CLIMATE POLICY INITIATIVE

# Moving to a Low-Carbon Economy: The Impact of Policy Pathways on Fossil Fuel Asset Values


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David Nelson
Morgan Hervé-Mignucci
Andrew Goggins
Sarah Jo Szambelan
Thomas Vladeck
Julia Zuckerman


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| Contact | David Nelson, david.nelson@climatepolicyinitiative.org |

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## About CPI

Climate Policy Initiative is a team of analysts and advisors that works to improve the most important energy and land use policies around the world, with a particular focus on finance. An independent organization supported in part by a grant from the Open Society Foundations, CPI works in places that provide the most potential for policy impact including Brazil, China, Europe, India, Indonesia, and the United States.

Our work helps nations grow while addressing increasingly scarce resources and climate risk. This is a complex challenge in which policy plays a crucial role.

# Executive Summary

Energy plays a central role in the global economy, and for more than a century one of the cheapest and most prevalent sources of energy has been fossil fuels — coal, oil, natural gas, and the power that has been generated from these fossil fuels. Unfortunately, fossil fuel use has also been a major source of carbon emissions; in 2010, fossil fuels burned for energy contributed close to two-thirds of anthropogenic greenhouse gas emissions.[1] Addressing climate change will invariably reduce or change fossil fuel use, and in all likelihood reduce the value of fossil fuel resources.

Some observers worry that a switch away from fossil fuels will not only have a significant cost to the global economy, but could also absorb the investment capacity of the financial system and even undermine the financial system if investors were burdened with worthless fossil fuel investments. We examine the impact of a low-carbon transition on the investment capacity of the global financial system in a companion paper, "Moving to a Low-Carbon Economy: The Financial Impact of the Low-Carbon Transition." That paper shows that the increase in financial capacity due to reduced investment needs and operating costs for fossil fuel assets more than offsets the increased investment required for lower carbon investments, even when "stranded assets" (investor losses in existing fossil fuel assets) are taken into account.

In this paper, we examine the question of stranded assets: What impact would a low-carbon transition have on the value of investor portfolios when:

- Some fossil fuel assets become valueless as they are no longer needed and are left unexploited as demand falls?
- Other assets that continue to produce lose value as a result of price declines resulting from lower demand?

Most importantly, we examine how the decline in value would be spread between governments and investors and among various countries, and how both the level of stranded assets and their distribution depends on policy. For this analysis, we have built regional and global economic models for each of the fossil fuel industries — coal, oil, natural gas, and power — as a tool to assess stranding risks for various assets and their owners and investors. These models estimate risk by comparing two extreme scenarios — one where no action is taken on climate change and one where the IEA's low carbon goals are achieved — to quantify risks and assess how they may be allocated between various groups and investors.[2] Actual risks are lower, as markets have built in expectations for climate action, but these two scenarios provide benchmarks for comparison.

Our analysis finds the following:

**Governments, their citizens, and taxpayers, rather than private investors and corporations, face the majority of stranding risk.** This risk is concentrated in resource-owning and producing countries, particularly major oil producers. Governments own 50-70% of global oil, gas, and coal resources and collect taxes and royalties on the portion they do not own. Thus, it is unsurprising that governments would bear close to 80% of the $25 trillion of value difference for producers under our two scenarios.

**Only some of the value at risk would actually be lost in the transition — most of the value would be transferred from one economic actor to another, or one country to another.** For example, a falling oil price may hurt producers but benefit consumers.

- **Some of the lost value represents lost revenue collected by fossil fuel-producing governments from their own citizens. When these transfers are excluded, the total value at risk falls from $25 trillion to $15 trillion.** Almost half of the potential stranding for governments represents lost profits and taxes that countries would raise from sales to their own citizens at world market prices. In practice, many energy producers subsidize local fossil fuel products compared to world prices, thus returning some value back to their consumers at the expense of taxpayers or service recipients. Even when adjusting for these transfers or potential subsidies, governments still face twice the risk that investors do. (To put this number in perspective, $15 trillion is equivalent to approximately 6% of the

1 Intergovernmental Panel on Climate Change, 2014. Contribution of Working Group III to the Fifth Assessment Report: Technical Summary. Available at: http://mitigation2014.org/report/final-draft

2 To evaluate and quantify stranded asset risk, we use two scenarios to represent the extreme outcomes. One is based on business as usual, where no additional climate relevant policy action is taken. The other is based on the IEA's low carbon scenarios, including the 2DS scenarios from the 2012 Energy Technology Perspectives (ETP) modelling, the 450 ppm scenario from 2013 World Energy Outlook (WEO), and the 2DS from the 2014 World Energy Investment Outlook (WEIO). Stranding risks are calculated as the difference in the value of specific assets and resources between the two scenarios – given the impact on pricing, costs and production.

value of global stocks, bonds, and loans in 2013 (not including other assets), or less than 1% of projected global GDP from 2015-2035.)[3]

- **Net consuming countries would be better off with lower fossil fuel consumption, but producers would lose value.** The benefits of lower prices to consumers in countries like Europe, China, India, Japan and even the U.S., will more than offset the value declines to their producers. The net benefit to China and Europe will each exceed $1 trillion, but the loss in value to some oil-exporting countries could also exceed $1 trillion.

**Across the four fossil fuel industries, oil accounts for the majority of value at risk, but coal holds the largest emissions reductions potential.** Even though reducing oil consumption makes up less than 15% of the emissions reductions in IEA's low-carbon scenario, oil accounts for close to 75% of the fossil fuel asset value at risk in the low-carbon transition, because of oil's high marginal production costs and high profit margins. By contrast, coal faces lower costs and lower profits, and so has less value at risk — it accounts for approximately 80% of the emissions reductions in IEA's low-carbon scenario with just 12% of the asset value at risk.

**Policy will determine both the net impact of stranding and how the impact is distributed. For many countries, the right policy mix could create a net benefit.** Stranding is a function of changed consumption and expectations, which are in turn affected by changes in policy, pricing, technology, and behavior. Indeed, technology and behavior are also likely to be driven by policy. However, the range of policy options can lead to different responses from producers, consumers and investors, affecting the total net stranding cost and how that cost is spread among different investors, consumers, taxpayers, and governments.

- **Price or tax-based policies that reduce demand would produce very different results than innovation-based policies.** One policy alternative would be to rely solely on prices as the mechanism to shift consumption and investment — for example through taxes on energy consumption or reduction of fossil fuel subsidies. Consumption responds predictably to higher prices as consumers make investments in efficiency, relocate or change consumption mix. All of these responses have a cost. In our oil model, when using taxes to increase retail prices, the cost to consumers of seeking alternatives combined with value loss to producers outweighed the benefits to taxpayers through tax receipts, leading to a global net stranding cost of $3 trillion under our two scenarios. On the other hand, if innovation, new technology, or other policy mechanisms could shift demand without a cost to consumers, there would be a net gain of $7 trillion, despite the lower government tax receipts.
- **A combination of innovation and price policies probably works best.** A more realistic approach would combine the two, leading to net stranding within the range given above. Taxes have an initial advantage because they are a more certain policy tool than innovation. Tax revenue can then be channeled to support further innovation — and the more successful innovation is, the lower taxes will be needed to reach a low-carbon trajectory. Moreover, studies of the price elasticity of demand for oil suggest that a good deal of innovation and behavior change is driven by price changes; in fact, it could be argued that prices are the main driver of innovation and behavior change. Thus, the two policy pathways are not strictly alternatives, but could be complementary.
- **For global commodities such as oil and the globally traded portion of gas and coal, national policies have a global impact.** For global commodities, the policies of one country spill over to have an impact on other countries. For example, one nation's demand reduction can reduce global prices. Again using oil as an example, lower price increases would be required to reach global goals if all countries participate. However, if only net consuming countries were to institute price-based policies, these countries could still achieve 80% of the global target with 95% of the net benefit of global action — and if they did act, net producing countries would benefit from reducing their consumption as well. Innovation policy would have an equally important cross-border impact.
- **Policies that reduce demand are more effective than those that restrict supply.** We also

3 Source for global financial asset values: Deutsche Bank, 2014. Mapping the World's Financial Markets 2014. Available at: http://www.etf.db.com/DEU/DEU/Download/Research-Global/47e36b78-d254-4b16-a82f-d5c5f1b1e09a/Mapping-the-World-s-Financial-Markets.pdf

Source for GDP data and growth projections: International Monetary Fund, 2014. World Economic Outlook Database.

assessed the costs of supply restrictions or producer taxes. In our model, these policies only curtail demand by raising prices to consumers as in the price scenario. The result is significantly higher costs to consumers without the offsetting benefit of higher tax receipts, but significantly higher profits and value to producers. Outside of OPEC, our analysis shows that such a policy could involve significant losses to the acting country.

- **Delaying policy action can markedly increase stranding costs.** Our analysis is based on the assets and investments in the ground as of 2014. Investments and valuations change on a daily basis. Delaying policy action or continuing with uncertain policy creates the risk that more investments will be made and that valuations — and potential stranding — of fossil fuel assets increase. Clear signals will ensure that the right investments continue at a reasonable cost while investments that are at risk of stranding in the future are avoided.

**While policy has an important impact on asset stranding, this impact will be colored by the specifics of the assets and industry and economy in which it competes.** We found several specific factors that need to be considered, including the physical nature and location of resources which determine the markets in which the fossil fuels compete, nations' growth rates and asset bases, nations' energy strategies and resource endowments, potential substitution of one fossil fuel for another, and the timing of policy action.

**Investors have different options for managing risk.** Financial investors can easily adjust their investment strategies to minimize the asset stranding risks they face, while governments play numerous policy levers to maximize the value of their resources. Fossil-fuel producing corporations face bigger challenges.

## Policy Implications

Assessing these risks and minimizing them requires careful analysis of the policy options available to meet climate change goals and how these interact with the specific industry and resources. A wide range of outcomes is possible, and the policy mix chosen will influence not just potential value at risk or potential gain, but also who the winners and losers are in the transition. Our analysis of stranding risks offers the following insights for policymakers:

1. To minimize asset stranding, policymakers could do well to first focus on reducing coal. Reducing coal consumption accounts for approximately 80% of the IEA's projected carbon emissions savings in the move to a low-carbon future,[4] while representing approximately 12% of potential stranded asset value at risk.
2. Phasing out coal depends upon strategies and policies for power generation and other uses of coal:
   - Coal fired power generation in developed countries can meet most of their goals by phasing out their plants at the end of their natural lives and adapting operating modes to a low carbon weighted system.
   - Constraining coal fired generation in emerging markets in the face of growing energy demand creates an urgent need to develop alternative energy solutions and improved energy efficiency, especially in China and India (see point 5 below).
   - Coal mining will require different solutions across the major uses of coal in power generation, iron and steel making, other industrial usage, and residential and heating use. Finding alternatives to coal in China and India is a key challenge.
3. Effective oil paths to a low carbon trajectory include reducing demand (for example through consumption taxes or the reduction of fossil fuel subsidies) driven by net consuming countries, investment in alternative fuels, and innovation. Additionally, there are policy tools that can reduce undesired distributional effects.
4. Gas has a medium term future as a bridging fuel in power generation, though to minimize stranding, it will need to peak around 2030.
5. Financial mechanisms can further reduce the impact of stranding. In emerging economies, providing renewable energy subsidies through low-cost debt or dollarizing renewable energy tariffs can reduce the cost to governments and energy consumers by up to 30%. In developed economies, changing financing and business models can reduce the cost of renewable energy by as much as 20%, making it more competitive with fossil fuel electricity generation.
6. Governments need to develop strategies to address the budget consequences of phasing out fossil fuel production.

Ultimately, the global economy needs to address century-old imbalances borne from years of structuring the economy around fossil fuel-derived energy. Policy decisions made today will direct the course of the economy for years to come.

4 This figure compares the business-as-usual scenario to a low-carbon or 450 ppm scenario.

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# 1. Introduction

For more than a century and a half, the world's economies, industries, and even financial sectors have developed around relatively cheap, readily available fossil fuels and abundant land. Governments and corporations have invested trillions of dollars in fossil fuel and land development, and nearly every economic sector in every country is affected by the cost, reliability, and availability of energy derived from fossil fuel. At the same time, the environmental consequences of burning more fossil fuels and converting more land are growing. Together land and energy account for nearly all global carbon emissions, while four fossil fuel industry sectors — oil, coal, natural gas, and fossil fuel electricity generation — by themselves represent about two-thirds of the potential greenhouse gas mitigation needed to stay within a target of 450 ppm atmospheric $CO_2$ concentrations[5] — the level that the Intergovernmental Panel on Climate Change (IPCC) believes is consistent with a reasonable likelihood of limiting global temperature increases to 2°C.

With so much at stake, one of the difficult questions in addressing climate change is what to do with the assets, resources, and investments that are no longer needed or useful in a low-carbon economy. How will the owners of these assets and others who benefit from their use, including governments, companies, consumers, and investors, suffer — or benefit — as a result of measures to reduce greenhouse gas emissions?

Our analysis focuses on the four fossil fuel industries, evaluating the potential impact that a transition to a low-carbon economy might have on investors, consumers, producers, and governments and, crucially, how policy can shape that impact. Through a series of modeling exercises that detail potential transition mechanisms, we show that policy is the main determinant of winners and losers.

This paper summarizes the main findings from this analysis, drawing the main lessons from each of the four separate analyses of global and national oil, coal, gas, and fossil fueled power industries.

It is divided into the following sections:

- **Methodology:** Section 2 presents the methodology used to estimate economic value at risk in the low-carbon transition. We use a broad definition of stranded assets that encompasses changes in value as well as changes in production.
- **Who is most at risk and why:** In section 3, we analyze how stranded asset risk (based on asset ownership and other factors, such as royalties and contracts) breaks down between governments and private investors, and across the four fossil fuel industry sectors.
- **How assets get stranded:** Section 4 focuses on the role of policy in determining the extent of asset stranding, as well as which assets are stranded across the global economy. We assess the impact of different policy instruments (consumption taxes, innovation, and supply restrictions) on asset values.
- **The importance of industry specifics:** In section 5, we discuss how different characteristics of resources, industry structures, and historical investment patterns affect stranding risk in markets for oil, coal, gas, and power around the world.
- **Managing stranding risk:** In section 6 we examine the perspective of three different types of owner/investors — governments, corporations, and financial investors — to evaluate their exposure and ability to manage the risk of stranding.
- **Conclusions and recommendations:** Finally, in section 7 we draw the lessons together to highlight our conclusions and recommendations for policymakers.

5 McKinsey and Company, "Greenhouse gas abatement cost curves," 2010.

# 2. Methodology: Defining stranded asset risk and the CPI methodology for estimating value at risk

"Stranded assets" is a term that has recently become popular in the climate change debate. It describes the phenomenon that certain assets like coal mines, oil fields, and forests will need to remain "in the ground" in order to prevent a rise in global temperatures of 2°C or less. When investors or governments have invested in these assets or otherwise expected to benefit from them, these investors have a value at risk. When these assets are left unexploited or decline in value because of actions to reduce the threat of climate change, these unexploited assets are then deemed "stranded." Stranded assets can include physical assets (such as power plants) or resources (such as oil).

For both economists and investors, stranding goes beyond whether an asset ceases to operate due to the stranding event; it also considers whether an asset loses value due to the change. The distinction is important: it is the loss of value, rather than just the loss of production, that will be of concern to most investors. As we will see, the value of most fossil fuel assets will rise or fall depending on different policy approaches even though only some of these resources will be left in the ground.

*Asset stranding could limit the ability of the financial system to finance new investments*

The impact of the transition on asset stranding will depend on where we start from, where we go, and how we get there — that is, upon current market expectations, the ultimate shape of the transformed economy, and the policy, technology and economic paths followed during the transition. These three elements will define the adjustment that investors will need to make.

When the value of an existing asset falls, there is no obvious immediate cash impact on the economy. After all, the physical asset is still an asset that could be used in the same way as before, only the price has changed. However, there is an important impact on the ability of an economy to finance its growth and investment needs. Take the example of a homeowner whose house value falls 50%. After the price drop, the owner may no longer be able to borrow against the house to finance home improvements or buy additional properties, and, in the worst case, may no longer be able to pay off the debt. For the energy industries, stranded assets related to the transition could be particularly important if the very companies expected to finance the transition, like electric utilities, are the ones who no longer have the financial firepower to make new investments. For the economy as a whole, a large enough quantity of stranded assets could cause systemic risk with indirect effects throughout the global economy.

## 2.1 CPI's approach to estimating stranded assets

Our approach to stranded assets has three components. First, we define when assets are considered to be "stranded" due to the low-carbon transition, which requires understanding how investors currently perceive the possibility of a significant move to a low-carbon future. Next, we define a set of scenarios to represent the low-carbon transition and develop a methodology for quantifying the impact of that transition on fossil fuel asset values. Finally, we refine the basic model to reflect the important differences between markets in different fossil fuel industries and regions; these specifics have a major impact on the risk of asset stranding across different markets.

### 2.1.1 When is an asset stranded?

For an individual, business, or government to face asset stranding in the low-carbon transition, three things must occur:

**They must own assets or resources that are stranded or otherwise rely upon the output of these assets for future profits.** Similarly, consumers will be impacted if the transition raises costs or requires changes to business practices and consumption patterns. Understanding the relative impact on consumers, producers, and governments across different regions of the world is an important element of understanding the stranded asset risks.

**The value of these assets must change, either because the output is no l onger needed or because the price for the output has changed.** In order for any stranding to occur as a result of the low-carbon transition, either production from an asset must fall, production costs must rise, or prices for the asset's output must fall. There are a number of ways that these circumstances could occur, but a direct link to climate change will most likely be the result of policy. In particular, consumption taxes could suppress demand and thus reduce wholesale prices, production taxes could raise costs, regulation could restrict development, and innovation or efficiency policy could suppress demand. The applicability and effectiveness of any of these policies depends on the market and regulatory structure of the sector in question. Of course, a shift to low-carbon systems could also involve other factors, such as general technological innovation and traditional environmental regulation — both of which have driven significant changes in asset values in the past.

Within the four fossil fuel sectors — oil, coal, gas, and power — we find a diverse set of market and regulatory structures that lead to very different outcomes. For example, the global nature of the oil market means that policies that restrict output are less effective, but also means that local policies that suppress consumption will have global impacts.

**This change in value must be unexpected and not reflected in current asset valuations.** For owners and investors to lose value, the change in circumstances related to climate change must not be reflected in current valuations. Our analyses contrast the size and shape of the fossil fuel industries in a business-as-usual world versus a low-carbon world. However, current valuations may already have fallen to reflect some climate change risks. Furthermore, many investors may be positioning their portfolios to minimize risk and to respond automatically as markets react to evolving climate change policy risks. We address investor positioning in section 7.

### 2.1.2 Quantifying stranded assets

The fundamental building blocks for our analysis are supply and demand models. Box 1 describes our modeling approach.

As discussed in section 2.1.1, asset stranding is about a change in policy, behavior, technology, or markets that causes outcomes to be different from expectations, causing investors, including governments, to lose revenues, profits, and value. Thus, estimating stranded asset risk requires a comparison of asset values under two worlds:

- One that the market and investors were expecting (or are expecting) at the time investments are made, and
- A world where material policy changes are made that affect these markets in ways that reduce prices, increase costs, or reduce production.

