EXHIBIT 1

The White House
Office of the Press Secretary

For Immediate Release October 05, 2016

Remarks by the President on the Paris Agreement

Rose Garden

**Please see below for a correction, marked with an asterisk.

3:30 P.M. EDT

THE PRESIDENT: Good afternoon, everybody. Today is a historic day in the fight to protect our planet for future generations.

Ten months ago, in Paris, I said before the world that we needed a strong global agreement to reduce carbon pollution and to set the world on a low-carbon course. The result was the Paris Agreement. Last month, the United States and China -- the world's two largest economies and largest emitters -- formally joined that agreement together. And today, the world has officially crossed the threshold for the Paris Agreement to take effect.

Today, the world meets the moment. And if we follow through on the commitments that this agreement embodies, history may well judge it as a turning point for our planet.

Of course, it took a long time to reach this day. One of the reasons I ran for this office was to make America a leader in this mission. And over the past eight years, we've done just that. In 2009, we salvaged a chaotic climate summit in Copenhagen, establishing the principle that all nations have a role to play in combating climate change. And at home, we led by example, with historic investments in growing industries like wind and solar that created a steady stream of new jobs. We set the first-ever nationwide standards to limit the amount of carbon pollution that power plants can dump into the air our children breathe. From the cars and trucks we drive to the homes and businesses in which we live and work, we've changed fundamentally the way we consume energy.

Now, keep in mind, the skeptics said these actions would kill jobs. And instead, we saw -- even as we were bringing down these carbon levels -- the longest streak of job creation in American history. We drove economic output to new highs. And we drove our carbon pollution to its lowest levels in two decades.

We continued to lead by example with our historic joint announcement with China two years ago, where we put forward even more ambitious climate targets. And that achievement encouraged dozens of other countries to set more ambitious climate targets of their own. And that, in turn, paved the way for our success in Paris -- the idea that no nation, not even one as powerful as ours, can solve this challenge alone. All of us have to solve it together.

Now, the Paris Agreement alone will not solve the climate crisis. Even if we meet every target embodied in the agreement, we'll only get to part of where we need to go. But make no mistake, this agreement will help delay or avoid some of the worst consequences of climate change. It will help other nations ratchet down their dangerous carbon emissions over time, and set bolder targets as technology advances, all under a strong system of transparency that allows each nation to evaluate the progress of all other nations. And by sending a signal that this is going to be our future -- a clean energy future -- it opens up the floodgates for businesses, and scientists, and engineers to unleash high-tech, low-carbon investment and innovation at a scale that we've never seen before. So this gives us the best possible shot to save the one planet we've got.

I know diplomacy *can be [isn't always] easy, and progress on the world stage can sometimes be slow. But together, with steady persistent effort, with strong, principled, American leadership, with optimism and faith and hope, we're proving that it is possible.

And I want to embarrass my Senior Advisor, Brian Deese -- who is standing right over there -- because he worked tirelessly to make this deal possible. He, and John Kerry, Gina McCarthy at the EPA, everybody on their teams have done an extraordinary job to get us to this point -- and America should be as proud of them as I am of them.

I also want to thank the people of every nation that has moved quickly to bring the Paris Agreement into force. I encourage folks who have not yet submitted their documentation to enter into this agreement to do so as soon as possible. And in the coming days, let's help finish additional agreements to limit aviation emissions, to phase down dangerous use of hydrofluorocarbons -- all of which will help build a world that is safer, and more prosperous, and more secure, and more free than the one that was left for us.

That's our most important mission, to make sure our kids and our grandkids have at least as beautiful a planet, and hopefully more beautiful, than the one that we have. And today, I'm a little more confident that we can get the job done.

So thank you very much, everybody.

END
3:35 P.M. EDT

EXHIBIT 2

SEPTEMBER 2016

THE SKY'S LIMIT

WHY THE PARIS CLIMATE GOALS REQUIRE A MANAGED DECLINE OF FOSSIL FUEL PRODUCTION

OIL CHANGE INTERNATIONAL

PUBLISHED IN COLLABORATION WITH

This report was researched and written by Greg Muttitt with contributions from Hannah McKinnon, Lorne Stockman, Steve Kretzmann, Adam Scott, and David Turnbull. It was edited by Collin Rees. All are with Oil Change International.

Oil Change International is a research, communications, and advocacy organization focused on exposing the true costs of fossil fuels and facilitating the coming transition towards clean energy.

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Design: paul@hellopaul.com

Cover Image: Looking west from Qian'an, iron and steel plant smokestacks. Hebei Province, China, 2014.

September 2016

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350.org	http://www.350.org
Amazon Watch	http://amazonwatch.org
Asian Peoples' Movement on Debt and Development	http://www.apmdd.org
Australian Youth Climate Coalition	http://www.aycc.org.au
Bold Alliance	http://boldnebraska.org/tag/bold-alliance
Christian Aid	http://www.christianaid.org.uk
Earthworks	https://www.earthworksaction.org
Equiterre	http://www.equiterre.org
Global Catholic Climate Movement	https://catholicclimatemovement.global
Health of Mother Earth Foundation	http://www.homef.org
Indigenous Environmental Network	http://www.ienearth.org
IndyAct	http://www.indyact.org
Rainforest Action Network	http://www.ran.org
STAND.earth	http://www.stand.earth

IF YOU'RE IN A HOLE, STOP DIGGING

CONTENTS

ABBREVIATIONS USED IN THIS REPORT

AR5	Fifth Assessment Report of the IPCC
Bbl	Barrel
Bn Bbl	Billion Barrel
Bcf/d	Billion Cubic Feet Per Day
BNEF	Bloomberg New Energy Finance
°C	degrees Celsius
CCS	Carbon Capture and Storage
CO_2	Carbon Dioxide
EV	Electric Vehicle
GDP	Gross Domestic Product
Gt	Billion Metric Tons
Gtce	Billion Metric Tons of Coal Equivalent
$GtCO_2$	Billion Metric Tons of Carbon Dioxide
GW	Billion Watts (A Measure of Power)
GWh	Billion Watt-Hours (A Measure of Energy, or Power Supplied/Used Over Time)
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LULUCF	Land Use, Land Use Change and Forestry
mbd	Million Barrels Per Day
Mt	Million Metric Tons
Mtoe	Million Tons of Oil Equivalent
OECD	Organisation for Economic Co-operation and Development
OPEC	Organization of the Petroleum Exporting Countries
SEI	Stockholm Environment Institute
Tcf	Trillion Cubic Feet
TW	Terawatts
UNFCCC	United Nations Framework Convention on Climate Change

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EXECUTIVE SUMMARY

In December 2015, world governments agreed to limit global average temperature rise to well below 2°C, and to strive to limit it to 1.5°C. This report examines, for the first time, the implications of these climate boundaries for energy production and use. Our key findings are:

- The potential carbon emissions from the oil, gas, and coal in the world's currently operating fields and mines would take us beyond 2°C of warming.
- The reserves in currently operating oil and gas fields alone, even with no coal, would take the world beyond 1.5°C.
- With the necessary decline in production over the coming decades to meet climate goals, clean energy can be scaled up at a corresponding pace, expanding the total number of energy jobs.

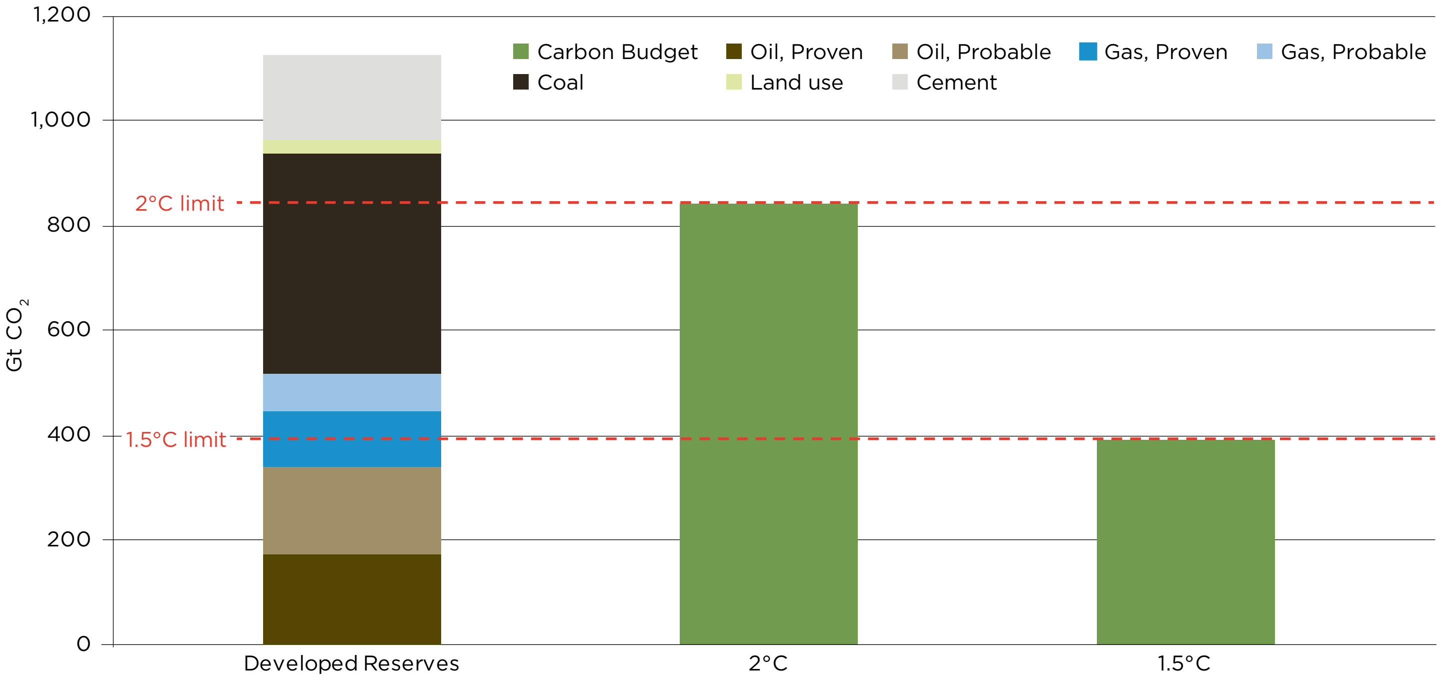
One of the most powerful climate policy levers is also the simplest: stop digging for more fossil fuels. We therefore recommend:

- No new fossil fuel extraction or transportation infrastructure should be built, and governments should grant no new permits for them.
- Some fields and mines – primarily in rich countries – should be closed before fully exploiting their resources, and financial support should be provided for non-carbon development in poorer countries.
- This does not mean stopping using all fossil fuels overnight. Governments and companies should conduct a managed decline of the fossil fuel industry and ensure a just transition for the workers and communities that depend on it.

In August 2015, just months before the Paris climate talks, President Anote Tong of the Pacific island nation of Kiribati called for an end to construction of new coal mines and coal mine expansions. This report expands his call to all fossil fuels.

View of Suncor Millennium tailings pond and tar sands mining operations north of Fort McMurray.

Figure ES-1: Emissions from Developed Fossil Fuel Reserves, Plus Projected Land Use and Cement Manufacture



Sources: Rystad Energy, International Energy Agency (IEA), World Energy Council, Intergovernmental Panel on Climate Change (IPCC)

ENOUGH ALREADY

The Paris Agreement aims to help the world avoid the worst effects of climate change and respond to its already substantial impacts. The basic climate science involved is simple: cumulative carbon dioxide (CO_2) emissions over time are the key determinant of how much global warming occurs.[a] This gives us a finite *carbon budget* of how much may be emitted in total without surpassing dangerous temperature limits.

We consider carbon budgets that would give a likely (66%) chance of limiting global warming below the 2°C limit beyond which severe dangers occur, or a medium (50%) chance of achieving the 1.5°C goal. Fossil fuel reserves – the known below-ground stocks of extractable fossil fuels – significantly exceed these budgets. For the 2°C or 1.5°C limits, respectively 68% or 85% of reserves must remain in the ground.

This report focuses on the roughly 30% of reserves in oil fields, gas fields, and coal mines that are already in operation or under construction. These are the sites where the necessary wells have been (or are being) drilled, the pits dug, and the pipelines, processing facilities, railways, and export terminals constructed. These *developed reserves* are detailed in Figure ES-1, along with assumed future emissions from the two major non-energy sources of emissions: land use and cement manufacture.

We see that – in the absence of a major change in the prospects of carbon capture and storage (CCS):[b]

- The oil, gas, and coal in already-producing fields and mines are more than we can afford to burn while keeping likely warming below 2°C.

- The oil and gas alone are more than we can afford for a medium chance of keeping to 1.5°C.

a The carbon budgets approach does not apply to other greenhouse gases, whose effects are factored into the calculation of carbon budgets in the form of assumptions about their future emissions.
b CCS has not been successfully deployed at scale despite major efforts, and there are doubts as to whether it will ever be affordable or environmentally safe.

WHEN YOU'RE IN A HOLE, STOP DIGGING

Traditional climate policy has largely focused on regulating at the point of emissions, while leaving the supply of fossil fuels to the market. If it ever was, that approach is no longer supportable. Increased extraction leads directly to higher emissions, through lower prices, infrastructure lock-in, and perverse political incentives. Our analysis indicates a hard limit to how much fossil fuel can be extracted, which can be implemented only by governments:

- No new fossil fuel extraction or transportation infrastructure should be built, and governments should grant no new permits for them.[c]

Continued construction would either commit the world to exceeding 2°C of warming, and/or require an abrupt end to fossil fuel production and use at a later date (with increasing severity depending on the delay). Yet right now, projected investment in new fields, mines, and transportation infrastructure over the next twenty years is $14 trillion – either a vast waste of money or a lethal capital injection. The logic is simple: whether through climate change or stranded assets, a failure to begin a managed decline now would inevitably entail major economic and social costs.

The good news is that there is already progress toward stopping new fossil fuel development. China and Indonesia have declared moratoria on new coal mine development, and the United States has done so on federal lands. These three countries account for roughly two-thirds of the world's current coal production. In 2015, U.S. President Barack Obama rejected the proposed Keystone XL tar sands pipeline by noting that some fossil fuels should be left in the ground, and there is growing recognition of the importance of a climate test in decisions regarding new fossil fuel infrastructure.[d] There is an urgent need to make the coal moratoria permanent and worldwide, and to stop new oil and gas development as well.

Ending new fossil fuel construction would bring us much closer to staying within our carbon budgets, but it is still not enough to achieve the Paris goals. To meet them, some early closure of existing operations will be required. Every country should do its fair share, determined by its capacity to act, along with its historic responsibility for causing climate change. With just 18% of the world's population, industrialized countries have accounted for over 60% of emissions to date, and possess far greater financial resources to address the climate problem.

Most early closures should therefore take place in industrialized countries, beginning with (but not limited to) coal. While politically pragmatic, the approach of stopping new construction tends to favor countries with mature fossil fuel industries; therefore, part of their fair share should include supporting other countries on the path of development without fossil fuels, especially in providing universal access to energy. Therefore:

- Some fields and mines – primarily in rich countries – should be closed before fully exploiting their reserves, and financial support should be provided for non-carbon development in poorer countries.

Additionally, production should be discontinued wherever it violates the rights of local people – including indigenous peoples – or where it seriously damages biodiversity.

c This does not mean stopping all capital investment in existing field and mines, only stopping the development of new ones (including new project phases).
d http://ClimateTest.org

A MANAGED DECLINE AND A JUST TRANSITION

Stopping new construction does not mean turning off the taps overnight. Existing fields and mines contain a finite stock of extractable fossil fuels. Depleting these stocks, even including some early closures, would entail a gradual transition in which extraction rates would decline over a few decades. This is consistent with a rate of expansion of clean energy that is both technically and economically possible.

We consider a simple modelling of world energy sources under two scenarios: 50% renewable energy by 2035 and 80% by 2045, both with a complete phase-out of coal usage, except in steel production. It is compared with the projected oil and gas extraction from existing fields alone.

We conclude that:

- While existing fields and mines are depleted over the coming decades, clean energy can be scaled up at a corresponding pace.

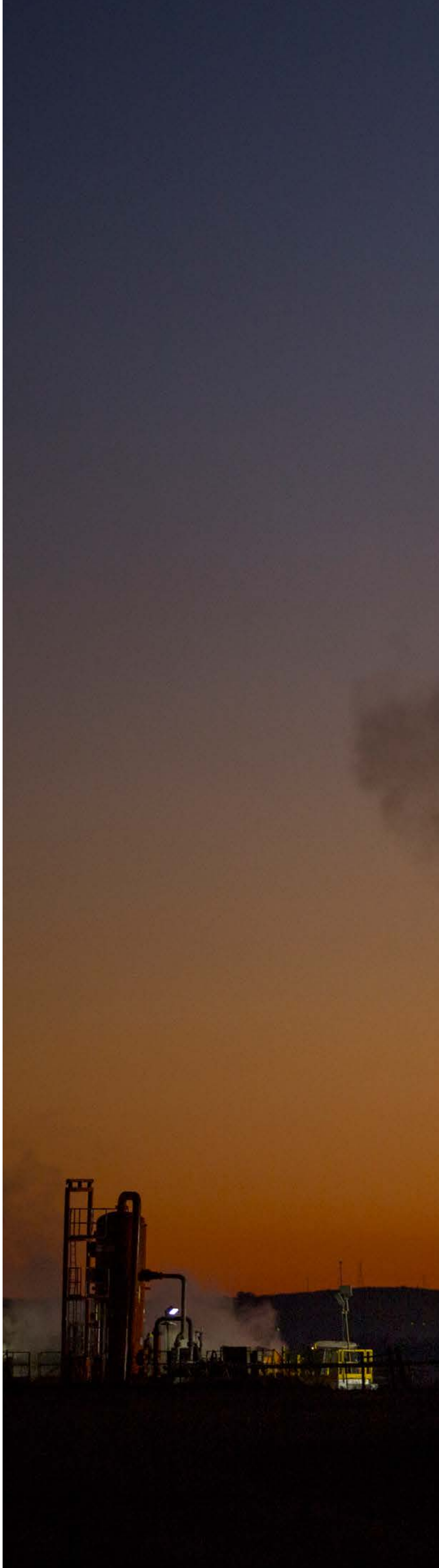
While this pace of renewable energy expansion will require policy support, it continues existing trends. In many countries – large and small, rich and poor – clean energy is already being deployed at scale today. Denmark now generates more than 40% of its electricity from renewable sources, Germany more than 30%, and Nicaragua 36%. China is now the largest absolute generator of renewable electricity, and expanding renewable generation quickly. In most contexts, the costs of wind and solar power are now close to those of gas and coal; in some countries renewable costs are already lower. The expansion of renewable energy will be harder where there are weak grids in developing countries, hence the importance of climate finance in supporting a non-carbon transition.

As for transportation, electric vehicles are now entering the mainstream and are on course to soon be cheaper than gasoline or diesel cars. With sufficient policy support and investment, the growth in clean energy can match the needed decline in fossil fuel extraction and use.

While there are clear advantages to clean energy – lower costs, greater employment, reduced local pollution, and ultimately greater financial returns – the transition will not be painless. Energy workers' skills and locations may not be well matched to the new energy economy. Whole communities still depend on fossil fuel industries. There is a vital need for a careful, just transition to maximize the benefits of climate action while minimizing its negative impacts.

Governments should provide training and social protection for affected energy workers and communities. Where appropriate, they should require energy companies to offer viable careers to their workers in non-carbon areas of their business. Governments should also consult with communities to kick-start investments that will enable carbon-dependent regions to find a new economic life. Waiting is not an option; planning and implementation must begin now:

- Governments and companies should conduct a proactively managed decline of the fossil fuel industry and ensure a just transition for the workers and communities that depend on it.



A flare burns near a hydraulic fracturing drilling tower in rural Weld County in northern Colorado, the most intensively fracked area in the United States.

Aerial view of seismic lines and a tar sands mine in the Boreal forest north of Fort McMurray, northern Alberta.

©Jiri Rezac/Greenpeace

1. CLIMATE SCIENCE AND CARBON BUDGETS

Burning of fossil fuels – oil, gas and coal – is driving one of the biggest challenges facing the world today: climate change. Extreme weather events, rising oceans, and record setting temperatures are already wreaking havoc on hundreds of millions of lives and livelihoods around the world. In the absence of strong action to reduce emissions, these impacts will get significantly worse throughout the course of the twenty-first Century:[1]

- A large proportion of the earth's species faces increased risk of extinction, as many cannot adapt or migrate as fast as the climate changes. Lost species will never return.
- Crop yields will be severely reduced, potentially causing hunger on a mass scale. The Intergovernmental Panel on Climate Change (IPCC) reports a one-in-five chance (in terms of proportion of model projections) that yields of wheat, corn, rice and soy will decrease by more than 50% by 2100, and a further one-in-five chance that they will decrease by between 25% and 50%: in either case the consequences would be catastrophic.
- Water supplies too will become stressed, especially in dry and tropical regions.
- Cities will increasingly be hit by storms and extreme precipitation, inland and coastal flooding, landslides, air pollution, drought, water scarcity, sea level rise and storm surges.

This report sets out the decisions and actions that can be taken now to avoid the worst of these impacts on lives and livelihoods, on economies and ecosystems.

WELL BELOW 2°C, AND AIMING FOR 1.5°C

During the first decade of the twenty-first century, 2°C of warming above pre-industrial levels was often seen as a "guardrail" of a safe climate. Since then, new findings have indicated that view to be too optimistic. Runaway climate change – in which feedback loops drive ever-worsening climate change, regardless of human activities[e] – are now seen as a risk even at 2°C of warming.[2]

A two-year review within the United Nations Framework Convention on Climate Change (UNFCCC), based on inputs from scientists and other experts, summarized the evolving understanding: "The 'guardrail' concept, in which up to 2°C of warming is considered safe, is inadequate and would therefore be better seen as an upper limit, a defense line that needs to be stringently defended, while less warming would be preferable."[3]

There has been limited study of specific climate impacts at 1.5°C, but some initial findings suggest significantly lower risks than at 2°C. Bruce Campbell of the Consultative Group for International Agricultural Research (CGIAR) estimates that 2°C of warming could reduce African maize yields by 50% compared to 1.5°C of warming,[4] while a recent assessment by Carl-Friedrich Schleussner and others identified several differential impacts between 1.5°C and 2°C of warming:[5]

- Heat extremes would become both more frequent and of longer duration at 2°C than at 1.5°C.
- Reductions in water availability for the Mediterranean region would nearly double from 9% to 17% between 1.5°C and 2°C, and the projected lengthening of regional dry spells would increase from 7% to 11%.
- Wheat yields would be reduced by 15% at 2°C compared to 9% at 1.5°C in a best estimate; the reduction could be as bad as 42% at 2˚C versus 25% at 1.5°C.
- The difference between 1.5°C and 2°C is likely to be decisive for the survival of tropical coral reefs.

For these reasons – and due to the moral call from small island states and other vulnerable nations – governments meeting in Paris set more ambitious goals than at previous UNFCCC meetings. The Paris Agreement established the goal of "holding the increase in global average temperature to well below 2°C above preindustrial levels and pursuing efforts to limit the temperature increase to 1.5°C above preindustrial levels."[6]

Still, the specific commitments that governments made in Paris were not sufficient to deliver these long-term goals. The Climate Action Tracker estimates that current global commitments (as stated in countries' Intended Nationally Determined Contributions to the UNFCCC) would result in 2.7°C of warming by the end of the century.[7] In this report we explore what is necessary to actually meet the Paris goals.

e Examples include release of methane due to melting permafrost or accelerated dieback of Amazon rainforest.

CARBON BUDGETS

Many existing analyses of the energy transition start from the current energy system, and attempt to plot what they consider pragmatic rates of change from the status quo. In some cases, such an approach fails to deliver the emissions reductions needed. In that vein, oil companies have often used their energy forecasts to claim that preventing dangerous climate change is simply impossible:

- BP: "Emissions [will] remain well above the path recommended by scientists."[8]
- Shell: "We also do not see governments taking the steps now that are consistent with the 2°C scenario."[9]
- ExxonMobil: "It is difficult to envision governments choosing this [low carbon] path."[10]

In this report we take the opposite approach: we start from climate limits and translate into what needs to happen to the energy system in order to achieve them. We find that what is necessary is also achievable.

We know from atmospheric physics that the key factor determining the extent of global warming is the cumulative amount of carbon dioxide (CO_2) emissions over time.[11] Because CO_2 stays in the atmosphere for centuries, it has been accumulating for many decades and continues to do so.[12] To keep warming within any particular limit – all else being equal – there is a maximum cumulative amount of CO_2 that may be emitted. (Non-CO_2 greenhouse gases are treated differently – see Box 1)

In the same way that an individual, business, or government has a budget corresponding to the resources they have, how long they need them to last, and the consequences of debt or deficit, a carbon budget does the same for greenhouse gas pollution. This is an important and helpful way to understand what we can afford to burn when it comes to fossil fuels (and other sources of emissions), and to drive conversations about the most effective and fairest ways to divide the budget between regions and types of fossil fuels.

In this report we analyze the carbon budgets calculated by the IPCC, to examine their implications for the energy system. We consider two climate limits: a likely chance (66%) of limiting global warming to below 2°C, and a medium chance (50%) of limiting it to below 1.5°C. These budgets are shown in Table 1, deducting emissions that have occurred since the IPCC compiled them.

Some scenarios and analyses, such as the International Energy Agency's 450 Scenario, are based on a 50% chance of staying below 2°C of warming.[13] Since 2°C is considered an absolute limit beyond which severe dangers occur, these 50% odds may be considered imprudent; hence other analyses such as United Nations Environment Programme's annual Emissions Gap report use the budget for delivering a 66% chance of avoiding those dangers, as do we in this report.[f] However, we use a 50% chance of reaching 1.5°C because it has been set as an aspirational goal in the Paris Agreement, rather than an absolute maximum.

Table 1: Global Carbon Budgets for Likely Chance of 2°C and Medium Chance of 1.5°C

($GtCO_2$)	2°C	1.5°C
Post-2011 Budget (from IPCC)[14]	1,000	550
Emissions 2012 to 2015[15]	157	157
Post-2015 Budget	843	393

Sources: IPCC, Global Carbon Project

Box 1: Carbon Budgets and Other Greenhouse Gases

The carbon budgets concept applies to CO_2, because of the way it accumulates in the atmosphere over many decades. The budgets concept cannot be used in the same way to account for other greenhouse gases, which have a more complex warming effect because they do not last for as long in the atmosphere. Methane is the most important of these other gases.

In the short term, methane is a much more potent greenhouse gas than CO_2. However, because methane molecules break down after an average of twelve years, their direct warming effect occurs only during those years after they are emitted, while they are still present in the atmosphere. Methane also has indirect effects lasting beyond twelve years, due to feedback loops in the climate system.[g] Because these loops do not follow a linear relationship with cumulative emissions, they cannot be described using carbon budgets.

For these reasons, carbon budgets as discussed in this report relate only to CO_2. However, other greenhouse gases are factored in when the sizes of CO_2 budgets are calculated. Assumptions are made about what other gases' future emissions will be, and so if those assumptions change, then the sizes of carbon budgets change. Recent studies have indicated that methane leakage rates from natural gas facilities in the United States are much higher than previously thought, especially as a result of hydraulic fracturing, or "fracking."[16] Such changed assumptions may require CO_2 budgets to be revised downward, which would allow for less CO_2 to be emitted.

f There is an argument on that basis that we should require a better than 66% of staying below 2°C – a 33% chance of failure is frightening, given the severity of what failure actually means. The IPCC provides budgets only for 33%, 50%, and 66%, partly as a relic of earlier decisions on how to quantify English-language terms such as "likely" and "unlikely." While some scientists have calculated carbon budgets that would give 80% or 90% probabilities, in this report we use the IPCC budgets, as they are the most-reviewed and most-authoritative options. However, we do so with the following proviso: to be more confident of staying below 2°C, budgets would be smaller and require more dramatic action than outlined here.

g For example, short-term warming caused by methane's direct greenhouse effect may cause ice to melt, reducing the extent to which solar radiation is reflected, and hence leading to greater absorption of heat, even beyond the methane's atmospheric lifetime.

URGENT EMISSIONS CUTS

To put the carbon budget numbers in context, we can compare them with current rates of emissions.

We see from Table 2 that reducing emissions is urgent: at current rates of emissions, the carbon budget for a likely chance of limiting warming to 2°C will be fully exhausted by 2037, and by 2025 for a medium chance at 1.5°C.

For the world to stay within either of these temperature limits, rapid emissions cuts are required. Figure 1 shows a range of scenarios for emissions pathways that would lead to achieving the likely chance of 2°C or medium chance of 1.5°C outcomes. For 2°C, emissions need to reach net zero by around 2070, and for 1.5°C they must do so by 2050 – and in both cases they must fall steeply, starting immediately.

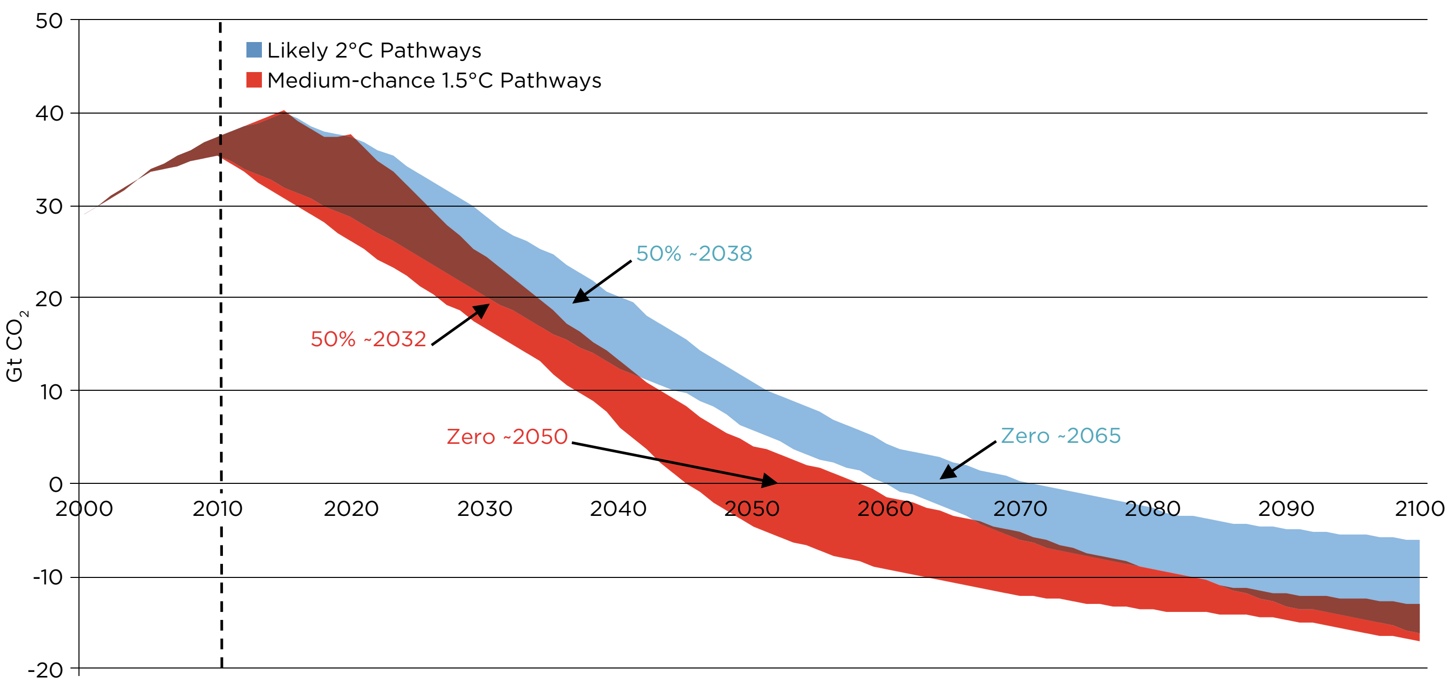
Note that these scenarios assume that "negative emissions" technology will occur in the second half of the century, through approaches such as bioenergy with carbon capture and storage or direct air capture. If we want to avoid depending on unproven technology becoming available, emissions would need to be reduced even more rapidly.

Table 2: Global Carbon Budgets for Likely Chance of 2°C and Medium Chance of 1.5°C, in context

	2°C	1.5°C
Post-2015 Budget ($GtCO_2$)	843	393
Current Global Emissions ($GtCO_2$)[17]	39.2	39.2
Years Remaining at Current Rate	21.5	10.0
Year Exhausted at Current Rates	2037	2025

Sources: IPCC, Global Carbon Project

Figure 1: Range of Global Emissions Pathways in Scenarios Consistent with Likely Chance of 2°C or Medium Chance of 1.5°C[18]



Sources: Joeri Rogelj et al

BOX 2: A History of Carbon Budget Analyses

This report continues a tradition of work by scientists and campaigners showing how global carbon budgets limit the amount of fossil fuels that can safely be extracted and burned.

It has been known for more than 20 years that cumulative emissions of CO_2 are a key determinant of how much the planet warms. The IPCC's Second Assessment Report in 1995 observed that in climate models all pathways leading to a particular temperature outcome had similar cumulative emissions.[19] Indeed, the notion of carbon budgets goes back at least to the early 1990s.[20] Further scientific study has developed our understanding of how this works in relation to the carbon cycle, forming a major theme in the IPCC's Fifth Assessment Report in 2013-14.

The pioneering step was taken by Bill Hare, then Climate Policy Director of Greenpeace, in what he called the 'carbon logic'. His 1997 paper, "Fossil Fuels and Climate Protection" showed that if burned, the fossil fuel reserves that were known at that time would release at least four times as much CO_2 as could be afforded while keeping warming below 1°C, or twice as much as the budget to keep below 2°C.[21] Several campaign groups (including Greenpeace, Oilwatch, Rainforest Action Network, Project Underground, and Amazon Watch) used the analysis to argue that exploration for new reserves should be stopped, but it was many more years before such calls started to gain traction.

In 2009, an influential paper was published in the journal Nature by Malte Meinshausen and seven co-authors (including Hare, who by then worked with Meinshausen at the Potsdam Institute for Climate Impact Research). They found that only 43% of the world's fossil fuels could be burned before 2050 if the world was to have a 50% chance of keeping warming below 2°C, or 27% of reserves for a 75% chance.[22]

Based on Meinshausen's research, in 2011 the Carbon Tracker Initiative published a report coining the term 'unburnable carbon' and describing its potential consequences for financial markets.[23] Carbon Tracker continues to examine the implications of stranded assets, which are long-term fossil fuel investments that will fail to generate returns because they were made assuming the world will not sufficiently act to address climate change.

Bill McKibben brought this analysis to a wider audience in 2012 in an article in Rolling Stone entitled "Global Warming's Terrifying New Math." In it, he argued that three simple numbers – the 2°C limit, the 565 Gt CO_2 budget for an 80% chance of staying within the limit, and the 2,795 Gt CO_2 of fossil fuel reserves – added up to global catastrophe.[24] The following year, Mike Berners-Lee and Duncan Clark published an analysis of reserves versus carbon budgets in a book, "The Burning Question".

In 2015, Christophe McGlade and Paul Ekins assessed which reserves might be left unburned if emissions were constrained within carbon budgets through an escalating carbon price. Their paper in Nature concluded that 88% of global coal reserves should remain unburned for a 50% chance of staying below 2°C. Even after assuming significant development of CCS, this proportion dropped to just 82% of global coal reserves. 75% of Canada's tar sands would have to remain unburned, or 74% with CCS.[25]

This report is inspired by that history of earlier work, and aims to build on it by turning the focus to reserves in fields and mines that are already operating.

FOSSIL FUEL RESERVES

After a company finds and then develops a deposit of oil, gas, or coal, it will generally extract the deposit over a period of several decades (see Figure 4 on page 20). *Reserves* are the quantity of known oil, gas, or coal that can be extracted in the coming years, with current technology and in current economic conditions.[h]

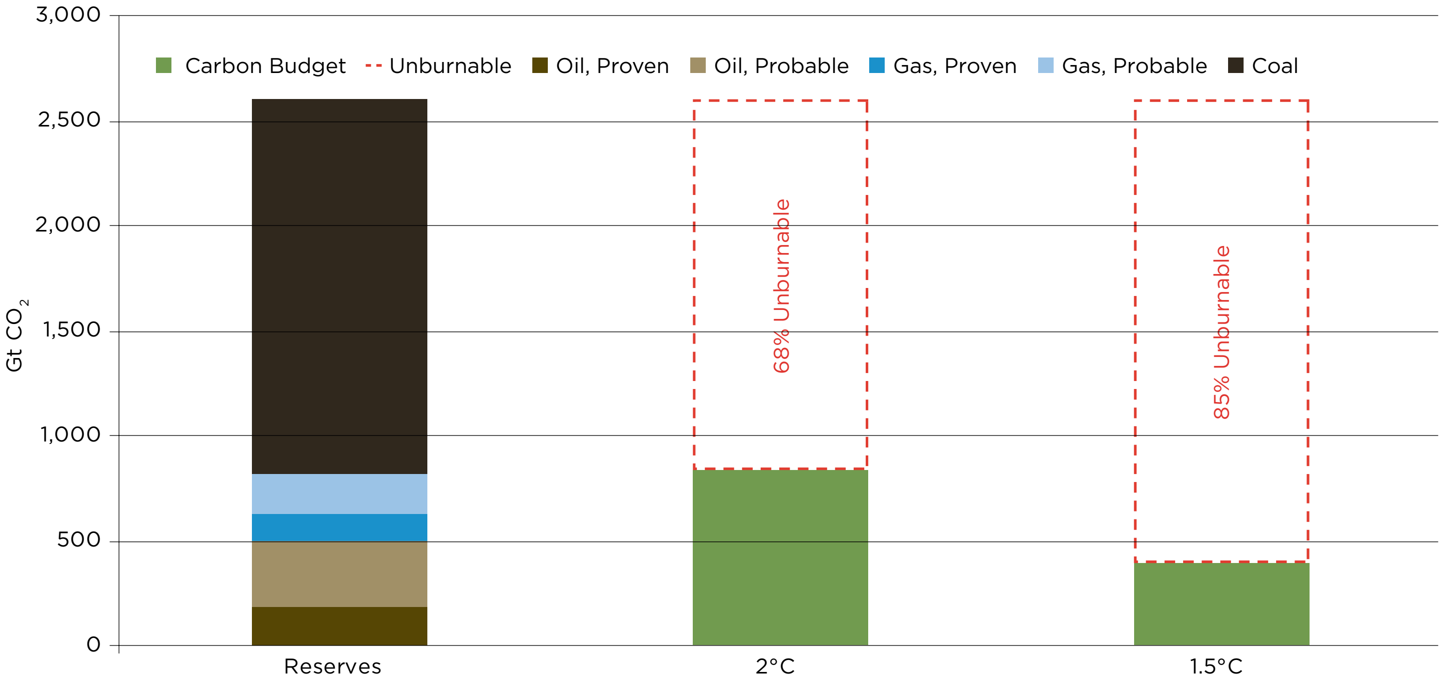
In Figure 2 we compare carbon budgets with fossil fuel reserves, echoing earlier work to translate climate limits into energy limits (see Box 2). For oil and gas, both proven and probable reserves are shown, while for coal only proven reserves are shown (see Appendix 1).[i]

We see that for a likely chance of keeping warming below 2°C, 68% of reserves must remain in the ground. For a medium chance of limiting warming to 1.5°C, 85% of reserves must remain underground.

This conclusion is based on an assumption that carbon capture and storage (CCS) is not widely deployed. CCS is a process in which some of the CO_2 released from burning fossil fuels is captured, compressed, and stored underground in deep geological reservoirs – thus enabling fossil fuels to be burned without releasing all of their carbon into the atmosphere. The problem is that the technology needed is far from proven: it has been deployed only in a few pilot settings, and without significant success (see Appendix 3); meanwhile, there are reasons to believe its costs may remain prohibitive, and questions about its environmental safety.

If CCS is eventually proven and deployed, it might provide a welcome means of further lowering emissions. However, we take the view that it would not be prudent to be dependent on an uncertain technology to avoid dangerous climate change; a much safer approach is to ensure that emissions are reduced in the first place by reducing fossil fuel use and moving the economy to clean energy. Therefore, we apply that assumption throughout this report.[j]

Figure 2: Global Fossil Fuel Reserves Compared to Carbon Budgets for Likely Chance of 2°C and Medium Chance of 1.5°C[28]



Sources: Rystad Energy, World Energy Council, IPCC

h Reserves are a subset of resources, which are an estimate of all the oil, gas, or coal that might one day be extracted. There are two criteria that define reserves:
(i) They have been identified – they have a specified location and grade/type (whereas resources also include those that are expected or postulated to exist, based on geological understanding)
(ii) They can be extracted with currently available technology and under current economic conditions (whereas resources also include those that rely on speculative future technologies or commodity prices)[26]

i An overview of government-reported data for nine countries that together account for 60% of proven coal reserves suggests additional probable reserves of around 350 Gt of coal in those countries, equivalent to 885 Gt of CO_2. However, coal data is plagued by unreliability and inconsistent definitions, so this estimate should be taken with caution.[27]

j As noted, we are taking a different approach from the IEA's 450 Scenario, which assumes large-scale CCS will become available, hence requiring only modest reductions in fossil fuel usage while having a 50% chance of staying within 2°C.

Excavators pile up coal on a quay at the Port of Lianyungang in Lianyungang city, east China's Jiangsu province, 10 November 2013.

2. ENOUGH OIL, GAS, AND COAL ALREADY IN PRODUCTION

We have seen that existing fossil fuel reserves considerably exceed both the 2°C and 1.5°C carbon budgets. It follows that exploration for new fossil fuel reserves is at best a waste of money and at worst very dangerous. However, ceasing exploration is not enough, as that still leaves much more fossil fuel than can safely be burned.

