WHITE PAPER

OCTOBER 2015

ASSESSMENT OF THE SCALE OF POTENTIAL INDIRECT EMISSIONS DUE TO HIGHER OIL USE

Chris Malins, Stephanie Searle, Nikita Pavlenko

THE INTERNATIONAL COUNCIL
ON CLEAN TRANSPORTATION

www.theicct.org

communications@theicct.org

BEIJING | BERLIN | BRUSSELS | SAN FRANCISCO | WASHINGTON

ACKNOWLEDGEMENTS

With thanks to Richard Plevin and Sonia Yeh. We are grateful for the generous support of the David and Lucile Packard Foundation, which allowed this report to be produced.

1225 I Street NW, Suite 900, Washington DC 20005

www.theicct.org | communications@theicct.org

EXECUTIVE SUMMARY

The inclusion of indirect land use change (ILUC) emissions in the life-cycle assessment of biofuels in several biofuel policies has led to increased attention to the question of whether there are similarly important indirect emissions terms that could, or should, be added when assessing the life-cycle carbon intensity (CI) of fossil fuel production. In this report, we consider six potential indirect emissions sources that could be associated with fossil fuel production. We find that for several of these effects, the magnitude of any associated emissions is highly uncertain, and that in some cases even the sign of the emissions impact is uncertain. Some of these effects apply only to marginal increases in fossil fuel use. Others, such as military involvement and development-induced deforestation, also potentially could be caused by biofuel production. Several indirect effects may result in modest increases in emissions associated with a marginal increase in fossil fuel use or, equivalently, a failure to marginally reduce fossil fuel use. The effects we have considered are listed in Table A.

Table A. Overview of Indirect Effects of Fossil Fuel Production

INDIRECT EFFECT	BRIEF DESCRIPTION	RANGE OF POSSIBLE MAGNITUDE*	EFFECT ALSO APPLIES TO BIOFUELS?	NOTES
Induced land development	Development of infrastructure (e.g., roads) increases rate of deforestation	0 to 1 gCO_2e/MJ	Yes	Would be more significant if allocated entirely to a small subset of oil sources
Military involvement	Emissions resulting from U.S. security action in Middle East and other oil producing regions	0 to 2 gCO_2e/MJ	Yes, potentially	Would be more significant if allocated entirely to a small subset of oil sources
Carbon intensity of the marginal oil	Changes in oil demand may disproportionately affect lower/higher carbon intensity sources	-5 to +10 gCO_2e/MJ	No	Could be positive or negative, sensitive to time horizon of assessment and political decisions in oil producing countries
Accidents (including oil spills and oil fires)	Irregular and unplanned accidental events may result in significant greenhouse gas emissions	<0.01 gCO_2e/MJ	Yes, to a lesser extent	Can be considered negligible
Co-products and the carbon intensity of refining	Changing fuel demand affects efficiency and output of refining industry	±5 gCO_2e/MJ	No	Could be positive or negative depending on how co-products are replaced
Price effects	Price-mediated change in fuel demand as a result of mandated changes in fuel consumption	N/A	Yes	If such a term were applied to marginal increases in petroleum demand it would almost certainly be negative

* Positive values for increases to life-cycle emissions from marginal change in fossil fuel use, negative for reductions.

Only two of the indirect effects we have considered here are believed to have the potential to result in a significant emissions impact that could be on the same scale as estimated ILUC emissions for biofuels. The first is the price effect of a change in fuel demand, also known as “indirect fuel use change” or the ”rebound effect.” For all current alternative fuel support policies this effect would be expected to increase the carbon emissions associated with additional biofuel use, if counted into the biofuel life cycle, or equivalently reduce the carbon emissions associated with additional fossil fuel use, if counted into the fossil fuel lifecycle. As this term is omitted from biofuel life-cycle assessments, and generally not directly accounted for in environmental regulations that could affect overall fuel use, it would be inconsistent to apply it to the petroleum life cycle in the present context.

The second indirect effect is the carbon intensity of the marginal oil supply. The most carbon intensive fuel production processes currently in significant use are about 20 gCO_2e/MJ more carbon intensive than the average. There is no consensus in the literature on what the true marginal oils are in either the short or long term, and it is exceedingly difficult to predict. Rather than one single source, it is certain that in reality there is a “basket” of marginal oils. Even if some, like the Canadian tar sands, have higher carbon intensities than the global average, others, like some tight oil projects, will have lower emissions. Even a 10 gCO_2e/MJ change in the fossil fuel baseline would have a limited impact on the support available to most alternative fuels under either the Renewable Fuel Standard or under performance-based carbon emissions reduction standards. We therefore consider it appropriate at present for alternative fuel regulations to continue to use an average fossil fuel carbon intensity baseline value, although further research in this area would be valuable.

None of the effects considered in this analysis would invalidate the use of an average or baseline carbon intensity value for fossil fuels in alternative fuel support legislation. Given that ILUC from biofuels is likely an order of magnitude larger than the possible indirect emissions factors associated with fossil fuel use, there is no reason that indirect effects estimated for fossil fuels need to be developed before ILUC factors could be implemented in regulations. ILUC emissions completely change the overall life-cycle emissions assessment of some biofuels, but effects considered here would make only a modest difference to the baseline carbon intensity of fossil fuels.

The only effect that may be large enough to make a fundamental impact to the understanding of the outcomes of a regulation is the price effect, or fossil rebound. Rebound effects are common to many environmental policies. The question of whether rebound effects should be included in carbon intensity values for regulatory purposes is complex and beyond the scope of this review. Even if none of these effects are included in regulatory emission factors, these indirect effects remain an interesting area for study and an important question for future regulatory impact assessment.

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1. INTRODUCTION

In the United States, Canada and the European Union, government policies are in place to support the supply of alternative transport fuels such as biofuels. One reason governments have adopted these policies has been to reduce the net greenhouse gas (GHG) emissions associated with the transport sector. Since 2008, several regulatory policies have differentiated between biofuels based on their calculated life-cycle carbon emissions intensity. The life-cycle carbon intensity represents a sum of various GHG emissions associated with producing biofuels, generally including at least emissions associated with growing or obtaining feedstock for the production of biofuels, emissions resulting from the processes used to transform that feedstock into a liquid fuel, and emissions resulting from transporting and distributing the feedstock and fuel. The assessment of life-cycle carbon emissions intensity is referred to as life-cycle analysis (LCA).

In both the U.S. Renewable Fuel Standard (RFS2) and the European Renewable Energy Directive (RED), biofuels are required to deliver certain minimum levels of carbon reductions relative to the fossil fuels they are intended to displace. In the RFS2, the level of carbon reduction is part of determining what category of renewable fuel each biofuel falls within (renewable, advanced or cellulosic), and therefore the value that can be obtained from the policy by the biofuel supplier. The biofuel suppliers then produce the necessary volume of each category of biofuel, as stipulated in RFS2, in order to meet the law's mandate. The RED establishes a broader set of minimum thresholds for GHG emission savings, which increase over time.

In contrast, under California's Low Carbon Fuel Standard (CA-LCFS), British Columbia's Renewable and Low Carbon Fuel Requirement Regulation (RLCFRR), and the upcoming Clean Fuels Program in Oregon and Clean Fuel Standard in Washington, there is no minimum level of carbon reduction required to be eligible for support. The level of support available for each gallon of fuel supplied is determined by the level of carbon savings offered compared to a reference fossil fuel.

Finally, in the European Fuel Quality Directive (FQD), minimum GHG emissions reduction thresholds for biofuels are coupled with a GHG intensity target for the overall fuel mix in the EU, which provides added value to fuels with higher carbon savings.

In all these policies, therefore, the assumed baseline carbon intensity of the fossil fuel can affect the potential emissions savings available from the policy to suppliers of any given alternative fuel. For this reason, in all these policies not only has there been an assessment of the life-cycle carbon intensity of various alternative fuel pathways, but also of the life-cycle carbon intensities of the fossil gasoline and diesel that these alternative fuels are intended to displace in the liquid fuel market.

Several of these regulations (CA-LCFS, RFS2, RED, FQD) now characterize the GHG emissions that are expected to be caused indirectly by increasing demand for biofuels due to indirect land use change (ILUC). This term refers to the expectation that increased demand for agricultural commodities will lead to a combination of increased supply and reduced demand in other sectors, that part of the increase in supply will result from bringing new land into agricultural production, and that bringing new land into agricultural production will normally result in GHG emissions due to reductions in levels of carbon stocks in the soil and biomass on that land.

