Escaping the Grasp of Foreign Oil: Potential Greenhouse Gas Emissions from Domestic, Nonrenewable Alternatives

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ABSTRACT

The United States' reliance on petroleum imports for transportation fuel is no longer sustainable. Whether energy independence via alternative nonrenewable feedstocks is ultimately more environmentally sustainable than conventional oil depends on the impacts associated with each domestic alternative. Replacing petroleum-based fuels with those derived from U.S. reserves of oil shale or coal could bring increased global warming. The purpose of this study is to investigate what a transition to the two aforementioned sources of fuel would mean to future climate change. To assess the quantity of fuel necessary to replace all transportation fuels derived from oil imports, I calculated the future U.S. fuel gap. Using geological survey data, I then determined whether the U.S. possesses ample reserves of either coal or oil shale to meet this gap. To quantify whether it would be environmentally beneficial to pursue these alternatives, I projected the potential greenhouse gas emissions that would result following a transition to each. Using life cycle assessment data, I projected emissions for five scenarios: coal with and without carbon capture and storage (CCS), oil shale with and without CCS and a petroleum baseline scenario. From these projections, I found that oil shale-based transportation fuels coupled with carbon sequestration technology could mean comparable greenhouse gas emissions to conventional oil. Nonetheless, before any conclusions are made regarding the environmental sustainability of each fuel feedstock, all other ecological implications including those on a regional scale must be taken into account.

KEYWORDS

coal, oil shale, transportation fuels, energy independence, climate change

INTRODUCTION

The United States' reliance on petroleum imports for transportation fuel is no longer sustainable. Economically, an increased dependence on foreign sources of energy raises many concerns about the potential impacts of oil shortages on industry. Periods of oil scarcity could potentially jeopardize industrial production and stunt future growth (Lyons 1979). Increased oil imports also impact the trade balance. Oil imports are currently the single largest contributor to the trade deficit, accounting for approximately 342 billion dollars in imports in 2008 (Dixon et al. 2010). Petroleum imports are also accompanied by many security concerns. Of the nearly 237 billion dollars the United States spent on petroleum imports in 2007, $150 billion was disbursed to nations that the U.S. State Department classified as "dangerous or unstable"(Lefton and Weiss 2010). Beyond the economic and security implications, oil imports are not sustainable from an environmental perspective with the transportation industry currently accounting for the second largest contribution to greenhouse gas emissions in the U.S. (Morrow et al. 2010). By providing an avenue away from petroleum imports, energy independence could help the United States become more sustainable.

Whether energy independence via alternative nonrenewable feedstocks is ultimately more sustainable than conventional oil depends on the environmental implications associated with each domestic alternative. Oil shale and coal offer two domestic resources capable of producing transportation fuel, and both present similar environmental challenges. The extraction of coal and oil shale from the earth often means extensive mining, practices that frequently call for the removal and displacement of all rock, soil and wildlife from above the buried fuel source (Fox 1999). Accelerated soil erosion resulting from mining activities can cause the leaching of heavy metals like arsenic and lead into local water supplies (Skogerboe et al. 1979). Furthermore, regional acidification caused by a combination of acid mine drainage and acid rain remains a major concern associated with the mobilization of coal and oil shale for use in the transportation industry (Reinhardt 1981). Another significant environmental concern associated with any carbon-based transportation fuel is climate change. Global warming is one of the more far-reaching environmental influences accompanying the use of fossil fuels due to its ability to alter ecosystems all across the world. With this in mind, before a pathway towards energy independence is selected to replace oil imports, the United States must consider each alternative fuel's greenhouse gas potential.

Although oil shale and coal offer two domestic avenues to achieving energy independence, their contribution to climate change may dwarf that of conventional oil. From a greenhouse gas perspective, the life of a transportation fuel can be divided into two processes: production and combustion. Considering that upon combustion each of these fuels regardless of their original feedstock generate comparable quantities of emissions (Mangmeechai 2009), the difference in carbon footprint between conventional oil and these synthetic fuels originates in each fuel's production process. In the cases of both oil shale and coal, the conversion process to transportation fuels requires an energy-intensive gasification process (Chen et al. 2011). To generate this input energy, power plants have historically burned other fossil fuels, namely coal, a development that speaks to the increased greenhouse gas footprint that would accompany the use of oil shale and coal for transportation (Jaramillo et al. 2007). A transition to either coal or oil shale as a means of replacing oil imports could substantially increase greenhouse gas emissions. A rise in emissions could exacerbate the effects of climate change, potentially leading to unprecedented environmental destruction (Considine and Dalton 2008). Before the United States chooses a path towards energy independence, a study must be conducted to project the environmental impact of such a transition. By concentrating on the global warming potential of each domestic alternative to oil, this study will complement related studies, which generally focus on energy independence from a political or financial perspective.

