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ISSUE BRIEF: Volume 7, Numb

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FOSSIL FUEL STRANDED ASSETS: EFFICIENT MARKET OR CARBON BUBBLE?

April 12, 2017

"Practical men who believe themselves to be quite exempt from any intellectual influence, are usually the slaves of some defunct economist."

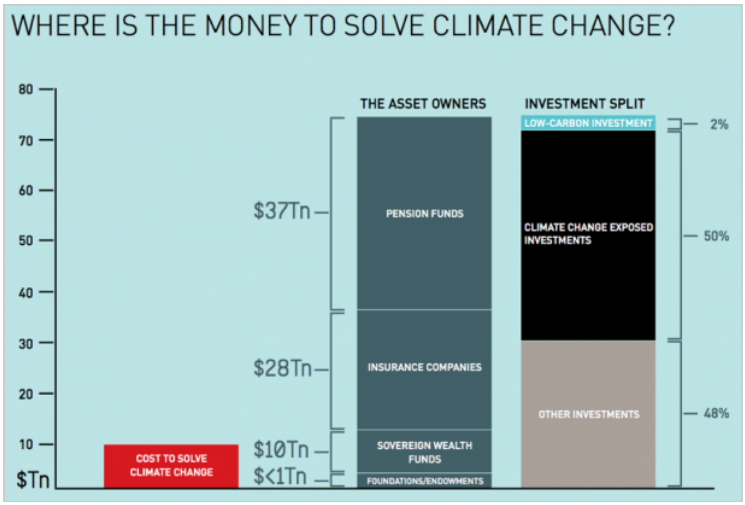
- John Maynard Keynes

From an economics perspective, environmental sustainability entails an intergenerational capital allocation problem. To what extent should society deplete stocks of natural capital in order to increase artificial capital, given that future generations' utility depends on both types **[1]**? The existence of externalities and market frictions mean that free market outcomes can be suboptimal, requiring either public policy or the internalization of these factors into private decision making. In the case of climate change externalities, society at large appears to significantly misallocate financial capital:

On the one hand, clean energy is under-funded. The think tank Ceres estimates $12.1 trillion needs to be invested in new clean power generation over the next 25 years to limit climate change to 2°C **[2]**; Similarly, the International Energy Agency reports in its World Energy Outlook 2016 that a "2 degree pathway would require a much deeper and faster reallocation of capital" towards low-carbon energy **[3]**.

On the other hand, fossil fuel reserves may be over-funded. McGlade and Ekins in Nature calculate that "globally, a third of oil reserves, half of gas reserves and over 80 per cent of current coal reserves should remain unused from 2010 to 2050 in order to meet the target of 2°C." **[4]** Full extraction of these reserves is inconsistent with climate mitigation, leading to a potentially massive "carbon bubble" for investors if these reserves become stranded assets **[5]**.

Will the capital stock allocated towards fossil fuels become stranded? The answer depends on how efficiently the capital market has incorporated information about the carbon budget. This article seeks to point out that market efficiency is not a universal guarantee and that specific evidence suggests fossil fuel assets may be mispriced. The threat of irreversible destruction to both natural and financial capital implies the centrality of capital allocation when addressing climate change. While the capital allocation problem applies generally to society at large, this article contextualizes it with the example of the University of Pennsylvania's recent policy choice against fossil fuel divestment.



(**Image:** Where is the Money to Solve Climate Change? **Source:** Asset Owners Disclosure Project)

The Efficient Market Paradox

In advocating against the University of Pennsylvania divesting from fossil fuels, Dillon Weber has argued that "the efficient market hypothesis tells us that these risks are already incorporated into the company's stock prices and returns, meaning even with the potential of a massive stranded-assets scenario fossil fuel companies can still be a sound investment for years to come." **[6]** Mr. Weber repeated the same argument based on market

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efficiency at the University Council Open Forum in December 2015, and was a voting member of the Trustees' Ad Hoc Advisory Committee that resulted in the Board of Trustees rejecting fossil fuel divestment in September 2016.