The assessment of indirect emissions such as ILUC is often referred to as consequential LCA, because it involves assessing the consequences in a system of increasing (or sustaining) demand for a given biofuel. In contrast, an attributional LCA approach assigns each source of emissions to one or more production activities for a given product or service. The phenomenon of ILUC is discussed in detail by Malins et al. (2014). In RFS2, the U.S. Environmental Protection Agency (EPA) considers emissions associated with agricultural production on a consequential rather than attributional basis. The inclusion of ILUC in the LCA of fuels under these regulations is a result of the expectation that ILUC emissions could significantly alter the carbon savings delivered by given biofuels. In the CA-LCFS, for example, the inclusion of ILUC emissions calculated with the Global Trade Analysis Project (GTAP) model (California Air Resources Board, 2015) can make a significant difference in the number of LCFS credits that can be generated by first-generation biofuels, such as corn ethanol.

Given that indirect GHG emissions are considered in the life cycle of biofuels, it may be necessary to consider indirect emissions associated with the increased, or sustained, use of the fossil fuel alternatives in order to maintain consistency between the standards for fossil fuels and biofuels. In short, are there any emissions associated with fossil fuel production that, like ILUC for biofuels, are of an order of magnitude that suggests they need to be reflected in the LCA of the fossil fuel comparator values used in the various regulations mentioned above? This paper identifies several potential indirect emissions that may be associated with fossil fuel production, reviews the existing literature on these impacts, and draws conclusions about the potential contribution of these indirect emission sources to the life-cycle emissions of fossil gasoline and diesel.

2. POTENTIAL SOURCES OF INDIRECT EMISSIONS ASSOCIATED WITH FOSSIL FUELS

ICF International (ICF) in a 2013 report identified six potential sources of indirect emissions associated with fossil fuel use:

1. Induced land development.
2. Military involvement.
3. Accidents.
4. Marginal effects, comprising effects on fossil fuel sources, effects on operation of refineries, and effects on electricity generation.
5. Price effects, including indirect fuel use change, sometimes referred to as the fossil rebound.
6. Export of co-products to other markets.

The CA-LCFS indirect effects working group, which was convened during 2010, had a subgroup dealing with the Indirect Effects of Other Fuels (IEOF). This group identified a longer list of potential indirect effects, including:

1. Hydrogen production.
2. Coke and other co-product accounting.
3. Replacing steel with aluminum in vehicles.
4. Spills.
5. Future changes in the carbon intensity of the California crude mix.
6. Expansion of marginal oil sources, including tar sands, coal-to-liquids (CtL), and gas-to-liquids (GtL).
7. Changes in carbon intensity of refining.
8. Oil field fires.[1]
9. Road based deforestation.[2]
10. Tar sands deforestation.[3]
11. Protection of oil supply.[4]
12. Iraq reconstruction.[5]
13. Macroeconomic effects.[6]

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[1] Identified in a 2009 report by Life Cycle Associates for the New Fuels Alliance.

[2] Ibid.

[3] Ibid.

[4] Ibid.

[5] Ibid.

[6] Ibid.

In this report, informed by these previous studies, we consider the following categories of indirect effects:

1. Induced land development, including road based and oil sand based deforestation.
2. Military involvement.
3. Carbon intensity of the marginal oil, including potential for expanded unconventional fossil fuel production.
4. Accidents, including oil spills and oil fires.
5. Co-products and the carbon intensity of refining.
6. Price effects.

We consider these categories to cover all effects listed above, with the exception of replacing steel with aluminum in vehicles. This effect was not included in the final report of the CA-LCFS IEOF subgroup, and we do not consider the use of biofuels to be a major driver of light weighting in the vehicle fleet. Each of the above indirect effects is discussed in turn below.

3. INDUCED LAND DEVELOPMENT, INCLUDING ROAD BASED AND OIL SAND BASED DEFORESTATION

3.1. ROAD-INDUCED LAND USE CHANGE

Unnasch et al. (2009), quoting NASA's Earth Observatory website (2008), note that:

> *Logging, both legal and illegal, often follows road expansion (and in some cases is the reason for the road expansion). When loggers have harvested an area's valuable timber, they move on. The roads and the logged areas become a magnet for settlers — farmers and ranchers who slash and burn the remaining forest for cropland or cattle pasture, completing the deforestation chain that began with road building.*

Given this reported linkage between road building and deforestation, it has been suggested that oilfield development in the Amazon and similar high-conservation-value environments could be a driver of significant carbon emissions from deforestation in the land corridors surrounding oilfield access roads. The reported link between road infrastructure development and deforestation is likely real, but it is more difficult to establish precisely to what extent the development of oilfields drives additional forest loss, as opposed to affecting merely the location of forest loss. Wunder (1997) notes that "one could ... question the additional deforestation impact of the oil boom: Maybe road construction directed settlers to specific areas, but in counterfactual terms, the same amount of deforestation might have occurred elsewhere, even without oil production." It is exceedingly difficult to develop a robust counterfactual for where and to what extent deforestation may have occurred without oilfield-related road development.

Unnasch et al. attempt to bookend the potential magnitude of indirect emissions associated with road-induced increases in deforestation by undertaking a simple calculation for the case of Ecuador. In their example, using data from Viña et al. (2004), they consider the assumption that all emissions from deforestation within 5 km of petroleum exploration induced road building can be attributed to petroleum exploration. For Ecuadorian oil production, they find this would imply 0.6 to 1 gCO_2e/MJ of ILUC emissions depending on the chosen amortization period (0.6 roughly corresponds to a 30-year amortization for 20 years).

There are many alternative assumptions that would alter this result. The most significant possible change that would increase the calculated emissions would be to attribute a larger amount of deforestation to oil roads — say 10 km, 20 km or more from the roads in question. On the other hand, there are alternate assumptions that would reduce the emissions attributed. Most importantly, it is unclear what fraction of road-linked deforestation is additional to what would have occurred anyway. If, say, only a third of road-linked deforestation is additional and the rest could be treated as simply moved, that would imply a lower carbon emission. One could also reduce the distance from the oil roads within which deforestation is attributed — Viña et al. provide assessment at 1, 2 and 5 km — or assume that only a fraction of the deforestation within the chosen corridor was induced by road building. Combining an assumption that only half of deforestation is induced by the presence of the road with an assumption that only a third of this induced deforestation was additional would reduce the implied carbon emissions by a factor of six, for instance. We believe it is reasonable to treat the value calculated by Unnasch et al. as an upper bound on the emissions that should be attributed to Ecuadorian oil production.

ICF International (2013) follows the lead of Unnasch et al. in assessing this source, concluding that "the emissions from induced land development from fossil fuels are therefore much smaller than ILUC from biofuels; this estimate [from Unnasch et al.] is 1/24th to 1/110th of the estimated ILUC from biofuel feedstocks."

The CI value range presented by Unnasch et al. provides an order of magnitude estimate for induced carbon emissions that could be assigned to Ecuadorian oil, but Ecuador is only a modest sized oil-producing nation, and contributes 556,000 barrels per day of petroleum, or about 0.6% of the global oil supply.[7] If one assumed that all global oil production is equally responsive to demand changes,[8] i.e., that Ecuador supplied 0.6% of any marginal increase in oil demand due to lower alternative fuel use, then induced land use changes in Ecuador would add less than 0.01 gCO_2e/MJ to the carbon intensity implications of using marginally more petroleum.

There may be other countries in which similar links exist between oil exploration and induced deforestation. Total oil production across major oil producing nations with significant tropical forests — Ecuador, Brazil, Venezuela, Mexico, Angola, Indonesia, Malaysia, Colombia, Vietnam, and Equatorial Guinea — comes to around 20% of global oil production. If these counstries all experienced induced deforestation at the same rate as the Unnasch et al. estimate for Ecuador, this would imply an emissions factor of up to 0.2 gCO_2e/MJ for the typical marginal increase in oil consumption. This is very much a high-end estimate. As noted above, the Ecuador figure is likely somewhat lower than the Unnasch et al. estimate; the reason that data was available for the Ecuadorean case is because it was considered a strong case of oil-industry induced deforestation; and a significant fraction of the oil production across those countries is not within rainforest areas. On that basis, we conclude that the actual total carbon implication of road-induced deforestation is almost certainly no more than 0.1 gCO_2e/MJ. This is between 100 and 1000 times lower than estimates of ILUC emissions associated with corn ethanol production.

