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

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

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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

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.

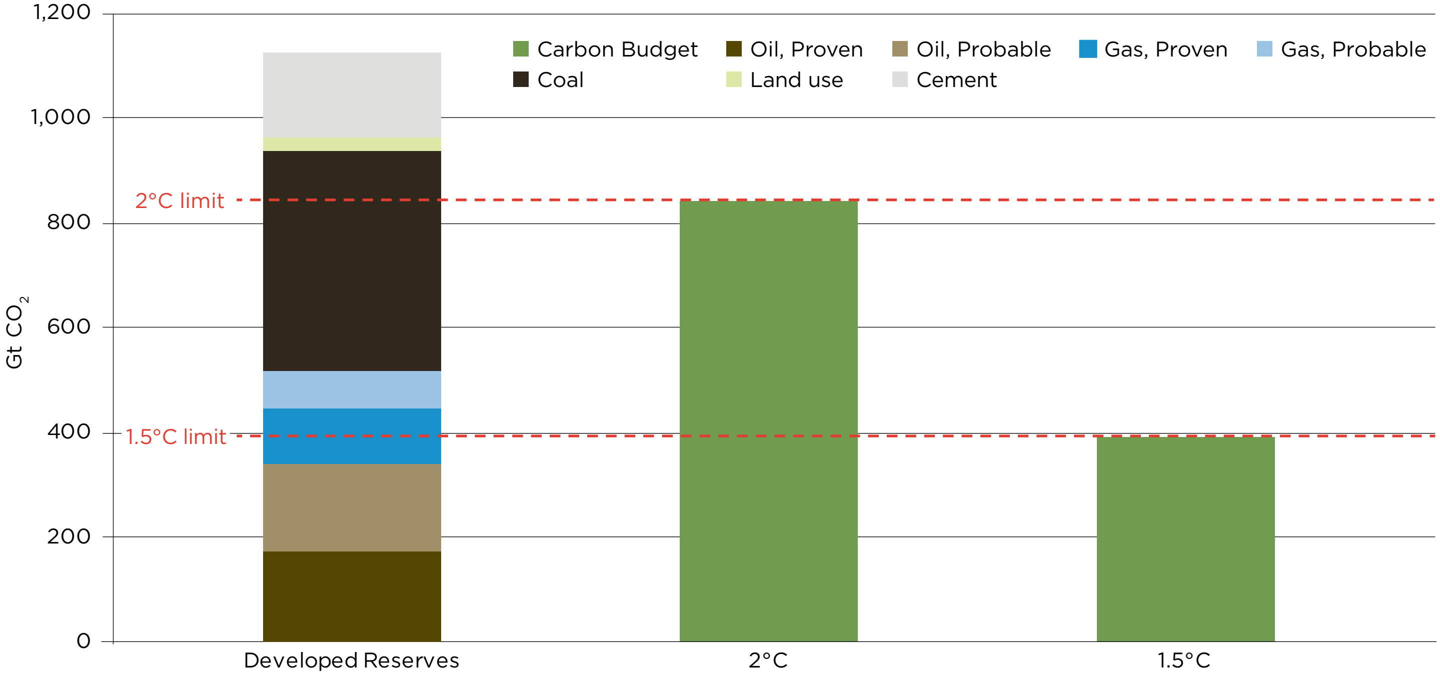
One of the most powerful climate policy levers is also the simplest: stop digging for more fossil fuels. We therefore recommend:

- 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.

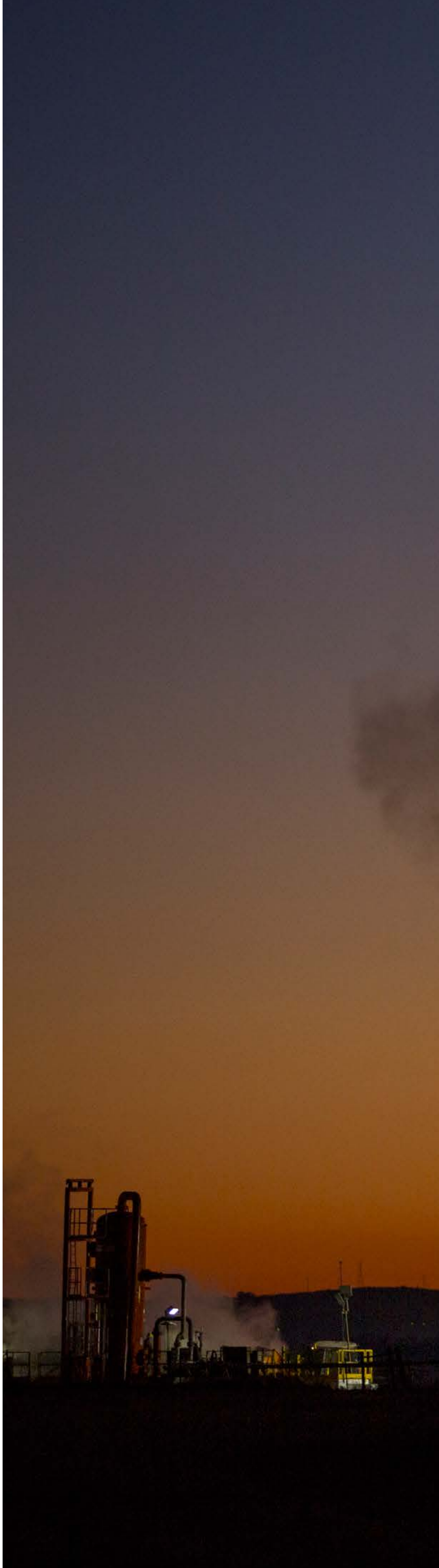
While this pace of renewable energy expansion will require policy support, it continues existing trends. In many countries – large and small, rich and poor – clean energy is already being deployed at scale today. Denmark now generates more than 40% of its electricity from renewable sources, Germany more 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.

©Les Stone/Greenpeace

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.

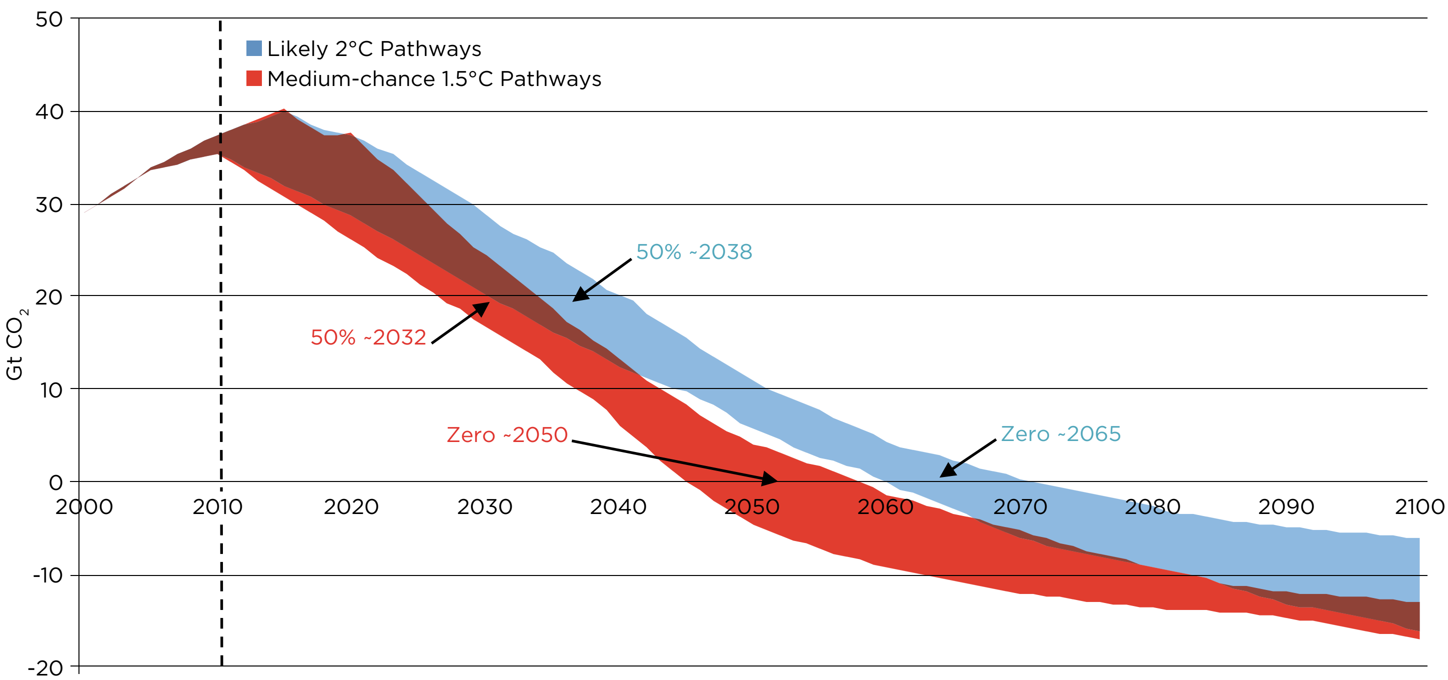
Note that these scenarios assume that "negative emissions" technology will occur in the second half of the century, through approaches such as bioenergy with carbon capture and storage or direct air capture. If we want to avoid depending on unproven technology becoming available, emissions would need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