Eugene Fama, the Nobel-winning pioneer of efficient markets theory, summarizes the concept: "in an efficient market at any point in time the actual price of a security will be a good estimate of its intrinsic value." **[7]** Financial economics literature commonly discusses three forms of market efficiency that can be tested empirically, related to how well markets incorporate information about the assets: weak form (prices reflect all historical price information), semi-strong form (prices reflect all publicly available information), and strong form (prices reflect all information, public and private) **[8]**.

Yet arguing that asset mispricing cannot ontologically exist in the context of endowment management is contradictory, because fund managers are expensive. If an investor (e.g. the Penn Trustees) truly believed that markets reflect all available information then any active strategy cannot consistently beat the market, so there "would be no value added by portfolio managers and investment strategists." **[9]** Belief in fully efficient markets compels the endowment to only invest in market index funds, which clearly have fees lower than salaries for the Office of Investments. As Weber realizes, "the University has a cadre of [investment] staff" to which it "devotes no small amount of resources." **[10]** Moreover, Penn's endowment strategy explicitly contradicts strict market efficiency, since the endowment "focuses on areas with the greatest inefficiencies across asset classes, strategies, and geographies." **[11]**

In addition to this contradiction, a substantial body of economics research points to the existence of inefficient markets. Grossman and Stiglitz demonstrate theoretically that competitive markets are not always in equilibrium, because otherwise "those who arbitrage make no (private) return from their (privately) costly activity"; contrary to efficient market advocates, they show that costless information is a necessary (rather than just sufficient) condition "for prices to fully reflect all available information." **[12]** Nobel Laureate and *Irrational Exuberance* author Robert Shiller's "From Efficient Markets Theory to Behavioral Finance" traces the introduction of behavioral economics in explaining empirical market anomalies and the well-documented history of financial bubbles **[13]**; Research literature demonstrates that after certain events, there is often "a slow drift in the stock price of the firm after the event, apparently reflecting a gradual process of learning the good or bad news associated with the event" - a scenario that would be "inconsistent with the efficient markets hypothesis." **[14]**

The consistent track record of highly successful investors further challenges a simplistic acceptance of market efficiency. While his returns speak for themselves, Warren Buffett disagreed with the efficient market hypothesis when saying that "market prices are frequently nonsensical" and explained: "when the price of a stock can be influenced by a 'herd' on Wall Street with prices set at the margin by the most emotional person, or the greediest person, or the most depressed person, it is hard to argue that the market always prices rationally." **[15]**

Biases in Fossil Fuel Valuation

Simply debunking the efficient market hypothesis as a blunt bludgeon of universal truth does not prove the existence of a fossil fuel carbon bubble in this particular case. Public markets are overall thought to be fairly efficient. The beauty of markets is their ability to balance out disagreements about the intrinsic valuations of assets. However, in the words of "Random Walk", in order to neutralize a "systematic rather than random" discrepancy between price and intrinsic value, it is necessary that "the many intelligent traders attempt to take advantage of this knowledge." **[7]** Even when there is "room for disagreement", as Fama would say, where investors might systematically overvalue an asset, an insufficient number of investors taking the opposite

view would result in the persistence of systematic biases. In this context, industry-specific valuation biases point to market inefficiencies for fossil fuel companies

In practice, prevailing industry valuation methodology assumes full extraction of fossil fuel reserves: the “most common and widely accepted method to value an oil and gas company is a Net Asset Value Analysis” or NAV **[16]**. Unlike a DCF, the NAV approach is more accurate for companies with an upstream or exploration and production focus, and assumes “that the company adds nothing to its reserves and that it produces 100% of its reserves until it runs out of natural resources completely.” **[17]** The assumption that “reserves are depleted” is the standard NAV methodology employed by analysts **[18]**. While markets can efficiently resolve symmetric under and over-valuations, the full extraction assumption is standard practice employed widely across analysts and therefore represents a systematic valuation bias (only over-values).