DEVELOPED RESERVES

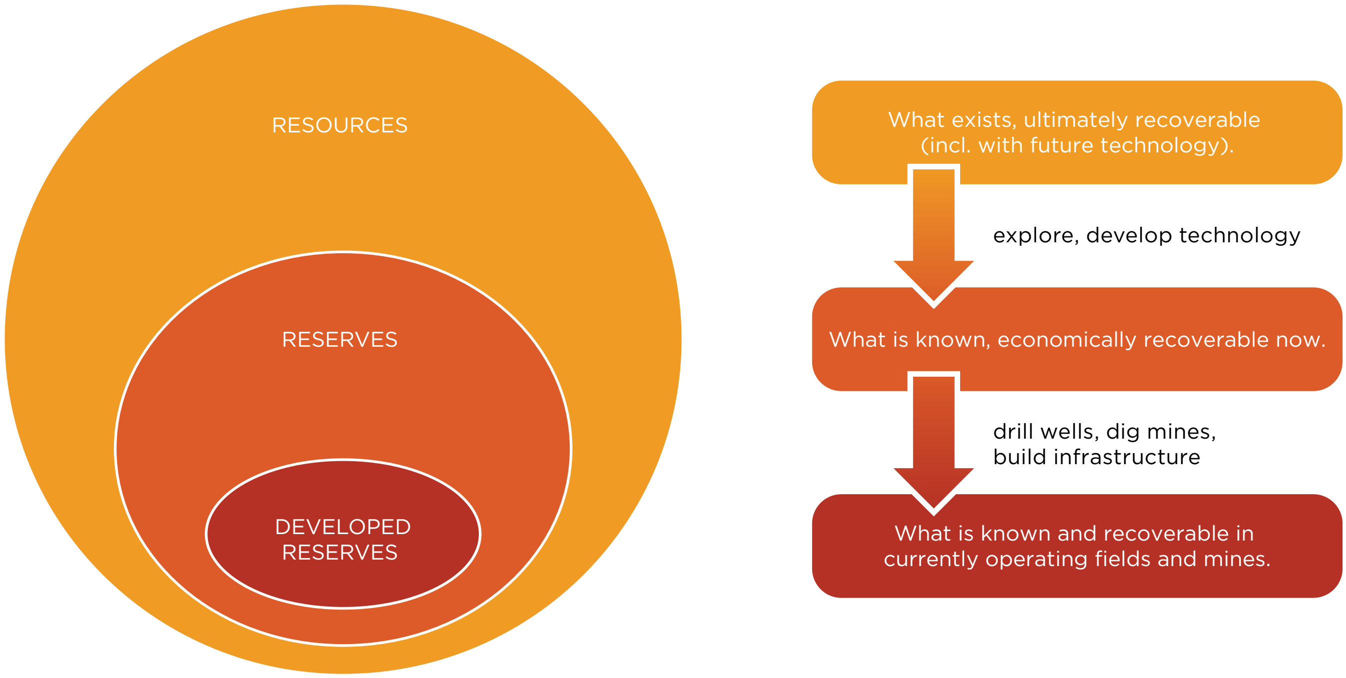
We now turn to the question of how much room exists within the carbon budgets for development of new oil fields, gas fields, and coal mines.

Figure 3 explains three categories of fossil fuels in the ground:

- **Resources** that might one day be extracted, some of which are geologically "expected" but yet to be actually found.
- **Reserves** that are known and extractable using today's technologies and in today's economic conditions.
- **Developed Reserves** that can currently be extracted from oil fields, gas fields and coal mines that are already operating – for which the wells have been drilled and the pits dug, and where the pipelines, processing facilities, railways, and export terminals have been constructed.

We focus on the smallest of these three measures: 'developed reserves'. If no new fields or mines are developed, production of each fossil fuel will decline over time as existing fields and mines are depleted, eventually reaching zero. A finite amount of cumulative production would thus occur with no new development, which we have estimated in Table 3.

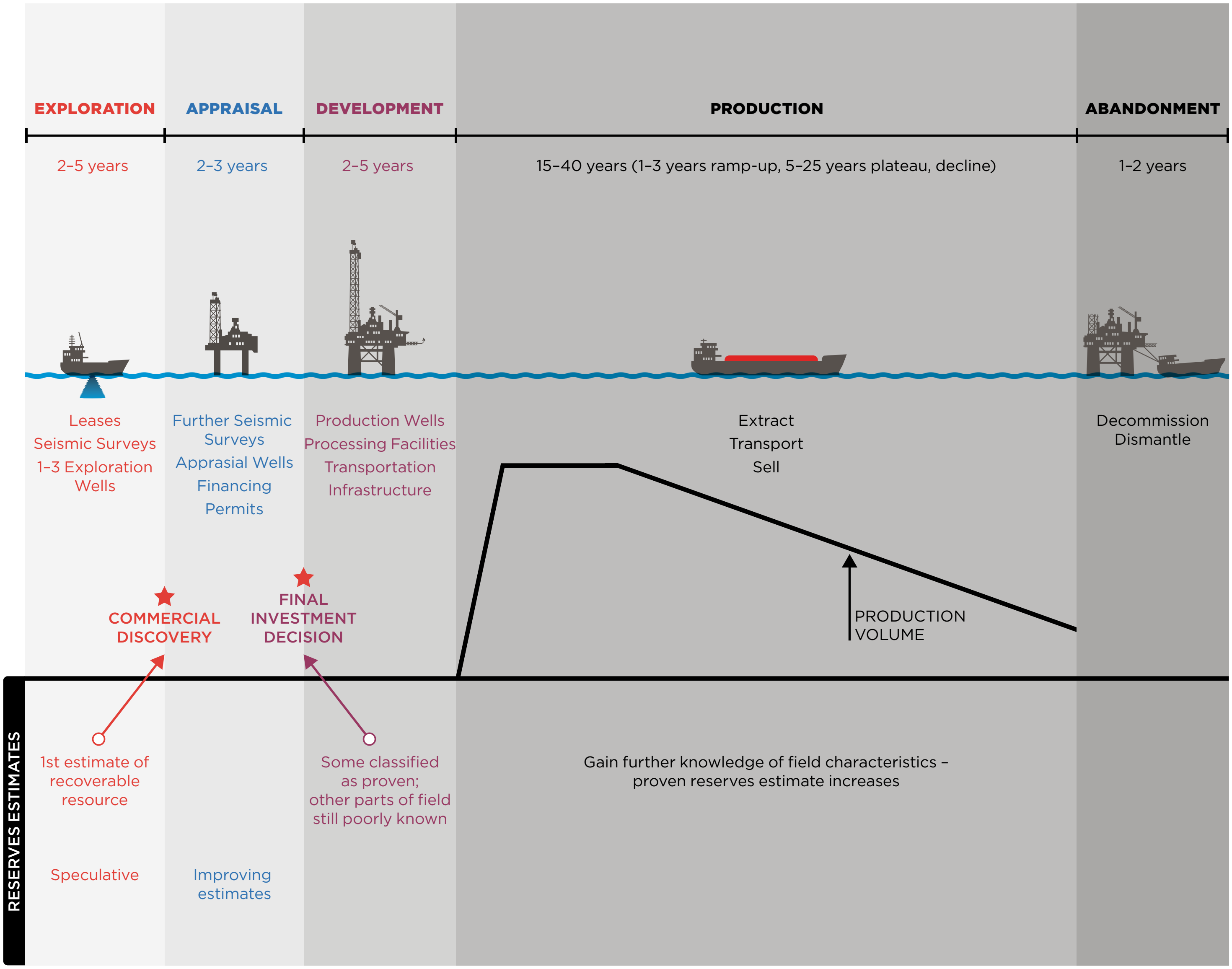
Figure 3: Three Measures of Available Fossil Fuels



Source: Oil Change International. Not to scale.

Figure 4: Lifecycle of an Oil or Gas Field

Source: Oil Change International



For oil and gas fields, we use data from Rystad Energy's UCube, a database of upstream oil and gas projects.[29] Rystad creates this data using a combination of company reports, regulatory information, and modeling. We have included fields that are currently being developed – for which shovels are in the ground – as well as those already producing, as the under-construction ones are "committed" in a similar sense. Because the estimates of reserves in existing fields are sensitive to oil and gas prices, we have used Rystad's base case, which projects the prices Rystad considers most likely over coming years.

Rystad provides data at the level of an "asset", which roughly divides the oil and gas universe into units for which a separate investment decision is made, based on its assessed profitability. For this reason, we do not count the reserves that would be unlocked in future development phases of a producing field as "developed." For example, we count the 3.6 billion barrels of oil that can be extracted with existing infrastructure on BP's Mad Dog field in the Gulf of Mexico as developed, but not the further 10.7 billion barrels that would be unlocked by its planned Mad Dog Phase 2 development, which would involve additional infrastructure investments.

For coal mines, we use estimates from the International Energy Agency (IEA), which are comprised of data from various sources combined with the IEA's own analysis.[30] It should be noted that available data for coal is generally of poorer quality than for oil and gas (see Appendix 1). Data is not available for coal mines under construction.

Table 3: Developed Reserves and CO_2 Emissions, from Existing and Under-Construction Global Oil and Gas Fields, and Existing Coal Mines[31]

	Reserves	Emissions
Oil, Proven	413 bn bbl	175 Gt CO_2
Oil, Probable	400 bn bbl	169 Gt CO_2
Gas, Proven	1,761 Tcf	105 Gt CO_2
Gas, Probable	1,130 Tcf	68 Gt CO_2
Coal, Proven	174 Gtce	425 Gt CO_2
TOTAL		942 Gt CO_2

Sources: Rystad Energy, IEA

DEVELOPED RESERVES COMPARED TO CARBON BUDGETS

Figure 5 compares developed reserves with the carbon budgets. In addition to emissions from energy (the burning of the three fossil fuels), we must also consider two other sources of emissions:

- Land use, especially changes in forest cover and agricultural uses;
- Cement manufacture, where aside from any energy usage, CO_2 is released in the calcination reaction that is fundamental to cement production.[k]

In both cases, we use relatively optimistic projections of emissions this century, assuming climate action, while noting that these sit within a wide range of projections, from those assuming business-as-usual to those involving speculative new technologies. This range is shown in Table 4 (more details in Appendix 2). There is considerable variation in modelled land use emissions.[l] If emissions from these two sources are not reduced to zero by the end of this century, they could occupy a larger share of the remaining carbon budgets, leaving less for fossil fuel emissions.

It can be seen from Figure 5 that (in the absence of CCS):

- The emissions from existing fossil fuel fields and mines exceed the 2°C carbon budget.

A recent study by Alex Pfeiffer and colleagues at Oxford University found that the "2°C capital stock" of power plants will be reached in 2017, by projecting the emissions from power plants over their full 40-year lifespans. In other words, if any more gas or coal plants are built after next year, others will have to be retired before the end of their design lives, in order for the world to have a 50% chance of staying below the 2°C limit (for a 66% chance of 2°C, that capital stock was reached in 2009, meaning early retirements are already required).[32] We have reached a similar conclusion for the capital stock in fossil fuel extraction.

NO MORE FOSSIL FUELS

In 2015, President of Kiribati Anote Tong wrote to other national leaders urging an end to the development of new coal mines, "as an essential initial step in our collective global action against climate change".[33] As a low-lying island in the Pacific, Kiribati is a nation whose very existence is threatened. Our analysis in this report supports his call, and extends it further.

If we are to stay within the agreed climate limits and avoid the dangers that more severe warming would cause, the fossil fuels in fields that have already been developed exceed our global carbon budget. Therefore, we conclude that:

- No new oil fields, gas fields, or coal mines should be developed anywhere in the world, beyond those that are already in use or under construction.[m]
- Similarly, no new transportation infrastructure – such as pipelines, export terminals, and rail facilities – should be built to facilitate new field and mine development (this does not preclude replacing existing infrastructure such as an old, leaky pipeline).[34]

Governments and companies might argue that early closure of coal could make space for new development of oil and gas. This substitution argument might have worked if the total developed reserves were equivalent to well below 2°C or 1.5°C. But instead, Figure 5 shows that developed reserves exceed the 2°C carbon budget and significantly exceed the 1.5°C budget. Furthermore:

- Oil and gas emissions alone exceed the 1.5°C budget.

If governments are serious about keeping warming well below 2°C and aiming for 1.5°C, no new oil or gas development would be permitted, even if coal, cement, and deforestation were stopped overnight.

LEAST-COST APPROACHES

Many analyses of emissions pathways and climate solutions assess the "least-cost" routes to achieving climate targets.[n] Such an analysis – with the same targets we have used in this report – might not lead to the conclusion that no new fields or mines should be developed. Although developed reserves will often be cheaper to extract than new reserves because capital has already been spent, that is not always the case. A new Saudi oil field may cost less to develop and operate than simply maintaining production from an existing Venezuelan heavy oil field, for example. In optimizing the global economics, a least-cost approach might suggest that rather than precluding new development, we should instead close the Venezuelan field early and open the Saudi one. In this report we take a different approach.

There are two rationales for using least-cost models to assess the best way of achieving a given climate target: predictively, assuming a markets-based mechanism for delivering change; or normatively, on grounds that the least total cost implies the greatest net benefit to humanity.

As it relates to this report, the predictive role will hold only if we expect that sufficiently strict market-based policies will be put in place to achieve climate goals. In the absence of these policies, the predictive role is lost. Those policies do not currently exist; and in fact, in Section 4 we will argue that market-based, demand-side policies alone may not be enough to transform the energy system to the extent climate limits require.

k Calcium carbonate (limestone) is heated to break it into carbon dioxide and calcium oxide, the largest ingredient used to make cement clinker: $CaCO_3 \rightarrow CaO + CO_2$. The heat may come from coal or gas, but those emissions are counted within the energy total: the additional component here is the CO_2 from the calcination reaction.

l Many scenarios include significant negative emissions, from bioenergy with CCS (BECCS), biochar, and afforestation. In this report, we have based our conclusions on an assumption that CCS is not deployed at scale, based on unpromising experience to date (see Appendix 3). Extending this precautionary assumption could potentially increase the assumed land use emissions, and reduce the share of carbon budgets available for fossil fuels.

m It should be noted that we have not included probable reserves of coal, due to lack of data and for the other reasons listed in Appendix 1. So more precisely, our conclusion is that coal mines should not continue producing beyond their proven reserves. Similarly, if new technology enabled greater recovery from existing oil and gas fields, further restraint would be needed.

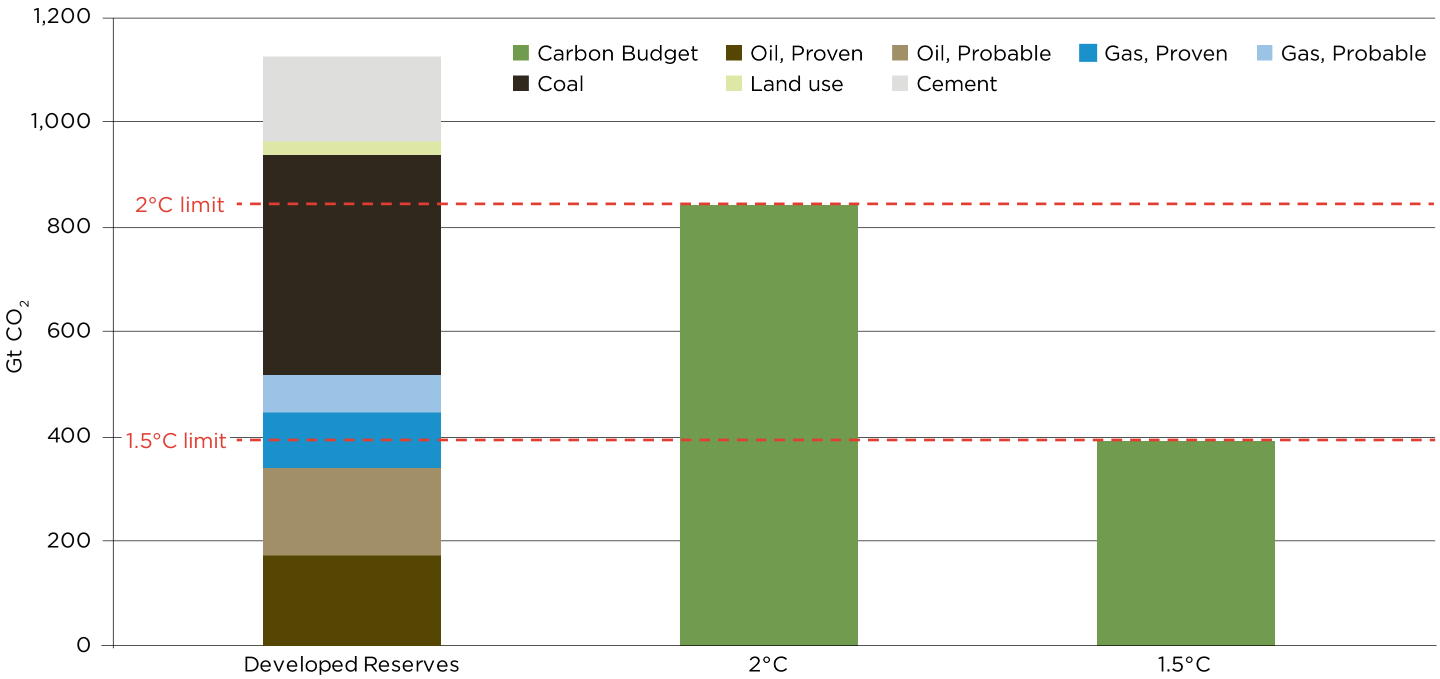
n They commonly do so using an integrated assessment model, which combines both physical effects of emissions in the climate system, and economic effects of energy in the economy. Such models are used to generate the emissions scenarios featured in IPCC reports, such as those shown in Figure 1.

Table 4: Assumed 2015 to 2100 Emissions from Land Use and Non-Energy Emissions from Cement Manufacture (see Appendix 2 for details)

Gt CO_2	Assumed Base Case	Range
Land Use	21	-206 to 57
Cement Manufacture	162	150 to 241

Sources: IPCC Scenarios Database, IEA

Figure 5: Emissions from Developed Reserves, Compared to Carbon Budgets for Likely Chance of 2°C and Medium Chance of 1.5°C



Sources: Rystad Energy, IEA, World Energy Council, IPCC

Examining the normative rationale, we run into the important question of how the climate goal is to be achieved. It is a sad reflection on climate politics that leaders find it easy to make principled or pragmatic arguments for why others should take action, but much harder to see arguments for why they should do so themselves. No government seems to need much excuse to carry on extracting or burning fossil fuels: the logic leaps quickly from "someone can extract if conditions ABC are met" to "I can extract as much as I like." This is one reason why we focus on overall global limits.

Since political action is required, we should look for solutions that are not just economically optimized, but politically optimized. Politically, it is much more difficult to demand the loss of physical capital – on which dollars have been spent, and steel and concrete installed – than to relinquish the future hope of benefits from untapped reserves. Shutting an existing asset leads to an investor losing money, and if a government shuts it by decree the investor will demand compensation. That lost money is a powerful disincentive for all parties involved. In contrast, stopping plans for the construction of unbuilt facilities mostly involves the loss of potential future income, since the amount spent on exploration is relatively small.

Similarly, existing jobs held by specific people generally carry more political weight than the promise of future jobs. This can even be the case when policy decisions may lead to more jobs than the present ones that would be lost. We will examine this in more detail in Section 4 and 5.

Mountaintop removal coal mining on Cherry Pond and Kayford mountains in West Virginia 2012.

THE FRONT LINES OF EXPANSION

The consequence of our analysis is that no new extractive or facilitating infrastructure should be built anywhere in the world. We identify here the countries where the most expansion is proposed. If these expansions go ahead, they could be the worst culprits in tipping the world over the edge.

(i) Coal

The world's largest and fifth-largest coal producers, China and Indonesia, have declared moratoria on new coal mine development. The second-largest producer, the United States, has implemented a limited moratorium on new coal mines on public lands. These three countries account for roughly two-thirds of the world's coal production (or 60%, if US production on non-federal lands is excluded).[35] The first priority must be to make these moratoria permanent, and to extend the U.S. moratorium to all coal mining in the country.

The two countries that are currently proceeding with major coal mining development are Australia and India:

- **Australia:** Nine coal mines are proposed in the Galilee Basin in Queensland. They would have combined peak production of 330 Mt of coal per year, amounting to 705 Mt CO_2 of emissions per year – if this were a country, it would be the world's 7th largest emitter.[36] Table 5 shows the six mines that have filed applications for regulatory approval, with estimated recovery of 9.6 billion metric tons of coal over their lifetimes, leading to 24 Gt of CO_2 emissions. This would total 6% of the global carbon budget for 1.5°C. Three further mines – Watarah's Alpha North, GVK/Hancock's Alpha West, and Vale's Degulla – have not yet started the approvals process.

- **India:** In 2015, the government of India set a target of tripling national coal extraction to 1.5 billion metric tons per year by 2020, with majority-state-owned Coal India Limited increasing its extraction to 1 billion metric tons per year, and other companies increasing from 120 Mt per year to 500 Mt per year.[38] Most commentators expect production growth to fall well short of these goals; the IEA's projection of production from existing and new mines is shown in Figure 6. Data are not available on the reserves in new mines.

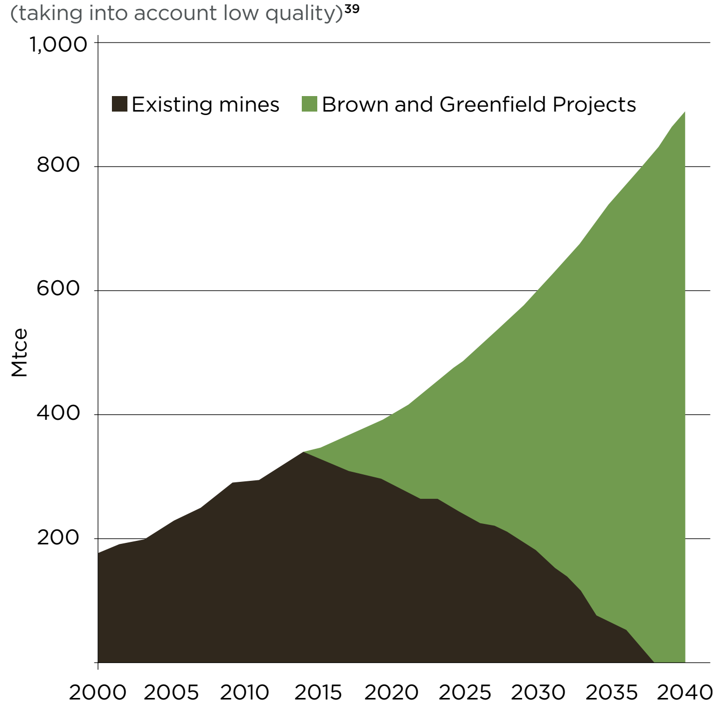
It should be noted that India has done less than most countries to cause the climate problem: despite having 18% of the world's population, it has accounted for just 3% of historical global CO_2 emissions.[40] And with per capita GDP of just $1,600, the country has an urgent need for economic development. Therefore, many argue with good justification that it is unreasonable to expect a country like India to bear an equal burden of addressing climate change to those with far greater historic responsibility. At the same time, it is difficult to see how the world can avoid dangerous climate change if this coal expansion goes ahead. The solution could be a generous support package, primarily provided by the wealthy countries that are most responsible for climate change, including climate finance and technology transfer, to help India pursue a low-carbon development path.

Table 5: Proposed Coal Mines in Australia's Galilee Basin[37]

Mine	Company	Expected recovery / Mt coal
Carmichael	Adani	5,000
China Stone	MacMines	1,800
China First	Watarah Coal	1,000
Alpha	GVK / Hancock	840
Kevin's Corner	GVK	470
South Galilee	Bandanna/AMCI	450
TOTAL		9,560

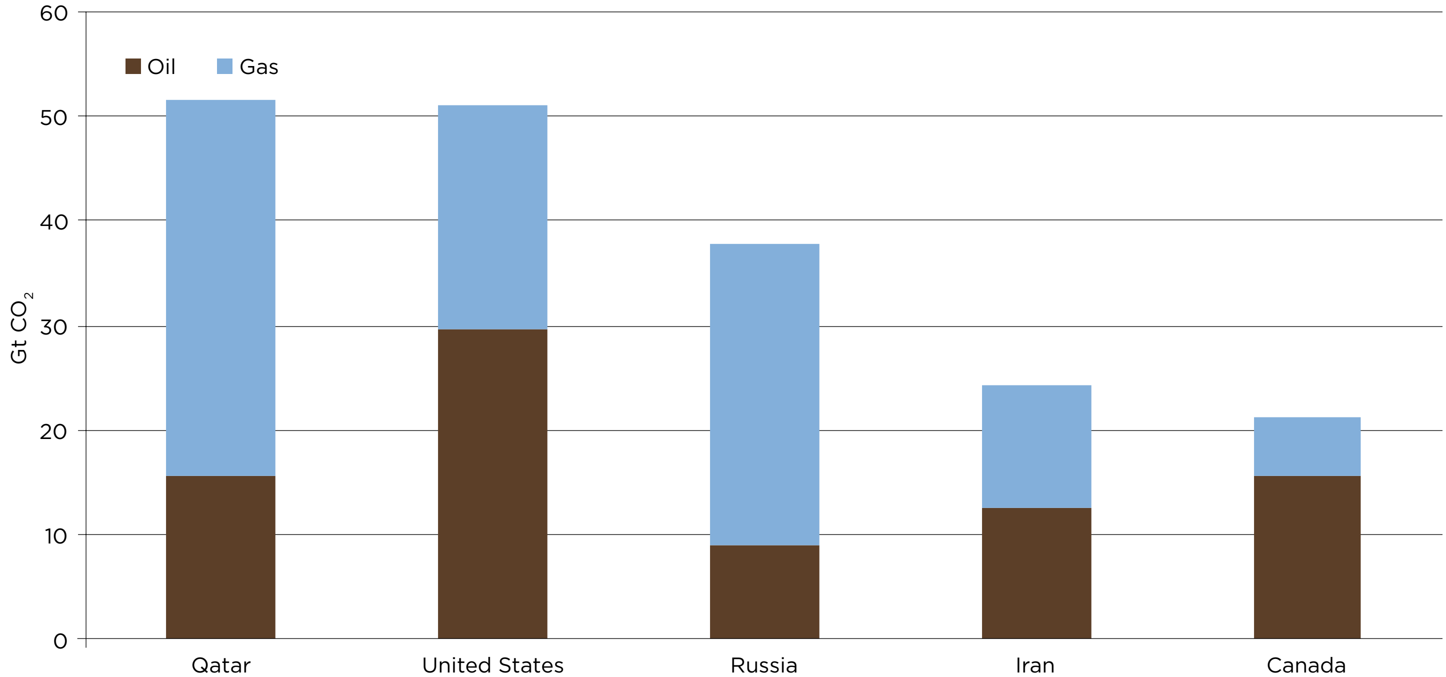
Sources: Individual Project Environmental Impact Statements

Figure 6: Projected Indian Coal Production from Existing and Proposed Mines, in Million Metric Tons of Coal Equivalent (taking into account low quality)[39]



Source: International Energy Agency

Figure 7: CO_2 Emissions from Largest Proposed New Oil and Gas Developments



Source: Rystad Energy

(ii) Oil and Gas

The largest proposed oil and gas developments, as projected by Rystad, are shown in Figure 7.

They comprise:

- **Qatar:** Along with partner ExxonMobil, state-owned Qatar Petroleum plans to expand gas and oil production on the massive North field in several new phases, although this is not expected until prices increase. The projected 52 Gt of lifetime CO_2 emissions would on their own exhaust 13% of the 1.5°C budget.
- **United States:** Major ongoing fracking developments, particularly for oil in North Dakota's Bakken, and Texas' Permian and Eagle Ford shales, and for gas in the Appalachian Basin's Marcellus-Utica shale. These are all proceeding in spite of low prices, and would add another 51 Gt of CO_2 emissions.
- **Russia:** Gazprom proposes several major gas and oil developments in the Yamal Peninsula in Arctic northwest Siberia, though this is not expected until prices increase. They would add 38 Gt of CO_2 emissions.
- **Iran:** The Iranian government is currently preparing an auction of several fields and exploration blocks to foreign companies, with initial offerings expected in late 2016 or early 2017. The emissions would amount to 24 Gt CO_2.
- **Canada:** Proposed expansion of tar sands extraction in Alberta depends on the construction of new pipelines, which have been stalled due to public opposition. Two major new pipelines are currently proposed, one by Kinder Morgan to the west coast and another by TransCanada to the east coast. Projected emissions are 21 Gt CO_2.

It can be seen from the chart that new gas development is as much of a threat as new oil development.

Proceeding with any of the above oil, gas, or coal expansions – the world's largest new sources of new carbon proposed for development – could commit us to far more than 2°C warming.

3. TRIMMING THE EXCESS

We saw in the previous section that stopping new fossil fuel construction can get the world closer to staying below 2°C of warming, but still is not enough (see Figure 5). Some closure of existing operations will be required to limit warming to 2°C. To have a chance of staying below 1.5°C, significant closures will be needed.

We have noted that closing existing facilities is more politically difficult than not building new ones. Stopping new fossil fuel construction minimizes the number of existing operations that need to be closed early. In this section we will consider where the necessary early shut-downs could or should take place.

Environmental justice is a priority principle for considering where to stop fossil fuel extraction. Extraction should not continue where it violates the rights of local people – including indigenous peoples – nor should it continue where resulting pollution would cause intolerable health impacts or seriously damage biodiversity. Fossil fuels have a long and violent history of being associated with such violations, stopping which is important in its own right.

COAL MINES

An obvious candidate for early closure is the coal sector. Coal accounts for the largest share of resources, the largest CO_2 emissions intensity, and the largest emissions per unit of power generated. Furthermore, coal's use in power generation is readily substitutable by renewable energy,[o] at least in countries and regions with mature electrical grids. Coal mining is also less capital-intensive than oil or gas extraction, so it is less costly to retire a coal asset early (although coal mining is also more labor-intensive, raising issues of its closure's impact on workers – see Section 5).

This does not mean that all coal should be phased out before any action to restrict existing oil and gas extraction. Poorer countries rely disproportionately on coal for their energy, compared to oil and gas: coal accounts for 19% of primary energy in industrialized countries in the Organisation for Economic Co-operation and Development (OECD), but 37% of primary energy in non-OECD countries.[42] There is danger that placing too much emphasis on coal may put an unfair share of the burden on the very countries who did least to cause the climate problem and who have the least financial and technological capacity to transform their economies. We will examine these issues in more detail shortly.

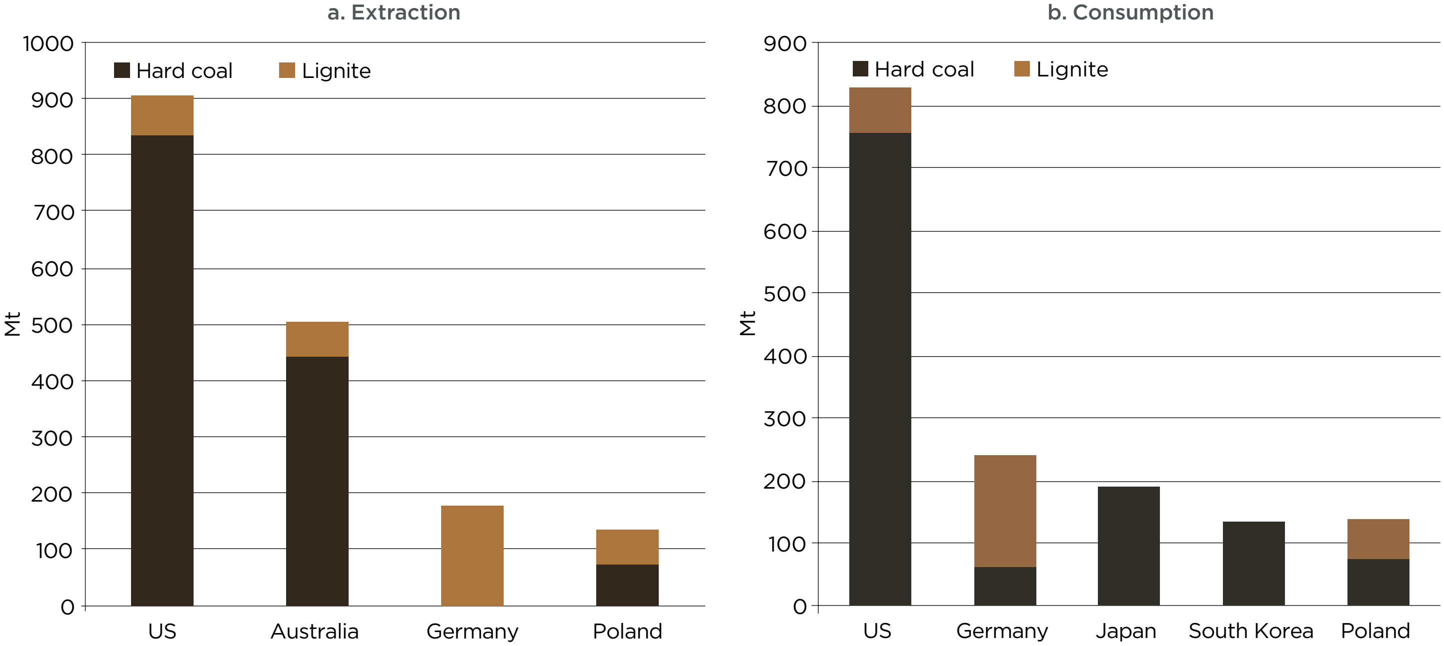
As a starting point, there is little justification for continued mining or burning of thermal coal in industrialized countries. Figure 8 shows that the OECD countries extracting the most coal are the United States, Australia, Germany, and Poland.

China has already adopted a policy of closing some existing coal mines, which will cut its annual production capacity by between one to two billion metric tons of coal, depending on implementation. For comparison, China currently extracts 3.7 billion metric tons, (though these capacity reductions will not translate to a 25% to 50% cut in output because of current overcapacity, but they will reduce China's developed reserves.)[43]

o Around 17% of coal demand is used in steel production. Research and development is under way to seek to make steel without coal; some projects have instead used forestry-derived charcoal, and earlier-stage technologies include polymers or natural gas. Steel is also highly recyclable, boosting recycling levels from the current 30% could help reduce the level of demand.[41]

The Shengli open-cast coal mine in Xilinhot, Inner Mongolia, China, 2012.

Figure 8: Partying Like it's 1899:[44] **OECD Countries (a) Extracting and (b) Burning the Most Coal** (2014 data)



Source: German Federal Institute for Geosciences & Natural Resources (BGR)

EQUITY: ALLOCATING FAIR SHARES

Some poorer countries see extraction and use of fossil fuels as a means to achieve economic empowerment, by providing either domestic energy or revenue from exports. At the same time, the greatest impacts of climate change will fall on poorer countries which have done the least to cause the climate problem. A study commissioned by the Climate Vulnerable Forum estimates that climate change already causes 400,000 deaths per year, 98% of which occur in developing countries as a result of increases in hunger and in communicable diseases. The current estimated 1.7% reduction in global gross domestic product (GDP) due to climate change is disproportionately felt by the world's poorest nations, the Least Developed Countries, whose GDP is being reduced by 7%.[45]

In contrast to the least-cost approaches discussed in the previous section, the appropriate question is not only which solution incurs the least cost to humanity as a whole: we must also consider a just distribution of who incurs the cost, such that each country contributes its fair share to address the global problem of climate change.

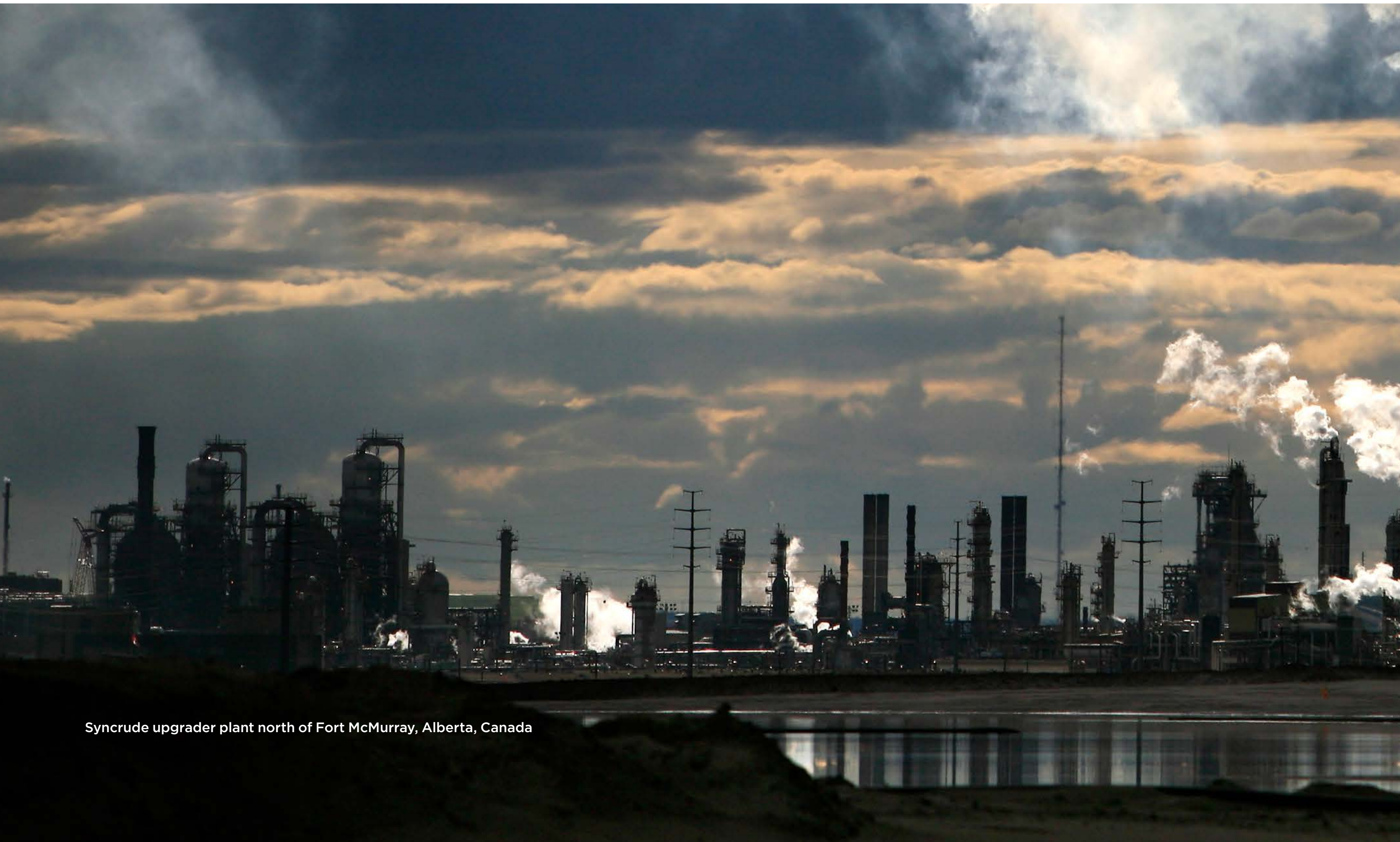
We have argued that ending the construction of new fossil fuel infrastructure is a politically pragmatic approach to avoiding dangerous climate change. The problem is that much of current fossil fuel extraction is located where it may not be most needed or justified in terms of fairness; examples include oil, gas, and coal in the United States and Russia, oil in Canada, oil in Saudi Arabia, and coal in Australia.

A forthcoming paper by Sivan Kartha and colleagues at the Stockholm Environment Institute argues that climate politics contain an unresolved tension between two different views of fossil fuel extraction: one of "extraction as pollution," and another of "extraction as [economic] development."[46] The authors point out that this tension goes right back to the 1992 UNFCCC treaty, whose preamble says: "States have [...] the sovereign right to exploit their own resources pursuant to their own environmental and developmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction."

At the level of emissions, where most climate policy has historically focused, this tension has been addressed through the principles of equity. Most importantly, the duty to cut emissions rests more with countries that carry greater responsibility for causing the problem (those with greater historic emissions), and with those that have most capacity to act (the wealthiest countries).[47] Industrialized countries, which account for just 18% of the world's population, are responsible for 60% of all historical CO_2 emissions.[48]

Already, important questions arise. How do these principles of responsibility and capacity translate to the fossil fuel supply side? How does the "resource curse" – the paradox that those countries with the most natural resources sometimes have less economic development success – diminish the developmental value of fossil fuels, or the historic responsibility for their extraction? How do demand-side equity and supply-side equity interrelate?

Oil Change International is working with the Stockholm Environment Institute on a paper that more fully explores these questions and makes concrete proposals for an equity framework on fossil fuel



Syncrude upgrader plant north of Fort McMurray, Alberta, Canada supply. For now, it is clear that whatever the details, the onus of climate action remains on wealthier countries both to take action themselves, and to help finance and facilitate further action in countries that do not have the resources to do so themselves.

Countries with low levels of fossil fuel infrastructure have an opportunity to seek sustainable development along a low-carbon pathway, leapfrogging to clean energy without the risk and cost of investing in assets that may become stranded when climate action makes them obsolete. In this regard, it should be noted that some of the greatest ambition for energy transition comes from small, poor, and vulnerable countries, such as Costa Rica, Nicaragua, Djibouti, and Vanuatu (see Box 3 in Section 5).

However, in return such countries can and should rightly demand financial support from industrialized countries, given the advantages these nations have drawn from fossil fuels, and conversely the challenges for poorer countries of integrating variable renewables in weaker grids. This may include investment and transfer of technologies in renewable energy, as well as in other industries that can provide alternatives to revenue from fossil fuel extraction.

Other developing countries that have relied more on fossil fuel extraction or combustion will similarly require finance to facilitate a transition, in a manner that protects the livelihoods of those working in the energy industry and diversifies their revenue bases and broader economies. Some fossil fuel exporters have grappled with the challenge of how to lift their people out of poverty while addressing climate change. Ecuador, for instance, has proposed charging a tax on oil exports to wealthy countries, to increase revenue while also incentivizing lower oil use.

We conclude:

- To achieve the Paris goals, no new fossil fuel extraction infrastructure should be built in any country, rich or poor, except in extreme cases where there is clearly no other viable option for providing energy access.
- Since rich countries have a greater responsibility to act, they should provide finance to poorer countries to help expand non-carbon energy and drive economic development, as part of their fair share of global action. Particularly important will be financial support to meet the urgent priority of providing universal access to energy. Around the world, over a billion people have no electricity in their home. Nearly three billion rely on wood or other biomass for cooking or heating. Lack of access to energy in households and communities threatens the achievement of nearly every one of the Sustainable Development Goals that the international community has set to fight poverty, hunger, and disease.
- To stay within our carbon budgets, we must go further than stopping new construction: some fossil fuel extraction assets must be closed before they are exploited fully. These early shut-downs should occur predominantly in rich countries.
- Extraction should not continue where it violates the rights of local people – including indigenous peoples – nor should it continue where resulting pollution would cause intolerable health impacts or seriously damage biodiversity.