In practice, it is impossible to know exactly what investors should have assumed at the time of investment, and we cannot know with precision what mix of policy and other changes will affect these markets, but we can make estimates based on coherent scenarios developed from credible analytical groups like the International Energy Agency (IEA).

*The basis of our analysis for all of the commodity markets (oil, and most coal and gas) is supply and demand modeling*

To begin evaluation and quantification of stranded assets, and thus inform effective planning and policy decision related to asset stranding, we begin from two scenarios. One is based on business as usual, where no additional climate relevant policy action is taken. The other is based on the IEA's low-carbon scenarios, including the 2DS scenarios from the 2012 Energy Technology Perspectives (ETP) modelling, the 450 ppm scenario from 2013 World Energy Outlook (WEO), and the 2DS from the 2014 World Energy Investment Outlook (WEIO). Both sets of scenarios are likely to overstate the impact of stranded assets:

- **The business-as-usual scenarios** are likely to imply higher asset valuations than current market expectations, as investors assume at least some policy action to curb greenhouse gas emissions. For example, major oil companies like Exxon and Shell typically use reasonably high carbon prices in their investment evaluation process.[6] Furthermore, metrics that investors typically use to value companies,

6 Carbon Disclosure Project. 2013. "Use of internal carbon price by companies as incentive and strategic planning tool: A review of findings from CDP 2013 disclosure."

**Box 1: Modeling asset stranding with supply and demand models**

Staying within emissions budgets will require lower demand and production of many fossil fuels. The question we need to ask is: How will the mechanisms used to cut emissions and reduce production affect the value held by all relevant asset owners? This question is particularly relevant because assets will not just stop producing on their own. Their owners will stop producing only if the economic value of producing from these assets disappears or if they are prevented from producing by changes to law or policy. But, the policy employed to reduce production from one asset is likely to have an effect on the value of all the other assets as well. To understand why this is the case, we need to start with how assets are valued and the basic market dynamic of supply and demand.

In a market, the value of a commodity is determined by supply and demand. An efficient commodity market would rank potential supply sources from the cheapest (including the cost of delivering the product to the consumer) to the most expensive. This ranking becomes a supply curve, as in Figure 1. For any level of demand, the most efficient market would only take the least expensive products to produce.

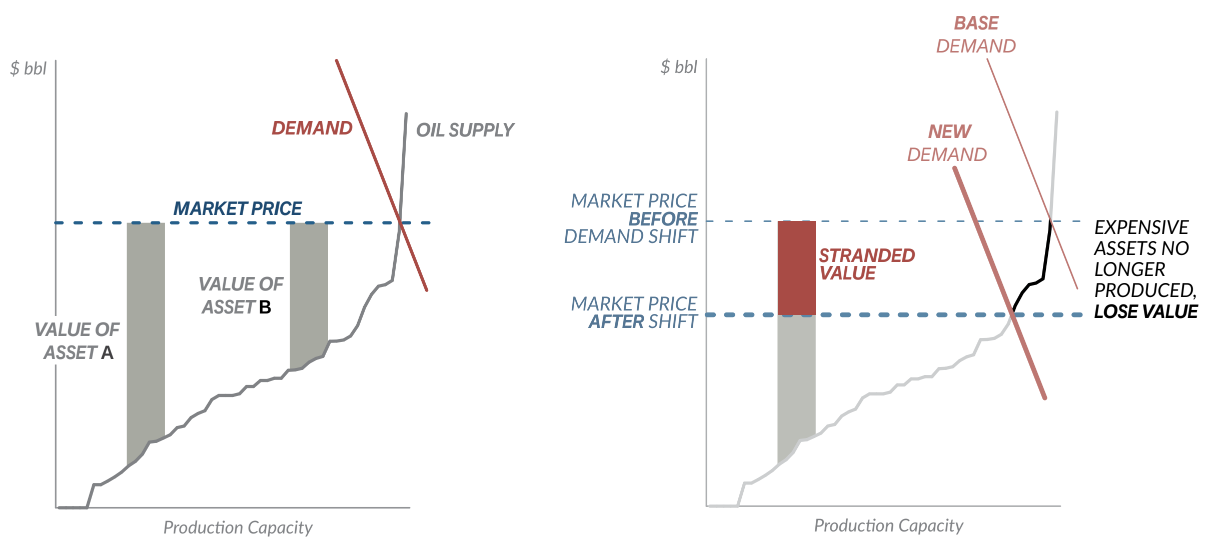
Similarly a demand curve expresses consumer preferences. If prices get too high, consumers will reduce demand. In commodity markets, the market price is determined by the intersection of the supply and demand curves.

The value of a production asset, on the other hand, depends upon its production cost relative to the market price. Thus, by virtue of having lower production costs, the value of Asset A in Figure 1 is correspondingly higher per unit of production than asset B.

Figure 2 shows how asset values change if demand falls. Lower demand would drive down prices to a new market price. More expensive assets (those in the yellow oval at right) would no longer be economic to produce, stop producing, and lose all of their value. Other assets that are less expensive to produce may continue at the same output, but will see a fall in the market price that they receive for their output. Of course, consumers usually gain from lower prices.

Thus estimating stranded asset risk requires supply and demand analysis for each commodity. Crucially, the supply curve analysis only includes future costs over which the owner/investor has control. It does not include past investments.

Figure 1 and Figure 2: Asset value depends on production costs and market price



As an example, imagine a mining company that has just invested $100 million in a mine that can then produce coal at a cost of $50 per tonne. The company expects profits on the sale of the coal will be worth $50 million. But new technology lowers consumer demand for coal, and the price that the mining company receives dips below $50/tonne. The mine no longer makes a profit, and likely stops producing. The mining company loses the original $100 million invested and the $50 million of expected profit; the company faces a total stranding risk of $150 million. Stranding can also occur when prices are high enough for the miner to continue producing: if prices exceed $50, but remain below what the company projected at the time it made the investment, the company would earn less than the $50 million in profit it expected. The difference between the profits the company expected and the (lower) ones it ended up with are considered stranded. Stranding includes both the investment that has been made as well as the change in the value of the resource itself.

Of course, important questions include:

- Who owns both the investment that is no longer used and the resource that is in the ground? They can often be different where, for example, the government owns the resource and collects royalties on it.
- What mechanisms determine how demand and supply fall? Different policies will work on the supply curve, the demand curve, or both.

including price-to-earnings[7] (Forward PE) and five year growth expectations, show that markets expect industries like integrated oil and gas companies and electric utilities to grow more slowly than the market in general.

- **The low-carbon scenarios** reflect a best estimate as to a feasible path to a low-carbon economy. However, as technology and the economy evolve, new, low-cost carbon reducing opportunities are likely to emerge, while existing ones will become cheaper. By reacting and selecting the set with the lowest cost, the path to 2DS is likely to become less costly, with different sets of asset stranding. For example, the rapid decline in solar PV pricing has exceeded expectations from just two years ago.

*Our estimates for asset stranding are based on scenario analysis, to provide a guide to the potential magnitude of stranding*

While there are many potential paths for reduced fossil fuel consumption that could lead to a lower carbon economy, we have used the IEA scenarios as an example of a consistent scenario in order to scale the potential magnitude of shifts in value. Thus, we use the business as usual and 2DS/450 ppm scenarios not as definitive numbers, but rather as a guide on which to base quantitative evaluation that helps size the potential impact of stranded assets, understand how asset stranding costs could be distributed, and identify the potential impact of policy on stranding and implications for policymakers. The actual outcome will be affected by policy, technology and economic development, as well as the timing and ambition of global energy and climate action. Our analysis is designed to provide insight on the potential impact of climate action on asset values and the distribution of that impact, as well as how policy can be used to maximize benefits and minimize losses.

7 The price of a company shares divided by earnings. Higher PEs generally reflect market expectations that a company's earnings will grow, making the company more valuable.

### 2.1.3 Evaluating stranded asset risk for fossil fuel assets

So, how do we calculate the potential value that would be at risk in a sector or by a producer? CPI developed individual models to estimate stranding in each of the four fossil fuel sectors studied. The oil, coal and gas models are based upon supply costs for each of the relevant markets. Comparing demand for various countries and regions around the world under a scenario where there is no action to reduce consumption in response to climate change and one where the 450 ppm scenario level is met, we determine both which production assets would no longer be needed and how the price for the commodity would be changed. We reduce consumption from the most expensive assets, after taking into account investment that has already been made, as well as transportation costs and constraints.

The oil, coal, and gas models are based on five basic inputs: price, quantity, production cost, ownership, and taxes.

- **Production cost, ownership, and taxes** we allocate based on commercially available data sources, such as the Rystad database of 66,000 global oil and gas fields and various other cost and ownership data sources.
- For the **price and quantity** of coal, gas, and oil production, we have developed our own supply and demand modelling to forecast which production would be curtailed because it is too expensive to operate under different scenarios and how prices in commodity markets would react to falling demand under a transition.
  - » These supply models are based on aggregations of cash costs and investment costs from the same data sources, adjusted to account for the impact of sunk costs, transport costs, investment returns and in the case of gas, the interrelationship between oil and gas supplies.
  - » The oil demand model is based on IMF forecasts for country by country GDP growth, and historical multipliers for the relationship between GDP and oil consumption in the absence of price changes. Then, based on a number of studies of oil sensitivity to price changes, we forecast how demand would change for any given future price expectations.

» Demand for coal, oil, gas, and power under the low-carbon scenarios is based directly on the IEA low-carbon scenarios.

» By comparing these demand estimates against the supply curves generated by the supply models, we can estimate market price and which production assets will be needed in a given year.

With this in hand, price minus cost is the value achieved per unit of production which can then be multiplied by quantity or output to define yearly profit. We split this profit between royalties and taxes and corporate profits and then assign the specific assets to companies and countries. We then discount annual profits from 2015 to 2035 to estimate value for any given asset. We use a discount rate of 8% to represent the return in the general market that the re-invested revenues from these assets could support were they not to be stranded. Higher or lower discount rates affect the headline number, but do not materially alter the relative impact and insight that this analysis brings. Finally, we compare asset values by owner between the business-as-usual and low-carbon scenarios to estimate the asset stranding impact on various players.

For power plants, we estimated the risk of stranding for existing plants (those already built as of 2014). Stranding from 2015-2035 was estimated in two components: the value stranded due to plants retiring before the end of their useful lives, and the value stranded due to plants being utilized less frequently (known as factoring down). In the low-carbon scenario, we assume that coal-fired power plants without pollution controls retire at 40 years, and plants with pollution controls retire at 60 years.

- **For plants retired at 60 years** we made the assumption that they could feasibly stay in service for an additional 20 years if not retired. The stranded value of these plants was calculated as the profits they would have realized through 2035, discounted back to 2015 at an 8% discount rate. For plants retired at 40 years we assumed there would be no stranded value since these plants would have to install costly environmental controls to comply with clean air regulations in order to continue operation, effectively offsetting any future profits.
- **For plants factored down** in the 450 ppm scenario we estimated how many fewer hours the fleet would operate relative to the business-as-usual scenario on an annual basis from 2015 to 2035. Profits were then calculated per MWh over the study period and discounted back to 2015.

Central to estimating both components was deriving a per MWh profit for coal plants in the U.S., EU, and OECD Asia (Japan and South Korea) — the only regions where stranding in the 450 ppm scenario is likely to occur. To accomplish this, we modeled marginal costs for a range of power plants using fuel and operational cost data from the EIA, IEA, and Bloomberg among other sources.[8] The spread between coal plant marginal cost and the marginal cost of a baseload natural gas combined cycle was taken as the estimated profit per MWh for use in the stranding calculations. Recognizing that gas prices are likely to change over the study period, we projected prices of $5.5/GJ in the U.S., $7/GJ in the EU, and $10/GJ in OECD Asia. To assign the share of power plant assets to particular owners and regions, we used the Platts World Electric Power Plants Database and information on specific projects from various news sources.

### 2.1.4 Stranding risk depends on the specifics of markets and resources

We tailored our modeling effort to reflect the particular circumstances of different fossil fuels and regions. Our analysis reflects the following key differences between the four fossil fuel industries studied (oil, coal, gas, and power plants) that affect the potential impact of the low-carbon transition on asset values.

**Some fossil fuel assets compete in global markets, while others are restricted to local markets.** Of the different fossil fuels, oil markets are the most global, while power plants are the least. Thus for oil, policy, technology and economic changes in one region tend to affect oil prices — and, through prices, production — across the world. On the other hand, power plants are mostly affected by regional, national or even sub-national policy. Coal and natural gas fall in between, with about one-sixth of global production traded on global markets (seaborne coal, liquefied natural gas, and long distance pipeline gas) and the rest on mainly regional markets.

8 Gas price projections are based on CPI analysis of gas market dynamics, as well as price data from Bloomberg and Federal Energy Regulatory Commission, 2013, National Natural Gas Market Overview: World LNG Landed Prices, August 2013. Coal prices are from International Energy Agency, 2013, "Coal Medium-Term Market Report." Assumptions about capital costs and operations and maintenance for power plants are based on Energy Information Administration, 2013, Updated Capital Cost Estimates for Utility Scale Electricity Generating Plants, available at: http://www.eia.gov/forecasts/capitalcost/pdf/updated_capcost.pdf

Our modeling approach reflects these differences: For oil we use a global model, for power a series of regional models, and for coal and gas a global model that incorporates supply and demand and pricing in each region into a global model that accounts for trade and transport costs.

We also take into account the potential influence of national and regional policy decisions on global markets. Our oil analysis includes projections of OPEC's response to changes in the global oil market during the low-carbon transition (section 4.1). We also assessed the potential impact of China's coal reserve management policy on coal asset values both within and outside China (section 5.2).

**The dynamics of pricing and regulation determine how the low-carbon transition will change asset values:** Market dynamics differ across the four fossil fuel sectors, as does the role of policy. In particular, market design and revenues for power plants are heavily influenced by regulators in many regions. Our modeling reflects these differences across fossil fuel markets and focuses on the potential for policymakers and regulators to minimize asset stranding.

**The dynamics of asset stranding are different for natural resources and for manufactured assets:** Coal, oil, and natural gas are resources that exist and retain some potential value even if they are not extracted; their value depends on how they are (or are not) actually put to use in the economy. Power plants and other infrastructure assets are built and upgraded based on investors' expectations of future profits; if a plant reaches the end of its useful life and is retired, or if it is not built in the first place, no value is stranded.

# 3. Who is most at risk and why

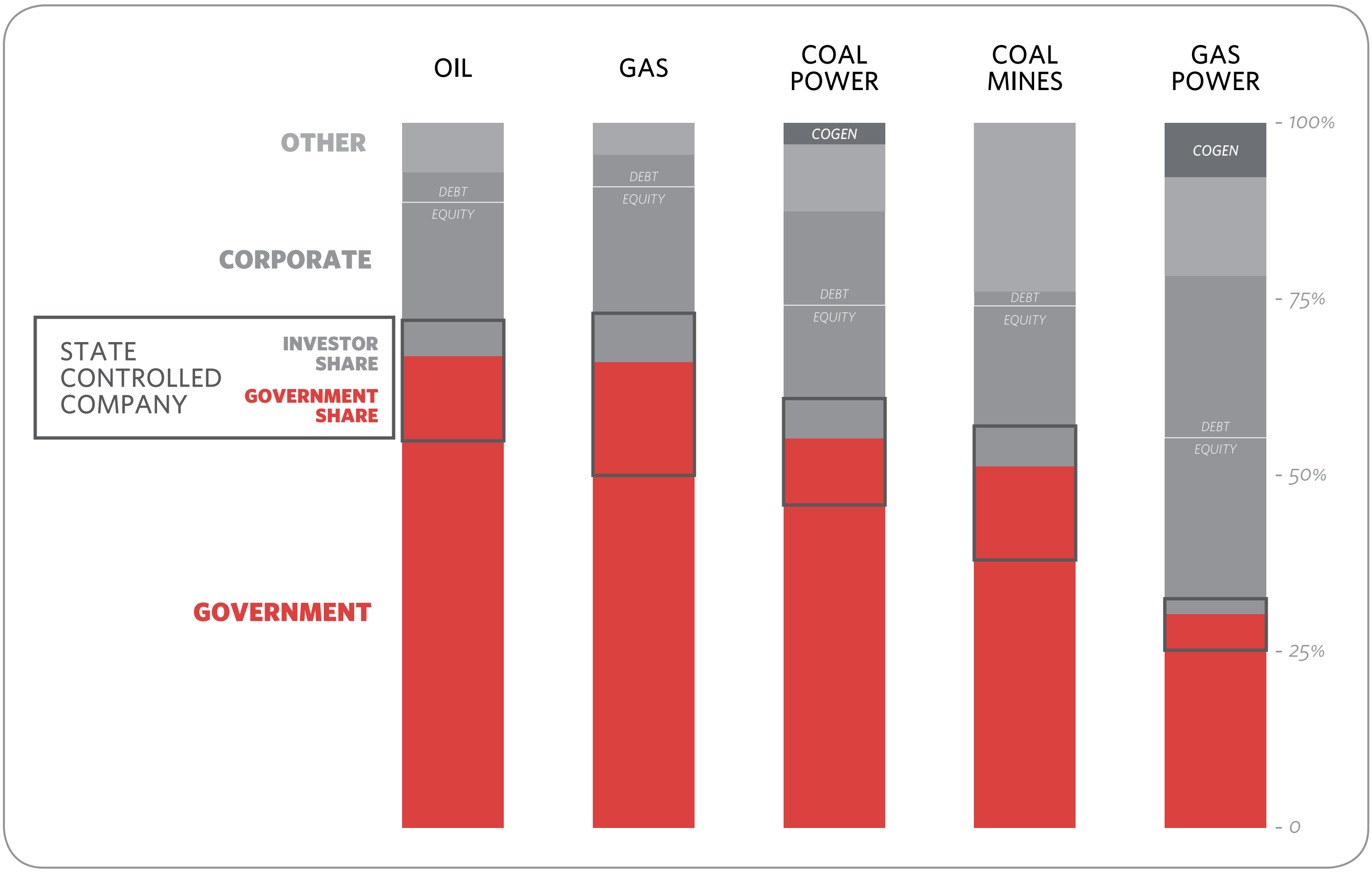
If stranding risk depends on a change of expectations, then it should be the owners of the fossil fuel resources and related assets that have both the biggest expectations and the biggest risks. Asset ownership has three basic components: ownership of natural resources, ownership of manufactured assets and equipment, and licenses and rights that grant ownership of specific revenue streams. In most countries, mineral resources are the property of the government, which then can license the right to develop these resources or chose to develop the assets itself. In other countries, property owners also own mineral rights. Alongside the oil fields and coal deposits lie the equipment, assets, and knowledge that companies and governments have developed to exploit these resources. Tying this all together are licenses, contracts and regulation, which may be used to assign the right to a specific revenue stream from a fossil fuel resource. Investors rely upon all three to make their investments. In determining who would bear risks related to fossil fuel asset stranding, we consider all three components of ownership.

To begin our analysis of who is at risk, we first look at how ownership of production was split between different types of actors in 2013 — considering private ownership as well as licenses and government contracts allocating ownership to private actors. We then discuss how taxes and contractual mechanisms can shift these risks, generally back to consumers or the government. Finally we will provide a first glimpse at the results of our stranded cost modeling, showing how value at risk is split between fuel types and between governments versus investors.

