Barriers to Decarbonization

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Introduction and Summary:

In response to dire warnings from the International Panel on Climate Change (IPCC) about the necessity of quick action to profoundly reduce fossil fuel greenhouse gas emissions, a number of groups are endorsing plans that have ambitious targets that, if widely accepted and followed, would, the advocates believe, reach the preferred goal of the Paris Agreement—to prevent a rise of 2.7 degrees F. (1.5 degrees Centigrade) in average global temperature. These plans, some of which call for "zero net carbon" or elimination of fossil fuels for electricity generation, require immediate action to reach Green House Gas (GHG) reduction targets by 2030 and 2050.

This essay is not intended to dispute the findings of the IPCC nor the goal of these plans to prevent the worst climate outcomes. My intention is to identify some serious barriers to meeting the goals by the desired dates. Without acknowledging these barriers, it is unlikely that strategies will be developed to overcome them and also unlikely that the goals will be met.

Although there are many barriers to decarbonizing our economy, I will focus here on four of the most important ones:

1. *Economic growth, as measured by per capita Gross Domestic Product (GDP), is a primary goal of our society, but is inappropriate as a primary goal if the future matters.* GDP is a poor measure of social welfare. Growth erases, over time, reductions in energy use. Growth cannot be sustained in a world with limits.
2. *The existing energy, transportation, manufacturing, and agriculture infrastructures (and the policies that enable them), require fossil fuels for both construction and maintenance. The infrastructures were designed around use of cheap fossil fuels, especially for transportation and heating buildings..* Some of the infrastructures are designed to facilitate a corporate dominated global economy, making a more local economy less competitive. These pervasive and complex infrastructures, (roads, bridges, power lines, pipelines, etc) cannot be rapidly changed. Simply plugging alternative energy sources into these infrastructures does not adequately avoid carbon emissions or discourage inefficient energy use.
3. *"Renewable," "carbon clean," "carbon free," or "carbon neutral" energy alternatives all have carbon and environmental footprints. These energy sources are used primarily to generate electricity and cannot easily fill the roles of liquid fossil fuels (such as jet fuels). Increasing reliance on electricity for heating, cooking, and transportation, when the majority of grid sources are fossil fuels, leads to inefficiencies. Those energy sources that are intermittent require storage to smooth out supply and prevent temporary shortfalls.* Batteries depend on mined, non-renewable resources that may not be economically viable at scales needed to meet decarbonization targets. Ironically, the more reliant we are on intermittent sources, the more need there might be for fossil fuels for backup when energy storage is not sufficient to prevent energy supply disruptions.
4. *Some of the corporations that benefit from the status quo have undue influence over policy formation*. Those benefiting from the current energy infrastructure will not easily

be convinced to relinquish that advantage. Some of these major greenhouse gas emitters have economic leverage over the media, government, and technological development. "Solutions," where these companies have undue influence, often become distorted to meet the narrower goals of these companies, rather than wider goals of society.

A common theme of these barriers is the tendency to conflate what should be with what is, or what is promised, with what is real.

Our current consumption patterns and life-styles are taken as a given, even though these have been changing for decades and some of these changes have made us more dependent on fossil fuels. There is an assumption that no one will want to change their consumption habits. Instead, it is argued, our society can surely come up technological fixes to continue our current energy use trends.

The problem, however, might not be primarily due to the technologies we use to reach our goals, it might be the goals themselves. Rather than seek technologies that allow us to "sustainably" continue wasting resources at an accelerating rate, this report suggests that the "developed" nations should be finding ways to consume less.

There are no easy answers for overcoming the barriers. The first step, however, is acknowledging their existence. This report, however, does have suggestions that include:

- Find more appropriate measures of social or ecological welfare than the GDP.
- Measure progress at decarbonization not by how many solar panels and wind generators go up, but how many fossil fuel electric generators go down and how much energy use in transportation goes down.
- Many efficiency and conservation strategies have high returns on investment and make economic sense whether or not climate change is a factor. These strategies have "negative costs," and are economically superior to "Business as Usual" (BAU). These should be the first wave of investments as they would save consumers money.
- Rather than just substitute "green energy" sources for fossil fuels, design buildings, communities, and societies, that have less need for any fuels. Do long term planning for a smoother transition from this world to that.
- We need a double bottom line to measure decarbonization progress. Coupled with carbon emission reductions, there must be increases in natural carbon sequestration—most notably increases in the area and volume of forests. CO2 emission reductions alone can *slow the rate* at which carbon dioxide is increasing in the atmosphere, but sequestration by forests can *remove* carbon dioxide from the atmosphere.
- Energy policy affects not only climate change, but also biodiversity and social inequities and stresses. Policy must address all the above, not just CO2 emissions. "Solutions" should strive to avoid expansion of "sacrifice zones"—single use areas of landscape used as a source or sink of industrial production, including of energy.
- Ending the domination of policy by large corporate interests is a major challenge that requires much more discussion. A first step is to follow the money and expose the problem at all levels—cities, states, nations, universities, think tanks, and more. What's good for the large corporation is not synonymous with what is good for society.

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Economic Growth

Economic growth, as measured by the per capita GDP, has been a major goal for nearly every modern society, regardless of economic philosophy—be it capitalism, socialism, fascism, or communism. This belief, that economic growth is required to promote social well being, is so central that it is rarely questioned, even when it is a precipitating cause, rather than a solution, to societal problems..

And yet, this measurement has some rather obvious flaws as a gauge of public welfare. Even though our GDP is increasing, we are now contemplating a future where the climate is increasingly unstable, biodiversity is imperiled, aquifers are being depleted, and our industrial civilization, based on this spectacular growth over the last two centuries, is unlikely to be sustainable.

The per capita GDP figure is an average. It does not reveal problems that could come from serious inequities in a given country. For example, most of the benefit of growth might be going to a very wealthy minority, and might not be trickling down. The wealth of the vast majority of citizens might, in real terms, be stagnant, or even declining, yet the per capita *average* could still increase. If Bill Gates walked into a bar with a dozen guys sitting at the counter, he could truthfully say, "On average, we are all billionaires."

The GDP does not differentiate between sales of goods and "bads." All transactions that increase the GDP are interpreted as a benefit—even sales of addictive or harmful products or services, such as tobacco, gambling, or junk food.

The GDP does not differentiate between wealth and "illth." Increases in money spent on prisons or military is not a measure of social well being. The money spent on drugs or operations to treat heart disease, diabetes, depression and other problems associated with diet, pollution, or lack of exercise, is not a measure of health. The money spent on jails (the United States has the highest proportion of its citizens in jails), police, military, or weapons, is not a measure of social welfare. Yet, growth in these products or services all help to increase the GDP.