We also note that alternative fuels may also in some cases be associated with new transport infrastructure development, and therefore may also have an induced deforestation impact. For example, Malins (2012) notes that in Indonesia and Malaysia road infrastructure develops around the growing palm oil industry, supporting further deforestation. It is not clear, and would be difficult to determine, whether the likely magnitude of transport-infrastructure related ILUC would be greater in gCO_2e/MJ terms for alternative fuels or for petroleum fuels.

3.2. LAND USE EMISSIONS ASSOCIATED WITH THE CANADIAN TAR SANDS

Petroleum production from the Canadian tar sands constitutes a growing share of the global petroleum supply, but its unique extraction process poses the potential for additional GHG emissions from land disturbance. Unnasch et al. note that not only is tropical deforestation associable with oil production, but boreal forest loss in Canada is being caused by expansion of tar sands oil production, both directly and indirectly through associated forest fragmentation due to infrastructure development.

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[7] http://www.eia.gov/beta/international/analysis.cfm?iso=ECU

[8] This assumption may of course not be valid, but we are not aware of any reason to believe that Ecuadorian supply is particularly sensitive to U.S. gasoline demand compared to the average. Issues around identifying marginal oils are discussed in Chapter 5.

The destruction of boreal forest due to tar sands surface mining, or alternately in situ processing of tar sands, can result in immediate emissions from biomass and soil carbon losses, as well as ongoing emissions from foregone sequestration and methane emissions from tailings ponds. Yeh et al. (2010) estimate the sum of these emissions to be as high as 0.83 to 10.24 gCO_2e/MJ of refinery feedstock for tar sands recovered via surface mining, and 0 to 0.23 gCO_2e/MJ for tar sands recovered via in situ extraction. A more recent assessment by Cai et al. (2015) provides a narrower range of land use disturbance emissions, estimating lifetime production-weighted emissions of 1.87 to 1.90 gCO_2e/MJ for surface mining and 0.56 to 0.89 gCO_2e/MJ for in situ extraction. Separately, Cai et al. estimate fugitive CO_2 and methane emissions from tailing ponds to add 0.9 to 1.1 gCO_2e/MJ for surface mining, whereas in situ extraction generates from 0 to 4.5 gCO_2e/MJ, depending on whether bitumen or synthetic crude oil is stored in batteries.[9]

While both surface mining and in situ processing directly disturb land, they also influence land disturbance outside of their direct project footprint by way of seismic lines, roads, pipelines, and power lines. Jordaan, Keith and Stelfox (2009) estimate that once these factors are taken into consideration, the total land disturbance associated with in situ technology is comparable to surface mining. Land use change emissions from this type of infrastructure development used for tar sands mining should be considered direct emissions. Induced carbon losses due to fragmentation (the process by which a large forest is separated into a series of smaller patches from roads, etc.) could correctly be considered as indirect emissions, but we are not aware of any serious attempt to quantify such losses.

Furthermore, parts of the Western Canadian Sedimentary Basin (WCSB) are located on top of peat deposits, which are more carbon-dense than forest land. Open-pit mining releases the collected carbon in peat deposits as well as causing foregone sequestration. Rooney, Bayley, and Schindler (2011) estimate that land use change emissions from projects on Canadian peatlands that were approved at the time of writing will release 11.4 to 47.3 million metric tons of stored carbon and reduce the carbon sequestration potential of this land by about 6,000 to 7,000 metric tons of carbon per year.

The magnitude of land use change emissions from oil sand mining is very significant and should be included in life-cycle assessments. However, most of these emissions occur as a direct result of petroleum production. Direct emissions from land disturbance should be considered in the direct part of the fuel life cycle, and indeed are included as direct emissions in the Oil Production Greenhouse gas Emissions Estimator (OPGEE), and should thus not be considered as indirect effects under the scope of this paper.

3.3. CONCLUSION ON INDUCED LAND DEVELOPMENT

The CARB IEOF subgroup did not discuss these emissions in their final report, which could suggest that the subgroup also felt they could be treated as negligible. ICF (2013) concludes that "lack of available quantifiable data and no consensus on whether the global emissions will decrease or increase as a result of the induced land development implies that this emission source cannot be allocated to the fossil fuel life cycle." Unnasch et al. reach a slightly different conclusion, supported by the following argument:

> *Oil production activities associated with tropical forests result in GHG emissions that may be over 0.5 g/MJ … This GHG intensity is greater than many of the*

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[9] A battery in this case refers to a system of tanks and surface equipment to store and separate oil sands products.

> *emission sources calculated in the GREET model ... While the factors that contribute to GHG emissions are uncertain (soil carbon disturbance, fate of above ground biota, etc.), such emissions do, however, appear quantifiable and should be included in life cycle calculations.*

Overall we conclude that it is appropriate to treat ILUC emissions as negligible from the point of view of setting fossil fuel comparator carbon intensity values for alternative fuel support regulations. ILUC emissions are likely below 0.1 gCO_2e/MJ when averaged across the overall fuel supply. They may however be more significant and potentially up to the order of 0.5 gCO_2e/MJ, as suggested by Unnasch et al., when differentiating the carbon intensity of crude oil from different regions, as has been done with OPGEE for the CA-LCFS. Emissions of the order of 0.5 gCO_2e/MJ would be considered of enough significance for inclusion in the GREET or OPGEE models.

Direct land use change emissions associated with oil production are already included in OPGEE, and have been assessed for the Canadian tar sands in several reports. With additional evidence, it could be appropriate to consider adding emissions factors for induced deforestation to the life-cycle intensity calculated for specific crude oils, such as Ecuadorian crudes. Taking that step would, however, imply that infrastructure-induced emissions should also be assessed for alternative fuels. Any assessment of these emissions for either oil or alternative fuels will have a high level of associated uncertainty, even compared to recognized uncertainties in ILUC estimation, and is unlikely to make a fundamental change to the carbon intensity assigned to any given fuel. Thus we would not consider this a priority area for further research.

4. MILITARY INVOLVEMENT

Some commentators have argued that the carbon emissions resulting from U.S. military involvement in oil producing regions should be added to the carbon intensity assessed for petroleum fuels. The most detailed presentation of the argument is probably the one presented by Liska and Perrin in 2010 in the journal *Environment: Science and Policy for Sustainable Development.* Liska and Perrin argue that "military activity to protect international oil trade is a direct production component for importing foreign oil—as necessary for imports as are pipelines and supertankers — and therefore the greenhouse gas (GHG) emissions from that military activity are relevant to U.S. fuel policies related to climate change," and that "warships are to oil what combine harvesters are to biofuels."

Liska and Perrin consider two categories of military emissions that may be associable with the U.S. oil supply. The first are emissions resulting from general ongoing security operations in the Middle East. The second are emissions resulting from larger U.S. military interventions in the Middle East, notably the Iraq war. One could also assess emissions associated directly with the active protection of oil supply routes, for instance protection of tanker traffic around the Horn of Africa, but Liska and Perrin do not include an estimate for this more limited question.

The basic methodology used is to estimate expenditure associated with military activity in the Middle East, and assign carbon emissions to the expenditure proportionately from the overall carbon budget of the U.S. military. The central estimate of expenditure associated with oil supply protection ($84 billion) is taken from an average of values quoted by Delucchi and Murphy (2008), with lower and upper bound values of $27 billion and $73 billion; Copoulos (2007), with a central estimate of $138 billion; and Dancs, Orisich and Smith, (2007), whose central estimate is $97 billion. Note, however, that Delucchi and Murphy (2008) provide a rather lower value of $6 billion to $25 billion for the fraction of U.S. Gulf expenditure that can be attributed to the supply of U.S. motor fuels. Using these lower expenditure numbers would significantly reduce the emissions factors that would be calculated based on the Liska and Perrin methodology of assuming emissions are proportional to expenditure. Also note that the Copoulos value includes some fraction of Iraq war expenditure, and therefore Liska and Perrin may be implicitly double counting Iraq war emissions in some of their estimates. Liska and Perrin do, however, emphasize the 2007 paper by Dancs, Orisich and Smith as the most recent and preferred source.

The resulting emissions factors are shown in Table 4.1.