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Oil workers at the Rumaila oil refinery, near the city of Basra, Iraq. 2013

©AP Photo/Nabil al-Jurani

4. WHY FOSSIL FUEL SUPPLY MATTERS

Over the last three decades, climate policy has focused almost exclusively on limiting the combustion rather than the extraction of fossil fuels. While there is a certain intuitive sense to that, because it is combustion that physically releases CO_2 into the atmosphere, this is far from the only way to address the problem. By contrast, ozone protection was achieved by regulating the production of chlorofluorocarbons (CFCs) and other chemicals, rather than trying to influence their usage and release (for example by a deodorant tax or quota).

Around 95% of the carbon extracted in oil, gas, or coal is subsequently burned and released into the atmosphere as CO_2. As such, the amount of carbon extracted is roughly equal to the amount that will be emitted.

There are two routes by which extracted carbon may not end up in the atmosphere:

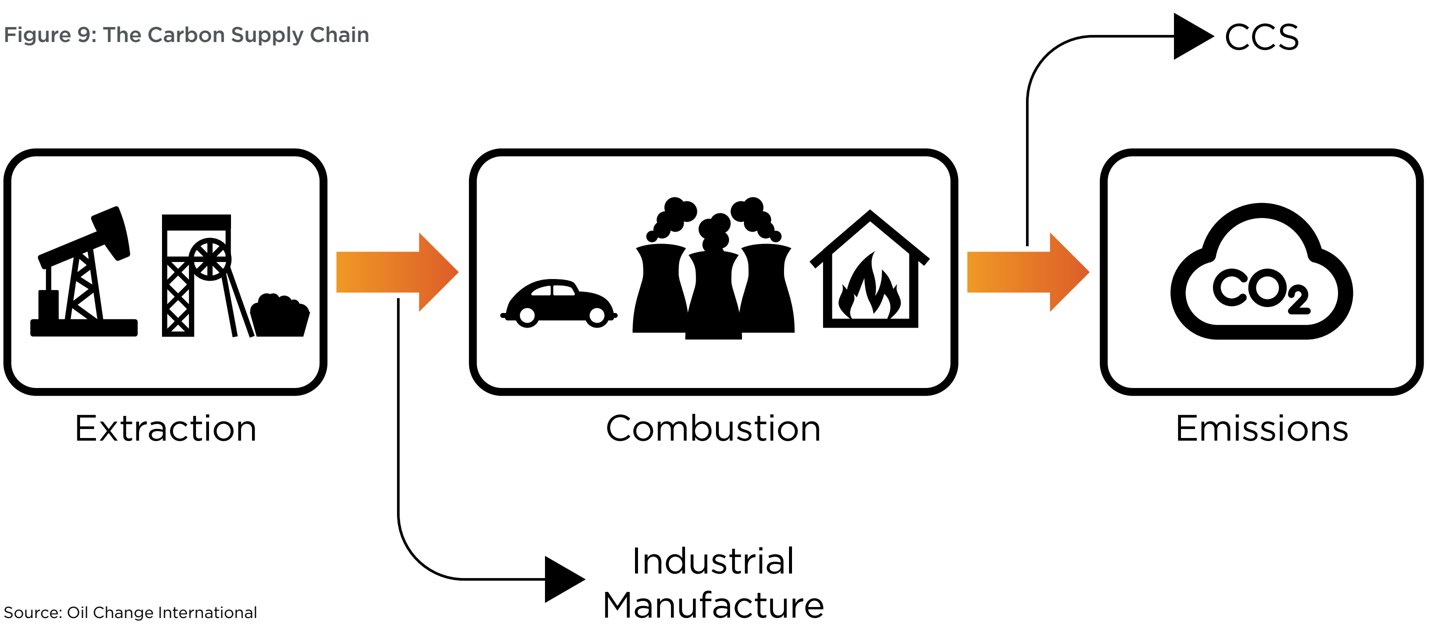
- Small amounts of oil and gas are used in industrial manufacturing of plastics, chemicals, fertilizer, and other products. In 2011, non-combustion uses accounted for 14% of U.S. oil consumption, 2% of gas consumption, and 0.1% of coal consumption – combined, these total just 6% of the carbon in U.S. fossil fuel consumption.[49] Even in some of these cases, the carbon still ends up in the atmosphere as the finished products decompose.
- In theory, CO_2 emissions could be captured. However, CCS has barely been deployed to date, despite strong advocacy since the 1990s by the fossil fuel industry. Due to slow development of the technology, even if CCS were developed at scale – and it is questionable whether it could be at affordable cost – the carbon budget would only be extended by an estimated 12-14% by 2050 (see Appendix 3).[50]

Apart from these exceptions – one of them minor, and the other currently tiny with uncertain prospects – any carbon that is extracted in fossil fuels ends up in the atmosphere as CO_2, as shown in Figure 9.

THREE POSSIBLE FUTURES

We have seen that the reserves in developed fields and mines exceed the carbon budget for a likely chance of staying below 2°C. As a result of this arithmetic, adding any new resource can logically do only one of two things (in the absence of CCS): either add to the excess of emissions above 2°C, or cause an asset to be stranded elsewhere.

Figure 9: The Carbon Supply Chain



Source: Oil Change International

To illustrate what this means, we extend this basic logic to all new sources of fossil fuel. There are three scenarios:

- **Managed Decline:** No further extraction infrastructure is developed, existing fields and mines are depleted over time, and declining fossil fuel supplies are replaced with clean alternatives to which energy workers are redeployed, thus preventing dangerous climate change.

- **Stranded Assets:** Companies continue to develop new fields and mines, governments are eventually successful in restricting emissions, and the resulting reduction in demand causes many extraction assets to become uneconomic and shut down, causing destruction of capital and large job losses.

- **Climate Chaos:** Companies continue to develop new fields and mines, none are stranded, and the resulting emissions take us well beyond 2°C of warming, with resulting economic and human catastrophe.

In reality, the scenarios are not mutually exclusive – the future will be some combination of all three. However, we know that each new field or mine must contribute to one of the following outcomes; if developed it will either cause stranded assets and/or dangerous climate change. Figure 10 illustrates the situation: the aggregate effect of many such decisions will be to cause considerable warming above 2°C, and/or considerable stranding of assets.

The "managed decline" scenario is explored in more detail in Section 5. This scenario requires deliberate policy decisions to cease development of new fields, mines, and infrastructure.

If that decision is not made, economic and political factors will determine the ratio of "climate chaos" (see Section 1) to "stranded assets," which we outline below. We will then consider how fossil fuel supply relates to emissions, in order to better identify the economic and political factors that arbitrate between the two scenarios.

STRANDED ASSETS

The concept of stranded assets has entered the climate debate in the last few years, especially through the work of Carbon Tracker Initiative.[51] It has been taken up by many in the financial sector, including banks such as HSBC[52] and Citi,[53] and Bank of England Governor Mark Carney.[54]

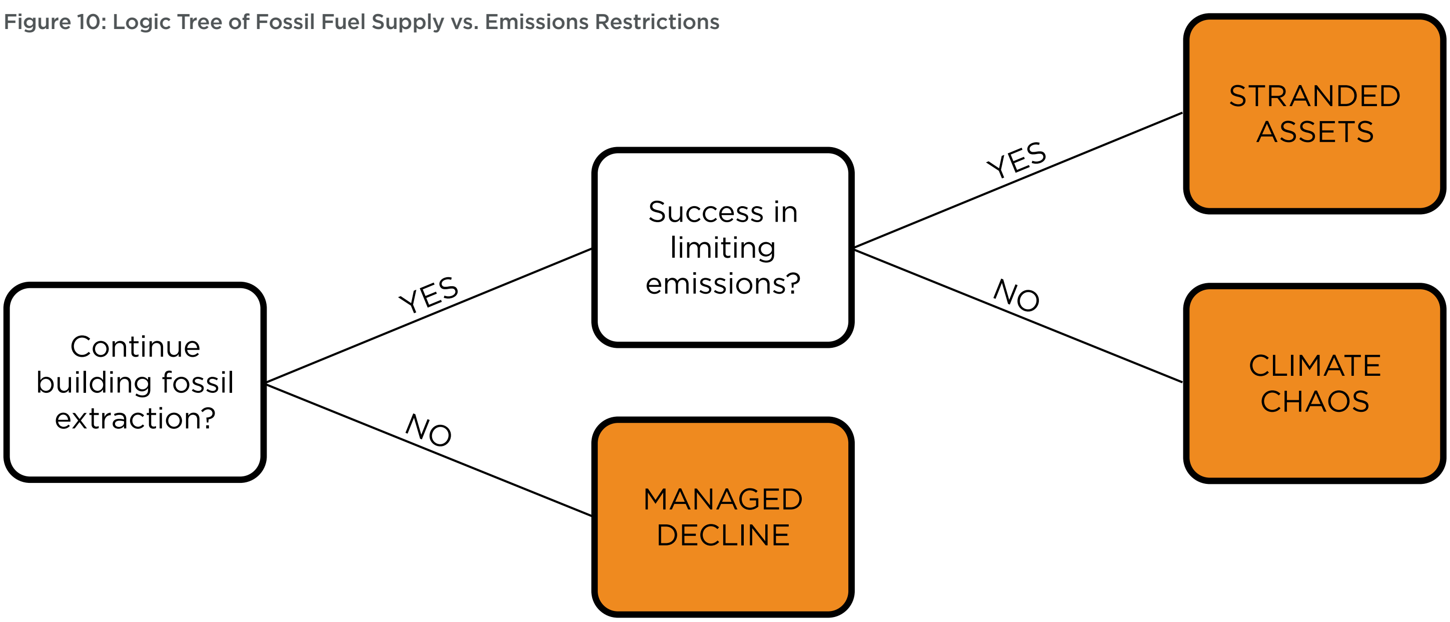
If we assume that a combination of government policy and technological change is successful in limiting warming to below 2°C or to 1.5°C (and that CCS prospects do not radically improve), demand for fossil fuels will fall rapidly, resulting in a significant decrease in fossil fuel commodity prices. This in turn will make many extraction projects unprofitable, leading to significant losses for investors.

To estimate the scale of stranding, Table 6 gives estimates of projected capital expenditure over the next 20 years that will potentially be wasted: over $10 trillion in new oil fields, gas fields, and coal mines, and up to $4 trillion in transportation infrastructure such as pipelines, railways, and port terminals. (For comparison, projected ongoing and maintenance capital expenditure on existing fields and mines is just over $6 trillion).[p]

On top of this, there would be stranding of downstream assets such as power plants and refineries, the estimation of which is beyond the scope of this report.

The "stranded assets" scenario is not something we can regard as a problem only for financial institutions. It would be bad news for pension-holders, for those employed by the fossil fuel industry, and for

Figure 10: Logic Tree of Fossil Fuel Supply vs. Emissions Restrictions



Source: Oil Change International

p Comprising $4.4 trillion on oil, $1.5 trillion on gas and $0.35 trillion on coal

Table 6: Potential for Asset Stranding: Projected (Public and Private) Capital Expenditures on New Fields and Mines, 2014-35 (2012 Dollars)

	Extraction Projects[55]	Transportation Projects[56]
Oil	$6,270 bn	$990 bn
Gas	$3,990 bn	$2,630 bn
Coal	$380 bn	$300 bn
TOTAL	$10,640 bn	$3,920 bn

Sources: International Energy Agency, Rystad UCube

the wider population dependent on a stable economy. Inevitably, if fossil fuel extraction is maintained or increased, then staying within climate limits would require a much faster pace of reductions than if a managed decline begins now. This means much more disruption, more expenditure on faster development of alternative infrastructure, and the loss of more jobs at a quicker rate.

"Stranded assets" is not the only scenario that causes economic loss. On top of the severe human costs of greater disease, starvation, and lost homes, the economic costs of climate change are vast, encompassing infrastructure damage and the decline of sectors such as agriculture and insurance. Estimates since the Stern Review of 2006 have commonly put the impact at several percent of global GDP by the late twenty-first century, and a more recent study of historic correlations between temperature and economic activity suggested that unmitigated climate change could cause as much as a 20% reduction in 2100 output.[57] Another study on the impact on financial investments estimated that $2.5 trillion of financial assets could be at risk.[58] The economic disruption of climate change would also cause major job losses across numerous sectors, and would do so in a chaotic way that would make transitional support even more difficult.

In contrast to the combination of these two costly scenarios, managed decline of fossil fuel extraction offers a more reasonable path forward.

SUPPLY AND DEMAND

In recent years, many governments have adopted the apparently contradictory goals of reducing emissions while encouraging increased fossil fuel extraction. In the absence of CCS, these two goals cannot both be achieved at a global level: if emissions are to be reduced, total fossil fuel consumption must be reduced, which in turn means that total fossil fuel extraction must be reduced as well.

When pressed, governments and companies tend to square the circle by assuming that it is someone else's production that will get constrained and some other investor's bet that will go sour. However, they never specify which other country or company's production they anticipate will be stopped, or why, or how.

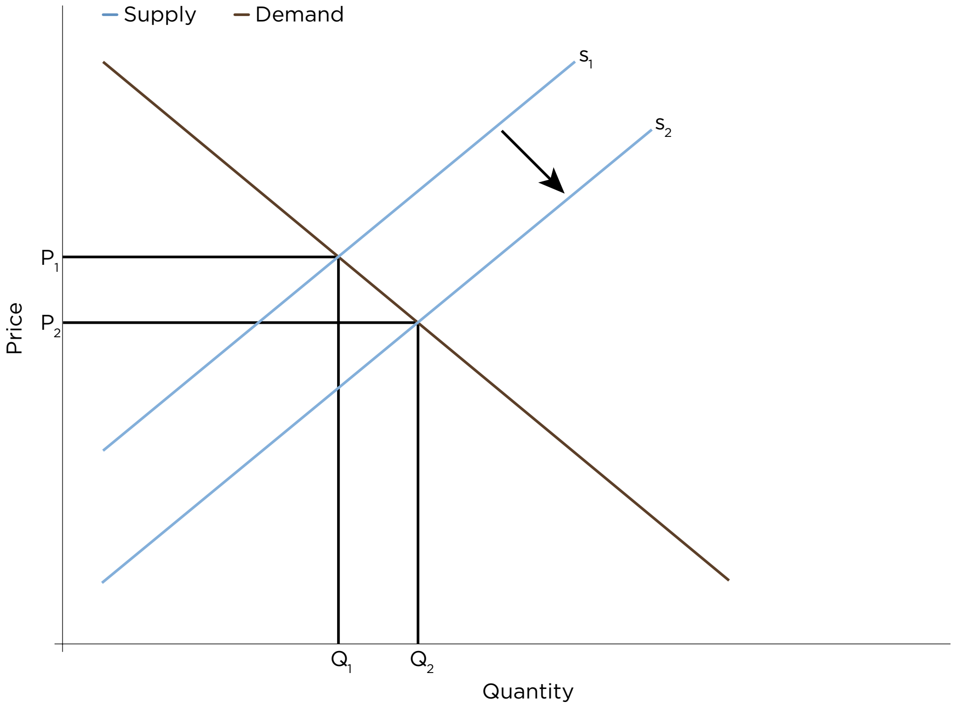
Some commentators insist that climate change should only be addressed on the demand side.[59] But the trouble with this view is that the act of increasing supply makes it harder to cut emissions.

(i) More Supply = Lower Price = Higher Demand

While climate policy has addressed fossil fuels almost entirely on the demand side, there has been an implicit assumption that markets will then simply allocate the aggregate demand between suppliers. However, this is not how energy markets work.[60]

Over the history of the modern energy industry, there have been times when demand has led events, and times when supply has done so. For an illustration of supply leading the way, consider the present-day situation. U.S. oil extraction expanded from 6.8 million barrels per day (mbd) in 2010 to 11.7 mbd in 2014,[61] stimulating a fall in price, which was exacerbated when the Organization of the Petroleum Exporting Countries (OPEC) decided in November 2014 not to cut its production to compensate. The resulting low oil prices led to global oil demand growing at the fastest pace in five years,[62] and to the fastest increase in U.S. gasoline consumption since 1978.[63]

Figure 11: Impact of Policy to Encourage Supply on Supply / Demand Equilibrium



This should not be surprising, as it is what basic economic theory tells us: supply does not simply passively match demand, but interacts with it in dynamic equilibrium.[q] Figure 11 shows how supply and demand interact: the actual quantity consumed and produced is determined by the point where the two lines cross. A policy designed to increase extraction or lower its costs – in this example, weak environmental regulation of hydraulic fracturing in the United States – will move the supply curve to the right and/or downward. The resulting new equilibrium has a lower price and a higher quantity. In short, the increase of supply has also increased consumption, and thereby emissions.

(ii) Lock-In of Production

Once a field or mine has been developed, it will generally keep producing. In other words, the act of developing it locks in future production. This is because once capital has been expended, an investor has strong incentives to avoid letting the asset become stranded. This is illustrated in Figure 12, where cash flow is negative in the early phase as capital is invested. The project only receives income once oil production begins, after three years. In the higher-price scenario, it takes a further nine years to pay back the invested capital, and the project finally begins making a profit around Year Twelve. In the lower-price scenario, the project never breaks even.

If the company knew beforehand – in Year Zero – that the price would follow the lower path, it would not move ahead with the project. But once the project has been developed, the economic incentives push for continued production even if it means a long-term loss on the capital invested, since closing down would lead to an even greater loss. As long as the red curve is rising in Figure 12, continued production reduces the ultimate loss. It is only if the price received is less than the marginal operating cost (the curve bends downward) that it is better to stop before losses increase.

In sum, a company will not proceed with a new project if commodity prices are less than the total operating and capital costs, but will close down an-already developed project only if prices hit the much lower threshold of marginal operating costs. In other words, any given action to reduce demand becomes less effective as soon as extraction projects have been developed and operation is ongoing.

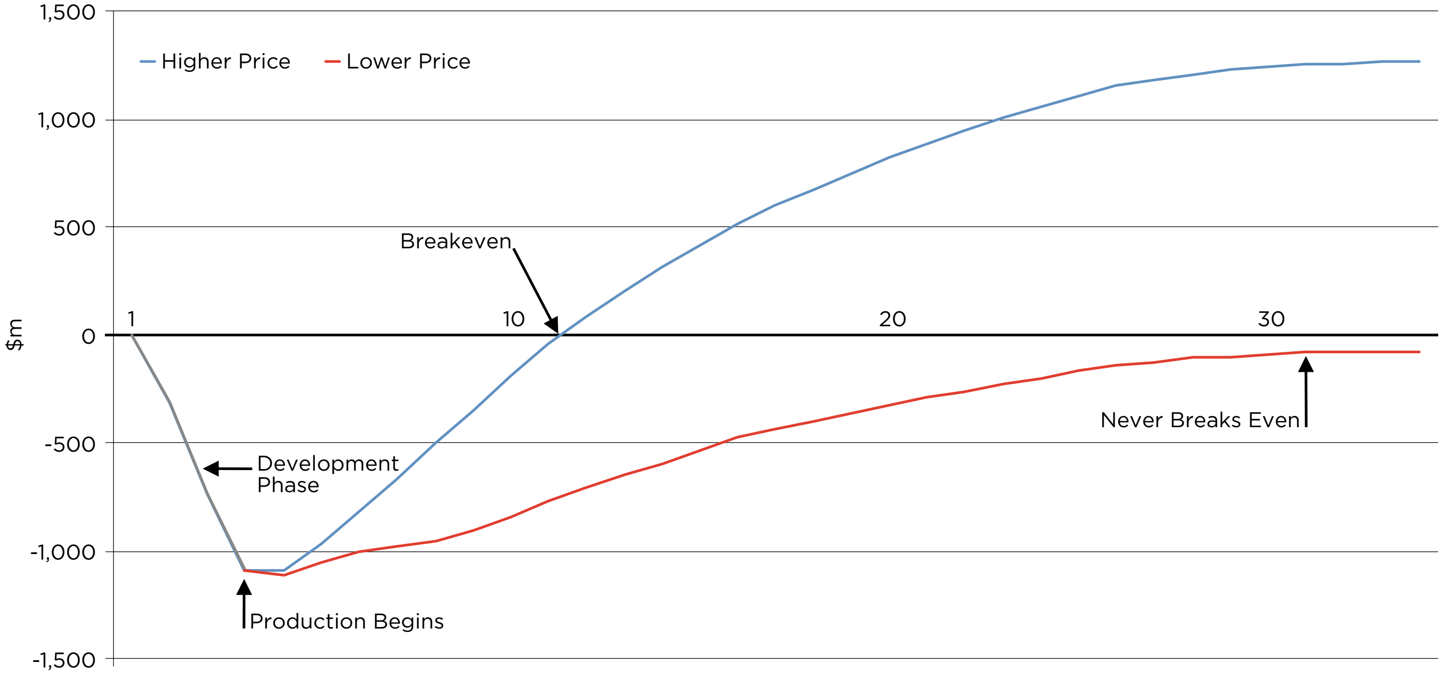
(iii) Perverse Political Effects

As well as the perverse economic impacts of increasing fossil fuel supply, there are also perverse political impacts. Governments tend to act more strongly to protect existing industries than to stimulate future ones, because of the political clout of real jobs held by identifiable people (as opposed to abstract numbers), and because of the lobbying power of dominant industries.

When fossil fuel prices are low, governments often feel political pressure to reduce taxes on fossil fuel production or provide other subsidies to keep companies producing. For example, the United Kingdom cut the highest tax rate on North Sea oil production from 80% to 68% in 2015 and again to 40% in 2016.[64] Noting declining profitability since 2011 (when coal prices began their slide), the Indonesian Coal Mining Association is calling for the government to guarantee cost-based prices in order to enable continued expansion.[65] The effect of subsidies expanding or maintaining supply translates through the price mechanism again into increasing demand and increased emissions.

q This mechanism breaks down if there is a perfect swing producer, which adjusts its own supply to maintain equilibrium at a certain level. Even before 2014, OPEC's ability to act was in reality limited by physical, political and economic factors (if it had been a perfect swing producer, the price would not have fluctuated). Now that Saudi Arabia and OPEC have decided not to fulfil that role even partially, and instead to maximize their production, the market reflects this model.

Figure 12: Cumulative Discounted Cash Flow for a Typical Fossil Fuel Project[r]



Source: Oil Change International

r Cash flow is the total income minus total (undepreciated) expenditure in any year. Discounting adjusts this to account for the time value of money, reflecting both the cost of capital and the opportunity cost of not investing it elsewhere.

5. MAKING AN ENERGY TRANSITION HAPPEN

Twenty-five years of climate politics has thoroughly embedded the notion that climate change should be addressed at the point of emissions, while the supply of fossil fuels should be left to the market. That view is now no longer supportable (if in fact it ever was). Our analysis indicates a hard limit on the amount of fossil fuels that can be extracted, pointing to an intervention that can only be implemented by governments. We conclude that:

- Governments should issue no further leases or permits for new oil, gas, or coal extraction projects or transportation infrastructure.

While this would mark a significant change in the direction of climate policy, it is also the least disruptive and least painful option. As we saw in the previous section, in the absence of a dramatic turnaround for CCS, further building of fossil fuel extraction infrastructure will lead us only to two possible futures, both of which entail vast economic and social costs.

What we propose in this report is the easiest global approach to restraint: when in a hole, stop digging.

A GRADUAL TRANSITION

Existing fields and mines contain a large amount of oil, gas, and coal, which will be extracted over time. Rates of extraction will decline without development of new resources and infrastructure, but the decline is far from precipitous. The fastest decline will be in fracked shale, where wells produce for only a few years. Other fields often last much longer.

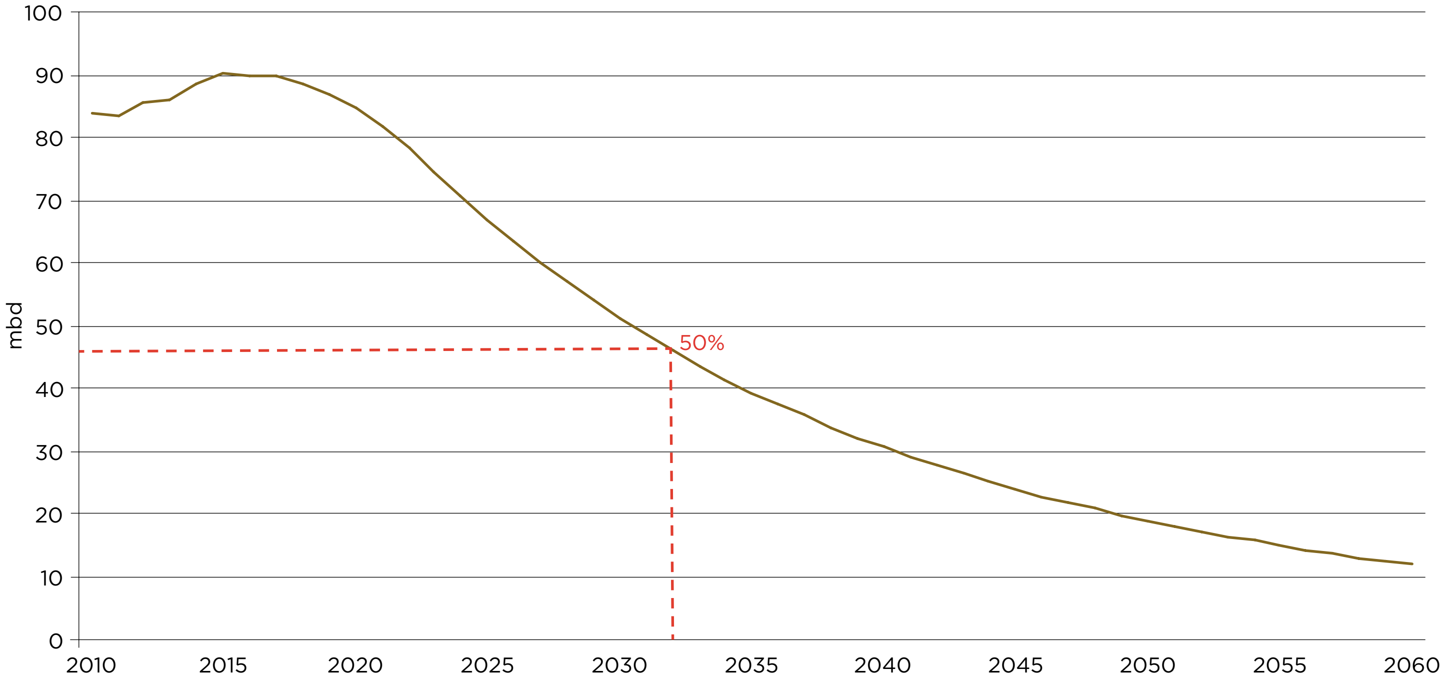
Figures 13 and 14 show Rystad's projection of oil and gas extraction from existing fields and those under construction, in its oil price base case[s]: extraction (and hence global supply) would fall by 50% by the early 2030s. Data is not available for coal.

This projection should not be alarming. Remember that emissions must decline rapidly, to net zero by 2070, for a likely chance of staying below 2°C, or by 2050 for a medium chance of staying below 1.5°C (see Figure 1 on page 13). For emissions to decline, fossil fuel use (and consequently extraction) must decline at the same overall rate.

Simply restricting supply alone would lead to increased prices, potentially making marginal production in existing fields and mines viable. The amount ultimately extracted and emitted would still be lower (see Figure 11 on page 34), but may not be as low as carbon budgets allow. A more powerful policy approach would be to pursue reductions in supply and demand simultaneously. As long as the two remain roughly in sync, prices will remain more stable, and "leakage" – where reductions in one country's extraction are offset by increased extraction in another country – will be minimized. The two policy approaches can also be mutually reinforcing, as declining supply of fossil fuels stimulates more private investment in alternatives, and vice versa.

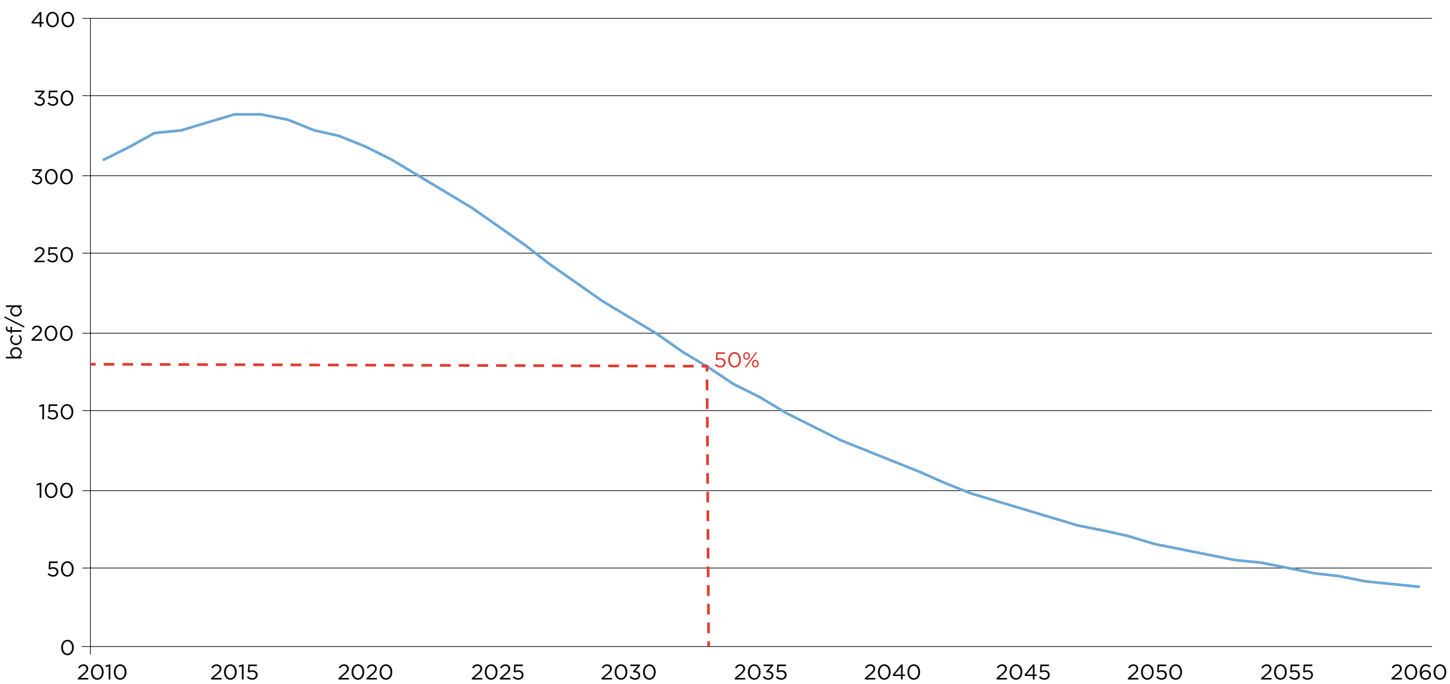
s A higher price would lead to slower decline, as companies would invest more capital expenditures even in existing fields. Conversely, a lower price would lead to faster decline.

Figure 13: Projected Global Oil Production from Existing and Under-Construction Fields[66]



Source: Rystad Energy

Figure 14: Projected Global Gas Production from Existing and Under-Construction Fields[67]



Source: Rystad Energy

BOX 3: The Remarkable Growth in Renewable Energy

Renewable power generation is growing exponentially: wind at around 20% per year globally, and solar at around 35% per year.[68] Wind generation has more than doubled since 2010, while solar has doubled nearly three times in that period. Compounded over many years, these growth rates add up rapidly: if wind and solar sustained their current global growth rates, they would exceed current coal and gas power generation in 2029.[69] At some point, growth rates will slow down, but there is no indication that it is happening yet.

Denmark, a relatively small country, generates 40% of its electricity from renewables (mainly wind), and is aiming for 100% renewable generation by 2035.[70] In 2015, Germany – the world's fourth largest economy – generated nearly one-third of its power from renewables, primarily wind and solar.[71]

Small and large developing countries are moving to renewables too. Costa Rica produces 99% of its electricity from renewable sources, including hydro, wind, and geothermal.[72] Neighbouring Nicaragua generates up to 20% of its electricity from wind, and 16% from geothermal.[73] Djibouti is aiming for 100% of its energy to be renewable by 2020, much of it off-grid solar.[74] Vanuatu currently generates 43% of its electricity from renewables, and aims for 65% by 2020 and 100% by 2030, with much of the growth coming from grid-connected wind and solar, and off-grid solar.[75] In absolute terms, China is set to overtake the United States in 2016 as the largest generator of wind and solar power.[76] China is also showing the fastest growth in wind and solar installations: 2015 was a record year in which its wind capacity grew by 33.5% and grid connected solar capacity by 73.7%.[77]

India has a target of a twenty-fold increase in solar power to 100 GW by 2022, which would take it to more than twice China's current level.[78]

In many countries, wind and solar are already cost-competitive with fossil fuel and nuclear power generation. A recent Deutsche Bank survey of sixty countries found that solar has reached grid parity in fully half of the countries already.[79] And costs are falling fast. The International Renewable Energy Agency reports that the levelized cost of electricity from utility-scale solar fell by 58% between 2010 and 2015, and could fall by a further 59% between 2015 and 2025.[80]

New transportation technologies, specifically electric vehicles (EVs), are also developing fast. Battery costs – a major element of the price of an EV – are falling quickly, as lithium-ion battery costs fell 65% from 2010 to 2015.[81] Further cost declines and performance improvements are widely expected, with some projecting a further 60% cost decline by 2020.[82] Financier UBS predicts that by the early 2020s, the purchase price of an EV will be only very slightly higher than a petroleum-fueled car, with only small a fraction of the fuel and maintenance costs.[83]

In 2016 and 2017, three different mass-market, long-range electric car models are being launched in the United States, with dozens more expected by 2020. China aims to have five million EVs on the road by 2020, while several European countries (including Norway, France and Germany) have recently announced that they to no longer allow sales of petroleum-fueled cars after either 2025 or 2030.[84]

An oil storage facility in Linden, New Jersey USA.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CLEAN ENERGY REPLACES FOSSIL FUELS

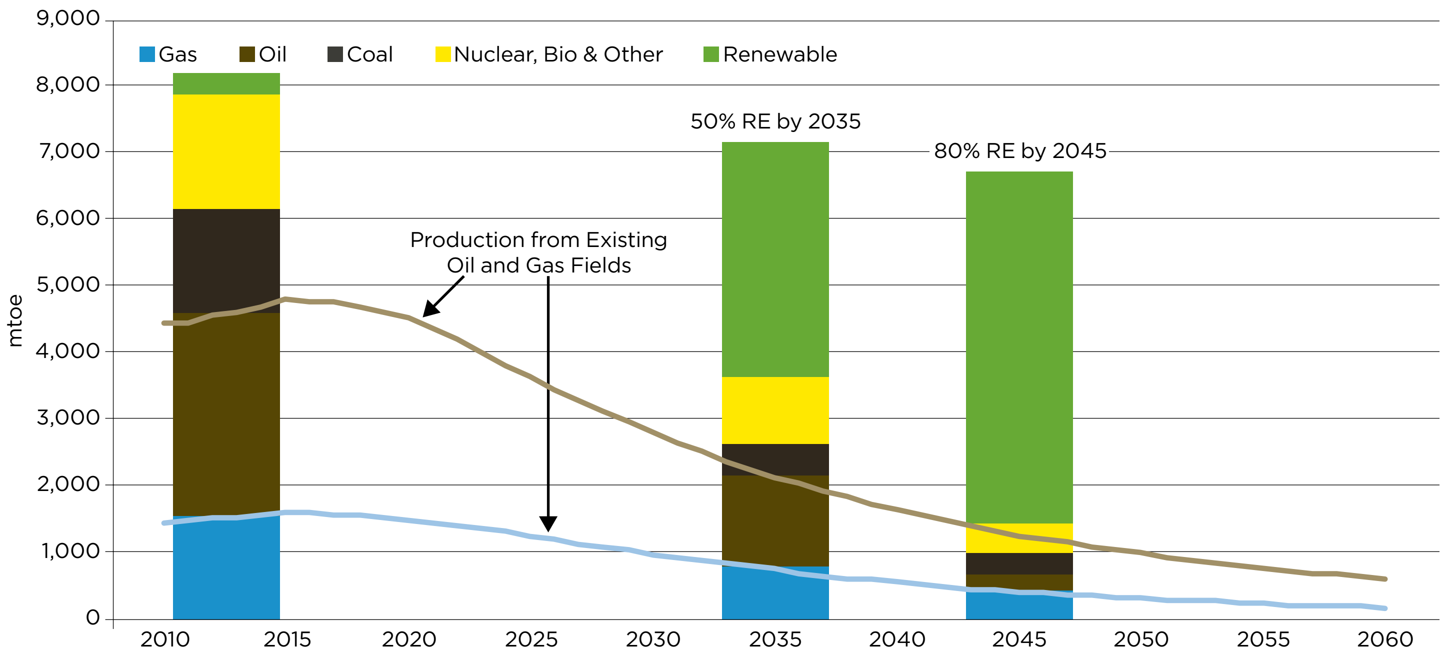
Renewable power technologies are not only possible; they are already in use at scale in many countries, growing rapidly, and often cost less than gas or coal generation (see Box 3). Electric vehicles are at an earlier stage of development than renewable power, but may be able to penetrate the market more rapidly: whereas a power plant has a typical lifetime of 40 years, cars generally last for around ten years.

A common objection to renewable energy relates to the challenges of intermittency. However, this problem is often overstated. For example, the chief executive officer of the northeast Germany electrical grid says the country can get up to 70% to 80% wind and solar even without "additional flexibility options" such as storage.[85] A 2012 report by the National Renewable Energy Laboratory found that with existing storage capacity, the U.S. grid can handle as much as 50% wind and solar penetration.[86] To go further, affordable storage solutions are now emerging, from lithium ion batteries to compressed air and others. Residential battery storage systems entered the mainstream market in the US and Australia in 2015, and the coming years are also expected to see increasing deployment of grid-scale storage.[87] The bigger challenges will be expanding renewable energy in weaker grids in developing countries, emphasizing again the importance of climate finance to facilitate the transition.

We now examine what is needed to replace depleting fossil fuel extraction, by comparing the residual oil and gas demand that will remain while aggressively moving to clean energy, with natural depletion of existing oil and gas fields (as shown in Figures 13 and 14, on page 37). Using a simple model of progressive electrification of energy-consuming sectors and progressive conversion of electricity generation to renewables, we convert the final energy consumption projected in the IEA's 450 Scenario in two scenarios: 50% renewable energy by 2035 and 80% by 2045. In both we assume a complete phase-out of
coal usage, except in steel production. The results are shown in Figure 15 (see detailed calculation and assumptions in Appendix 4).[88]

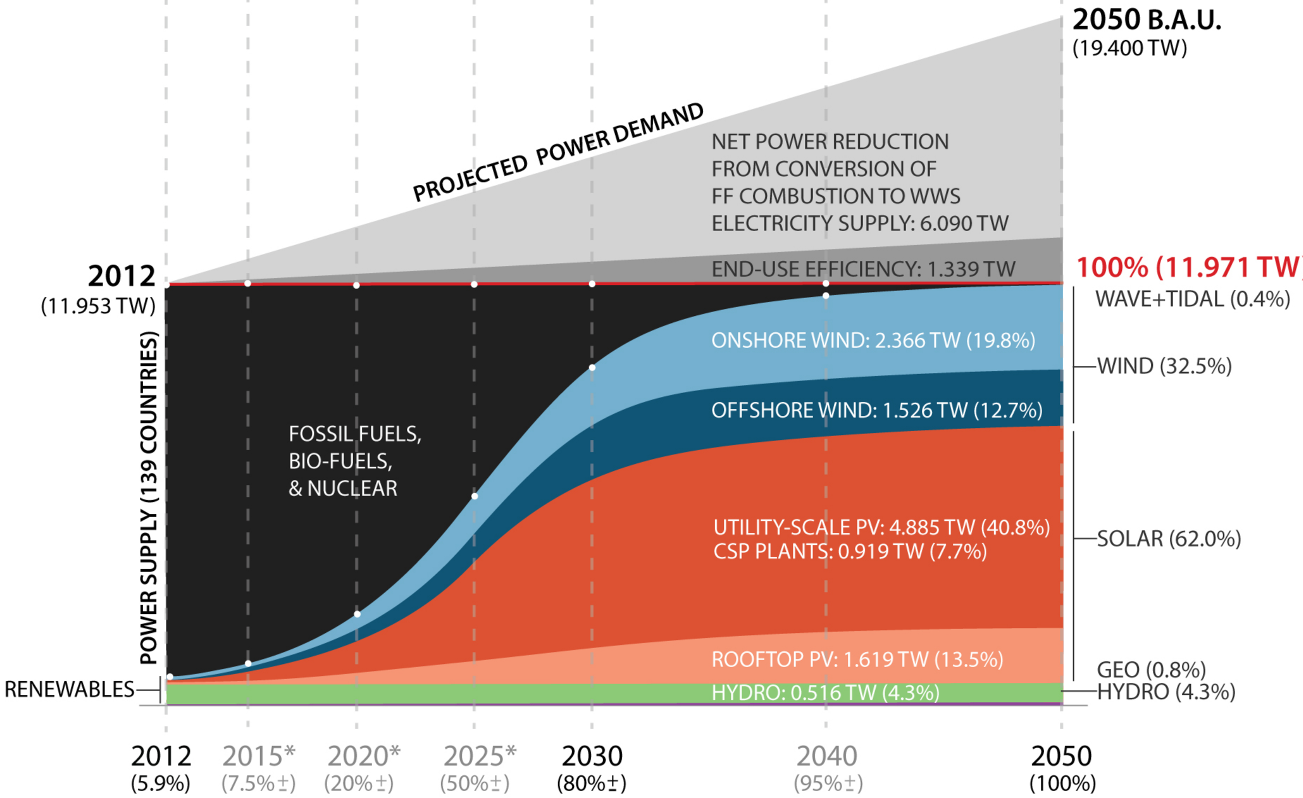
We see in the Figure that in 2035, expected oil and gas production from existing fields roughly matches the requirement with a 50% renewable energy penetration. Further depletion to 2045 leaves greater production than would be required while moving to 80% renewable energy.