The GDP does not account for "external costs," such as the health or environmental damage caused by manufacture and use of products. Unless companies are forced to pay fines, these impacts, however great, are not part of the calculations in the cost of goods.

Having an increasing GDP as a goal encourages waste. The more stuff people consume, the better it is for the GDP. So, fads and fashions that lead people to throw out objects that soon become "passé'" are considered a good thing. Planned obsolescence, which also leads to a greater turnover of goods, is also a benefit to the GDP. So is excessive packaging and junk mail. Mine it up, use it up, and throw it out. The faster the turnover, the better for the GDP. But not for the rest of life on earth.

Consuming twice as much energy as the average European, especially if much of the difference in consumption is due to waste, does not make Americans twice as happy or healthy, but it does increase the GDP.

The GDP does not recognize the difference between income and capital depletion. Depleting aquifers faster than they can be replenished, using up high quality sources of ores or oil, clearing forests for agriculture, are all forms of natural capital depletion. Real income is an increase in interest, not a decline in principal. Capital depletion is not sustainable, unless "sustainable" means "for the short term."

When growth is too slow, the Federal Reserve lowers interest rates so that it is easier to borrow money. Low interest allows people to buy what they previously could not afford and keep the economy rolling. Our economy has government debt, business debt, and household debt. And with that debt comes interest. There are limits as to how high the interest on the debt can go and still have money available to finance more growth.

It should be obvious that perpetual growth on a planet with limits is not sustainable. One economic justification of depletion economics, however, is that the economy will find substitutes for any resource that becomes too expensive to mine or grow. But what are the substitutes for pure water or clean air? What are the substitutes for lost species?

Our society has used cheap fossil fuels to grow at an unprecedented rate to reach an unprecedented size, especially since 1950. But, our society is not as impressive at maintaining the buildings, roads, bridges, pipe lines, and power lines as it is at constructing them.

At some point, the cost of maintaining what we already have uses up more money, materials, and energy than can be afforded to allow further growth. And much of the energy and materials needed to maintain infrastructure, especially such items as roads and bridges, require fossil fuels—asphalt, concrete, and steel, for example.

As economist Kenneth Boulding wrote, "Anyone who believes exponential growth can go on forever in a finite world is either a madman or an economist."

Attempting to promote perpetual growth as a primary goal for society leads to some serious ethical considerations. For the economy to grow more, people have to consume more. This growth in consumption is such a vital goal for the economy that companies have to constantly remind consumers of their duty to consume. Wherever people's attention might stray, there are messages reminding them to go out and buy. Newspapers, magazines, television, radio, the Internet, billboards, hats and t-shirts… We see corporate ads and logos so much, that most of the time, we are only barely aware of them.

After 9/11, President Bush was so concerned that the public might be distracted from our duty to consume that he urged us to defy the terrorists, who were threatening our way of life, by going shopping.

The advertisements often appeal to moral weakness—such as pride, envy, gluttony, lust, greed, or sloth. If encouraging these vices leads to more consumption, that is justified as a public good. Virtues, such as frugality, humility, generosity, patience, or self-reliance, if widely adopted, would lead to less consumption, which would be a threat to our economy..

Economist J.M. Keynes, in touting the benefit of greed to spur development suggested that: "For at least another hundred years we must pretend to ourselves and to every one that fair is foul and foul is fair: for foul is useful and fair is not. Avarice and usury and precaution must be our gods for a little longer still. For only they can lead us out of the tunnel of economic necessity into daylight."

E.F. Schumacher's summation of this logic was: "The road to heaven is paved with bad intentions."

We have serious inequities in wealth and income within our society and between our society and others. People, however, have found ways to justify such outcomes for thousands of years as something merited, or even as divinely established. But what is even harder to comprehend ethically, are the growing inequities between our generation and the ones to follow. Our generation is taking the goldmine and leaving future generations the shaft.

In a way, generational inequities are an unfortunate side effect of normal business accounting. With Net Present Value (NPV), it is routine to discount future costs and benefits. In such an accounting world, it is more advantageous to consume now, rather than later, even if the "later" is not for us, but our descendants. The decision of our generation to deplete natural capital was made without the consent of future generations. If they did have a say, they would surely prefer a more generous generational legacy.

There are economists, even Nobel laureates, who recognize the weaknesses of assuming that, by happy coincidence, an increase in GDP also inevitably improves health, social welfare, and ecological well being. Some economists are trying to work out more appropriate alternative ways to measure progress towards these key goals. The way to measure health, social welfare, and ecological soundness is through criteria that actually measure health, social welfare, and ecosystem stability, not by how much money is spent on related goods and services.

Existing infrastructure and policies.

Our existing infrastructures, and the policies that guided their development, were constructed in an age when fossil fuels were relatively cheap and abundant. It is not just fossil fuels that are a problem; the structure of the system dependent on them is a problem.

Take, for example, electric power generation from gas, coal, or oil. These energy systems require mining and refining fossil fuels. These activities can lead to gas leaks, oil spills and the destructive removal of mountaintops. The fuel is transported by train, truck, barge, or pipeline, and there can be more leakage and accidents on the way.

Most large, centralized power plants waste more energy as heat than they gain as electricity. Many coal-based power plants are less than 40% efficient. Further energy is lost over long, high-voltage power lines. Land is taken up for the powerline corridors, removing large swaths of carbon-sequestering trees. Inefficient appliances add yet one more level of waste from generation to consumption.

Our transportation system was designed around relatively inexpensive liquid fossil fuels. Towns have been built around dispersed housing, shopping malls, and industrial parks—all of which assume one has a car to get from one place to another. The automobile, in such an area, has what Ivan Illich called a "radical monopoly"—you need a car to get around, even if you are too poor to own one.

Our landscapes have been shaped with roads, bridges, gas stations, and parking lots—huge amounts of land are taken up just to enable wheeled transportation running on internal combustion engines. All of this infrastructure, including that designed for cars, trucks, trains, airplanes, and ships, was built, and is maintained by massive inputs of fossil fuels. Around 61,000 square miles of the United States are paved, mostly with asphalt. A key ingredient of asphalt is oil.

Our transportation infrastructure has evolved to support a global economy. Resources can be mined anywhere in the world and shipped to manufacturing centers where global companies can find a combination of the cheapest labor, energy, taxes, and regulation that allow the highest returns on investment. Because the mining and manufacturing are often far away, the human, energy, and environmental impacts of these activities tend to be out of sight and out of mind for the consumer.