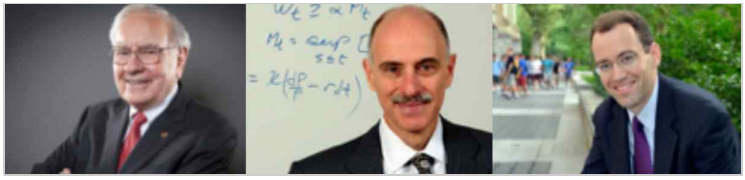
Why do “the many intelligent traders” not arbitrage these biases away? Belief in market efficiency can act as a self-fulfilling anti-prophecy and hamper efficient reaction to information about the potential carbon bubble. Market efficiency can only arise if relevant new information percolates into analysts’ updated valuations and translate into tangible trading decisions. Many investors and articles that inform them, however, justify continued investment on the basis that all proven reserves can indeed be extracted and thus confidently confirming prevailing valuation methods. Market participants who make the common counterargument that fossil fuel demand will remain strong would fall into this camp **[19]**. Since valuation methods have historically assumed full depletion of reserves, the prevalence among most investors of the belief for market efficiency in fossil fuel companies (to the extent that it discourages more rigorous analysis of the carbon bubble) actually dampens market efficiency.

Furthermore, short-term analyses may fail to properly account for the carbon budget. In attempting to illustrate the certainty of NAV methods, IHS explains in “Deflating the ‘Carbon Bubble’” that intrinsic valuation of fossil fuel companies are primarily (albeit not entirely) based on the value of proved reserves, about “90% of which are expected to be monetized in 10 to 15 years.” **[19]** Yet behavioral biases in valuation practice suggests lack of full information incorporation. Based on a survey of industry analysts, a 2017 report ominously titled “All Swans are Black in the Dark” found that equity research firms generally “only look at the next five years” to incorporate risk considerations **[20]**. The systematically mismatched time horizons between risk considerations (up to 5 years) and sources of material carbon bubble risks (on the order of 10 to 15 years or beyond) represent a behavioral myopia bias. Similarly, a survey of the world’s 500 largest institutional investors, “including pension funds, sovereign wealth funds, insurance companies, foundations and endowments,” found that only “7% of assets owners are able to calculate their emissions.” While these general patterns of inadequate carbon bubble risk assessment still leave room for savvier valuations by specific investors, the overall market practice indicates major obstacles to efficient price formation **[21]**.

A Growing Carbon Bubble

All proven reserves today already exceed the carbon budget, so pouring more money into more reserves further jeopardizes the ability to fully extract. Yet the industry spends massive capital expenditures to continually grow the reserve base. For example, global upstream capex is expected to increase by 5% in 2017 **[22]**. Heede and Oreskes’s peer-reviewed carbon budget analysis shows that the “core climate threat” for investor-owned entities “is capital investment in finding and developing new reserves.” **[23]** About $2.2 trillion of capex over the next 10 years would be unneeded (thus potentially stranded) under the IEA 450 scenario of limited climate change **[24]**. In other words, even if the market prices accurately reflect intrinsic value of the proven reserves today (i.e. even if most of the IHS “10 to 15 years” of reserve NPV is safely monetized), any additional capex is converting shareholder value into more risky reserves. Consider an analogy: being able to extract

current proven reserves is like surviving one round of Russian roulette; using the generated cash to continually acquire and develop new reserves is like spinning the barrel and pulling the trigger over and over.



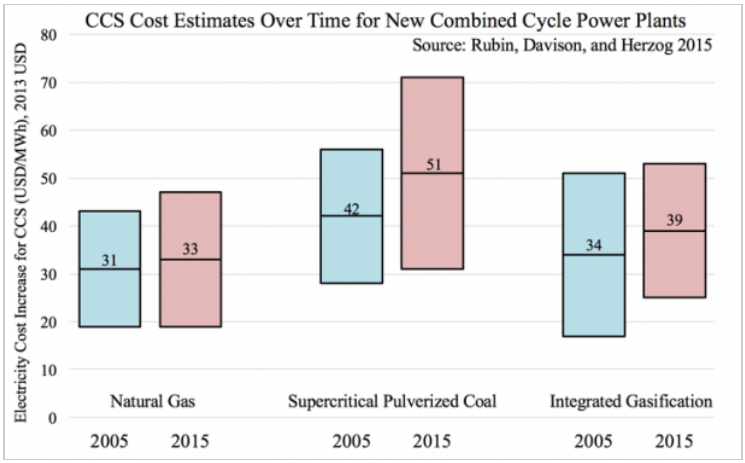
(**Image:** Individuals affiliated with the University of Pennsylvania whose work challenges naive faith in the efficient market hypothesis. From left: Warren Buffett attended Wharton 1947-1949, Sanford Grossman taught at Wharton 1989-1999, Peter Ammon is Penn's Chief Investment Officer.)

