dilemma. On the one hand, as Ackerman and colleagues document in “The Economics of 350,” there is ample evidence that—in conventional economic terms—the costs of steep reductions in emissions to reach 350 parts per million (ppm) in atmospheric CO2 are quite manageable.

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Carbon capture and storage may not win the race to demonstrate that carbon can be economically removed from the atmosphere; numerous other inventions and proposals are beginning to appear. For example, recent scientific efforts to extract CO2 directly from the air have attracted the attention of investment capital. It is important to keep developing new technology—but at the same time, public policy cannot wait for or count on technologies that are still in the works. It is certainly possible to imagine some other means of mopping up unwanted CO2 emissions—the matter transmitters of *Star Trek* would no doubt do the job. Yet unless science fiction becomes reality, achieving net negative emissions will remain an enormous challenge.

Costs of Emissions Reduction: Five Examples from across the Globe

At least five research groups—four academic research teams publishing in peer-reviewed journals and one well-known consulting firm—have modeled global scenarios that lead to 350 ppm of CO_2. These scenarios impose only moderate reductions in GDP—and one of them found that new climate investments might accelerate economic growth, creating new jobs for the unemployed. (Many research studies model emissions and impacts of all greenhouse gases, not just CO_2. We have limited our attention to CO_2 to highlight key numbers of current policy interest.)

Scenario 1

The first report we consider is by Detlef van Vuuren, Michel den Elzen, and others at the Netherlands Environmental Assessment Agency (MNP).[3] Their scenario relies initially on energy efficiency and on reduction of non-CO_2 greenhouse gases. These measures are low cost, but their potential is soon reached. By midcentury, the model relies on carbon capture and storage (applied to virtually all remaining coal use), expanded sequestration (especially in large carbon plantations in East Asia, South America, and the former Soviet Union), bioenergy production, and some expansion of the roles of both non-hydro renewable and nuclear power (hydropower is assumed to be at or near its maximum potential).

Further reductions in later years depend on changes in energy use. In the second half of this century, the authors project that hydrogen fuel cells will become affordable, reducing emissions in transportation at moderate cost. Carbon prices will rise steeply, but most emissions will be eliminated long before prices reach their peak (electricity is virtually decarbonized at “only” \$55–\$82 per ton of CO_2 equivalents. By the end of this century, they estimate that fossil fuel use will be virtually eliminated (the small continuing uses will be for electricity production associated with carbon capture and storage), and biomass energy production with carbon capture and storage will remove large amounts of carbon from the atmosphere.

The cost of the scenario peaks at about 2 percent of world output at midcentury. Analysis of the regional impacts of this scenario finds that costs would be high for the Middle East and North Africa and the former Soviet Union, the regions most dependent on oil and gas production. Member countries of the Organisation for Economic Co-operation and Development (OECD) would experience medium costs, while other regions would have lower costs or even gains. Nations that rely most heavily on oil and gas revenues would stand to lose under a global climate deal—a pattern of regional impacts that has been confirmed in other research as well.[4]

Scenario 2

The GET model, developed by Christian Azar and Kristian Lindgren at Chalmers University in Sweden, has also been used to project the costs of reaching 350 ppm of CO_2 by 2100.[5] It presumes that, by midcentury, nuclear and hydroelectric power are already at their maximum potential, and it limits wind and solar power to 30 percent of electricity demand due to intermittency. Oil as the dominant transportation fuel is eventually replaced by hydrogen, with solar energy used to produce it. Carbon capture and storage is vitally important in this model, shrinking the cumulative cost of mitigation over this century from \$26 trillion to \$6 trillion when carbon capture and storage is applied to both fossil and biomass energy.

In this model, costs peak at 5 percent of GDP in 2030 without carbon capture and storage—or at 3 percent of GDP in the 2070–2080 period with it. In the 350 ppm with carbon capture and storage scenario, coal use is roughly constant throughout the century, but carbon capture and storage enters around 2020 and applies to virtually all coal use by 2060. Solar hydrogen appears around 2060 and is the largest source of energy in the global system by 2100. Biomass rises in importance until about 2060 and then remains constant; carbon capture and storage is applied to biomass energy starting around 2050 and applies to almost all remaining fossil energy by 2100. Oil declines rapidly after 2040; natural gas remains important until near the end of the century but with increasing use of carbon capture and storage after 2050.