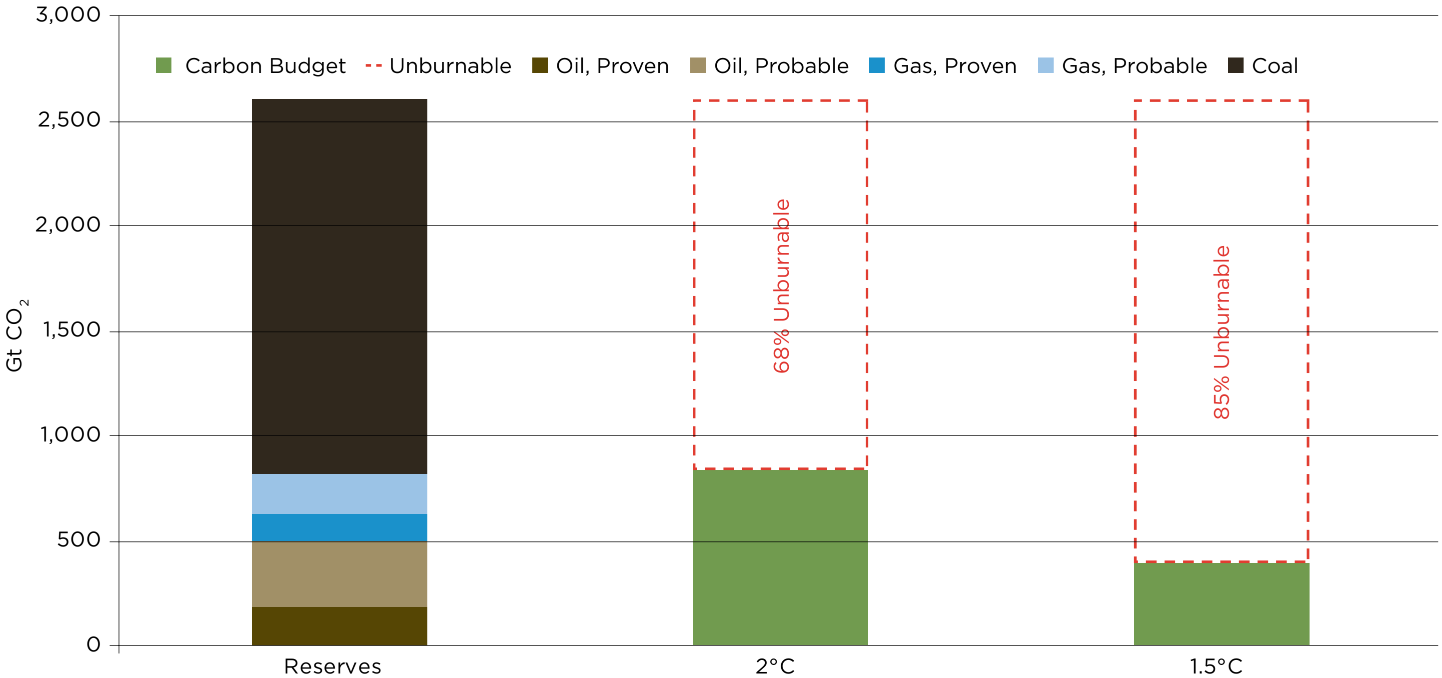
In Figure 2 we compare carbon budgets with fossil fuel reserves, echoing earlier work to translate climate limits into energy limits (see Box 2). For oil and gas, both proven and probable reserves are shown, while for coal only proven reserves are shown (see Appendix 1).[i]

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.

© Associated Press, Wang Chun.

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

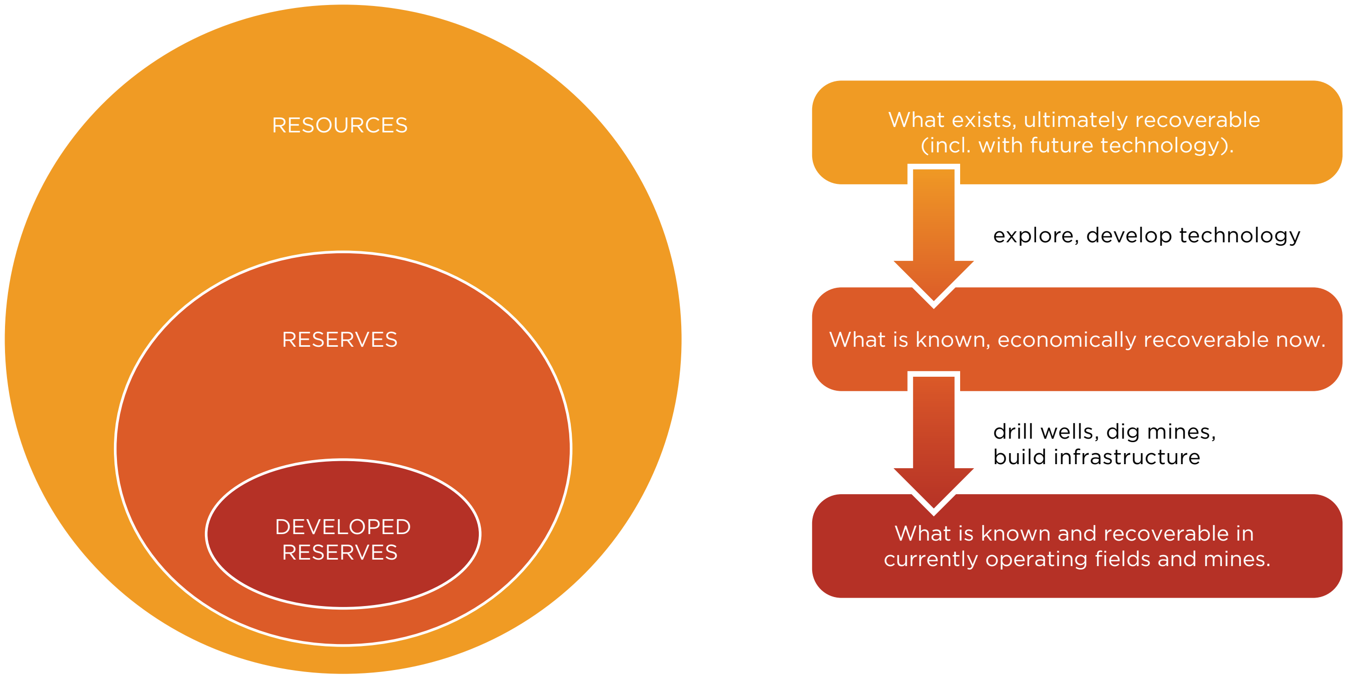
We now turn to the question of how much room exists within the carbon budgets for development of new oil fields, gas fields, and coal mines.