Why are companies growing the carbon bubble through capex? In general, corporate net income can be returned to shareholders (as dividends or buybacks) or plowed back to expand business activity. A Harvard Business Review article analyzes fossil fuel investments using the framework of the "overvaluation trap," which "occurs when the capital markets overvalue a company's equity—and especially when stock overvaluation is common in a particular sector." **[25]** The HBR article explains that in order to keep the valuations "propped up, executives running big oil invest aggressively in finding more reserves; should they stop spending on new exploration and development, it would signal to investors that their current reserves aren't worth as much." Thus a principal-agent problem emerges: fossil fuel reserve managers need to maintain reserve-to-production ratios to maintain extant stock valuations. This conflict also arises because of compensation structure. For example, executives at the world's largest 5 oil companies received $1 trillion in bonus compensation, over a period of 9 years, linked to activity in the exploration and development of new reserves **[26]**. Managers of fossil fuel reserves are paid to perpetuate the carbon bubble.

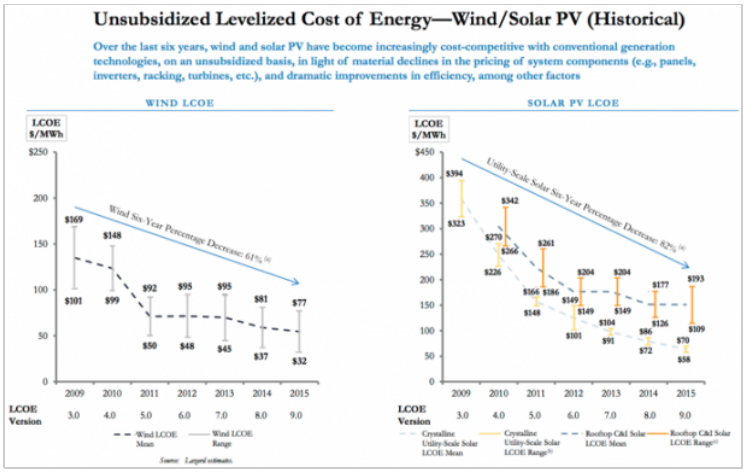
Carbon Capture as a Possible Mitigant

Can clean coal save assets from becoming stranded? If carbon capture and sequestration (CCS) technology becomes sufficiently feasible and affordable, then more of current fossil fuel reserves can be burned without exceeding the carbon budget. However, basic chemistry poses major challenges to implementation. Stoichiometrically, CO_2 is 3.67 times heavier than the C of coal, and CO_2 is 2.75 times heavier than the CH_4 of natural gas **[27]**. As a result, for coal and natural gas reserves that get combusted in power plants the "mechanism for capturing and processing" this large mass of emissions is "potentially larger in scale than the mechanism for burning the coal and gas in the first place." **[28]** For the oil reserves that result in combustion, almost all emissions end up as gasoline, diesel, jet fuel, or heating oil **[29]**. These emission sources are disparate, rather than concentrated at central power plants - the requisite ambient air carbon capture would be even more scientifically challenging since the emission concentrations would be much lower than at a stationary point source.