Scenario 3

Another analysis, conducted by Terry Barker and Katie Jenkins at the Cambridge Centre for Climate Change Mitigation Research (4CMR), at Cambridge University, projects that in a global economy characterized by slow growth and high unemployment, a program of investment in emissions reduction will increase employment and economic growth at a cost of between 2 to 3 percent of GDP by 2030, achieving 450 ppm of CO2-e by 2100.[6]

This study, which is less explicit about specific technology choices, suggests that moderate-to-high carbon taxes could shift the electricity system to low-carbon options, including coal and gas with carbon capture and storage, renewable resources, and nuclear power. Taxes could also propel the wholesale adoption of electric cars by 2050.

Scenario 4

Ottmar Edenhofer and his colleagues at the Potsdam Institute for Climate Change Research (PIK) have also engaged in extensive studies of low stabilization targets. In a major EU research project, these researchers compared the projections of four different models for the costs of achieving stabilization targets from 400 to 550 ppm of CO2-e.[7] One model projects economic gains from the investments in mitigation; the three others, from different research groups, make relatively consistent projections, showing cumulative GDP losses through 2100 of 1.7 percent or less, even for the 400 ppm of CO2-e target (which is equivalent to about 300 ppm of CO2). Biomass and carbon capture and storage assumptions are crucial to costs everywhere; in contrast, nuclear power plays only a minor role. The lowest stabilization scenarios also require expansion of non-biomass renewables, with the level of biomass use determining the level of mitigation costs.

Scenario 5

McKinsey & Company, an international consulting firm, has looked at the cost of greenhouse gas abatement from the bottom up, most recently in a study that examined the potential and the costs of more than 200 abatement opportunities from now through 2030.8 The study found that there is the technical potential to reduce global emissions 35 percent below 1990 levels, or 70 percent below business as usual, by 2030—if all measures with costs below $84 per ton of CO2-e are adopted. The total investment would be $280 billion to $490 billion annually by 2030, or less than 1 percent of global GDP in that year, on a stabilization trajectory that reaches 450 ppm of CO2-e (350 ppm of CO2) by 2200.

The McKinsey study's projected emissions reductions consist of three roughly equal categories: energy-efficiency opportunities, such as more fuel-efficient cars, better insulated buildings, and more advanced manufacturing controls; low-carbon energy supply, shifting from fossil fuels to wind, nuclear, or hydro power, as well as equipping fossil fuel plants with carbon capture and storage capability; and forestry and agriculture changes, such as halting deforestation, switching to rapid reforestation, and changing agricultural practices to increase carbon sequestration in soils.

In addition to identifying the substantial opportunities for negative-cost emissions reductions (many of them from energy efficiency), the McKinsey research also points out that the cost estimates are sensitive to the price of oil. As the price of oil rises, the costs of investment in emissions reduction are largely unchanged, but the value of the saved energy increases, implying a lower net cost. The basic forecast assumes an oil price of $60 per barrel; every $10 per barrel increase, if accompanied by proportional increases in other energy prices, cuts average abatement costs by $4 per ton of CO2-e. Although the report does not spell it out in these terms, this formula implies that at an oil price of $90 per barrel, the entire emissions reduction of 38 gigatons of CO2-e would have zero net cost.

Many of the model results discussed here express costs as percentages of GDP, a measure that is natural to economists but may seem opaque to other readers. Most scenarios put the cost of mitigation at between 1 and 3 percent of global GDP—in 2008 terms, that's somewhere between $600 billion and $1.8 trillion. This would be an annual, recurring cost that will have to be paid for many years. Yet as we noted at the beginning, this is far from an impossible burden.