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.

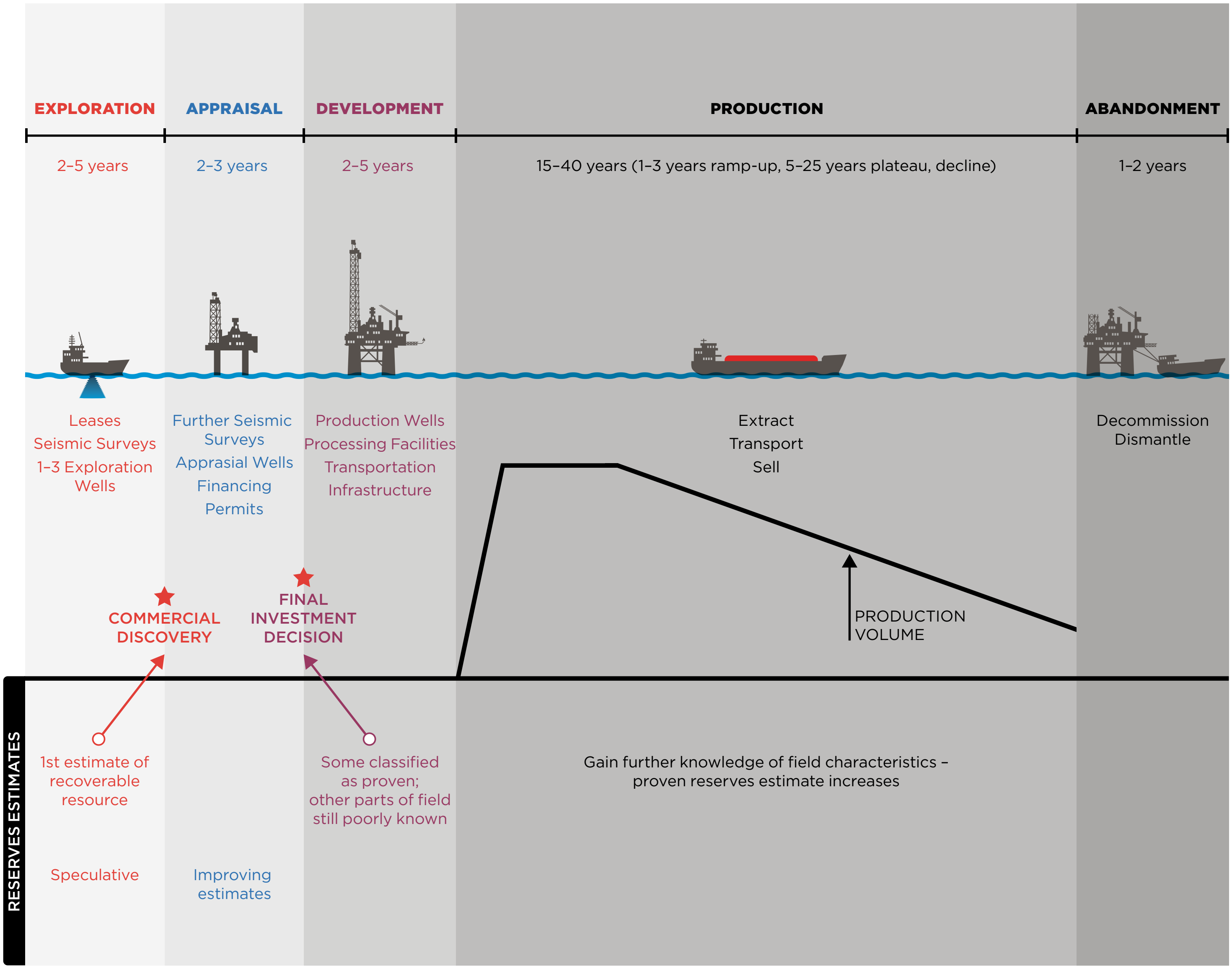
Figure 3: Three Measures of Available Fossil Fuels



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.

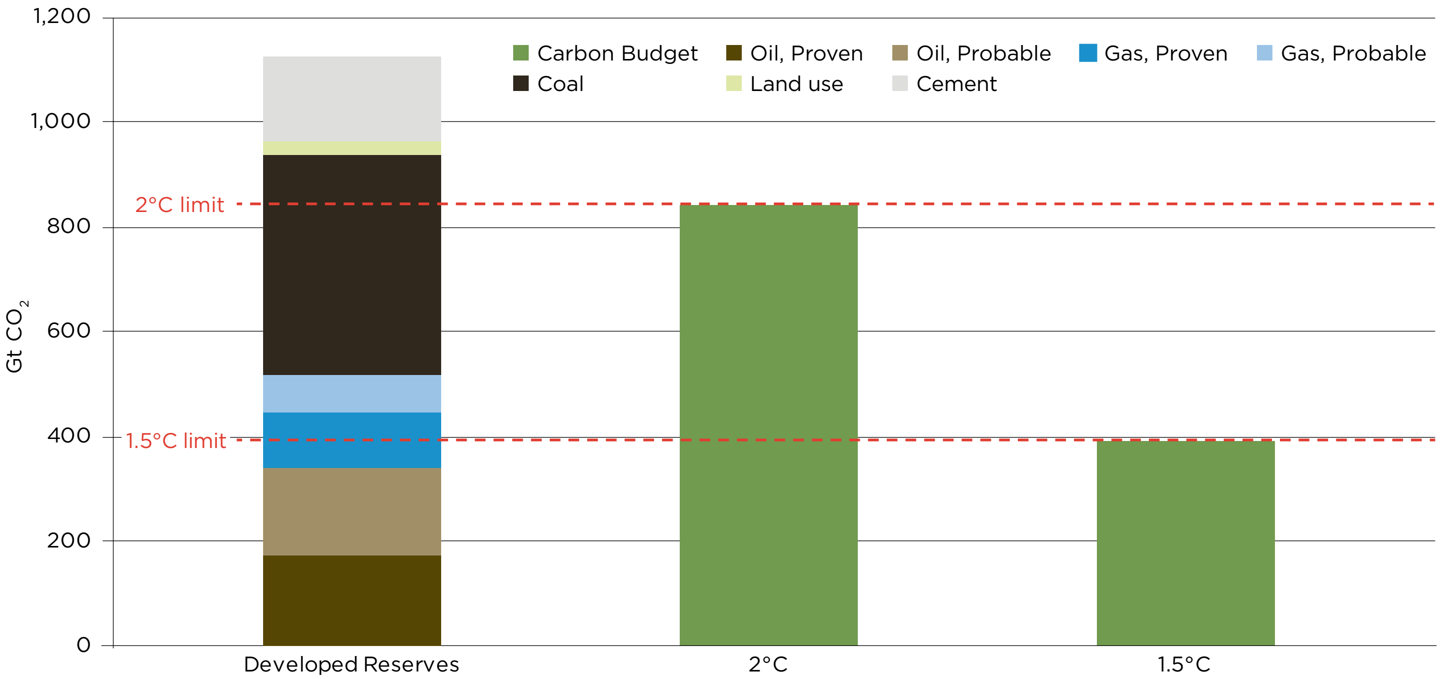
n They commonly do so using an integrated assessment model, which combines both physical effects of emissions in the climate system, and economic effects of energy in the economy. Such models are used to generate the emissions scenarios featured in IPCC reports, such as those shown in Figure 1.