Table 4.1 Emissions factors from military involvement presented in Liska and Perrin (2009)

	OIL SECURITY, ATTRIBUTIONAL (gCO_2e/MJ)	OIL SECURITY, CONSEQUENTIAL (gCO_2e/MJ)	IRAQ WAR, ATTRIBUTIONAL (gCO_2e/MJ)	TOTAL, ATTRIBUTIONAL (gCO_2e/MJ)
Divided across U.S. imports of Gulf gasoline	8.1	17.5	10.1	18.2
Divided across all U.S. gasoline use	0.9	2.0	1.2	2.1

The emissions factors identified as attributional by Liska and Perrin in Table 4.1 are assessed on the basis of assessing total military emissions associated with U.S. oil supplies, and assigning these proportionately across petroleum products. That results in 46% of the emissions being allocated to gasoline. The second column presents an alternative consequential viewpoint. For the consequential assessment, it is argued that eliminating U.S. imports of Gulf oil would allow total cessation of U.S. security presence in the Middle East. In connection with this, Liska and Perrin note that total mandated corn ethanol supply under the Energy Independence and Security Act of 2007 (EISA) would be almost adequate to displace all gasoline derived from Gulf oil imports. The consequential value is larger because all Middle East related military carbon emissions are then allocated to gasoline.

While this larger value is presented as consequential, the narrative developed to justify full allocation of these emissions on a consequential basis is unconvincing for several reasons and cannot be compared to the consequential logic applied in the allocation of ILUC emissions to biofuels. Most importantly, it is manifestly naïve to suggest that eliminating direct imports of Gulf oil would necessarily result in, or allow, total U.S. military disengagement from the Middle East. As noted by Leiby (2012), the oil market is global and connected, and simply avoiding direct oil imports from regions considered to have security challenges would not be enough to insulate the U.S. from the negative impact of potential supply disruptions and oil price shocks. Indeed, for moderate reductions in U.S. gasoline consumption it is not clear that one should expect any marginal change in U.S. force projection in oil producing regions. One could therefore argue with at least equal narrative force that the correct consequential assumption would be to allocate no military emissions reduction to a marginal reduction of petroleum demand. Liska and Perrin present this alternative narrative themselves: “It can also be argued that imports might be reduced by only 50% instead of completely, and in that case we would expect little if any reduction in oil security activity, given that no less effort may be required to provide safe passage for half of current ships compared to all of them.”

Unnasch et al. present an alternative allocation of military emissions to oil protection. For this estimate, they assume that 50% of total U.S. military fuel use in the period 2001-2006 can be attributed to protection of oil supply, and allocated those emissions across all transportation fuel used in the U.S. in the same period. On that basis, they assess an emissions factor of 1.6 gCO_2e/MJ. Allocating these emissions only to Persian Gulf imports would put an emissions factor of 7.1 gCO_2e/MJ on those imports. This estimate assigns emissions including large emissions associated with the Iraq war to U.S. transport fuel use. A further 0.3 gCO_2e/MJ on U.S. transport fuels and 1.4 gCO_2e/MJ on Persian Gulf imports are calculated for the emissions implication of Kuwaiti oil fires after the first Gulf war.

In considering the results from both studies, ICF International (2013) notes that Liska and Perrin’s emissions factors are predicated on allocating emissions only to U.S. fuel use. The same would be true of Unnasch et al. Allocating military emissions across all global Gulf oil exports would reduce the emissions factor for Gulf oil by 86%. On the question of whether emissions factors related to military engagement should be included in the European Fuel Quality Directive, ICF concludes that “the link between military involvement and petroleum production cannot be objectively measured and it is uncertain to what degree military emissions should be attributed to the fossil fuel life cycle,” and therefore that, “it is our opinion that the linkages between military activities and fossil fuel life-cycle emissions are suitably tenuous that they can be excluded from the life-cycle boundary.”

4.1. CONFLICT EMISSIONS AND THE IRAQ WAR

Several of the sources presented in the preceding section discuss the possibility of allocating emissions from the Iraq war or other conflicts to the oil supply. As shown in Table 4.1, this could provide an additional emissions factor comparable to the highest estimates for the emissions factor from general military engagement in oil supply security. Allocating emissions associated with the Iraq war to the oil supply is contentious for several reasons. The publicly given reason for the invasion of Iraq was that Iraq was believed to be developing weapons of mass destruction. It is well beyond the scope of this paper to attempt an analysis of the reasons for the Iraq war, but there remains no consensus on the extent to which guaranteeing the oil supply was a primary reason for the invasion, as opposed to regional security, U.S. domestic security and enhancing U.S. access to oil revenues.

In considering whether it is appropriate to allocate these types of emissions to the petroleum supply, it may be useful to make a comparison with the assumptions underlying the analysis of ILUC from biofuel production. As discussed by Malins et al. (2014), it is logically necessary that biofuel feedstock comes from somewhere in the agricultural economy, and in the long term this must be through some combination of increased overall productivity, reduced consumption in other sectors and expansion of the agricultural land base. ILUC analysis proceeds through economic models that assess scenarios for the possible balance of these factors when there is a marginal increase in biofuel demand. In contrast, it is not at all logically necessary that the U.S. should engage in more or less conflict if there is a marginal change in oil demand. Currently, biofuel supply in the U.S. accounts for approximately 10% of the overall U.S. transport fuel supply. The U.S. remains heavily exposed to the oil market despite aggressive expansion of biofuel use. Even if biofuel use were doubled or tripled, it would remain heavily exposed to the oil market. There is good reason to believe that U.S. military engagement is contextualized by demand for oil for motor fuels, but it is much more difficult to argue convincingly that a marginal change in motor fuel demand on the sort of scale that can be delivered by current alternative fuels would alter patterns of U.S. activity in any way.

Finally, we note that it has been argued that food and water insecurity are and will continue to be important factors in driving conflict. Brinkman and Hendrix (2011) argue that “food insecurity — especially when caused by a rise in food prices — is a threat and impact multiplier for violent conflict.” Monshipouri (2015) argues that “long-term solutions with regard to the Tigris and Euphrates rivers are indispensable to any peace plan involving those within the two-river system, given their central location in the wider region and the current volatility of Iraq.” Given that there is considerable evidence that increasing biofuel demand can increase food insecurity (Malins et al., 2014), and a smaller but growing body of discussion on the potential for biofuel production to increase water stress (e.g., Varghese, 2007), it would be reasonable to conclude that if military emissions should be allocated to oil production, there would also be a need to allocate military emissions to biofuel production.

4.2. CONCLUSIONS ON EMISSIONS FROM MILITARY INVOLVEMENT

Liska and Perrin as well as Unnasch et al. conclude that if military emissions they consider to be associated with oil supply security are allocated across all U.S. transport fuel use, the resulting emissions adder would be up to 2 gCO_2e/MJ. Both of these studies make extremely strong assumptions in proposing to allocate military emissions to the oil supply as an indirect emission source. In particular, neither presents a convincing case that a marginal change in oil use in the U.S. would lead to a reduction in military carbon emissions of this scale. Rescaling the Liska and Perrin result to reflect the amount of U.S. military expenditure Delucchi and Murphy attribute directly to U.S. transport fuels and excluding Iraq war emissions would result in an emissions factor of about 0.15 gCO_2e/MJ.

At the level of 0.15 to 2 gCO_2e/MJ, adding military emissions to the fossil fuel baseline CI under an alternative fuel support regulation would have very little impact on compliance choices or the value delivered by any given alternative fuel. Estimates of ILUC associated with corn ethanol are generally 5 to 50 times higher than even the top of this range. Arguably, the appropriate consequential allocation of military emissions to a marginal change in oil use is zero when considered on the scale of existing biofuel programs.

It is analytically challenging to make a convincing estimate of these emissions; there is great uncertainty in the correct value; and these emissions have a relatively small impact on the overall life cycle for even the highest estimates when allocated across all U.S. transport fuel use. A reasonable case can be made that if fossil fuels are to have military emissions assessed against them then a similar assessment should in the future be made for biofuel use. We therefore believe that it is reasonable and appropriate for military emissions to be ignored in the assessment of fossil fuel comparators for alternative fuel regulations.