Occasionally, some people express concern over exploited labor or despoiled landscapes resulting from these global economic forces, but we are assured these problems are temporary. Global growth, we are told, will eventually bring higher wages and more environmental protections, so we have to be patient—waiting for these benefits to come, in the future.

These people somehow know the future. All we have to do is let the economy and technology work their magic and social and environmental progress are inevitable. We don't have to do anything—progress will happen by itself.

If growth inevitably leads to social progress, then our economy represents the future for less developed economies. Seeing how far we have to go towards dealing with social inequities or environmental damage might lead lesser developed countries to wonder just how long they'll have to grow, since it will take many decades for them to get to where we are now—and that is obviously not enough.

Agriculture in the United States is dependent on irrigation, tillage, chemical fertilizers, and chemical pesticides, all of which require fossil fuels. The trend has been toward fewer farmers on bigger farms, and fewer cultivar varieties.

Fossil fuels are used to process, refine, package, ship (sometimes thousands of miles), cool, and freeze harvested products. There are also impacts to biodiversity from monocultures and pesticides; lowered resiliency due to smaller genetic diversity of crops; water pollution from pesticide and chemical fertilizer runoff; and depletion of aquifers from irrigation in dry climates.

Infrastructures for electric power generation, transportation, agriculture, housing, and manufacturing include structures that were designed to last for decades. They cannot be easily replaced in one or two decades. Just maintaining these infrastructures, even if "green energy" is added to the mix, would still require massive inputs of fossil fuels.

Alternatives to fossil fuels.
How nice it would be if there were some "green energy" source that could allow unlimited economic growth with no impact to the earth or to the atmosphere. Alas, all the alternatives to fossil fuels have some negative environmental footprints. Even if there were no negative impacts from energy production itself, unlimited growth in the consumption of stuff could still not be maintained in a world with limits.

The hope with "green" alternatives is that their impacts, at least with regards to greenhouse gasses, are less than those of fossil fuels. And there are also hopes that these alternatives can completely replace fossil fuels. There are, however, barriers to scaling up these low-carbon energy sources. And some of these barriers require technical fixes that are not economically viable at this time.

The alternatives being considered are, at best, imperfect substitutes for the use of fossil fuels for producing electricity. They are far from perfect substitutes for liquid fuels, such as gas or diesel, for transportation. Reliance on liquid biofuels (such as ethanol), was once touted as a "renewable" alternative to fossil fuels for transportation. In reality, ethanol made from GMO corn, has only had a limited impact, and is driven by subsidies.

The energy returned on energy invested (EROEI) for corn ethanol is marginal, or, more likely, negative. The impacts on land, water, and even, at times, the price of food have been negative enough so that the major boosters of corn ethanol are Archer Daniels Midland, corn farmers, and occasional candidates in the Iowa caucuses.

There are, however, big supporters of running cars and trucks on electricity, using battery storage. Electric cars, at present, make up a tiny percent of the national fleet. Building new cars, building batteries, and setting up a new infrastructure to serve electric vehicles would initially require consumption of a lot of fossil fuels and other resources, given our current energy infrastructure.

In 2018, there were more than 276 million registered motor vehicles in the United States. Replacing all of these gas/diesel vehicles with electric vehicles would create a carbon debt that would take decades to pay back. To run these vehicles would require a significant increase in electric generation—depending on the state, anywhere from 15% to more than 55%. With our current mix of power plants, much of the electricity would come from fossil fuels, until or unless these are replaced by "greener" electric power producers.

At present, replacing the entire fleet of motor vehicles with electric powered vehicles is problematic. More than 70% of all goods shipped in the US is by tractor-trailer trucks. Electric 18 wheelers are not presently commercially viable. Electric cars currently cost thousands of dollars more than gas powered cars. It would take a long time to pay back a $10,000 differential in purchase price for an electric car with just fuel savings. There are lower cost ways to reduce carbon emissions than spending thousands of dollars more for a vehicle with less range.

While solar, wind, and nuclear might not emit carbon in the process of generating electricity, it takes fossil fuels to manufacture needed components, such as concrete, steel, aluminum, or plastic. These power sources also currently rely on rare earth metals, much of which comes from China. There are environmental impacts from mining, refining, and disposing of these products. And it is not clear if mines for these materials can meet the projected future demands

The existing grid is set up to provide electricity on demand. When the demand is high, more power plants come on line or ramp up to meet the demand. Wind and solar, however, are dispersed and intermittent. They have to cover a lot of ground to replace more concentrated power sources. More ground means a bigger footprint. That footprint can displace acres of farm or forest land and can be a major eyesore for some who are not enamored of industrial sightscapes.

An added, not insignificant, footprint are the many miles of powerline corridors that have to be expanded to connect isolated large hydro, or wind and solar farms to the grid. To the extent that forests are cleared for energy farms and powerline rights-of-way, many tons of carbon get removed from the forest ecosystem. Most of this carbon is released to the atmosphere in the short term. There is also the loss of annual sequestration of carbon from the atmosphere.

To meet the goals of the Paris agreement would require not only reducing carbon emissions, but increasing carbon sequestration. Carbon dioxide can stay in the atmosphere for decades, or even more than a century. Simply reducing carbon emissions slows the increase of carbon in the atmosphere, but does not reduce carbon dioxide. Forests, through photosynthesis, *can* take carbon dioxide out of the atmosphere. Cutting down forests for power line corridors makes the goal of increased carbon sequestration more difficult to achieve.

Intermittency presents some serious problems when solar and wind make up a higher percentage of the grid (more than 20%). Rather than respond to demand, they respond to availability of breezes and sunshine. Solar does not work so well at night or during extended cloudy periods. Wind doesn't work so well when the area is in the doldrums. There are, however, varying strategies to deal with the problem of a mismatch between supply and demand.

One solution is to have large-scale batteries or other storage systems, such as compressed air, massive fly wheels, or pumped water. Battery storage adds more environmental and energy footprints as well as making these intermittent energy sources much more expensive, though more able to match supply with demand.

Lithium ion batteries, the most popular for new solar/wind systems (and electric cars), do not last as long as solar panels. Most of the lithium comes from a dry area in Bolivia, Argentina, and Chile. It takes a lot of water to bring the salts to the surface and process the metal—500,000 gallons per metric ton of lithium. Less than 5% of lithium batteries are presently recycled, so they are a source of toxic contamination, from not just lithium, but also nickel and cobalt.