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.

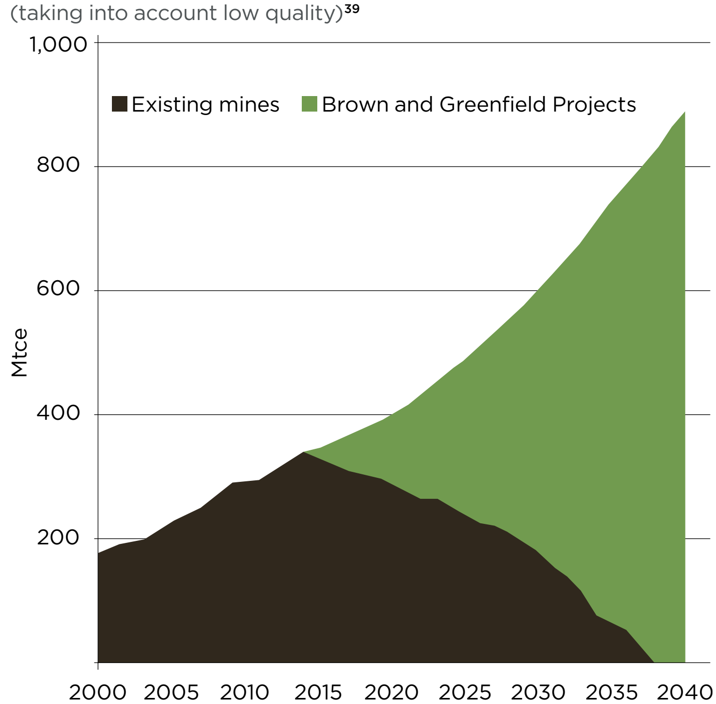
It should be noted that India has done less than most countries to cause the climate problem: despite having 18% of the world's population, it has accounted for just 3% of historical global CO_2 emissions.[40] And with per capita GDP of just $1,600, the country has an urgent need for economic development. 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

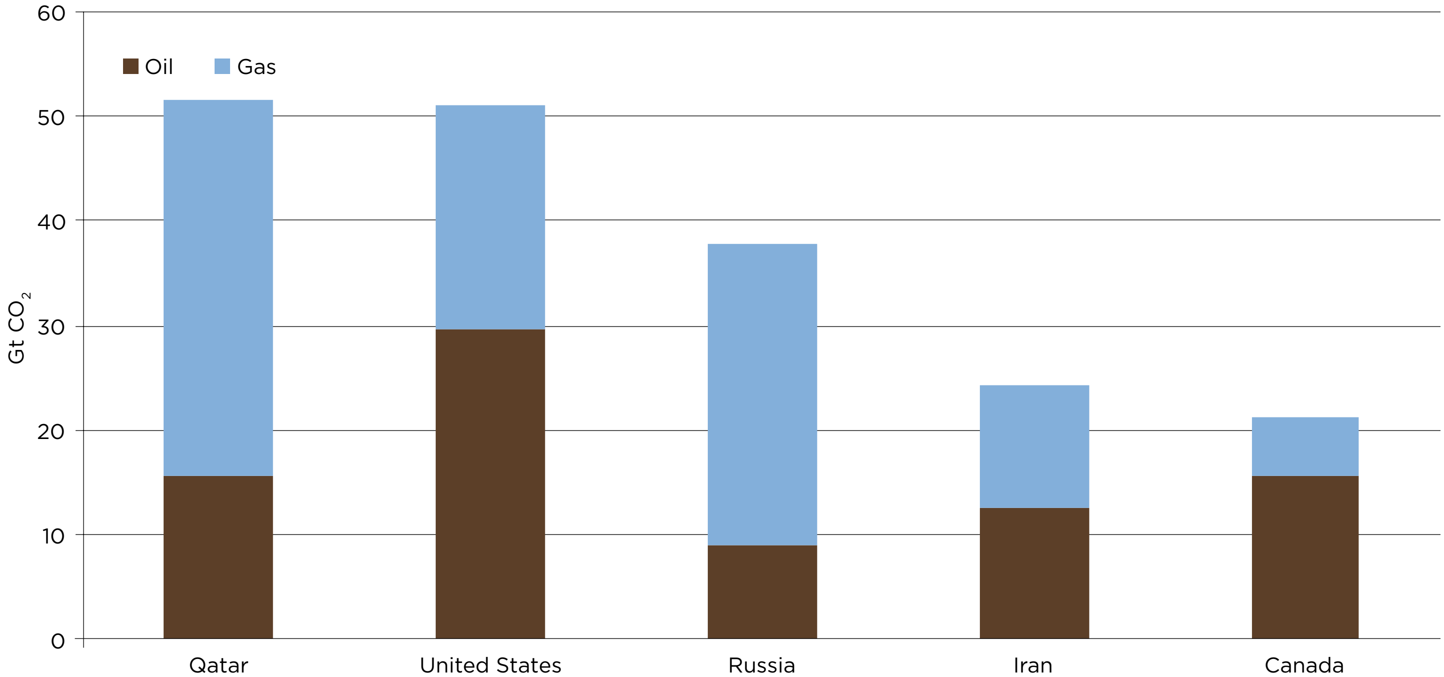
Sources: Individual Project Environmental Impact Statements

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.

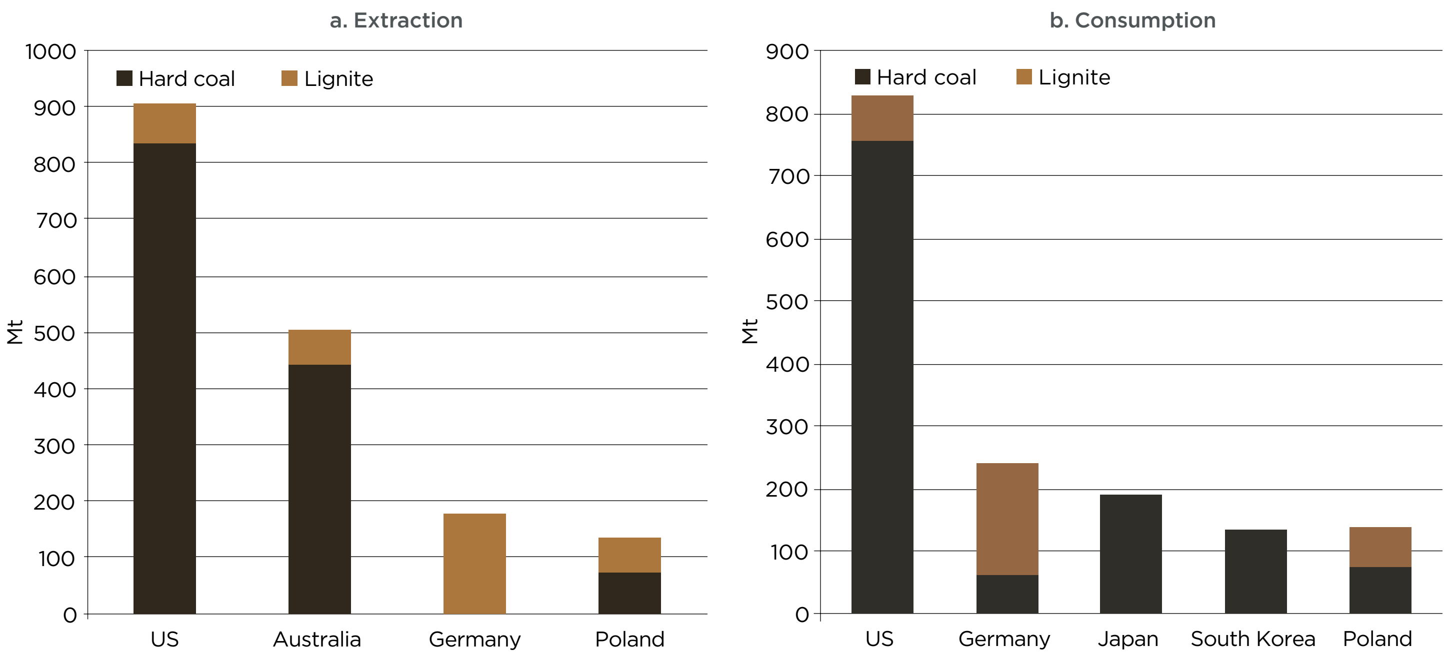
As a starting point, there is little justification for continued mining or burning of thermal coal in industrialized countries. Figure 8 shows that the OECD countries extracting the most coal are the United States, Australia, Germany, and Poland.