The ultimate goal of this study is to determine which domestic alternative to petroleum imports between coal and oil shale would be least detrimental from a climate change perspective. To accomplish this goal, I must meet two objectives. First, I must determine whether there are sufficient reserves of each domestic fuel source to replace oil imports and make energy independence viable for the next twenty-three years (a period that should allow for enough time for the construction of an infrastructure compatible with more environmentally friendly renewable resources). Second, I must be able to project the relative greenhouse gas emissions for each alternative. In meeting these objectives, my results will help determine which alternative fuel sources between coal and oil shale will be least environmentally detrimental as the United States pursues short-term energy independence.

METHODS

Assessing the fuel gap

To determine the quantity of fuel necessary to replace all transportation fuels derived from oil imports, I calculated the future U.S. fuel gap, or the difference between the national demand and the domestic supply of petroleum-based transportation fuels. This discrepancy is the amount of domestically produced fuel that the U.S. would have to provide to avoid imports. To assess the fuel gap, I used the Energy Information Administration's (EIA) projections for U.S. petroleum-based, transportation fuel consumption as well as domestic crude oil production (EIA 2011). I chose the EIA projections after assessing the viability of each projection's associated assumptions (Table 1). To determine the amount of oil-based transportation fuels that could be generated from the EIA's projections of domestic oil production, I assumed that on average one barrel of oil accounts for approximately 26.7 gallons of useable fuel (Rivero 2002). Furthermore to account for the fraction of domestically produced petroleum sold abroad, I assumed an export rate of 39%, which corresponds to the current level (EIA 2011).

Table 1. EIA Projections' Associated Assumptions. The following are a number of key assumptions on which the EIA projections are based. (For more information on these as well as additional assumptions not mentioned, please see the EIA's 2011 Annual Energy Outlook for the Reference Case)

1	Current Regulations and existing laws will remain unchanged until 2035.
2	U.S. Crude Oil Production will increase by an average of 0.6% annually as oil prices rise and technology improves.
3	In 2035, the oil price will reach $125/barrel.
4	Consumption of Transportation Fuels with rise by an average of 0.5% annually in the U.S.
5	E85 (85% ethanol: 15% petroleum) consumption will increase by an average of 26.3% annually and will account for nearly 30% of all transportation fuel consumption by 2035.
6	Consumption of petroleum-based transportation fuels will increase by an average of 0.2% annually

Domestic reserves of alternative fuels

To determine whether the United States possesses ample reserves of either coal or oil shale to satisfy the fuel gap, I reviewed a number of geological surveys and studies (Table 2 &

Table 3). With the aid of reports published by organizations like the USGS and the EIA, I determined the quantities of potential domestic reserves of coal and oil shale. Estimates of potential reserves can vary between reports so I both examined each paper's methodology and created high and low estimates based on a variety of references. I used this suite of estimates in order to establish consensus on whether there are enough reserves to fill the fuel gap.

Table 2. Estimated U.S. Coal Reserves, by reference. The following are all of the surveys and reports I found discussing the quantities of coal reserves in the United States.

Source	U.S. Coal Reserves (Rounded to the Nearest billionth ton)
EIA 2010	261
Rohrbacher and McIntosh 2010	258
USGS 2009	256
WEC 2010	238

Table 3. Estimated U.S. Oil Shale Reserves, by reference. The following are all of the surveys and reports I found discussing the quantities of oil shale reserves in the United States.

Source	U. S. Oil Shale Reserves (Rounded to the Nearest billionth ton)
WEC 2010	315
EIA 2011	285
Mercier et al. 2011	260
USGS 2011	210

Using conversion ratios and energy content statistics that allowed me to project the potential quantities of transportation fuel that can be derived from the U.S. reserves, I determined whether the U.S. possesses ample supplies of either alternative to close the fuel gap. I assumed that one ton of coal yields on average 63 gallons of transportation fuel (Hook and Aleklett 2010). By comparison, one ton of oil shale generates approximately 25 gallons of the same quality fuel (Mushrush et al. 1997). Because the quality of transportation fuel is comparable regardless of whether it was derived from petroleum, coal or oil shale, I assumed a common energy content value of 135,000 BTUs/gallon of fuel (Kamara and Coetzee 2009). Through the application of these energy content and conversion statistics, I was then able to weigh the estimates of potential reserves against the fuel gap in terms of quantities of transportation fuels.

Greenhouse gas projections

To quantify whether it would be environmentally beneficial to pursue each of the alternatives to petroleum-based transportation fuels, I projected the potential greenhouse gas emissions that would result from a transition to those alternatives. I established five possible scenarios (two for coal, two for oil shale and one for conventional petroleum as a baseline) based on the assumption that the fuel gap would be entirely fulfilled by one of the three fuel sources. For both coal and oil shale, I instituted scenarios that examined prospective greenhouse gas emissions with and without the implementation of carbon sequestration. Using emission factors taken from life cycle assessments that pertained to each specific scenario (Table 4), I projected the potential greenhouse gas emissions (in billion tons of carbon dioxide equivalent) for each alternative based on the quantity of fuel necessary to satisfy the fuel gap. By comparing the projected emissions resulting from a transition to coal to those associated with a transition to oil shale, I was able to determine which of the two pathways towards energy independence would contribute the least to climate change. Furthermore, in contrasting each alternative's projected emissions with the petroleum baseline scenario, I then could assess the greenhouse gas potential of coal and oil shale relative to the status quo.