These engineering limitations translate into CCS being technologically immature and expensive, especially when compared with the dramatic recent improvements in renewable energy technology. Based on a cost comparison by Rubin, Davison, and Herzog (researchers at Carnegie Mellon, IEA, and MIT), CCS technology costs as much in 2015 as it did back in 2005, if not slightly more expensive **[30] (https://web.archive.org/web/20191227055959/http://www.cmu.edu/epp/iecm/rubin/PDF%20files/2015/Rubin_et_al_ThecostofCCS_IJGGC_2015.pdf)**. Research into CCS has thus far yielded a zero return on investment in terms of affordability. Looking forward, ongoing research shows promising areas of cost improvements, but these are still in early pre-pilot stages **[31]**. From an investment management perspective, continuing to invest in fossil fuel reserves with the hope of CCS technology improvements de-stranding these assets is essentially a highly concentrated bet on a single immature technology. If all hopes to solve the carbon bubble are pinned on CCS, then investments tied to fossil fuel reserves would be akin to a venture capital fund focusing exclusively on early R&D stage CCS pre-startups.



In contrast, wind levelized cost of energy (LCOE) has decreased 61% from 2009 to 2015 and utility-scale solar LCOE decreased 82% **[32]**. Lazard's most recent LCOE calculations show that utility-scale solar PV and wind energy have become cheaper than nuclear, coal, and even natural gas combined cycle **[33]**. Based on this trend, capital investments to further scale up clean energy is likely to continue a positive feedback loop where economies of scale and learning-by-doing drives additional cost improvements.



(**Image:** Unsubsidized Leveled Cost of Energy: Wind/Solar PV (Historical) **Source:** Lazard, Ltd.)

Empirical Performance: Betting Against the Carbon Bubble

Correcting the carbon bubble would require more of Fama's "many intelligent traders." An example of one might be Robert Litterman, who co-developed the famous Black-Litterman model for asset allocation with Fischer Black during his 23-year tenure in quantitative strategies and risk management at Goldman Sachs. He states: "a savvy investor, particularly an educational endowment, recognizes that people do become more rational over time," and therefore such an investor "would see the risk embedded in the stranded assets in their portfolio **[34]**. With his guidance, the World Wildlife Fund entered a simple swap derivative where it gives returns from a coal index and an oil sands index to Deutsche Bank, in exchange for returns from the S&P 500 **[35]**. This swap is essentially "a bet that stranded assets will underperform the equity market."

Litterman's bet has borne out over the period of January 2011 to January 2014, the "Stranded Assets Total Return Swap" has yielded an annualized net total return of 21.7% with a -36% correlation to the market index **[36]**. Thus this strategy reduced portfolio risk while increasing returns. Note that the strategy generated these returns despite this sample period coinciding with favorable oil prices, i.e. prior to the oil price drop in late 2014.

How would this strategy of long-market, short-stranded-assets fare more recently? Consider the strategy of going long the fossil free version of the S&P 500 total returns index (FFIUST) and short the normal S&P 500 total returns index. By construction, this is equivalent to divesting the companies with fossil fuel reserves and reinvesting the cash into the broader market. Using the total returns accounts for the effect of dividends (often cited as a major benefit from oil and gas company stocks) and buybacks. An international version of the strategy can be constructed with the MSCI ACWI, which captures "all sources of equity returns in 23 developed and 23 emerging markets," along with its version excluding companies with significant fossil fuel reserves. The following results were obtained with daily returns series from Bloomberg.

Start Date	Index	Total Return	Total Return (Fossil Free)	Annualized Std. Dev.	Annualized Std. Dev. (Fossil Free)
6/30/2013	S&P	58.03%	63.71%	12.67%	12.58%
	ACWI	35.23%	39.72%	10.88%	10.67%
6/30/2016	S&P	13.53%	14.45%	8.54%	8.43%
	ACWI	13.44%	13.95%	7.30%	6.57%

Table 1. Performance of Market Indices Including and Excluding Fossil Fuel Reserves (Start Until March 23, 2017)

Table 1 shows that for a market index portfolio, divesting from fossil fuel reserves is a strictly dominating strategy. In both periods and for both market indices, the fossil free version has both a higher return as well as lower volatility as measured by standard deviation. Note that the more recent sample period (June 30, 2016 and after) sees a relatively favorable oil price environment as well as possible fossil fuel upside from President Trump's election. Despite these favorable conditions, divestment in these various scenarios would have improved risk-adjusted returns.