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.

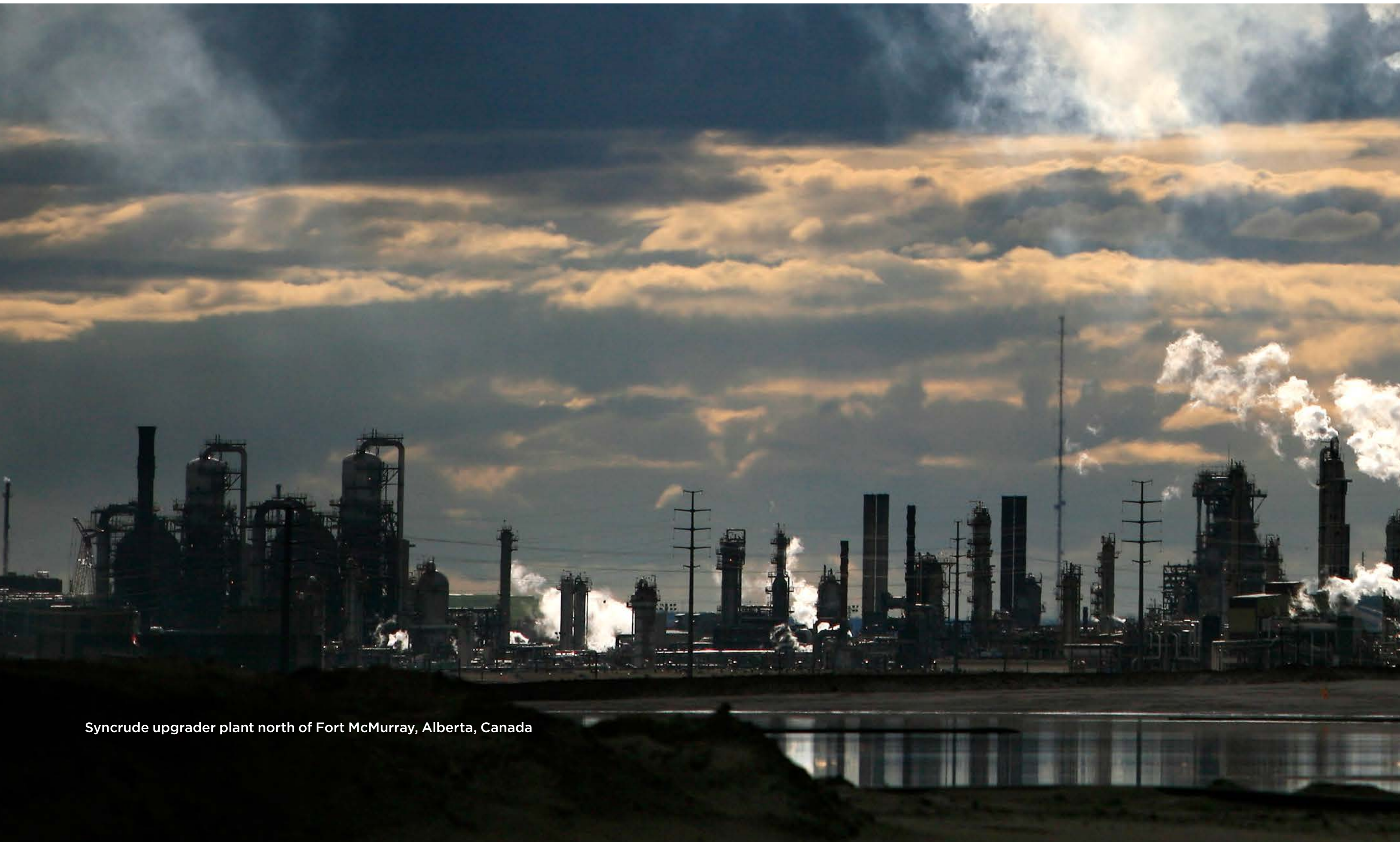
We have argued that ending the construction of new fossil fuel infrastructure is a politically pragmatic approach to avoiding dangerous climate change. The problem is that much of current fossil fuel extraction is located where it may not be most needed or justified in terms of fairness; examples include 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:

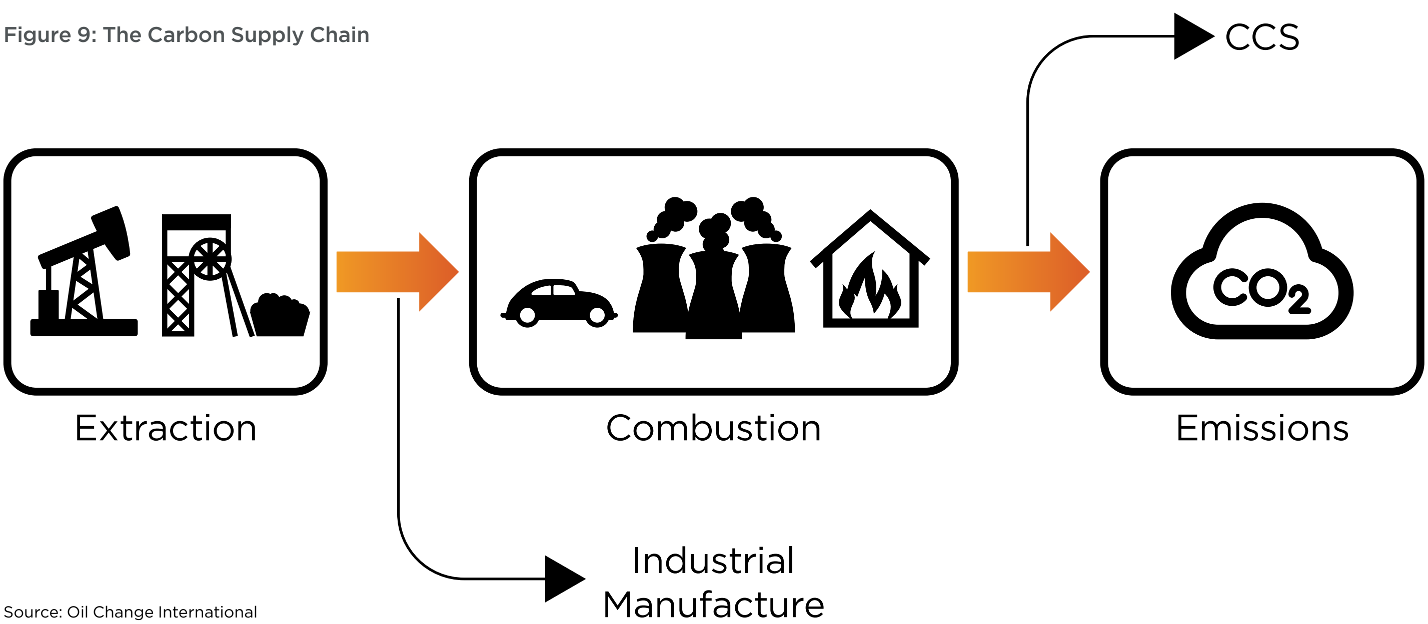
- Small amounts of oil and gas are used in industrial manufacturing of plastics, chemicals, fertilizer, and other products. In 2011, non-combustion uses accounted for 14% of U.S. oil consumption, 2% of gas consumption, and 0.1% of coal consumption – combined, these total just 6% of the carbon in U.S. 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]