Table 4. Summary of Emission Factors. To project greenhouse gas emissions for each energy scenario, I used the following emission factors taken from a variety of life cycle assessments.

Fuel Feedstock	CCS	Emission Factor (gCO_2e/BTU fuel)	Source
Coal	With	0.122	Bartis et al. 2008
		0.131	Chen et al. 2011
	Without	0.235	Bartis et al. 2008
		0.270	Brandt and Farrell 2007
Oil Shale	With	0.099	Brandt 2008
		0.107	Mangmeechai 2009

	Without	0.137	Brandt 2008
		0.186	Brandt 2009
Petroleum	Without	0.094	Wang et al. 2004

RESULTS

Assessing the fuel gap

The EIA projects that the United States will produce 349 quadrillion BTUs of petroleum-based transportation fuels over the next 23 years. Of this supply, only 213 quadrillion BTUs will be available in the U.S. after accounting for exports. Over this same period, the EIA predicts that the United States will consume approximately 800 quadrillion BTUs of fuel. This cumulative discrepancy amounts to 587 quadrillion BTUs of transportation fuel necessary to close the fuel gap (Fig. 1).

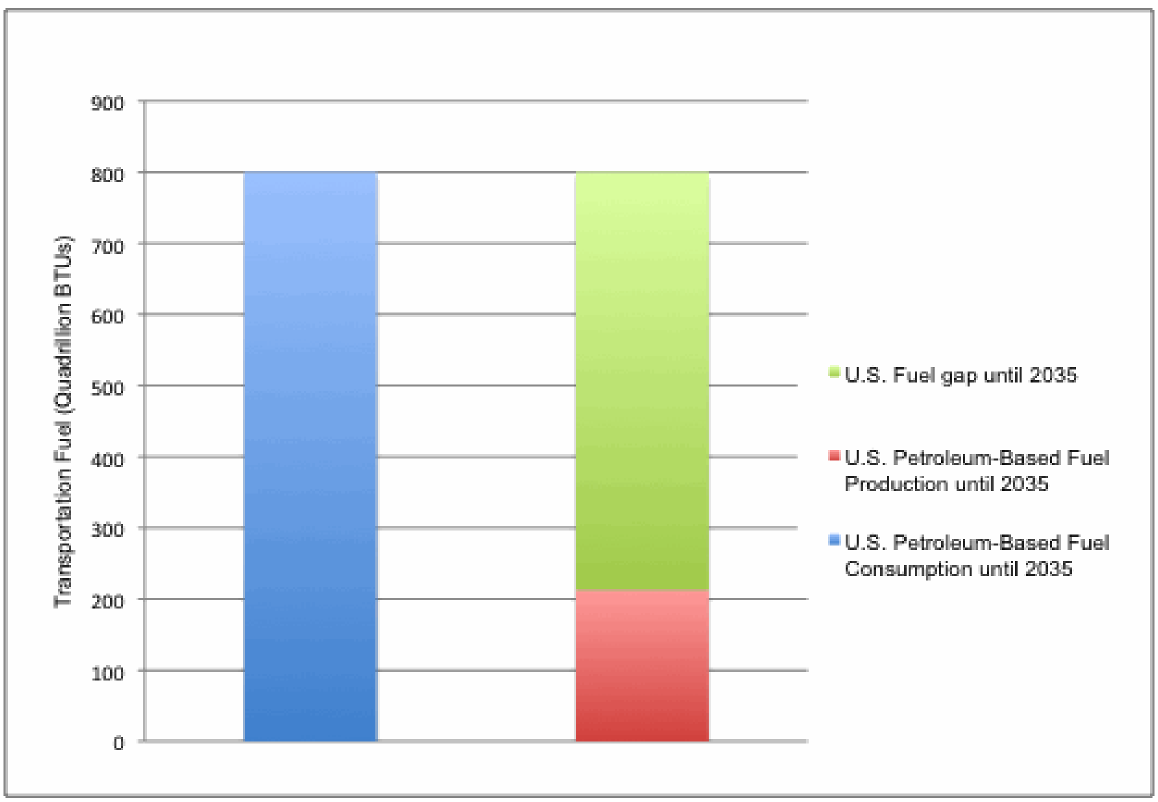

Fig. 1. Sizing up the fuel gap. The fuel gap separating U.S. production of transportation fuel over the next 23 years (until 2035) and national consumption of transportation fuel over this same period is approximately 587 quadrillion BTUs.