Conclusions and Recommendations

Our most important conclusion is that a 350 ppm stabilization target will not destroy the economy. On the contrary: we found widespread agreement that sound economic analysis supports policies to promote energy conservation, development of new energy technologies, and price incentives and other economic measures to redirect the world economy onto a low-carbon path to sustainability—at entirely affordable costs.

Agreement with this conclusion, of course, is not universal. At one extreme, business groups warn that moderate reductions called for in recent U.S. legislation would cripple the economy—and some economists, quite mistakenly in our view, worry more about the costs of climate policy than about the risks of climate damages.[1] At the other extreme, some environmental groups anticipate "win-win" economic outcomes and large net savings from eliminating carbon emissions. But between these extremes is a growing body of research that finds that even very ambitious emissions reductions aimed at reaching 350 ppm might only cost 1–3 percent of world output.

Is the estimated cost of a global climate change strategy of 1–3 percent of world GDP a large or a small number?

The answer depends on how seriously you take the risks of climate change. If we believe that inaction could lead to massive ice sheet melting, flooding in some areas and droughts in others, crop failures, extinctions, and other disasters, then spending a few percent of output to protect ourselves and our descendants against so much harm seems reasonable. In private life, many people spend a few percent of their income on fire and life insurance to protect against unlikely disasters, such as residential fires or the deaths of young parents. In public life, climate protection is insurance for the planet and future generations.

The low price of fossil fuels in the United States skews the discussion by masking the true costs of our energy use. We recommend putting a price on carbon, either as a tax or through a cap on emissions; a cap would likely be adopted as part of an allowance or emissions permit system. There is ongoing debate about the merits of auctioning allowances each year, the approach we prefer, versus freely allocating them to potentially affected business and other interests, the approach that has often been favored in Congress. These approaches have very different effects on the distribution of income but could have the same effect on the price of carbon.

It is preferable for the high fuel price to be imposed by a tax or cap rather than by private markets, even if the effect on consumers is the same. When market forces push up the price of oil, as they did in 2008, the extra revenues go to oil producers, not to the public. When oil prices remain high, incentives are created for environmentally destructive production of energy—from oil shale, oil sands, and increasingly deep, dangerous offshore drilling. In contrast, a high price imposed by policy creates incentives for consumers to conserve, but not for producers to engage in costly production from easily damaged resources. An oil tax transfers revenues to the government, which can use them for environmental investment, other public purposes, or refunds to citizens.

Predicting the future—what will happen next week or next month—is challenging; predicting a century of technological and economic change is inescapably fraught with uncertainty. Nonetheless, the best available estimates imply that we can, indeed, afford the economics of 350. What we cannot afford is too little climate policy, too late.

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Key Concepts:
The goal of 350 parts per million (ppm) atmospheric CO2 is supported by the best and most up-to-date science, by ethical considerations, and by economic analyses.
The approaches to get to 350 ppm include reforestation, carbon capture and storage, biochar, and a reduction in energy consumption.
The world can reach 350 ppm at a cost of less than 3 percent of global GDP.
Stopping global warming and protecting the Earth's climate is a daunting challenge. To avert a crisis, we must develop petroleum-free transportation, dramatically change how we create and use energy, and much more. These changes carry a cost, and especially in difficult times there is strong resistance to spending very much at all to protect the planet. Many think moving too aggressively could lead to economic disaster. Some economists advocate only slow, gradual responses to climate change, lest the costs of mitigation become too large.

 The physical science of the atmosphere is not determined by cautious economists, however. The more CO2, the hotter the world will get, the faster sea level will rise, and the more erratic our weather patterns will become. Doubling the amount of CO2 that was in the air before the Industrial Revolution—from 280 parts per million (ppm) in 1750 up to 560 ppm, a milestone we will reach in a matter of decades under business as usual—could raise the average global temperature by 3 °C (5.4 °F); newer studies actually project increases of up to 6 °C (11 °F).

 To protect our planet, we propose setting a target of 350 ppm and taking prompt, decisive action to enable us to attain that goal.

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Policy