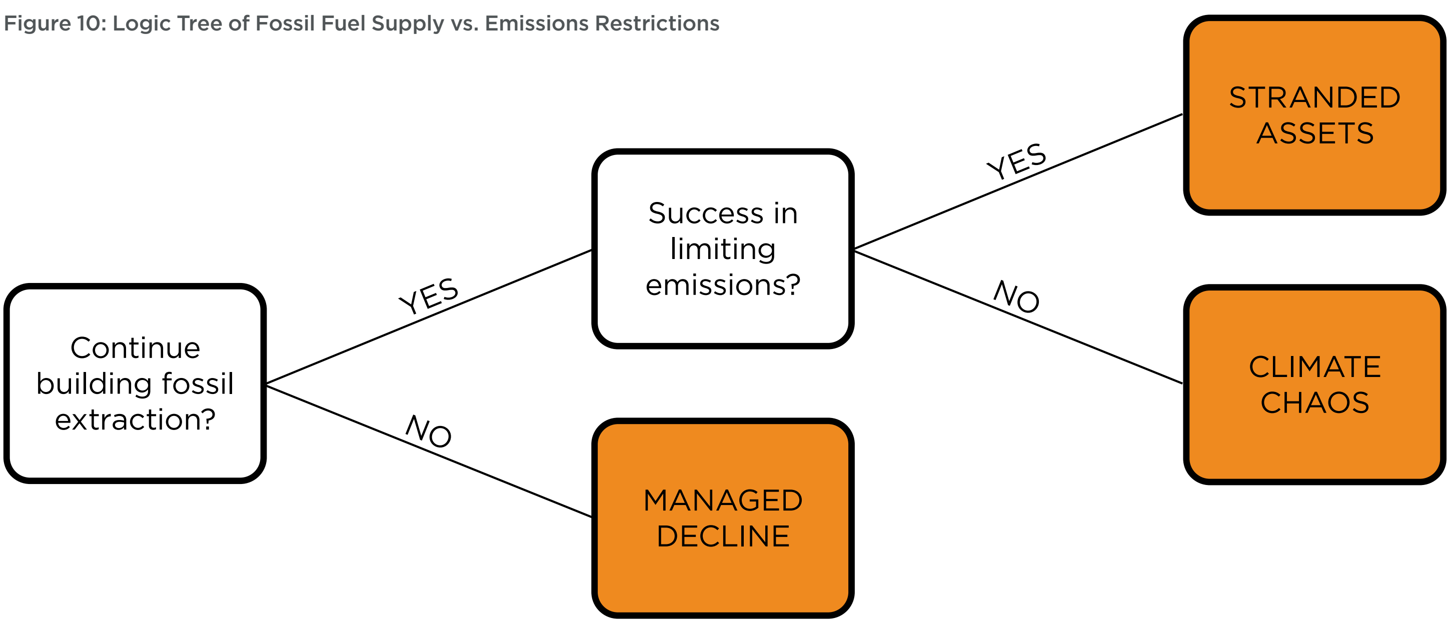
If we assume that a combination of government policy and technological change is successful in limiting warming to below 2°C or to 1.5°C (and that CCS prospects do not radically improve), demand for fossil fuels will fall rapidly, resulting in a significant decrease in fossil fuel commodity prices. This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

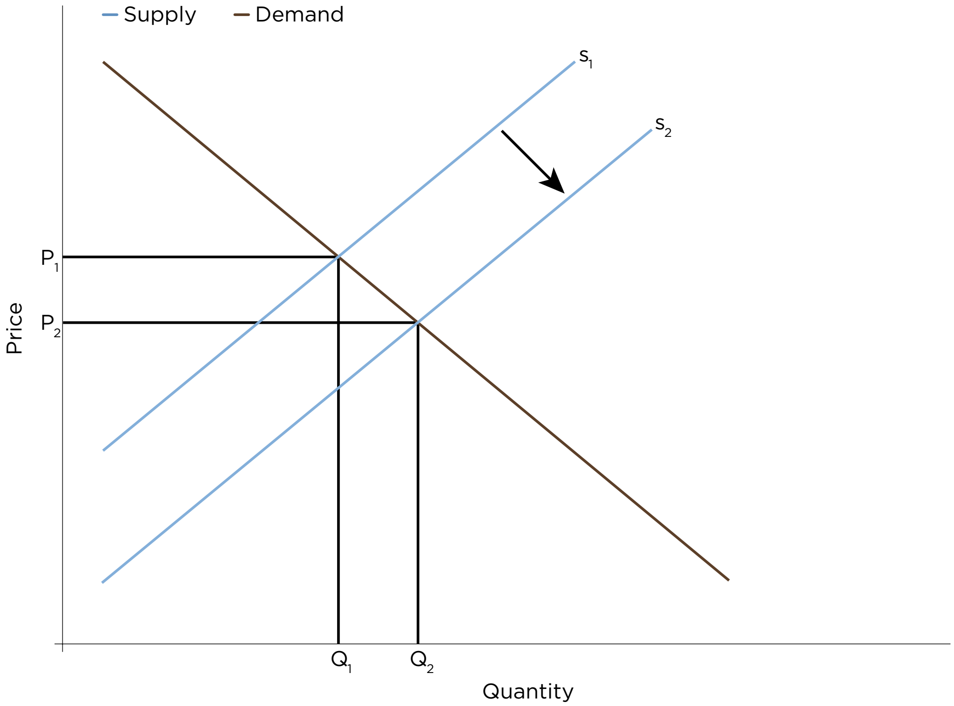
Some commentators insist that climate change should only be addressed on the demand side.[59] But the trouble with this view is that the act of increasing supply makes it harder to cut emissions.

(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.