Two thirds of the world's supply of cobalt comes from the Democratic Republic of Congo, one of the poorest countries in the world. Proponents for these batteries argue that the process of making and disposing of these batteries will be more environmentally benign in the future, so it is OK to continue current polluting processes now. They also argue that the current rate of price reductions will continue into the future, but there are concerns from others that multiplying the annual production of batteries by a factor of five or more will lead to bottlenecks and shortages.

Even if battery or other storage systems could be ramped up in more environmentally acceptable ways to even out an intermittent energy supply, storage alone is not sufficient for long periods of low solar and wind supply. Most large-scale battery backups are good for minutes, or hours, but not for days of cloudy weather or low winds. For this, there needs to be backup energy, and this backup has to be big enough to meet all electrical grid needs at the times that both solar and wind are underperforming.

In the northern latitudes, solar does not perform well from November to February. The hours of sunlight are fewer, the angle of the sun is lower (with more shadows), and the days are cloudier. Sunlight is not good at penetrating snow. Solar can underperform for weeks at a time in winter. Batteries cannot fill gaps that large.

At present, the most popular backups are natural gas generators, because they can more quickly ramp up and down than coal or nuclear. Natural gas is also considered a "clean" fossil fuel, because combined cycle gas generators are more efficient (close to 60%) compared to coal (close to 40%), and less polluting. Less polluting unless one considers methane leakage from not only drilling and capturing, but also from pipelines and storage. Methane is a more potent greenhouse gas than carbon dioxide.

There is a technological fix for fossil fuel power plants to make them more "green"—carbon capture and storage (CCS). Systems have already been developed that can remove 90% of the $CO2$ from even a "dirty" fuel like coal. But, like batteries for solar and wind, CCS systems make the power plants more expensive and less efficient. CCS does not eliminate other issues with fossil fuels, such as air and water pollution, spills, leaks, accidents from mining, drilling, shipping, and use.

Large hydro dams could play a role in creating energy when wind and solar are at low levels. Large hydro, however would be difficult to scale up from where it is now. Many of the best sites are already taken and getting permits to build more dams would be difficult. The dams have major impacts on river ecosystems, blocking fish migrations, and affecting nutrients, silt deposits, and estuaries. The sizeable areas impounded for the artificial lakes have become major sources of methane, as well as carbon dioxide, leaking from submerged vegetation. When dams collapse, the results can be catastrophic. As climate change leads to more droughts, hydro dams will require backup energy.

Biomass is considered by some a "renewable" alternative to fossil fuels for backup to solar and wind. The argument made by biomass supporters is that what gets cut down and burned is replaced by other trees that are growing. Using biomass, supporters argue, is "carbon neutral"—adding no new carbon to the atmosphere. And besides, they claim, the wood is just "waste"—less suitable for lumber or pulp wood—that would have rotted anyway. This "waste" wood, can sometimes be whole trees, including tops and branches" that are not suitable for pulpwood or lumber.

In Europe, biomass for electricity generation is the number one “renewable energy” source. Biomass is expected to make up 60% of “renewable” energy in Europe by 2020. Some of the biomass fuel used in Europe is cut in the United States and shipped over the ocean to countries where, after the long journey, the wood fuel is still considered “green” and suitable for renewable energy portfolios. Because biomass is considered “carbon neutral,” promoters of this technology claim that there are zero carbon emissions.

This simple “carbon neutral” argument surely does not apply to all products in all circumstances. The “carbon neutral” designation ignores what is cut, how it is cut, what is left after cutting, how much the wood is processed, how far it is hauled, or how efficient the biomass plants are.

Cutting lots of wood from a forest can lead to less carbon sequestration. Heavy cutting can lead to soil carbon losses. Much of the carbon in forests is in the soil. Processing with heat (to make pellets) takes energy. So does shipping long distances from forest to processing plants and from processing plants to biomass plants.

The argument that one shouldn’t calculate carbon emissions from biomass because the emissions are absorbed by other trees stretches credulity. Do the trees only sequester carbon dioxide from their burned brethren, or would they also sequester carbon dioxide from fossil fuels? If so, why subtract the sequestration from one and not the other? A better solution is to calculate emissions and sequestration separately.

Stand-alone biomass electric generators can be very inefficient and can emit more carbon dioxide per unit of electricity produced than even coal. How “green” can burning trees to make electricity be if it leads to less carbon sequestration and more carbon emissions?

Regardless of the strained logic behind biomass, biomass plants, at present, are not economically competitive with other commercial energy sources. In New England, biomass plants are kept open with public subsidies. Some of the plants have failed even with the subsidies.

While biomass is supposed to be “carbon neutral,” nuclear power is touted as being “carbon free.” That is, of course, if you ignore mining, refining, transportation, construction with steel, concrete, and rare earth metals, decommissioning, building a waste repository, shipping wastes, etc.

Nuclear reactors are more suited as a base power source, rather than as a backup for solar or wind. Nuclear power does not ramp up and down to meet short-term needs as easily as natural gas electric generators.

Nuclear power, which was originally advertised as too cheap to meter, has been languishing as of late, because it is so expensive to build and get new plants on line. The Westinghouse Corporation went bankrupt after going 13 billion dollars over budget for power plants in Georgia and South Carolina. Their new approach to building, shipping pre-fabricated sections, was supposed to speed up the process of building. It did not. Part of the problem was regulatory delays.

In the United States, many plants are aging, and some have already been shut down. Some plants have aged prematurely due to embrittling, cracking, corrosion, leaks, and ruptures. Decommissioning can cost hundreds of millions of dollars (or more) per plant. After many decades of promises and after the government has already spent 15 billion dollars on developing Yucca Mountain, in Nevada, as a nuclear waste repository, there is still no place to ship high-level nuclear waste.

Because there is no waste repository, decommissioned plants store nuclear waste on site at costs of millions of dollars a year for monitoring and security—a cost without a return. From 1946 until 1993 (when the practice was banned by international treaty) 13 countries disposed of low-level nuclear waste by dumping it in the ocean. The philosophy at the time was that the solution to pollution is dilution.

Some forms of radioactive waste have half-lives of thousands of years. Plutonium-239, for example, needs to be isolated for hundreds of thousands of years. It is sobering to note that the United States is less than 250 years old.