Domestic reserves of alternative fuels

Coal

Based on several geological surveys, the U.S. possesses sufficient domestic reserves of coal to fulfill the fuel gap until 2035. I have found that the United States reserves of recoverable coal range between 261 billion tons and 238 billion tons (EIA 2010, WEC 2010). With that in mind, the amount of liquid fuel available in the United States' coal reserves range between 2000 and 2200 quadrillion BTUs, well above the 587 quadrillion BTUs necessary to meet the fuel gap over the time span considered for this study (Fig. 2).

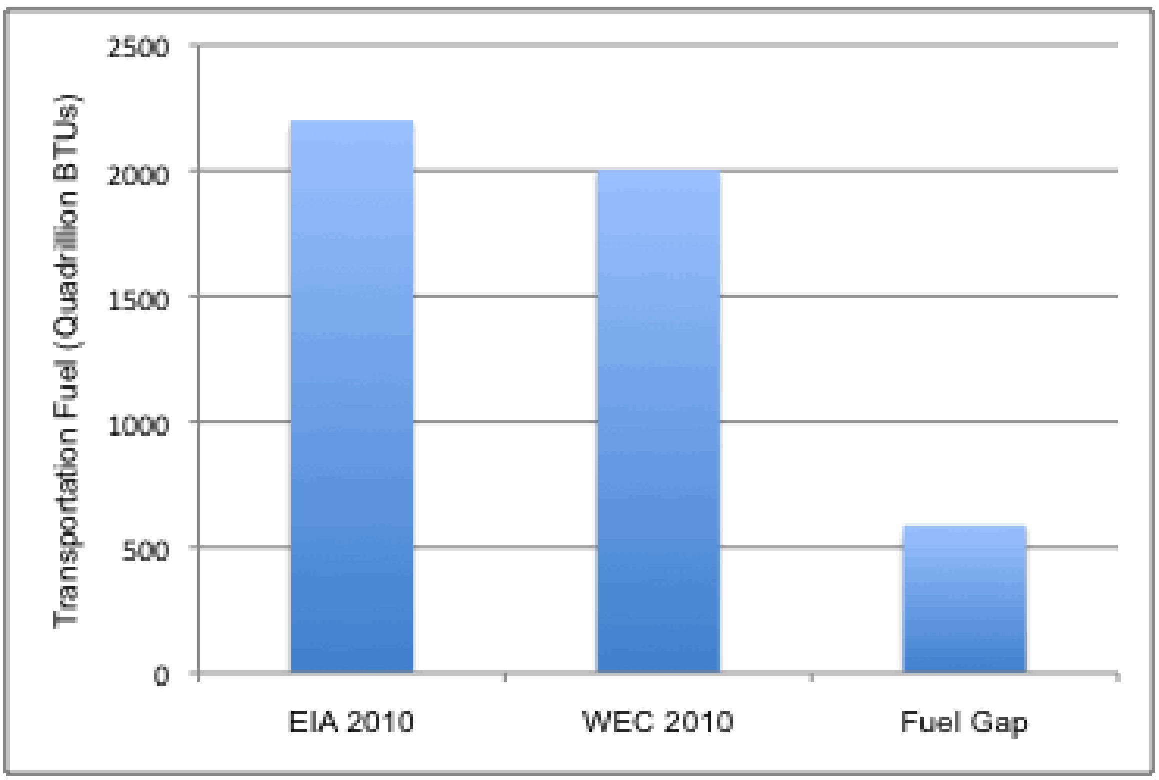

Fig. 2. Potential quantities of coal-based transportation fuels. I found that the United States possesses sufficient reserves of coal to satisfy the fuel gap.

Oil shale

Based on data from several geological surveys, the United States possesses adequate reserves of oil shale to close the fuel gap until 2035. I found that estimates of extractable domestic oil shale reserves range between 210 and 315 (USGS 2011, WEC 2010) billion tons. Based on these figures, there are between 710 and 1060 quadrillion BTUs of liquid fuel available in the United States' oil shale reserves (Fig. 3).