Start Date	Index	Annualized Total Return	Annualized Standard Deviation	Market Beta
6/30/2013	S&P	1.49%	1.00%	-1.01%
	ACWI	1.14%	0.87%	-2.24%
6/30/2016	S&P	1.27%	0.86%	-1.80%
	ACWI	0.68%	0.73%	-1.50%

Table 2. Performance of Short Fossil Fuel Reserves, Long Market Strategies (Start Until March 23, 2017)

Table 2 shows that divesting from fossil fuel reserves and rebalancing the portfolio to the broader market index would have generated positive returns with relatively low volatility (thus implying high Sharpe ratios), as well as negative market correlations. These results from the more recent period serve as a robustness check to Litterman's results. Note that the orders of magnitude are different because WWF's pure swap is essentially a more concentrated version than the ones constructed from the fossil-free indexes.

Start Date	Market	Endowment Level 1 Equity ($ Million)	Estimated Lost Value from Not Divesting ($ Million)
6/30/13	US (S&P)	1,194.2	67.9
	All (ACWI)	1,630.8	73.2
6/30/16	US (S&P)	1,169.1	10.8

	All (ACWI)	1,731.4	8.9

Table 3. Rough Estimate of Continued Fossil Fuel Investment's Impact on Endowment

Table 3 integrates the information about the opportunity cost of not reallocating fossil fuel investments with information about the University of Pennsylvania's endowment. In the financial statements, the Level 1 equity represents liquid investments that have ready market prices, and thus would roughly align with the S&P and ACWI. Considering only these parts of the endowment's public equity (thus representing a conservative estimate) for US and overall markets (including domestic, developed, and emerging), Table 3 shows loss estimates on the order of magnitude of millions.

Conclusion

Sustainability for society at large requires the balanced preservation of both financial and natural capital. Similarly, investment managers have a fiduciary duty to look out for the interests of its beneficiaries; institutional investors with a long-term mission including future generations (such as foundations or endowments) should therefore also aim to preserve the natural capital that sustains all biological life.

How can this apparent tension between finance and environment be resolved in the case of climate change? Historical performance demonstrates that reallocating capital away from fossil fuel reserves would not hurt risk-adjusted return, and in fact may improve it. But past performance does not guarantee future returns. In terms of forward-looking information, economic literature combined with industry practices suggest the presence of persistent market inefficiencies for fossil fuel reserves, so these assets are likely to be stranded and mispriced, i.e. a carbon bubble exists which may be perpetuated by behavioral and institutional valuation biases. In this context, investing in the carbon bubble is unsustainable for both financial and environmental capital.

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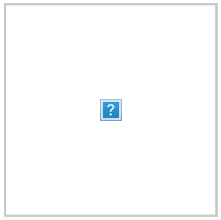

(/web/20191227055959/https://publicpolicy.wharton.upenn.edu/live/news/3202-regulating-consumers-rights-to-repair-products-the/for-students/blog/news)

Regulating Consumers' Rights to Repair Products: The Debate Between Convenience and Intellectual Property Rights (/web/20191227055959/https://publicpolicy.wharton.upenn.edu/live/news/3202-regulating-consumers-rights-to-repair-products-the/for-students/blog/news)

The War in Afghanistan: The Counterterrorism and Counternarcotics Connection (/web/20191227055959/https://publicpolicy.wharton.upenn.edu/live/news/3189-the-war-in-afghanistan-the-counterterrorism-and/for-students/blog/news)

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RESOURCE SPOTLIGHT:

Federal Reserve Economic Data (FRED®)

An online database consisting of more than 72,000 economic data time series from 54 national, international, public, and private sources. FRED®, created and maintained by Research Department at the Federal Reserve Bank of St. Louis, goes far beyond simply providing data: It combines data with a powerful mix of tools that help the user understand, interact with, display, and disseminate the data.

Quick link to data page: **http://research.stlouisfed.org/fred2/tags/series (https://web.archive.org/web/20191227055959mp_/http://research.stlouisfed.org/fred2/tags/series)**

See all **data and resources (/web/20191227055959mp_/https://publicpolicy.wharton.upenn.edu/data-resources/)** »

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