Figure 15: Final Energy Consumption by Source With 50% Renewable Penetration in 2035 and 80% in 2045, Compared to Depletion of Existing Oil and Gas Fields (See Appendix 4)



Sources: IEA, Mark Jacobson et al, Rystad Energy, Oil Change International analysis

Figure 16: Projected Power Demand and Fuel Source, in Jacobson et al's Roadmap for 139 Countries



Source: Mark Jacobson et al

Mark Jacobson of Stanford University and colleagues have developed detailed roadmaps for how 139 countries could achieve 80% renewable energy by 2030, and 100% by 2050, as shown in Figure 16.[89] These are much faster rates of conversion than we have outlined above. For each country's projected energy demand – including electricity, transportation, heating/cooling, and industry – Jacobson's team considers what level of each renewable energy source would be required, using only technologies that are available today. They take into account the wind, solar and water resource, land area and infrastructure for each country, and allow for intermittency. A small proportion of transportation and industrial energy uses hydrogen as a fuel carrier.

What Jacobson and his colleagues have shown is the *technical* feasibility of obtaining 100% of energy from wind, water and solar by 2050, and 80% of it by 2030. The technology can deliver, and there is sufficient available resource, while taking up just 0.25% of the 139-country land area, mostly in deserts and barren land (plus a further 0.7% for spacing between wind turbines, which can be used at the same time for farmland, ranchland, grazing land, or open space). They have also shown that the transformation will create a major net addition to the number of energy jobs, compared to continuing with fossil fuels.

Jacobson's calculations are not just a theoretical possibility. In a global survey of 1,600 energy professionals by consultancy DNV GL, nearly half of respondents said they believed the electricity system they work in could achieve 70% renewable generation by 2030, if there were sufficient political will.[90]

How much does all this cost? Over recent years, estimates of clean energy costs have been consistently revised downward, while estimates of the cost of climate change have been revised upwards. In many parts of the world, wind and solar are cost-competitive with gas and coal power generation, and with fast-falling costs they soon will be elsewhere as well (see Box 3).

Bloomberg New Energy Finance (BNEF) estimates that by 2027, it will be as cheap to build a *new* wind or solar plant as to run an *existing* coal or gas plant. BNEF projects that to have a 50% chance of keeping warming to 2°C, $14 trillion of clean energy investments would be needed over the next 25 years; however, $9 trillion would occur even in the absence of policy intervention.[91] While in this report we focus on achieving a greater probability of staying below 2°C, and aiming for 1.5°C, which

Table 7: Case Studies of Rapid Energy Transitions

Country	Technology / Fuel	Market or Sector	Period of Transition	No. of Years from 1% to 25% Market Share	Population Affected (millions)
		End Use Energy Technology			
Sweden	Energy Efficient Ballasts	Commercial Buildings	1991-2000	7	2.3
China	Improved Cookstoves	Rural Households	1983-1998	8	592
Indonesia	Liquefied Petroleum Gas Stoves	Urban and Rural Households	2007-2010	3	216
Brazil	Flex-Fuel Vehicles	New Automobile Sales	2004-2009	1	2
United States	Air Conditioning	Urban and Rural Households	1947-1970	16	52.8
		Energy Supply			
Kuwait	Crude Oil and Electricity	National Energy Supply	1946-1955	2	0.28
Netherlands	Natural Gas	National Energy Supply	1959-1971	10	11.5
France	Nuclear Electricity	Electricity	1974-1982	11	72.8
Denmark	Combined Heat and Power	Electricity and Heating	1976-1981	3	5.1
Ontario, Canada	Coal	Electricity	2003-2014	11*	13

Source: Benjamin Sovacool

* The Ontario case study is the inverse, showing how quickly the province went from 25% coal supply to zero.

would require a greater proportion of clean energy, the BNEF estimate gives a useful ballpark figure. It should be compared with the projected $14 trillion in new fossil fuel extraction and transportation (Section 4), not to mention investment in power plants and refineries.

As a result of increasing cost-competitiveness, much new energy investment is now indeed going into clean energy. However, the rates of renewable penetration in Figure 15 – sufficient to replace fossil fuel decline – are greater than would occur due to market forces alone. The point is that policy intervention is needed to drive investment decisions solely into clean energy, to build sufficient institutional capacity to carry out the investments, and to stop expansion of fossil fuels. The cost competitiveness shows that the net cost of those interventions will be modest, or even negative. We would further note that one of the biggest barriers to the transition is the estimated $452 billion G20 countries currently provide in subsidies every year to fossil fuel extraction.[92]

Is such a large-scale transformation possible, at such a speed? Benjamin Sovacool of Aarhus University has pointed to several energy transformations at the national-level – in both end-use and supply technologies – that took place on these kind of timescales, shown in Table 7.[93] In several cases, a concerted and coordinated effort by government was vital to facilitating the transition, through subsidies, establishing pilot programs, retraining workers, and regulation. A worldwide transition away from fossil fuels is of course a larger and more complex undertaking than these examples, but as Sovacool notes, "previous transitions may have been accidental or circumstantial, whereas future transitions could become more planned and coordinated, or backed by aggressive social movements or progressive government targets."

We conclude that:

- Gradual decline of fossil fuel extraction by depleting existing oil and gas fields and phasing out coal is replaceable with existing clean energy technologies, without major extra cost.

JUST TRANSITION

The implications of limiting global warming to below either 2°C or 1.5°C are significant. It will require a fundamental transformation of the energy industry, beginning immediately and taking place over the next three to four decades. There are many advantages to this transition, even aside from its necessity to prevent dangerous climate change:

- Renewable energy sources generate power more cheaply than coal or gas in many parts of the world, and soon will do so nearly everywhere (see Box 3).
- Electric vehicles commonly offer higher performance than internal combustion engines, and are also expected to be cheaper within the next five years.
- Clean energy industries employ many more people per dollar invested and per GWh generated than fossil fuel industries. A study by the United Nations Industrial Development Organization found that $1 million creates twice as many jobs if invested in renewable energy and energy efficiency as it would if invested in fossil fuels.[94] Meanwhile, the United Kingdom Energy Research Centre finds that a GWh of electricity from wind and solar creates five times as many jobs on average as a GWh of electricity generated from gas and coal.[95]
- Reduced fossil fuel pollution will have massive benefits for health: coal burning alone is estimated to cause 366,000 deaths per year in China and 100,000 per year in India.[96]
- Some analysts argue that given diminishing returns from developing oil and gas at the frontiers, investors in oil companies would obtain higher returns from a phased wind-down of the companies than by their high-cost continuation.[97]

However, the process of transition will not necessarily be painless for individuals, companies, regions, and countries. It will affect fossil fuel energy workers, many of whom may not have the right skills or be in the right location to smoothly transition into clean energy jobs. It will also affect people working to service fossil-based utilities and worksites, whose positions are often more precarious than jobs directly in energy companies. Many energy jobs lie in construction rather than operations, and so in the short term, an end to fossil fuel construction may lead to a more rapid decline in job numbers than in volumes of fossil fuels. Communities may be hit by a loss of revenue or local economic activity, and cultural impacts in places where a community has been long associated with a particular employer or industry.

Action by governments is therefore needed to conduct the energy transition in a way that maximizes the benefits of climate action while minimizing hardships for workers and their communities. Trade unions and others have developed a framework for a just transition in relation to climate change, the importance of which is recognized in the preamble of the Paris Agreement.[98] In 2015 the International Labour Organization adopted guidelines on just transition.[99] Key elements of a just transition include:[100]

- **Sound investment**s in low-emission and job-rich sectors and technologies.
- **Social dialogue and democratic consultation** of social partners (trade unions and employers) and other stakeholders (such as communities).
- **Research and early assessmen**t of the social and employment impacts of climate policies.
- **Training and skills development** to support the deployment of new technologies and foster industrial change.
- **Social protectio**n alongside active labor markets policies.
- **Local economic diversificatio**n plans that support decent work and provide community stability in the transition.

As Jeremy Brecher of Labor Network for Sustainability points out, all of this is achievable and has several relevant precedents in the United States.[101] At the end of World War II, the G.I. Bill of Rights provided education and training, loan guarantees for homes, farms, and businesses, and unemployment pay for returning veterans. It was vital to their reintegration into American society and to the transition to peace. Another military example was the 2005 Base Realignment and Closing Commission (BRAC), which provided communities around closing bases with planning and economic assistance, environmental cleanup, community development grants, and funding for community services, as well as counselling and preferential hiring for affected workers.

In the energy sector, the current Obama Administration Power+ Plan, which offers support for communities previously dependent on coal, has many of the features of a just transition, including funding for job training, job creation, and economic diversification.

The job and skill profiles of workers who could potentially be affected vary widely, and therefore require different strategies. For workers currently employed in fossil fuel extraction or use, incumbent companies must support workers and either offer career progress in non-fossil fuel parts of the company or provide them with transferable skills to navigate the labor market with better chances for success. For communities and workers that depend indirectly on fossil fuel economic activity, public authorities must anticipate the need for new sources of revenue and support investments to transform their economies.

The most critical questions lie in how industry and policymakers will conduct an orderly and managed decline of fossil fuel extraction, with robust planning for economic and energy diversification. As Anabella Rosemberg of the International Trade Union Confederation writes, "Job losses are not an automatic consequence of climate policies, but the consequence of a lack of investment, social policies, and anticipation."[102]

National governments should seek to stimulate new economic growth in regions previously dependent on fossil fuel industries, and in new industries to take their place. Most importantly, leaving things until carbon budgets are mostly exhausted would result in disruptive change that would be sudden, costly, and painful. By starting now, the transition can be managed efficiently and fairly, to the maximum benefit of everyone involved.

6. CONCLUSION

In the Paris Agreement, 195 governments agreed to limit global warming to "well below 2°C" above pre-industrial levels, and to aim for a temperature increase of not more than 1.5°C. In this report, we have used the concept of carbon budgets, drawn from the Fifth Assessment Report of the IPCC, to explore what this would mean in practice.

We find that the oil, gas, and coal in already-developed fields and mines (that is, where the infrastructure has been built) exceeds the amount that can be burned while likely staying below 2°C, and significantly exceeds the amount that can be burned while staying below 1.5°C. Any new fossil fuel infrastructure that is built would require a corresponding early retirement of existing infrastructure. Given the political and economic difficulties of closing down existing facilities, we recommend that:

- No new fossil fuel extraction or transportation infrastructure should be built worldwide.

Instead, we should allow for the gradual decline of existing operations, over the coming decades, and invest strongly in clean energy to make up the difference. We have seen that there is no economic or technical barrier to making this transition over this time frame: the only requirement is political will.

To minimize the costs of the transition, governments should conduct robust planning for economic and energy diversification. The principles of just transition should be applied, to ensure workers and communities benefit from the shift to a clean energy economy, rather than be harmed by it.

The conclusions in this report will take some by surprise, and cause alarm with others. They imply serious alterations to the global economy, will be resisted by some of the most profitable companies ever known, and will necessitate bold and decisive action by governments on a scale not seen thus far.

But the conclusions are also remarkably straightforward at their core. To keep from burning more fossil fuels than our atmosphere can withstand, we must stop digging them out of the ground. With this report, we put forward recommendations on how to go about doing just that in a sufficient, equitable, economically efficient, and just fashion.

Vehicles work at an open-pit coal mine near Ordos in northern China's Inner Mongolia Autonomous Region, 2015.

APPENDIX 1: DEFINITIONS OF RESERVES

Since fossil fuel reserves are located beneath the earth's surface, estimating their quantity is based on inherently limited information drawing on interpretation and judgment of geological data, as well as assumptions about economics and operations. Quantities of reserves are therefore distinguished by the degree of confidence in them: proven, probable, and possible.

The most commonly cited estimates for reserves in fact refer only to proven reserves, a quantity defined (where probabilistic methods are used) as having a 90% likelihood that the amount actually recovered will exceed the estimated amount.[103] This is because the principal use of the concept of reserves is to help investors assess the value of a company by providing an indicator of its future potential production. For this purpose, the most relevant estimate is the more certain one, as it carries less risk.

Since it requires such a high degree of confidence, the proven reserves figure understates what can be expected to in fact be extracted, even based on current knowledge. For anticipating the future impact on the climate (or indeed on energy markets), it is more relevant to consider a realistic estimate of what will be extracted. In this report, we therefore also state probable reserves of oil and gas, taking proven plus probable to refer to the best estimate of the quantity that will ultimately be extracted in the absence of climate constraints. We interpret this as the mean (expected) value.[t]

Contrary to what might then have been expected, the proven-plus-probable reserves figures we use in this report are actually lower than those in the BP Statistical Review of World Energy, which claims to give proven reserves. The reason is that BP takes at face value the amounts claimed by countries such as Venezuela, Saudi Arabia, and Canada, whose measurements lack transparency, are widely suspected to be inflated, and/or rely on broader-than-usual definitions of proven reserves. Rystad Energy – our source of reserves data – instead makes judgments of what reserves are realistically extractable.[104]

Estimates of probable reserves are harder to obtain than of proven. In particular, there are no reliable data available for probable reserves of coal, and definitions vary significantly between countries. Even data on proven coal reserves is of much poorer quality[u] than data on oil and gas, for which there have been efforts to align definitions and compile global reserves data from company and government reports.[v] The IEA notes that due to the sheer scale of coal reserves and substitution by gas, there has been little interest in coal surveys since the start of the twenty-first century.[107]

The implication is that the quantity of reserves is a less important determinant of future production for coal than for oil and gas (another important underlying factor is air pollution regulations).[108] For these reasons, in this report we use only proven reserves for coal.

t While definitions vary, it should be noted that we differ from the more common usage of "proven + probable" to refer to the median estimate. Our reason is that whereas the median is a useful quantity for considering a single field, median values cannot be arithmetically added due to the mathematics of probability, whereas mean values can be.

u For example, the BP Statistical Review takes its coal reserves data from the World Energy Council's World Energy Resources, which is only published every three years: thus the 2016 BP publication contains data relating to 2011. Availability of reliable coal data is especially limited for China, by far the world's largest coal producer. The World Energy Council has not updated its China data since 1992.[105]

v Estimates of reserves held by listed companies are relatively reliable and easily available. This is because listed companies are required by financial regulators to report their reserves, and the definitions and rules are quite strict. But the majority of the world's oil, gas and coal reserves are held by public sector companies, for which reporting is much less standardised and so there is less certainty in the numbers. This uncertainty is reflected for instance in debates on the actual level of Saudi Arabia's oil reserves.[106]

APPENDIX 2: ASSUMPTIONS ON LAND USE AND CEMENT PRODUCTION

This appendix explains the basis for the estimates of future emissions from land use change and cement production, used in Figure 5.

LAND USE

For emission projections from land use, we use IPCC AR5 scenario database found at https://tntcat.iiasa.ac.at/AR5DB/.[109]

There is considerable variation among the scenarios. For the base case assumption, we use the median; for the range calculations we use the interquartile range. All are shown in Table A2-1.

CEMENT MANUFACTURE

Of all CO_2 emissions, the emissions from the calcination reaction in cement manufacture are among the most difficult to reduce, particularly given that cement is such a fundamental material for construction that there are no foreseeable prospects for its widespread substitution. There are four possible routes to reducing these emissions:[110]

- Blending other materials such as fly ash, blast furnace slag, or natural volcanic materials, to reduce the clinker content of cement.
- Using high-performance cement to reduce the cement content in concrete.
- Making clinker from substances other than calcium oxide, such as magnesium oxides derived from magnesium silicates.
- Carbon capture and storage (CCS).

Neither novel clinker ingredients nor CCS are proven technologies, with both existing only in a few pilot settings (see Appendix 3). And in much of the world, the cement content of concrete is already minimized; no estimates are available for potential further optimization.

Blending, the final potential option, is commonly used. The IEA estimates that the average clinker content of cement could be reduced from 79% in 2006 to 71% in 2050.[111] In a subsequent publication, the IEA adjusted this to an improvement from 80% in 2009 to 67% in 2050.[112] In our base case, we assume that CO_2 emissions per metric ton of cement produced are reduced in proportion to the reduced clinker content on a straight-line basis up to 2050 (and that the increased amount of blended substitutes does not cause new emissions), but that no further improvements occur after 2050. In the worst case, we assume no change in emissions intensity from 2015.

The IEA projects an increase in global cement production from 3,800 Mt in 2012 to between 4,475 Mt (low-demand scenario) and 5,549 Mt (high-demand scenario) in 2050.[113] We assume the volume of cement production grows until 2050 according to the IEA's low-demand scenario, and then remains at the 2050 level for the rest of the century.[w] In the worst-case element of the range, we assume the high-demand scenario until 2050, and then continued growth at the same rate for the rest of the century, up to 6,944 Mt in 2100.

If the technologies of novel clinker ingredients and CCS turn out to be successful, emissions from cement manufacture could be reduced to close to zero at some point in the second half of this century. Drawing on the same studies by the IEA and discussions with cement industry experts, climate scientist Kevin Anderson suggests that in this scenario total cement emissions could be limited to 150 Gt of CO_2 from 2011 till eventual phase-out later this century.[115]

Table A2-1: Cumulative CO2 Emissions from Land Use, 2015 to 2100

Median	21 Gt CO_2
1st Quartile	-206 Gt CO_2
3rd Quartile	57 Gt CO_2

Source: IPCC Scenarios Database

Table A2-2: Range of Cement Emissions, 2015 to 2100

	Best Case	Base Case	Worst Case
Cumulative Cement Production, 2015-2100 / Gt	N/K	377	487
Calcination Emissions (t CO_2) per Tonne of Production, 2100 (Declining from 0.49t/t in 2012)	0	0.41	0.49
Total Emissions / Gt CO_2	150	162	241

Sources: IEA, Kevin Anderson

w Once urbanisation and development reach a certain level, a country's cement consumption declines to a lower level as major infrastructure has already been built, and construction is reduced to maintenance and replacement. When this happens in enough countries, the world will reach "peak cement."[114]

APPENDIX 3: CARBON CAPTURE AND STORAGE

Carbon capture and storage (CCS) is a process in which the CO_2 released from burning fossil fuels is captured, compressed, and stored underground in deep geological reservoirs. Although CCS has been strongly advocated since the 1990s by the fossil fuel industry and others, it has barely been deployed to date, a record the Financial Times describes as "woeful."[116] Due to slow development of the technology, even if CCS were developed at scale it is estimated that the carbon budget would only be extended by 12% to 14% by 2050.[117]

While CCS technology is well understood in theory, many actual projects have been beset with problems. The only operating joined-up CCS power project, Boundary Dam, came on line in Canada in 2014. The plant has struggled to operate as planned, suffered considerable cost-overruns, and been forced to pay out for missing contracted obligations.[118] The leading U.S. project, Kemper, is already over two years late and $4.3 billion over budget.[119]

A fundamental question about CCS is whether stored CO_2 might be at risk of leaking from underground reservoirs. If it did, it could add large quantities of CO_2 to the atmosphere, at a time when it is too late to stop emissions. While the reservoir integrity question has been modeled, there is a shortage of empirical evidence, especially over extended periods of time. Part of the problem is that of the twenty-two CCS projects built to date, sixteen have been used in enhanced oil recovery.[120] In these cases, studies have focused largely on the objective of increasing short-term reservoir pressures in order to force more oil out, and not so much on long-term storage integrity.[121] The IPCC believes that the risks are low, for "well-selected, designed, and managed geological storage sites."[122]
In that light, it is troubling that the world's first industrial scale CCS project, the Sleipner project in Norway, started in 1996 and assumed to be safe until it was discovered to have fractures in its caprock in 2013.[123] The other major problem facing CCS is its cost. Even CCS advocates recognize the "outstanding commercial challenges" that projects around the world face.[124] It is estimated that CCS could increase the cost of coal-fired electricity plants by 40% to 63% in the 2020s.[125] In 2015, Shell Chief Executive Officer Ben van Beurden conceded that CCS is too expensive without government subsidies.[126]

Faced with these many challenges, CCS now appears to be experiencing a cooling of government and industry interest.
Last year, the United Kingdom cancelled its competition for commercial-scale CCS projects[127] and the United States terminated funding for the FutureGen CCS retrofitting demonstration project.[128] Earlier in 2015, four leading European utilities pulled out of the European Union's Zero Emission Platform, a long-term project to study and develop CCS technology, jointly stating, "We currently do not have the necessary economic framework conditions in Europe to make CCS an attractive technology to invest in."[129]

A tailings pond at the Suncor Steepbank/Millenium Mine in the Canadian tar sands. Alberta, Canada, 2014.

APPENDIX 4: OIL AND GAS REQUIREMENT IN CLEAN ENERGY SCENARIOS

This appendix explains the basis for our calculations of renewable energy required to replace depleting fossil fuels, in Figure 15. We use the model of 139 countries developed by Mark Jacobson of Stanford University,[130] to consider two scenarios: 50% average renewable energy in 2035, and 80% in 2045. In both scenarios, steam coal is entirely phased out; we examine therefore the remaining oil and gas requirement.

APPROACH AND ASSUMPTIONS

In the model, all energy-using sectors are progressively electrified, and electricity generated using wind, concentrated solar power, geothermal, solar photovoltaic, tidal, wave, and hydropower. No new hydro dams are built, but existing ones are maintained. A small amount of the electricity is used to produce hydrogen for some transportation and industrial applications.

The estimates are all based on final energy consumption.

We use projections of 2035 and 2045 energy demand by extrapolating on a straight line from the International Energy Agency's 450 Scenario,[131] broken down by sector (industry, transportation and buildings) and fuel. We adjust these demand estimates using Jacobson's conversion factors, to account for the higher energy-to-work conversion efficiency of electricity compared to combustion of fossil fuels.

In the 50%-by-2035 scenario, we use the IEA 450 Scenario's estimates of coking coal use, with zero steam coal. In the 80%-by-2045 scenario, we assign 10% of industrial final energy to coking coal.

To simplify, we further assume:

- 50% renewable energy is achieved by electrifying 90% of energy for buildings, 60% for industry, and 30% for transport; and then generating 84% of electricity with renewables.
- 80% renewable energy is achieved by electrifying 95% of energy for buildings, 85% for industry, and 80% for transport, and generating 90% of electricity with renewables.

Table A4-1: Global Final Energy Consumption by Source With 50% Renewable Penetration in 2035 and 80% in 2045 (Using Jacobson Model)

mtoe	50% by 2035	80% by 2045
Industry		
Coal	473	332
Oil	69	0
Gas	298	0
Electricity	1,565	2,057
Heat	56	0
Bioenergy	128	0
Other RE	19	31
SUB-TOTAL	**2,608**	**2,420**
Transport		
Oil	1,180	149
Electricity	703	1,392
Biofuels	271	123
Other	191	76
SUB-TOTAL	**2,345**	**1,739**
Buildings		
Coal	0	0
Oil	17	0
Gas	22	0
Electricity	1,995	2,428
Heat	17	0
Bioenergy	70	0
Other RE	96	161
SUB-TOTAL	**2,217**	**2,589**
TOTAL	**7,168**	**6,748**
Power		
Coal	0	0
Oil	95	90
Gas	463	437
Nuclear	226	213
Bioenergy	42	40
Renewable	3,436	5,097
SUB-TOTAL	4,263	5,876
Totals by fuel		
Oil	1,360	239
Gas	783	437
Coal	473	332
Nuclear	226	213
Bioenergy	511	163
Other	264	76
Renewable	3,551	5,289
TOTAL	**7,169**	**6,748**

Sources: IEA, Mark Jacobson et al, Oil Change International analysis

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	Clean energy	Fossil fuels
Brazil	37.1	21.2
Germany	9.7	7.6
Indonesia	99.1	22
Korea	14.6	13.6
South Africa	70.6	33.1

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Bn bbl	Rystad 2P reserves	BP Statistical Review "proven" reserves
Saudi Arabia	182	267
United States	128	55
Russia	109	102
Iran	100	158
Canada	92	172
Iraq	90	143
Qatar	52	26
Venezuela	44	301
UAE	43	98
China	42	19
Kuwait	41	102
Brazil	40	13
Kazakhstan	29	30
Nigeria	19	37
Norway	16	8
Libya	15	48

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EXHIBIT 3

nature climate change

LETTERS

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Assessment of the climate commitments and additional mitigation policies of the United States

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Current intended nationally determined contributions (INDCs) are insufficient[1] to meet the Paris Agreement goal of limiting temperature change to between 1.5 and 2.0 °C above pre-industrial levels[2], so the effectiveness of existing INDCs will be crucial to further progress. Here we assess the likely range of US greenhouse gas (GHG) emissions in 2025 and whether the US's INDC can be met, on the basis of updated historical and projected estimates. We group US INDC policies into three categories reflecting potential future policies, and model 17 policies across these categories. With all modelled policies included, the upper end of the uncertainty range overlaps with the 2025 INDC target, but the required reductions are not achieved using reference values. Even if all modelled policies are implemented, additional GHG reduction is probably required; we discuss several potential policies.

On 12 December 2015, representatives from 196 countries to the United Nations Framework Convention on Climate Change (UNFCCC)'s 21st Conference of Parties (COP-21) in Paris reached a landmark climate agreement[2] limiting global temperature increase, which will require balancing GHG emissions and sinks after mid-century.

In addition to setting a specific GHG emissions reduction target for 2025 (26–28% below the 2005 level[3]), the US INDC outlined specific steps for achieving these reductions, including existing and planned policies addressing light- and heavy-duty vehicles, appliance and equipment standards, building codes, electricity generation, hydrofluorocarbon (HFC) emissions, methane (CH_4) emissions and federal government operations.

A number of independent entities have examined the US INDC goal and policies to determine their likelihood of success. All conclude that existing federal policy will make it challenging to meet the US INDC, but opinions vary as to the likelihood of achieving the targets with additional federal actions. Eight previous studies are cited and compared with our work in the Supplementary Note.

Unlike most prior studies, our study models the final version of the Clean Power Plan (CPP) and includes a thorough accounting of other policies, including potential policies such as the Montreal Protocol amendment for HFC gases. Our study is also unique in that it estimates uncertainty ranges for historical and projected baseline GHG emissions, updates CH_4 emission estimates to reflect current scientific understanding, estimates GHG savings and uncertainty ranges for each policy, and provides a delineation of policy types spanning three categories. This detailed treatment of US climate policies will be invaluable for policymakers and other stakeholders, as US climate policy progresses toward the 2025 INDC target.

We undertake a comprehensive evaluation of historical and projected baseline US GHG emissions, focusing on key policy years 2005 and 2025. Beginning with the US Department of State's Climate Action Report (CAR)[4] and Second Biennial Report (SBR)[5], we make a number of revisions to both historical and projected emissions using consistent global warming potentials and recent updates to projected energy use, HFC emissions and land CO_2 uptake. Moreover, we make upward revisions to CH_4 emissions based on recent regional, US and global assessments. We also perform a comprehensive uncertainty analysis. See Methods for more information.

Our revised estimates produce a range in 2005 net GHG emissions from 6,323 to 7,403 $MtCO_2e$ (full uncertainty range). For 2025, net GHG emissions range from 0.6% above to 11.8% below the corresponding 2005 level. The change in net GHG emissions relative to the CAR[4] is positive in both 2005 and 2025. See Fig. 1. The largest uncertainty components are due to energy sector emissions, land sink uptake, and CH_4 emissions ($\gtrsim$400 $MtCO_2e$ each in 2005, larger in 2025).

We then estimate GHG emission impacts for a number of policies listed in Table 1, based on the US INDC. In addition, we include some policies not specified in the INDC, including commercial building codes, targets for manure and fertilizer management, and recent California legislation. Reduction estimates and uncertainty ranges are based on published reports by the federal government, independent entities or our own analysis. Some policies mentioned in the INDC, as well as existing state policies, are not modelled as they are included in the 2015 US Department of Energy's Annual Energy Outlook[6] baseline, from which our analysis proceeds.

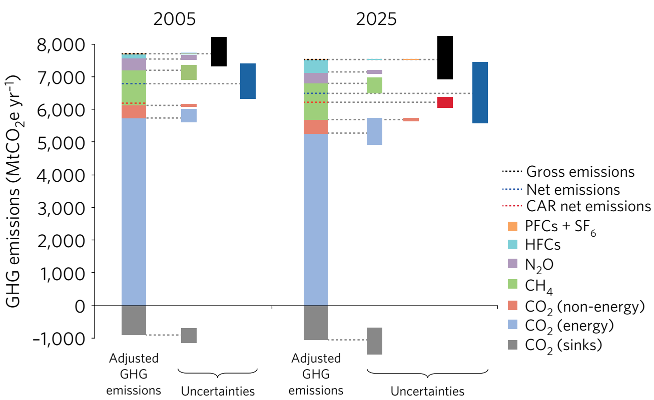

Figure 1 | Baseline 2005 and 2025 greenhouse gas (GHG) emissions with uncertainties shown for each category of emissions. Climate Action Report (CAR)[4] net GHG emissions shown for reference. CO_2, carbon dioxide; CH_4, methane; N_2O, nitrous oxide; HFCs, hydrofluorocarbons; PFCs, perfluorocarbons; SF_6, sulfur hexafluoride; $MtCO_2e$, million tonnes CO_2 equivalent.

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Table 1 | Summary of estimated greenhouse gas (GHG) emissions reduction in 2025 from policies.

Category	GHG	Policy description	Value range			Full uncertainty†	
			Reference	Min.	Max.	Min.	Max.
					($MtCO_2e$)		
A	CO_2	CPP (final rule)	241	226	255	221	267
		Electricity and buildings (California SB350)‡,§	13	13	13	13	14
	N_2O	Fertilizer management (policies in SBR)‡	10	10	10	9	13
	HFCs	Phase-out (Final EPA SNAP rule)	59	54	64	54	72
B	All	California 2030 GHG target (Executive Order)‡,*	65	65	65	64	68
	CO_2	Appliance standards (2015–2016)	27	27	27	27	29
		Building codes (residential, 2015–2025)‖	23	23	23	23	24
		Federal government operations (Executive Order)	26	26	26	25	27
		Heavy-duty vehicles (proposed)*	41	36	46	36	48
	CH_4	Oil and gas (proposed)*	13	12	14	8	16
		Landfills (proposed)*	18	18	18	13	21
C	CO_2	Enhanced CPP (proposed rule)¶	407	393	435	384	455
		Appliance standards (2017–2025)	29	29	29	28	30
		Building codes (commercial, 2015–2025)‡,‖	29	29	29	29	31
	CH_4	Oil and gas (aspirational target)	121	116	125	85	146
		Manure management (voluntary roadmap)‡	21	3	40	2	46
	HFCs	Phase-out (Montreal Protocol amendment)	67	55	79	55	88
Subtotals	All	Category A	323	303	342	306	356
		Category B	214	208	220	196	234
		Category C	674	625	737	596	784
		All	1,211	1,136	1,299	1,099	1,373

Abbreviations: Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), Clean Power Plan (CPP), Senate Bill (SB), Second Biennial Report (SBR), US Environmental Protection Agency (EPA), Significant New Alternatives Policy (SNAP), million tonnes CO_2 equivalent ($MtCO_2e$), minimum (min.), maximum (max.), intended nationally determined contribution (INDC). †Parameter uncertainties across GHG categories are added in quadrature, except for CH_4, which was not considered to be a Gaussian distribution, but a simple range. As a result, sums of quantities in these columns do not necessarily equal the indicated subtotals. ‡Not included in INDC. §SB350 (50% renewable electricity and doubled rate of building energy efficiency savings by 2030)[14]. ‖Only residential building codes were specified in the US INDC. Because such codes cannot be mandated federally and are adopted to varying degrees at the state level, we have categorized future residential building codes as a Category B action. For commercial building codes, we have categorized future actions as Category C since no federal targets have been specified. ¶Reductions shown are incremental to the CPP final rule. *See 'Note added in proof'.

Policies are divided into three categories depending on current status:

- Category A: Passed legislation or final rule (finalized by late 2015).
- Category B: Proposed legislation, proposed rule, or executive order.
- Category C: Announced target, potential policy or voluntary measure.

The rationale for categorizing different types of policy is discussed in Supplementary Methods, 'Modelled policies.' Implied in this categorization is a decreasing likelihood of policy impact in 2025 in moving from Category A to C.

Combining all of our 2025 estimates together, including uncertainties arising both from the inherent range of impacts as well as parameter uncertainty, results in GHG emission reduction ranges shown in Table 1 and Fig. 2.

The CPP contributes the most to GHG emissions reductions. Two versions are modelled: the final rule, and an enhanced version based on the proposed rule. The final rule, published in October 2015[7], is included in Category A, with estimated reductions from 221 to 267 $MtCO_2e$ in 2025. These estimates do not include some additional reductions that may have been assumed to take place elsewhere in the energy system. However, the earlier proposed rule is much more ambitious[8], with total savings that are more than twice as large; therefore, this policy is included in Category C as something that the US might later pursue.

Five other policies—CH_4 oil and gas aspirational target[9], California's 2030 GHG target[10], two HFC policies (the US Environmental Protection Agency (EPA)'s Significant New Alternatives Policy (SNAP)[11] and Montreal Protocol amendment[12]), and the heavy-duty vehicle efficiency proposed rule[13]—each have impacts of between 36 and 146 $MtCO_2e$, or 3.2 to 10.7% of total reductions. Of these, only SNAP is a Category A policy. We estimate that the remaining 10 policies, which span Categories A, B and C, collectively reduce emissions between 177 and 251 $MtCO_2e$ (16.1 to 18.3% of total reductions).

The US INDC pledges a 26 to 28% reduction below the 2005 GHG emission level in 2025. Considering the uncertainties discussed above, this produces a 2025 target ranging from 4,553 to 5,478 $MtCO_2e$. The difference between this target and the estimated 2025 emissions without INDC policies results in an 'emissions gap' ranging from 896 to 2,121 $MtCO_2e$, with a reference value of 1,510 $MtCO_2e$ corresponding to a 4.8% reduction below the 2005 level.

Including policies that the US has actively adopted (Category A) results in remaining emissions between 5,230 and 7,135 $MtCO_2e$. While it would appear that there is some overlap with the target emissions range, as the high end of the 2025 target is higher than the low end of remaining emissions, this is not the case. Because of the way these ranges are correlated with common assumptions about energy-related CO_2 emissions, land sinks, and CH_4 emissions, the estimated emissions gap after including Category A reductions is 551 to 1,805 $MtCO_2e$, or 8.7 to 24.4% of the 2005 level. See Fig. 3.

Including Category B policies results in an emissions gap of 340 to 1,586 $MtCO_2e$, while including Category C policies as well lowers the gap to between −356 and 924 $MtCO_2e$. While the low end of this latter range is indeed negative, indicating emissions 5.6% lower than the maximum 2025 target (26% below the 2005 level), it corresponds to favourable assumptions for all parameters, and implementation of all policies. The upper end, corresponding to less favourable parameter assumptions, is 12.5% above the minimum 2025 target (28% below the 2005 level), indicating that further reductions will be necessary to close this gap with confidence. We briefly discuss policy options below; for more information, see Supplementary Discussion.

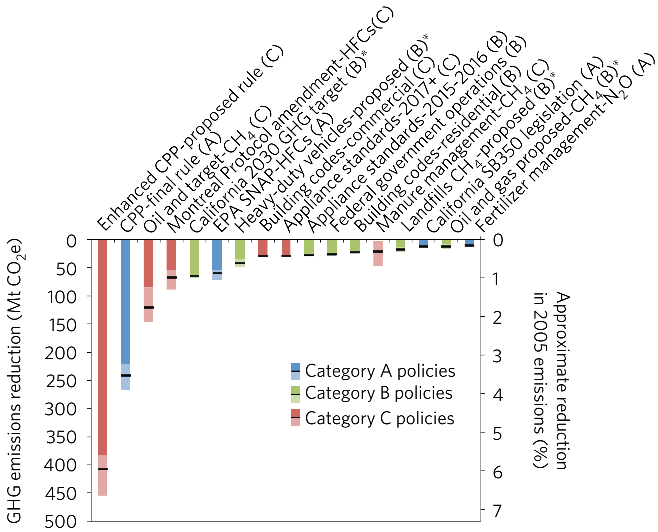

Figure 2 | Rank-ordered greenhouse gas (GHG) reduction estimates in 2025 by policy. Lighter coloured bars indicate full uncertainty ranges. Black horizontal lines denote reference values. CO_2, carbon dioxide; CH_4, methane; N_2O, nitrous oxide; HFCs, hydrofluorocarbons; MtCO_2e, million tonnes CO_2 equivalent; EPA, US Environmental Protection Agency; SNAP, Significant New Alternatives Policy. *See 'Note added in proof'.

In the electricity sector, an aggressive phase-out of coal and natural gas generation, with accompanying increases in renewables, energy efficiency and possibly nuclear generation could be enacted. As an example, California plans to meet a 33% renewable electricity target in 2020, and 50% in 2030[14], as well as phase-out coal generation by 2030[15]. Several other states[16] are also actively reducing electricity-sector GHG emissions. Together, these strategies could even exceed proposed rule CPP reductions (see Supplementary Discussion, 'Extensions of the CPP').

Vehicle electrification represents an important GHG emission reduction strategy in the transportation sector, due to the lower GHG intensity of electricity- versus petroleum-powered vehicles. California and seven other states[17] have a 2025 target of 3.3 million zero net emission vehicles; if scaled to the US, it would encompass 16 million vehicles, 6% of projected stock. Such a target could save more than 50 MtCO_2e and also reduce air pollution.

Policies that shift mobility use from private vehicles to lower GHG modes (public transit, non-motorized mobility, and on-demand shared-ride vehicles), such as in California[18], could be strengthened. Moreover, vehicle automation could significantly lower GHG emissions[19], although increased usage might undermine some savings.

Current biofuels targets have been reduced from 36 billion gallons of ethanol-equivalent originally proposed for 2022[20]. However, there may be more than 1 billion tonnes of US biomass available by 2030, sufficient for 70 billion gallons[21], with significant GHG savings.

Hydrogen can be produced from many sources and could reduce GHG emissions across multiple sectors. Federal spending of ~*US*$100 million annually supports ambitious hydrogen production, storage and fuel cell goals, but more could be done to realize them, such as increased commercialization and infrastructure efforts[22].

Electrifying building and industrial heating can reduce emissions when electricity has a lower GHG emissions intensity than fossil sources[23]. Electric heat pumps are far more efficient than combustion, and high-temperature industrial approaches can provide higher throughput, space savings and improved quality[24].

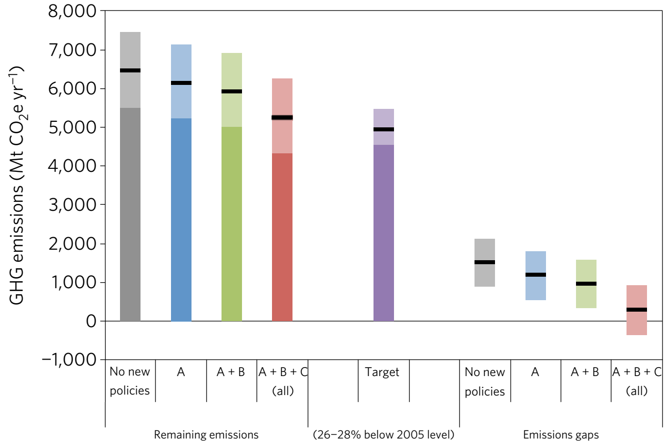

Figure 3 | Estimated remaining 2025 greenhouse gas (GHG) emissions, target and emissions gaps by policy category. Lighter coloured bars indicate full uncertainty ranges. Black horizontal lines denote reference values. Colour code: No new policies (grey); Category A (blue); Categories A + B (green); Categories A + B + C (red); Target (purple). MtCO_2e, million tonnes carbon dioxide equivalent.

The majority of oil and gas sector CH_4 leaks probably come from a minority of 'super-emitters' that, if identified and addressed, could reduce sector emissions 65 to 87%[25]. Moreover, landfill CH_4 emissions could be reduced by 90% in new facilities, and up to 60% in older ones[26].

The use of slow-release fertilizers has been shown to reduce N_2O emissions by 35%, without a corresponding increase in labour[27]. With the majority of the 345 MtCO_2e of estimated 2025 N_2O emissions due to agriculture, such an application would result in much larger reductions than assumed under current federal policy[5].

Additional HFC reductions of ~33% or 82 MtCO_2e yr^{-1} in 2025 could come from more aggressive Montreal Protocol amendments[28].

A variety of land management practices could enhance carbon storage, reducing 2030 CO_2 emissions by >40 MtCO_2e yr^{-1} in California (The Nature Conservancy, unpublished data, 2015), with greater potential nationally.

Finally, GHG emissions trading now being pursued in a handful of US states[10,29] as well as internationally[30] could unlock low-cost GHG reduction strategies, lowering total emissions while saving money.

In conclusion, updated estimates of 2005 and 2025 US GHG emissions, along with estimates of the impacts of US INDC policies, indicate that additional mitigation measures will probably be required to reduce US GHG emissions to the 2025 INDC target (26–28% below the 2005 level). Promising strategies exist spanning multiple sectors and technologies. Time is short, so it is vital for the US to develop achievable plans to maintain pressure on other nations to support the Paris Agreement.

Note added in proof: The recent passage of California SB 32 on 25 August 2016 codifies the statewide GHG emissions reduction target (Executive Order B-30-15) in law[31]. Furthermore, the US Environmental Protection Agency and the US Department of Transportation's National Highway Traffic Safety Administration jointly finalized the heavy-duty vehicle standards on 16 August 2016[32], and the US Environmental Protection Agency finalized its CH_4 emissions standards for oil/gas and landfill sectors on June 3, 2016 and July 15, 2016, respectively[33,34]. All these changes elevate the corresponding policies from Category B to A. However, this Letter was resubmitted before these changes occurred, so they were not incorporated in the analysis.

Methods

Methods and any associated references are available in the online version of the paper.

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Author contributions

M.W. performed HFC policy analysis and comparison to prior studies; J.B.G. performed all other calculations and analysis. J.B.G. and M.W. wrote the manuscript and addressed reviewer concerns.

Additional information

Supplementary information is available in the online version of the paper. Reprints and permissions information is available online at www.nature.com/reprints. Correspondence and requests for materials should be addressed to J.B.G.

