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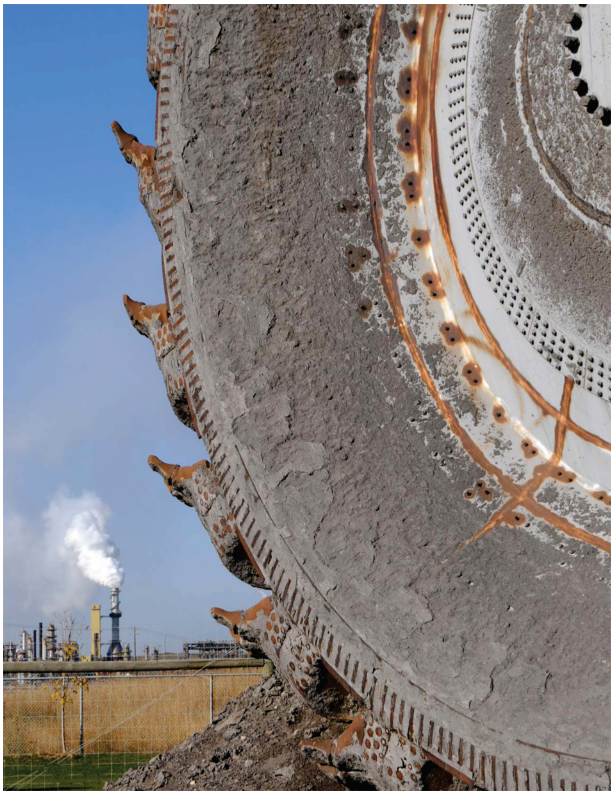
Feature

The Truth About Dirty Oil: Is CCS the Answer?

JOULE A. BERGERSON*
DAVID W. KEITH
University of Calgary, Alberta, Canada

Does carbon capture and sequestration (CCS) make sense in the oil sands?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The rapid expansion of oil sands production in northern Alberta is under scrutiny worldwide due to concerns about its environmental, social, and economic impacts. Environmental concerns include climate change impacts from CO_2 emissions along with more local environmental impacts such as dead birds, cancer clusters, and destruction of boreal forests. Within Canada, oil sands have become an important driver of economic growth, so producers and governments are under simultaneous pressure to reduce environmental impacts while maintaining their economic competitiveness (*1*–*5*).

The environmental footprint of oil sands production is hotly contested; here we aim to clarify divergent claims about CO_2 emissions by exploring how various choices about the scale of analysis (i.e., system boundaries) determine the emissions estimates, the technologies available to reduce emissions, and perspectives and strategies of stakeholders (Table 1). We pay particular attention to carbon capture and storage (CCS), showing how divergent views about its cost-effectiveness emerge from divergent choices about the scale of analysis.

Debate about the future of oil sands development is so contentious that even the name of the resource is disputed: proponents typically use *oil sands* while opponents use *tar sands*. We use *oil sands* not to express our views on the debate, but because *tar* is technically incorrect because tars are products of biomass combustion and are chemically distinct from bitumen. The source material is neither oil nor tar but bitumen, but is most generally described as an example of ultraheavy oil.

Current Oil Sands Operations, Greenhouse Gas Emissions, and Energy Use

Oil sands are a mixture of bitumen, sand, and water. Alberta's oil sands are second only to Saudi Arabia in terms of the size of oil reserves globally (*1*). The recovery, extraction, and processing of bitumen to products such as transportation fuels are energy intensive processes, using mostly natural gas and electricity, and consequently result in significant greenhouse gases (GHGs) emissions. Roughly 1.3 million barrels-per-day (bpd) of bitumen (~1.5% of world demand) is produced through two extraction techniques; surface mining and in situ recovery (*6, 7*). Surface mining (~55% of current production) is used in shallow oil sands reserves using open-pit mines where the bitumen is then extracted using hot water. In situ production (~45% of current production) from underground reservoirs uses both cold and thermal technologies to recover and extract the bitumen and move it to the surface (*7*). There is no clear environmental winner between in situ and mining methods. Per barrel of synthetic crude oil, mining projects typically have lower energy use and CO_2 emissions as well as better resource extraction efficiencies (i.e., less energy and resources per barrel of bitumen produced), whereas in situ projects have lower water use and a smaller direct land-use footprint, though if habitat fragmentation is counted their life cycle land use impacts may be greater (*8*).