## 3.1 Who owns fossil fuel assets at risk

Energy has tremendous strategic value for nations, so national governments have sought to control the production, price, and value of these assets. As shown in Figure 3, governments own over half of global fossil

Figure 3. Government and Investor Share of Fossil Fuel production




Note: Equity/debt splits are estimated based on typical debt-equity ratio for asset types. For oil and gas, these numbers include all 2013 production (Rystad). Power data come from Platts and include capacity from the U.S., EU28, China, India, Russia, Japan, South Korea, Indonesia, Ukraine, Australia, and South Africa, which we estimate to account for 93% and 75% of global coal and gas-fired generation capacity. Coal asset ownership is based on a country's 2012 coal production by ownership type. Total production figures were taken from the BP Statistical Review. Bottom-up production data were analyzed by CPI and taken from Bloomberg, BankTrack's coal production database, various government and investor reports, and the IEA's 2013 Coal Medium-Term Market Report.

*Governments, as custodians and beneficiaries of their natural endowments, may have the most to lose. National and regional governments continue to own or control well over half of fossil fuel assets.*

fuel production and control as much as 70% of oil and gas production through companies that are wholly or majority owned by governments. For coal production and coal-fired power plants the figure is closer to 60%, while it is lower for gas-fired power plants. These figures include government owned companies that have private investors because they have listed minority shares on exchanges. The diagonal shading in the figure represents these "listcos" with the darker shaded area depicting the minority share held by investors.

Notably, publicly traded corporations whose main business is mining or energy production own only just over one-quarter of the coal, oil, and gas production by output, including the investor shares of publicly traded, majority government owned and controlled companies. Another smaller share of production is privately held, has unidentified ownership, or in the case of industrial co-generation, may be owned by publicly traded corporations that use the energy output from power plants, but whose main business might be manufacturing or steel production.

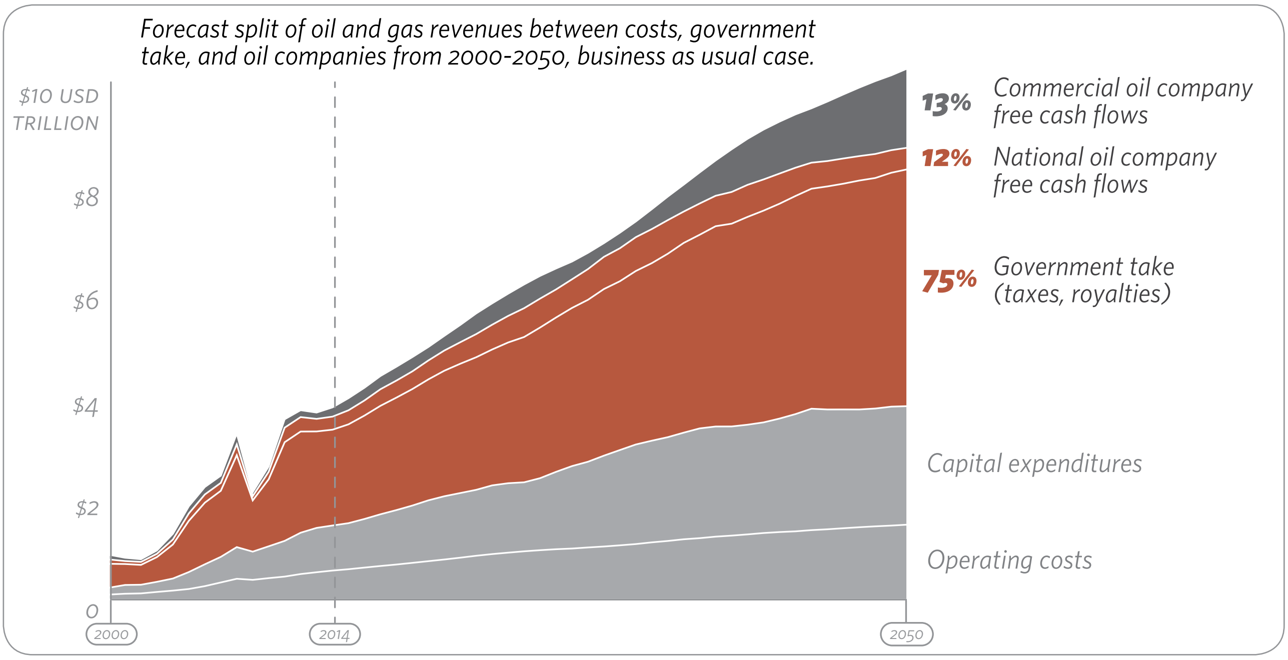
## 3.2 How risks fall on investors and companies versus governments and others

Even those assets that are not owned or produced by governments usually provide significant value for governments and their economies. On one hand, governments collect royalties and taxes on production that can be major contributors to government budgets. They also collect corporation tax from companies operating in their jurisdiction and income tax from workers in the industries.

Focusing just on the royalties and production taxes, Figure 4 shows how revenue from global oil production is split between extraction and production costs — that is, capital investment and operating expenses — and free cash flows that are generated from the production.

Free cash flows are one measure of profit that includes the return of capital that has already been invested. The sum of these cash flows, discounted to account for the return required on investments, is one measure of the value of these assets. As in the figure, this value is split between government take in the form of taxes and royalties, and the free cash flow received by private and government owned (national) oil companies. By this

Figure 4: Governments and government-owned companies will receive close to 87% of the net present value of future oil production between 2014 and 2050



**Box 2: Production sharing contracts place more stranding risk with governments**

For energy resources developed by the private sector, most governments seek to minimize the leakage of value from the government to the private sector. Governments have become very good at developing regulation, contracting, licensing, royalty and taxation regimes that keep most of the value of energy resources for the government. To keep private sector returns and financing costs at a relatively low level, these regimes typically provide some revenue certainty to the private investors, with the result being that governments bear a much larger share of the risk of higher or lower energy prices, or higher or lower production volumes. Typical examples include power generation that is built under a regulatory system that provides a fixed return on investment. Another example is oil and gas production sharing contracts.

Figure 5: Between 2013 and 2035, nearly 25% of oil is expected to be produced under production-sharing contracts

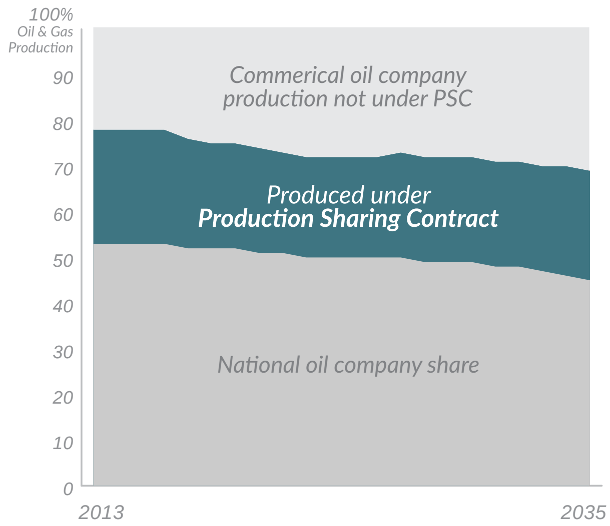



Figure 5 shows that almost one-quarter of global oil and gas production between now and 2035 is set to be produced by commercial oil companies under production sharing contracts (PSCs) or production sharing agreements. This production represents nearly half of the production from commercial oil companies.

Under PSCs, oil production is typically split between "cost oil" and "profit oil". The first tranche of production is typically allocated to cost oil, until the producer's costs have been covered. Any oil that is left (the profit oil) then is split between the producer and the host government, with the host typically receiving a much larger share. Since costs must be covered first, if oil prices fall or costs rise (including taxes), the producer will receive a greater share of the oil production. One interesting result is that when oil prices rise, production from commercial oil companies will fall, as their share of PSC output falls. PSCs can be structured in many ways, with different allocations between cost and profit oil that can vary depending on the oil price. In Figure 6, we modeled a typical PSC to determine what percentage of value flows to the host versus the producer. Due to the various contract parameters, this value depends upon the oil price. Alternatively, we calculated the percentage of risk due to a change in the oil price that would be borne by the host rather than the producer. For most oil price scenarios, the host has more than 80% of the oil price exposure.

The result is that resource owning governments may be even more exposed to commodity price risks driven by climate change policy than their 90% share of value indicates.

Figure 6: Under production sharing contracts, the host government holds most of the risk if prices decline

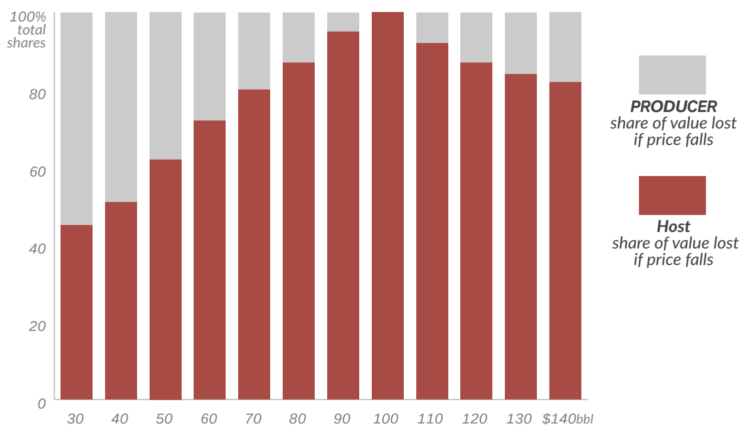


Figure 7. Value at risk from reducing production in accordance with IEA 450 ppm and 2DS Scenarios (2015-2035)

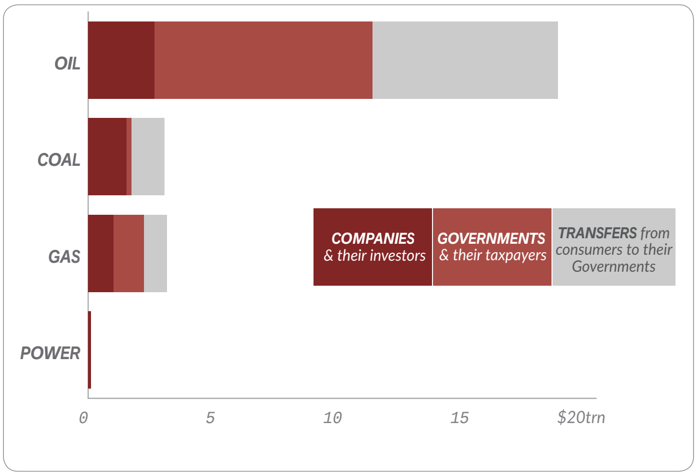
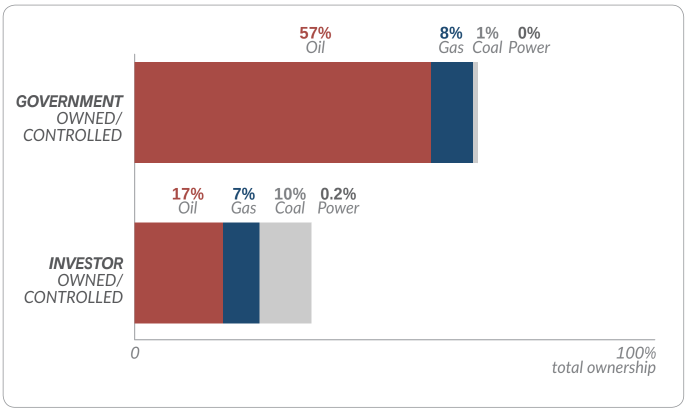



Figure 8: Split of total fossil fuel value at risk between government and private investors (excludes transfers between governments and domestic consumers)




measure, the government share of global oil production value — that is, the combined government take and national oil company profits — represents nearly 90% of the value of global oil reserves and facilities.

Even so, these estimates likely overestimate the share of risk that is borne by private investors for a number of reasons. First, many assets are regulated, to provide low-cost, lower-risk energy supplies to domestic consumers. For regulated assets, one result is that much of the risk associated with price changes or falling demand is passed back to consumers or governments, in exchange for lower financing costs and lower prices. Among the power plant assets, for instance, regulated assets represent 55% of U.S. and 100% of Japanese power plants.

*Through taxes and royalties, governments benefit even more from energy resources and production assets than the ownership figures would suggest*

In the oil and gas sector, almost half of production by commercial oil companies is under a form of contract, typically a production-sharing contract (explained further in Box 2). Under the terms of these contracts, oil revenues are split between the company and the host government. In order to reduce risk to the company, and keep incentive costs down and thus increase value for the host government, these contracts typically allow companies to recover costs first, before profits are shared in a way that strongly favors the host. Thus, as revenues fall, profits decline first and the impact falls disproportionately on the host government. Our analysis shows that for a typical contract as much as 80-90% of the risk of price declines would revert to the host government. In our analysis in Figure 3 we have not made this adjustment for the global figures, as governments' exposure to price shifts is highly sensitive to assumptions and contract structures. Furthermore, we would argue that if prices fell, some countries might be forced to reduce royalties to avoid making their production uneconomic and losing all the remaining value from their production as companies ceased production, once again shifting risk to the governments in the long term.

## 3.3 Governments bear significantly more risk than companies or investors

With a higher share of value we would expect government to bear a higher share of the risk, particularly risks associated with declining value or production. Figure 7 presents output from our industry models estimating the potential value that could be lost under the IEA 450 ppm scenario compared with a business-as-usual scenario (for more information on scenarios and methodology, see section 1).

Figure 8 presents the breakdown of total value at risk between investors and governments.

The total value at risk, when discounted to current money including an appropriate return on capital, is just under $25 trillion, of which approximately 80% is the potential decline in value to governments for resources extracted from their territory.[9] As we'll see in the next

9 These estimates assume that fossil fuels that have access to global markets re-

chapter, policy pathways can drastically alter whether that total value is lost or not — policy intended to minimize asset stranding can achieve the needed emissions reduction at a much lower cost, or, even a net gain. Here, we'll explain in more detail the $25 trillion at risk.

The decline in value comes from both losing profitable production and receiving lower prices from production where prices decline due to falling demand. However, if fossil fuel prices were to fall in response to lower global demand, almost half of the government value at risk would come from the lower profits that governments would receive for sales to their own residents — that is, transfers between consumers and their own governments. In practice, many producer countries subsidize their own energy consumers, providing fossil fuels at prices far below market levels. Furthermore, those countries that already charge higher prices could easily achieve the exact same emissions reductions by taxing oil consumption of domestic consumers if prices fell. Thus, the portion of the value at risk labeled "transfers between governments and their consumers" only notionally reflects governments' exposure to the risk of value decline, so the true risk to governments is closer to the light red bar in Figure 7. Excluding transfers between governments and their own residents brings down the total value at risk from $25 trillion to approximately $15 trillion. Even so, governments bear two-thirds of the total risk, primarily from declines in revenues from their exports of fossil fuels.

*With a greater share of value, governments also face a greater share of the risks associated with climate change including reduced demand or prices for fossil fuels.*

Looking across the four fossil fuel sectors, the majority of the lost value will be borne by governments as owners and royalty collectors in the oil sector. (The estimates presented here account for royalties, but they do not account for regulation and contract structures like the production sharing contracts described in Box 2.) The large impact on oil is partly due to the fact that the value of oil production over that period is more than three times that of either natural gas or coal. The global nature of the oil industry adds to the impact, as reduced demand affects prices globally, reducing the value of oil even for local producers.

Table 1 breaks down the stranding risk by region. Since most of the value at risk is in the oil industry, it is unsurprising that the largest share of value at risk is in major oil-producing regions. These numbers represent the value at risk for producers only; they do not include the financial benefit to consumers from reduced demand and lower prices. In addition, these totals include transfers between governments and domestic consumers and therefore likely overstate the true value at risk, as explained above.

Table 1: Value at risk by fuel and region (2013$, trillions)

| REGION | OIL | COAL | GAS | POWER | TOTAL |
|---|---|---|---|---|---|
| U.S. | 2.7 | 0.4 | 0.3 | 0.028 | **3.4** |
| EU | 0.4 | 0.1 | 0.1 | 0.003 | **0.6** |
| China | 0.7 | 0.9 | - | - | **1.6** |
| India | 0.2 | 0.2 | - | - | **0.4** |
| Brazil | 1.1 | - | - | - | **1.1** |
| Russia | 1.6 | 0.2 | 0.6 | - | **2.5** |
| Other Oil Producers* | 9.9 | - | 0.6 | - | **10.5** |
| Other Coal Producers** | - | 0.8 | 0.4 | - | **1.2** |
| Rest of World | 2.0 | 0.5 | 0.9 | 0.002 | **3.4** |
| **Total** | **18.5** | **3.0** | **3.0** | **0.032** | **24.6** |
| **Total** excluding transfers between governments and domestic consumers | **11.2** | **1.7** | **2.2** | **0.032** | **15.1** |

* Includes OPEC members as well as Canada, Kazakhstan, Mexico, and Norway.
** Includes Australia, Colombia, Indonesia, and South Africa.

ceive market prices (adjusted for transport costs). Fossil fuels that are constrained out of global markets by transport costs or other constraints receive fair market returns.

## 4. How assets get stranded

Asset stranding does not happen spontaneously. As discussed in section 2, assets are stranded when a shift in policy causes asset values to diverge from previous expectations of their levels. In the case of fossil fuel assets, the risk of stranding hinges on what steps governments take to address climate change.

The preceding analysis shows that most of the global value at risk is in the oil sector, with much of the value at risk held by governments. As we'll see in section 5.4, there are also important interactions between the markets for different fossil fuels.

In this section, we show that a combination of innovation and policies that suppress demand for fossil fuels can lead to global economic gains. We also show that while all countries are better off if they act together to suppress oil demand, even if net oil consuming countries like China, India, U.S., and EU act alone, these countries can realize gains. Finally, we argue that regardless of asset type, policies that suppress demand are more beneficial than policies that suppress supply.

The analysis below highlighting the costs associated with innovation and tax policies should be interpreted as an estimated range of policy costs, not two stark policy choices. In practice governments will likely implement a combination of these two types of policies, so we expect the true cost or benefits to fall somewhere between the two.

### 4.1 The causes of asset stranding and the importance of policy

To illustrate the significant role policy plays in driving asset stranding, we use as an example the oil industry, where nearly three-quarters of fossil fuel stranding risk lies. The risk is high partly because oil reserves are relatively large and the value of oil is relatively high compared to other fossil fuels. The most important reason, however, lies in the global nature of the oil market compared to other fossil fuels and the relative sensitivity of oil prices to demand. We have modelled supply and demand for oil through 2035 as a function of the oil price. When oil demand falls, the most expensive new production is no longer needed and the remaining producers compete to sell oil into an oversupplied market. Prices fall as a result.

To assess the stranding risk, we forecast the producer price for oil that would be consistent with output at the IEA 450 ppm scenario levels. We then compare this with our forecast of oil demand and supply. We have also modelled the impact that OPEC could have and found that given recent changes to non-OPEC supply and at the projected levels of demand, OPEC would be unlikely to be able to maintain, or benefit from, higher oil prices as the lost profit from production they would need to remove from the market would exceed the benefits of the higher prices. Table 2 lists the global oil price that we project under a business-as-usual scenario and under two alternate low-carbon (450 ppm) transition pathways. In one scenario, demand is brought down to levels consistent with 450 ppm using only price instruments and existing technologies. In the other, demand adjusts to 450 ppm without the use of price instruments — for example, through customers switching to an innovative substitute — and oil prices fall as a result.