Competing financial interests

The authors declare no competing financial interests.

Methods

Historical US GHG emissions were obtained from the US Environmental Protection Agency (EPA)'s 2015 GHG emissions inventory[35], which provided annual historical estimates from 1990 to 2013. We also examined emissions data from EPA's 2014 GHG emissions inventory[36], which provided annual historical estimates from 1990 to 2012, for additional information about HFC and perfluorocarbon (PFC) emissions. EPA's 2016 draft inventory[37] reported emissions to 2014, and makes important revisions to prior year estimates, suggesting that historical (including 2005) net emissions were higher by >300 $MtCO_2e\ yr^{-1}$. However, as the data were not finalized, we did not utilize them in our analysis.

Other data sources provided both historical and projected emissions. The US Department of State's 2014 US Climate Action Report (CAR)[4] and 2016 Second Biennial Report (SBR)[5] provided five-year estimates for all GHGs from 2000 to 2030 (plus some years between 2010 and 2015). The US Energy Information Administration's 2015 and 2016 Annual Energy Outlook (AEO) reports[6,38] provided annual energy-related CO_2 emissions to 2040, and the EPA's 2015 Significant New Alternatives Policy (SNAP) report[11] provided HFC emissions in 5-year intervals from 2010 to 2030.

The SBR was released after our initial analysis was completed, and its projected baseline GHG emissions included some, but not all, policies we modelled in our analysis. As a result, it was not possible to use the SBR projections to represent future emissions in the absence of federal actions in support of the US INDC. Therefore, we have retained the CAR projections with some important modifications.

For energy-related CO_2 emissions, we used 2015 AEO projections[6] modified to subtract bunker fuel emissions (in accordance with Intergovernmental Panel on Climate Change (IPCC) inventory reporting guidelines[4]), and included projected emissions from US territories estimated from historical EPA data[35]. We also subtracted some industrial CO_2 emissions reported by the CAR as non-energy emissions. (The 2016 AEO, which included projections with and without the CPP, was released too recently to be incorporated into this analysis. However, we did utilize a small additional GHG saving arising from outside the electricity sector as a result of the CPP that was not included in the EPA analysis[8]; see Supplementary Methods, 'Historical and projected baseline US GHG emissions' for details.)

For non-energy CO_2 emissions, we retained the CAR projections (none were separately provided in the SBR). For land use CO_2, we used SBR projections, as they reflected important recent revisions in estimated future land use practices and resulting CO_2 absorption. Emissions of non-CO_2 GHGs were expressed in CO_2 equivalent units using 100-year global warming potentials (GWPs) from either the IPCC Second Assessment Report (SAR)[39] or Fourth Assessment Report (AR4)[40]. The AR4 GWPs were used in the US INDC and all data sets except the EPA's 2014 GHG inventory and the CAR, which used SAR GWPs. For consistency, we converted non-CO_2 emissions from SAR to AR4 GWPs, as described in Supplementary Methods, 'Global warming potentials (GWPs).' We retained these adjusted CAR emission projections for N_2O, PFCs and SF_6. For HFCs, however, the EPA recently made significant upward revisions to projected baseline emissions in its 2015 SNAP report[11], so we used those projections instead.

A number of recent studies point toward important differences between CH_4 emission estimates from EPA, and those based on measurements obtained from towers, aeroplanes and satellites[41–47]. As a result, we used a correction factor of $1.50^{+0.25}_{-0.40}$ times the EPA's GHG values for historical CH_4 emissions and the CAR's AR4-adjusted projected emissions, resulting in increases in estimated CH_4 emissions of 354^{+177}_{-283} $MtCO_2e$ in 2005 and 368^{+184}_{-295} $MtCO_2e$ in 2025. While these upward revisions represent the latest scientific understanding, considerable uncertainty remains. More detail about these corrections can be found in Supplementary Methods, 'CH_4 adjustments.'

To characterize uncertainty in energy-related CO_2 projections, we examined the 2015 AEO reference case along with 13 side cases[6]. We found that total CO_2 emissions in 2025 varied by approximately $\pm 4\%$, and used this range to characterize future uncertainty. The additional uncertainty arising from our modifications to the AEO projections were found to be negligible. See Supplementary Methods, 'Uncertainty estimates,' for details. For CH_4, as noted above, we used a correction factor with uncertainty bounds.

In addition to the above uncertainties, we used EPA's own uncertainty estimates[35] for GHG emissions in 2013 to estimate intrinsic uncertainty. We used separate 95% uncertainty interval estimates for each GHG except for CO_2, where we used separate uncertainty estimates for energy, non-energy and land sink emissions. We assumed that the relative uncertainty in each GHG category would remain the same in other years, including 2005 and 2025, and applied these estimates to all adjusted emissions estimates except CH_4 (since our own estimate of uncertainty was far larger than what EPA assumed).

EPA parameter uncertainty estimates were combined in quadrature as per standard error propagation methods. Other sources of uncertainty, which had minimum/maximum ranges but no formal confidence intervals, were linearly combined (that is, without quadrature) to obtain a maximum uncertainty range, which we refer to as 'full uncertainties.'

For each INDC policy listed in Table 1, we developed GHG reduction estimates based on federal government analyses, extrapolations from independent analyses, and synthesis from scientific literature. 'High' and 'low' bracketing uncertainty estimates were developed for most policies; others utilized single-point values. To these ranges we added intrinsic uncertainties described above to arrive at full uncertainty estimates. When subtracting GHG emissions policy reductions from baseline emissions, care was taken to include intrinsic uncertainties only afterward, to avoid overestimating the uncertainty.

More details are given in Supplementary Methods, 'Modelled policies,' but in brief, we estimated 2025 policy impacts as follows:

(1) Clean power plan. We used EPA's analysis of its final rule (Category A, despite a current legal challenge[48]) to obtain a range of GHG savings[8]. For the enhanced version of the CPP (Category C), we used EIA's analysis[49] of the proposed rule to estimate a range of GHG savings across scenario variants, and subtracted this range from estimated final rule savings.

(2) Appliance and equipment standards. We performed trend analysis on historical estimates in ref. 50 to estimate future savings in electricity and natural gas, converting to GHG emissions via data from ref. 51 and EIA[6]. Category B represented savings from standards finalized through 2016, whereas Category C included savings from potential new standards through 2025.

(3) Building codes. We based our estimates for future residential (Category B) and commercial (Category C) building code energy savings on state-by-state projections of ref. 52, converting to GHG emissions in a similar manner as for appliance and equipment standards (see above).

(4) Heavy-duty vehicles. We used estimates from EPA and US Department of Transportation of their proposed rule[13] (Category B; see 'Note added in proof') policy for medium- and heavy-duty vehicles spanning multiple scenarios and calculation methods to provide a range of GHG savings.

(5) Federal government operations. We used the Administration's own estimate[53] of GHG savings from clean electric and thermal energy sources, reduced energy use in federal buildings and federal vehicle fleets, and similar savings from major federal suppliers for this Category B executive order.

(6) CH_4 mitigation. Using our revised higher emissions rates of CH_4 from US sources, we adjust percentage savings estimates for certain CH_4 reduction policies:

Oil and gas. We used the Administration's estimate of its proposed rule[54] (Category B; see 'Note added in proof') GHG savings range. We also used the Administration's aspirational target (Category C) of a 40 to 45% sector reduction from the 2012 level by 2025[55].

Landfills. Category B (see 'Note added in proof') savings are based on an EPA proposed rule analysis[56].

Manure management. We base savings on the Administration's voluntary biogas roadmap[57] (Category C) savings estimates.

No other federal policies exist with quantitative reduction targets for CH_4, so none were included.

(7) N_2O mitigation. We used the difference between adjusted CAR[4] and SBR[5] N_2O emissions as a proxy for current federal policy (Category A) fertilizer management N_2O savings discussed in the SBR.

(8) HFC mitigation. We used estimated reductions from EPA's 2015 SNAP[58] regulations (Category A), while larger reductions are based on compliance with a proposed Montreal Protocol amendment (Category C)[59].

(9) California policies. California has the most aggressive GHG emissions reductions policy of any state in the US[60]. We used the CALGAPS model[61] to simulate recently passed California renewable portfolio standard and building efficiency legislation (SB350, Category A) and the statewide GHG emissions reduction target (Executive Order B-30-15, Category B; see 'Note added in proof'). These policies are additional to the federal CPP, because California is expected to meet its CPP obligations with existing policies 'years ahead of schedule'[62] and projects its own GHG emissions in 2030 to be 34% below the CPP target[63], or 15 $MtCO_2e$, higher than our estimated savings from SB350. The statewide GHG emissions reduction target is estimated from the difference between the 2030 target of 40% below the 1990 level[10] and expected emissions from all other existing policies[61].

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EXHIBIT 4

THE ECONOMIC RECORD OF THE OBAMA ADMINISTRATION: ADDRESSING CLIMATE CHANGE

September 2016

EXECUTIVE OFFICE OF THE PRESIDENT OF THE UNITED STATES
COUNCIL OF ECONOMIC ADVISERS

Contents

Executive Summary

The impacts of climate change are being felt now, and if unchecked, greenhouse gas emissions threaten the future of both national and global welfare and economic output. That is why, since taking office, President Obama has demonstrated his commitment to fighting climate change through a diverse set of policy mechanisms. Since 2008, he has implemented policies that provide incentives for renewable energy and improve the energy efficiency of homes and appliances; developed the first-ever federal greenhouse gas pollution standards for power plants, light-duty cars and trucks, and commercial trucks, buses, and vans; invested in research and development to support innovative clean energy technologies, and furthered international cooperation to drive down greenhouse gas emissions and limit global temperature rise. Encouraging trends in energy consumption, carbon emissions, and the deployment of cleaner energy since 2008 illustrate the progress the nation has made during the Obama Administration to transition to an increasingly low-carbon economy, while also recovering from the Great Recession. In line with long-standing policy for major regulations, standards aimed at reducing greenhouse gas emissions have been assessed using rigorous benefit-cost analysis. This report reviews the economic rationale for policy intervention to slow climate change, selected policies pursued and the progress made to date, and the foundation this Administration has established for a continued transition toward an increasingly low-carbon economy in the years to come. The key findings of the report are outlined below.

The impacts and economic costs of climate change are being felt today and are expected to intensify.

- Fifteen of the sixteen warmest years on record globally have occurred between 2000 and 2015, and 2015 was the warmest year on record.
- Though it is difficult to attribute individual weather events to climate change, some extreme weather events have become more frequent and intense, consistent with climate model predictions.
- The number of weather events that have led to damages in excess of one billion dollars has been increasing in recent years due to both climate change and economic development in vulnerable areas.

Current and future climate change costs readily justify policy intervention, which also has important benefits for economic efficiency.

- Greenhouse gas emissions are a classic environmental externality and, without policy intervention, the quantity emitted is too high. The prices of goods and services in our economy need to reflect their full costs, including the costs of the impacts of greenhouse gas emissions associated with their production and consumption.
- Policies that internalize these costs will improve social welfare while reducing the odds of catastrophic climate events. In addition to the costs to-date, delaying policy action can increase both future climate damages and the cost of future mitigation.

The carbon footprint of the U.S. electricity portfolio has declined, with dramatic increases in renewable energy and lower carbon intensity of fossil fuel-fired generation.

- Renewable energy capacity from non-hydro resources has tripled between 2008 and 2015, and the share of U.S. electricity generation from these resources has increased from under 3 percent in 2008 to 7 percent in 2015 as the costs of wind and solar, in particular, have fallen dramatically. The United States now generates more than three times as much electricity from wind and 30 times as much from solar as it did in 2008.
- We have reduced the carbon intensity of our fossil-fuel portfolio. The quantity of carbon dioxide emitted per unit of electricity produced from fossil fuels has dropped by 13 percent since 2008, and in April 2015, the share of electricity generation using natural gas surpassed the share produced from coal for the first time on record.
- Both the increase in renewable energy and the shift towards natural gas have lowered emissions in the power sector. CEA analysis shows that 66 percent of the carbon intensity reduction from the power sector since 2008 in the United States is attributable to a shift towards lower-carbon fossil fuels (mostly increased generation from natural gas), and 34 percent is attributable to increased generation from zero-carbon renewable resources.

The energy and carbon intensity of the U.S. economy has also declined notably.

- Energy intensity, which refers to energy consumed per dollar of real GDP, has been steadily declining over the past four decades and fell by 11 percent from 2008 to 2015. Energy intensity is projected to decline another 17 percent by 2025.
- The total amount of energy consumed has also dropped. Total energy consumption in the United States was 1.5 percent lower in 2015 than in 2008, and U.S. petroleum consumption was 2 percent lower in 2015 than it was in 2008, while the economy grew more than 10 percent over this same period.
- Carbon intensity, the amount of carbon dioxide emitted per energy consumed, has declined by 8 percent from 2008 to 2015, and carbon dioxide emitted per dollar of GDP has declined by 18 percent over this period. Shifts toward lower-carbon fossil-fuel resources and zero-carbon renewable resources have allowed the economy to grow while carbon intensity has fallen.
- Changes in energy intensity, carbon intensity, and economic growth have all played important roles in decreasing emissions. CEA analysis shows that the decline in emissions relative to 2008 can be decomposed into 40 percent from decreased energy intensity, 29 percent from decreased carbon intensity, and 31 percent from the lower than expected level of GDP after unanticipated shocks such as the large shock from the Great Recession.
- U.S. carbon dioxide emissions from the energy sector fell by 9.5 percent from 2008-2015, and in the first 6 months of 2016, they were at the lowest level in 25 years.

Since taking office in 2009, President Obama has laid the foundation for a continued transition to a low-carbon economy using policies that generate substantial net economic benefits.

- Forward-looking policies in the power sector put in place during the Obama Administration establish the Administration's commitment to halting climate change. Last year, EPA finalized the first-ever national standards to address carbon pollution from power plants, which are projected to reduce carbon dioxide emissions by 32 percent from 2005 levels by 2030. Though the realized net economic benefits of the standards will depend on the methods states choose to comply, estimates project net benefits of $15 to $27 billion just in 2025, rising to $25 to $45 billion in 2030.[1]
- In addition, in 2015, President Obama extended tax credits for wind and solar projects. These credits were first extended in the American Recovery and Reinvestment Act and are expected to reduce carbon dioxide emissions by more than 200 million tons in 2020, alone. The tax credit extensions help support continued investment in these growing industries.
- The first-ever greenhouse gas standards for light-duty cars and trucks, finalized by the Obama Administration in two phases in 2010 and 2012, are projected to reduce carbon dioxide emissions by around 6 billion metric tons over the lifetime of new vehicles sold between 2012 and 2025. The Phase 2 standards are expected to generate net economic benefits of $326-$451 billion over the lifetime of models sold in 2017-2025.
- The Administration put in place the first-ever national fuel economy and greenhouse gas emission standards for commercial trucks, buses, and vans (referred to as medium- and heavy-duty vehicles), finalized in two phases in 2011 and 2016. Together, these standards are projected to reduce carbon dioxide emissions by around 2.5 billion metric tons. The Phase 2 standards will generate estimated net economic benefits of $117-$229 billion over the lifetime of models sold in 2018-2029.
- The Administration put in place energy efficiency standards for buildings, homes and appliances that will reduce both emissions and utility bills for American families and businesses. For example, new standards for commercial air conditioning and heating equipment sold between 2018 and 2048 are projected to have net economic benefits of $42 to $79 billion.
- The first ever methane pollution standards for new sources in the oil and gas sector are projected to substantially reduce emissions from these sources and help the United States to achieve our goal to reduce methane emissions by 40 to 45 percent below 2012 levels by 2025.
- Major Federal investments in clean energy research and development have already supported and will continue to support innovation that generates long-run benefits.

[1] Throughout this document, CEA reports results directly from agencies' regulatory impact analyses (RIAs) without converting constant dollar estimates to a common year, to maintain consistency with those RIAs. Net benefits of the regulations discussed here, in constant 2015 dollars, would be $17 to $27 billion (in 2025) and $26 to $47 billion (in 2030) for new standards on carbon pollution from power plants; $354 to $490 billion (model years 2017-2025) for light-duty vehicle fuel economy and greenhouse gas standards; $120 to $236 billion (model years 2018-2029) for heavy-duty vehicle fuel economy and greenhouse gas standards; and $42-$79 billion (2018-2048) for commercial air conditioning and heating energy efficiency standards.

The Administration has worked to make sure that climate change mitigation, a global public good, is a global effort.

- The Administration's leadership helped bring nearly 200 nations together to sign the Paris Agreement, a historic agreement that establishes a long-term, durable global framework with the aim of keeping climate warming to well below 2 degrees Celsius.
- Through an array of other agreements – ranging from global accords on hydrofluorocarbons to bilateral agreements with China to reduce emissions – the Administration has used diplomacy to make sure that the effort to combat climate change is a global one.

Introduction

Addressing climate change and transitioning to a clean energy system are some of the greatest and most urgent challenges of our time. The impacts of climate change are real and being felt today. That is why President Obama has taken action to address climate change through domestic and international leadership. At the 2014 UN Climate Change Summit, President Obama stated:

> "There's one issue that will define the contours of this century more dramatically than any other, and that is the urgent and growing threat of a changing climate."

Without proactive steps to reduce greenhouse gas (GHG) emissions and slow the climate warming already being observed, future generations are left with the costly burden of facing impacts from a changed climate on our planet. From an economic perspective, the causes of global climate change involve a classic negative environmental externality, whereby the social costs of activities that emit greenhouse gases exceed the private costs, demonstrating the need for policy action.

Addressing the environmental externalities from climate change involves changing the long-run trajectory of our economy towards a more energy efficient and lower greenhouse gas-emitting path. Since mitigating climate change serves a global public good affecting all countries, it also involves working with other countries to reduce greenhouse gas emissions worldwide. In addition to mitigation, addressing climate change involves building resilience to current and future impacts, developing adaptation plans and preparing for the changing frequency and severity of extreme events.

Since President Obama took office, substantial strides have been made in transforming the energy system, and the energy intensity and carbon intensity of the economy have fallen. Most notably, in 2013, the President released a Climate Action Plan to map out the framework for the United States' transformation to a more energy efficient and lower greenhouse-gas emitting economy. Steps taken by the United States along with extensive negotiations subsequently helped pave the way for the 2015 Paris Agreement in which more than 190 countries committed to take concrete steps to reduce greenhouse gas emissions.

This report reviews the economic rationale for the Administration's efforts on climate change and the transformation of the energy system. It provides an overview of a selection of the most important policy efforts and then examines the key economic trends related to climate change and energy, many of which have already been influenced and will be increasingly influenced going forward by policy measures under the Climate Action Plan. These trends include increases in electricity generation from natural gas and increases in renewable energy, improvements in energy efficiency, and shifts in transportation energy use. The report also seeks to understand the sources of these trends, by decomposing emissions reductions in the power sector as attributable to lower-carbon fossil fuel-resources and renewable energy generation, as well as decomposing emissions reductions in the entire economy as attributable to lower energy intensity, lower carbon intensity, and a lower than expected level of GDP. Understanding the driving forces behind these trends allows for an assessment of how the multitude of policy mechanisms utilized in this Administration have helped the United States pursue a more economically efficient path that addresses environmental and other important externalities.

Consistent with long standing policy, the Administration has worked to ensure that regulations that affect carbon emissions and other climate related policies are undertaken in an efficient and cost effective manner. Rigorous regulatory impact analyses (RIAs) demonstrate that economically efficient mechanisms were used to achieve climate goals.

The Administration's climate policies go well beyond what is discussed in this report. Rather than provide a comprehensive review of implemented and planned policies, the report focuses on the economics of domestic actions to reduce greenhouse gas emissions and transition to cleaner sources of energy. Additional Federal policies and programs are assessed in other Administration documents, including CEA reports.[2]

[2] For discussion of clean energy investments under the American Recovery and Reinvestment Act, see CEA (2016c). For additional reviews of the Administration's climate policies, see White House (2016c), DOE (2015j), EPA (2015a), and Department of State (2016b).

I. The Rationale for Climate Action

The Impacts of Climate Change Are Observed Now and Are Expected to Grow

Climate change is not just a future problem—the costly impacts of changing weather patterns and a warming planet are being felt now. Fifteen of the sixteen warmest years on record globally have occurred between 2000 and 2015, and the 2015 average temperature was the highest on record.[3] The trend is continuing in 2016, with each of the first seven months in 2016 setting a record as the warmest respective month globally in the modern temperature record, dating to 1880; in fact, July 2016 marked the 15th consecutive month that the monthly global temperature record has been broken, the longest such streak in 137 years of recordkeeping by the National Oceanic and Atmospheric Administration.[4] Not only are temperatures rising on average, but heat waves—which have detrimental human health impacts—have also been on the rise worldwide since 1960.[5] Among extreme weather events, heat waves are a phenomenon for which the scientific link with climate change is quite robust; for example, studies suggest that climate change made the 2003 European heat wave that killed 70,000 people at least twice as likely as it would have been to occur without climate change, and that deadly heat in Europe is ten times more likely today than it was when that deadly 2003 heat wave hit.[6]

In addition to heat waves, wildfires and certain types of extreme weather events such as heavy rainfall, floods, and droughts with links to climate change have become more frequent and/or intense in recent years.[7] As illustrated in Figure 1, the annual number of U.S. weather events that cause damages exceeding $1 billion has risen dramatically since 1980, due both to climate change and to increasing economic development in vulnerable areas.[8] An intense drought that has plagued the West Coast of the United States since 2013 led to California's first ever state-wide mandatory urban water restrictions.[9] As atmospheric levels of carbon dioxide have increased, the amount of carbon dioxide dissolved in the ocean has risen all over the world, increasing ocean acidification and threatening marine life. Further, over the past 100 years, the average global sea level has risen by more than seven inches, leading to greater risk of erosion, flooding, and destructive storm surges in coastal areas.[10]

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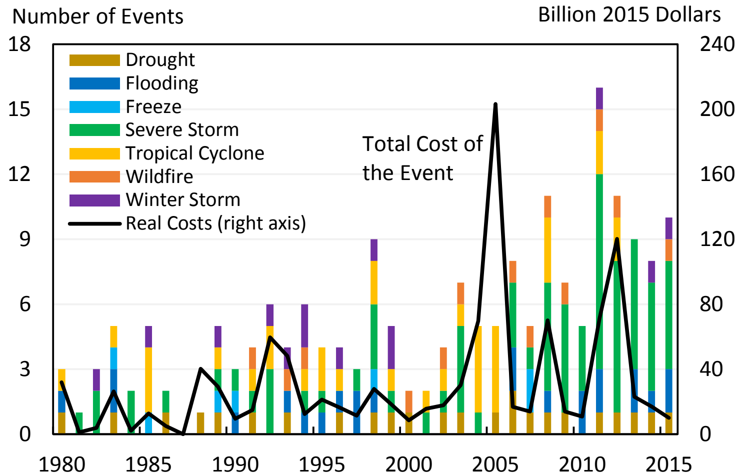
[3] NOAA (2016a).
[4] NOAA (2016b).
[5] IPCC (2013).
[6]Christidis et al. (2015), Stott (2004), Robine et al. (2008).
[7] Department of State (2016b).
[8] NOAA (2016c). Regional economic development can increase the magnitude of damages from weather-related events because economic growth increases the assets (and population) at risk.
[9] Brown (2014).
[10] IPCC (2013).

Figure 1: U.S. Billion-Dollar Event Types, 1980-2015



Source: National Oceanic and Atmospheric Administration.

Growing research also links climate change with diminished health and labor productivity in the United States, due to both temperature and pollution increases.[11] For example, recent research finds that when daily maximum temperatures exceed 85 degrees Fahrenheit, U.S. labor supply is reduced by as much as one hour per day (relative to the 76 to 80 degree range) for outdoor industries, such as construction and farming.[12] Studies also suggest strong links between warming and mortality—an additional day of extreme heat (above 90 degrees Fahrenheit) can lead to an increase in annual age-adjusted U.S. mortality rates of around 0.11 percent relative to a day in the 50 to 60 degree range.[13] Warmer temperatures can also lead to higher urban levels of ozone, an air pollutant that affects people and vegetation.[14] For example, in the California agricultural sector, a decrease in ozone concentration by 10 parts per billion can lead to a more-than 5 percent increase in worker productivity.[15] These studies represent just a small selection of the growing body of evidence on the economic costs of climate change.

Based on the current trajectory and the results of climate science research, the economic costs from warmer temperatures and changing weather patterns are expected to grow in the coming years. Increased temperatures due to climate change could lead to a 3 percent increase in age-adjusted mortality rates and an 11 percent increase in annual residential energy consumption (as

[11] A comprehensive analysis by the EPA discusses the economic, health and environmental benefits to the United States of global climate action, summarizing results from the peer-reviewed Climate Change Impacts and Risks Analysis (CIRA) project (EPA 2015a).
[12] Graff Zivin and Neidell (2014).
[13] Deschênes and Greenstone (2011). This study and the others cited here exploit inter-annual weather variation to estimate climate impacts. As such, they may overstate climate impacts, because less-costly adaptation activities may be available over longer time horizons in response to permanent climate changes than are available in response to short-term weather shocks.
[14] Melillo et al. (2014).
[15] Graff Zivin and Neidell (2012).

demand for air conditioning increases) in the United States by the end of the century.[16] Average U.S. corn, soybean and cotton yields may decrease by 30-46 percent by 2100, assuming no change in the location and extent of growing areas, and assuming that climate warming is relatively slow.[17] Extreme heat is also expected to affect labor productivity and health: by 2050, the average American will likely see the number of 95 degree Fahrenheit days more than double compared to the last 30 years, and labor productivity for outdoor workers may fall by as much as 3 percent by the end of the century. [18] The Risky Business Project (2014) estimates that within the next 15 years, assuming no additional adaptation, higher sea levels and storm surges will increase costs of damages from coastal storms by $2 to $3.5 billion per year in the United States, and these costs will rise to $42 billion per year by the end of the century. Based on emissions trajectories in 2014, the report finds that by 2050, existing U.S. coastal property worth between $66 and $106 billion will be at risk of being inundated, with the Eastern and Gulf coasts particularly affected (again, assuming no additional adaptation).

Economic Rationale for Action on Climate Change

The impacts of climate change present a clear economic rationale for policy as a means to both correct market failures and as a form of insurance against the increased risk of catastrophic events.

Addressing Externalities

Climate change reflects a classic environmental externality. When consumers or producers emit greenhouse gases, they enjoy the benefits from the services provided by the use of the fuels, while not paying the costs of the damages from climate change. Since the price of goods and services whose production emits greenhouse gases does not reflect the economic damages associated with those gases, market forces result in a level of emissions that is too high from a social perspective. Such a market failure can be addressed by policy. A first-best policy would respond to this market failure by putting an economy-wide price on the right to emit greenhouse gases. In the absence of a uniform carbon price to regulate emissions, however, other climate policy mechanisms can improve social welfare by pricing emissions indirectly. For example, incentivizing low-carbon alternatives can make carbon-intensive technology relatively more expensive, shifting consumers toward less carbon-intensive products, and thus reducing emissions. Energy efficiency standards can reduce energy use, implicitly addressing the external costs of emissions and resulting overconsumption of energy. Gasoline or oil taxes help to directly address the external costs due to emissions from the combustion of oil.

Some policies to address the climate change externality have an additional economic motivation based on other market failures. For example, reducing carbon dioxide emissions through low-

[16] Deschênes and Greenstone (2011).

[17] Schlenker and Roberts (2009). Like the studies on human health, economic estimates of the agricultural impacts of climate change are based on inter-annual weather variation and may overstate climate impacts, if less costly adaptation activities are available over long time horizons in response to permanent climate change.

[18] Risky Business Project (2014).

carbon electricity often also reduces the emissions of local and regional air pollutants that cause damage to human health, a second environmental externality.

There are also innovation market failures where some of the returns from investment in innovation and new product development spill over from the firm engaged in innovation to other firms, leading to an underinvestment in technological innovation relative to efficient levels. For example, there is substantial evidence that the social returns from research and development investment are much higher than the private returns due to some of the knowledge spilling over to other firms.[19] While not specific to the energy area, the failure to internalize the positive spillovers to research into technologies that would reduce carbon emissions is compounded by the failure to take into account the external cost of carbon emissions.

Correcting Other Market Failures

Other market failures that may be partly addressed by climate-oriented policies include information market failures due to inadequate or poor information about new clean energy or energy-efficient consumer technologies, and network effects (i.e., a situation where the value of a product is greater when there is a larger network of users of that product) that consumers do not consider in their decisions regarding the purchase of new clean energy technologies. While not market failures, per se, vulnerability to supply disruptions and the potential macroeconomic effects of oil price shocks provide additional reasons to invest in clean transportation technologies. These factors, taken together, can lead to an underinvestment in research, as well as underinvestment in energy efficiency and deployment of clean energy, and provide additional economic motivations for policy. For example, energy efficiency standards may help address information market failures and policies promoting clean transportation infrastructure may reduce vulnerability to supply disruptions.

Insurance against Catastrophe

Despite a large body of research on how human activities are changing the climate, substantial uncertainty remains around the amount of damage that climate change will cause. This is because there are cascading uncertainties from key physical parameters (e.g., the exact magnitude of the global temperature response to the atmospheric buildup in greenhouse gases), to the regional manifestations of global climate change, to the vulnerabilities of different economic sectors, and the response measures that could decrease impacts. For example, climate scientists have developed probability distributions of the sensitivity of the climate to increases in the concentration of carbon dioxide in the atmosphere, and there is some small, but non-zero probability of extremely high climate sensitivity.[20] With the possibility of high climate sensitivity,

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[19] See Jaffe and Stavins (1994) or Gillingham and Sweeney (2012) for more on innovation market failures in the context of clean energy.

[20] According to the IPCC, equilibrium climate sensitivity is *likely* in the range 1.5°C to 4.5°C (high confidence), *extremely unlikely* less than 1°C (high confidence), and *very unlikely* greater than 6°C (medium confidence) (IPCC 2013).

coupled with the possibility of high future greenhouse gas emissions, the risk of irreversible, large-scale changes that have wide-ranging and potentially catastrophic consequences greatly increases. The term "tipping point" is commonly used to refer to a "critical threshold at which a tiny perturbation can qualitatively alter the state of development of a system." [21] When it comes to climate, at a tipping point, a marginal increase in emissions could make a non-marginal—and potentially irreversible—impact on damages. Hypothetical climate tipping points could lead to catastrophic events like the disappearance of Greenland ice sheets, the destabilization of Indian summer monsoon circulation, or changes in the El Niño-Southern Oscillation.

It is impossible to know precisely how likely or how costly these low-probability, high-impact events, or "tail risks," are, but climate science indicates that there is reason for concern. Moreover, economists have been increasingly interested in understanding how these tail risks should be incorporated into policy choices. Most notably, a series of papers by Martin Weitzman lay out an analytical framework for understanding policy under conditions with catastrophic fat tail risks (i.e., the risk of a catastrophe that has more probability weight than it would in a normal distribution[22]). Weitzman's analysis points out that under certain conditions, the expected costs of climate change become infinitely large.[23] While there has been an active debate in the literature regarding the conditions under which Weitzman's findings may apply, his work both underscores the importance of understanding tail risks, and provides an economic rationale for taking early action to avoid future, potentially large risks.[24] Just as individuals and businesses routinely purchase insurance to guard against risks in everyday life, like fire, theft, or a car accident, climate policy can be seen as protection against the economic risks—small and large—associated with climate change.

Delaying Action on Climate Change Increases Costs

When considering climate change policy from an economic perspective, it is critical to consider not just the cost of action but also the cost of inaction. Delaying climate policies may avoid or reduce expenditures in the near term, but delaying would likely increase costs substantially in the longer run. The economic literature discusses two primary mechanisms underlying the substantial increase in costs from delayed action.

First, if delay leads to an increase in the ultimate steady-state concentration of carbon dioxide, then there will be additional warming and subsequent economic damages in the long run. Using the results of a leading climate model, CEA (2014) estimates that if a delay causes the mean global temperature to stabilize at 3 degrees Celsius above preindustrial levels instead of 2 degrees, that delay will induce annual additional damages of approximately 0.9 percent of global output. (To

[21] Lenton et al (2008).

[22] For example, a Student's t-distribution is a fat-tailed distribution.

[23] Weitzman's "Dismal Theorem" is presented and discussed in several papers: Weitzman (2009), Weitzman (2011), and Weitzman (2014). Further analyses of the "theorem" include Newbold and Daigneault (2009), Nordhaus (2009), and Millner (2013).

[24] In fact, Weitzman's conditions are not necessary for there to be an economic motivation: there is a broader economic motivation for a precautionary policy with a sufficiently risk averse or loss averse decision-maker.

put that percentage in perspective, 0.9 percent of output in the United States in 2015 alone was over $160 billion in 2015 dollars.) The next degree increase, from 3 degrees to 4 degrees, would incur even greater *additional* costs of approximately 1.2 percent of global output. It is critical to note that these costs would be incurred year after year.

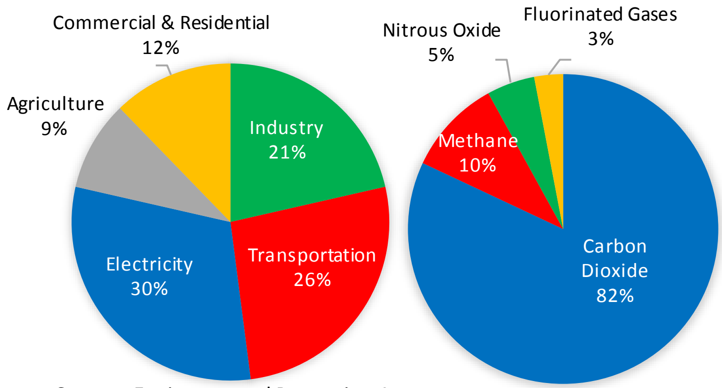
Second, if the delayed policy aims to achieve the same carbon target as a non-delayed policy, then the delayed policy will require more stringent actions given the shorter timeframe. More stringent actions will generally be more costly, though technological innovation can make future mitigation cheaper than it is today, lowering the future cost of low-carbon technologies needed to meet the target. In addition, since investment in innovation responds to policy, taking meaningful steps now sends a long-term signal to markets that the development of low-carbon technologies will be rewarded. At the same time, this signal creates a disincentive for investing in new high-carbon infrastructure that would be expensive to replace later on. CEA (2014) estimates the costs of delaying the achievement of a specific target – by these calculations, if the world tries to hit the goal stated in Paris of less than a 2 degree increase in the global mean surface temperature relative to pre-industrial levels, but waits a decade to do so, the cost of limiting the temperature change would increase by roughly 40 percent relative to meeting the goal without the decade delay.[25]

[25] These estimates, as further described in CEA (2014), are developed from a meta-analysis of research on the cost of delay for hitting a specific climate target.

II. Administration Climate Policies

Since 2009, the Administration has undertaken numerous steps towards both mitigating climate change and responding to its effects. Greenhouse gas emissions in the United States amounted to 6,870 million metric tons of carbon dioxide equivalents in 2014 (the most recent inventory), and these emissions are spread over several sectors, as shown in the left chart of Figure 2.[26] In 2014, carbon dioxide emissions made up 82 percent of total greenhouse gas emissions, methane 10 percent, nitrous oxides 5 percent, and fluorinated gases 3 percent (right chart of Figure 2).[27] The electricity sector in 2014 generated the largest share of emissions–nearly a third–motivating the President's Clean Power Plan and clean energy investments (discussed below). Transportation follows with 26% of emissions, motivating a variety of efficiency and innovation policies in the transportation sector.[28]

Figure 2: Greenhouse Gas Emissions by Type and Sector in 2014



Source: Environmental Protection Agency

The Administration's steps to address greenhouse gases cover nearly all sectors and gases. These steps help reduce emissions both now and in the longer term by promoting low-carbon electricity, dramatically improving energy efficiency for many products, facilitating the transition to a cleaner transportation system, reducing emissions of high potency greenhouse gases, and bolstering our forest carbon sink. In parallel, they have also promoted resilience, with a variety of programs focused on adapting to a changing climate. This section highlights just a few of the Administration's many climate and energy initiatives. Section IV will discuss outcomes.

[26] These are gross greenhouse gas emissions. Note that the Administration's multi-year GHG reduction targets are based on GHG emissions, net of carbon sinks.

[27] EPA (2016a).

[28] The most recent EPA GHG annual inventory is from 2014. In June 2016, the rolling 12-month average emissions estimates from the U.S. Energy Information Administration suggested that transportation emissions had exceeded those from electric power generation for the first time since 1979.

Promoting Cleaner Electricity Generation

Supporting Growth of Renewable Energy

President Obama has made substantial investments in renewable energy supported by federal policies that promote research, development, and deployment of renewable energy. These policies help address the underinvestment in renewable energy due to environmental externalities as well as the underinvestment in R&D due to knowledge spillovers. The Administration signaled its strong support for clean energy from the beginning by making a historic investment in clean energy in the American Recovery and Reinvestment Act (ARRA) (also referred to as the "Recovery Act"). The macroeconomic demand shock of the Great Recession required a bold policy response that included stimulus spending along with tax cuts and aid to affected individuals and communities. The Administration's decision to focus an important part of that spending (about one-eighth of the total) on clean energy was a vital step in pushing the economy towards a cleaner energy future, and a foundational step for supporting continued progress throughout the President's eight years in office.

ARRA extended and expanded the Production Tax Credit (PTC) and the Investment Tax Credit (ITC), critical policies directly focused on renewable energy. These policies provide subsidies for renewable energy production and installation to help address the unpriced externalities that place renewable energy at a disadvantage. In December 2015, the Administration secured a five-year extension of the PTC and ITC, signaling to developers that renewable energy continues to be an area worthy of greater investment.[29]

ARRA also created two new programs to support renewable energy generation – a set of loan guarantees for renewable energy project financing (the 1705 Loan Guarantee Program) and cash grants for renewable energy projects (the 1603 Cash Grant Program). The 1705 program supported construction of the first five solar PV projects over 100 MW in the United States. The 1603 program provided $25 billion to support total installed renewable energy capacity of 33.3 GW.[30] ARRA also included funding for energy efficiency projects, clean transportation, grid modernization, advanced vehicles and fuels, carbon capture and storage, and clean energy manufacturing; in total, ARRA provided more than $90 billion in funding to help spur clean energy industries and activities.[31]

Since ARRA, the Administration has undertaken a set of efforts to help ensure that renewable energy is accessible to all Americans and underserved communities, in particular. Launched in July 2015, the National Community Solar Partnership, part of the Administration's SunShot

[29] Bailey (2015).

[30] CEA (2016c).

[31] See CEA (2016c) for more on the impacts of these policies and more detail on clean energy support provided by ARRA. Some funded programs were extended or had greater take-up than anticipated, so the total allocation of ARRA-related clean energy programs will be more than $90 billion; CEA calculations indicate that just under $90 billion of ARRA clean energy-related dollars had been spent by the end of 2015.

initiative, is fostering innovation in financing and business models and spreading best practices to facilitate adoption of solar systems in low and moderate income (LMI) communities.[32] The Department of Housing and Urban Development is facilitating Property Assessed Clean Energy (PACE) financing to make it easier and more affordable for households to finance investments in solar energy and energy efficiency.[33] The Administration has set a goal to bring 1 gigawatt (GW) of solar to low and moderate income families by 2020, and the U.S. Department of Agriculture has awarded almost $800 million to guarantee loan financing and grant funding to agricultural producers and rural small businesses.[34] The Administration has also set a goal for the U.S. Department of the Interior to approve 20,000 MW of renewable energy capacity on public lands by 2020, and has set ambitious annual goals for the U.S. General Services Administration to purchase minimum percentages of its electricity from renewable sources, reaching 100 percent in 2025; both of these update and expand on earlier such goals in the Energy Policy Act of 2005.[35] The Administration has also expanded opportunities to join the solar workforce with programs like the Solar Instructor Training Network, AmeriCorps funding, and Solar Ready Vets to help reach the goal of training 75,000 workers to enter the solar industry by 2020.[36]

Carbon Pollution Standards for Power Plants

In August 2015, the President and the EPA announced the finalization of the Clean Power Plan (CPP)—the first-ever national carbon pollution standards for existing power plants. This historic action by the United States to address environmental externalities from carbon dioxide emissions focuses on the power sector, the source of just under one-third of all greenhouse gas emissions and the largest source of U.S. carbon dioxide emissions in 2014.[37]

The CPP sets emission performance rates for fossil fuel-fired power plants based on the best system of emission reduction the EPA found was available, considering cost, energy impacts, and health and environmental impacts. The CPP translates those rates into state-specific goals and provides states with broad flexibility to reach the goals. For example, a state can choose a mass-based standard, which limits the total number of tons of carbon dioxide from regulated plants and can be achieved with a cap-and-trade system or another policy approach of the state's choice. As an alternative, the state can comply with a rate-based standard, whereby the state requires regulated sources to meet a specified emissions rate (the amount of emissions generated per unit of electricity produced) through a number of policy approaches. This flexibility allows states to choose cost-effective approaches to reducing emissions that are tailored to meet the state's own policy priorities. Further, for greater economic efficiency gains, the CPP permits

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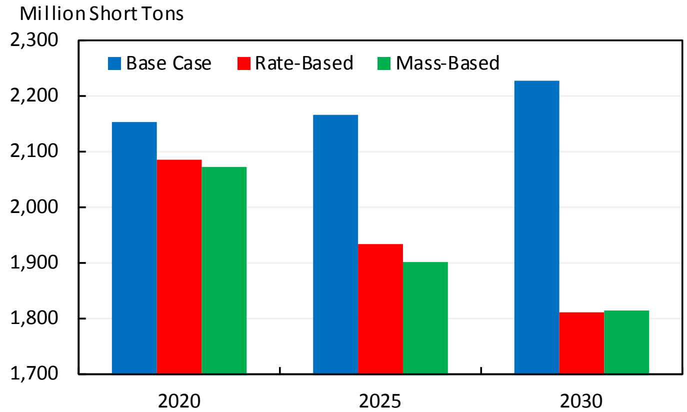
[32] White House (2015c). The SunShot initiative in the U.S. Department of Energy, launched in 2011, has the goal of making solar electricity cost competitive with conventional forms of electricity generation by 2020.
[33] White House (2016g).
[34] USDA (2016).
[35] White House (2015b, 2013b).
[36] White House (2015c).
[37] EPA (2015b).

emissions trading across states; affected electric generation units (EGUs) can trade emissions credits with EGUs in other states with compatible implementation plans. [38]

When the CPP is fully in place, CO_2 emissions from the electric power sector are projected to be 32 percent below 2005 levels by 2030, resulting in 870 million tons less carbon pollution in 2030, equivalent to the annual emissions of 166 million cars.[39] Not only will the CPP help mitigate climate change, but it will also protect the health of American families by reducing asthma attacks in children and preventing premature deaths and non-fatal heart attacks by reducing emissions of other harmful air pollutants, and will help to provide an incentive for further innovation to lower the costs of low-carbon energy.[40] Figure 3 shows the projected emissions reductions under the CPP. The base case bars refer to a world with all other current policies, while the rate-based and mass-based bars indicate what carbon dioxide emissions from the power sector are projected to be under the CPP if all states opt for each type of plan.