Some sources claim that the oil sands are up to 5 times more emissions intensive than conventional oil, whereas others claim that they are 10% more intensive (*9, 10*). Both claims can be defended. The discrepancy arises from an artful choice of the scale of analysis (Table 1). The central source of confusion is whether or not the energy intensity and GHG emissions are measured from the well-to-tank (WTT) or over the full life cycle (well-to-wheels [WTW], from extraction of the resource through to the use of the fuel in a vehicle). About 60–80% of full life cycle emissions result from driving/operating the vehicle (*9*). So, if one looks only at the extraction emissions, takes a relatively high value for oil sands extraction, and compares it to extraction emissions from a relatively

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TABLE 1. Summary of CO_2 Emissions and Potential Mitigation Measures at Three Scales of Analysis

Scale of Analysis	CO_2 Emissions	Potential mitigation measures
Well-to-tank (WTT)	~2-3 times greater than conventional oil	Options discussed above plus: 1. vehicle efficiency 2. vehicle electrification 3. alternative fuels (e.g., biofuels)
Well-to-wheel (WTW)	~10-20% greater than conventional oil	1. vehicle efficiency 2. vehicle electrification 3. alternative fuels (e.g., biofuels)
Economy wide	WTW emissions are ~2% of Canadian and US emissions	1. electric sector (e.g., wind, nuclear, solar, fossil +CCS) 2. transportation sector - options discussed above (WTT and WTW) plus modal switching (e.g., to bus or rail) 3. buildings sector 4. conservation

low-emission conventional oil process one can say that oil sands emissions are a factor of 5 times worse than conventional oil. However, if one looks at the full life cycle and across the range of emissions from oil sands and conventional crudes, then it is also true that typical oil sands projects are only about 10−20% worse than conventional (*9*). There is wide variability in both cases. A recent study by our research group reviewed published literature and concluded that while the extraction energy intensity and GHG emissions associated with oil sands are typically higher than those of conventional production, “it is not inconceivable that an oil sands pathway may perform better than a conventional oil pathway, under certain circumstances” (*9*).

If the scale of analysis is that of the entire economy, the value commonly referenced for economy wide emissions is that oil sands constitute ~5% of Canada’s emissions (*11*) (which is roughly 0.1% of global emissions (*12*)). However, this estimate does not consider WTW emissions: it only accounts for the processing that occurs in Canada and therefore excludes much of the refining and transport emissions. Also, this estimate does not include the use of transportation fuels in vehicles, which occurs throughout North America (NA); approximately two-thirds of oil sands products end up in the U.S. (*13*). All told, the WTW emissions of oil sands products constitute roughly 2% of total emissions in Canada and the U.S.

The Environment Canada Reference Emissions Forecast has projected production increasing from 1.2 (in 2006) to 3.6 million bpd by 2020 with emissions increasing from 29 to 110 Mt-CO_2/year when they would grow to 12% of Canada’s emissions (*14*). Thus the scale of the oil sands emissions problem depends on perspective. On the one hand, 5% or even 10% of a small economy results in only a small contribution to a global problem. Even if all oil sands operations were shut down tomorrow, Canada would still be one of the top GHG per capita emitters in the world. However, emissions from oil sands continue to grow, yet in order to stabilize atmospheric carbon, (all) emissions will need to be reduced to near zero.

Where/How Can Technology Cut Emissions?

While oil sands have been extracted since the late 1960s, early projects were not economic. A series of incremental improvements in mining technology, process heat integration, etc., gradually made them more economic. The oil price increases that began in the mid 1990s triggered a boom in oil sands investments, so that by 2007 more than $10 billion/y of new capital was flowing into oil sands projects (*14*). During this recent boom, the investments shift from mining toward SAGD is driven primarily by the low capital cost of SAGD projects and the low price of gas relative to oil.