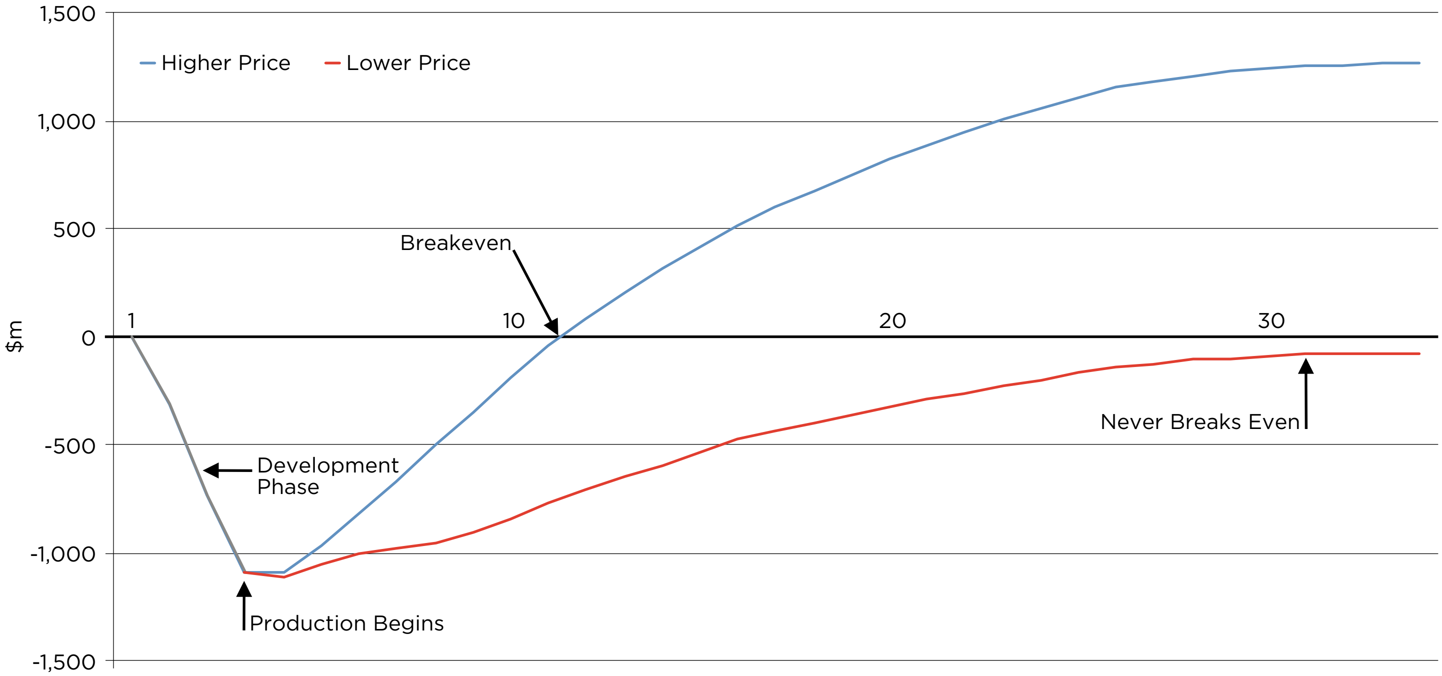
(iii) Perverse Political Effects

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.

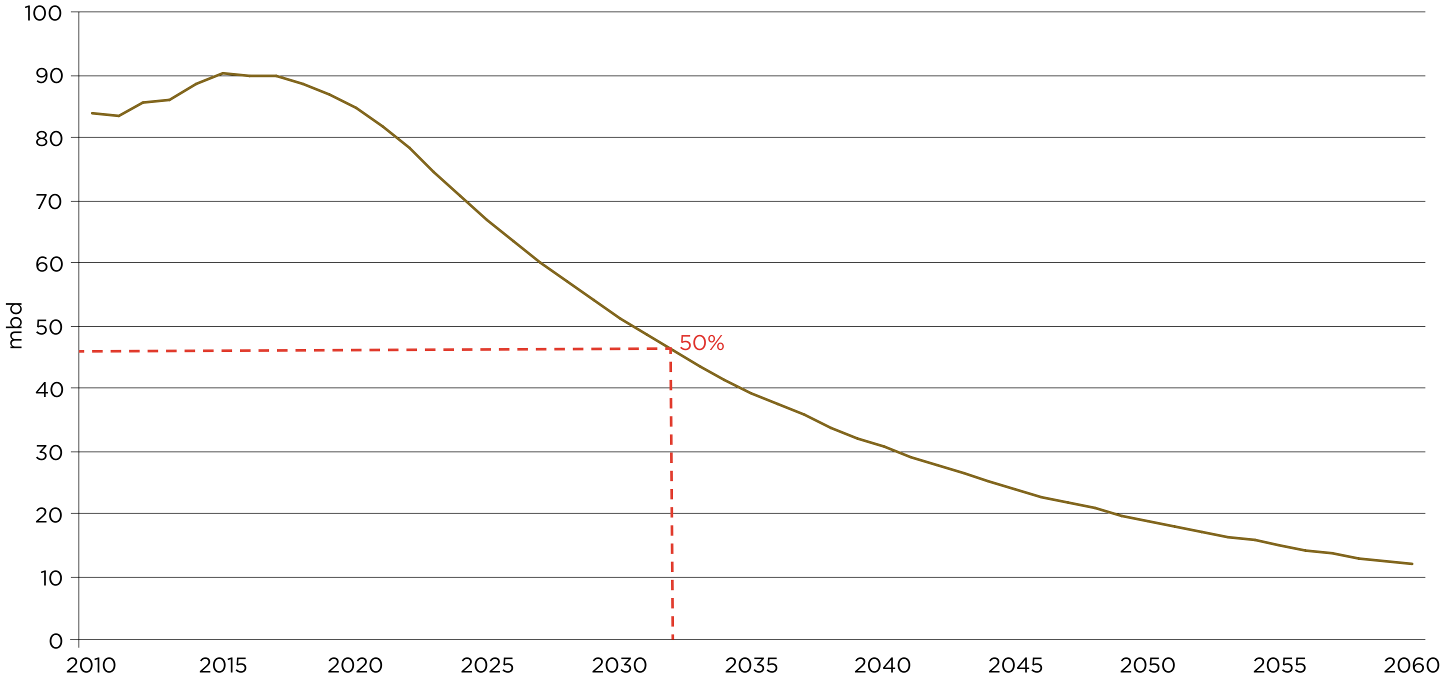
Figures 13 and 14 show Rystad's projection of oil and gas extraction from existing fields and those under construction, in its oil price base case[s]: extraction (and hence global supply) would fall by 50% by the early 2030s. Data is not available for coal.

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.

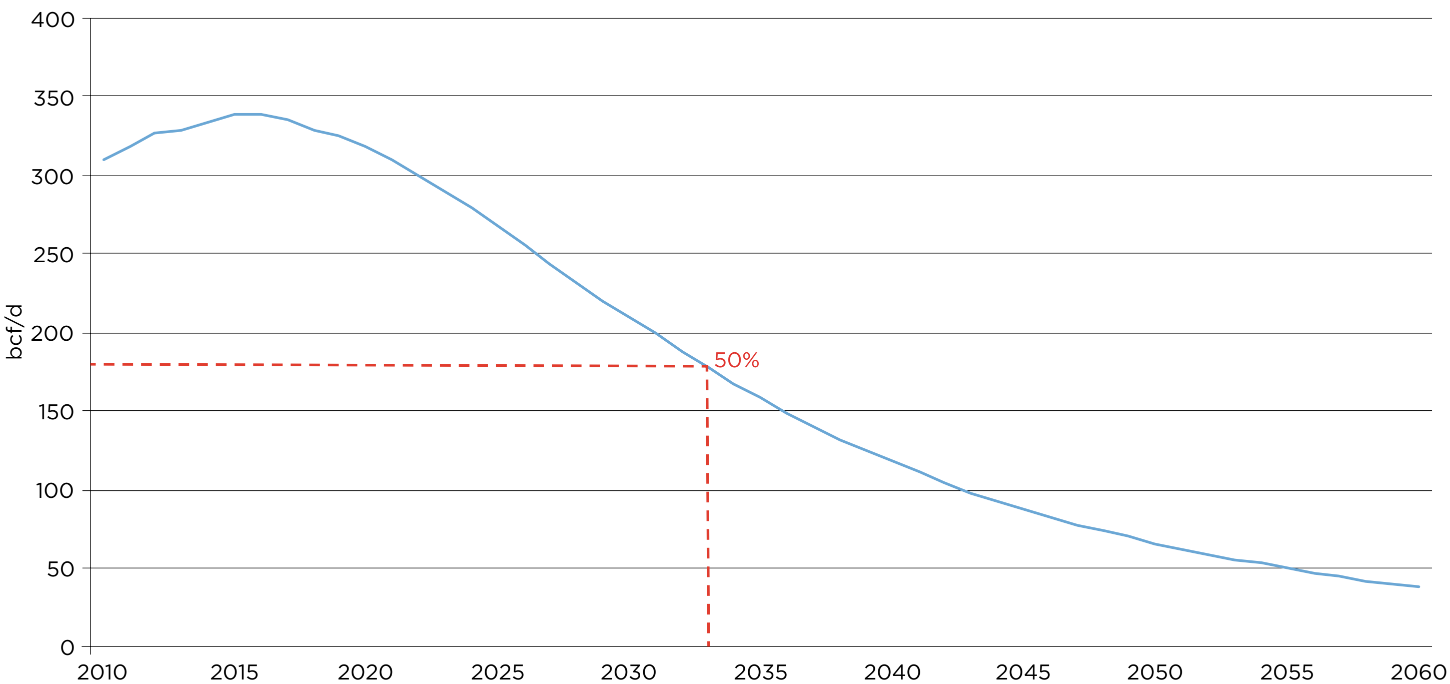
s A higher price would lead to slower decline, as companies would invest more capital expenditures even in existing fields. Conversely, a lower price would lead to faster decline.