Figure 3: Clean Power Plan Projected Carbon Dioxide Emissions



Source: Environmental Protection Agency.

The rigorous benefit-cost analysis performed for the CPP projects that it will generate substantial net benefits to the U.S. economy. Given the flexibility afforded states in compliance with the CPP's emissions guidelines, estimates of benefits and costs are not definitive – both benefits and costs will depend on the compliance approaches states actually choose. Using federal estimates of the social cost of carbon dioxide (SC-CO2), discussed further below, along with estimates of the co-benefits from the CPP's reductions in health damages from fine particulate matter and ozone, the CPP's regulatory impact analysis projects net benefits to the U.S. economy in 2020 of $1.0 to $6.7 billion, depending on the compliance approaches states choose. Net benefit estimates increase significantly in later years, with a projected range of $16 - $27 billion in 2025, and $25 - $45 billion in 2030.[41]

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[38] EPA (2015b).
[39] EPA (2015b, 2015c).
[40] EPA (2015i).
[41] EPA (2015b). The regulatory impact analysis for the CPP reports estimates in constant 2011 dollars. In 2015 dollars, the net benefits to the U.S. economy would be $1.1 to $7.1 billion in 2020, $17 to $27 billion in 2025, and $26 to $47 billion in 2030.

Quantifying the Benefits of Avoided Carbon Emissions

Benefit-cost analysis is the well-known approach to determining whether any given policy will provide net benefits to society. Benefit-cost analysis of a policy that yields reductions of greenhouse gas emissions requires an estimate of the benefits of those reductions. The question is non-trivial, as estimating the impact of marginal increases in emissions requires calculations over long time spans and distributions of climate sensitivities and socioeconomic outcomes. To take on this task, the Obama Administration established a federal Interagency Working Group (IWG) in 2009 to develop estimates of the value of damages per ton of carbon dioxide emissions (or, conversely, the benefits per ton of emissions reductions). The resulting social cost of carbon dioxide (SC-CO2) estimates, developed in 2009-2010, provide consistent values based on the best available climate science and economic modeling, so that agencies across the federal government can now estimate the benefits to society of emissions reductions. Before these estimates were available, impacts of rules on greenhouse gas emissions had been considered qualitatively, or had been monetized using values that varied across agencies and rules. Creating a single SC-CO2 was an important step in ensuring that regulatory impact analysis of federal actions reflects the best available estimates of the benefits of reducing greenhouse gas emissions.

The IWG updated the original 2010 SC-CO2 estimates in May 2013 to incorporate refinements that researchers had made to the underlying peer-reviewed models. Since then, minor technical revisions have been issued twice – in November 2013 and in July 2015. Both of these resulted in insignificant changes to the overall estimates released in May 2013. The IWG also sought independent expert advice from the National Academies of Sciences, Engineering, and Medicine (NAS) to inform future updates of the SC-CO2 estimates. In August 2016, the IWG updated its technical support document to incorporate January 2016 feedback from the NAS by enhancing the presentation and discussion of quantified uncertainty around the current SC-CO2 estimates. The NAS Committee recommended against a near-term update of the estimates, themselves. Also in August 2016, the IWG issued new estimates of the social costs of two additional GHGs, methane (CH_4) and nitrous oxide (N_2O), applying the same methodology as that used to estimate the SC-CO2.

To estimate the SC-CO2, SC-CH4, and SC-N2O, three integrated assessment models (IAMs) are employed. IAMs couple models of atmospheric gas cycles and climate systems with aggregate models of the global economy and human behavior to represent the impacts of GHG emissions on the climate and human welfare. Within IAMs, the equations that represent the influence of emissions on the climate are based on scientific assessments, while the equations that map climate impacts to human welfare ("damage functions") are based on economic research that has studied the effects of climate on various market and non-market sectors, including its effects on sea level rise, agricultural productivity, human health, energy system costs, and coastal resources. Estimating the social cost of emissions for a given GHG at the margin involves perturbing the emissions of that gas in a given year and forecasting the increase in monetized climate damages relative to the baseline. These incremental damages are then discounted back to the perturbation year to represent the marginal social cost of emissions of the specific GHG in that year.

The estimates of the cost of emissions released in a given year represents the present value of the additional damages that occur from those emissions between the year in which they are emitted and 2300. The choice of discount rate over such a long time horizon implicates philosophical and ethical perspectives about tradeoffs in consumption across generations, and debates about the appropriate discount rate in climate change analysis persist (Goulder and Williams 2012, Arrow, et al. 2013, Arrow, et al. 2014). Thus, the IWG presents the SC-CO_2 under three alternative discount rate scenarios, and, given

(continued)

the potential for lower-probability, but higher-impact outcomes from climate change, a fourth value is presented to represent the estimated marginal damages associated with these “tail” outcomes (IWG 2015, IWG 2016). All four current estimates of the SC-CO2, from 2010-2050, are below.

Table B1: Social Cost of CO2 - 2010 - 2050 (in 2007 dollars per metric ton of CO2)

Discount Rate Year	5% Average	3% Average	2.5% Average	High Impact (95th Pct at 3%)
2010	10	31	50	86
2015	11	36	56	105
2020	12	42	62	123
2025	14	46	68	138
2030	16	50	73	152
2035	18	55	78	168
2040	21	60	84	183
2045	23	64	89	197
2050	26	69	95	212

Source: Interagency Working Group (2016).

Sources: IWG (2013, 2015, 2016), Goulder and Williams (2012), Arrow et al (2013, 2014).

Improving Energy Efficiency and Conservation

Since improving energy efficiency also reduces emissions, it too can help improve economic efficiency when correcting environmental externalities or information market failures. Administration initiatives have already succeeded in improving energy efficiency in millions of homes around the country, reducing energy costs, and cutting energy use by the Federal Government, with greater improvements forthcoming in future years. Technological shifts have aided greatly in efficiency improvements. For example, LED lighting has seen a nearly 90 percent decrease in cost per kilolumen since 2008. The costs of lithium-ion battery packs for electric vehicles have fallen from above $1,000/kWh in 2007 to under $410/kWh in 2014, with estimates for leading manufacturers coming in as low as $300/kWh.[42]

Improving Energy Efficiency in Buildings and Homes

In the President’s first term, the Departments of Energy and Housing and Urban Development completed energy efficiency upgrades in over one million homes, saving families on average more than $400 each on their heating and cooling bills in the first year alone. [43] The President

[42] Nykvist and Nilsoon (2015), DOE (2015j).

[43] White House (2016h).

also launched the Better Buildings Challenge in 2011, a broad, multi-strategy initiative to improve energy use in commercial, industrial, residential, and public buildings by 20 percent over ten years.[44] More than 310 organizations have committed to the Better Buildings Challenge, and the partners have saved over 160 trillion Btus of energy to date, leading to $1.3 billion in reduced energy costs.[45]

Conservation Standards for Appliances and Equipment

Since 2009, the Department of Energy's Building Technologies Office has issued 42 new or updated energy efficiency standards for home appliances, which are projected to save consumers more than $540 billion on their utility bills through 2030, and to cut carbon dioxide emissions by 2.3 billion metric tons.[46] The products covered by standards represent about 90 percent of home energy use, 60 percent of commercial building use, and 30 percent of industrial energy use, which taken cumulatively, represent around 40 percent of total primary energy use in 2015.[47] By 2030, the cumulative operating cost savings from all standards in effect since 1987 will reach nearly $2 trillion, with a cumulative reduction of about 7.3 billion tons of CO_2 emissions.[48]

Pricing the external costs from greenhouse gas emissions would increase the likelihood of consumers adopting these options on their own, but when the greenhouse gas-emitting energy is underpriced, then programs to help move consumers towards a more energy-efficient outcome can improve economic efficiency. Each of these standards has been subject to rigorous benefit-cost analysis, and each has economic benefits in excess of costs. This ensures that such standards not only reduce GHG emissions, but do so in an economically efficient way. For example new rules for commercial air conditioning and heating equipment sold between 2018 and 2048 are projected to have net economic benefits of $42 to $79 billion.[49]

Transportation

Since 2009, President Obama has implemented policies that reduce emissions from the transportation sector—one of the largest sources of U.S. greenhouse gas emissions.[50] Again, these policies can help internalize environmental externalities and address information market failures. Through improvements to the fuel economy of gasoline- and diesel-powered cars and trucks, and the technological progress that has been made on hybrid and electric drivetrains, the transportation sector has made substantial improvements to date, and the Administration has put policies in place to ensure that these improvements will continue for years to come. In addition, the Administration has continued to implement rules regarding Renewable Fuel Standards in ways that reduce the carbon intensity of our transportation sector.

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[44] DOE (2016f).
[45] DOE (2016g).
[46] DOE (2016b).
[47] Calculation based on total energy use by sector from the EIA's Monthly Energy Review (MER), Table 2.1.
[48] DOE (2016b).
[49] DOE (2016e). The net benefits of these new rules are represented in 2014 dollars. In 2015 dollars, these rules are expected to have slightly higher net benefits that round to the same figures ($42 to $79 billion).
[50] EPA (2016a).

GHG and Fuel Economy Standards for Cars and Trucks

Under this Administration, the EPA and the National Highway Traffic Safety Administration have issued GHG emission and fuel economy standards for light-duty passenger vehicles and the first-ever GHG and fuel economy standards for medium- and heavy-duty trucks. The latest set of standards for passenger vehicles will reduce new vehicle GHG emissions by nearly one half and nearly double the average new vehicle fuel economy.[51] Combined, the Phase 1 and Phase 2 GHG and fuel economy standards for light-duty vehicles are projected to reduce GHG emissions by 6 billion metric tons over the lifetime of vehicles sold from 2012 to 2025.[52] Building on the first-ever GHG and fuel economy standards for new medium- and heavy-duty vehicles built between 2014 and 2020, issued in 2011, EPA and NHTSA finalized "Phase 2" standards in 2016 that will further raise fuel economy for these vehicles through 2027. Combined, the Phase 1 and Phase 2 heavy-duty vehicle standards are expected to reduce GHG emissions by 2.5 billion metric tons over the lifetime of vehicles sold from 2014-2029.[53]

Achieving these goals will require a variety of innovations and investments by auto firms that they may have not previously undertaken because emissions are unpriced, because fuel efficiency is often undervalued by consumers, and because vehicle purchasers are not always the entities paying for the fuel.[54] These investments may unlock new technologies to further reduce transportation emissions. For example, firms with innovative low-emissions technologies may sell compliance credits or license technology to other firms, given the flexibility provisions in the vehicle emissions standards, providing an incentive for innovation.[55] Figure 4 shows fuel economy standards over time, including the major increase since 2008.

[51] NHTSA (2012).

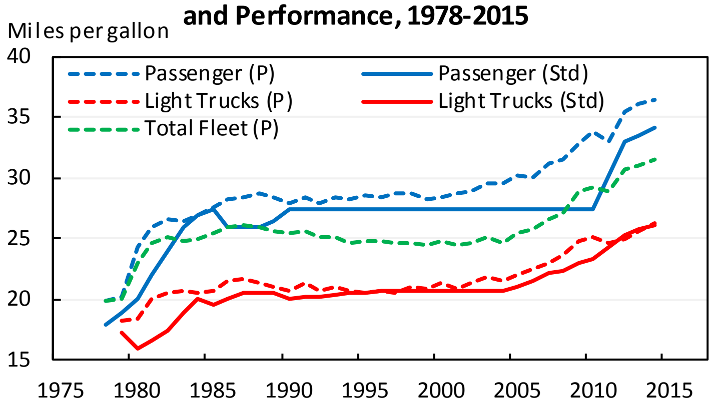
[52] EPA and NHTSA (2012).

[53] EPA and NHTSA (2016).

[54] The lack of investment may be due to multiple market failures including from the unpriced positive externalities from innovation (Bergek 2008).

[55] Economic theory and empirical evidence suggest that trading and other market-based approaches provide greater incentives for technological innovation than do prescriptive regulations that would achieve the same level of emissions reduction (Keohane 2003, Popp 2003).

Figure 4: Corporate Average Fuel Economy Standards and Performance, 1978-2015



Note: Dotted lines represent actual performance (P) and solid lines represent the relevant fuel economy standard (Std).
Source: Energy Information Administration

Developing Electric Vehicle (EV) Technology

In March 2012, the Administration launched "EV Everywhere," an electric vehicle Grand Challenge that seeks to make electric vehicles as affordable and convenient to own as gasoline-powered vehicles within the next decade.[56] Much of the focus of this initiative is to foster early-stage innovation, an endeavor that helps to address innovation market failures since the social return from such innovation is greater than the private return. EV Everywhere has already spurred dramatic technological and cost improvements in EV technology. In addition, since 2010 DOE investments through the Grand Challenge have contributed to a 50 percent reduction in the modeled high-volume cost of electric vehicle batteries, and DOE has invested in industry, national laboratory, and university projects that explore how to make EV batteries even more efficient and cost-effective.[57] Since the program's launch, hundreds of employers have joined the Workplace Charging Challenge pledging to provide charging access for their employees.[58] These policies are examples of some of the incentives the Administration has implemented to support EVs; others include tax credits for purchase of electric vehicles, support for domestic electric vehicle battery manufacturing, and more than $6 billion in ARRA funds for programs to promote research and development of advanced vehicle technologies.[59] Much like owning a car was difficult until enough people had cars that gas stations were plentiful, the network effects of electric vehicles provide an economic case for a policy push supporting the necessary services to move the industry towards critical mass.

[56] DOE (2012).
[57] DOE (2014b).
[58] DOE (2016j).
[59] CEA (2016c).

INVESTING IN CLEAN ENERGY RESEARCH AND DEVELOPMENT

Research and development in clean energy is essential to climate change mitigation because improved technologies will reduce the cost of producing and distributing clean energy. The research and development (R&D) market failure from imperfect appropriability of innovations—in which innovations spill over to other firms and the innovative firm cannot fully capture the returns—is particularly important in early stage R&D because the private return to basic innovation is relatively low and the social return is high. The gap between social and private returns to clean energy innovations is magnified by the additional environmental externalities that private firms do not internalize (Nordhaus 2011). Since many clean energy technologies are in fledgling stages and require foundational developments, the R&D market failure leads to significant underinvestment in R&D for those technologies, suggesting a role for policy.

The Obama Administration has made significant investments in clean energy R&D. The American Recovery and Reinvestment Act (ARRA) directed a substantial amount of its clean energy funding to research and development. This included funding for the Advanced Research Projects Agency – Energy (ARPA-E) program, which funds clean energy projects that are in early innovation stages and have high potential societal value. ARPA-E's first projects were funded by ARRA, and it has since sponsored over 400 energy technology projects. ARRA set a precedent for continued investment in clean energy R&D; subsequent fiscal budget proposals have included significant funding to continue such programs.

The 2013 Climate Action Plan structured the Administration's continuing commitment to investment in clean energy R&D. Consistent with the goals of the Plan, the DOE's Office of Energy Efficiency and Renewable Energy (EERE) launched the SunShot Initiative, which funds solar energy R&D. The EERE Wind Program funds R&D activity in wind energy technologies, including offshore and distributed wind. EERE's Geothermal Technologies Office conducts research on geothermal systems in order to lower the risks and costs of geothermal development and exploration. Additionally, EERE supports R&D in cleaner transportation technologies through a variety of programs: the Hydrogen and Fuel Cells Program funds basic and applied research to overcome the technical barriers of hydrogen production, delivery and storage technologies as well as fuel cell technologies. The Bioenergy program supports R&D in sustainable biofuels, with a focus on advanced biofuels that are in earlier stages of development but can take advantage of existing transportation infrastructure by providing functional substitutes for crude oil, gasoline, diesel fuel and jet fuel. The Vehicles Technologies Office funds R&D to encourage deployment of electric cars by developing advanced batteries, electric drive systems and lightweight vehicles. These efforts combined represent billions of dollars invested in clean energy R&D.

Public investment in R&D helps correct for private underinvestment due to market failures and moves investment towards efficient levels, allowing for cost reductions in clean energy use. Clean energy technology costs have declined significantly since 2008, and the Administration's R&D investments may have played a role in this trend. More importantly, these investments will help to ensure that positive trends in clean energy penetration and greenhouse gas emissions reductions continue into the future, since the economic benefits of R&D—particularly in early stage innovations—accrue over a very long time horizon.

Source: Nordhaus (2011).

Reducing Emissions from High Potency Greenhouse Gases

To further help address the environmental externality from greenhouse gas emissions, the Administration has also developed policies to reduce the emissions of other potent greenhouse gases, such as hydro-fluorocarbons (HFCs) and methane. When the President launched his Climate Action Plan in June 2013, he pledged to reduce emissions of HFCs through both domestic and international leadership.[60] Through actions like leader-level joint statements with China in 2013 and with India in 2016, the United States has been leading global efforts to secure an ambitious amendment to the Montreal Protocol to phase down HFCs. At the same time, we have taken important steps to reduce HFC consumption domestically under EPA's Significant New Alternatives Policy (SNAP), a Clean Air Act program under which EPA identifies and evaluates substitutes for industrial chemicals and publishes lists of acceptable and unacceptable substitutes. The Administration has also announced a suite of private sector commitments and executive actions that are projected to reduce HFCs equivalent to more than 1 billion metric tons of carbon dioxide emissions globally through 2025.[61]

The President has also taken steps to reduce methane emissions, which accounted for 10 percent of U.S. greenhouse gas emissions in 2014. In January 2015 the Administration set a goal of reducing methane emissions from the oil and gas sector by 40 to 45 percent from 2012 levels by 2025, which would save up to 180 billion cubic feet of natural gas in 2025—enough to heat more than 2 million homes for a year.[62] The Administration's commitment to this goal was reaffirmed and strengthened in March 2016 in a joint statement with Prime Minister Trudeau of Canada, in which both countries pledged to reduce methane emissions from the oil and gas sector and to explore new opportunities for additional reductions.[63] In May 2016, EPA finalized methane pollution standards for new and modified sources in the oil and gas sector, and the agency has taken the first steps toward addressing existing sources under forthcoming standards. EPA regulations promulgated in July 2016 will substantially reduce emissions of methane-rich gases from municipal solid waste landfills.

Climate Resilience

Even with all of the efforts to reduce emissions, the impacts of climate change are already occurring and will continue into the future. Ideally, economic estimates of climate change impacts will project the ability of individuals, firms and markets to adapt to these impacts (and the costs of such adaptation), and policies to encourage climate resilience will be informed by research on the degree of anticipated private investment in adaptation, and any anticipated gaps in such investment based on market failures or other factors. Relative to research on climate change damages and the impacts of mitigation, economic research on resilience is less developed, however, making it difficult to quantify the impacts of specific policies.

[60] EPA (2016b).
[61] White House (2015e).
[62] White House (2016a).
[63] White house (2016i).

The economic literature suggests that some impacts of climate change, particularly the rise in extreme temperatures, will likely be partly mitigated by increased private investment in air conditioning,[64] and that movement to avoid temperature extremes, either spending more time indoors in the short run, or relocating in the long run, could also reduce climate impacts on health.[65] Similarly, in the agricultural sector, farmers may switch crops, install or intensify irrigation, move cultivated areas, or make other private investments to adapt to a changing climate, and are likely to make at least some investments for which they experience net benefits in the long run, though existing evidence is mixed regarding the likely extent and impact of private adaptive responses in agriculture.[66] In terms of extreme events, countries that experience tropical cyclones more frequently appear to have slightly lower marginal damages from a storm,[67] suggesting some adaptive response. Recent work finds no evidence of adaptation to hurricane frequency in the United States, but significant evidence of adaptation for other OECD countries.[68]

Private adaptation measures are costly, and the extent to which they will mitigate climate impacts is uncertain. From an economic perspective, building resilience to the current and future impacts of climate change—a critical component of the President's Climate Action Plan—is prudent planning and akin to buying insurance against the future damages from climate change and their uncertain impacts.

[64] Deschênes (2014), Deschênes and Greenstone (2011), Barreca et al. (2016).
[65] Deschênes and Moretti (2009), Graff Zivin and Neidell (2014).
[66] Auffhammer and Schlenker (2014), Schlenker and Roberts (2013), Fishman (2012).
[67] Hsiang and Narita (2012).
[68] Bakkensen and Mendelsohn (2016).

BUILDING RESILIENCE TO CURRENT AND FUTURE CLIMATE CHANGE IMPACTS

The Obama Administration has implemented many policies and actions to support and enhance climate resilience. For example, in 2013, the President signed an Executive Order that established an interagency Council on Climate Preparedness and Resilience and a State, Local, and Tribal Leaders Task Force made up of governors, mayors, county officials, and Tribal leaders from across the country. The Task Force developed recommendations on how to modernize Federal Government programs to incorporate climate change and support community resilience to its impacts. The Administration has responded to a number of these recommendations, for example, by implementing the National Disaster Resilience Competition that made nearly $1 billion for resilient housing and infrastructure projects to states and communities that had been impacted by major disasters between 2011 and 2013. Government agencies have also provided additional support for Federal-Tribal Climate Resilience and support for reliable rural electric infrastructure. In addition, the Administration developed and launched a Climate Data Initiative and Climate Resilience Toolkit to improve access to climate data, information, and tools. A new Resilience AmeriCorps program was also established; through this program, AmeriCorps VISTA members are recruited and trained to serve low-income communities across the country by developing plans and implementing projects that increase resilience-building capacity.

The Department of Transportation (DOT) now includes improving resilience to the impacts of climate change as a primary selection criteria for its Transportation Investment Generating Economic Recovery (TIGER) grants, which provide $500 million in Federal funds to improve transportation infrastructure while generating economic recovery and enhancing resilience in communities. Similarly, the newly created FASTLANE grant program includes improving resilience to climate impacts as a primary selection criterion. In 2014, USDA created Climate Hubs in partnership with universities, the private sector, and all levels of government to deliver science-based information and program support to farmers, ranchers, forest landowners, and resource managers to support decision-making in light of the increased risks and vulnerabilities associated with a changing climate.

President Obama has also used executive action to establish a clear, government-wide framework for advancing climate preparedness, adaptation, and resilience, and directed Federal agencies to integrate climate-risk considerations into their missions, operations, and cultures. As of 2016, thirty-eight Federal agencies have developed and published climate adaptation plans, establishing a strong foundation for action. These plans will improve over time, as new data, information, and tools become available, and as lessons are learned and actions are taken to effectively adapt to climate change through agencies' missions and operations.

The Administration is developing government-wide policies to address shared challenges where a unified Federal approach is needed. For example, the Federal Government is modernizing its approach to floodplain management through the establishment of the Federal Flood Risk Management Standard (pursuant to E.O. 13690, Establishing a Federal Flood Risk Management Standard and a Process for Further Soliciting and Considering Stakeholder Input), in part to ensure that Federally-funded projects remain effective even as the climate changes and flood risk increases. To promote resilience to wildfire risks, E.O. 13728, Wildland-Urban Interface Federal Risk Mitigation, directs Federal agencies to take proactive steps to enhance the resilience of Federal buildings to wildfire through the use of resilient building codes. E.O. 13677, Climate Resilient International Development, promotes sound decision making and risk management in the international development work of Federal agencies. Pursuant to

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E.O. 13677, the Department of the Treasury, the U.S. Agency for International Development, the Millennium Challenge Corporation, the State Department, the U.S. Department of Agriculture, and other Federal agencies with international development responsibilities have established guidelines and criteria to screen projects and investments against potential climate impacts, with a goal of making these investments more climate resilient.

In March 2016, the President signed a Presidential Memorandum: Building National Capabilities for Long-Term Drought Resilience with an accompanying Action Plan. Drought routinely affects millions of Americans and poses a serious and growing threat to the security of communities nationwide. The Memorandum lays out six drought-resilience goals and corresponding actions, and permanently establishes the National Drought Resilience Partnership (NDRP) as an interagency task force responsible for coordinating execution of these actions. These actions build on previous efforts of the Administration in responding to drought and are responsive to input received during engagement with drought stakeholders, which called for shifting focus from responding to the effects of drought toward supporting coordinated, community-level resilience and preparedness.

III. Progress To-Date in Transitioning to a Clean Energy Economy

In recent years, the United States energy landscape has witnessed several large-scale shifts, with technological advances greatly increasing domestic production of petroleum and natural gas while renewable energy sources, particularly wind and solar energy, have concurrently seen a sharp rise in production. These shifts provide important context for the progress to date on decreasing greenhouse gas emissions, energy intensity, and carbon intensity. For example, renewable production provides zero carbon energy, while the rise in natural gas electricity generation, a relatively lower-carbon fossil fuel, has displaced some coal-based energy generation that had a higher carbon content.

In the past decade, the United States has become the largest producer of petroleum and natural gas in the world.[69] U.S. oil production increased from 5 million barrels per day (b/d) in 2008 to a peak of 9.4 million b/d in 2015, which sizably reduced U.S. oil imports. More importantly for climate outcomes, U.S. natural gas production increased from 20 trillion cubic feet (Tcf) in 2008 to 27 Tcf in 2015. Both increases were largely due to technological advances combining horizontal drilling, hydraulic fracturing, and seismic imaging.

The U.S. energy sector has simultaneously undergone a transformation toward lower-carbon energy resources. The United States has both reduced the energy intensity of its economic activity and shifted toward cleaner energy sources, both of which have reduced emissions. This section documents the progress made to date in the transition to a clean energy economy and analyzes the contribution of different factors to that transition. We consider the role of increased renewable energy production which provided additional zero carbon energy; increased energy efficiency which reduced energy consumption for a given amount of economic output; domestic natural gas production, which reduced gas prices relative to coal; and shocks to the economy, most notably the Great Recession which affected the level of GDP from which the recovery began.

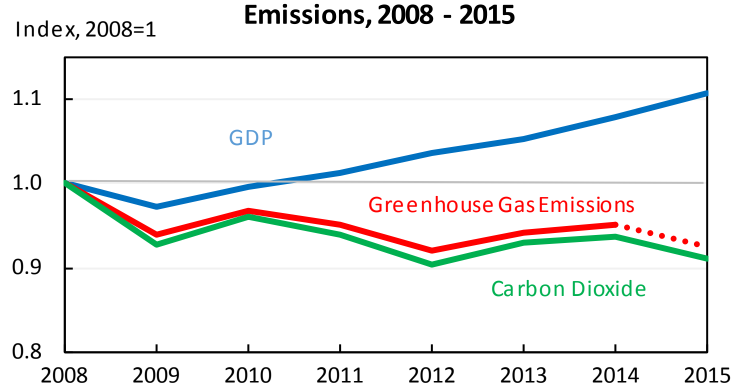
Reduced Growth in Greenhouse Gas Emissions

Greenhouse gas emissions, dominated by carbon dioxide emissions, grew steadily until 2008.[70] Since 2008, both carbon dioxide emissions and total greenhouse gas emissions have been declining. While the economic downturn in 2008-9 certainly contributed, Figure 5 shows that emissions have declined since 2008, while GDP has risen after a drop in the beginning of the period. Figure 6 shows that the decline since 2008 in carbon dioxide emissions from the electric power sector, which made up roughly 30 percent of total emissions in 2014, has been particularly noticeable.[71] In fact, carbon dioxide emissions from electricity generation in 2015 were the

[69] EIA (2016e).
[70] EPA (2016a).
[71] EPA (2016a).

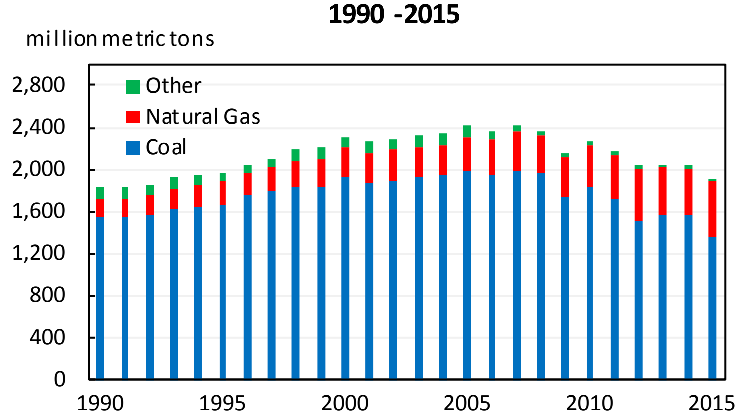
lowest since 1993, after peaking in 2007, and in the first half of 2016, carbon dioxide emissions from the energy sector in the United States were at the lowest level in 25 years. [72]

Figure 5: GDP and Greenhouse Gas and Carbon Dioxide Emissions, 2008 - 2015



Source: Environmental Protection Agency, Energy Information Administration, and Bureau of Economic Analysis.
Note: Total emissions from EPA is available through 2014; 2014-2015 trend is estimated using change in CO2 emissions from the energy sector from the EIA.

Figure 6: Electric Power Sector Carbon Dioxide Emissions 1990 -2015



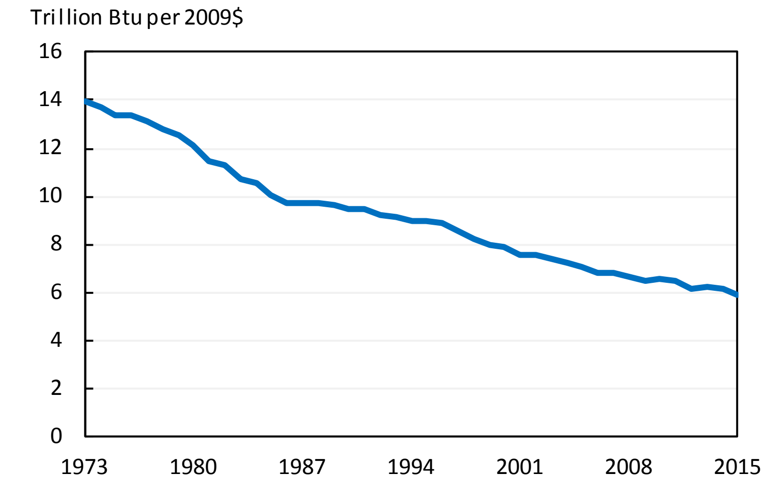
Source: Energy Information Administration.
Note: Other includes emissions from the petroleum, geothermal, and non-biomass waste electric sectors.

The decline in emissions, which has continued even as the economy has recovered, has stemmed from two major shifts in U.S. energy consumption patterns over the past decade: a decline in the amount of energy that is consumed per dollar of GDP and a shift towards cleaner energy. The amount of energy used to produce one dollar of real GDP in the United States, or the energy intensity of real GDP, has declined steadily over the past four decades, and today stands at less than half of what it was in the early 1970s (Figure 7). Since 2008, the energy intensity of real GDP has fallen by almost 11 percent (Figure 8). [73] Meanwhile, cleaner energy sources like natural gas

[72] EIA (2016a).
[73] The uptick in 2012 in Figure 8 is due to a number of early nuclear plant closures.

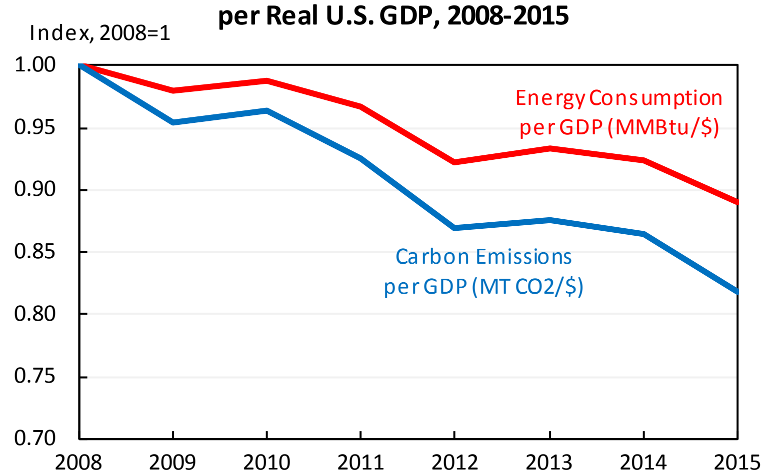
and zero-emitting sources like renewables have increasingly displaced the use of dirtier fossil fuel sources. This shift has led to an even larger decline in carbon emissions per dollar of real GDP, which is more than 18 percent lower in 2015 than it was in 2008 (Figure 8).

Figure 7: Energy Intensity of Real U.S. GDP, 1973-2015



Source: Energy Information Administration.

Figure 8: Carbon Emissions and Energy Consumption per Real U.S. GDP, 2008-2015



Source: Energy Information Administration.

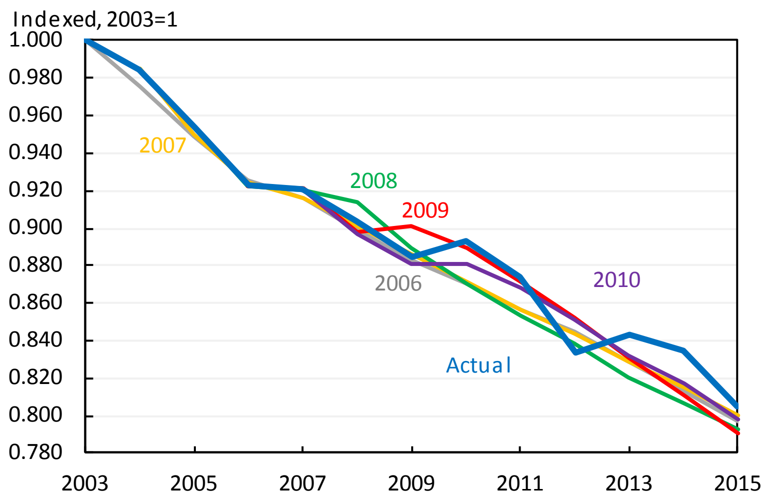
The next subsections discuss these trends, before turning to an analysis of how these trends have contributed to the decline in carbon dioxide emissions.

Declining Energy Intensity

Recently, total U.S. energy consumption has been falling – with consumption in 2015 down 1.5 percent relative to 2008. The fact that the U.S. economy is using less energy while continuing to grow reflects a decline in overall energy intensity that is due to both more efficient use of energy resources to complete the same or similar tasks and to structural shifts in the economy that have led to changes in the types of tasks that are undertaken. The continuation of these long-run changes is spurred by market forces and supported by energy efficiency policies and have been occurring for decades, as shown in Figure 7 above.

This continual trend of declining economy-wide energy intensity was also predictable based on historical projections from the U.S. Energy Information Administration (EIA).[74] Figure 9 plots both the observed decline in energy intensity in the U.S. economy, as well as EIA projections of the decline in energy intensity going back to 2003.[75] Not only has the decline in energy intensity been relatively steady, but it has tracked closely with predictions. Changes in energy intensity come from both policy and technological shifts. The fact that it has been predicted to decrease over time comes from assumptions that technology will continue to develop and policies will continue to encourage efficiency. With the extensive energy efficiency policies implemented by the Administration over the past several years, EIA projects energy intensity to decline another 17 percent by 2025.[76]

Figure 9: Energy Intensity Projections and Actual



Source: Energy Information Administration, CEA calculations.

Although the aggregate energy intensity has been steadily and predictably moving downward, aggregation masks differences across sectors of the economy. One notable example is the transportation sector, which has driven a decline in U.S. petroleum consumption relative to both recent levels and past projections.

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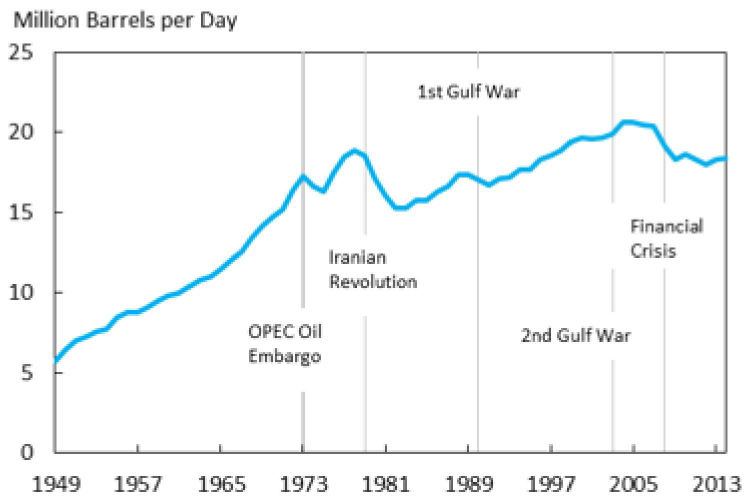
[74] EIA forecasts do include existing policies, as well as finalized policies with impacts in the future that have been projected at the time of the forecast.

[75] Figures 9, 12, 13, and 14a-14c use an index, with actual U.S. energy intensity in 2003 set equal to 1.0, and actual and projected energy intensity since 2003 expressed relative to that baseline. Projections use annual (negative) growth rates for energy intensity from the 2006, 2007, 2008, 2009, and 2010 EIA *Annual Energy Outlook*.

[76] EIA (2016a). Energy intensity (QBtu / GDP) metric is calculated from AEO 2016 reference case projections of annual energy use and GDP (EIA 2016a).

Petroleum consumption was 2 percent lower in 2015 than it was in 2008,[77] while the economy grew more than 10 percent over this same period. Over the longer term, petroleum consumption peaked in 2004, and the subsequent decline over the next several years surprised many analysts (Figure 10). The actual consumption of oil in 2015 was more than 25 percent below EIA projections made in 2003 for consumption that year. Moreover, the surprising decline in consumption relative to past projections is expected to grow over the next decade to 34 percent in 2025 (Figure 11). This trend through 2014 was primarily attributed to a population that was driving less and rising fuel economy in the light-duty fleet.[78]

Figure 10: U.S. Petroleum Consumption, 1949-2015

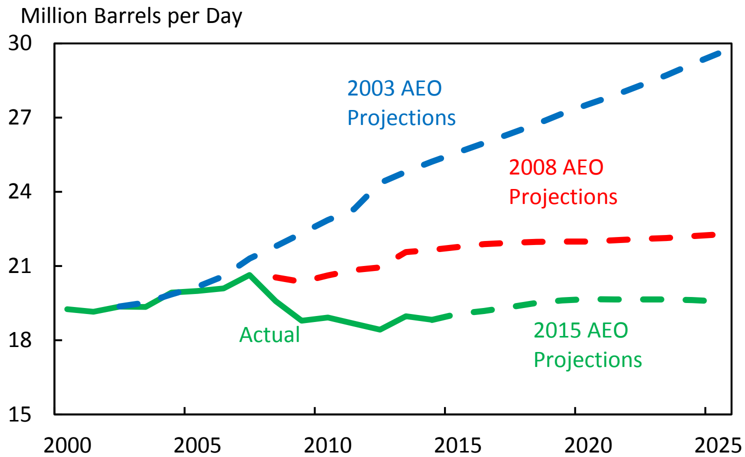


Source: Energy Information Administration.

[77]EIA (2016f).

[78] See CEA (2015) for a more detailed analysis. In 2015-2016, low gasoline prices have led to significant increases in vehicle miles travelled (VMT); VMT reached a 6-month record high in the first half of 2016 (Federal Reserve Bank of St. Louis 2016). Since low oil (and thus low gasoline) prices are expected to continue at least through the end of 2016 (EIA 2016c), the upward trend observed in 2015 may continue in 2016.

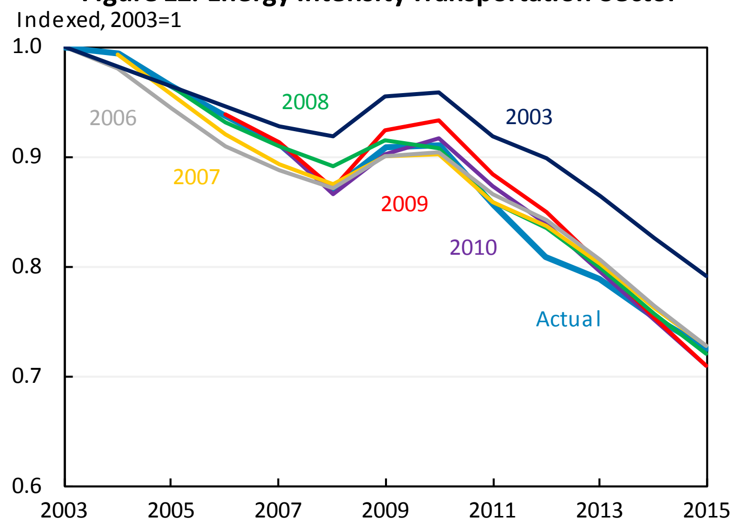
Figure 11: Total U.S. Petroleum Consumption, 2000-2025



Source: Energy Information Administration, Annual Energy Outlook (AEO).

With this petroleum consumption surprise, the energy intensity in the transportation sector has declined beyond that which was projected by EIA in 2003, as seen in Figure 12.

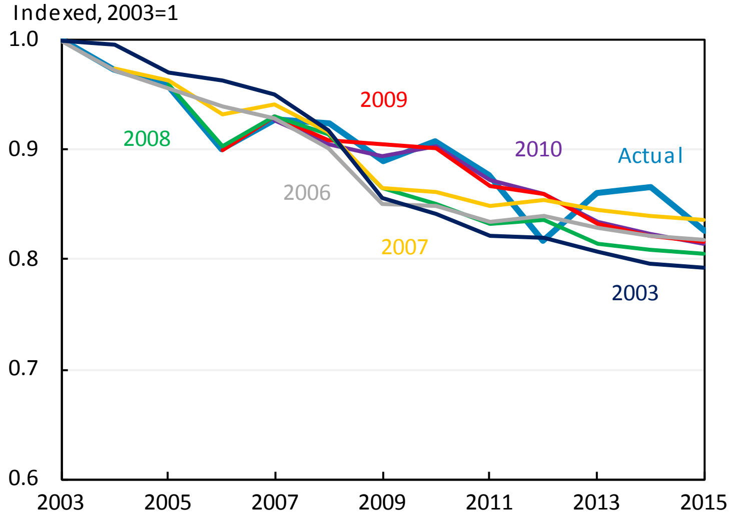
Figure 12: Energy Intensity Transportation Sector



Source: Energy Information Administration, CEA Calculations.