As shown in the third row of Table 2, this modelling demonstrates an important dilemma in the oil transition. If demand falls to the 450 ppm levels, oil prices are likely to fall. By 2035, the 450 ppm price for oil could be less than half of our forecast for the business-as-usual scenario. This decline in price is the most important contributor to oil asset stranding risk.

Table 2. Oil prices consistent with achieving 450 ppm oil demand levels using strictly price-based policy tools versus policies that decrease consumption exclusively through non-price policy tools ($2014/bbl)

| POLICY SCENARIO | PROJECTED OIL PRICE IN 2025 | PROJECTED OIL PRICE IN 2035 |
|---|---|---|
| Business-as-usual forecast | $152 | $209 |
| Price level required to suppress demand to 450 ppm targets using price-based policy tools only | $232 | $290 |
| Price realized by producers in scenario where 450 ppm targets met through demand reductions with no price-based policy tools | $80 | $101 |

Note: The price levels for 2025 and 2035 stated above are those that would be realized exclusively through either policies that increase price levels or policies that reduce demand. Policies that support substitution of oil demand through innovation (plug-in electric vehicles, biofuels, fuel cells, etc.) fall into this second category.

Yet, if prices were to stay low, and no other action were taken, demand would grow. Our demand modelling suggests that prices would need to be almost 40% higher than the business as usual case to suppress demand to the 450 ppm levels. With higher prices, over time consumers would buy more efficient cars or electric vehicles and move closer to work, logistics chains would shift to reduce transport costs, and prices would spark innovation in new energy saving technologies.

The question for the transition is how to bridge the gap between producer prices under a 450 ppm scenario and consumer prices consistent with lowering demand. The choice of measures and policies to reduce production and consumption will have a profound impact on the cost and potential benefits of reducing greenhouse gases. The impact on how those costs and benefits are divided among producers, consumers, and governments nationally, and among countries internationally will be even more marked. Two broad policy choices emerge:

- Reduce energy demand (for example by raising energy taxes or removing fossil fuel subsidies) to give consumers price signals equivalent to that of higher commodity prices, while the resulting decline in demand leads to lower prices for producers; or,
- Innovate to shift demand by creating low-cost or more attractive alternatives.

For either of these solutions, the impact on the economy and investment extends beyond just the stranding loss faced by producers. With taxes, governments will benefit from tax receipts while consumers will suffer from higher prices, although governments could lower other taxes to compensate them for their higher costs. In the case of innovation, consumers will benefit from lower fuel prices, as even in the 450 ppm scenario, oil demand would continue at around 80% of today's level.

*The policies that governments use to induce the transition to a low-carbon economy will affect the overall impact of the transition as well as who loses and who benefits.*

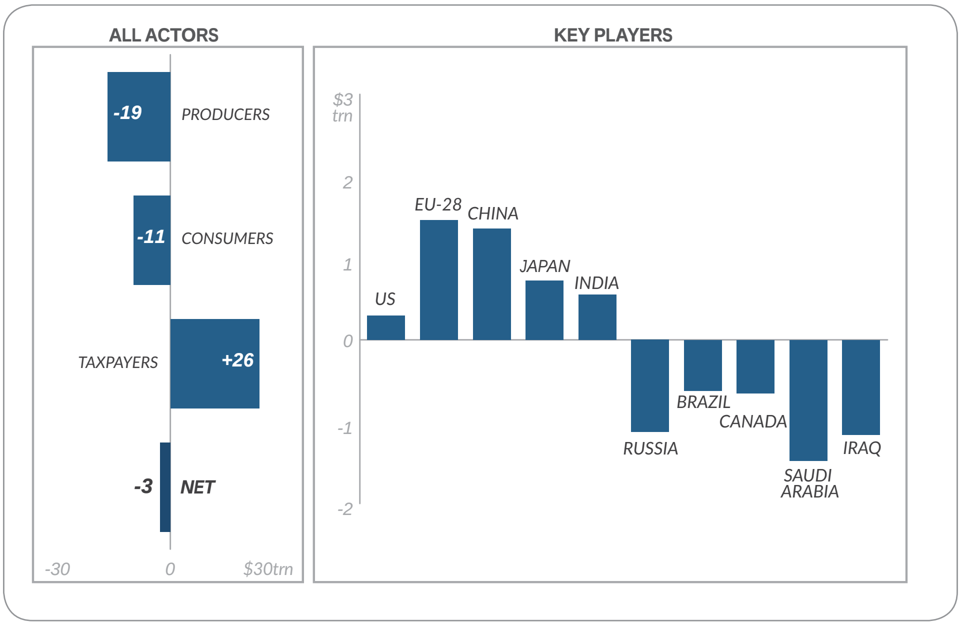
*In a transition away from oil, policies that reduce demand can result in an economic cost of $3 trillion, while innovation can result in a $7 trillion benefit. Practically speaking, innovation and taxes can work effectively as complements.*

### 4.1.1 Stranding through prices or taxes

Figure 9 shows the impact of a price-based policy pathway on producers, consumers, and taxpayers, as well as the net impact on the economy as a whole. When taxes are the primary mechanism for consumption reduction, the net stranding impact — on governments, producers and consumers — amounts to $3 trillion of lost value. This figure accounts for all of the investment required to make the transition on the consumer side as well as the producer side. The windfall to governments from tax revenues would be greater than the cost to consumers, creating an option for governments to counteract some of the negative political and social consequences of raising energy prices, for example through rebates to taxpayers.

The right-hand side of Figure 9 shows the net impact to key economies around the world of a reduction in oil demand based solely on consumer price instruments. Net consuming regions would benefit on net from this approach, because tax revenues would more than balance out the losses to consumers. Net producing regions would face losses.

Figure 9: Net benefits to different actors within the economy of moving to a low-carbon pathway using only price-based policy tools and already established technologies ($ trillions)



### 4.1.2 Stranding through innovation, behavior, and regulation

In contrast to the previous scenario, if technological innovation, increased efficiency, behavior change, and regulation rather than taxes were the driver for reductions in demand, there would be a significant

*Innovation, efficiency, and behavior policy, if developed and implemented at a low cost, would benefit all countries economically*

net economic benefit, and the distribution of benefits would change. These policies and actions also have economic costs, including investment in research or new infrastructure, loss of perceived value to consumers (for example, driving smaller cars), or loss of economic efficiency. Yet if these costs can be kept low, they could provide substantial value to the global economy compared to a purely tax-based approach by reducing the cost to consumers of finding and using alternatives to oil consumption, as shown in Figure 10.

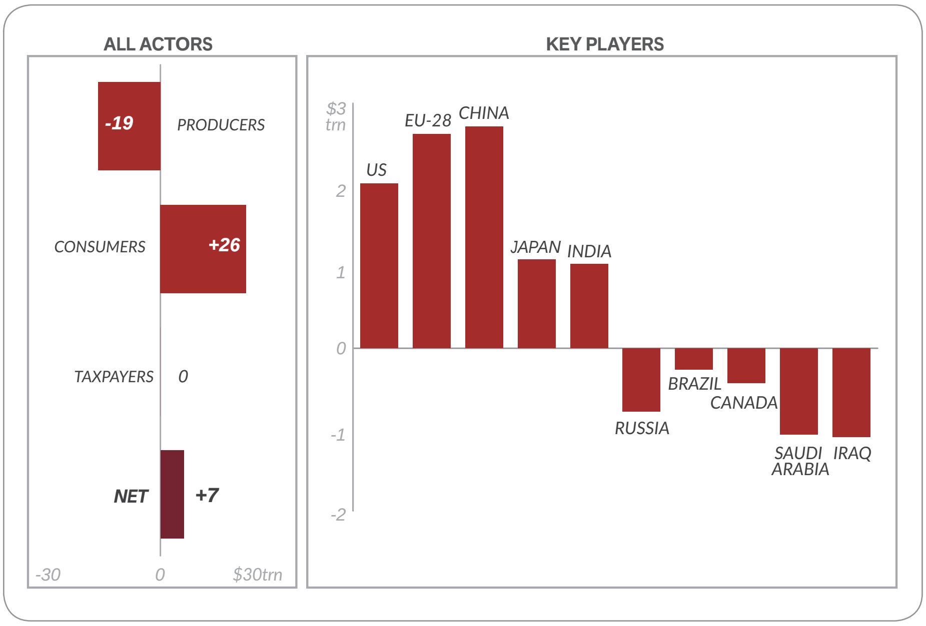
If innovation resulted in improved efficiency or created low-cost energy alternatives, it could spark a transition without the need for consumer trade-offs. In this scenario, taxes would not be needed and lower fuel expenses to consumers would result in net economic benefits of $7 trillion. Assuming that innovation could achieve the goals at a relatively low cost with an acceptable level of risk, this could be a very attractive policy route to take. However, innovation would not provide the windfall to government accounts that a tax might provide.

### 4.1.3 Pricing and innovation policy complement eachother

In effect, the two modeled policy pathways represent a best-case and worst-case picture of the costs of the energy transition. Innovation represents the best-case scenario, where the needed reduction in fossil fuel demand can be achieved without any direct cost. As in Figure 10, if such a demand decline could be achieved without taxes, a net value of $7 trillion could be achieved, $10 trillion better off than achieving the decline solely through consumption taxes. Taxes represent the worst-case scenario, where there is no innovation to lower the cost of reducing fossil demand and consumers must bear the entire cost of switching. In reality, any policy solution will fall in between the two extremes.

Innovation and taxes can work effectively as complements. Taxes have an initial advantage because they are a more certain policy tool than innovation. Tax revenue can then be channeled to support further innovation — and the more successful innovation is, the lower taxes will be needed to reach a low-carbon trajectory. Moreover, the impact of taxes depends on the price elasticity of demand — that is, on how quickly consumers respond to an increase in price. Studies of the price elasticity of demand for oil suggest that a good deal of innovation and behavior change is driven by price changes; in fact, it could be argued that prices are the main driver of innovation and behavior change.[10] Thus, the two policy

Figure 10: Net benefits to different actors within the global economy of reducing demand without using price-based policy tools




10 Examples include: Bernstein sell-side analysis; Gately, D., and Huntington, H.G. 2002. The Asymmetric Effects of Changes in Price and Income on Energy and Oil Demand. Energy Journal 23:19–55; Greene, D., and Ahmad, S. 2005. Costs of U.S. Oil Dependence: 2005 Update. Oak Ridge National Laboratory. Available at: http://cta.ornl.gov/cta/Publications/Reports/ORNL_TM2005_45.pdf

pathways are not strictly alternatives; they are closely related, and a combination of the two could create overall economic gain.

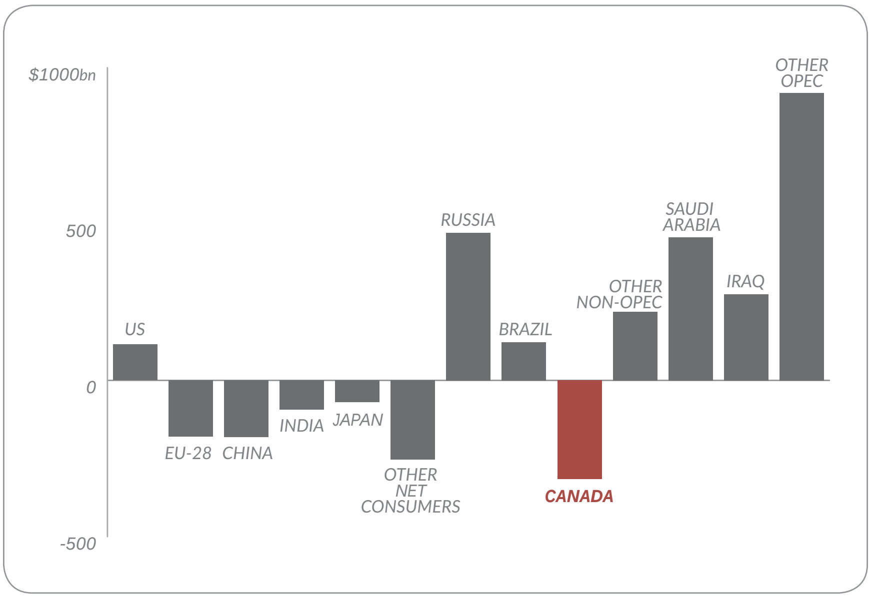
## 4.2 The relative effectiveness of policies affecting energy demand versus those that affect supply

An alternative to raising consumption taxes or innovation is restricting the development of new oil production, or placing other restrictions on oil supply. However, this seemingly attractive option runs into problems. We find that restricting the supply of oil from some regions would primarily result in production shifting to other regions, along with an increase in the price of oil. Net consuming countries would lose in this scenario, and producers that did not restrict their production would benefit.

When oil development is restricted, producers will have an incentive to develop new, more expensive, fields. As prices rise, most net producers will benefit (at the expense of net consuming countries), even if demand falls due to the higher prices.

*Due to the global nature of the oil market, reducing demand for oil is more effective than restricting the supply of oil. Net oil consuming regions would benefit from reducing demand, even if they act without net producers.*

Figure 11: Net impact of restricting development of Canadian oil




An additional problem is that supply restrictions rely on a producing country to sacrifice its economic position for the benefit of many others. In Figure 11 we take the example of Canada restricting the increase in output from oil sands projects. Removing new oil sands projects from the supply curve will modestly increase prices and thus lead to a reduction in consumer demand. Higher prices will impact net consuming countries like China and the EU, while other net producers will benefit substantially. When producers act together to restrict demand, the temptation for each individual country to resist the restrictions and produce more becomes ever higher as prices increase. With so many potential producers, restricting supply to keep prices high becomes very difficult, as witnessed by the difficulties OPEC has had over the years in maintaining quotas and discipline. The same argument holds for producer taxes as at least one producing country needs to be willing to raise taxes and producer costs high enough to stop production, thus losing all value and royalties from that resource.

**Box 3: Regional analysis: Net oil consumers would benefit from reducing demand, even if they act alone**

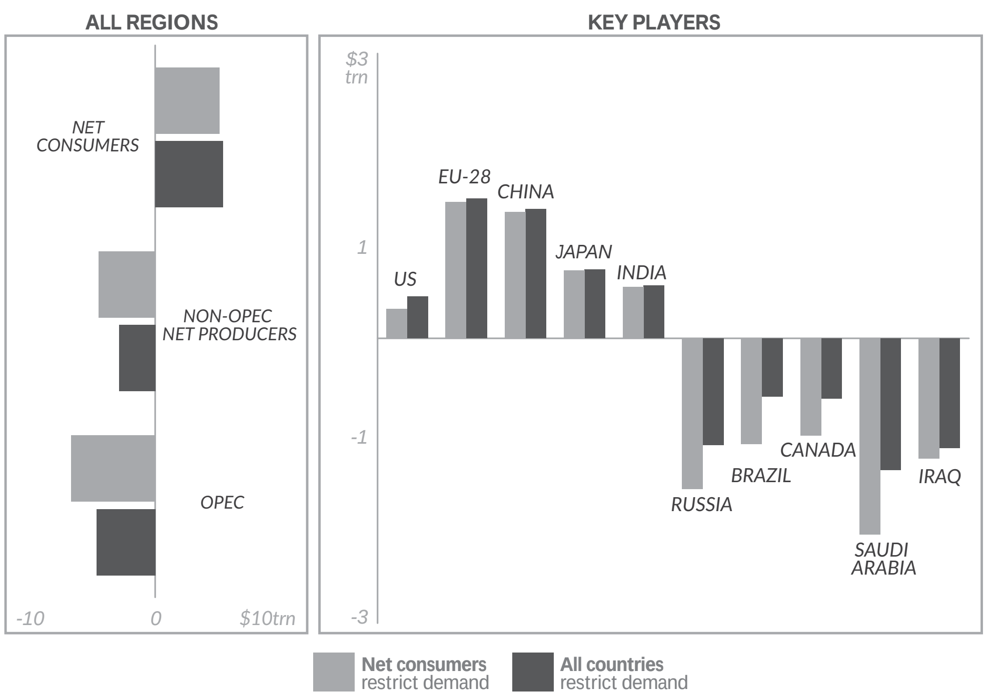
Net oil consuming regions — including the U.S., EU, China, and India — would benefit from using consumption taxes to reduce demand. These countries would benefit even if other countries did not join the policy effort. Net producers would see the price and value of their output fall, but if demand reduction policies became widespread, even producing countries would benefit from decreasing their own demand for oil.

While the global economy as a whole could benefit from decreasing demand for oil, the impact would vary substantially across regions — in particular, between regions that are net oil consumers (importers) and those that are net oil producers (exporters).

For example, as shown in Figure 12, net oil consuming regions, including the U.S., EU, China, and India, would be better off if there were widespread use of consumption taxes to restrict oil demand. The increase in tax revenues that would come from the consumption tax would exceed the higher cost to consumers, as pre-tax wholesale oil prices fall with lower demand. In fact, our analysis suggests that if all countries were to restrict demand through taxes, slightly more than half of the impact of the tax would be borne by oil producers, as their price realizations fell. Other policies to reduce demand for oil, such as the reduction of fossil fuel subsidies, may have a similar effect.

However, it is unlikely that all countries would agree to using a tax, especially net producers that could see profits decline. Nevertheless, our analysis indicates that there would be significant benefit to net consuming countries even if all countries did not participate. For example, our model indicates that the net consuming countries would continue to benefit from a tax policy to reduce demand, even if the net producers did not participate (see light gray bars in Figure 12). By reducing consumption on their own, net consumers could achieve 80% of the reduction in oil usage consistent with a low-carbon pathway and would still receive 95% of the total financial benefit they could see with global action. Further, with enough net consumers participating, net producers would find themselves better off if they, too, were to control their demand through taxation.

Figure 12. Net impact by country of using taxes to reduce demand to 450 ppm levels



# 5. Industry and market factors affect stranding risk in different markets

While policy, technology, or behavior and consumer preferences are the drivers of stranding, the impact that any of these have on value at risk depends on the market into which the fossil fuel outputs are sold and the assets' relative market position.

There are large differences between the markets and competitive landscape of different fossil fuels. Oil is now predominantly used in applications such as transport, where the high energy density and relative ease of transport and storage provide value. Coal is more abundant, often easier to extract and refine, and provides lower-cost energy. There are wide production cost differences among the oil and gas reserves that are being produced around the world; for coal the cost differences are smaller, but the transport cost differentials can be much higher. These factors lead oil to be both higher priced and the most globally traded of the fossil fuels. The higher value of oil is also an important reason why, as previously discussed in section 3.3, oil represents around 80% of stranding value at risk.

As we have discussed, asset stranding depends upon the changes in the expected value of the asset due to the change in policy or other asset stranding event. Thus both the value and expectations for policy are key determinants of stranding. The value of any asset or resource, in turn, depends upon what it can be used for, how much it costs to develop and transport to users, and what it would cost to replace. A gallon of water next to a large lake has little value, as it is easy to replace at a very low cost, but that same gallon of water could be very valuable in the middle of a desert.

Thus, understanding the impact of policy on asset stranding is not possible without a thorough understanding of the competitive market into which the resources will be sold and how those markets will be affected by the stranding event or policy. Significantly, the scope of the competitive markets are even different within specific fossil fuels, as the difficulty and cost of transporting many coal and gas resources effectively splinters coal and gas into many regional markets (with a global market for the most easily transportable resources), whereas oil markets are mostly global.