While major nuclear accidents involving large-scale exposure of the public to radiation are rare, such incidents, when they do occur, are catastrophic. For example, tens of thousands of people had to be evacuated from the vicinity of the disasters in Chernobyl in Ukraine in 1986 and Fukushima in Japan in 2011. Those reactor problems have still not been fully fixed. The economic costs connected with those failures are, potentially, enormous.

Nuclear power in the United States would have been difficult to develop were it not for the Price Anderson Act (of 1957) which committed billions of dollars of government money for liability in case of a severe nuclear accident.

While nuclear engineers have, presumably, learned from past mistakes, that does not mean that they have engineered their plants for any possible mishap. Engineers cannot know what they do not know. It is foolish to think that such a complex technology can be rendered "fool proof" because there are too many unknowns. Douglas Adams noted that, "A common mistake that people make when trying to design something completely foolproof is to underestimate the ingenuity of complete fools."

The risks of severe accidents go up as the number of plants increases and as the competency of those running the plants decreases. Risks go up in politically unstable countries with "captured" regulatory agencies. And risks go up when countries do not have the financial or personnel resources to deal with disasters.

When nuclear power plants are in their prime, they can go for many months without stop, and can choose refueling shutdowns to coincide with lower energy demands. The backups to nuclear power plants when they do shut down are fossil fuel power plants, not wind or solar. And when large nuclear power plants shut down for extended repairs, or for good, fossil fuel backups have to be sizeable.

Ironically, because of global warming, some nuclear power plants are being exposed to conditions for which they were not designed. Nuclear power plants require a lot of water to cool the reactors. There are regulatory limits as to how warm the water can be. In the last decade, there have been instances in both the US and Europe when these temperatures have been exceeded, and either the plants have been shut down or cut back. As the climate warms, more nuclear plants will have to shut down more days unless a fix is developed.

Also, the engineers who designed the plants did not anticipate that jelly fish or seaweed would clog up the coolant tubes. But this has happened in nuclear plants in a number of countries worldwide. Global warming is also leading to droughts inland, reducing cooling water supplies for plants near rivers. And global warming linked with rising sea levels and storm surges also threatens the safety of coastal nuclear power plants.

In summary, the major power sources expected to take the place of fossil fuels have footprints and flaws. There are technological fixes being researched and tried, but so far these make the energy sources more expensive, not less, and these technological fixes have their own footprints.

Demand Reduction

There is another power source that is cheaper than even fossil fuels, and it doesn't have to be developed; the technology is practical right now. Investment in this power source can, in some circumstances, pay back with double digit annual interest. This energy source is called "demand reduction," or, as Amory Lovins called it, "Negawatts." This means finding ways to use less energy in general as a first strategy, rather than adding on new, expensive, power sources to make up for wasteful, or even frivolous uses.

For example, if you have a hole in the wall, the first strategy for staying warm should be to close the hole in the wall, rather than buy a new, bigger furnace. If you do buy a new heating system, it would be less expensive after you fix the hole, because there would be a lower demand. The system could be even smaller If the house were better insulated and weatherized.

People who have solar off-grid systems quickly learn that it is less costly to have super energy efficient refrigerators, lights, washing machines, and computers rather than to add more solar panels and batteries to run inefficient equipment. Electric stoves, hot water, and space heat require a huge, expensive system to have adequate electricity on demand. Solar hot water heaters, and passive solar buildings, however, do make both energy and economic sense.

For those on the grid, if aggressive efficiency and conservation are the first line of energy investment, energy costs per household or business can go down even if the price of energy goes up. Electric cooking, hot water, and space heating on the existing grid mean using fossil fuels to make electricity (with an efficiency of around 30% when one considers all the losses from converting fuel to electricity) and then converting the electrify back into heat. It is far more efficient to use the fossil fuels directly for heat (with efficiencies of 80-95%).

While these changes can lead to great energy use reductions, even more savings can be had in the long run by designing buildings, communities, and transportation systems to purposely use less energy. Decentralized power systems, for example, can use "waste heat" to heat buildings or water, rather than the atmosphere or the local river. This could double energy production efficiency.

Individual houses can be designed to be highly efficient for heat and light, and more thoughtful design of communities can lead to neighborhoods that are less dependent on individual cars, but more friendly for walking, bikes, and public transportation. Such design was built into communities before the age of automobiles. It is one of the reasons why many European countries use half the energy per capita as the United States—their cities were built before the age of autos; while in the US, cities, such as Los Angeles, were designed after WWII, in The Age of the Auto.

If demand reduction is successful, older, less efficient power plants could be shut down, rather than be needed for backup. Of course, if we have a society based on growth, all the savings from demand reduction would be erased over time. Over the last 50 years in the United States, homes have gotten bigger, while households have gotten smaller. Appliances have gotten more efficient per unit, while households have gotten more and bigger appliances.

The problems we are facing are not merely technological, they are also cultural. To prevent overshoot and collapse would require our society to shift towards a conserving culture rather than be dependent on endless growth in consumption. But such a shift could be disastrous for our current economic structure. Rather than conserve, consumers are urged to splurge on expensive products that denote greater status and heightened pleasure. There are no advertisements dominating the airwaves urging us to be frugal.

Resistance to change

The plans for our society solving the climate-change problem require that the public and our government commit to a change of direction *right now* and require massive efforts to start reaching the goals of fossil fuel reductions within a decade. Those who benefit from the status quo of concentrated wealth and power, however, will not willingly relinquish that wealth and power that quickly. As John Kenneth Galbraith wrote: "People of privilege will always risk their complete destruction rather than surrender any material part of their advantage."

The first strategy of resisting change is denial. Threatened industries trot out their own “experts” who claim that there is no proof of any harm or flaws. These industries can use the same public relation firms that successfully resisted serious restrictions on cigarettes for decades. When that strategy is no longer effective, the next is to make sure that any solution maintains the power and profitability of the status quo.

The influence of the largest corporations and richest individuals over the direction of our society is profound. The 100 largest corporations are estimated to be responsible for over 70% of worldwide fossil-fuel carbon emissions.

An obvious strategy to reduce global carbon emissions would be to go after the worst first—the over-consumers who are living or promoting an opulent life style. But these are the people and organizations that have the most influence on policy.

Large corporations own or sponsor the media. Corporations help finance candidates, especially ones who might sit on important committees. These companies also fund "think tanks" that influence public policy. State and federal policies—on taxation, regulation, subsidies, military policy---are all subject to influence from the biggest corporations. Some presidents and governors, elected with support of industry money, blatantly appoint industry lobbyists or allies to run government agencies, including regulatory agencies.

