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TECHNICAL MEMORANDUM

Date: April 24, 2017
To: Grand Canyon Trust and the Center for Biological Diversity
From: Dustin Mulvaney, PhD, Ben Toscher, MS, & Tiffany Wise-West, PhD,
EcoShift Consulting, LLC
Subject: **Greenhouse Gas & Water Footprints of Oil Shale & Tar Sands Resources & Projects in the Upper Colorado River Basin**

1. INTRODUCTION & HIGHLIGHTS

The objective of this study was to determine the water footprint and greenhouse gas (GHG) emissions footprint for **oil shale (OS)** and **tar sands (TS)** lands available for lease, and projects under lease or proposed in the Upper Colorado River Basin. Areas analyzed in this project are mainly federal lands, but also include some private and state lands.[1] In 2012, the Bureau of Land Management designated 132,220 acres of STSAs as available for TS development and 678,700 acres of public lands for OS development.[2]

- Oil shale water & GHG footprint estimates are based on federal lands available under a Research Demonstration and Development (RD&D) lease and specific proposed and existing OS development projects.
- Tar sands water & GHG footprint estimates include specific proposed and existing developments and federal commercial lease-available Special Tar Sands Areas (STSAs).

Table 1 shows resource volumes for federal lands available for lease with ranges for the water and GHG emissions footprints associated with developing these federal OS and TS resources. The fossil fuel resource volumes (MMbbls or million barrels) are based on in place estimates from the USGS and DOI (see footnotes 6 through 8). All sources and assumptions are in the appendices. In place resources with a yield greater than 25 gallons per ton and 25 feet thick (depending on the formation) or more were considered economically viable. Wyoming is an exception, where a less rich resource led assessors to screen the resource with 15 gallons per ton and 15 feet thick.[3]

[1] SITLA (School and Institutional Trust Lands) lands are also available Utah, but were not included in the scope except where they are included in an existing or proposed TS or OS development.

[2] Department of Interior. 2013. Approved Land Use Amendments/Record of Decision for Allocation of Oil Shale and Tar Sands Resources on Lands Administered by the Bureau of Land Management in Colorado, Utah, and Wyoming and Final Programmatic Environmental Impact Statement. March 2013. http://ostseis.anl.gov/documents/docs/2012_OSTS_ROD.pdf

[3] USGS used a lower economic threshold for fossil fuel deposit inventories in Wyoming to account for the extensive, but less rich, resource.

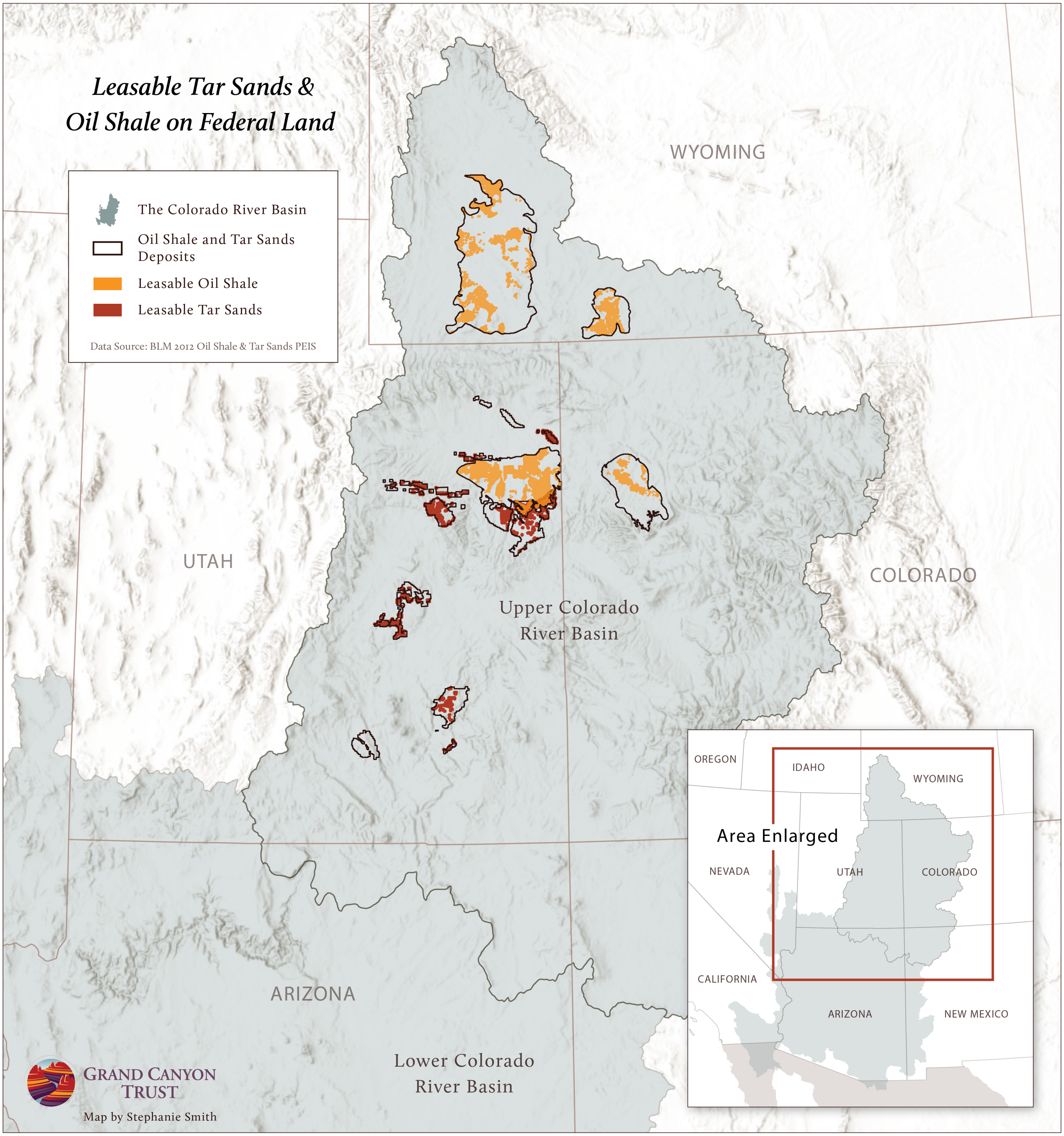
Leasable Tar Sands &
Oil Shale on Federal Land
The Colorado River Basin
Oil Shale and Tar Sands Deposits
Leasable Oil Shale
Leasable Tar Sands
Data Source: BLM 2012 Oil Shale & Tar Sands PEIS
WYOMING
UTAH
COLORADO
Upper Colorado River Basin
ARIZONA
Lower Colorado River Basin
OREGON
IDAHO
WYOMING
Area Enlarged
NEVADA
UTAH
COLORADO
CALIFORNIA
ARIZONA
NEW MEXICO
Grand Canyon Trust
Map by Stephanie Smith