In this section we highlight five ways in which resources, industry structure, or national circumstances can influence the value of assets and thus affect how policy changes could impact asset stranding:

- The physical nature and location of resources determines the size, shape and competitiveness of the markets into which the fuels must compete;
- The existing asset base — as well as the economic growth of the relevant market — will determine whether existing assets will need to be closed, or whether growth expectations need to be reduced;
- Potential substitution and other contractual and physical relationships will mean changes in one fuel market may affect another;
- National energy strategies and resource endowments will help frame both value expectations and policy impacts;
- Finally, the timing of action — which could be dictated by any of the market or political consideration — can also have an important impact.

We further explore these factors in the next section.

## 5.1 Local versus global markets: Coal and gas have many local sub-markets, while oil is mostly global

The physical and financial characteristics of demand and supply in each fossil fuel market determine the impact of policy and other forces.

### 5.1.1 Oil markets: A global market and high resource value drive higher stranding risk

Crude oil is a heterogeneous resource that needs to be separated and refined into the oil products, like gasoline and diesel for cars and trucks, aviation fuel, bunker fuel for cargo ships, heating oil, or tar and asphalt for roads. Heavier crudes will produce less gasoline and aviation fuel and may require more refining to enhance their value. Yet despite this heterogeneity, global markets work relatively well to give refiners and oil producers incentives to maximize the value of the products produced from each barrel of oil, directing the heavier, lower value barrels to refiners that are best equipped to refine these barrels. The prices of oil products, like gasoline, reflect this trading of crude between producers and refiners, while the price of crude reflect the highest value for a crude given its location and the potential mix of product it can produce. The result is that, despite the heterogeneity of crude oil, the relationship between crude prices is well established and typically driven by a series of "benchmark" crude prices. Another result is that the price of most crude, regardless of quality and location, is affected by the global crude market.

Thus, the value of any particular crude production can be estimated on the basis of a benchmark oil price estimate, and differentials that account for transport and crude quality. Table 3 shows our estimate for these differentials for a few typical crudes.

One consequence of the global market is that the impact of any local change is likely to eventually spread across the entire oil market, but local policies can also get diluted. As discussed in Section 4, net consuming regions can act together in a way that can significantly impact stranding, and even result in significant gains.

### 5.1.2 Coal markets: Abundant resources and local markets reduce stranding

Coal represents a significant opportunity to reduce emissions with relatively low stranding risk — it represents 80% of the emissions reductions in IEA's 450 ppm scenario, and we estimate that it holds only 12% of the total asset stranding risk.

Like oil, coal is a heterogeneous product. However, there is less scope to refine or blend coal into the distinct products. Primarily, coal can be grouped into two main products:

- Coking or metallurgical coal, which comprised about 13% of global coal production in 2012,[11] is used mainly as a source of carbon in primary steel production;
- Steam or thermal coal, which is used to produce electricity, heat, and steam for industrial and residential use.

Table 3: Selected crude oils showing the combined quality and transport differential relative to the Brent benchmark (USD, 2014)

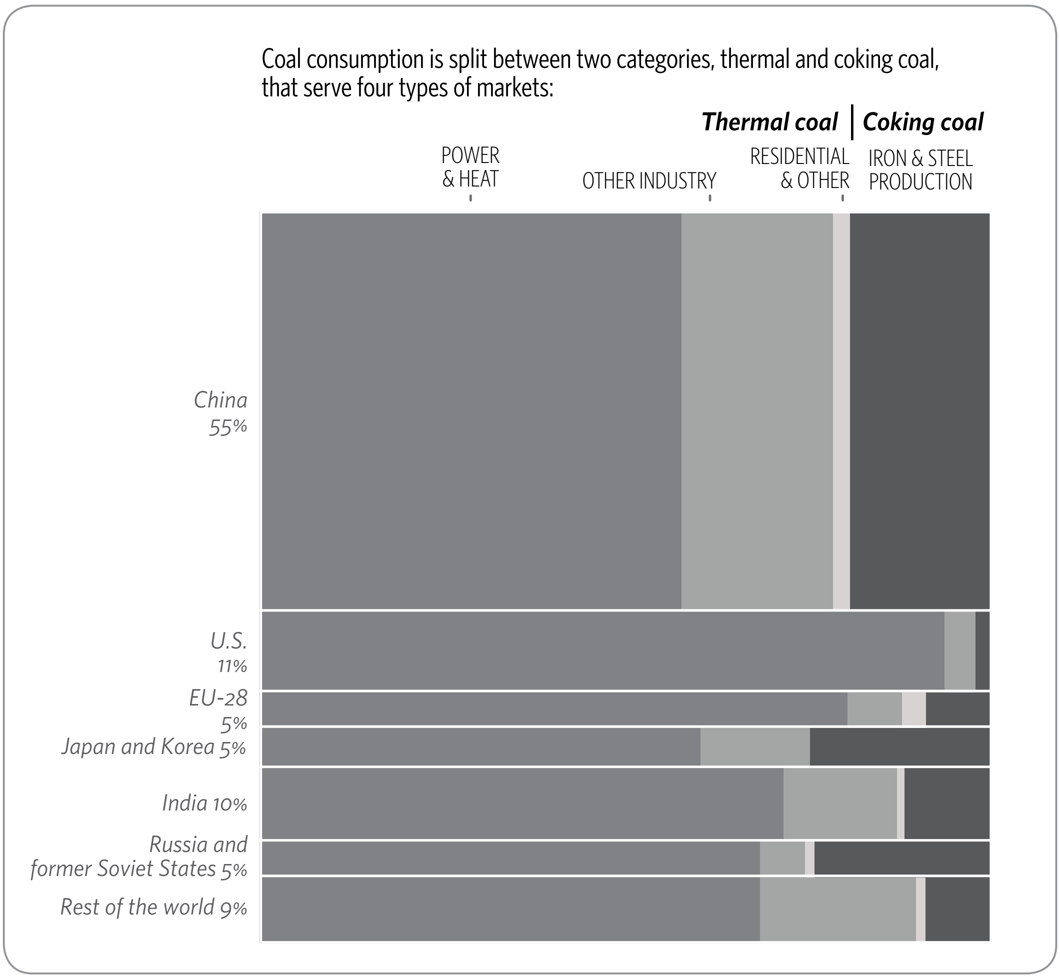
| CRUDE TYPE | ORIGIN | QUALITY AND TRANSPORT DIFFERENTIAL |
|---|---|---|
| Brent | Europe | -- |
| Maya | Mexico | -12.3 |
| Malaysian Basket | Malaysia | 5.1 |
| Saudi Basket | Saudi Arabia | -27.3 |
| Urals | Russia | -60.5 |

Source: Rystad 2014; Brent is a blend of crudes from the region around the North Sea; Maya is a crude blend comprised of oil from the Cantarell and Ku-Maloob-Zaap fields; Malaysian and Saudi baskets represent the range of crudes produced in those countries; Urals crude is from western Russia and generally represents the type of crude exported from that country.

The mix of demand for these coal types varies by country as a function of development and resources, as in Figure 13.

The main stranding risk lies with thermal coal, as there are many potential low-carbon substitutes and it is

Figure 13: Coal consumption by region and end use totaled 6,860 Mt in 2011




Source: EIA, 2013 Coal Information Report

11 International Energy Agency, 2013. Coal Information 2013. Table II.1.

Table 4: Breakdown of coal consumption by market type and region (2012, est.)

| | ISOLATED REGIONAL MARKETS (INCLUDING MINE-MOUTH) | CONNECTED REGIONAL MARKETS | NET IMPORTED COAL |
|---|---|---|---|
| North America | 30% | 70% | 0% |
| China | 56% | 37% | 7% |
| India | 57% | 24% | 19% |
| Europe | 45% | 30% | 25% |
| Russia | 50% | 50% | 0% |
| Japan, South Korea, Taiwan | 0% | 0% | 100% |

Source: BGR, 2013 Energy Study - Reserves, Resources and Availability of Energy Resources; World Energy Council, World Energy Resources 2013 Survey; Lawrence Berkeley National Laboratory, China Energy Databook Version 8.0.

thermal coal that represents the largest share of energy-related carbon emissions.

Coking coal is more difficult to replace. Coking coal may be a good candidate for carbon capture and sequestration, for two reasons. First, it is a smaller and more self-contained market than thermal coal (meaning that there is less competitive pressure to keep prices down). In addition, the gas produced at steel mills has a higher concentration of $CO_2$ than the gas emitted from power plants, so a steel mill could capture the same amount of $CO_2$ with a smaller (and therefore less expensive) CCS facility than would be required at a coal-fired power plant.[12] Our analysis incorporates only a small risk of stranding for coking coal.

Within thermal coal the energy, sulfur and moisture content and the location of the coal mine creates other sub-markets. Lignite which represents approximately 12% of global coal production, for instance, has a lower energy content per tonne. As a result, transport costs per unit of energy are higher. Typically transport costs are high enough that it makes more sense to locate the power plant on or near the coal mine, rather than transporting the coal. Beyond lignite, there are other coals that do not have transport links with national or global coal markets, either because of low energy content, the cost of transport, or a lack of infrastructure to transport the coal to global markets.

Finally, even for high quality coal with good transport potential, some coal feeds self-sufficient coal markets where domestic prices are linked to local markets rather than global markets. This applies to much of the coal in the U.S.

For the purposes of stranding analysis we identify four different types of markets. Table 4 gives the current breakdown of these markets across key coal-consuming regions.

- **"Mine-mouth" resources:** For these coal resources, the quality of coal and location make transport expensive relative to the energy value of the coal. In this case, power plants and other demand are located next to the mine, since the cost of transporting the electricity is usually lower than the cost of shipping the coal. With this arrangement the mine is a captive supplier of the power plant, so coal prices are usually set on a regulated or cost pass- through basis under contract. Mine-mouth resources are thus not exposed to any price effects as a result of policy and demand changes, but only face volume risk. Since many mine-mouth resources are relatively low-cost and also provide local energy security, they also tend to face lower volume reductions than international coal.
- **Isolated regional markets:** Some markets are reasonably self-sufficient in coal production, with the cost of transport, or lack of transport facilities, making imported coal too costly to compete with local sources. The markets may be regulated (and thus effectively

Table 5: Most U.S. thermal coal is traded within regional markets

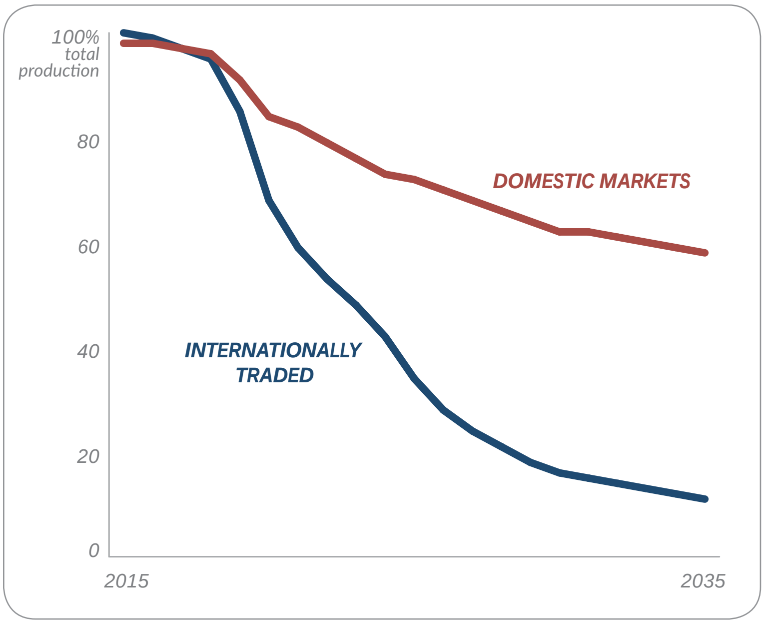
| DESTINATION | PERCENTAGE OF TOTAL U.S. THERMAL COAL PRODUCTION BY VOLUME |
|---|---|
| In-state power plants | 29% |
| Out-of-state power plants | 60% |
| Other domestic uses (e.g., industrial) | 5% |
| Exported internationally | 6% |

Source: U.S. Energy Information Administration. All data are from 2012. In-state and out-of-state data from EIA's Fuel Receipts and Cost Time Series File, 2012 Final Release; other domestic uses from 2012 Annual Coal Report; exports from EIA and U.S. Department of Commerce, Monthly Report EM 545.

12 International Energy Agency and CCUS Action Group, 2013. CCUS AG Working Group on CCS in Industrial Applications: Background Paper. Available at: http://www.iea.org/media/workshops/2013/ccs/industry/backgroundpaper.pdf

Last, G.V., and M.T. Schmick, 2011. Identification and Selection of Major Carbon Dioxide Stream Compositions. Pacific Northwest National Laboratory. Available at: http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-20493.pdf

Figure 14: Percent decline in thermal coal production from business-as-usual to low-carbon scenario, 2015-2035 (by volume)




"mine-mouth") or they may price coal to their own internal market supply and demand. The United States is the most important example of a regional market, as most other markets face some sort of international price pressure, either through import potential, or the pricing of export opportunities. As shown in Table 5, the large majority of thermal coal extracted in the U.S. stays within the country, with 60% traveling within the country to power plants in other states. Because of this, U.S. coal producers are relatively insulated from global market dynamics. (By contrast, most metallurgical or coking coal produced in the U.S. is exported and competes on global markets.)

Table 6: Projected price for seaborne coal under business-as-usual and low-carbon scenarios

| SCENARIO | PROJECTED PRICE IN 2025[a] | PROJECTED PRICE IN 2035 |
|---|---|---|
| Business as usual | $84 | $91 |
| 450 ppm | $60 | $56 |

[a] Price given is for coal from major exporters.

- **Regional markets with international price pressures:** Countries such as China, Europe or India may produce large amounts of coal, but with well-established infrastructure and relatively low-cost import potential, international prices can influence local prices. In China, for instance, much of domestic production is delivered to ports, where it is put on cargo ships to deliver to seaports along the coast that feed demand in eastern China. Thus, logistically Chinese coal is on the same footing as imported coal, because both domestic and imported coal is arriving at the same ports. Most non-mine-mouth Chinese coal is traded off a benchmark that is related to import coal prices, exposing Chinese coal to global pricing risk. However, much of Chinese coal is produced by government-owned companies, and coal tariffs are partially regulated by the government. This means that most of the potential stranding risk rests between government and consumers, and the government can influence the risk of stranding through policy decisions.

- **Internationally traded coal:** Approximately one-sixth of global coal is traded on international markets — either placed on freighters and shipped around the world, or on rail (primarily from Russia to Europe and China). International coal is a heavily traded commodity that is priced, like oil, through a complex system where traders balance shipping costs and coal differentials to set prices at different locations for different coal qualities. Like oil, changes in one region can have effects on the price of coal traded around the world.

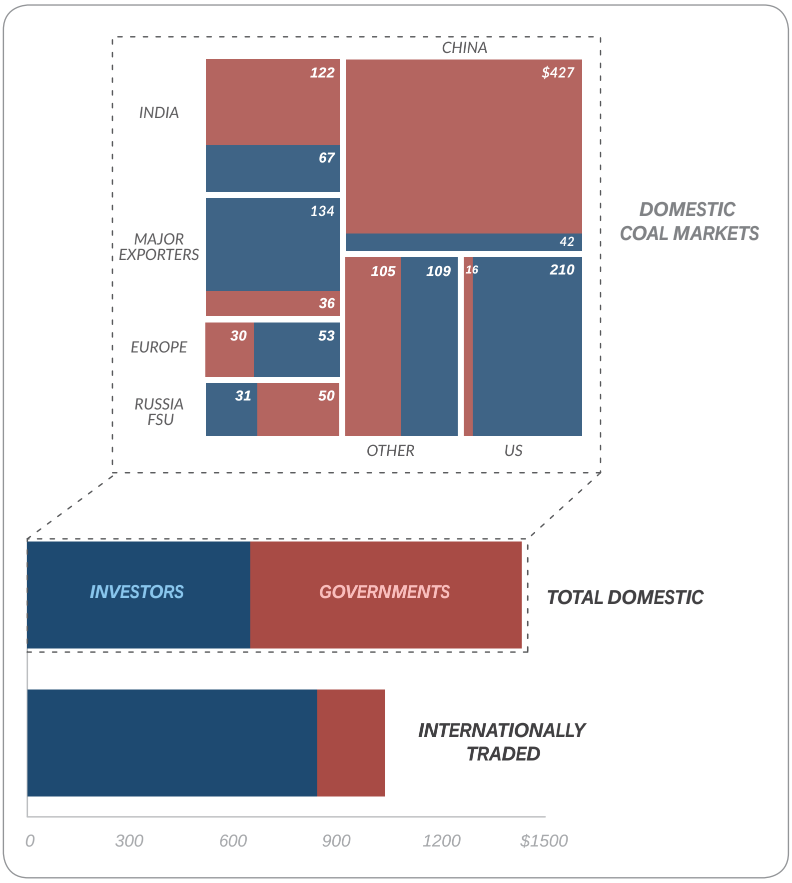
Figure 14 summarizes the share of coal that our model indicates would not be produced during the low-carbon transition, for internationally traded coal and domestic coal (which includes regional markets with and without international price pressures).

Internationally traded coal, which is at greater risk of stranding, is also more heavily investor-owned than domestic coal. As shown in Figure 15, investors own approximately 80% of internationally traded coal value at risk of stranding but own less than half of the value at risk for domestic coal. Compared to the oil market, where governments own or control the vast majority of assets and revenues at risk, coal stranding risk is more evenly balanced between investors and governments. Global coal prices would see a less dramatic difference than oil prices under the low-carbon scenario, as shown in Table 6, because coal has lower marginal production costs and profit margins.

### 5.1.3 Sensitivity to stranding in oil and coal markets

Figure 16 highlights an important consequence of these factors: the supply curve for coal is much flatter than for oil. That is, the most expensive coal needed to meet demand (in this case for the international seaborne market, but excluding transport costs) is only 30% higher than average production costs, while for oil the most expensive production can be several times higher than average production costs. Since the marginal production cost (that is the most expensive production needed to meet demand) sets the price, falling demand has a much lower impact on coal prices than on oil prices. The result is that changes in coal demand have a much smaller impact on prices and value lost than in the case of oil.