This conclusion matches the conclusions in ICF International (2013), which states “the methodologies examined for estimating and attributing GHG emissions are subject to a large number of arbitrary assumptions that greatly influence the results, … do not demonstrate a convincing method for evaluating GHG emissions, … [and do not] provide sufficient evidence of a valid link between military activities and fossil fuel production.” It is likely that military emissions terms would be more significant if applied against only one crude oil source, as for instance in the differentiated carbon intensity assessment of marketable crude oil names undertaken by CARB under CA-LCFS, but we note that it would almost certainly be highly contentious under international trade norms to penalize oil from a given exporting country to account for U.S. military activity in any given region.

5. CARBON INTENSITY OF THE MARGINAL OIL, INCLUDING POTENTIAL FOR EXPANDED UNCONVENTIONAL FOSSIL FUEL PRODUCTION

Existing alternative fuel supply regulations that use fossil fuel comparator values in all cases seek to estimate a typical baseline or average life cycle carbon intensity value. The implicit assumption made in assessing carbon savings is that every additional megajoule of alternative fuel supply displaces a megajoule of supply of fossil fuel at this typical carbon intensity, and the carbon saving calculation follows simply from that assumption. There is reason to believe that the assumption that one megajoule of alternative fuel use displaces precisely one megajoule of fossil fuels is not always correct, and this is discussed further in Chapter 8. It may also not be true that the fossil fuel displaced by an increasing alternative fuel supply has the average carbon intensity of all fossil fuel supplied, in which case there is a case to use a marginal fossil fuel carbon intensity value for the baseline, rather than an average value.

In general, one would expect that as oil demand decreases, the supply of the oils that are the most expensive to produce would tend to reduce first. If at least some of the most expensive to produce oils are also more energy intensive to produce (such as tar sands oil), then the marginal barrel of oil may have a higher carbon intensity than the average barrel.

In a 2010 study by Pieprzyck and Kortlüke, Engineered Research Architecture (ERA) considers the question of marginal oil displacement for the Verband der Deutschen Biokraftstoffindustrie e.V. (VDB, the German biofuel industry association). They argue that in the short term reduced oil demand will not necessarily cause cessation of production of more expensive oils. This is first because oil supply is affected by political decision making, notably by the Organization of the Petroleum Exporting Countries (OPEC), which considers factors other than costs. ERA notes that “in September 2008 the OPEC reduced their quota by over 3 million barrel/day, while non-OPEC production [including tar sands oil] remained on a constant level.” Second, much of the cost of some of the more expensive oil options is upfront investment cost. Once projects are underway, there is an incentive to continue producing oil to recoup those investment costs, even if margins become relatively low. ERA argues that “the most expensive oil (such as tar sands or deep water oil) will continually be produced as long as the retail price is higher than the production costs.” In the short term, therefore, ERA would expect the oil resources that would be left unexploited due to increased alternative fuel supply would have fairly typical carbon intensities. In the longer term, however, ERA argues that “biofuel objectives … especially endanger yields of very expensive and risky marginal sources, causing international oil companies to invest less in these technologies.” De Buck et al. (2013) have similarly argued that investment in tar sands oil resources will be sensitive to oil price.

The CA-LCFS IEOF subgroup considered this issue, and the final report (ARB, 2010) carries two diverging perspectives on the subject. The first opinion suggests that unconventional oil resources are both more expensive to produce than conventional resources and tend to have higher carbon intensity. This opinion echoes the ERA conclusion that while cuts by OPEC may be the dominant short term response to reduced oil demand, higher production cost projects are likely to be marginal in the longer term: “In the short term and on a macro scale, crude oil extraction is mainly influenced by OPEC production cuts," but, "the influence of OPEC productions cuts will fall in the medium- and long- term."

ERA presents an alternative narrative to this on the carbon intensity of marginal oil, concluding "the comparison of the greenhouse gas balances of various fossil fuels with their production costs shows that there is no direct correlation between the level of greenhouse gas emissions and production costs." ERA argues, therefore, that "the most expensive crude oil is only the dirtiest oil when costs are completely internalized." This reflects the results of life-cycle analysis studies of oil production, such as Energy-Redefined (2010) and Malins et al. (2014), which show that there is considerable variation in the carbon intensity even of conventional oil production pathways.

The first perspective from the sub-group does not come to any conclusion with regard to the likely magnitude of a difference in CI between the average and marginal oil supply, but believes it is something that should be examined further. "California should initiate research investigating the marginal barrel of crude oil and its effects vis-a-vis alternative fuel use," the authors write.

The second perspective from the sub-group focuses on the time frame in question for the CA-LCFS. This perspective argues that "the time frame we are considering is very important … The short-term is 5 to 10 years in the future, which is the time horizon of the LCFS implementation. Thus, significant changes to the crude slate … are very unlikely to be observed in the next 10 years and potentially longer." This perspective echoes again the expectation that short-term production changes will come from OPEC quotas. It concludes that "the LCA conducted for the LCFS should continue to use an average value to represent the carbon intensity of crude." Unnasch et al. also consider this question, with conclusions similar to the first perspective from the sub-group.

It is important to note that all of the analysis discussed above was undertaken before the significant drop in oil price that has happened since August 2014. Unlike the changes to OPEC production quotas in 2008 discussed by ERA, the last year has been notable for a muted reaction by OPEC to a changing supply-demand balance, with changes in production occurring largely in North America. Canada's *Globe and Mail* reported in February 2015[10] that:

> *"The Organization of Petroleum Exporting Countries is declaring an early victory in its battle for global oil markets, saying low prices will cut non-OPEC supply growth by a third this year while boosting demand.*
>
> *OPEC said Monday that it now expects non-cartel countries to increase production by 850,000 barrels a day in 2015, down from its previous forecast of 1.27-million b/d. It slashed its outlook for U.S. supply growth by 130,000 barrels per day, and for Canada, by 20,000 b/d, saying falling capital investment and idled drilling rigs will bite into planned production increases."*

This change in OPEC's policy on how to respond to demand changes suggests that the assumption that OPEC supply will be more responsive to demand in the short term may no longer be true. Arguably the strongest response to price in the last year has come from the U.S. shale oil industry, as noted in the quote above, with some response also

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[10] http://www.theglobeandmail.com/report-on-business/industry-news/energy-and-resources/opec-trims-outlook-for-canadas-oil-production-in-2015/article22856507/

seen in tar sands production. These changing OPEC policies have implications for the marginal oil, but also for the fossil rebound effect (cf. section 8.1). The experience of the past year confirms that political decisions are a key determinant of which oils respond to marginal changes in demand.

ICF summarizes the ERA, IEOF sub-group and Unnasch et al. reports as follows:

> *"The reports conclude that the marginal fossil fuel resource consumed will depend on the time horizon and will be influenced by a number of factors including cost, OPEC production limits, national energy policies, and other factors."*

ICF concludes that "the information currently available on marginal changes in the fossil fuel resource consumed is insufficient to include these effects as an indirect emissions source in the scope of the FQD," and that "there are … a number of uncertainties that would influence the direction of this effect."

Cai et al. (2015) find that the most carbon intensive tar sands fuel production pathways currently in significant use are about 20 gCO_2e/MJ more carbon intensive than an average value for conventionally produced fossil fuels. The least carbon intensive processes are up to about 10 gCO_2e/MJ less carbon intensive than an average value. Even if fully half of the marginal oil supply were from in situ tar sands projects, this would imply that the marginal carbon intensity of the fossil fuel supply could be about 10 gCO_2e/MJ higher than an average value. However, it is likely that the true marginal oil basket is much more varied. For instance, OPEC in the quote above expects only 13% of the change in North American oil production in 2015 to occur in Canada.

5.1. CONCLUSIONS ON CARBON INTENSITY OF THE MARGINAL OIL

The following broad conclusions can be taken from the reports that have looked at this question in the past:

1. In the short term, alternative fuels are at least as likely to cause changes in OPEC production levels, and therefore displace conventional oil, as to reduce production of high cost oils. However, in the past year it is noteworthy that OPEC production has not replied strongly to price changes.
2. In the long term, reduced oil demand is likely to start reducing investment in higher cost projects.
3. There is variation in the carbon intensity of high cost oil production pathways, but it is likely that in general these will tend to have a higher carbon intensity than the current average mix of crude oils.
4. There is no clear existing basis to quantitatively estimate the carbon intensity of the marginal crude oil production source, but it is a question that could be analytically addressed in principle.