In contrast, the residential sector showed less of a decline in energy intensity than was projected by EIA in 2003, and even than in some later projections (Figure 13). The actual residential energy intensity did decline substantially—likely due in part to energy efficiency standards —but sits above the level that was projected in most prior years for 2015. This greater-than-expected energy intensity in the residential sector may be due to factors such as new electronic appliances being plugged in, a slow-down of replacement of older appliances after the economic recession began in 2008, or a shift in preference for house size or energy consumption at home.

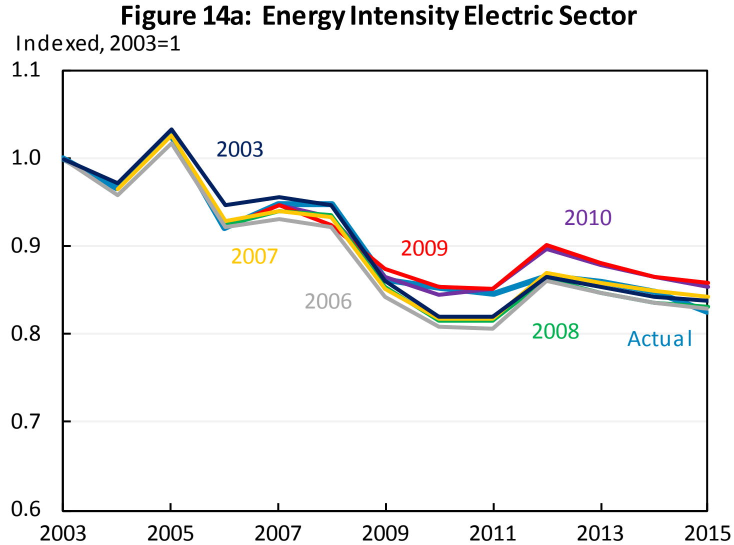
Figure 13: Energy Intensity Residential Sector



Source: Energy Information Administration, CEA Calculations.

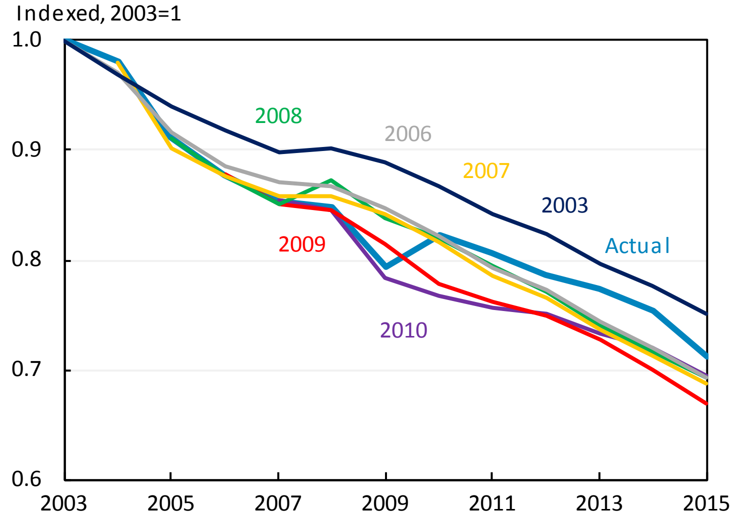
Energy intensity in the electric power and commercial sectors (Figures 14a and 14c, respectively) in 2015 tracked quite closely to prior projections. Actual 2015 energy intensity in the industrial sector (Figure 14b) was below what would have been predicted in 2003, though closer to later predictions.

Figure 14a: Energy Intensity Electric Sector



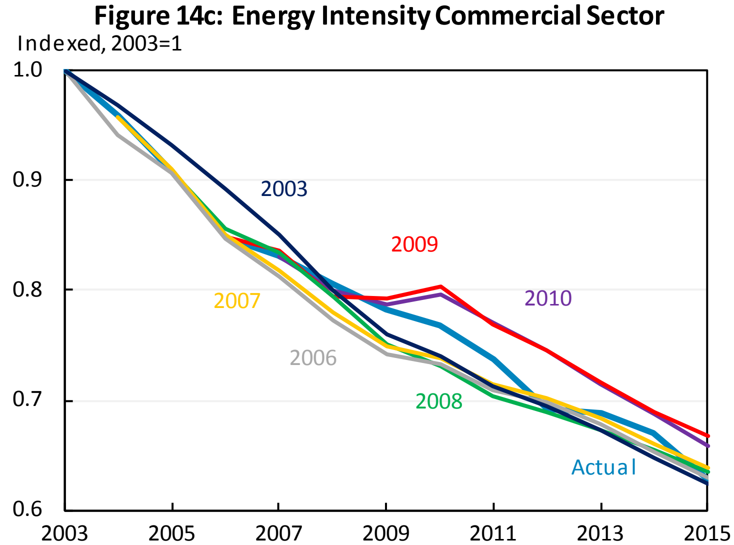
Source: Energy Information Administration, CEA Calculations.

Figure 14b: Energy Intensity Industrial Sector



Source: Energy Information Administration, CEA Calculations.

Figure 14c: Energy Intensity Commercial Sector

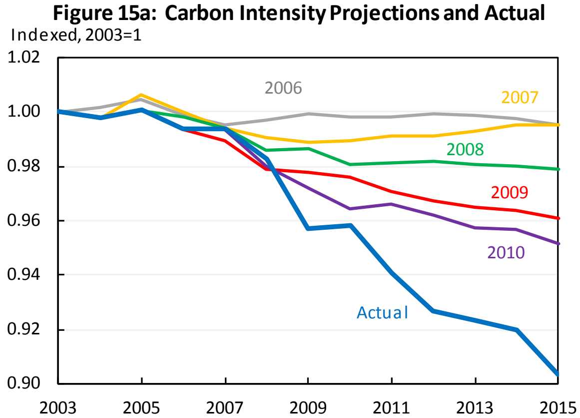


Source: Energy Information Administration, CEA Calculations.

Declining Carbon Intensity

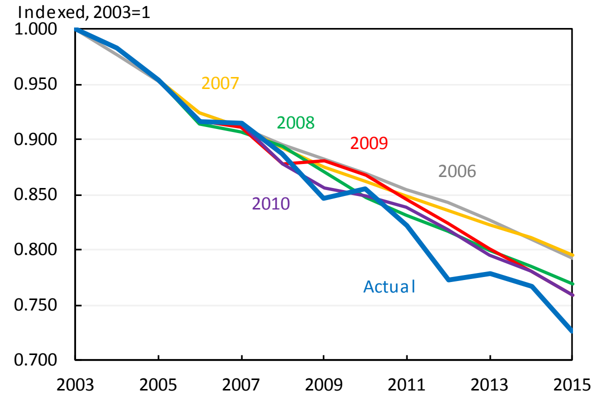
While the energy intensity of the economy has continued a relatively steady downward trend, carbon intensity—carbon emissions per unit of energy consumed—has had a much more dramatic shift, relative to projections, in the past decade. Projections made in 2008 and in prior years showed carbon intensity holding relatively steady. However, since 2008, carbon intensity has fallen substantially and continues to fall—leading to revised projections nearly every single year. Figure 15a shows the observed carbon emissions intensity of energy use in the U.S. economy, as well as several EIA projections. Beginning in 2008, these projections are all noticeably above the observed carbon intensity. Figure 15b shows that carbon emitted per dollar of GDP has also declined over this period, and declines exceed predictions.

Figure 15a: Carbon Intensity Projections and Actual



Source: Energy Information Administration, CEA calculations.

Figure 15b: Carbon Emissions per GDP Projections and Actual



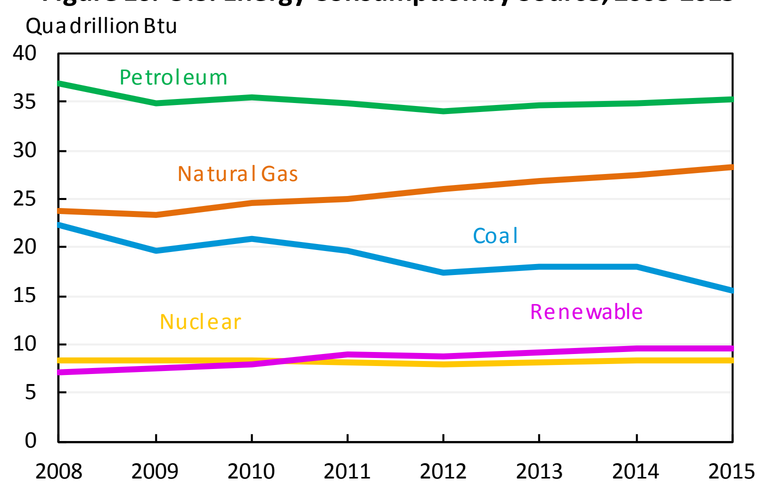
Source: Energy Information Administration, CEA calculations.

There are two primary reasons for the declining carbon intensity: a considerable shift to natural gas (a lower-carbon fossil fuel) and a remarkable growth in renewable energy, especially wind and solar.

Shift to Lower-carbon Fossil Fuels in the Power Sector

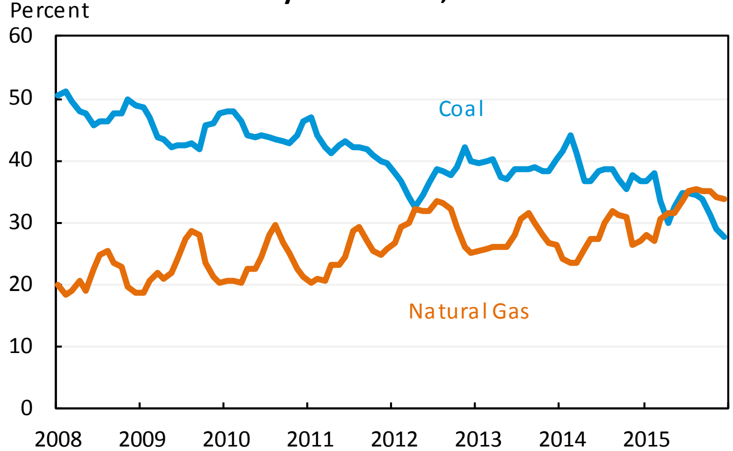
The shift to lower carbon fossil fuels can be seen in Figure 16. Since 2008, coal and petroleum consumption have fallen 30 and 4 percent, respectively. Meanwhile, natural gas consumption has risen by almost 19 percent, with much of this increase displacing coal for electricity generation. This is due, in large part, to the surge in U.S. natural gas production discussed earlier. In fact, the share of electricity generation using natural gas surpassed the share produced from coal in 2015 for the first time on record (Figure 17). As natural gas is a much lower-carbon fuel than coal for electricity generation, this shift has contributed to lower carbon intensity.

Figure 16: U.S. Energy Consumption by Source, 2008-2015



Source: Energy Information Administration.

Figure 17: Coal and Natural Gas Share of Total U.S. Electricity Generation, 2008-2015

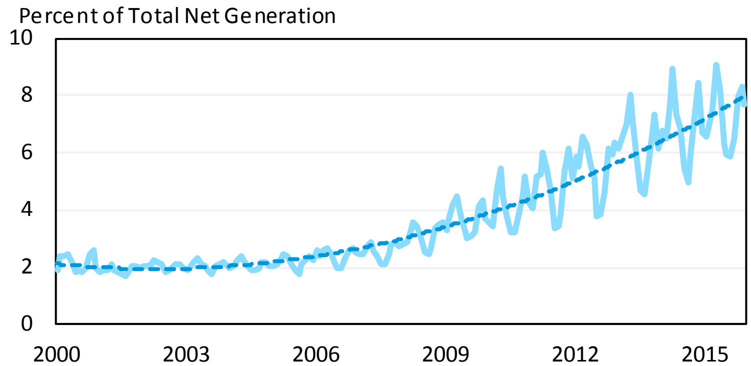


Source: Energy Information Administration.

Trends in Clean Energy

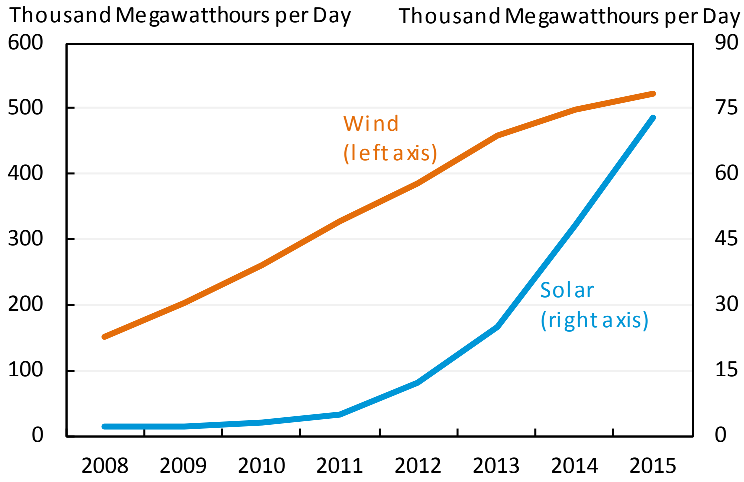
Clean energy has undergone notable trends since 2008: electricity generation from renewable energy has increased and costs of key clean energy technologies have fallen as there have been sizable efficiency gains in renewable energy. As seen in Figure 18, the share of non-hydropower renewables in U.S. electricity generation has increased from 3 percent in 2008 to 7 percent in 2015. Figure 19 shows that at the end of 2015, the United States generated more than three times as much electricity from wind and 30 times as much from solar as it did in 2008. Many factors have contributed to this growth, including improved technologies and falling costs, state renewable portfolio standards, other state and local policies, and the major Federal initiatives discussed earlier.

Figure 18: Monthly Share of Non-Hydro Renewables in Net Electric Power Generation



Note: Dotted line is a smoothed trend, shown to dampen the strong seasonal patterns (the share of non-hydro renewables drops during the winter and summer-both seasons of high power generation demand).
Source: Energy Information Administration.

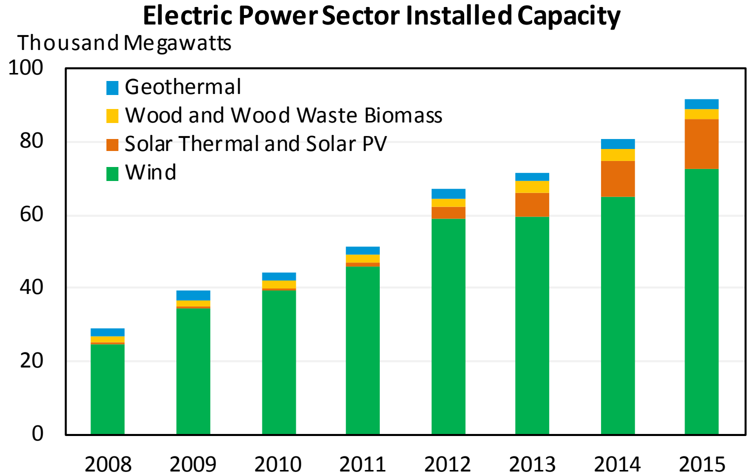
Figure 19: Electricity Generation from Wind and Solar



Source: Energy Information Administration.

This rapid growth in new electricity generation from renewable sources comes from rapid growth in renewable energy capacity. Electric generation capacity refers to the maximum output that a generator can produce, while electricity generation refers to the actual electricity produced. As illustrated in Figure 20, non-hydro renewable energy capacity in the United States more than tripled between 2008 and 2015, from less than 30 gigawatts to almost 100 gigawatts. Most of the increase was driven by growth in wind and solar capacity, and deployments in the first half of 2016 suggest a continuing trend. From January through June 2016, no new coal capacity was installed; solar, wind and natural gas added 1,883 MW, 2,199 MW, and 6,598 MW of new installed capacity, respectively, over the same period.[79]

Figure 20: U.S. Non-Hydro Renewable Energy Electric Power Sector Installed Capacity



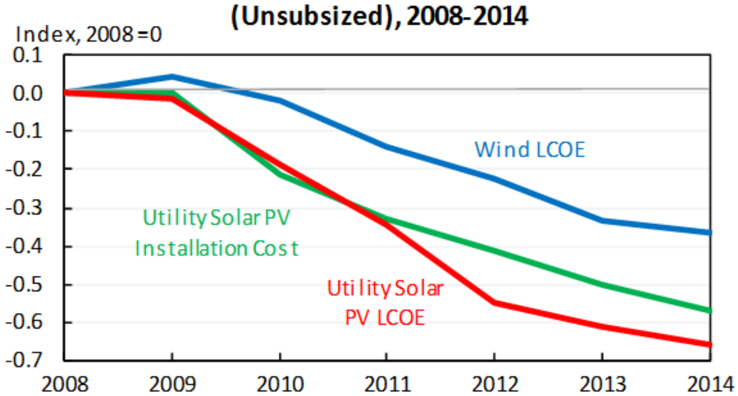
Source: Energy Information Administration.

[79] FERC (2016).

One reason for increases in renewable electricity generation and capacity is the decline in the cost of renewable energy as well as other notable clean energy technologies. A common metric for comparing cost competitiveness between renewable and conventional technologies is the "levelized cost of electricity" (LCOE). The LCOE can be interpreted as the per-kilowatt-hour cost (in real dollars) of building and operating a generating plant over an assumed financial life and duty cycle. Several key inputs are taken into account when calculating LCOE, including capital costs, fuel costs, fixed and variable operations and maintenance costs, financing costs, and an assumed utilization rate for each plant type (EIA 2015). Because solar and wind technologies have no fuel costs, their LCOEs are highly dependent on estimated capital costs of generation capacity and can vary substantially by region. While using the LCOE as a measure of technology cost has drawbacks, and energy project developers may not always rely on this metric when assessing project costs, it provides a helpful benchmark for understanding changes in technology costs over time.

Wind and solar LCOEs have fallen substantially since 2008. Figure 20 shows that the LCOE for onshore wind technologies has decreased on average by almost 40 percent from 2008 to 2014, based on unsubsidized LCOE, that is, the cost of wind electricity without considering the benefits from federal tax incentives. Installation costs for solar PV have decreased by 60 percent, and LCOE for solar has fallen by almost 70 percent. [80]

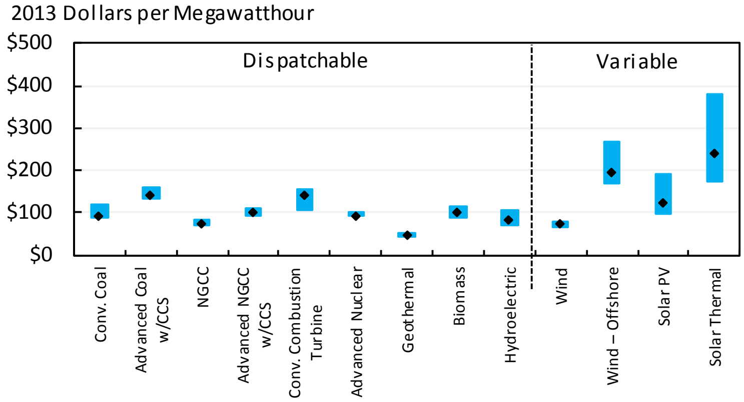
Figure 21: Change in Costs for Onshore Wind and Solar (Unsubsized), 2008-2014



Sources: Wind: NREL (2015), LBNL (2014), Lazard (2009, 2015), Bloomberg New Energy Finance (2015); Solar: LBNL (2015), NREL (2015), Lazard (2015), Bloomberg New Energy Finance (2015), GTM Research & Solar Energy Industries Association (2016), Fu et al. (2015).

[80] LBNL (2015), NREL (2015). LCOE for wind is estimated by average power-purchase agreement (PPA) prices plus estimated value of production tax credits available for wind, and average PPA prices for solar PV.

Figure 22: Total System LCOE Comparison Across Generation Technologies (Unsubsidized), 2020 Forecast



Note: Shaded region reflects minimum and maximum of range. NGCC is natural gas combined cycle. CCS is carbon capture and storage. PV is photovoltaics.
Source: Energy Information Administration.

Here the measure of LCOE does not include local, state and federal tax credits or other incentives for renewable energy. When these incentives are also considered, the cost declines described above mean that in many locations renewable energy costs are at or below the cost of fossil fuels. Renewables are truly reaching "grid parity," which means that the cost of renewables is on par with the cost of new fossil-generated electricity on the grid. Although wind and solar have been considered more expensive forms of new generation, current ranges of unsubsidized costs are showing some wind and solar projects coming in at lower costs than some coal generation. Further, forecasts show a trend toward increasing grid parity in the future. For example, forecasts for wind and solar PV costs from the EIA and the International Energy Agency (IEA) suggest that the unsubsidized technology cost of new wind and solar will be on par with or below that of new coal by 2020 (Figure 22).[81] Moreover, there are already places in the United States where new wind and solar can come online at a similar or lower cost than new coal.[82] Note that EIA projections suggest that the unsubsidized LCOE for wind and solar will continue to be above that for natural gas (conventional combined cycle), on average across the United States, in 2018 and 2022.[83]

Decomposition of the Declining Carbon Intensity

To better understand what is driving the declining carbon intensity, CEA estimates the portion of carbon intensity in electricity generation decline due to two factors: a reduced carbon intensity of fossil-fuel generation driven by a shift toward natural gas resources, and an increase in electric

[81] The larger bounds in costs for some renewable technologies, such as solar and off-shore wind, reflect a range of potential technology options that are being considering for future commercial deployment of these developing technologies.
[82] Wind: NREL (2015), LBNL (2014), Lazard (2009, 2015), Bloomberg New Energy Finance (2015); Solar: LBNL (2015), NREL (2015), Lazard (2015), Bloomberg New Energy Finance (2015), GTM Research & Solar Energy Industries Association (2016), Fu et al. (2015).
[83] EIA (2016a).

generation from renewable resources. To do so, we use an analytical approach that develops estimates of counterfactual emissions holding constant the carbon intensities of the electric generating portfolio in 2008.

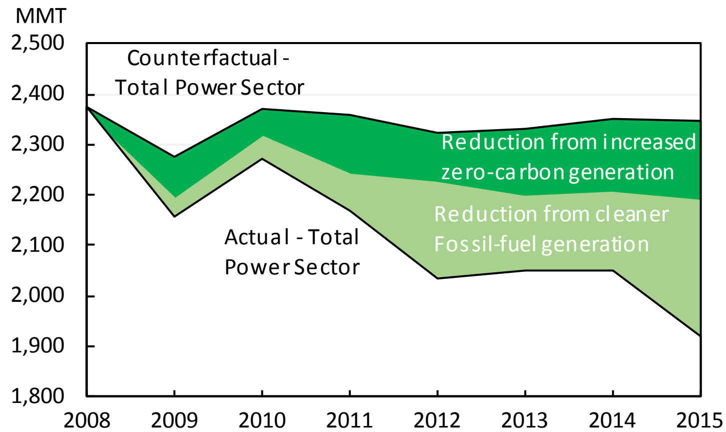
In particular, consider the case where the emissions factor associated with the portfolio of fossil-fuel electric generation, that is, the emissions per unit of energy generated from a fossil-fuel resource, in 2008 is held constant through 2015. As the emissions factor reflects the mix of resources in the fossil-fuel electric generating portfolio in 2008, this factor reflects the composition and efficiency of coal, natural gas, and petroleum generation resources in 2008. Applying this factor to the total electricity generated from fossil-fuel resources in 2009-2015 develops a counterfactual level of emissions had the portfolio of fossil-fuel resources remained constant in mix and efficiency over this time. Then, the difference between the quantity of emissions in the counterfactual and the observed emissions from electricity generated by fossil fuels during this time provides an estimate of emissions saved as a result of the reduction in carbon intensity of fossil-fuel electricity generation.[84] This reduction in carbon intensity is expected to stem primarily from increased natural gas generation, though would also include improvements in technical efficiency from fossil fuel resources. Much of the shift towards natural gas comes from rising supplies and falling prices of natural gas in the United States, though some may stem from policies that have aimed to account for and internalize some of the externalities of coal combustion.

Next, in a similar fashion, consider the emissions outcomes if the emissions factor from the entire portfolio of electricity generating resources in 2008 was held constant through 2015. The difference between these counterfactual emissions and total actual emissions from electricity generation would then represent the total avoided emissions from changes in the carbon intensity of the entire electricity portfolio. By subtracting total avoided emissions attributed to reduced carbon intensity from fossil fuel resources calculated as described above, the remaining difference between actual and counterfactual emissions can be attributed to an increase in resources with zero-carbon footprints, that is, an increase in the share of renewable energy resources.[85] For 2015, 284 million metric tons (MMT) (66 percent) of 428 MMT total avoided emissions was due to reduced carbon intensity from lower-carbon fossil resources, leaving 144 MMT (34 percent) attributable to increased generation from renewables. Figure 23 shows this decomposition from 2008 to 2015.

[84] This analytical approach holds fixed the observed kWh demand from fossil fuels and total power when estimating counterfactual emissions. To the extent that the shift to natural gas led to an increase in electricity demand, this approach would overstate the impact of coal-to-gas switching on reducing emissions.

[85] While this could include increased generation from nuclear power, the EIA shows that net generation from nuclear power remained fairly constant over the period, with an overall reduction in 2015 compared to 2008. Year to year fluctuations in nuclear or hydro power can affect annual changes in the contribution of non-carbon energy, but the overall result of significant contribution from non-hydro renewables over time is not altered by these sources, as both hydro and nuclear power saw small declines over the 2008-15 window.

Figure 23: Decomposition of Emission Reductions from Power Sector, 2008-2015



Source: Energy Information Administration, CEA Calculations.

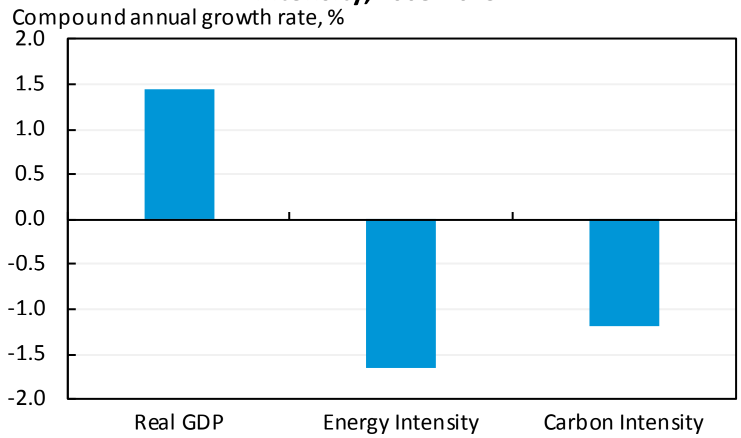
Decomposition of the Unexpected and Total Declines in Emissions

This section summarizes overall contributions to the observed emissions decline by decomposing reductions into those attributable to lower energy intensity, lower carbon intensity, and the difference from projections regarding the size of the economy in 2015. The decomposition analysis follows the methodology in CEA (2013), but with the added component of considering emissions from both "expected" and "unexpected" trends. The emissions considered in the analysis are energy-related carbon dioxide emissions, which comprised 97 percent of U.S. carbon dioxide emissions, and 83.6 percent of U.S. greenhouse gas emissions, in 2014.[86]

As an initial step, one could simply look at GDP growth, energy intensity, and the carbon intensity of energy production (Figure 24) to see what has influenced changes in emissions. Rising GDP, all else equal, causes an increase in emissions, but the declining energy intensity of output (energy usage per dollar of GDP) and the declining carbon intensity of energy (carbon emissions per energy usage) both pushed down on this tendency of emissions to rise as the economy grows.

[86] EPA (2016a).

Figure 24: Growth Rates of GDP, Energy Intensity and Carbon Intensity, 2008-2015



Source: Bureau of Economic Analysis, National Income and Product Accounts; Energy Information Administration, Monthly Energy Review (July 2016)

Alternatively, one can use expectations for the paths of these three variables to understand what drove emissions relative to a reasonable expectation in 2008. The general approach of this decomposition is to ask the following: starting in a given base year, what were actual or plausible projections of the values of GDP, energy intensity and the carbon intensity of energy out to the current year. These three values imply a projected value for the current level of carbon emissions. Then, relative to this forecast, what were the actual emissions, and what were the actual values of these three determinants of emissions? If, hypothetically, the forecasts of energy and carbon intensity were on track, but the GDP forecast differed from projections because of the (unexpected) recession, this would suggest that that the unexpected decline in carbon emissions was a consequence of the recession. In general, the forecasts of all the components will not match the realized outcomes, and the extent to which they vary – that is, the contribution of the forecast error of each component to the forecast error in carbon emissions – allows us to attribute shares of the unexpected decline in carbon emissions to unexpected movements in GDP, unexpected shifts in energy intensity, and unexpected shifts in carbon intensity.[87]

In the 2013 Economic Report of the President, this approach was performed to decompose emissions reductions from 2005 to 2012.[88] The analysis found that actual 2012 carbon emissions were approximately 17 percent below the "business as usual" baseline projections made in 2005, with 52 percent due to the lower-than-expected level of GDP, 40 percent from cleaner energy resources, and 8 percent from increased energy efficiency improvements above the predicted trend.

[87] Specifically, CO_2 emissions are the product of $(CO_2/Btu)\times(Btu/GDP)\times GDP$, where CO_2 represents U.S. CO_2 emissions in a given year, Btu represents energy consumption in that year, and GDP is that year's GDP. Taking logarithms of this expression, and then subtracting the baseline from the actual values, gives a decomposition of the CO_2 reduction into contributions from each factor.
[88] CEA (2013).

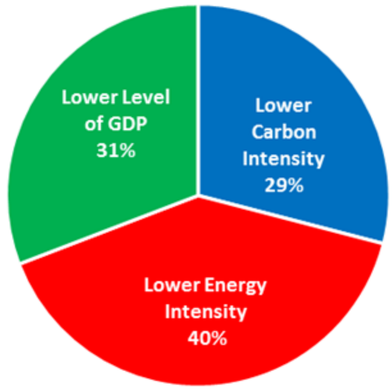
In new analysis, CEA has completed this decomposition approach in a similar fashion as in the 2013 Economic Report of the President, but over a different time frame: from 2008 to 2015 instead of from 2005 to 2012. In this decomposition, emissions in 2015 are compared to projections of emissions in 2015 made in 2008, based on the EIA's *Annual Energy Outlook* from 2008. Then, emissions reductions here can be seen as reductions above and beyond projections, or "unexpected" emissions reductions. As discussed above, energy intensity was projected to decline significantly over this time frame, and emissions reductions from energy intensity occurred largely as predicted. Thus, in this decomposition, energy intensity does not account for any of the "unexpected" emissions reductions, though it fell notably over the relevant time frame and contributed to realized declines in emissions. CEA's analysis suggests that 46 percent of unexpected emissions reductions in 2015 are attributable to a lower-than-predicted carbon intensity of energy, with the remaining 54 percent due to a lower level of GDP than projected in 2008.[89] The role GDP plays in the decomposition largely reflects the fact that the major financial crisis and recession were not anticipated in early 2008, when EIA's projections were made. However, a larger-than-expected decline in carbon intensity also contributes substantially and reflects other developments in recent years (for example, the shifts toward natural gas and renewables discussed earlier).

Figure 25 uses the same decomposition approach using the forecast of 2015 GDP to determine a "GDP surprise" but considers emissions reductions in 2015 compared to observed emissions in 2008, rather than projections for 2015. That is, the projections hold energy intensity and carbon intensity in 2008 constant over the period 2009-2015. In this manner, Figure 25 decomposes *total* emissions reductions since 2008 in a way that includes expected as well as unexpected movements in either energy intensity or carbon intensity.

Considering total emissions reductions compared to 2008, Figure 25 shows that 40 percent of total emissions reductions can be attributed to lower energy intensity, 29 percent to lower carbon intensity, and 31 percent to a lower level of GDP. The impact of lower energy intensity, while expected, was substantial.

[89] This is comparable to the CEA (2013) result.

Figure 25: Decomposition of Total CO_2 Emission Reductions, 2008-2015



Source: Bureau of Economic Analysis, National Income and Product Accounts; Energy Information Administration, Monthly Energy Review (August 2016) and Annual Energy Outlook (2008); CEA Calculations.

Decomposition of the Declines in Emissions by Sector

To further understand the decline in emissions since 2008, we consider emission declines separately by sector – residential, commercial, industrial, and transportation – and decompose total emission impacts from reduced energy intensity, reduced carbon intensity, and a lower level of GDP (due to unanticipated shocks, most notably the Great Recession) separately by sector. To perform the sector-by-sector analysis, we estimate the GDP contributions from each sector using data from the U.S. Bureau of Economic Analysis.[90] Then, we perform the same decomposition of total emissions reductions that was done for the economy as a whole in Figure 25.

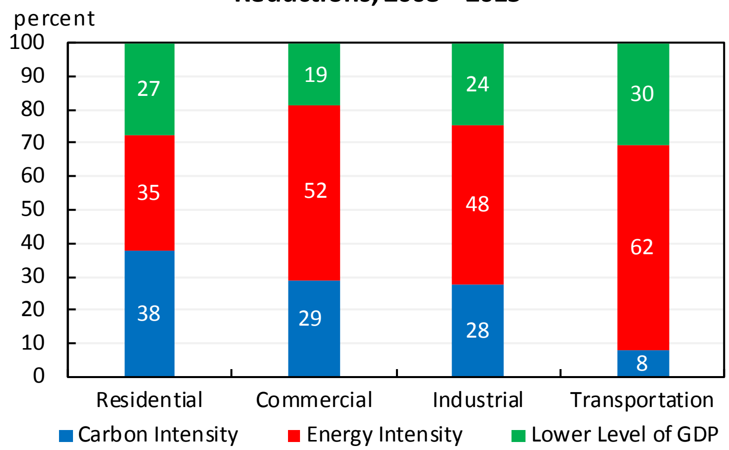
Results of the sectoral decomposition analysis are reported in Figure 26. In the residential sector, a lower level of GDP, lower energy intensity, and lower carbon intensity each played a similar role in reducing emissions from 2008 to 2015. For the transportation sector, a majority of emissions reductions (more than 60 percent) were due to a decrease in energy intensity. This finding could reflect the impact of increased fuel efficiency from light-duty vehicle fuel efficiency standards implemented by the Administration over this time, though the analysis cannot establish a causal link.[91] Reductions in energy intensity also played important roles (48-52 percent) in emissions reductions from the commercial and industrial sectors, possibly reflecting shifts toward less energy-intensive industries. Any influence of Administration energy efficiency policies (e.g., appliance standards) could also be captured here, though no causal link is established in this analysis.

[90] See the Appendix for more detail.

[91] Phase 1 of the first-ever medium- and heavy-duty vehicle standards, finalized in 2011, affected model years 2014-2018, so fuel economy standards for these larger vehicles could only have contributed to the energy intensity share at the very end of the period.

Lower carbon intensity also played a role in emissions reductions in the residential, commercial, and industrial sectors, responsible for 38, 29, and 28 percent of emissions reductions, respectively. In the residential sector, lower carbon intensity in regional electricity supply portfolios from shifts toward natural gas and zero-carbon energy resources would translate to reduced emissions from end-use electricity consumption. This impact would occur similarly for electricity-intensive commercial and industrial activities. Lower carbon intensity in the industrial sector could also result from substitution of lower-carbon natural gas for coal or oil in industrial processes.

Figure 26: Sectoral Decompostion of Total CO2 Emission Reductions, 2008 - 2015



Source: Bureau of Economic Analysis, National Income and Product Accounts; Energy Information Administration, Monthly Energy Review (August 2016); CEA Calculations.

How Administration Policies Meet Future Emissions Reductions Targets

In 2009, the President set a goal to cut emissions in the range of 17 percent below 2005 levels by 2020, a goal that was re-affirmed by the U.S. pledge at the 2009 United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties in Copenhagen. Subsequently, in 2015 the United States submitted its target to the UNFCCC to reduce emissions 26 to 28 percent below 2005 levels by 2025.[92] In the *2016 Second Biennial Report of the United States of America*, the U.S. presented results from an interagency effort to project the trajectory of GHG emissions through 2030, including the impact of U.S. policies and measures that have either been implemented or planned consistent with the Climate Action Plan. The report found that the implementation of all finalized and planned, additional policies, including measures which at the time had been proposed but not yet finalized, would lay the foundation to meet those targets.

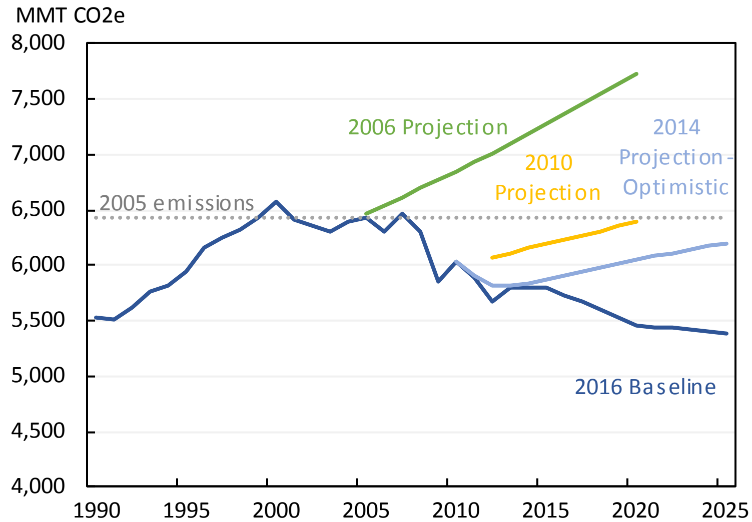
The estimates of U.S. GHG emissions take into account factors such as population growth, long-term economic growth, historic rates of technological change, and usual weather patterns. Projections for future emissions are modeled based on anticipated trends in technology

[92] White House (2015f).

adoption, demand-side efficiency gains, fuel switching, and implemented policies and measures. The report's estimates synthesize projected CO_2 emissions, non-CO_2 emissions, and CO_2 sequestration based on data from the Department of Energy, the Energy Information Administration, the Environmental Protection Agency, and the Department of Agriculture. The main source of uncertainty in emission projections is the range of land use, land-use change, and forestry projections (LULUCF), which approximate the ability of the land sector to remove CO_2 emissions from the atmosphere. The report therefore produces a range of projections using a set of modeling techniques from various agencies, which reflect differing perspectives on macroeconomic outlook, forest characteristics, and management trends. However, in part due to actions undertaken by the United States to bolster the forest carbon sink, the authors believe that the United States is trending toward a more high-sequestration ("optimistic") pathway.

The report estimates two emissions projection scenarios. The first, the *Current Measures* scenario, reflects the impact of those policies and measures that have been established up to mid-2015. This includes, most notably, the Clean Power Plan, more stringent light-duty vehicle economy standards, recent appliance and equipment efficiency standards, and actions to reduce agricultural emissions and bolster our forest carbon sink. However, the *Current Measures* scenario does not include measures that were not final at the time of the publication, such as then-draft standards for oil and gas methane, phase two heavy-duty vehicle standards, and the five-year extension of tax credits for wind and solar. Therefore, the *Current Measures* scenario underestimates the full impact of policies undertaken under the President's Climate Action Plan. Under the *Current Measures* scenario, GHG emissions are projected to decline 15 percent below the 2005 level in 2020 with an optimistic land sector sink (Figure 27). The effects of policies implemented under the Obama Administration are clear when comparing the 2015 projections to the 2006 projections, in which emissions were expected to increase by about 20 percent above 2005 levels by 2020. Clear progress in driving down projected GHG emissions can be seen since 2010 and even since 2014. The 2016 projections mark the first time a U.S. Climate Action Report has projected GHG emissions to fall based on existing policies because a large number of policies have been implemented in the past two years.

Figure 27: U.S. Net Emissions based on Current Measures

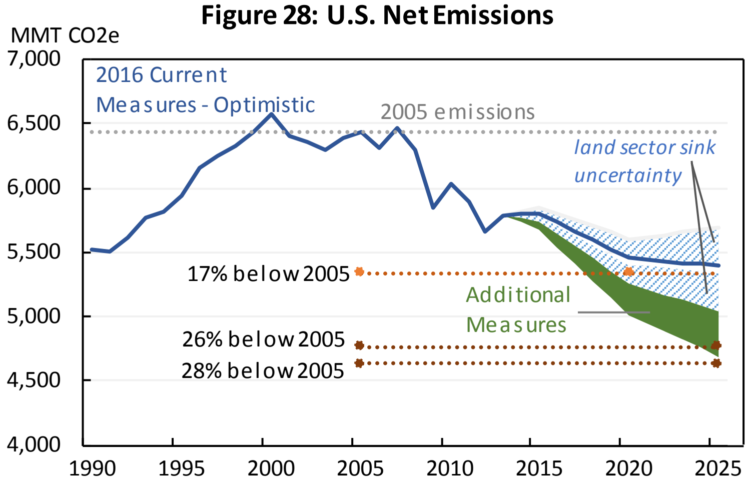


Source: U.S. Department of State (2016).
Note: The 2016 Baseline only includes policies finalized by mid-2015, so it underestimates the full impact of U.S. climate policies finalized under the Adminstration's Climate Action Plan through 2016.

Also in the report is an *Additional Measures* scenario that includes planned measures consistent with the Climate Action Plan, such as policies to cut methane and volatile organic compound emissions from oil and gas systems, and a proposed amendment to the Montreal Protocol to phase down production and consumption of hydrofluorocarbons. The report estimates the impact of planned policies separately on emissions of carbon dioxide, hydrofluorocarbons, methane and nitrous oxide. These estimates are synthesized and presented as a range due to uncertainty in policy implementation. The report projects that the *Additional Measures* scenario with an optimistic land sector sink will lead to emission reductions of at least 17 percent from 2005 levels in 2020, and 22-27 percent below 2005 levels in 2025 (Figure 28). Note that some of the policies included in the report as “additional measures” (for example, new GHG emissions standards for heavy-duty vehicles, and methane standards for new sources in the oil and gas sector) have already been finalized in 2016. If included, these would move the 2016 projection below its current position in Figure 28.