Figure 15: Potential stranded coal value held by investors and governments across different coal markets

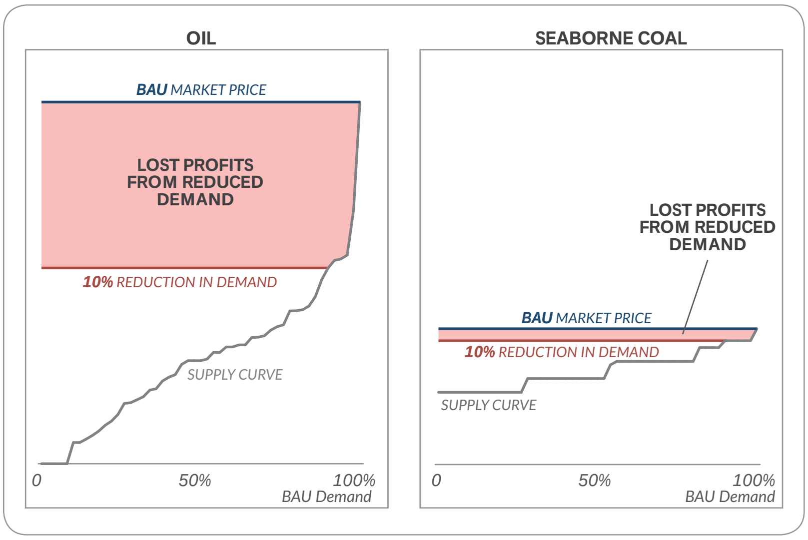



### 5.1.4 Natural gas markets: Low stranding in the short term, but imbalanced growth leads to longer-term risk

While natural gas resources are as diverse as oil resources, once the gas is processed and the impurities and liquid hydrocarbons removed, gas is much more homogeneous. The complications for gas arise out of the difficulty in transporting a gas rather than a solid or liquid. Gas can be transported either through pipelines, or by compressing the gas into a liquid and shipping it. Either way, transport can be very expensive, with infrastructure often costing billions of dollars. Thus, like coal, gas falls into either local markets, where pipeline gas dominates, or markets where liquefied natural gas (LNG) enters and can help set the price. North America, once again, is a regional market dependent upon local prices, while Asia is mostly an LNG market. Europe is a combination, where local and long distance gas from Russia compete against LNG. Approximately 10% of global gas is transported as LNG, but a further 15-25% is in markets where LNG affects the price.[13] Since the cost of liquefaction is high, significant price differentials can exist between markets where LNG sets the price and those where internal dynamics set the price. U.S. gas prices, for instance, are currently 77% below European and 84% below Asian LNG prices.[14]

As with coal, local producers benefit from the higher cost of imported (LNG) gas and are also less likely to be stranded.

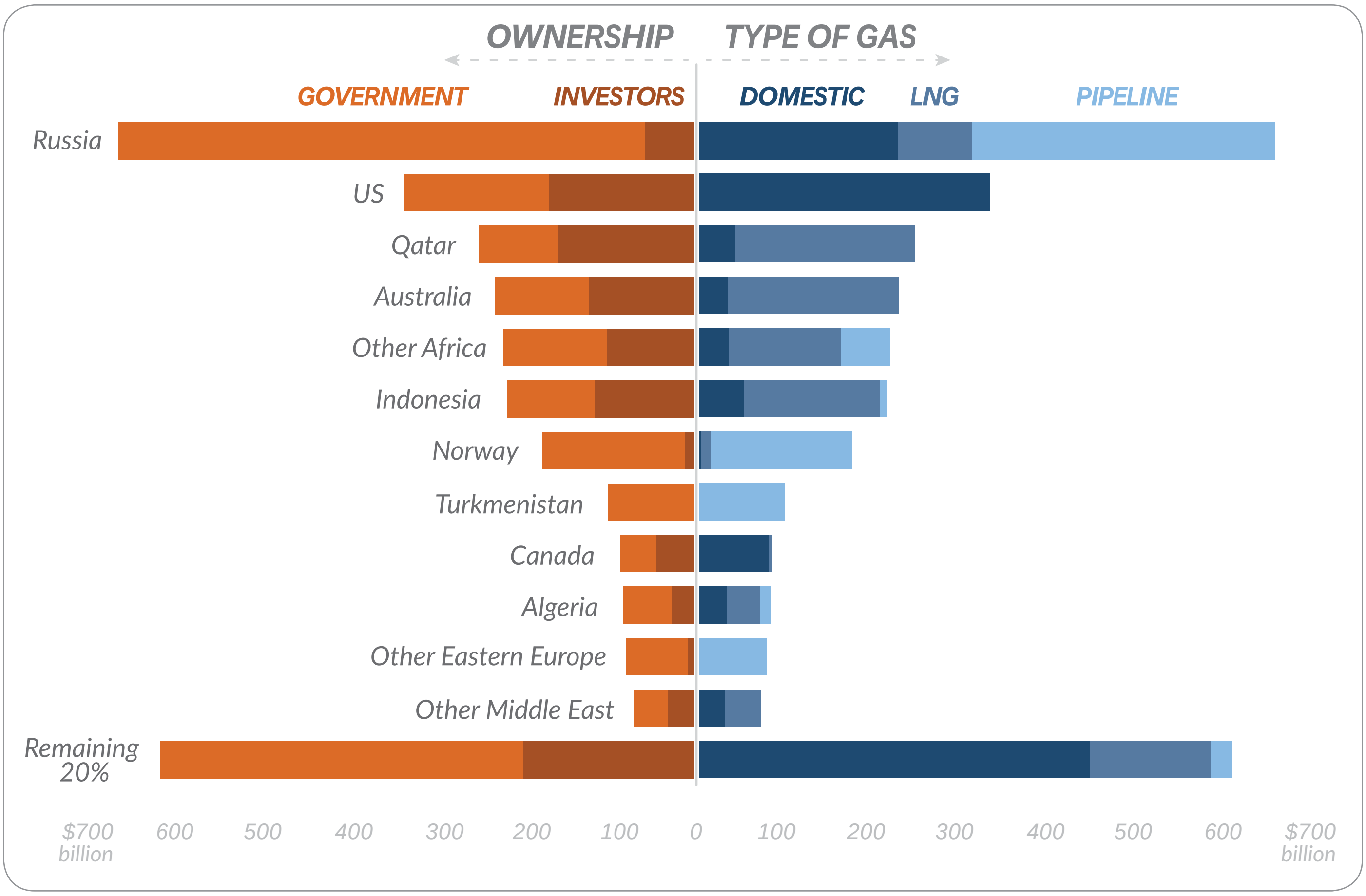
Figure 16: A 10% reduction in demand would cause significantly more stranding in oil than in coal, because of oil's steeper supply curve




13 Based on analysis of BP data. We assume that LNG affects the price in countries where LNG imports make up at least 10% of local consumption.

14 Based on analysis of data from IEA's World Energy Outlook 2013.

Figure 17 and Figure 18: Breakdown of gas stranding risk by region, type of gas, and ownership (in USD billion)

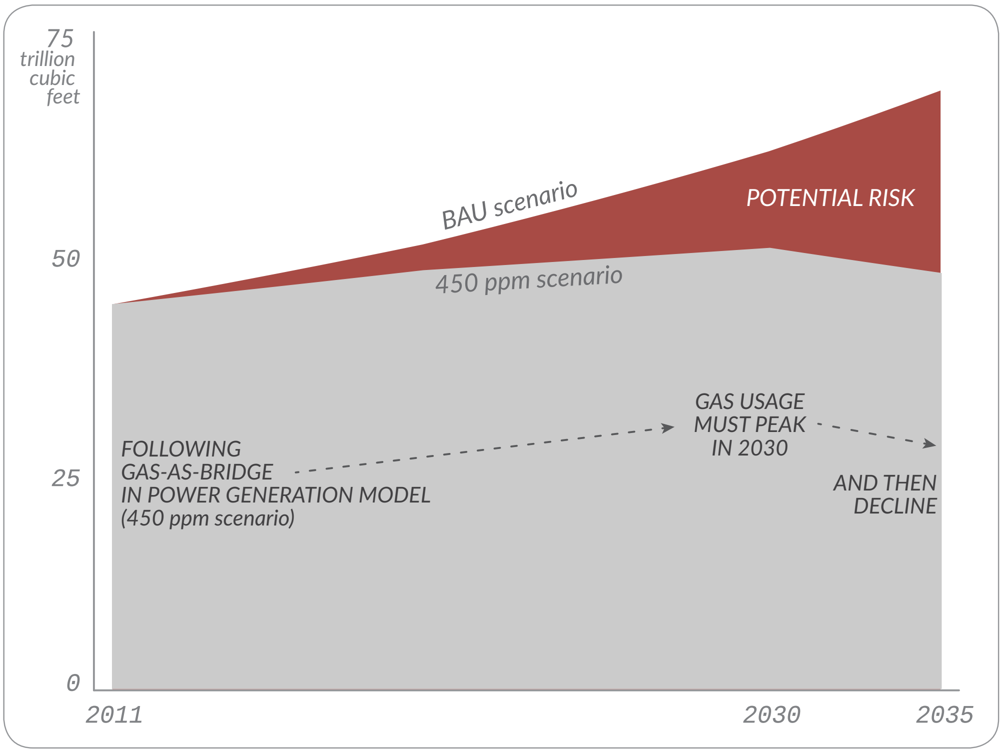



Figures 17 and 18 illustrate the results of our modeling of stranded gas assets. This highlights which countries stand to lose the most, on which markets they are losing and which type of actor stands to lose the most. For example, in this modeling, Russian production would be losing value because of a reduction in domestic demand but even more importantly because of exports towards Europe. With a transition, Russian exports would be hit harder since (1) there is an excess supply of gas going to Europe, which is Russia's main outlet for natural gas exports, (2) an infrastructure lock-in, (3) lower European gas demand (volume effect) and (4) both oil prices and are gas price indices are driven down (price effect). The Russian government, rather than investors, would be the hardest hit in this scenario as the largest Russian gas players are state-owned and as taxation from gas sales revenues collected by the state would be lower in this scenario.

One of the most important issues with gas is that it lies at the intersection of several fossil fuels. Gas can be used in power generation and heating, and therefore is a major competitor to coal. In fact, in the medium term, in many markets gas demand could grow under a 450 ppm scenario, replacing coal in markets like China and India and, due to its lower carbon content, helping to reduce carbon emissions. Gas also competes against oil in heating, power generation, and transport, while gas and oil reserves are often combined and exploited by the same companies. Section 5.4 gives further detail on the interactions between markets for gas, oil, and coal.

Given the need for natural gas plants to replace much of the generation from retiring coal plants in the IEA 450 ppm scenario, there will likely be no stranding of natural gas power plants globally through 2030. However, if natural gas plants are relied on exclusively to replace coal plant capacity in the short-term instead of as a bridge to a balanced generation mix consisting of a significant share of low-carbon generation technologies, then the valuations of gas plants may be at risk. Gas prices in the U.S. will rise over the next decade as the country begins exporting large quantities of liquefied natural gas (LNG). As LNG becomes more of an international market like oil is today, foreign demand will have a stronger impact on domestic prices. An unbalanced build-out of natural gas plant capacity in the short-term, both in the U.S. and in the developing world, could increase demand from the power sector to a point at which gas plants would become less competitive depending on the level of price increases realized. Figure 19 illustrates the trajectory of gas demand for power generation under the business-as-usual and low-carbon scenarios.

Figure 19: Gas usage in power generation will need to peak around 2030 under the 450 ppm scenario




High transportation costs means that local markets are somewhat insulated from international market dynamics. Two-thirds of gas is local markets, but LNG and long distance pipelines can influence the costs. This configuration means that gas markets are segmented into three major price zones (the Asian LNG market, the North American gas market, and the Continental European / UK gas markets), which are unlikely to converge because of transportation costs and infrastructure limitations. The pre-existence of gas export / import infrastructures (pipelines and/or LNG liquefaction plant and regasification terminal) and related long-term gas supply contracts limit the impact of stranding on exporting countries by ensuring that some of the demand is locked-in and that costs are passed along to consumers. The hedge is still imperfect as (1) LNG contracts are typically rather short-term, (2) long-term supply contracts can be renegotiated, and (3) gas transport infrastructure can become stranded as well.

We discuss the interaction between fossil fuels further in section 5.4.

### 5.1.5 Power markets: Lower stranding risk

Power differs from the other fossil fuel markets in two important aspects. First, it is the most local, with global transport being physically nearly impossible. Thus all power markets are local, with some price relationships flowing through coal, gas, and equipment prices. Second, most of the value of coal, gas, and oil are in the actual natural resources, rather than the equipment used to extract and refine the resources. Power has no natural resources and consists only of the conversion equipment. Thus, as in section 3, the value at risk in power is small compared to the other fossil fuels.

## 5.2 Faster growing economies face less stranding risk for existing assets, but adding new assets raises risk

While power assets may face less risk of stranding than actual hydrocarbons, they must be managed properly to keep the risk low and must be managed differently in developed versus developing markets.

Power plants present very different dynamics from those discussed in the preceding sections. As manufacturing assets, rather than natural resources, their lives are limited more by age and economics than recoverable reserves. Plants need occasional upgrading and retrofits to extend their lives and maintain their efficiency and competitiveness. Furthermore, recent legislation in the Europe and U.S. designed to address local air pollution has recently accelerated plant retirements,

*There is some room for growth in natural gas power generation, but gas must peak around 2030 to meet emissions reduction goals*

Figure 20: The EU and U.S. can get most of the way to a 450 ppm pathway for coal-fired power plants by phasing out plants at the end of their natural lives

1 Through 2020, some coal-fired power plants are likely to be shuttered rather than upgraded to meet **local air pollution standards**...

2 ...rather than reinvesting, some plants can be retired at the end of their **40-year expected life**...

3 ...more plants can be retired at the end of their **60-year expected life**.

The benefit of retiring plants on-schedule — rather than reinvesting to meet air pollution standards — is that very few coal-fired power assets are likely to be stranded to meet 450 ppm climate goals.

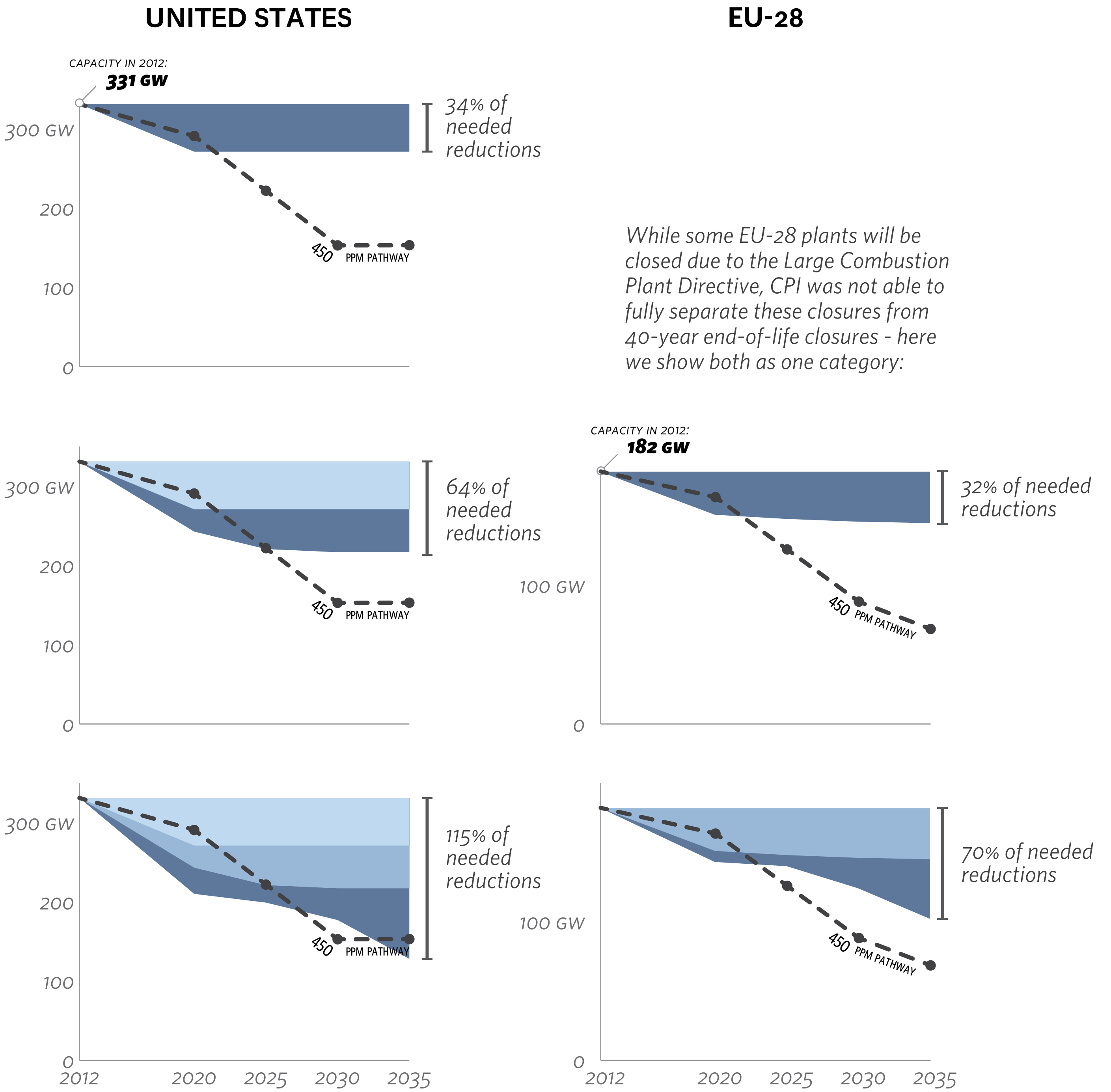
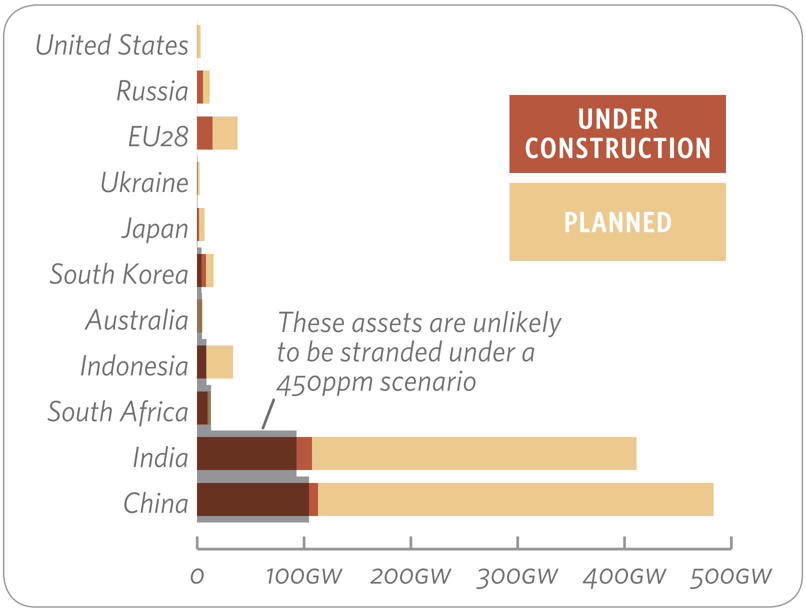


Figure 21: Planned coal plant construction in developing countries would risk stranding under the 450 ppm limit




This would also be consistent with the role that coal-fired power plants could play in a world with a greater penetration of renewable energy and nuclear, ensuring that the most value can be derived from these plants for the lowest amount of $CO_2$ emissions.

To offset the loss in output from these plants, demand would need to be addressed through greater use of renewables, energy efficiency, and, possibly, nuclear. Industry structure, financing and electricity system business models and operating systems all need to be addressed to facilitate greater penetration of renewable energy and nuclear.

In developing countries, under the IEA 450 ppm scenario, existing coal plant need not lose value but is under imminent threat from continued expansion of the sector. The IEA scenario allows all existing generation to operate through their normal lives, but allows only about half of the new coal-fired generation to be built that is already under construction (see Figure 21).