None of the previous reports reviewed here provide a compelling and conclusive case that higher carbon intensity oils (the Canadian tar sands are often invoked as an example) will be preferentially displaced by alternative fuels as compared to conventional oils. In the longer term, it may be that further analysis of market responses to recent changes in oil prices will shine additional light on the balance of responses between OPEC production, non-OPEC conventional production and unconventional production from sources such as the tar sands or fracking shale oil. If future analyses provide a clearer basis for predicting which oil production, and which oil investments, will be most affected by increasing alternative fuel supply, it may become appropriate to adopt fossil fuel baseline values based on the carbon intensities of these marginal oils. Based on the evidence currently available, however, we believe that using a baseline or average carbon intensity for the carbon intensity of oil production remains appropriate for alternative fuel regulations using fossil fuel comparators.

6. ACCIDENTS, INCLUDING OIL SPILLS AND OIL FIRES

Accidents in the oil industry generate GHG emissions in several ways that are typically outside the scope and boundaries of most life-cycle analyses. Accidents result in GHG emissions through the following pathways:

- Oil spills
  - CO_2 emitted from surface burning
  - Upstream emissions from production of additional oil to replace spilled oil
  - Emissions of non-CO_2 short-lived climate pollutants (SLCPs) from surface burning, most importantly black carbon
  - Emissions from cleanup operations
- Oil fires at wells and tanks
  - CO_2 emitted from combustion of the oil
  - Emissions of non-CO_2 SLCPs (e.g., black carbon) from combustion

Some oil is also lost from small spills when fueling vehicles from fuel dispensers. As ICF International (2013) argues, this is a type of “engineered loss” like fugitive emissions in natural gas systems that should be included as direct emissions in life cycle modeling. A value of 0.002 gCO_2e/MJ is indeed included in the GREET model for this source (Unnasch et al., 2009). Thus, we consider vehicle-fueling spills as outside the scope of this paper.

ICF estimated CO_2 emissions from global marine oil spills and concluded that on a per megajoule basis, these emissions are so low as to be negligible from the point of view of setting baseline fossil fuel emissions intensity (ICF International, 2013). Others have estimated GHG emission for specific oil spills; for example, Ryerson et al. (2011) estimated emissions from the Deepwater Horizon oil spill in 2010. We are not aware of any studies apart from ICF International (2013) that have attempted to quantify GHG emissions from accidents on a global scale. This is likely because when spills and fires occur the focus is on other environmental impacts. For oil spills on land and at sea, the main environmental concerns are the toxicity of the oil on animals and other living organisms and the health impacts of air pollution. The major concerns for oil well fires are the health impacts of air pollution and economic impacts from loss of the oil and from damage to oil well structures and equipment.

Below, we estimate and discuss GHG emissions from oil spills and oil well fires given available information.

6.1. CO_2 EMISSIONS FROM OIL SPILLS

Spills can occur at any point in the transportation or storage of petroleum. ICF International (2013) cites data from a 2007 study by TIAX to show that the largest source of spills is from marine vessels. TIAX compile data on the quantities of oil spilled by year, but only from 1973 to 2000; this data is not recent enough to use in estimating emissions from oil spills, especially as the quantity of oil spilled has declined dramatically from the 1970s to the present. ICF therefore uses recent data from the International Tanker Owners Pollution Federation (ITOPF) on the quantities of accidental oil spills from marine vessels in each year to estimate emissions.

Here, we update the ICF calculations estimating the GHG emissions from oil spills from marine vessels over the period 2000-2012. When oil is spilled at sea, a fraction is generally combusted by surface burning of the oil — this was around 5% for the Deepwater Horizon oil spill of 2010 (Perring et al., 2011). Some spilled oil decomposes biologically through oil-consuming microorganisms. It is unclear whether any, and how much, carbon remains sequestered in spilled oil over the long term. For a simplified assessment, this section estimates the amount of CO_2e that would be emitted if all of the spilled oil were combusted, or equivalently if it fully decomposed to CO_2. The next section discusses black carbon emissions specifically from surface burning.

Using data from ITOPF, ICF calculates that 1,671,240 barrels of oil were spilled from marine vessels over the period from 2000-2012. Over this period, the US Energy Information Administration reports 398 billion barrels of oil were supplied to all countries globally. Thus, approximately 0.0004% of the global oil supply was lost in accidental oil spills from marine vessels in that time frame. The additional combustion of this spilled oil would then add about 0.0004% to the carbon intensity of all oil supplied globally. Using a carbon intensity of 74.88 gCO_2e/MJ for the combustion of gasoline and diesel from EPA (2010), the additional GHG emissions from oil spills averaged out over the global oil supply comes out to around 0.0003 gCO_2e/MJ.

ICF also estimates the upstream emissions resulting from the production of the petroleum that would be needed to replace the spilled oil. Using the estimate of 11 gCO_2e/MJ for upstream emissions of petroleum production referenced in ICF International (2013), and the same logic as the above calculation for combustion of spilled oil, this 11 gCO_2e/MJ estimate for upstream emissions applies to 0.0004% of global oil supply, resulting in 0.00005 gCO_2e/MJ over the period 2000-2012.

These estimations only consider spills from marine vessels and do not include emissions from the combustion and replacement of oil spills occurring at other points along the oil transportation and storage chain. We have not found available data on the proportion of global oil spills that are from marine vessels over the period 2000-2012, but following the data for 1973-2000 by TIAX shown in ICF International (2013), we estimate that marine vessels spills account for very roughly half of all oil spills. We can thus double the estimates above to account for all other oil spills to 0.0006 and 0.00009 gCO_2e/MJ for combustion and upstream emissions, respectively.

6.2. BLACK CARBON EMISSIONS FROM OIL SPILLS

Surface burning of oil can result in high emissions of black carbon, a short-lived pollutant that acts as a strong climate forcer while residing in the atmosphere for several days to weeks. Black carbon typically is emitted through the incomplete combustion of fossil fuels or biomass, such as the surface burning of crude oil spills or forest fires. Black carbon emission from surface burning is not reflected in EPA's carbon intensity for diesel and gasoline[11] used in the above calculations, so here we estimate the climate impact in gCO_2e/MJ of black carbon separately.

Perring et al. (2011) estimate the quantity of black carbon produced from the Deepwater Horizon oil spill in 2010 from aircraft measurements of a plume during a surface burning event. Their estimate is 1,350 metric tons black carbon emitted from all surface burning

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[11] Some black carbon is emitted in the combustion of diesel and gasoline, but this is likely far less per megajoule of fuel than is emitted from surface burning of unrefined petroleum, so is ignored in these calculations.

from this spill. We assume the same rates of surface burning (5% of all spilled oil) and black carbon production for all accidental oil spills from marine vessels as for the Deepwater Horizon spill for this calculation. Approximately 4.9 million barrels of oil were released during this spill (USCG, 2011), which is around three times the amount spilled by marine vessels from 2000-2012. We note that the Deepwater Horizon spill is not included in the quantity spilled by marine vessels and represents an unusually large spill. Spills of this size do not occur in most years. Thus, total black carbon emissions from marine vessel spills from 2000-2012 are estimated at around 460 metric tons.

For reasons described above, the global warming potential (GWP) for black carbon can be uncertain, with the literature estimating a range of 330 to 2,240 on a 100-year timescale (U.S. EPA 2012). Using a mid-range estimate of global warming potential for black carbon of 900 (Bond et al., 2013), this comes out to around 414,000 metric tons CO_2e. Averaged over the global oil supply from 2000-2012, black carbon emissions from marine vessel spills would be around 0.0002 gCO_2e/MJ. Making the same assumption as above that this accounts for approximately half of all oil spills, we estimate the global warming impact of black carbon from all oil spills to be around 0.0004 gCO_2e/MJ.

6.3. EMISSIONS FROM CLEANUP OPERATIONS

We have not found any estimates of emissions from operations to clean up oil spills. The amount of petroleum combusted for energy in the course of oil spill cleanup is, however, clearly significantly less than the quantity of oil spilled, and therefore it seems reasonable to treat these as negligible.

6.4. EMISSIONS FROM OIL FIRES

Another type of accident not traditionally included in life-cycle analysis is oil well fires. These events usually occur during conflict. The most famous case is that of oil field burning following Iraq's withdrawal from Kuwait in 1991. There were fires at hundreds of oil wells at this time (Spektor, 1998). More recently, there were fires at oil tanks at Libya's Es Sider port in 2014, where it has been reported that 1.8 million barrels of oil were lost (Reuters, 2014).