Almost all oil sands production emissions come from energy use, so understanding the process that drives energy consumption in production is key to assessing emissions and the opportunities for reduction. Much of the innovation that has occurred to date has been motivated by technologies with the potential to reduce the cost of these operations. However, these technologies also have environmental consequences that must be considered. Table 2 shows several examples of emerging technologies related to the oil sands industry and the anticipated trade-offs. For example, a hybrid steam-solvent process has the potential to reduce the GHG emissions below those of a traditional in situ operation with the potential to also reduce costs below those of a traditional operation (assuming that the cost of the solvent is lower than the steam that is being offset, and that losses of solvent to the surrounding reservoir are not significant or have little impact on the ecosystem). Implementing CCS has the potential to greatly reduce GHG emissions while also increasing the costs and technological risk over a traditional oil sands operation. In several cases the cost and GHG emissions associated with a technology category could be either lower or higher than conventional technologies depending on two main factors. The first is that the technologies that are currently being developed are often at a precommericalization stage and therefore the expected performance is highly uncertain. The second is the fact that there is significant variability in the way that the technology could be implemented. For example, if the electrothermal technology performs at a commercial scale as successfully as it has in preliminary pilot applications that have been published to date, and the electricity provided to the process is created by a low-emitting energy source such as nuclear or a renewable energy, then the GHG emissions could be reduced while the costs could be higher than conventional extraction methods. Conversely, if there are efficiency impacts for the technology at commercial scale and the electricity is provided by coal-fired power, the costs could be lower than current technology but emissions could be higher.

There are a wide variety of technologies being developed to reduce emissions from oil sands operations. In each technology category there are also additional advancements that could further improve the potential for the technology. For example, in situ combustion could experience improved performance by employing an oxyfuel system to concentrate the CO_2 in the gas produced, thus facilitating the use of CCS technology. Similarly, the emissions associated with a fuel switch to heavier feedstocks such as coke or asphaltenes could be reduced by cofiring the heavier feedstock with

TABLE 2. Examples of Emerging Oil Sands Related Technologies and Their Trade-Offs

Mitigation Measure	Scale of Technology	Technology Category	Technology Description	Tradeoffs
1. Extraction Efficiency Improvements	a. In situ Extraction Technologies	Steam Processes	Improved efficiencies through improved well configuration and/or placement	Limited applicability across resource base, performance at commercial scale uncertain
		Solvent Processes	A combination of steam and solvents to reduce steam requirements and therefore natural gas combustion	Potential for partial upgrading in situ but solvent losses could reduce benefits
		In situ Combustion	Combustion of heavy portion of petroleum underground	Potential for partial upgrading in situ, higher recovery rates and reduced use of natural gas but less control over combustion and combustion of heavy portion of bitumen could lead to higher emissions
		Electric Heating	Electrodes in the reservoir heat the bitumen through electro-thermal, conduction, and convection	Potential benefits and costs depend on source of electricity used, commercial scale performance uncertain
	b. Mining Extraction Technologies	Operational Changes	e.g., shift to electricity or H_2 in mining vehicles	Small fraction of LC GHG emissions with significant costs
2. Lowering Carbon Intensity of Energy Inputs (WTT)	a. CCS	Fossil Fuels (e.g., natural gas, asphaltenes, coke)	Combustion/gasification of fossil fuels can be coupled with CCS technologies to remove CO2 from flue gas/syngas stream	Significantly lower emissions (>2/3 reduction from current), potential to greatly reduce natural gas consumption but higher cost
		Biomass Cofiring	Combustion/gasification processes mentioned above can use a combination of fossil fuels and biomass	Life cycle benefits (production of biomass provides additional carbon sink) could lead to net negative emissions - type and location of biomass is important
	b. Alternative Fuels	Nuclear	Potential use of non fossil fuels to supply the steam, electricity and/or hydrogen requirements of oil sands operations (including upgrading and refining)	Near zero emissions, but high cost, waste fuel disposal risks, public perception issues
		Biomass		biomass production provides emissions benefits - type and location of biomass is important

biomass. If this system is also coupled with CCS, the emission could become net negative (*15*). However, even a technology that could reduce the extraction emissions to near zero would be considered incremental because 60−80% of the emissions are still going to occur if the bitumen is eventually combusted in a vehicle (*9*). Because the emissions impacts of technologies depend so strongly on project-specific decisions, we should not expect emissions performance to improve automatically with accelerated technical innovation. Policies that discourage emissions will be required along with innovation in order to drive substantial adoption of low-emissions technology. There are also no technologies that are clearly superior in terms of both reducing costs and significantly reducing GHG emissions. In addition, other environmental impacts must also be considered. There are strong trade-offs between these disparate objectives.