In these countries, building new coal plant would lead to asset stranding, because the new plant would essentially replace — and strand the value of — an existing plant. While a new power plant may have value for the economy, some of the value of the new power plant is lost once the impact of stranding an older plant is taken into account. Given these dynamics, multilateral institutions considering supporting the development of new fossil fuel power plants in developing countries should take into account the net impact of the new plant, including the impact of stranding. For these countries, slowing growth of coal-fired power without curtailing economic growth requires significant development of new, lower carbon generation sources — including gas resources — and improvements in energy efficiency.

putting these regions on schedule to meet 2020 levels consistent with 450 ppm.[15] As shown in Figure 20, the U.S. and Europe could meet the IEA's transition path by reducing incremental investment to extend the lives of these plants. For example, by retiring all remaining plant in these regions without air pollution controls after 40 years of life, and all plant after 60 years of life, the U.S. and Europe come very close to their 450 ppm targets. The remaining reductions in emissions could be achieved by converting the remaining plant to follow load — that is, reducing the annual hours of operation from these plants. Dispatching these coal plants more often at times when the flexibility they provide the grid is most needed, and their energy is more highly valued, will offset potential value lost from reducing annual hours of operation.

Critically, with the right market design these plants can remain just as profitable despite operating for fewer hours annually. By pulling renewables out of the wholesale market and contracting them exclusively on long-term power purchase agreements, the wholesale energy price suppression that adversely affects thermal generators in markets with high penetrations of intermittent renewables can be alleviated. So although the coal-fired plants would operate less frequently throughout the year they would receive higher prices for the energy they produced, commensurate with the heightened need for flexibility they provide to a system with large-scale renewable deployment.

*Existing fossil fuel power plants need not lose significant value, but additional investment in new plants or life extensions will create value risks to existing plants. In fact, with the right market design, existing plants can remain just as profitable.*

15 The legislation referred to here is the Large Combustion Plant Directive (LCPD) in the EU and the Mercury and Air Toxics Standards (MATS) in the U.S.

**Box 2: Calculating stranded assets for power**

Given the role natural gas plays as a bridge fuel in any future energy transition we find no risk of gas power stranding through 2035 in the IEA scenarios. However, coal-fired power plant assets in the OECD, where fleets are closer to retirement than in developing countries, may lose value to stranding in two ways.

First, plants at 40 and 60 years that are retired lose value equal to the profits they would have otherwise received had those plants been repowered and continued operation. This study assumes plants could operate for an additional 10 years beyond retirement if repowered.

Our results indicate that stranding from plant retirements from 2015 to 2035 will cost coal-fired asset owners in the OECD $32 billion (2012$) — under 8% of global investment in power generation in 2013 alone.[a] All but $4 billion of that total is in the United States. Potential stranding in the U.S. is greater due to the relative size of the fleet and the absence of a price on carbon which results in larger profits to coal plants in the U.S. than in the EU.

Second, for countries to meet 450 ppm targets there must be a significant factoring down of the coal fleet in many cases, resulting in coal plants operating fewer hours annually. If wholesale electricity prices remain constant then there would be a loss in value equal to the profits coal-fired plants would have realized in those avoided operating hours.

To achieve the levels of renewable penetration in-line with the IEA 450 ppm scenario we assume that market structures will evolve so that renewables are exclusively on long-term power purchase agreements and only thermal generators participate in the wholesale energy market. Under this assumption it is expected that energy prices would rise to reflect the increased value of flexibility provided by thermal plants to balance low-carbon generation on the grid. Therefore, we find no additional asset devaluation arising from factoring down coal-fired plant in OECD countries.

[a] Total investment in power generation was $405 billion in 2013. IEA, 2014. World Energy Investment Outlook 2014 Factsheet: Power Sector. Available at: http://www.worldenergyoutlook.org/media/weowebsite/2014/weio/WEIO2014FactSheet3Power.pdf

Institutions providing funds for power plants in developing countries, such as multilateral development banks, must consider the overall impact on a country's development if an investment in a new asset could cause stranding in existing assets.

## 5.3 National resource endowments and energy strategies play a vital role

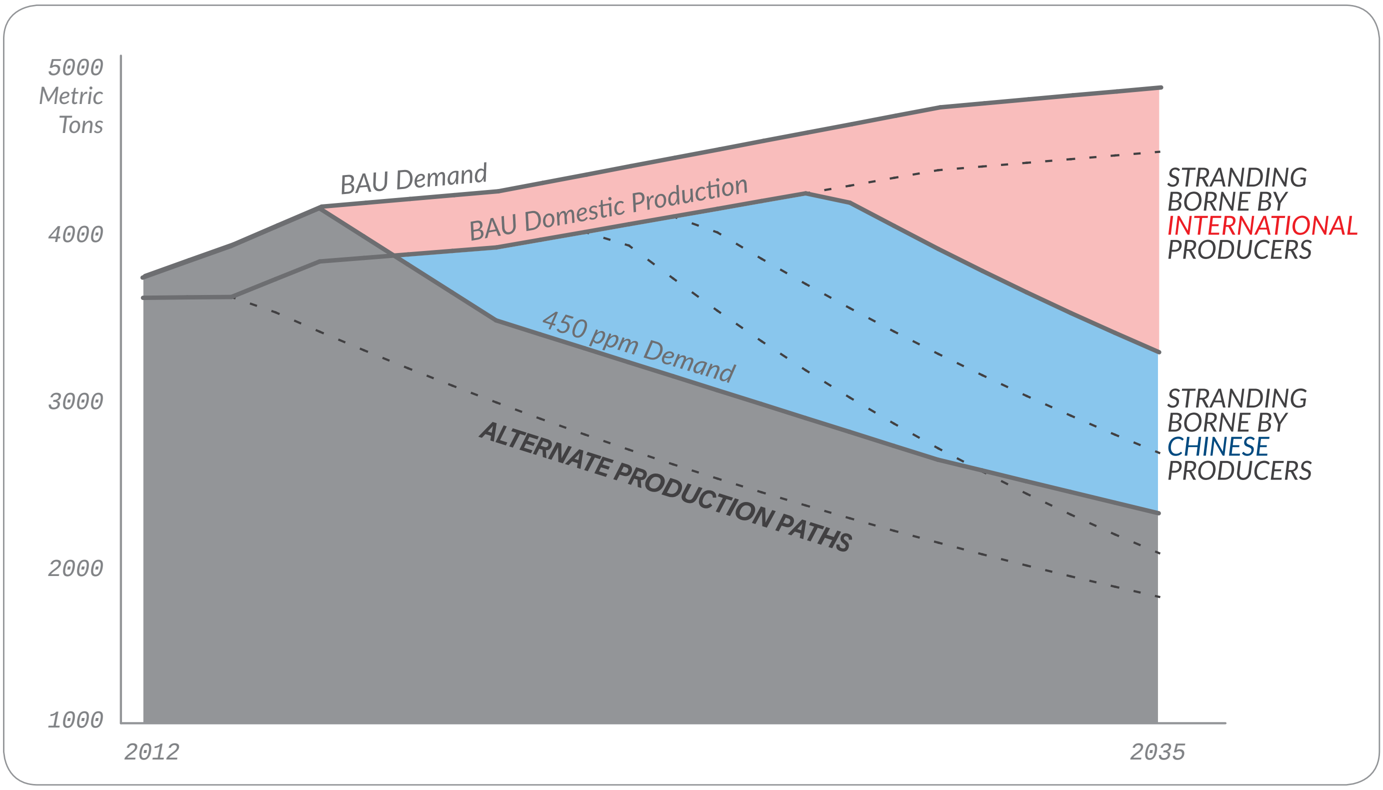
China has 13% of the world's total recoverable coal reserves, putting it third behind only the U.S. and Russia.[16] However, in 2012 China also accounted for just over half of global coal consumption.[17] Thus, despite the large reserves, it is becoming more apparent that China will find it increasingly difficult to meet all of its own coal demand from its own reserves, particularly if demand continues to grow.[18] Dwindling reserves open the prospect of declining energy security in the future, as well as less certainty and control over energy prices. China, like many other resource owners, faces the decision of how fast to use up domestic resources — enjoying lower cost in the near term but a quicker loss of energy security — and how much coal should be imported to save domestic supplies. From a stranded assets perspective, China's strategy matters, for the mix of domestic and international coal that China is

16 Based on 2011 data. EIA, n.d. International Energy Statistics: Total Recoverable Coal. Available at: http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=1&pid=7&aid=6

17 International Energy Agency, 2013. Coal Medium-Term Market Report, Table A.1, page 122.

18 Energy strategists often quantify this challenge using a country's reserve production ratio (R/P) — the number of years of production (at current levels) believed to be contained within the country's reserves. While there are reliable data on China's production, estimates of reserves are more divergent. The World Energy Council (WEC) estimates China has 114.5 billion tonnes of reserves, while Germany's Federal Institute for Geosciences and Natural Resources (BGR) estimates are an order of magnitude higher at 180.5 gigatonnes. Given current production levels, the WEC number implies an R/P ratio under 30 years, while the BGR implies just under 50. In addition, much of the difference in these estimates can be attributed to differences in what percentage of reserves can be recovered at a reasonable cost, and because there is some discretion in how one can interpret such estimates, it's possible to come up with combinations of reserve estimates and R/P ratios based on just the two WEC and BRG reserve estimates.

Figure 22: Alternate pathways for coal reserve management in China would affect the split between domestic and international asset stranding




expected to use, and then does use in response to climate change, will determine how coal stranding risk will be distributed between Chinese and international producers.

Part of the answer is that China has already begun to manage its coal use, switching from a coal exporter a decade ago to a net importer today. Furthermore, China's domestic coal competes extensively with internationally traded coal, since most of its domestic coal is shipped to the coast and then transported by barge to coastal cities.

Figure 22 illustrates some of the possible ways in which China could manage its thermal reserves, domestic production, and imports to meet demand in both business-as-usual and 450 ppm scenarios. As seen in this figure, China's reserve management will greatly affect whether a large portion of potential stranding will be borne by Chinese or international producers and asset owners. The gray area of the chart represents the quantity of coal that would be stranded in a 450 ppm scenario, with the red portion falling on international producers, and the blue area on Chinese producers. These areas vary widely, depending on Chinese reserve management.

Our base case for reserve management is based on reserve estimates of 180.5 gigatonnes from Germany's Federal Institute for Geosciences and Natural Resources (BGR), with a maximum of 30 years of reserves at current production, approximately the economic life of a new power plant. Using these constraints, Chinese production would peak in the middle of the next decade and begin to fall. This is consistent with other estimates that Chinese coal would peak in the mid-2020s.[19]

Using our base case, and our estimate that roughly two-thirds of Chinese thermal coal production is owned by state-owned enterprises, the Chinese government is the single largest coal asset owner at risk of declining production in the transition to the 450 ppm pathway. Yet in terms of asset values the Chinese government may not be at so much risk, so long as low-cost alternatives can be identified for Chinese coal. The red area in figure 22 represents losses to international coal producers that would be compounded by lower prices. In China, however, the lower production represented by the white area leads to improved energy security, and the economic cost of stranding can be avoided if the energy can be replaced economically.

19 For an example predicting peaking coal demand before 2030, see Fidley et al., 2012, China Energy and Emissions Paths to 2030, Lawrence Berkeley National Laboratory.

## 5.4 Despite local markets and fuel differences, there are many interactions between markets

Gas is at the intersection of all fuels, interacting with oil directly and coal indirectly through power markets. Therefore, there are important connections between stranding risks in other fuel markets and stranding risks in gas markets.

With a lower global oil demand, as is the case in the IEA 450 ppm scenario, the oil price is driven down. If oil assets were stranded due to a decrease in the global price of oil, this would also lead to gas stranding, particularly for LNG. This has three effects on gas prices highlighting the linkages between these two fossil fuel markets.

First, fuel oil (a residual product from oil refining used for heating) can be a substitute for gas, albeit a relatively expensive one. Gas production at the end of the global cost curve (i.e. global LNG) can be substituted if the marginal LNG price is higher than fuel oil price. A lower oil price competes with LNG and creates downward pressure on the marginal LNG price. Figure 23 illustrates that at prices around 12 USD/GJ in the 450 scenario consumers of LNG would instead switch to the lower priced fuel oil.

The second effect oil has on gas is that most long-term gas supply contracts involving pipelines (especially

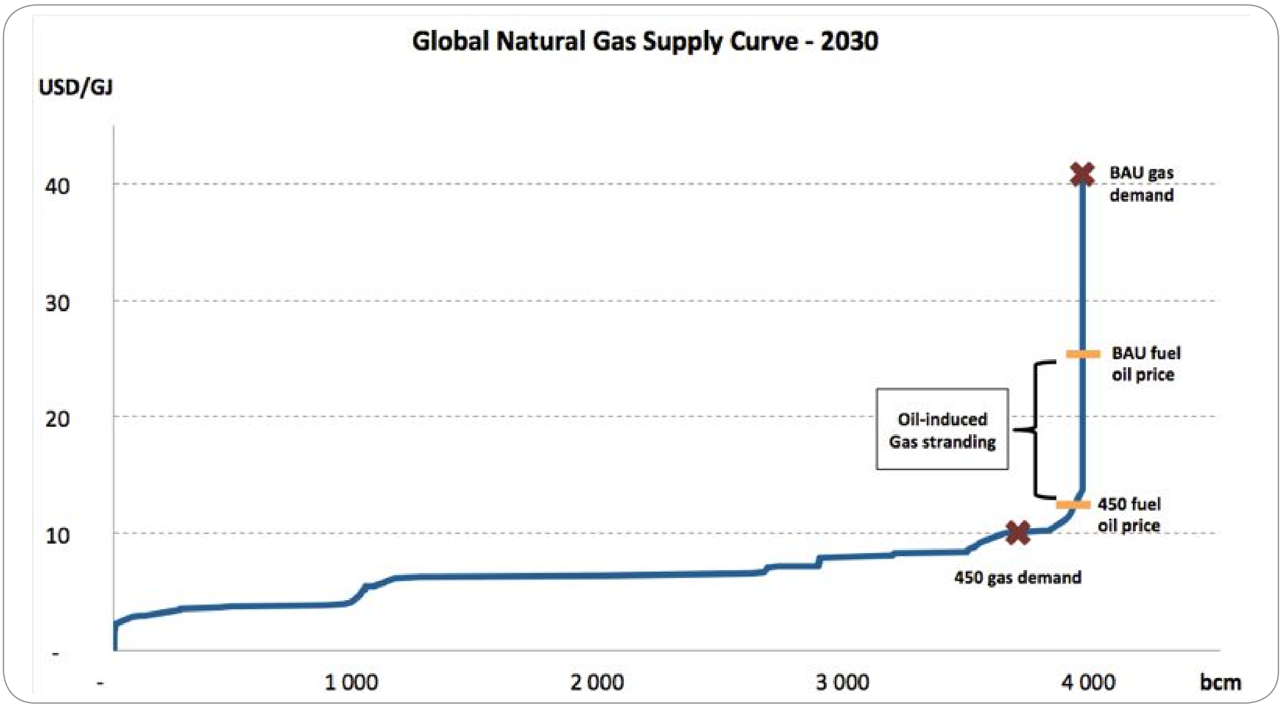
*A decline in oil prices could cause stranding for liquefied natural gas assets*

towards Europe) are indexed, at least partially in their pricing formula, on global oil prices. Should oil benchmark prices be pushed down, resulting gas index prices would be lower.

Third, downward pressure on gas import prices creates in turn downward pressure on domestic prices for markets where indigenous production is priced as a netback to imports, meaning that domestic prices are calculated based on the price of imports, with transportation costs subtracted. This practice is common in Europe.

In power markets worldwide the differential between the prices of coal and gas dictates what plants get constructed, and as result emissions from the power sector. Coal is cheap and abundant but can be significantly more expensive in regions that implement a carbon price on power generation. As described above, LNG prices are impacted by global oil markets and contracts as well as domestic supply.

Figure 23: A decline in fuel oil prices could cause stranding of natural gas resources



## 5.5 Delaying climate action may cause assets to be developed that may then be stranded

Fossil fuel assets, whether power plants, oil fields or coal mines, take time to build, require billions of dollars of investment in infrastructure, and then can be relatively long lived. Each year approximately $1.2 trillion is spent on energy-related infrastructure.[20] The analysis that we have presented assumes that the energy industry adapts to a new reality of lower demand and in many cases lower prices this year, making the appropriate decisions to reduce production growth and hold off investing in expensive projects that may not be needed. Uncertainty about future energy and climate needs, potentially driven by uncertain or delayed policy making, may encourage more investment than is necessary, leading to higher stranded costs and a greater impact.

The greatest risk of inaction is in developing countries, where building additional coal-fired power plants now could lead to asset stranding in the future. Figure 23 illustrates that although the existing fleet of coal-fired power plants in developing countries could continue operating through the low-carbon transition with little risk of stranding, there are many more power plants planned or already under construction that are not consistent with a 2-degree trajectory. If built, these additional power plants would increase the risk of stranding for existing plants. Governments of these countries — as well as financial institutions considering investing there — should carefully consider the stranding risk presented by new coal-fired power plants when considering whether these plants should be constructed.

20 IEA, World Energy Investment Outlook 2014. This figure is the annual average for investment between 2000 and 2013.

# 6. Investors, governments, and companies all face different prospects for managing stranding risk

The uncertainty over financial impacts raises the question of what this means for investors. Clearly, the large sums of value at stake, and the wide range of potential outcomes create inherent uncertainty and controversy in the minds of any investor, be they a government, institution, or an individual. The risk that each investor faces depends upon their investment position, their investment objectives, and their investment alternatives.

- Financial investors face little risk of major losses so long as they manage their risk and their portfolios, investing in liquid assets that they can sell as the impact of policy develops and risk increases.
- Energy companies and their employees are less able to dispose of their assets, including skills, illiquid assets and technical capabilities developed over decades, and thus face the greatest risks from climate change.
- Governments may seek to maximize the value of their resources, but as they control much of the policy that may lead to stranding, they have numerous policy levers they can play to reduce impact and recover lost value. The exception is the risk that they face from changes to international policies.

## 6.1 Determining exposure to stranded asset risk

The risks that investors in fossil fuel assets face depend on three factors:

- How much risk is currently not priced into fossil fuel investments: For investors, particularly financial investors, what matters is not how asset value will change versus the business as usual (that we have modeled here), but rather how much value might change from what the market currently expects and prices into asset values. Valuation multiples for the major integrated oil, gas and mining companies are significantly below those of the market in general, suggesting that markets are already pricing in some probability of climate action.
- The investor's objective in owning the asset: Many investors, especially large institutions and passive investors in index funds, seek to maintain or grow their relative share of the global or regional market. These investors diversify across the entire economy, owning shares of industries in correspondence to their weight in the market. They continually rebalance their portfolios to maintain an equal weighted portfolio. If fossil fuel asset values were to decline significantly, investors with equal weight positions would rebalance their portfolio as the market valuations evolved and would maintain their market-like performance. Only those investors who are overweight the sectors, especially those locked into illiquid, or difficult to sell, positions, would bear any risk. Of course, those who own the assets in the ground — such as governments and companies — are naturally overweight the sector and will not find it very easy to sell down their investments as risks materialize.
- Who ultimately bears the risk: In many cases, risks of declining asset values may not lie entirely, or even mostly, with the owners. Regulated power plants, for instance, transfer most risk back to consumers, partly in exchange for lower financing costs and ceding some control back to regulators. Likewise, many oil and gas fields are developed under contracts that pass most risk back to the host governments, as discussed in section 3.2. Policy can have a significant impact on the distribution of risks.

## 6.2 Exposure to stranded asset risk for different investors and stakeholders

### 6.2.1 Holders of corporate equity and debt

Much of the private sector's share of fossil fuel assets is held by corporations whose shares are publicly traded on stock markets. These shares are owned by a mix of investors ranging from large insurance companies, pension funds and mutual funds, to individuals and even other corporations. How these shareholders consider, and should consider, the potential risks presented by climate change depends on the strategy and objectives of the specific investors. Two major holders of corporate equity and debt are passive investors, who seek to hold a portfolio reflecting the market as a whole, and institutional investors, who tend to be larger and more sophisticated investors.