Whole sectors of our economy are dominated by fewer and fewer companies. These are not "free markets," in the technical sense, they are monopolies or oligopolies, where a handful of companies control 50% or more of the markets. In economic crises, as the one in 2008, the government can spend billions of dollars to prop up companies that are "too big to fail." Profits are privatized while losses are "socialized."

Anthropologist Roy Rappaport wrote that, "To regulate a general system such as a society or a forest in accordance with the narrow purposes of one of its sub-systems, such as a business firm or an industry, or even industry as a whole (as suggested by Calvin Coolidge's famous dictum 'The business of America is business') is to narrow the range of conditions under which the general system can survive."

Social, ecological, or climate-change goals can only be pursued to the extent that they do not interfere with the goals of the dominant economic/political forces. The public has been led to believe that climate change-related problems can be solved by technological means. The technologies that companies develop, however, are primarily designed to get a desired return on investment and increase market share and dominance, rather than to save the planet from overheating.

Technological Innovations

Industrially Appropriate	*Socially Appropriate*
Expensive, complex, and time-consuming to develop	Easily developed at local level
Ownership and control limited to few	Ownership and control available to many
Increases power of industry	Reduces social inequities
Increases public's dependence on industry	Increases self-reliance of individuals and communities
Requires centralized bureaucracy to run and protect technology	Allows decentralized, self-regulating communities
Ecological disruption or pollution OK if within legal limits	Produces little or no ecological disruption or pollution
Increases worker "productivity" (i.e., eliminates jobs)	Improves employment opportunities

Communities must adapt to needs of technology	Technology fits into needs of community
Causes rapid social/ecological change requiring more techno-fixes	Helps maintain social/ecological stability

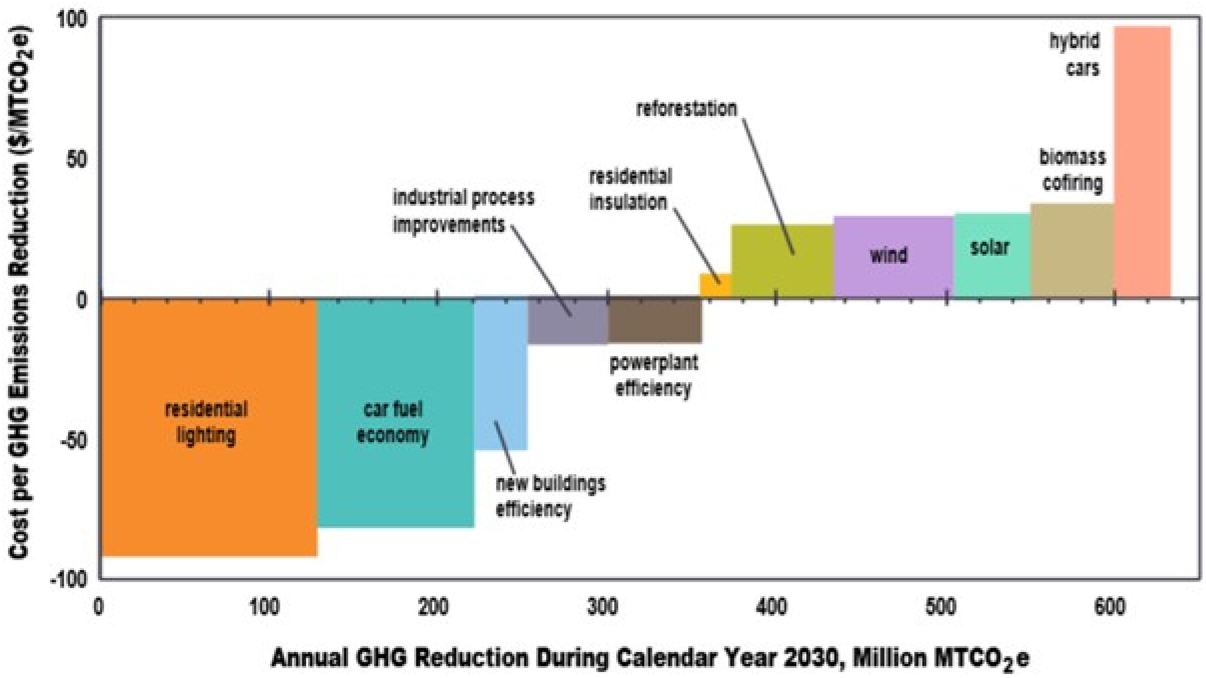
Energy comparisons
It should be clear that all energy sources have carbon and environmental impacts, but there are rational ways to find the least bad. One such system is to calculate the energy returned on energy invested—EROEI. Simple numbers for each energy source hide enormous variabilities due to location (especially for wind and solar), quality of ores (for fossil fuels or nuclear), the variables looked at and the boundaries of how far one wants to trace energy expenditures.

For example, in building a dam, one might look at not only the energy used to run a bulldozer, but the energy required to build the bulldozer. And some studies will ignore the energy cost in decommissioning or deconstructing the facility, be it dam or nuclear power plant, when it reaches the end of its usefulness. It makes a difference who does the calculations and what are their biases.

Our society has limited financial resources. It therefore makes sense to consider what energy options give the biggest bang for the buck. Some studies have analyzed the cost per ton of reducing CO2 emissions compared to business as usual (BAU). One such study, the McKinsey Marginal Abatement Cost Curve, found that carbon capture and storage (CCS) technologies connected with coal or natural gas are quite expensive--while solar, wind, and nuclear had a lower cost per ton. Even lower in cost were afforestation of abandoned pasture and restoring degraded land and better residential insulation.

But there were other strategies in the McKinsey chart that had moderate *negative* costs, such as power plant efficiencies or industrial process improvements. And some had big *negative* costs, such as more efficient lighting, car fuel economy and more efficient new buildings. A negative cost is not really a cost; it is a net savings compared to BAU.

ESTIMATE OF COST EFFECTIVENESS OF SELECT GHG EMISSIONS REDUCTIONS STRATEGIES IN THE U.S. (McKinsey & Company, 2007)



The numbers in the McKinsey study above are now considered out of date. Costs have been changing fairly rapidly, and so have guidelines for calculating these numbers. A newer comparison (that did not look at the conservation strategies that had the most favorable results in the previous study) found:

New source generation costs when compared to existing coal generation

Technology Cost Estimate	*($2017/ton CO2)*
Onshore Wind	25
Natural Gas Combined Cycle	27
Utility-scale Solar Photovoltaic	29
New Natural Gas with CCS	43
Advanced Nuclear	59
Coal Retrofit with Carbon Capture and Storage	85
New Coal with Carbon Capture and Storage	95
Offshore Wind	105
Solar Thermal	133

Source: Author's calculations updating methodology from Clean Air Task Force (2013) based on Energy Information Administration estimates from the 2018 Annual Energy Outlook. CCS refers to carbon capture and storage technology. Costs are projected for facilities that come on line in 2022. Costs do not incorporate federal renewable tax credits.