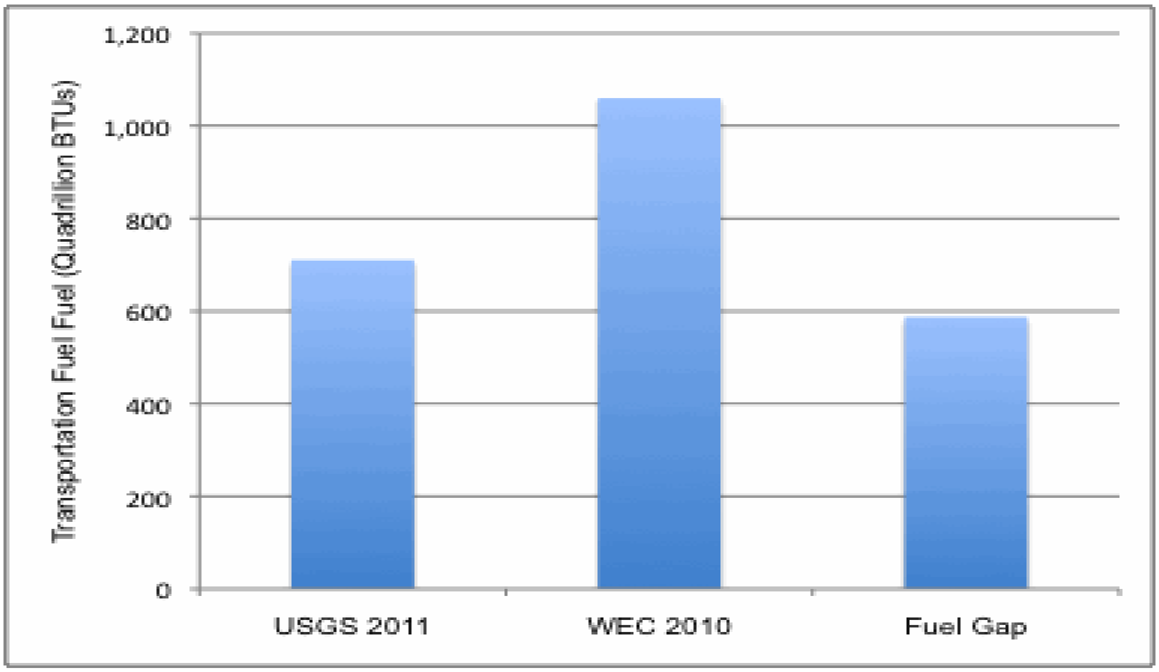

Fig. 3. Potential quantities of oil shale-based transportation fuels. I found that the United States possesses ample reserves of oil shale to satisfy the fuel gap.

Greenhouse gas projections

Coal

Using emission factors I procured from four different life cycle assessments, I have determined that greenhouse gas emissions would increase considerably following a transition from petroleum to coal-based transportation fuels (Fig. 4). Without carbon capture and storage technology, coal-based fuels would release between 138 and 158 billion tons of greenhouse gas emissions, constituting a 147 % and 184 % increase respectively from the 56 billion tons resulting in my petroleum-based business as usual scenario. With carbon sequestration technology, emissions would again increase from this baseline case, though only by between 29 and 40 % (72 and 77 billion tons respectively). Despite the implementation of carbon capture and storage practices, the greenhouse gas emissions from coal-based fuels would still be greater than those generated by fuels derived from conventional oil.