Fires at oil wells and tanks are much less common than oil spills, so it is very difficult to quantify emissions from these events as an average over time. If we assume that an event like that at Es Sider occurs once per decade, then $5x10^{-10}$% of all oil supplied globally is lost in such fires. According to EIA, 351 billion barrels of oil were supplied globally from 2005-2014. Making the same calculations for combustion, upstream emissions to replace the burnt oil, black carbon, and cleanup operations as above, this would result in around 1 billionth of 1 gCO_2e/MJ when averaged across global oil supply, which is negligible.

6.5. CONCLUSIONS ABOUT EMISSIONS FROM ACCIDENTS

We have roughly estimated emissions of CO_2 and black carbon from the surface burning, other decomposition, and cleanup operations from oil spills and combustion and cleanup from fires at oil wells and storage tanks, and have compared this to the global oil supply. These findings are summarized in Table 6.1.

Table 6.1. Estimated emissions attributable to oil spills and fires

EVENT	EMISSION SOURCE	TOTAL ANNUAL EMISSIONS (Thousand Metric tons CO_2e/Year)	EFFECT ON CARBON INTENSITY OF OIL (gCO_2e/MJ)
Oil spills	Combustion (representing surface burning and all other decomposition)	112	0.0006
	Upstream emissions from replacing oil	17	0.0001
	Black carbon from surface burning	32	0.0004
	Cleanup operations	0	0
Oil well and tank fires		0	0
Total		**161**	**0.002**

Total emissions from accidents are estimated at no more than 0.002 gCO_2e/MJ when averaged over the global oil supply. This is a rough estimate based on available information but indicates that emissions from accidents are extremely small and effectively negligible.

We note that accidents likely do occur for biofuels, with resulting emissions. The total magnitude of these emissions is likely much smaller than for petroleum, as biofuels tend to be consumed closer to where they are produced, are not generally produced in conflict zones, and generate lower black carbon emissions upon combustion. It would be appropriate to exclude emissions from accidents in life cycle assessments of both petroleum and biofuels.

7. CO-PRODUCTS AND THE CARBON INTENSITY OF REFINING

Just as existing regulations tend to assume that increased supply of alternative fuels displaces crude oil of average carbon intensity, so they tend to assume that the fuels displaced had average associated refinery emissions. While this may be a reasonable approximation, it is possible that marginal changes in fuel demand will have a smaller or larger effect on refinery emissions than the average value would suggest. One reason we might expect such disproportionate impact is that U.S. refineries tend to be optimized to produce more gasoline at the expense of producing less middle distillates, and this optimization has an associated cost in energy (see, for example, MathPro, 2013). Reducing gasoline demand may, therefore, allow U.S. refiners to run at improved energy efficiency. Taking these marginal effects into account in the U.S. would result in assigning a slightly higher carbon intensity default to gasoline displaced by alternative fuels and a slightly lower carbon intensity default to diesel displaced by alternative fuels.

Another issue, identified by Unnasch et al., is that changes in the quantity and type of oils being refined due to displacement could result in changes to the co-products generated by the refinery complex. Lower value co-products from oil refining include residual oils, which can be used for marine or stationery power applications, asphalt and petroleum coke. Co-products are already accounted for in the direct carbon intensity assigned to fossil fuel production, but the methodologies for doing this accounting vary. In particular, some methodologies apply through allocating emissions from the refinery process to different co-products, whereas others work through system expansion, in which there is an attempt to quantify the consequential implications of changing co-product supply. The various allocation approaches would fail to capture indirect effects from changing co-product availability through the global energy system. For example, if a reduction in petroleum coke supply led energy consumers to switch to natural gas, this could represent an emissions savings. On the other hand, a reduction in fuel oil supply could lead some energy consumers to switch to coal. Unnasch et al. note that,

> *"Assessing the market mitigated impacts of a reduction in residual oil and coke is a more complex question. The regional distribution of refinery co-products, their transport costs, and price elasticities would need to be taking into account. Complicating this analysis is the potential for fuel switching. A reduction in fuel oil for electric power generation could be met with a switch from oil to coal, natural gas or renewables. Efficiency improvements and conservation could also address a shortfall in fuel oil supply. Refineries could also adjust their mix of fuel oil output if prices rise."*

The CA-LCFS IEOF subgroup recommended that the impact of increased supply of co-products should not be considered an indirect effect but should be handled in the conventional LCA of fossil fuels by using the system expansion method (ARB, 2010). However, the GREET treatment of refining used to assess refinery emissions for the CA-LCFS currently uses allocation by process units, which could overlook some indirect impacts. Unnasch et al. conclude that "the fate of co-products should be addressed by assessing both their market mitigated impacts in order to estimate what energy resources are displaced and the effect of other economic factors." However, ICF finds there is inadequate data available to draw any conclusions on this subject: "There is currently a paucity of data available on changes in electricity generation that may result from increased demand for natural gas as a transportation fuel. The current level of information on this effect is insufficient to make a determination of the significance of its inclusion in the boundaries of the FQD." (ICF International, 2013)

Changes in energy efficiency due to changes to the product slate could be addressed through linear refinery modeling. MathPro (2013) assess the implications for refinery emissions of a 25% reduction in demand for jet fuel due to increased alternative jet fuel supply. The study finds an increase in the average carbon intensity of refining of 0.1 gCO_2e/MJ across all refined products. This is negligible in the context of setting a fossil fuel carbon intensity comparator, but if this increase in refinery emissions is attributed entirely to the reduction in jet fuel production it could represent an emissions factor of the order of 3 gCO_2e/MJ.[12] Based on that result, there may be a comparably sized but oppositely signed benefit associated with an increased ethanol supply reducing the demand for gasoline.

Marginal changes in refinery operation efficiencies result in indirect emissions on a lower order of magnitude than the emissions associated with ILUC from biofuels, but may still be large enough to warrant further consideration. The assessment of changes in refinery emissions also has the advantage of being a relatively well-defined analytical problem with existing tools able to provide quantified results, which distinguishes it from some of the other indirect effects discussed in this paper. On the other hand, a second perspective from the California IEOF sub-group argues that "refinery modeling is a complicated issue and it is unclear that existing analyses are appropriate for this purpose." It probably is fair to state that it is not possible to draw robust numerical conclusions from existing studies, but this would not preclude new analysis from being developed that would provide an acceptable answer. ICF concludes from its review of this topic that "in order to develop defensible and accurate estimates, refinery-specific modeling would be required to estimate how refineries would alter their product slate in response to changes in the supply of crude types and demand for refined products, and how these changes would affect the carbon-intensity of gasoline and diesel." (ICF International, 2013)

7.1. CONCLUSIONS ON REFINERY EMISSIONS AND CO-PRODUCTS

We agree with ICF that there is not currently any sound basis available to draw conclusions about whether alternative fuel driven changes in co-product output of the refining sector is more likely to reduce or increase global emissions, or to provide any strong estimate of the likely magnitude of such a credit/deficit. It is possible, though, to provide some rough bookends on the possible size of the effect by considering a simple calculation. MathPro (2013) reports petroleum coke as representing 840,000 barrels per day of U.S. refinery output in 2011, and residual fuel oil as 530,000 barrels per day, compared to about 13.3 million barrels per day of combined gasoline, diesel and jet fuel production. If a reduction in output of these co-products was replaced entirely by increased natural gas use, a 1 MJ reduction in refined product demand would be expected to translate roughly into a 3.5 gCO_2e/MJ emission credit. If, on the other hand, a reduction in output of these products was replaced entirely by increased coal use, a 1 MJ reduction in refined product demand would be expected to translate roughly into a 1 gCO_2e/MJ emission deficit. This frames the possible range of emission outcomes from changing co-product output. The true outcome is likely in between these. The best case

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[12] Note that the level of precision given by MathPro (2013) is insufficient to make this calculation with any accuracy, but the carbon intensity reduction implied is certainly in the range 1.5 – 6 gCO_2e/MJ.

scenario, in which all uses of residual oil and pet coke are replaced by natural gas use, would be a non-negligible term in the life cycle carbon intensity, but still substantially less than ILUC emissions estimated for most biofuels.