Note: in this study, new nuclear had a higher cost to reduce a ton of CO2 than wind, solar, or natural gas combined cycle. In the McKinsey study, nuclear had a lower cost per ton than wind or solar. It makes a difference who writes the study.

Another interesting comparison is life cycle greenhouse gas emissions (see https://en.wikipedia.org/wiki/Life-cycle_greenhouse-gas_emissions_of_energy_sources). These studies show that there is potential to reduce greenhouse gas emissions, but it depends on the location, the boundaries of the studies, and the bias of decision makers as to which technology is best to choose. The numbers vary from one study to another and the averages even within a study (such as the one above) hide the wide range of variances. The biggest bang for the buck, however, is to reduce demand through efficiency.

It is also worthwhile to restore natural forests (not short-rotation monocultures). Unlike conservation or renewable energy, which can *reduce* the rate at which carbon dioxide is increasing in the atmosphere, forests can *remove* carbon dioxide from the atmosphere. The Nature Conservancy estimates that what they call "Natural Climate Solutions" can provide 37% of the carbon reductions needed to meet 2050 IPCC goals. (see https://global.nature.org/initiatives/natural-climate-solutions/ncs-about) .

These energy and carbon analyses alone are not sufficient as a basis for decision, because we also need to consider social and ecological impacts as well.

Conclusion

What should we do to overcome the barriers to decarbonization identified in this essay? It is easy enough to come up with an, "all you have to do is" set of solutions. I've seen these in many books and articles that assume that somehow, everyone, starting today, will agree on the presented analyses and make major changes in federal policy that would reduce carbon to manageable levels over the next few decades. But such agreement does not seem likely in the short term in the United States. Indeed we have had governors, congress people, and even a president who are climate "skeptics."

Before we develop strategies to overcome the barriers to decarbonization, we must first acknowledge these barriers exist. We cannot grow ourselves out of the need to live within the limits of our planet. We cannot instantly transform our existing infrastructure and policies. Adding more solar panels and windmills is not the same as decreasing carbon emissions from fossil fuels—wind or solar need to be "instead of," rather than "in addition to." That technological fixes for the weaknesses of "carbon-free" energy are theoretically possible does not mean they are economically feasible at scale. And even if there are good ideas out there, they will get filtered through the existing web of political power and influence.

Public opinions are changing, none-the-less. We are reaching the point where the majority of the public is aware that a climate problem exists—not just in the future, but now. The climate has already started changing. Severe weather disasters, including droughts, fires, floods, and storms, are increasing in size, intensity, and frequency.

While there is a growing percentage of the public that agrees that the destabilization of the climate is due, in part, to carbon emissions from burning fossil fuels, there is, as yet, no consensus over what to do about it. According to a recent Gallup poll, by the widest margin since 2000, more Americans believe environmental protection should take precedence over economic growth when the two goals conflict.

Sixty-five percent now choose the environment. (https://news.gallup.com/poll/248243/preference-environment-economy-largest-2000.aspx) Polls, do not always translate into policy, but they do suggest an opportunity.

To the extent that changes made by businesses and government, over the next decade, are insufficient to prevent increased climatic instability, more and more resources will have to be expended to deal with increasing floods, droughts, super storms, fires, crop failures and the mass migrations and military conflicts that might also ensue.

Climate change, resulting from burning fossil fuels, is only one of many interconnected crises our global society is facing. We are also experiencing serious threats to biodiversity, fresh water systems, forests, soils, and oceans. Pollinating insects are in decline, as are insect-eating birds. Amphibian populations are threatened worldwide. Climate change will accelerate these trends. Consuming less energy and less stuff in the overdeveloped countries would be beneficial to all these environmental crises. Consuming more would exacerbate them. But consuming less violates some of our society's dominant economic priorities. So we let ourselves believe that some benign technology, yet to be fully developed, will absolve us from having to be frugal.

It is ironic that boosters of some of the technologies that are "needed" to meet projected future demands call those who question such technologies (and such projections) "science denialists." Accepting economic growth as a higher priority than maintenance of our biological life support systems is *not* a scientific view point, unless one believes in a new theory of the Universe where it is money that makes the world go round.

Our industrial society has been able to grow, to some extent, by writing off fairly huge areas of the landscape as ecological sacrifice zones. Ecological sacrifice zones are areas where there is conversion, simplification, or fragmentation of habitat, or serious toxic pollution. The landscape is converted from natural, self-regulating ecosystems to artificial ecosystems managed for human purposes or turned into literal wastelands. These include, landfills, ocean dead zones, oil spills, power-line corridors, pipe lines, feed lots, agricultural monocultures, roads, parking lots, dammed rivers…the list is long.

"Green energy," however well intentioned, will add to that list. Wind and solar combined make up less than 10% of what goes into the grid. And what is needed for the grid would increase if more end uses are electrified, such as cars, space heating, water heating, or stoves. If wind and solar are scaled up to take the place of fossil fuels and meet all these needs, the impact on the landscape would be a sizeable multiple of today's footprint.

It would be easier to accept these sacrifice zones if we knew that they would be limited, and more land would be set aside for natural processes. But our economy, if it continues to grow geometrically, will inevitably cause expansions of these sacrifice zones. According to one organization that calculates ecological footprints (https://www.footprintnetwork.org/our-work/ecological-footprint/), 80% of the people in the world are living in countries that already consume more resources than their ecosystems can renew.

We have a choice—to acknowledge the biological and physical limits now and try to live within them, or to leave that decision to our descendants, who will inherit from us a world with even more sacrifice zones and fewer natural options.

“A man is rich in proportion to the number of things he can afford to leave alone.” Thoreau.