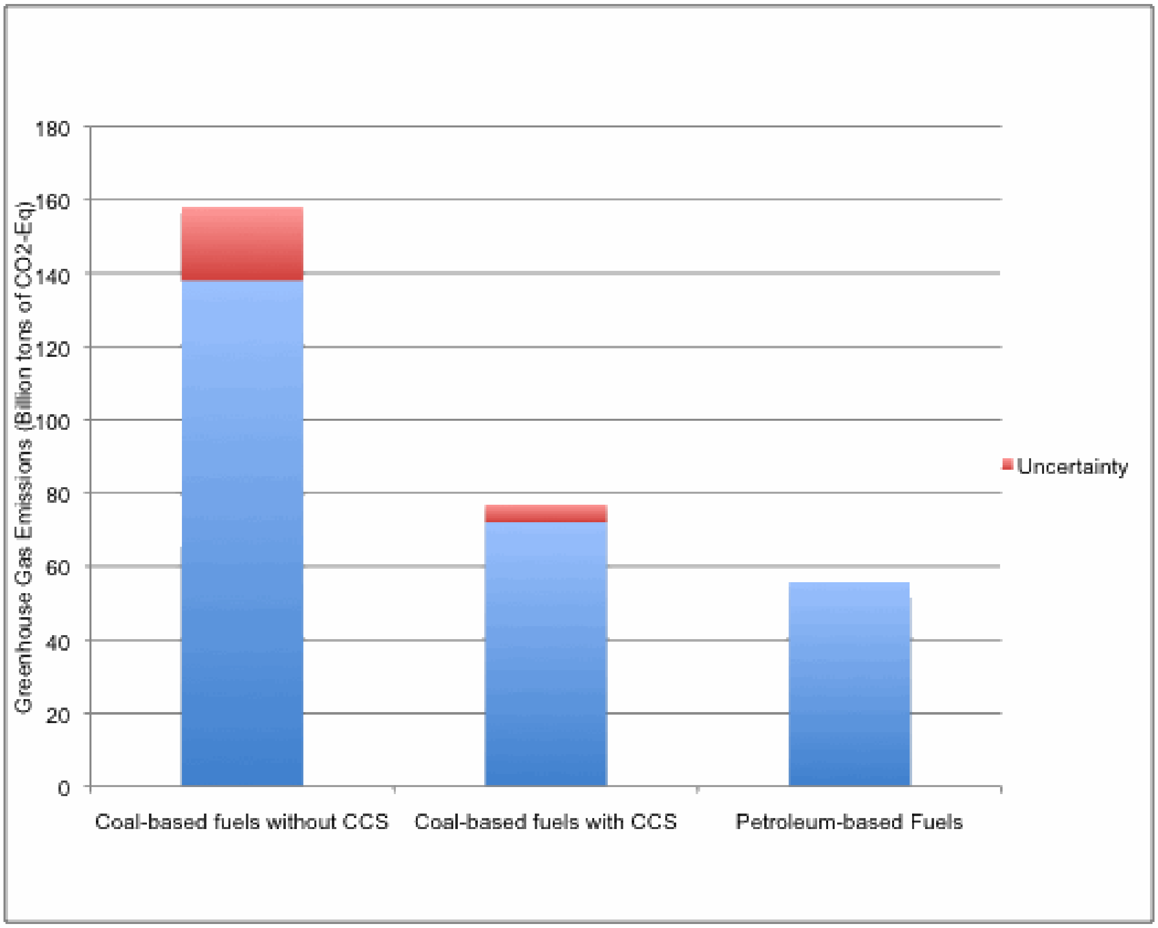

Fig. 4. Potential greenhouse gas emissions from coal-based fuels. I found that the greenhouse gas emissions resulting from a transition to coal-based fuels over the next 23 years would exceed emissions from petroleum-based fuels.

Oil shale

I calculated that the greenhouse gas emissions released in the production and use of oil shale-based fuels will be greater than those derived from conventional oil (Fig. 5). A shift to oil shale as a feedstock for transportation fuel without carbon sequestration technologies would release between approximately 80 and 108 billion tons of greenhouse gas emissions. With the implementation of carbon capture and storage practices, the potential greenhouse gas impact of fuels derived from oil shale fell to between 58 and 63 billion tons, constituting a 4 and 12 percent increase respectively from my petroleum baseline scenario. If accompanied by carbon sequestration technology, oil shale would offer a feedstock for transportation fuel with a comparable greenhouse gas impact to petroleum.