Passive investors or index funds seek to track the stock market or bond market on a daily basis. If the value of carbon intensive assets were to decline over time, and the value of low-carbon assets were to rise, these investors would lose on one side and win on the other, and in so doing continue to own the same proportion of the stock market — and by extension the economy. Since their implicit goal is to maintain relative performance compared to the market as a whole, they essentially have no climate change risk vis-à-vis their objectives.

Moreover, for these investors, making any significant move away from the index (for example, reducing investments in fossil fuel assets) in effect increases their risk. The market has already factored in some expectations about the likelihood and speed of a transition to a low-carbon system. By moving away from the market in their asset allocation, these investors would be making a bet that the markets are underestimating the likelihood or magnitude of the transition. Their future investment returns would therefore be more sensitive to the size and magnitude of the transition that ultimately results.

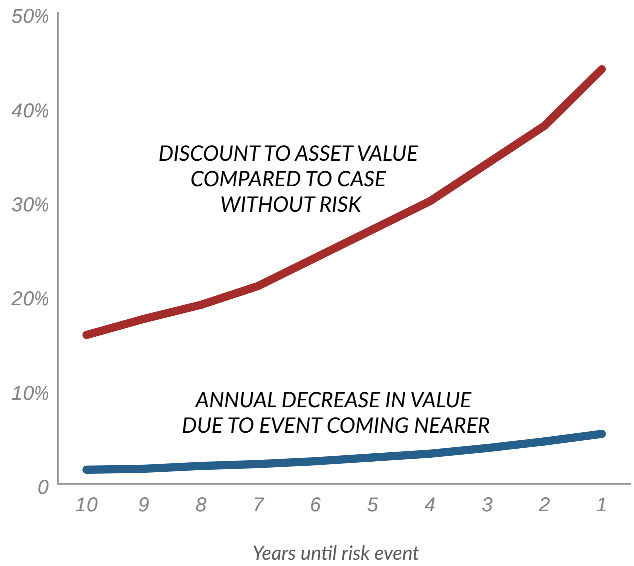
Institutions, active mutual fund managers, and other sophisticated investors are able to make more active bets, betting on trends like climate change to outperform the general market. Their sophistication and in-depth research enables them to take bets in expectation that the outperformance from the bets they get right will more than make up for the losses from the ones they get wrong. However, there are significant

**Box 3: The impact of even modestly long term risks is reduced by the expectations of significant annual returns**

Imagine an asset that has 20 years of life remaining but also faces a 50% chance that it will be forced to shut down in ten years. With an 8% expected annual return, this risk would decrease the value of the asset to an investor by 15.8%. However, one year later, the same 50% risk of closure would correspond to a 17.5% decrease in the value of the investment. In other words, waiting one year for more information would cost less than 2% in expected value — a figure that could easily be overwhelmed by changes in expectations, timing, or market conditions. Only in the final year before the possible shutdown does the impact of waiting one year exceed a 5% change in the current value of the asset. Thus, unless the investor has greater certainty than the market about whether an event will happen, entering or exiting an investment more than four to five years before the event creates too small an upside compared to the additional risk.

Finally, institutional investors tend to invest more heavily in corporate bonds than in corporate equities. The risk of climate change to the value of corporate bonds is significantly less as these investments are protected by the equity of the companies that issue the debt. That is, the first losses due to risks materialized are felt by the equity investors and only when these investors are wiped out, and the company goes bankrupt or defaults, do the debt investors lose significantly. Furthermore, risks that would have a material impact on the default probability of a bond would invariably lead to a downgrade of the bond rating which, in turn, could restrict institutions from owning that bond. Thus, as the risks became clearer, bondholders would reduce their positions and, in so doing, avoid complete loss.

Figure 24: Long-term risks have only a small impact on the current value of assets



limits to the climate change risk exposure for most of these investors as well.

First of all, it is this group that, generally, sets the market expectations for the rate and magnitude of loss (or gain) in value due to any trend. Thus, market valuations already tend to reflect the average expectations of institutional investors.

Second, these investors generally have explicit risk limits to prevent their customers (e.g., pension or life insurance holders or mutual fund investors) from losing too much due to a bad decision of a portfolio manager. To this extent, they are protected — within limits — by the same math that protects passive investors.

Third, these investors have relatively short investment horizons for their corporate equity share portfolios compared to either climate change risks or their own investment objectives. Institutional investors are often better equipped than other investors to take positions in anticipation of longer term gains. However, as outlined in Box 3, even these investors would need a very compelling case to suffer near-term underperformance in anticipation of long term gains.

### 6.2.2 Direct investors in infrastructure and private equity funds

Direct investors in projects and infrastructure, whether they are institutions, private equity funds, or individuals, take on significantly higher risk than investors in corporate equities. These investors hold a significant stake in assets such as coal-fired power plants or oil wells. Since these investments are not as easy to sell as stocks or bonds, the risk to the owners is higher. Direct investments are much less liquid than debt or equity investments, having no ready market in which to exchange or sell the assets. However, investors tend to hold these assets of part of a larger portfolio, thus reducing the impact of asset stranding risk on the investor's portfolio as a whole.

### 6.2.3 Corporations and their employees

While institutions and asset managers may own the largest part of many corporations and companies, other stakeholders in publicly traded corporations and privately held companies may have a significantly greater interest or risk associated with climate change. The employees of a company, in particular, are often substantial owners of the shares of their companies and have further invested their working lives and skills to creating the value that the company represents.

*Most owners of potentially stranded assets have tools available to manage the risk of stranding. Risks to investors depend on investment objectives and the investors' portfolio, but in general financial investors face much less risk than producer countries or companies and their employees.*

However, just because an asset may lose value does not mean that the asset will cease to produce. Therefore, it is possible that in many cases that many companies and assets will continue to operate even if asset and company values fall, limiting the impact on employees. Furthermore, as the risks become greater, companies will seek regulatory and contractual mechanisms to protect themselves from risks before investing further. Common mechanisms that pass risks back to governments or consumers include long-term contracts and cost-of-service regulation.

### 6.2.4 Governments

Countries and their governments may be the most exposed to loss due to climate change and its impact on the value of its assets. Countries and their governments are exposed to risks through the direct ownership they have of resources and state-owned companies, through the taxes and royalties they collect on assets owned by others, and through the indirect impact that climate change risks will have on economic growth and employment. We will address each in turn.

Assets owned directly by governments and their wholly owned national companies: Countries and their national, provincial, and local governments own and control the majority of carbon exposed assets in the world. As discussed in section 3, most of these assets are held directly by governments or by companies that are 100% owned by governments. These include national, provincial and municipally owned assets and companies.

Taxes and royalties: As discussed in section 4, a change in government policy is the biggest driver of climate change risk. For example, a decision to raise taxes to reduce demand and emissions could result in lost revenues for a purely commercial company. A government that wholly owns the energy company in question might find a very different equation. By raising taxes, the government could increase tax revenues more than the losses incurred by the government owned company, and therefore be better off. The government would presumably weigh that benefit against the potential political cost of raising taxes.

On the other side, governments that currently derive significant revenues from fossil fuel taxes would need to replace those revenues as fossil fuel usage shrinks during the transition to low-carbon systems — a phenomenon the OECD has called "carbon entanglement."[21]

Assets owned by partially privatized national companies. Many governments such as China, France, Norway, Russia, and Brazil have partially privatized some of their energy companies and listed these companies on stock markets, but have retained majority, controlling interests in these companies. For these companies government can still, at least in theory, control investment decisions, although private investors have some expectation that the government will make rational, economic decisions and protect their interests.

21 Organization for Economic Co-operation and Development, 2013. The climate challenge: Achieving zero emissions. Lecture by OECD Secretary-General Angel Gurría, London, 9 October 2013. Available at: http://www.oecd.org/about/secretary-general/the-climate-challenge-achieving-zero-emissions.htm

## 7. Conclusions and policy implications

There is a risk that fossil fuel assets will lose value as a consequence of measures taken to address climate change. This stranding risk can raise the cost of a transition to a low-carbon economy, reducing valuations, cash flows, and the net worth of asset owners, thus reducing the overall capacity of the financial system. The risk falls mainly with governments and fossil fuel companies themselves, and, to a lesser extent, investors in these companies.

Assessing these risks and minimizing them requires careful analysis of the policy options available to meet climate change goals and how these interact with the specific industry and resources. A wide range of outcomes is possible, and the policy mix chosen will influence not just how much value is at risk, but also who bears the risk and eventual financial cost. However, if the threat of the consequences of asset stranding is an important concern, policymakers could do well to first focus on reducing coal.

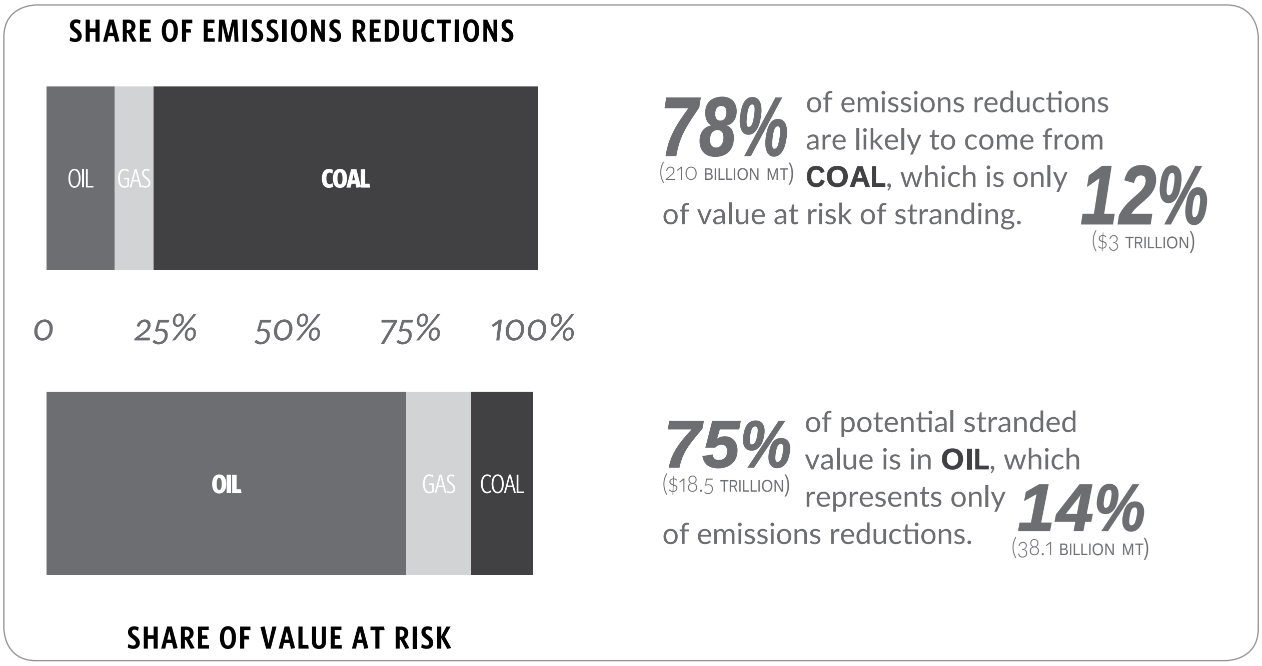
Figure 26 shows that reducing coal consumption accounts for approximately 80% of the IEA's projected carbon emissions savings (comparing their business-as-usual scenario versus their low-carbon or 450 ppm scenario), while our stranded cost analysis suggests that this coal reduction would comprise only 12% of potential stranded asset value at risk.

Reducing stranding risk resulting from strategies to reduce coal use requires different solutions for different markets:

**Coal-fired power generation in developed countries can meet most of the 450 ppm goal by phasing out plants at the end of their natural lives and adapting operating modes to a low-carbon system**

- Recent legislation to address air pollution (SOx, NOx, particulates and others) including the Large Combustion Plant Directive (LCPD) in Europe and Mercury and Air Toxic Standards (MATS) in the U.S., as well as low gas prices in the U.S., have accelerated plant retirements, putting these regions on schedule to meet 2020 levels consistent with 450 ppm.
- By retiring all remaining plant in these regions without air pollution controls after 40 years of life, and all plant after 60 years of life, the U.S. and Europe come very close to their 450 ppm targets.
- Converting the remaining plant to greater load following — that is reducing the annual hours of operation from these plants — would achieve the remainder of the required reductions.
- Reduced operating hours with more flexible operation would also be consistent with the role that coal-fired power plants could play in a

Figure 26: Potential emissions reductions ranked by stranding risk



world with a greater penetration of renewable energy and nuclear.

- The demand side could be addressed through greater use of renewables, energy efficiency, and possibly nuclear to reduce the demand for coal-fired power generation output.
- Industry structure, financing and electricity system business models and operating systems all need to be addressed to facilitate greater penetration of renewable energy and nuclear.
- Changing financing business models can, for instance, reduce the cost of renewable energy by as much as 20%, making it more competitive with fossil fuel electricity generation.
- Adjusting operating norms and investing in technologies such as energy storage and other demand response technology may achieve further significant reductions in the cost of alternative energy sources.

**Constraining coal-fired generation in emerging markets in the face of growing energy demand creates an urgent need to develop alternative energy solutions and improved energy efficiency**

- The IEA 450 ppm scenario suggests that countries like India and China need to significantly slow the growth of coal-fired generation.
- IEA scenarios allow all existing generation to operate through their normal lives, but allow only about half of the new coal-fired generation to be built that is already under construction. Building additional coal-fired power plants now could lead to significant asset stranding in the future.
- Slowing growth of coal-fired power without curtailing economic growth requires rapid development of new, lower carbon generation sources and improvements in energy efficiency.
- Gas-fired generation could be a bridge strategy if it can be developed at a reasonable cost and scale, both of which are challenges.
- Renewable energy provides another potential option, but unlike most fossil fuels, renewable energy is typically financed at local financial market conditions that can significantly increase the cost of renewable energy. Our research shows that financial market conditions in India increase the cost of renewable energy by 24-32%.[22] Providing renewable energy subsidies through low-cost debt or dollarizing renewable energy tariffs reduces the cost to many emerging nation governments and energy consumers of renewable energy by up to 30%.[23]
- Developing low-carbon development banking systems can bridge the gap and create lower-cost low-carbon opportunities, particularly by financing emerging market clean energy and infrastructure needs at global financing costs than at the higher local financing costs.

**Coal mining will require different solutions across the major uses of coal in power generation, iron and steel making, other industrial usage and some residential and heating use, but China and India are the key**

- Power generation is the major use of coal, but heating and steel making are also important.
- China represents over half of global coal consumption. In China, coal-fired power and heat represent 58% of coal consumption, steel and iron account for about 19%, residential use 3%, and other sectors the remaining 20%.[24]
- Steel production and related emissions are driven by industrial and economic growth, rather than industry or economy size. Thus, as growth falls and as growth switches from capital intensive models to service intensive models, coal use and carbon emissions will decline.
- Further declines in coal use in steel and iron consistent with a low-carbon trajectory will require technological innovation (including carbon capture and storage), increased use of recycled steel and greater efficiency.
- Use of coal in other industries and district and residential heating, even when used as combined heat and power, needs to be replaced by other fuels including gas, biomass, geothermal, and solar. Particular attention needs to be paid to replacing small scale mining of coal for local residential and commercial use which is widespread and particularly inefficient.

22 Climate Policy Initiative. 2012. Meeting India's Renewable Energy Targets: The Financing Challenge. Available from: http://climatepolicyinitiative.org/publication/meeting-indias-renewable-energy-targets-the-financing-challenge/

23 Climate Policy Initiative. 2014. Finance Mechanisms for Lowering the Cost of Renewable Energy in Rapidly Developing Countries. Available from: http://climatepolicyinitiative.org/publication/finance-mechanisms-for-lowering-the-cost-of-renewable-energy-in-rapidly-developing-countries/

24 International Energy Agency, 2013. Coal Information 2013. Table V.17.

Reducing coal will get emissions closer to the targets, but attention to oil use can also create carbon savings opportunities that, if structured properly, could reduce the impact of stranded assets.

**Effective oil paths to a low-carbon trajectory include policies to reduce demand, such as consumption taxes driven by net consuming countries or reduction of fossil fuel subsidies, investment in alternative fuels and innovation, and policies to reduce undesired distributional effects**

- With the right policies, the low-carbon transition can have a positive impact on the global economy. Innovation to reduce global demand for oil would have a net benefit of up to $7 trillion, which could then be redistributed across economic actors.
- Using price-based mechanisms to drive down oil demand — in the unlikely scenario where there is no innovation to decrease the cost of transition — would lead to a net cost of $3 trillion globally.
- Rebating some of the receipts from the consumer taxes on oil to taxpayers and consumers could reduce some of the undesired distributional effects of such a tax, while still creating the incentive on the margin for consumers to reduce demand.
- When the net impacts from consumers, producers and taxpayers are balanced, net consuming oil countries will be significant beneficiaries of this policy. These countries represent approximately ¾ of global oil consumption. Working together they can achieve most of the required reductions with a doubling of wholesale prices to consumers.
- These countries continue to benefit even if net producers do not institute a similar policy. Net producers, in fact, will be hurt more if they do not participate than if they do, and so will also have an incentive to raise consumer taxes on oil.
- The required amount of increased consumer taxes can be greatly reduced by further use of the proceeds for investment in innovation, alternative fuels, more efficient transport, and so forth.

**Gas has a medium term future as a bridging fuel**

- There is room for continued increase in natural gas use to help phase out coal use, but more work is needed to understand, quantify and prevent fugitive emissions
- More investment is needed in emerging markets to develop gas resources as an alternative to coal.
- Further development is needed to bring down the cost, and increase the supply of gas, particularly in the developing world, but also in the supply of LNG.
- There is a need to seek long term replacement fuels and continued efforts to lower carbon emissions from gas use.

Finally, beyond the global level of stranded assets, governments and policymakers need to address the potentially uneven distribution of value changes and the impact that it may have on specific regions and countries.

**Governments need to develop strategies to address the budget consequences of phasing out fossil fuel production**

- Producing countries may see substantial declines in budget revenues.
- The declines can be ameliorated through effective policy design and planning, but net consuming country policies will have a large impact on fossil fuel exporters.

**The global economy needs to address imbalances that have been created over more than a hundred years of structuring the economy around fossil fuel derived energy.**

- Commodity pricing, incumbent corporate structures and investor practices have been designed around, and therefore favor, fossil fuel.
- One result is that fossil fuels have access to global capital markets at global rates of returns, where energy like renewable energy often have access only to local markets, even though the product, energy, is the same, and emissions have a global impact. Emerging markets, which generally have higher return requirements, are particularly impacted.
- Capital markets and development banking solutions need to address this disparity and balance the financing conditions of clean energy and fossil fuels, particularly in emerging markets
- Industry structures need to accelerate their evolution to reduce the operational costs that

are currently imposed on clean energy due to their different operating characteristics.

- Greater involvement of consumers in the pricing and operation of electricity supply services, which can be facilitated by breakthroughs in storage and information technology, is needed.

More work is needed to explore different scenarios and to guide the design and implementation of policies and financial and business models. However, our initial analysis indicates that it is possible to limit the impact of asset stranding with the right mix of policies.