The Potential for CCS

The cost competitiveness of CCS depends on the scale of the analysis. On a WTT basis, CCS has the unique potential to enable very deep cuts in oil sands process emissions. That is, if you want to achieve significant emission reductions, on the order of 2/3 for WTT, then CCS or a fuel switch to carbon-neutral fuel (e.g., nuclear or biomass) are the only options. Whereas, on a WTW or whole economy scale CCS then competes with a range of other emission reduction options.

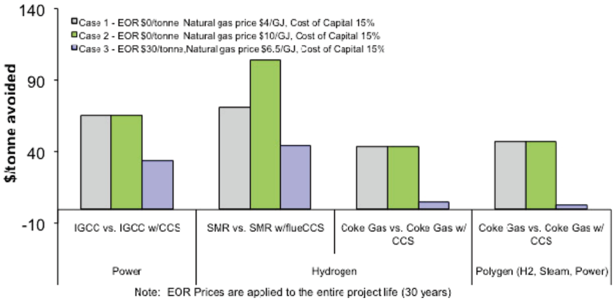
Published estimates of the cost of reducing CO_2 emissions using CCS vary by almost an order of magnitude (*16*). This variance in cost estimates is often misunderstood as a measure of uncertainty about the cost or performance of specific technologies with the implication that technologies are at their most uncertain early development phase. This interpretation is incorrect. While it is true that part of the variance arises from unavoidable uncertainties in assessing the cost and performance of unproven technologies, most of the variance in cost estimates arises from inconsistencies in analytical assumptions that exaggerate the technological uncertainty.

The total cost at a specific facility can be influenced by the following: (1) the costs for large energy-sector construction projects at the time and place at which the facility is constructed; (2) the cost of the CCS technology itself; and (3) the situation-specific costs that depend on the site and integration with a particular process.

For a specific project the cost of reducing emissions is the difference between (1) the cost of CCS (including the CCS facility and emissions); and (2) the cost (and emissions) of a non-CCS baseline. One must assume a baseline technology to calculate the cost of emissions reductions using CCS. Defining the baseline is difficult, as the choice of a baseline can have more influence on the dollar-per-tonne cost of mitigation than uncertainty in the cost of the CCS system itself. Because there is no clear best choice of baseline, analysts can adjust the baseline choice to steer the results in a preferred direction.

A CCS project should be compared to a system producing an equal quantity of the same product (such as hydrogen [H_2]) without CCS under the same market conditions. Most often several options exist for producing any given product. For example, significant amounts of H_2 are required to upgrade oil sands products. This H_2 can be produced from steam methane (CH_4) reforming (SMR) of natural gas or from asphaltenes, coke, or coal using a gasification system. If a gasification system is implemented to produce H_2 for the oil sands with CCS, it could be compared to either a SMR or a gasification baseline system to arrive at a cost of emission reduction estimate. The choice of the baseline will greatly impact the costs attributed to adding CCS. In this case the gasification system has much higher CO_2 emissions in the base case, but the cost of capture is lower, so the incremental cost of emissions reductions will be much higher when the SMR baseline is used and an average natural gas cost is assumed (~\$6/GJ) than the case where the gasification baseline system is used. In the former case, the cost difference includes the capital cost differences between the two H_2 producing technologies in addition to the incremental costs of the CCS technology itself. In addition, governments that approve construction and operation of these facilities must consider the supply and demand for natural gas and the potential effect of permitting a significant number of natural gas plants throughout Canada. The cost estimates are also extremely sensitive to the price of natural gas. In the example above the natural gas price could swing the cost of the SMR baseline case above or below the cost of the gasification baseline case and therefore is a key determinant in the cost differences.

Note that, because of baselines' uncertainty, estimates of the cost of producing SCO or other products with CCS (which depend on factors specific to the plant) are more robust than estimates of the cost of avoiding emissions (which depend on competitive technologies) and therefore on the oil market in which the producers operate. Figure 1 shows how the cost of avoiding emissions is strongly dependent on assumptions about baselines, gas prices, and applications of the technology.