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.

© AP Photo/Mark Lennihan

CLEAN ENERGY REPLACES FOSSIL FUELS

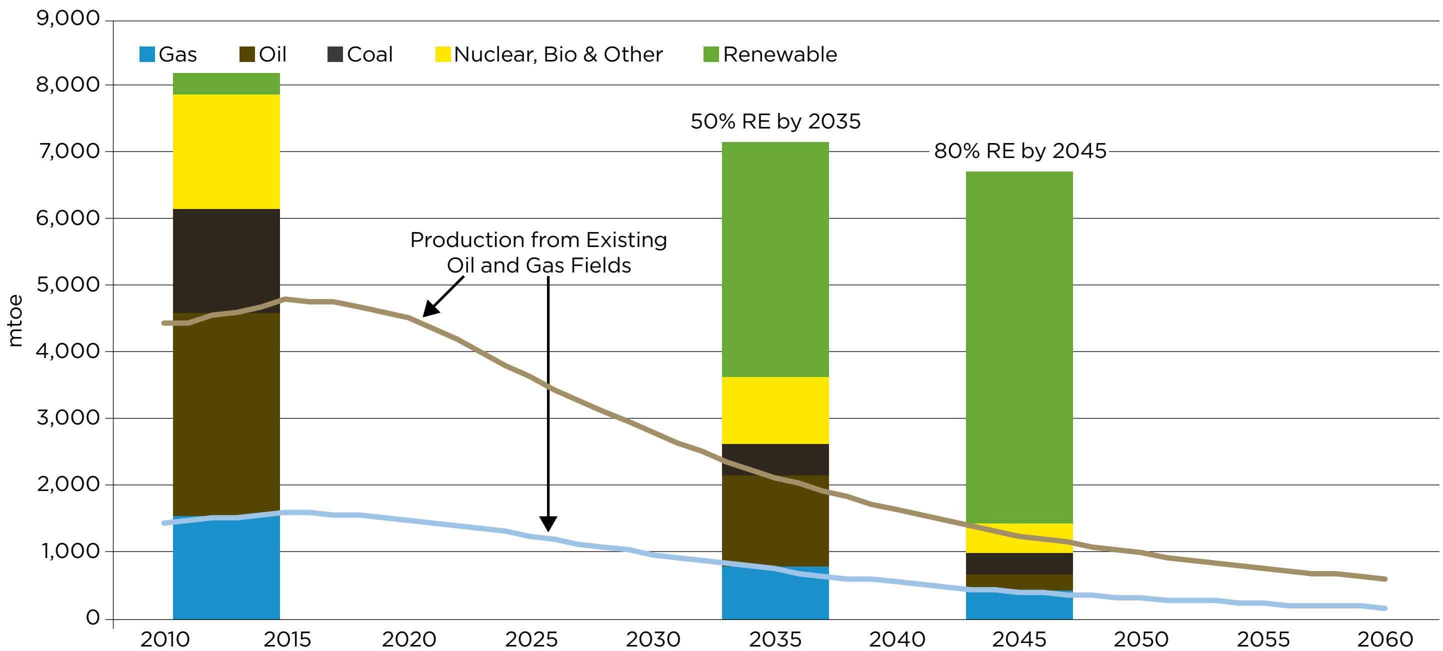
Renewable power technologies are not only possible; they are already in use at scale in many countries, growing rapidly, and often cost less than gas or coal generation (see Box 3). Electric vehicles are at an earlier stage of development than renewable power, but may be able to penetrate the market 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]

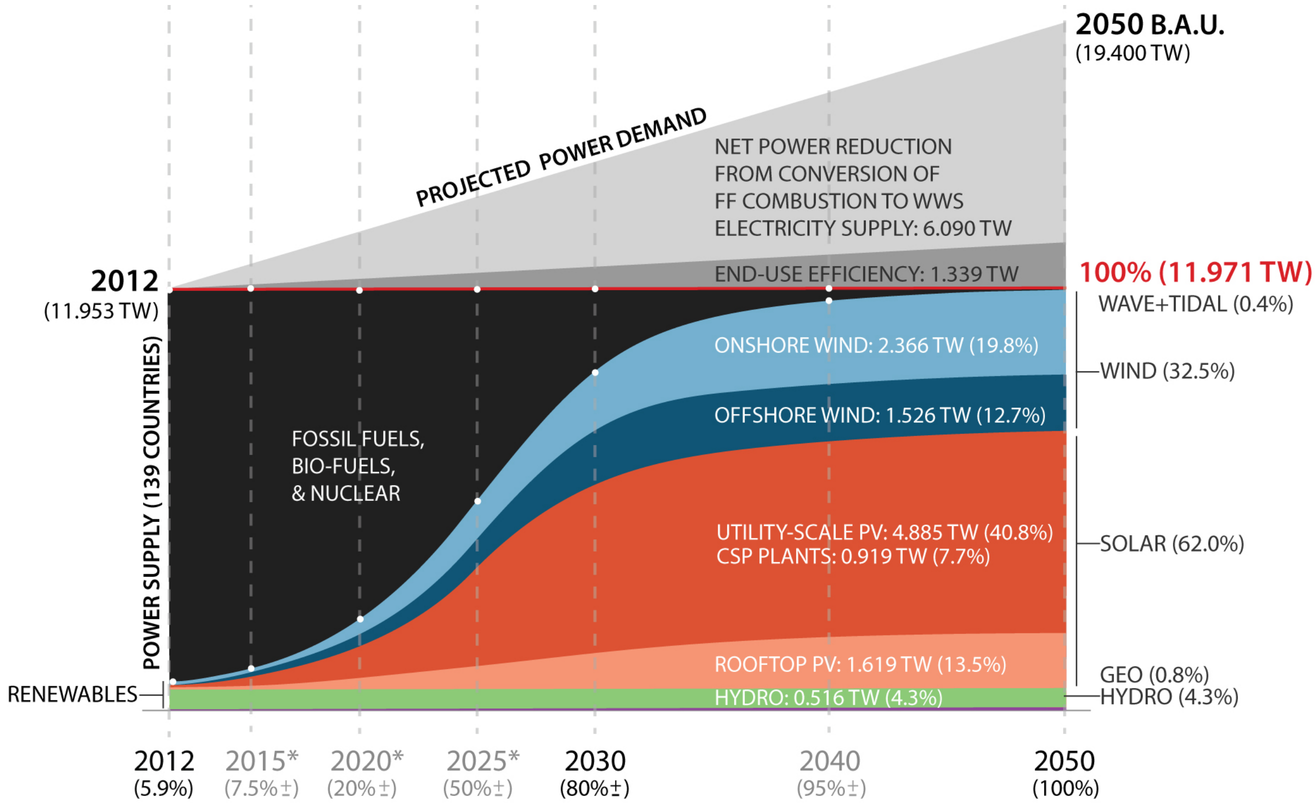
We see in the Figure that in 2035, expected oil and gas production from existing fields roughly matches the requirement with a 50% renewable energy penetration. Further depletion to 2045 leaves greater production than would be required while moving to 80% renewable energy.

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 investments** 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 assessment** 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 protection** alongside active labor markets policies.
- **Local economic diversification** 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.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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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