These projections show that recent administration actions on emission reduction policies are already moving the U.S. towards its targets. The additional implementation of currently planned policies will put the economy on track to meet the 2020 target and will build a foundation for meeting the 2025 target. Under this scenario, this level of emission reduction will occur even while the economy is projected to grow by 50 percent.

Figure 28: U.S. Net Emissions



Source: U.S. Department of State (2016).

Note: Major policies included in this figure as "additional measures" such as heavy-duty vehicle standards and methane rules for oil, gas and landfills have been finalized in 2016, and would further decrease the 2016 "current measures" projection if included.

IV. American Leadership in International Cooperation

As climate change mitigation is a global public good, international cooperation is essential for an effective and economically-efficient solution. The President's ambition and dedication to addressing climate change have helped transform the United States into a global leader on this issue. On December 12, 2015, more than 190 countries agreed to the most ambitious climate change mitigation goals in history.[93] The Paris Agreement establishes a long-term, durable global framework to reduce global greenhouse gas emissions where, for the first time ever, all countries commit to putting forward nationally determined contributions. The Agreement lays the foundation for countries to work together to put the world on a path to keeping climate warming well below 2 degrees Celsius, while pursuing efforts to limit the increase even more. [94] The nationally-determined contributions agreed to in Paris, though historic, will not halt climate change on their own, but the Paris Agreement provides a framework for progress toward that goal.

Building on Earlier Progress

In the lead up to the Paris Agreement in 2015, the United States worked bilaterally with many countries to build support for an ambitious Agreement in Paris. Most notably, starting in 2013, the United States and China intensified their climate cooperation, and in November 2014, President Obama and President Xi made a surprise announcement of their countries' respective post-2020 climate targets.[95] President Obama announced the ambitious U.S. goal to reduce emissions by 26 to 28 percent below 2005 levels by 2025, and China committed for the first time to implement policies leading to a peak in its carbon dioxide emissions around 2030 and an increase in the share of non-fossil fuels in primary energy consumption.[96] Further, in September 2015, President Obama and President Xi reaffirmed their commitment to a successful outcome in Paris, a shared determination to move ahead decisively in implementing domestic climate policies, strengthening bilateral coordination and cooperation on climate change, and promoting sustainable development.[97] In addition to working closely with China, the United States worked hand-in-hand with a broad range of countries to increase support for international climate action and an ambitious agreement in Paris, including with Brazil, Canada, India, Indonesia, Mexico, small islands, and many others.[98]

Mobilizing Climate Finance and Support for Developing Countries

The United States has remained a leader in the global effort to mobilize public and private finance for mitigation and adaptation. Since the 15th Conference of the Parties (COP-15) to the United

[93] White House (2015i).
[94] White House (2015i).
[95] White House (2014c).
[96] White House (2014c).
[97] White House (2015f),
[98] White House (2015h), White House (2015i), White House (2015g).

Nations Framework Convention on Climate Change in December 2009, the United States has increased its climate financing by fourfold for developing countries between 2010 and 2015.[99] In November 2014, President Obama pledged that the United States would contribute $3 billion to the Green Climate Fund to reduce carbon pollution and strengthen resilience in developing countries, the largest pledge of any country.[100] This strong U.S. pledge helped increase the number and ambition of other countries' contributions, and U.S. leadership helped propel initial capitalization of the fund to over $10 billion, a threshold seen by stakeholders as demonstrating serious donor commitment.[101]

At the Paris Conference, Secretary of State John Kerry announced that the United States will double its grant-based public climate finance for adaptation by 2020. As of 2014, the United States had invested more than $400 million per year of grant-based resources for climate adaptation in developing countries, providing support to vulnerable countries to reduce climate risks in key areas including infrastructure, agriculture, health, and water services.[102] The commitment that the United States and other countries have shown to mobilizing climate finance will help to support developing countries' transitions to low-carbon growth paths.

Sending Strong Market Signals

One of the most important components of the landmark Paris Agreement is that by sending a strong signal to the private sector that the global economy is transitioning toward clean energy, the Agreement will foster innovation that will allow the United States to achieve its climate objectives while creating new jobs and raising standards of living. The submission of ambitious national contributions in five-year cycles gives investors and technology innovators a clear indicator that the world will demand clean power plants, energy efficient factories and buildings, and low carbon transportation both in the short term and in the decades to come.[103]

Clean Energy Ministerial

The United States helped found the Clean Energy Ministerial, an ambitious effort among 25 governments representing around 75 percent of global greenhouse gas emissions and 90 percent of global clean energy investments. Through annual ministerial meetings (the U.S. hosted in 2010 and 2016), collaborative initiatives, and high-profile campaigns, the CEM is bringing together the world's largest countries, the private sector, and other stakeholders for real-world collaboration to accelerate the global clean energy transition. Twenty-one countries, the European Union, nearly 60 companies and organizations, and 10 subnational governments, made more than $1.5

[99] Department of State (2016a).
[100] White House (2014b).
[101] White House (2016a).
[102] White House (2015j).
[103] White House (2015i).

billion in commitments to accelerate the deployment of clean energy and increase energy access at the June 2016 Clean Energy Ministerial.[104]

Mission Innovation

On the first day of the Paris Conference, President Obama joined 19 other world leaders to launch Mission Innovation—a commitment to accelerate public and private global clean energy innovation. Twenty-two governments, representing well over 80 percent of the global clean energy research and development (R&D) funding base, have now agreed under Mission Innovation to seek to double their R&D investments over five years.[105] In addition, a coalition of 28 global investors committed to support early-stage breakthrough energy technologies in countries that have joined Mission Innovation.[106] The combination of ambitious commitments and broad support for innovation and technology will help ratchet up energy investments over the coming years, accelerate cost reductions for low-carbon solutions, and spur increasing greenhouse gas emissions reductions.

[104] https://www.whitehouse.gov/the-press-office/2016/06/02/fact-sheet-us-hosts-worlds-energy-ministers-scale-clean-energy-and-drive

[105] White House (2015d).

[106] White House (2015a).

V. Plans for the Future

Building on the progress to date in decreasing emissions and shifting toward a clean energy economy will require concerted effort over the coming years. Many of the policies and commitments begun by the President will have growing impacts over time, including several recently enacted policies mentioned above, as well as ongoing initiatives discussed below that form some of the next steps to continuing progress on climate issues. Also discussed below are some of the President's proposals for furthering clean energy goals that Congress has not yet acted upon, as well as potentially promising directions for longer-term climate policy.

North American 50 Percent Clean Energy Target

On June 29, 2016 at the North American Leaders Summit in Ottawa, Canada, Prime Minister Justin Trudeau, President Barack Obama, and President Enrique Peña Nieto announced the North American Climate, Energy, and Environment Partnership outlining several goals the three countries aim to achieve. Notably, a primary tenant of the Partnership is for North America to attain 50 percent clean power generation by 2025, including renewable, nuclear, and carbon capture, utilization and storage technologies, as well as demand reduction through energy efficiency. Each country will pursue these actions individually on a regional level by establishing specific legal frameworks and clean energy national goals, tailored to each country's unique conditions. Additionally, the three countries aim to drive down short-lived climate pollutants, such as reducing methane emissions from the oil and gas sector by 40-45 percent by 2025. Other elements of the national methane emissions-reducing strategies could target key sectors such as agriculture, and waste management. To improve energy efficiency, the Partnership intends to better align and further improve appliance and equipment efficiency standards: North American neighbors plan to align six energy efficiency standards or test procedures for equipment by the end of 2017, and to align ten standards or test procedures by the end of 2019. In order to advance integration of all clean energy sources, including renewables, the Partnership also strives to support the development of cross-border transmission projects that can play a key role in cleaning and increasing the reliability and flexibility of North America's electricity grid. At least six transmission lines currently proposed or in permitting review would add approximately 5,000 MW of new cross-border transmission capacity. The three economies will align approaches for evaluating the impact of direct and indirect greenhouse gas emissions of major projects, such as using similar methodologies to estimate the social cost of carbon and other greenhouse gases. In summary, the North American Climate, Clean Energy, and Environment Partnership Action Plan aims to advance clean and secure energy, drive down short-lived climate pollutants, promote clean and efficient transportation, protect nature and advance science, and show global leadership in addressing climate change.[107]

[107] White House (2016f).

Reforming the Federal Coal Leasing Program

Currently about 41 percent of U.S. coal is produced on federally-managed land, and this coal is responsible for about 10 percent of U.S. greenhouse gas emissions.[108] The President's 2016 State of the Union address called to "change the way we manage our oil and coal resources, so that they better reflect the costs they impose on taxpayers and our planet." Three days later, Department of the Interior Secretary Sally Jewell announced the first comprehensive review of the federal coal leasing program in over 30 years.[109] This announcement followed a series of listening sessions across the country starting in March 2015, initiated by Secretary Jewell, to consider if taxpayers and local communities were getting fair returns on public resources, how the coal leasing structure could improve in transparency and competitiveness, and how the federal coal program could be managed consistently with national climate change mitigation objectives.[110] The current structure neither prices externalities from coal combustion nor provides a fair return to taxpayers, making this review a crucial policy step (see CEA 2016a for discussion of the taxpayer fairness issues).

Through a Programmatic Environmental Impact Statement (PEIS) expected to be prepared over three years, the review will re-examine the Interior Department's current process to determine when, where, and how to provide leases and respond to feedback and concerns raised during the listening sessions as well as by the Government Accountability Office.[111] The review will inform how the Federal coal program can be reformed to provide a fair return to American taxpayers for public resources while considering the environmental and public health impact of federal coal production. The PEIS will also consider whether domestic coal exports should impact lease decisions and the impact of federal coal availability on the domestic energy portfolio, as well as on domestic and foreign coal markets.

While the review is underway, mining will continue under existing leases, but the Department of the Interior will pause new leases, with some limited exceptions. This is consistent with practices under the previous two programmatic reviews in the 1970s and 1980s. The Department of the Interior also announced a series of reforms to improve the transparency of the Federal coal program, including the establishment of a publicly available database to monitor carbon emissions from fossil fuels on public lands and to increase transparency from Bureau of Land Management (BLM) offices regarding requests to lease coal or reduce royalties. [112]

Proposals to Eliminate Fossil Fuel Subsidies

A transition to a clean energy economy means removing subsidies that encourage fossil fuel consumption and production, including the $4 billion in annual subsidies oil companies receive

[108] BLM (2016a).
[109] DOI (2016).
[110] BLM (2016b).
[111] GAO (2013).
[112] BLM (2016b).

from taxpayers. The President called on Congress to end these subsidies[113] and proposed eliminating inefficient fossil fuel subsidies in every Budget he has submitted, with the most recent Budget proposing to repeal $4 billion in subsidies to oil, gas, and other fossil fuel producers, as well as to expand the tax that supports the Oil Spill Liability Trust Fund to apply to oil sand crude oil.[114] Following through on these proposals is a step towards avoiding a policy bias towards fossil fuel energy consumption and giving clean energy production a more level playing field. Given the climate externalities associated with fossil fuel use, subsidizing fossil fuel consumption or production means that not only are the externalities unpriced, but more fossil fuels are consumed than a pure market outcome even without considering the externalities. Removing the subsidies moves the incentives towards the efficient outcome.

Proposal for 21st Century Clean Transportation

Announced in 2016, the President's 21st Century Clean Transportation Plan seeks to improve America's transportation accessibility and convenience, while reducing the emissions intensity of travel. The President's plan includes $20 billion in additional annual investments to reduce traffic and improve accessibility for work and school trips by expanding transit systems, adding high-speed rail in major corridors, modernizing freight systems, and supporting the Transportation Investment Generating Economic Recovery (TIGER) program, which provides grants for innovative transportation projects. The Plan also directs an additional $10 billion per year to support planning efforts by state and local governments to maximize the benefits of public investments. The funds will encourage land use planning and investments in infrastructure to support low-carbon transit options as well as the development of livable cities with resilient transit options. In addition, the Plan directs just over $2 billion per year toward the deployment of smart and clean vehicles and aircraft, supporting pilot deployments of autonomous vehicles, expanding the Diesel Emissions Reduction Act Grant Program, and investing in the safe integration of new technologies.

To fund these investments, the President proposed a $10 per barrel fee on oil, phased in gradually over five years. Revenues from the fee would provide long-term solvency for the Highway Trust Fund to maintain infrastructure, in addition to supporting new investments under the Plan. By placing a fee on oil, this policy would take a step towards ameliorating the current market failure that allows parties involved in emissions-generating activities to bear less than the full costs of that activity. Further, by directing revenues from the fee toward investments in a resilient and low-carbon transportation sector, the fee would incentivize private sector innovation and investment in clean transportation technologies.[115] A portion of the fee would also be directed to provide relief to vulnerable households.

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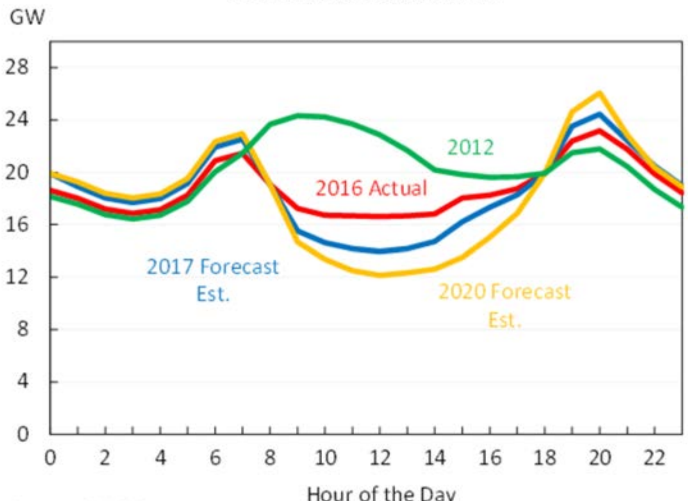
113 Slack (2012).
114 White House (2016e).
115 White House (2016b).

SUPPORTING INCREASING PENETRATION OF VARIABLE ENERGY WITH SMART MARKETS AND STORAGE

The two most rapidly growing renewable energy technologies, wind and solar, come with unique operating characteristics. The variable nature of their production profile creates new challenges for management of the electric grid, as compared to traditional generating resources with a more dispatchable output profile. For example, when considering the timing of output from wind and solar, the net electricity load, which is the demand for electricity less wind and solar generation, can exhibit a “duck curve” – where the low net load in the middle of the day ramps up quickly as the sun sets before trailing off as demand ebbs later at night – looking much like the neck, head, and bill of a duck. The figure below plots this curve for an illustrative spring day in California. We see that current levels of variable energy resource (VER) penetration begin to create this duck shape, increasingly so for future years, when VERs are projected to increase.

Net Load for March 31



Source: CAISO

In addition to the unique net load profile created by variable renewable resources, wind and solar output exhibits more idiosyncratic variation as compared to traditional resources, a feature which also creates additional grid management needs.

As penetration of variable energy resources has increased across the country and the world, so too has the development of technologies and operational changes to increase the flexibility of the electricity grid. In addition to increasing transmission, larger balancing areas, and system operational changes, smarter markets and energy storage and management systems can also support the flexibility requirements created by increased use of VERs. Smart markets, which refers to communications technologies and approaches that facilitate end-user responses in the demand for electricity, can be leveraged to allow demand to adjust to the true current cost of electricity. Dynamic electricity pricing structures, as well as technology that facilitates end-user adjustment of demand such as smart appliances, support integration of VERs by increasing the incentives and ability of consumers to modify their own electricity demand. Further, the recent proliferation of smart markets infrastructure with the deployment of 16 million smart meters since 2010 (DOE 2016h), lays the necessary foundation for these resources to support grid integration.

(continued)

Opportunities for energy storage to support integration are also rapidly expanding as the storage industry has seen dramatic cost reductions in the last decade from over $1,000 per KWh in 2007 to $400 per kWh today (Nykvist and Nilsoon 2015). Storage technologies support grid integration by temporarily storing electricity for later use during times of grid stress, as well as storing variable energy produced for use later that might otherwise be discarded due to low demand.

While analysts had previously claimed that variable energy penetration beyond 15 to 20 percent was not technically feasible (Farmer 1980, Cavallo 1993), instantaneous VER penetrations have already achieved high levels, with Texas hitting a record 45 percent of total penetration in March 2016 and Portugal running for four days straight on 100 percent renewables (wind, solar, and hydropower) (ERCOT 2016, APREN 2016). As more VERs increase the need and the value of grid flexibility, supporting the ability of smart markets and energy storage to provide grid integration services by ensuring that regulatory and electricity markets allow for the monetization of these resources will be critical to transition to an increasingly low-carbon grid (CEA 2016b).

Sources: CEA (2016b), CAISO (2016), DOE (2016h), Nykvist and Nilsoon (2015), ERCOT (2016), APREN (2016), Farmer (1980), Cavallo (1993).

Prospects for Carbon Pricing

In 2009, the President urged Congress to pass an energy bill that would have used market-based mechanisms to incentivize a clean energy transformation.[116] A bill with a proposed national cap-and-trade system passed in the House but was not voted upon in the Senate.[117] While over the President's terms the Administration has pursued a number of policies that indirectly price carbon-emitting activities, going forward, a widely-held view across a broad spectrum of economists is that policies that put a direct, uniform price on carbon are the most efficient and comprehensive way to both meet the goals set forth in the Paris Agreement and efficiently transition to a clean energy economy. Even with a comprehensive national carbon price, some additional federal climate policies (such as investments in clean energy research and development) would likely still be efficient.

[116] The New York Times (2009).
[117] Walsh (2010).

VI. Conclusions

As discussed in this report, the costs of climate change are large, the impacts are being felt now, and they will intensify in the future. Further, delaying policy action designed to halt climate change will likely increase its costs. There is strong economic rationale for policy to address climate change based on both correcting a market failure from the negative externality produced by greenhouse gas emissions, and as a form of insurance against catastrophes caused by global warming. Since the President took office, the United States has taken numerous steps to both mitigate climate change and respond to its effects. The Administration leveraged a diverse set of policy mechanisms, from tax credits for renewable energy technologies to the first-ever greenhouse gas emission standards for vehicles and power plants, to pivot the nation toward a greener economy while recovering from the Great Recession. With the implementation of these policies, renewable energy technology costs have declined, and deployment of clean energy technologies has increased. With the implementation of Administration policies, and with a concurrent increase in supply and decrease in the cost of natural gas, the carbon intensity of our electric portfolio has decreased, and the overall energy and carbon intensity of the economy has declined. All of these changes in the U.S. energy system, favorable to climate change mitigation, have occurred while GDP has risen.

Though the progress made to date in transitioning towards a clean-energy economy since 2008 presents only a portion of the Administration's accomplishments in the clean energy and climate change space, the future-looking policies established by this Administration, as well as proposals for further action, provide a pathway for the nation to continue this transformation to a low-carbon economy that achieves future emissions reductions goals. Some of the progress of the last eight years is due to policy and some from technological breakthroughs and changes in natural gas production. In order to meet U.S. climate goals, it will be essential to build on this progress by achieving the emissions reductions projected from a number of policies that are just beginning to be implemented, and by taking further actions. The Administration's significant investments in clean energy research and development also help to ensure that the decreases in carbon intensity and energy intensity analyzed here will continue over the long run.

Finally, as climate change is global in nature, the 2015 Paris Agreement provides a critical missing link between domestic and international climate goals. Adopted by over 190 countries in December 2015, the Agreement is the most ambitious climate change agreement in history, laying the foundation for a path to keep the global temperature rise well below 2 degrees while pursuing efforts to limit the increase even more.[118] The United States set a goal of a 2025 emissions level in the range of 26-28 percent below 2005 emissions levels, and the goals set forth in the President's Climate Action Plan provide a path for the United States to uphold this commitment. However, the work is not finished. Continued efforts in upcoming years are critical to achieving these goals and transitioning to an energy system that incorporates externalities into energy production and consumption decisions, moving toward economically efficient outcomes that support the goal of global climate change mitigation.

[118] White House (2015i).

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Appendix: Detail on Sectoral Emissions Decomposition Analysis

In order to do the decomposition on a sector-by-sector basis, consider that each of the four sectors contributes to a portion of GDP. To approximate a sector's GDP contribution, each sector is matched to category in the National Income Product Accounts (NIPA), with matchings below. Then, the percent of GDP is calculated for each sector. To calculate 2008 baseline projections, this observed contribution percent is multiplied by forecasts of GDP made in 2008. This way, the difference between the actual versus the baseline of sector GDP mirrors the difference between actual and projected GDP. Performing this mapping for each sector allows for the same identity to be used to decompose emissions in the total economy as for the sector by sector decomposition.

The energy consumption and emissions included for each sector can be found in EIA glossary and documentation materials for the Monthly Energy Review (MER) Tables 2.1 and Tables 12.2 – 12.5.

Residential sector
The account category used to approximate GDP contribution is the category for "Housing and Utilities", within Personal Consumption Expenditure - Services - Household Consumption Expenditures.

Transportation Sector
The account category used to approximate GDP contribution is the category "Transportation", within
Personal Consumption Expenditures - Services - Household Consumption Expenditures.

Industrial Sector
The account category used to approximate GDP contribution is the category "Goods", within Personal Consumption Expenditures.

Commercial Sector
The account category used to approximate GDP contribution is the category "Services" within Personal Consumption Expenditures.

EXHIBIT 5

Vox

TOPICS TRENDING

No country on Earth is taking the 2 degree climate target seriously

If we mean what we say, no more new fossil fuels, anywhere.

Updated by David Roberts · @drvox · david@vox.com · Oct 4, 2016, 7:00a

TWEET SHARE

Is it warm in here? | (Shutterstock)

One of the morbidly fascinating aspects of climate change is how much cognitive dissonance it generates, in individuals and nations alike.

The more you understand the **brutal logic of climate change** — what it could mean, the effort necessary to forestall it — the more the intensity of the situation seems out of whack with the workaday routines of day-to-day life. It's a species-level emergency, but almost no one is *acting* like it is. And it's very, very difficult to be the only one acting like there's an emergency, especially when the emergency is abstract and science-derived, grasped primarily by the intellect.

This **psychological schism** is true for individuals, and it's true for nations. Take the Paris climate agreement.

In Paris, in 2015, the countries of the world agreed (**again**) on the moral imperative to hold the rise in global average temperature to under 2 degrees Celsius, and to pursue "efforts to limit the temperature increase to 1.5 degrees." To date, 62 countries, including the United States, China, and **India**, have ratified the agreement.

Are any of the countries that signed the Paris agreement taking the actions necessary to achieve that target?

No. The **US is not**. Nor is the **world as a whole**.

The actions necessary to hold to 2 degrees, much less 1.5 degrees, are simply outside the bounds of conventional politics in most countries. Anyone who proposed them would sound crazy, like they were proposing, I don't know, a **war** or something.

So we *say* 2 degrees is unacceptable. But we don't *act* like it is.

This cognitive dissonance is brought home yet again in a **new report** from Oil Change International (in collaboration with a bunch of green groups). It's about fossil fuels and how much of them we can afford to dig up and burn, if we're serious about what we said in Paris. It's mostly simple math, but the implications are vast and unsettling.

Let's start from the beginning.

Staying beneath 2 degrees means immediately and rapidly declining emissions

Scientists have long agreed that warming higher than 2 degrees will result in widespread food, water, weather, and sea level stresses, with concomitant immigration, conflict, and suffering, inequitably distributed.

But 2 degrees is not some magic threshold where tolerable becomes dangerous. A two-year review of the latest science by the UNFCCC **found** that the difference between 1.5 and 2 degrees means heat extremes, water shortages, and falling crop yields. "The 'guardrail' concept, in which up to 2°C of warming is considered safe," the review concluded, "is inadequate."

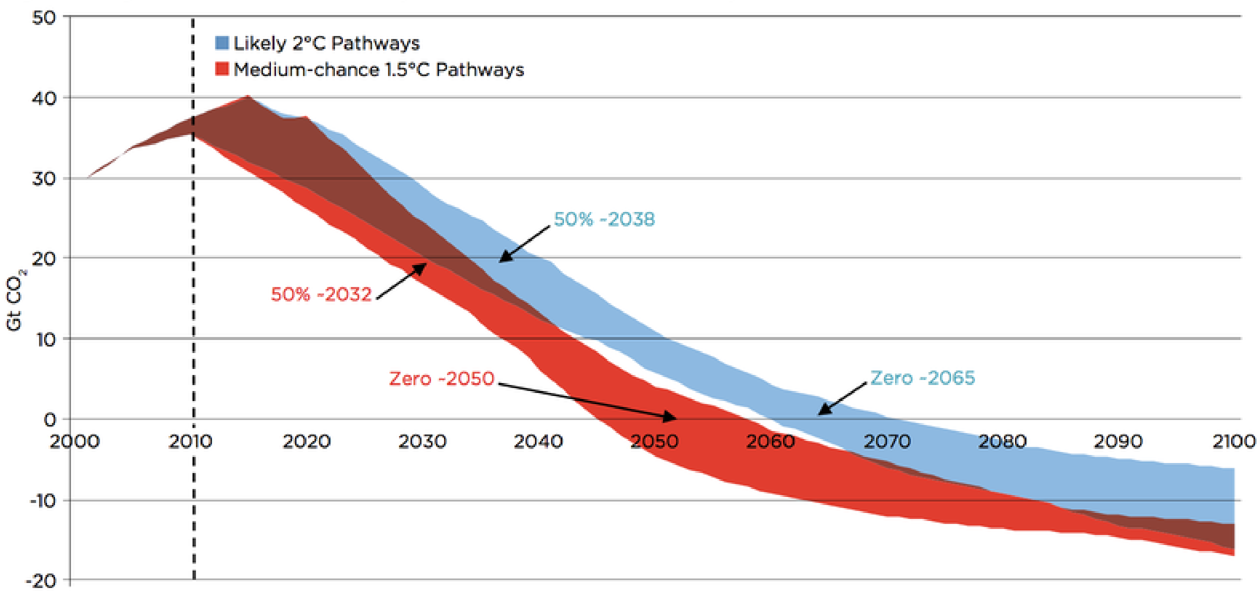
The report recommends that 2 degrees be seen instead as "an upper limit, a defense line that needs to be stringently defended, while less warming would be preferable."

This changing understanding of 2 degrees matters, because the temperature target we choose, and the probability with which we aim to hit it, establishes our "carbon budget," i.e., the amount of CO2 we can still emit before blowing it.

Many commonly used scenarios (including the **International Energy Agency's**) are built around a 50 percent chance of hitting 2 degrees. But if 2 degrees is an "upper limit" and "less warming would be preferable," it seems we would want a higher than 50-50 chance of stopping short of it.

So the authors of the Oil Change report choose two scenarios to model. One gives us a 66 percent chance of stopping short of 2 degrees. The other gives us a 50 percent chance of stopping short of 1.5 degrees. Here's what they look like:

Figure 1: Range of Global Emissions Pathways in Scenarios Consistent with Likely Chance of 2°C or Medium Chance of 1.5°C[18]



Sources: Joeri Rogelj et al

(Oil Change International)

This image should terrify you. It should be on billboards.

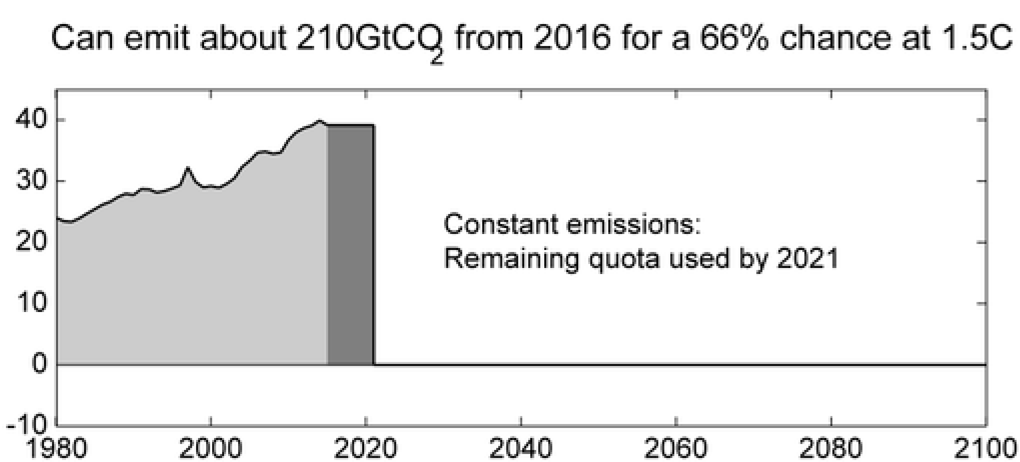
As you can see, in either scenario, global emissions must peak and begin declining immediately. For a medium chance to avoid 1.5 degrees, the world has to zero out net carbon emissions by 2050 or so — for a good chance of avoiding 2 degrees, by around 2065.

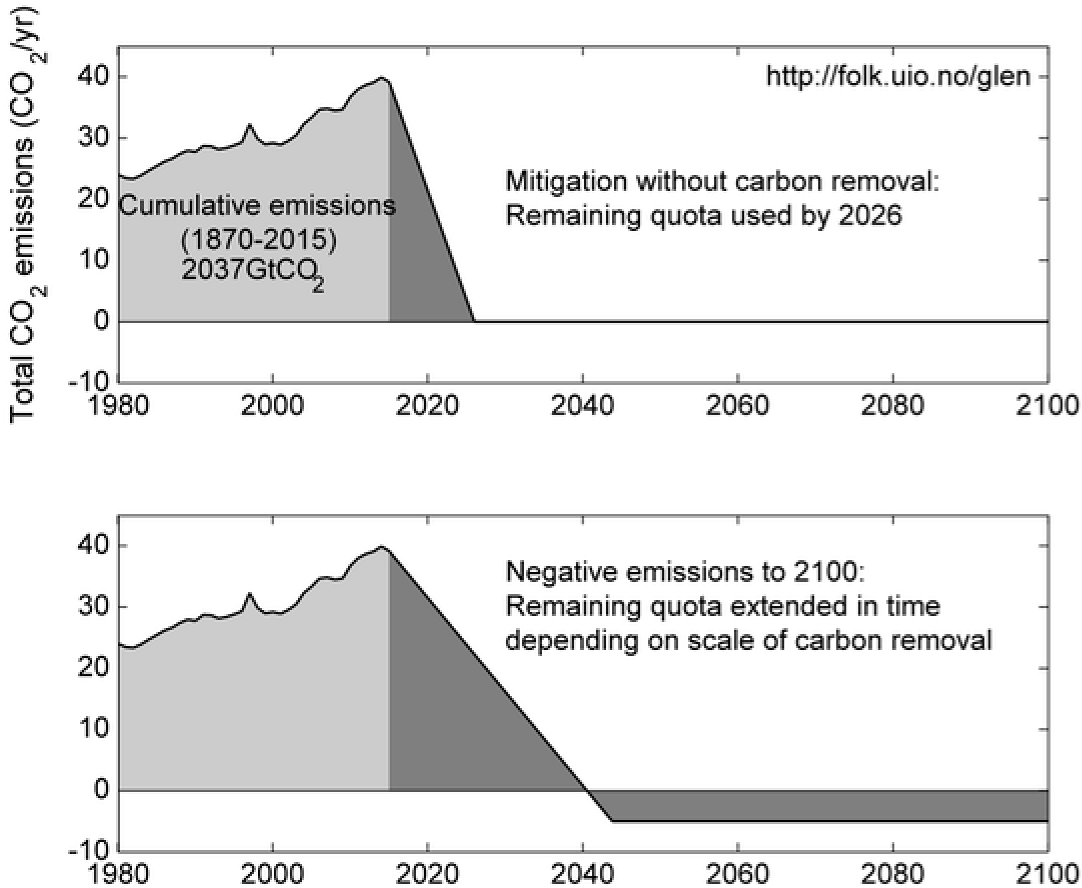
After that, emissions have to go negative. Humanity has to start burying a lot more carbon than it throws up into the atmosphere. There are several ways to sequester greenhouse gases, from reforestation to soil enrichment to **cow backpacks**, but the backbone of the envisioned negative emissions is **BECCS**, or bioenergy with carbon capture and sequestration.

BECCS — raising, harvesting, and burning biomass for energy, while capturing and burying the carbon emissions — is unproven at scale. Thus far, most demonstration plants of any size attaching CCS to fossil fuel facilities have been **over-budget disasters**. What if we can't rely on it? What if it never pans out?

"If we want to avoid depending on unproven technology becoming available," the authors say, "emissions would need to be reduced even more rapidly."

You could say that. This is from **climate researcher Glen Peters**, based on a scenario with a 66 percent chance of avoiding 1.5 degrees.





(Glen Peters)

Check out that middle graphic. If we really want to avoid 1.5 degrees, and we can't rely on large-scale carbon sequestration, then the global community has to zero out its carbon emissions by 2026.

Ten years from now.

There's no happy win-win story about that scenario, no way to pull it off while continuing to live US lifestyles and growing the global economy every year. It would require immediate, radical shifts in behavior worldwide, especially among the wealthy — a period of voluntary austerity and contraction.

That seems unlikely. So instead, let's assume copious negative emissions technology will be available in the latter half of the century, just to give ourselves the most room possible.

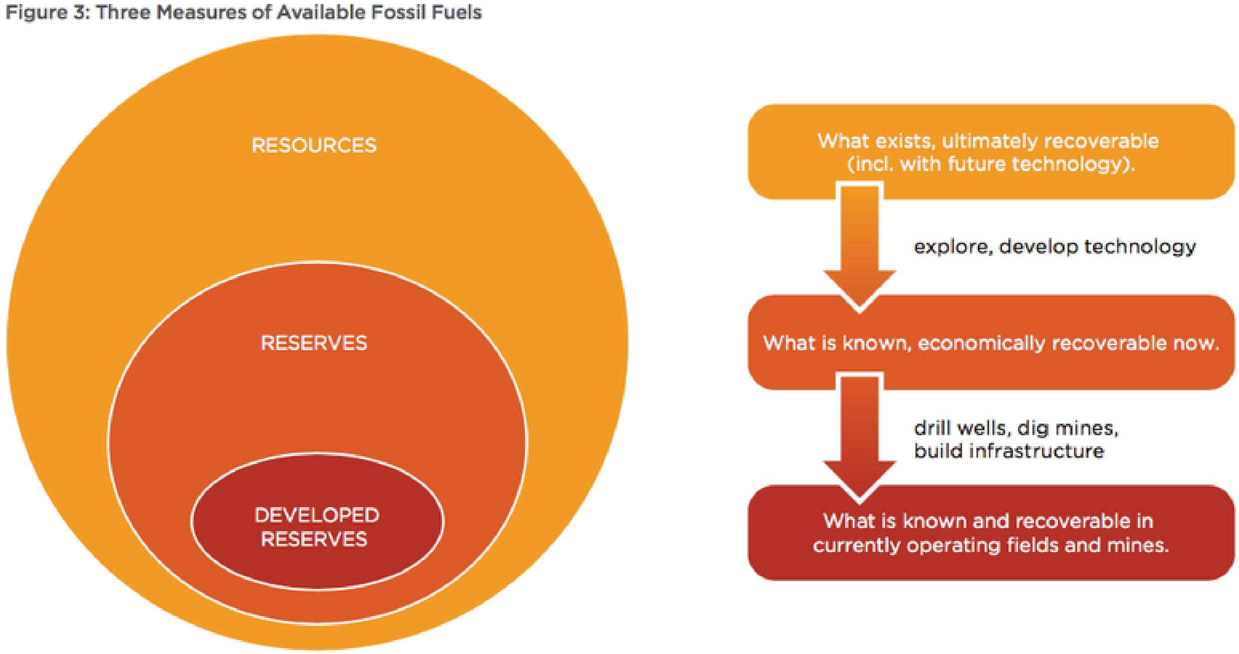
In those scenarios, how much of the world's fossil fuels can we burn? How much more can we find and dig up?

That math is daunting.

Staying beneath 2 degrees means ceasing all new fossil fuel development

First, a quick tour of terminology. There are fossil fuel resources (what is ultimately recoverable), reserves (what is known and economically recoverable), and developed reserves (what is known and recoverable in currently operating mines and fields). Here's a handy guide:

Figure 3: Three Measures of Available Fossil Fuels

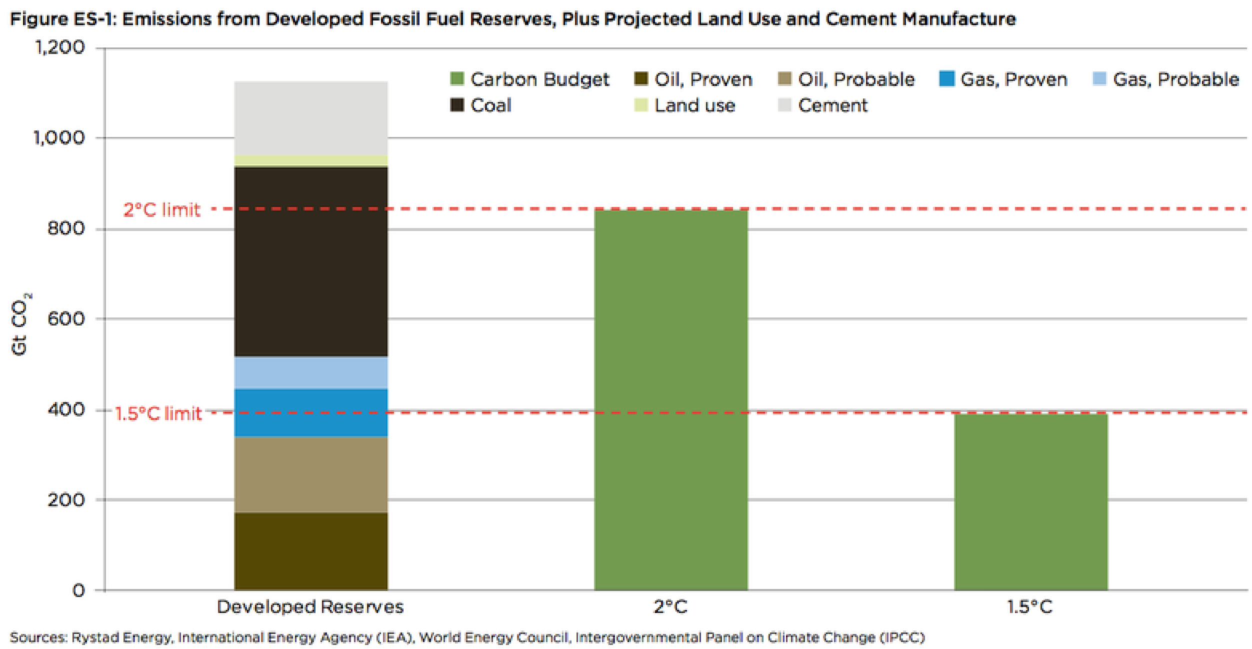


Source: Oil Change International. Not to scale.

(Oil Change International)

Now let's compare some numbers. It's pretty straightforward. Roughly 95 percent of the carbon contained in fossil fuels gets released into the atmosphere, so a ton dug up means a ton emitted, more or less.

How do our carbon budgets compare with our fossil fuel reserves?



(Oil Change International)

Another terrifying image.

On the left is global developed fossil fuel reserves. Remember the terminology: That's what we can likely get out of *currently operating fields and mines*. On the right are our carbon budgets, for the 2 degree and 1.5 degree scenarios respectively. Existing developed reserves exceed the 2 degree budget, and oil and gas alone break the 1.5 degree budget.

If we are serious about what we said in Paris, then no more exploring for new fossil fuels. No new mines, wells, or fossil fuel infrastructure. And rapid, managed decline in existing fossil fuels.

We are betting our species' future on our ability to bury carbon

An important note: The analysts at Oil Change assume that there *will* be BECCS from midcentury onward, but assume that CCS will *not* come online fast enough to substantially delay the decline of fossil fuels before then.

Obviously, that assumption could be wrong on either end. CCS could develop faster than expected or turn out to be utterly impractical and too costly on any time scale. It's too soon to know.

What is clear is that we are betting our collective future on being able to bury millions of tons of carbon. It's a huge and existentially risky bet — and maybe one out of a million people even know it's being made.

Humanity is in a desperate situation

There are modeling scenarios that show us hitting our climate targets. But we should take no comfort from them. The fact is, we have waited until perilously late to act on climate change, and our range of options has narrowed. We face three choices:

1) In the event that massive carbon sequestration proves infeasible, avoiding dangerous climate change will require an immediate and precipitous decline in global carbon emissions over a decade or two. Given that most present-day economic activity is driven by fossil fuels, it would mean, at least temporarily, a

net decline in economic activity. No one wants to discuss this, except climate scientist Kevin Anderson:

2) The second option is to immediately begin driving net global emissions down, hitting zero some time midcentury or shortly thereafter, and in the meantime develop the technology and infrastructure to bury millions of tons of carbon from biomass. Anderson explains **just what that means**:

> The sheer scale of the BECCS assumption underpinning the [Paris] Agreement is breathtaking – decades of ongoing planting and harvesting of energy crops over an area the size of one to three times that of India. At the same time the aviation industry anticipates fuelling its planes with bio-fuel, the shipping industry is seriously considering biomass to power its ships and the chemical sector sees biomass as a potential feedstock. And then there are 9 billion or so human mouths to feed.

3) The third option is to allow temperatures to rise 3 or even 4 degrees, which Anderson has **called** "incompatible with an organized global community." Such temperatures would bring suffering to hundreds of millions of people and

substantially raise the probability of runaway global warming that can't be stopped no matter what humans do. Runaway warming would, over the course of a century or so, serve to render the planet uninhabitable. Quite a legacy.

All of these are desperate options.

When climate activists say, "We have the technology; all we need is the political will," they act like that's *good* news. But think about the political will we need: to immediately cease fossil fuel exploration, start shutting down coal mines, and put in place a plan for managed decline of the fossil fuel industry; to double or triple the global budget for clean energy research, development, and deployment; to transfer billions of dollars from wealthy countries to poorer ones, to protect them from climate impacts they are most vulnerable to but least responsible for; and quite possibly, if it comes to it, to limit the consumptive choices of the globe's wealthiest and most carbon-intensive citizens.

That level of political will is nowhere in evidence, in any country.

So for now, it's cognitive dissonance.

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