Note: EOR Prices are applied to the entire project life (30 years)

FIGURE 1. Cost comparison among different applications of CCS. The basis of the analysis presented in Figure 1 was a study conducted by SFA Pacific Inc. led by Dale Simbeck in 2007 (*18*) which assessed the costs of various CCS technologies using Alberta-specific cost estimates and reflect the same overall economic assumptions (therefore reducing many of the sources of uncertainty discussed above). To calculate the incremental costs associated with various CCS projects, the technologies and applications considered, as well as the baseline system (without CCS) that are used to compare costs and emissions are defined first. Next, the capital and O&M costs associated with both systems and the difference between them are calculated (on an annualized basis) to render the incremental costs of CCS. The emissions avoided from the implementation of CCS are then calculated by taking the difference between the emissions of the baseline system and the CCS system after accounting for any differences in the amount of output produced. Finally, the annual cost for each case is divided by the annual CO_2 emissions avoided for each case to determine the incremental cost on a \$/tonne of CO_2 avoided basis. Four different technologies and three different scenarios are considered and presented in the figure. The technology to produce power is the integrated coal gasification combined cycle (IGCC), two options for H_2 production include SMR of natural gas and coke gasification. The option to produce multiple products (H_2, steam, and power) employs coke gasification technology. The first two scenarios consider two different natural gas prices (\$4/GJ and \$10/GJ, respectively). The third scenario considers potential revenue from the sale of the CO_2 produced for use in enhanced oil recovery (EOR) operations. The comparison among different applications of CCS shows that, under all circumstances, the natural gas based production of H_2 for use in the oil sands is more expensive than heavier fuel utilization to provide power, H_2, or a combination of hydrogen, steam, and power. Since the SMR system is the technology of choice in the oil sands to produce H_2 the analysis demonstrates that there are less expensive methods to use CCS to achieve CO_2 emission reductions.

Scale of Analysis Drives Stakeholder Perspectives

There is no doubt we must clean up many aspects of oil sands production and we must get serious about cutting carbon emissions to secure our climate, but that does not mean we should put all our emissions cutting chips on the oil sands. Unlike conventional pollutants which are local, nature does not care where carbon is emitted, so when we look to cut carbon we should first look to where it is least expensive to make the cuts. Can we capture oil sands carbon? Yes, but capture is easiest for the largest facilities and the ones that vent the most concentrated exhaust. Size matters: a typical in situ oil sands operation emits 10% of the carbon emitted by a typical coal-fired power plant. It is almost always less expensive to design-in capture from the beginning than to add it later. If we want to use CCS to go after carbon emissions the most cost-effective way to do it, the way that gets us the most environmental protection for tax payer dollars, is to focus on coal plants and large upgrader complexes not on the more dispersed emissions at Fort McMurray.

For each tonne of carbon pulled out of the ground during oil sands production less than 30% is emitted during fuel production while 60–80% of the life cycle emissions come from burning the fuel in vehicles (*9*). Since most of the carbon leaves Fort McMurray, AB as fuel, there is no way to make the oil sands carbon neutral on a WTW basis: even eliminating all emissions from oil sands operations would only be tackling about a quarter of their life cycle emissions. To solve the full problem we must re-engineer the transportation sector that drives oil sands development. Further, in the long run we cannot keep pulling carbon from the ground and pumping it into the atmosphere if we want a stable climate.

The environmental impacts of oil sands development have received a very high level of media exposure both in Canada and around the world. Media attention has been driven, in part, by environmental nongovernmental organizations (ENGO's) who have chosen to highlight the issue of oil sands development. The amount of media attention and attendant political pressure that ENGO's can exert is a scarce resource: more attention to one topic means less attention to others.

In some respects, the level of press and ENGO attention on oil sands is surprising. Oil sands operations amount to approximately 2% on a WTW basis of total emissions in

Canada and the U.S. (*14*). The rapid growth of emissions is commonly cited as a basis for concern, and in relative terms emissions are rising quickly, but that is because oil sands operations started from a small base. Oil sands emissions have more than doubled from 1990 to 2006 (*17*). However, the absolute increase in emissions from oil sands over the same period is less than the absolute increase in Canadian electric or transportation sector emissions, and far less than the increases in these sectors on a North American basis. Note that arguably, this wider comparison is fairer as Canadian oil sands serve the North American market.