There is a stronger case for considering the marginal impact on refinery sector emissions of changes to the ratio of gasoline to diesel production, as there is strong reason to believe that substitution of gasoline will provide a small emissions credit, while substitution of middle distillates will result in a small emissions deficit. Again, while there is evidence that these terms will be non-negligible on the scale of the full life cycle carbon intensity — on the order of 3 gCO_2e/MJ based on MathPro (2013) — these indirect emissions are much smaller than most ILUC emissions estimates. Given this scale of emissions, the use of either average or marginal refining carbon intensity values for the fossil fuel comparator would be justifiable in the context of alternative fuel support policies.

8. PRICE EFFECTS

8.1. INDIRECT FUEL USE CHANGE

Changes in fuel consumption in one region can have market-mediated effects on global fuel demand as a whole. The classic example is that of fuel efficiency improvements: as vehicles use less fuel per mile, fuel consumption decreases and as a result of the lower demand, fuel prices decrease. People take advantage of the drop in fuel prices to drive more than they used to, so the overall decrease in fuel consumption is lower than one would expect from the fuel efficiency improvements alone. This is known as the "rebound effect" or "indirect fuel use change."

Some believe indirect fuel use change should be included in life-cycle assessments for biofuel mandates. The logic is similar to the fuel efficiency example above: mandated biofuel consumption displaces some gasoline and diesel and as gasoline and diesel demand drops, the prices of these two commodities (and of oil as feedstock) drop, and this induces some additional consumption. Overall, most researchers agree that oil consumption will decline with biofuel mandates, but that the decrease in oil consumption will not be as large as the size of the biofuel mandate. While most analyses of indirect fuel use change treat it as an indirect effect of biofuel production, we include it here because the same effect could be understood as a result of reducing or increasing fossil fuel demand, as the mirror of increasing or reducing biofuel demand.

Carbon reduction policies that act through increasing fuel prices rather than mandating supply volumes, such as a carbon tax, would be expected to result in smaller indirect fuel use change effects. This is because the tax would increase the price of gasoline and diesel directly, offsetting and perhaps exceeding the price decrease driven by demand reduction. However a policy such as a carbon tax, which targets fossil fuel prices directly, may still have a slight market-mediated effect, as the drop in consumption in affected countries may trigger a drop in prices and "leakage" as untaxed countries increase their consumption.

The indirect fuel use change effect can be expressed as the increase in total global fuel consumption resulting from a biofuel mandate taken as a fraction of that biofuel mandate. For instance, without any rebound effect a biofuel policy that mandates 10% blending of biofuel in gasoline would decrease gasoline consumption by 10%. If the indirect fuel use change effect is 60%, the actual reduction in global petroleum consumption would be 10% x (1 - 60%) = 4%. The higher the indirect fuel use change effect for a biofuel mandate, the less the intended petroleum displacement is achieved.

Hochman, Rajagopal and Zilberman (2010) modeled the indirect fuel use change effect for global biofuel production in 2007. Averaged globally, biofuel was blended at a rate of 1.77%. They found this led to a decrease in international fuel prices of about 1.1%, and that the global amount of fuel consumed (including gasoline, diesel, and biofuels) increased by 1.5% to 1.6%. The increase in total fuel consumption was less than, but almost as large as, biofuel consumption. The indirect fuel use change effect in this study was thus estimated at around 87%. A 2011 paper by the same authors introduces a two-region model allowing differentiated responses in the region mandating biofuel consumption and the rest of the world. As an example they simulate a mandate for 7.5% blending of corn ethanol in gasoline in the U.S., supported by tax credits. The indirect fuel use change effect estimated is a reduction of 1% to 6% depending on elasticity assumptions. A more recent paper (Rajagopal and Plevin, 2013) models indirect fuel use change of different biofuel policy scenarios that differ in structure and treatment of ILUC accounting. Results from the six biofuel mandate scenarios estimate the indirect fuel use change effect at 20% to 50%.

Another paper (Chen and Khanna, 2012) compares the rebound effect of the U.S. Renewable Fuel Standard, California's Low Carbon Fuel Standard, and a carbon tax scenario. The estimated rebound effect in the gasoline market is highest for the RFS2 (51%) and slightly lower for the LCFS (47%), and negligible for the carbon tax scenario (due to the reasons given above). A later study by Smeets et al. (2014) presents a review of eight previous studies that addressed the rebound effect, and also presents new model results derived from the MAGNET general equilibrium model for the case of a European biofuel blend mandate. The central scenario of the six scenarios modeled is for a 10% European biofuel blend mandate. The authors find an overall rebound effect of between 17% and 34%, dependent on scenario.

Overall, these sources estimate the indirect fuel use change effect to be in the range of 0% to 90%. This effect could have a very large impact on the overall carbon intensity of biofuels if it were included in biofuel life-cycle assessments as the carbon savings from gasoline and diesel displacement could be reduced by a significant fraction. For very low carbon biofuels, such as cellulosic biofuel from wastes and residues that have been estimated to reduce GHG emissions by 100% or more compared to fossil fuels, accounting for indirect fuel use change would reduce the magnitude of GHG emission reductions, but the carbon savings would still be positive and meaningful. But for biofuels with relatively low carbon savings, for example corn ethanol, which is estimated to reduce GHG emissions by around 20% according to the RFS2 (EPA, 2010), accounting for indirect fuel use change could actually reverse the sign and make corn ethanol a net carbon emitter relative to fossil fuels.

Accounting for indirect fuel use change resulting from a biofuel mandate will have an opposite effect on well-to-wheel emissions from fuels, depending on whether it is allocated to biofuels or the fossil fuels they are intended to displace. Indirect fuel use change will tend to increase the life-cycle carbon intensity of biofuels. In contrast, if it is allocated instead to the life cycle of fossil fuels, it would instead result in a reduction in the life-cycle carbon intensity assessed for the fossil baseline.

Note that the modeled indirect fuel use change results in the literature discussed above assume rational economic actors seeking short-term profit maximization, but this is not always the case. For example, as discussed in Chapter 5, it is widely accepted that political imperatives affect oil supply decisions made by OPEC. Thus, how indirect fuel use change plays out in the real world cannot be predicted with certainty, and the economic model results should be interpreted in that context.

Similar sources of uncertainty and of non-economic decision making also add uncertainty to the analysis of the ILUC from biofuels. For instance, a 2009 report from the Food and Agriculture Organization of the United Nations discusses how some countries restricted food exports in order to isolate domestic food prices from the international market in response to the 2008 food price crisis, which would tend to reduce biofuel prices in those countries and marginally increase prices in others. Nevertheless, the position of OPEC as a pseudo-monopoly supplier is not reflected by any similarly powerful single actor in the food supply sector, and thus the uncertainty introduced in ILUC estimation by political action is likely less than that introduced in indirect fuel use change estimation.

8.2. MACROECONOMIC IMPACTS

Changes in the total production and consumption of energy in general, and petroleum in particular, can be expected to have broad economic impacts with resulting changes in global GHG emissions. For example, an increase in petroleum production in any particular location would support a certain number of direct and indirect jobs; a fraction of the persons employed might not otherwise have been employed; those persons would now have greater disposable income than otherwise and would increase their personal spending; this would support more economic activity and consumption of goods and services overall; this increase in consumption of goods and services would result in increased GHG emissions.

At the broader level, there is a general expectation that reduced energy prices will drive increased economic growth. The *Wall Street Journal*[13] reported that according to IMF director Christine Lagarde, "There will be winners and losers, but on a net-net basis, [falling oil price is] good news for the global economy." However, increased economic activity is normally associated with increased greenhouse gas emissions.

While this type of macroeconomic effect likely exists, assessing its magnitude and sign across the global economy would be an analytically challenging undertaking. We are not aware of any studies that have specifically assessed the change in GHG emissions that would result from macroeconomic impacts associated with a change in petroleum demand. Macroeconomic effects of policy change are an appropriate subject for policy analysis, but there is no history of including these types of emissions changes in regulatory life-cycle analysis, and we believe that that is a reasonable decision.

8.3. CONCLUSIONS ON PRICE EFFECTS

Indirect fuel use change and macroeconomic impacts may have significant effects on the life cycle GHG implications of marginal changes in petroleum and biofuel demand, and deserve further research. Nevertheless, as neither effect is typically included in life cycle assessments nor accounted for directly in existing fuel policies or regulations, and given the great uncertainty and analytical challenges associated with assessing these effects, we do not believe it would be appropriate to account for them in assessing the life-cycle carbon intensity of petroleum at this time.

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[13] http://www.wsj.com/articles/falling-oil-prices-spur-new-bets-on-global-economic-growth-1418001937

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