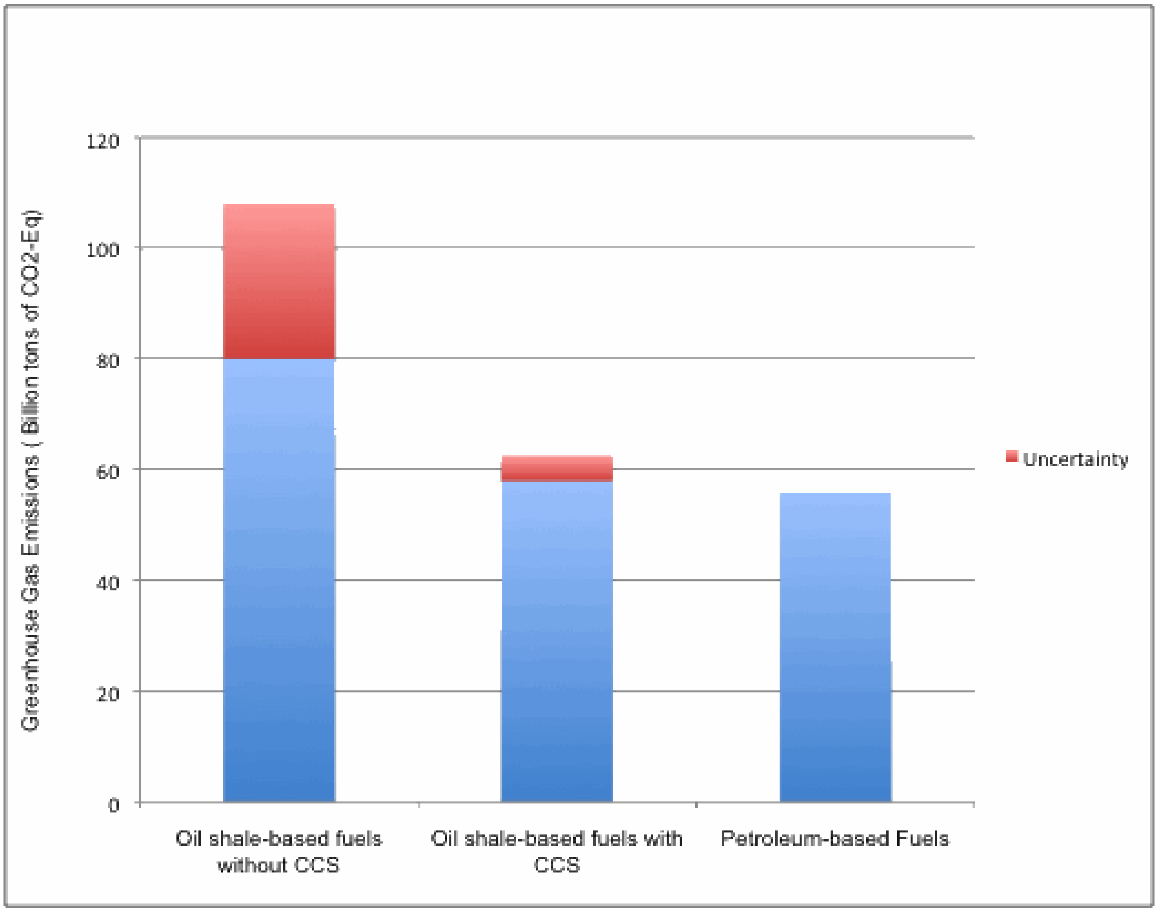

Fig. 5. Potential greenhouse gas emissions from oil shale-based fuels. I found that the greenhouse gas emissions resulting from a transition to oil shale-based fuels over the next 23 years would exceed emissions from petroleum-based fuels.

DISCUSSION

Although both coal and oil shale offer viable pathways towards achieving greater energy independence, a transition to either could further exacerbate the deterioration of ecosystems on both a global and local scale. There are sufficient domestic reserves of both oil shale and coal to close the fuel gap, but would a transition to either fuel be the environmentally responsible conduit towards greater energy independence? Oil shale-based transportation fuels coupled with carbon sequestration technology could mean comparable greenhouse gas emissions to conventional oil, but this finding alone does not speak to the litany of environmental concerns associated with this fuel source. A nationwide mobilization of either the coal or the oil shale transportation fuel industry could prove disastrous to ecosystems everywhere.

Weighing this study's greenhouse gas findings against those of similar studies

Table 1: Expected increase in greenhouse gas emissions following a transition to coal and oil shale

Fuel Feedstock	CCS	Study	Percent increase in GHG emissions relative to petroleum
Coal	With	This study	29-40
		Dooley 2009	10-60
		Ou et al. 2010	0-10
		Jaramillo et al. 2009	20-35
	Without	This study	147-184
		Ou et al. 2010	30-140
		Jaramillo et al. 2008	50-90
		Dooley 2009	80-120
Oil Shale	With	This study	4-12
		Gavrilova et al. 2010	5-10
		Dooley 2009	0-50
	Without	This study	44-96
		Dong et al. 2011	50-65
		Dooley 2009	70-150

Coal

In comparing my results for coal to similar studies, I found that the level of agreement fluctuated with the inclusion of carbon sequestration technology (Table 1). For the most part, my projections for the percent increase in greenhouse gas emissions of coal-based fuels with carbon capture and storage matched contemporary literature. Ou et al. (2010) have a lower estimate due to a higher assumed carbon capture rate: 90-95%, as compared with 85% used in this study as well as the others I examined. The percentage assumed in my study is based on what is currently economical in the United States (Parker and Dahowski 2008), as opposed to what is technologically feasible, a key distinction associated with the Ou et al. (2010) study. Shifting to a comparison of the studies that assessed coal's fuel prospects without carbon sequestration, of the three reports I examined, only the upper limits of the Ou et al. (2010) findings approached my projected range of emissions. In examining both the Dooley (2009) and Jaramillo et al. (2008) studies more closely, I have concluded that the divergence from my findings likely stems from a difference in assumed plant efficiency. In the life cycle assessments I used to project the greenhouse gas emissions for coal without CCS, the plant efficiency ranged between 52 and 55 percent, as compared with the 65 and 70 percent used in the Dooley (2009) and Jaramillo et al. (2008) studies respectively. After weighing my findings against similar studies, I have concluded that my projections of greenhouse gas emissions for coal-based transportation fuels are largely comparable.

Oil shale

After comparing my results to similar studies, I found that my projections for the greenhouse gas emissions resulting from the production of oil shale-based transportation fuels were again comparable (Table 1). In fact, both of the studies I examined that considered oil shale-derived transportation fuels with CCS displayed similar increases. Without the implementation of carbon sequestration, I again found that there was a great deal of overlap with the other two studies I examined, though the lower limit of my projections did moderately deviate from the Dooley (2009) findings. In evaluating this study more closely, I largely attribute this disparity to the oil shale processing technique assumed in the estimation of greenhouse gas emissions. In calculating the lower limit of my projections, I used a life cycle assessment based on the in situ processing technique. In contrast, the Dooley study considers the ex situ processing technique, as does the life cycle assessment I used to calculate the upper limit of my projections. Beyond the discrepancy between the lower limit of my estimate for oil shale without CCS and the results of the Dooley study, for the most part, my projections do mirror those of similar reports.