Climate impact is, however, proportional to absolute emissions. If the relative cost of cutting emissions was high in a given sector, then growing emissions alone would not solely justify major focus on cutting in that sector alone. In Alberta, for example, CO_2 emissions from coal-fired electric power exceed emissions from oil sands and the costs of reducing emissions from coal electricity are lower. Yet, coal-fired emissions in Alberta receive relatively little attention from ENGOs and the public.

Finally, one might anticipate that oil sands would be a low-priority issue for ENGO's because they are a nearly unique emission source in the global energy system: money and political capital spent to stop oil sands emissions cannot be easily transferred to stop emissions elsewhere (versus once developed technologies to reduce emissions from coal-fired power that could be used to address ~40% of global emissions).

Why then the focus on oil sands? One reason it makes strategic sense to focus on oil sands is that they represent the world's first major step into extra-heavy unconventional oil. Without strong climate policy, one might expect production of unconventional hydrocarbon fuels to increase dramatically in the coming decades as supplies of conventional oil become gradually tighter. A growing supply of unconventional transportation fuels would tend to moderate oil prices and would drive up emissions on a life cycle basis. Moreover, slowing or halting the development of oil sands and similar unconventional fuels such as coal-to-liquids will tend to push up prices for fossil transportation fuels easing the introduction of alternatives such as electric vehicles or biofuels. There is, therefore, a sensible strategic reason for ENGO's to devote substantial efforts to stopping the development of oil sands, efforts that are not directly related to their current environmental impact.

Technologies such as CCS can reduce oil sands production emissions. Indeed, it is technically possible to reduce process emissions to near zero. This could be achieved by co-utilization of fossil fuels and biomass as feedstock for supplying process heat or H_2 combined with CCS, because the "negative emissions" that come from the biofuels carbon captured using CCS can offset residual emissions elsewhere in the process (*15*).

Although it is technically possible to make deep reductions in oil sands WTT emissions, it is unclear if such a strategy makes sense. The cost of reducing these emissions will be high compared to emissions reductions achieved elsewhere in the economy. The environmental impacts of CO_2 emissions are the same wherever they occur, so seen through the lens of environmental cost−benefit analysis it makes little sense to devote major resources to reducing oil sands process emissions. Resources might be better spent on the long-run task of developing technologies that can decarbonize the transportation sector by moving it away from oil as a primary fuel. We hope that developing better public domain life cycle analysis of the technical potential, costs, and environmental impacts of oil sands technologies along with transparent methods to describe the trade-offs involved in decarbonizing the transportation sector will help clarify the messy interaction of strategic interests and contradictory claims at play in the oil sands debate, increasing the chance of choosing an economically sound path to a carbon-neutral future.

Joule Bergerson is an assistant professor in the Chemical and Petroleum Engineering Department, the Energy and Environmental Systems Group of ISEEE, and the Centre for Environmental Engineering Research and Education at the University of Calgary. She earned her Ph.D. in 2005 in a joint program of Civil and Environmental Engineering and Engineering and Public Policy at Carnegie Mellon University. Dr. Bergerson's primary research interests are systems-level analysis for policy and decision making of energy system investment and management. She has over nine years experience developing frameworks for the assessment of prospective technology options and their policy implications from a life cycle perspective. To date, her work has addressed fossil fuel derived electricity, oil sands development, and carbon capture and storage. David Keith is a Canada Research Chair of Energy and Environment at the University of Calgary. He has worked near the interface of climate science, energy technology, and public policy for twenty years. His work in technology and policy assessment addressed the capture and storage of CO_2*, the technology and implications of global climate engineering, the economics and climatic impacts of large-scale wind power, and the prospects for hydrogen fuel. As a technology innovator, he has built a high-accuracy infrared spectrometer for NASA's ER-2 and developed new methods for reservoir engineering to increase the safety of stored* CO_2*. He now leads Carbon Engineering, a start up company developing technology to capture* CO_2 *from ambient air at an industrial scale. Please address all correspondence regarding this manuscript to jbergers@ucalgary.ca.*

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