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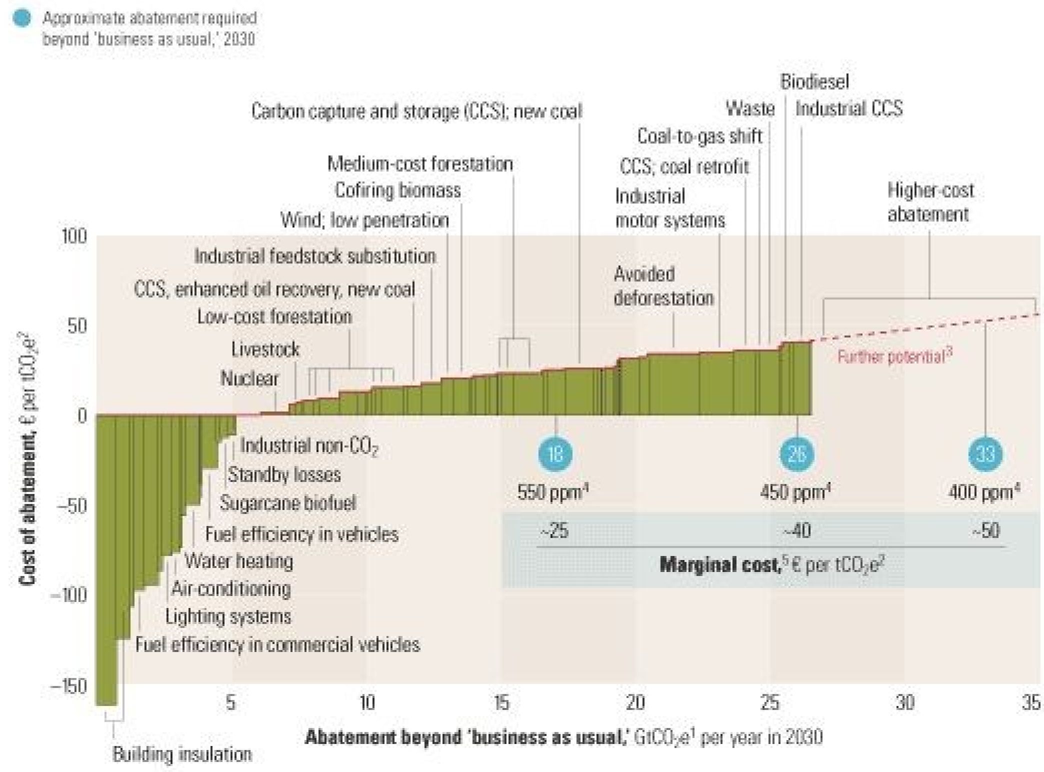

[1] $GtCO_2e$ = gigaton of carbon dioxide equivalent; "business as usual" based on emissions growth driven mainly by increasing demand for energy and transport around the world and by tropical deforestation.
[2] tCO_2e = ton of carbon dioxide equivalent.
[3] Measures costing more than €40 a ton were not the focus of this study.
[4] Atmospheric concentration of all greenhouse gases recalculated into CO_2 equivalents; ppm = parts per million.
[5] Marginal cost of avoiding emissions of 1 ton of CO_2 equivalents in each abatement demand scenario.

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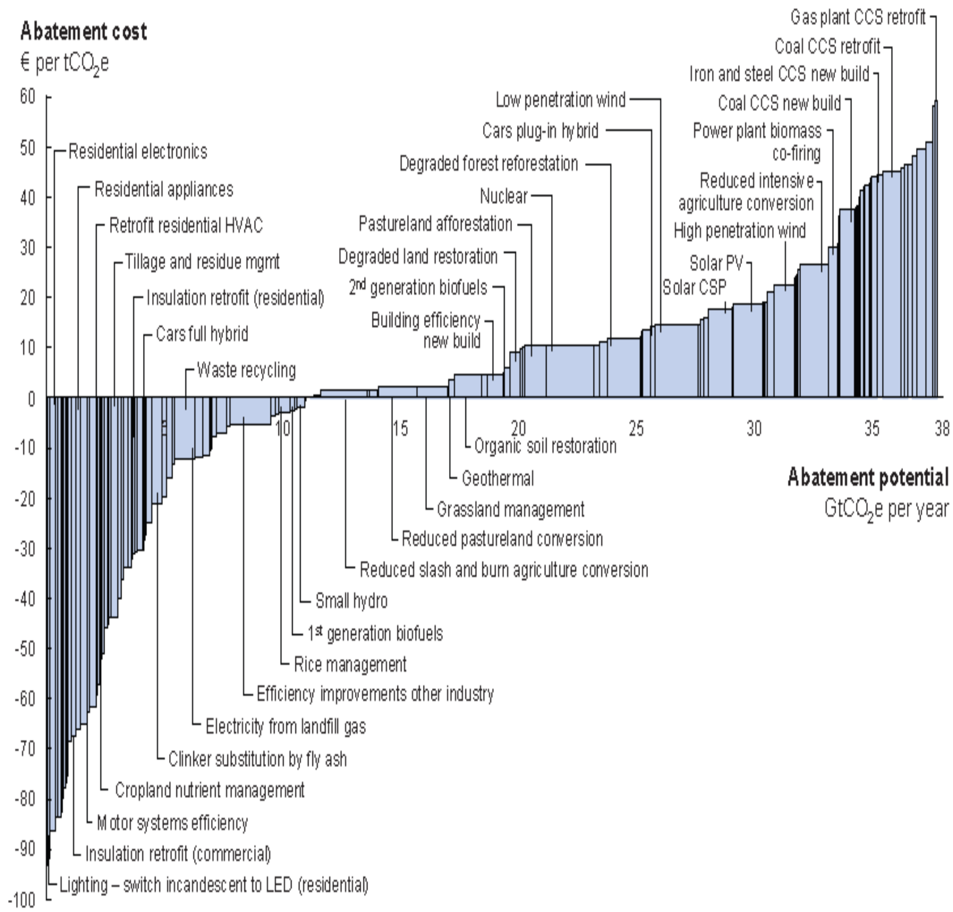
An additional 6 gigatons—almost a quarter of the total abatement potential at a cost of 40 euros a ton or less—could be gained through measures with a zero or negative net life cycle cost. This potential appears mainly in transportation and in buildings. Improving the insulation of new ones, for example, would lower demand for energy to heat them and thus reduce emissions. Lower energy bills would more than compensate for the additional insulation costs. According to our model, measures like these, as well as some in manufacturing industry, hold the potential to almost halve future growth in global electricity demand, to approximately 1.3 percent a year, from 2.5 percent.

As for measures that *would* have a net cost, we found that around 35 percent of all potential abatements with a net cost of up to 40 euros a ton involve forestry; 28 percent, manufacturing industry; 25 percent, the power sector; 6 percent, agriculture; and 6 percent, transportation.



Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €60 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.

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