Limitations

By considering only two of the many possible domestically available alternatives to oil imports, I have limited my ability to make inferences about which fuel pathway towards energy independence would serve as the best option from an environmental perspective. In addition, by examining only greenhouse gas potential, I have further limited my study. I selected oil shale and coal as the two alternative fuel sources to supplant petroleum imports based on the rationale that: (1) the conversion of each of these feedstocks to a synthetic form of oil is a well-understood process and (2) the transportation fuels derived from these two sources are compatible with the current petroleum infrastructure. If I were to include other domestically available fuel feedstocks like natural gas or ethanol, I could better address my original research question regarding which pathway towards energy independence would be least environmentally detrimental. Furthermore, by restricting the scope of my study to only consider the global, greenhouse gas repercussions of each fuel source, I neglect other regional and local environmental implications. Beyond including other environmental considerations and additional fuel feedstocks, my study's level of scientific inference is limited by the sources of data I used to calculate my projections.

How well my model predicts potential greenhouse gas emissions depends largely on the studies from which I extracted the data. By only using the EIA's projections in calculating the fuel gap, the accuracy of all three phases of my study rests in the reliability of the EIA's statistics. Though historically the EIA's projections have been a good measure of future energy standing, they tend to be conservative relative to similar studies (Neill and Desai 2005). By incorporating other projections, I could improve my model. Including additional geologic surveys of oil shale and coal would also allow for a more informed consensus as to domestic reserves of each. Additional sources of information would also account for a wider range of assumptions, which could enhance the accuracy of my projections. Ultimately, the incorporation of additional sources of data could further improve the viability of my results.

Future research

To better assess which domestically available fuel source offers the least environmentally detrimental pathway towards energy independence, researchers must: (1) examine other viable alternatives to oil imports beyond coal and oil shale such as natural gas, ethanol, and hydrogen and (2) consider the environmental implications of those alternatives outside of their potential impact on climate change and global warming. Although coal and oil shale serve as two reasonable alternatives to oil imports, the United States possesses other largely untapped resources that may be equally viable. With this in mind, it is essential that the United States considers all possible avenues towards energy independence. In addition to considering additional fuel sources, future research should include an assessment of other environmental considerations beyond those related to global warming and greenhouse gases. To better address the environmental repercussions of each fuel source, researchers must consider the local and regional impacts of both the extraction and the production of each alternative. Other environmental considerations may include the following: (1) Water use (2) Water quality (3) Land use (4) Soil quality (5) Impact on local biodiversity (6) Air Quality. To provide a comprehensive assessment of the environmental implications associated with each fuel source, researchers must be able to account for and quantify all of these considerations. It is only after researchers conduct a thorough environmental assessment of each viable alternative that they can say with any certainty which pathway towards greater energy independence would prove to be the least environmentally detrimental.

Broader implications

Though my study does provide insight into the potential greenhouse gas impacts associated with a transition to either coal or oil shale, it speaks little to the regional effects that would accompany increased extraction. With regards to coal specifically, mining practices, most notably mountaintop removal, is especially detrimental to local ecosystems (Fox 1999), as habitats for both aquatic and terrestrial organisms are left decimated (Bernhardt and Palmer 2011). In the cases of both oil shale and coal extraction, accelerated soil erosion is another area of concern (Reintam and Leedu 1992). Beyond the impacts of mining practices on land quality, water contamination from acid mine drainage and the mobilization of heavy metals like arsenic and selenium often proves disastrous to all organisms including humans that depend on those water supplies to survive (For additional information about coal’s impact on water quality see Weber et al. 2004, Schorr and Backer 2006, and Pumure et al. 2011, and for oil shale see

Schlegel et al. 2011, Selberg et al. 2009 and Trapido et al. 2006). The deterioration of local air quality is an additional concern with regards to both oil shale and coal, as higher concentrations of sulfur and nitrogen result in the emission of acid rain-causing NOx and SOx (See Gavrilova et al. 2010, You and Hung 1993). When seeking a nationwide resolution that would ensure energy security, it is easy to lose sight of regional implications, but before any determination is made as to which pathway would be least environmentally detrimental, all ecological implications regardless of scale must be taken into account.

The ultimate purpose of my project is to provide insight into which domestically available source of transportation fuel, between oil shale and coal, would offer a viable avenue away from oil imports while avoiding a substantial increase in greenhouse gas emissions. My findings showed that with the implementation of carbon sequestration technologies, oil shale would produce comparable amounts of emissions to conventional oil. With this in mind, my results potentially establish the basis for future legislation. If energy independence is the goal, government officials could make use of my results to substantiate an initiative for a transition to oil shale. In addition, my findings make a strong case for the implementation of carbon sequestration regardless of the alternative fuel source being discussed. The ultimate usefulness of my study rests in the number of insights that could serve as the foundation for future energy policy. Before legislators forge a path towards energy independence, they must consider the environmental implications associated with each viable alternative fuel source and my findings could assist in this environmental assessment process.

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