Table 1. Range of GHG and water footprints across all technologies, emission factors, and water use factors evaluated for ***"Available for Lease" Oil Shale (OS)*** *Resources in CO, WY and UT and* ***Tar Sands (TS)*** *in Special Tar Sands Areas (STSAs)* ***"Available for Lease for Commercial Development"*** *in Utah.*

Federal Resource	Resource Volume (MMbbls)	Area (ac)	GHG emissions footprint (GT CO_{2e})[4]	Water footprint (MMBbls Water)[5]
OS - Piceance Basin Available for Lease[6]	7,890	678,700	2.14 – 2.97	461 – 18,432
OS - Green River & Washakie Basin Available for Lease[7]	35,074		9.50 – 13.19	10,522 – 420,889
OS –Uintah Basin Available for Lease[8]	26,703		7.23 – 10.04	8,011 – 320,437
TS – Utah Special TS Areas (STSAs) Available for Lease for Commercial Development[9]	4,125	132,200	1.32 – 1.43	2,063 – 109,313
Totals	**73,792**	**810,900**	**20.19 – 26.63**	**21,057 – 869,071**

Water footprints are reported in units of millions of barrels of water (MMbbls water; 1 barrel equals 42 fluid gallons). GHG emissions footprints are reported in gigatons of carbon dioxide equivalent (GT CO_2e). The footprints for each project type were analyzed by several extraction technologies commonly proposed since there is a great deal of variation and speculation on the water use requirements for extraction of OS and TS. To provide context for the sum of all federal OS and TS, consider that:

- The range of projected GHG emissions footprint from developing 69,667 MMbbls of federal OS and 4,125 MMbbls of federal TS is at least 20.19 GT CO_2e and as much as 26.63 GT CO_2e.
- The GHG emissions associated with developing federal OS and TS resources is between three and 4.5 times U.S. 2014 GHG emissions (6.70 GT CO_2e).
- The water footprint of developing OS & TS on leasable federal lands (Table 1) equals one-fifth to eight times the annual flow of the Colorado River.

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[4] The GHG emissions footprint is the total well-to-wheels life cycle emissions from extracting, processing, and turning fossil fuel resources into final products.

[5] The water footprint is based on the local water use needed to extract and upgrade fossil fuel resources. Water used to refine final products or cool power plants is not included in this total.

[6] U.S. Geological Survey. 2010. In-Place Oil Shale Resources Underlying Federal Lands in the Piceance Basin, Western Colorado. Fact Sheet 2010–3041, Department of Interior, June 2010.

[7] U.S. Geological Survey. 2011. In-Place Oil Shale Resources Underlying Federal Lands in the Green River and Washakie Basins, Southwestern Wyoming. Fact Sheet 2011–3113, Department of Interior, October 2011.

[8] Department of Interior. (2013). Approved Land Use Amendments/Record of Decision for Allocation of Oil Shale and Tar Sands Resources on Lands Administered by the Bureau of Land Management in Colorado, Utah, and Wyoming and Final Programmatic Environmental Impact Statement. March 2013, Bureau of Land Management. http://ostseis.anl.gov/documents/docs/2012_OSTS_ROD.pdf

[9] U.S. Geological Survey. Natural Bitumen Resources of the United States. Fact Sheet 2006–3133 November 2006.

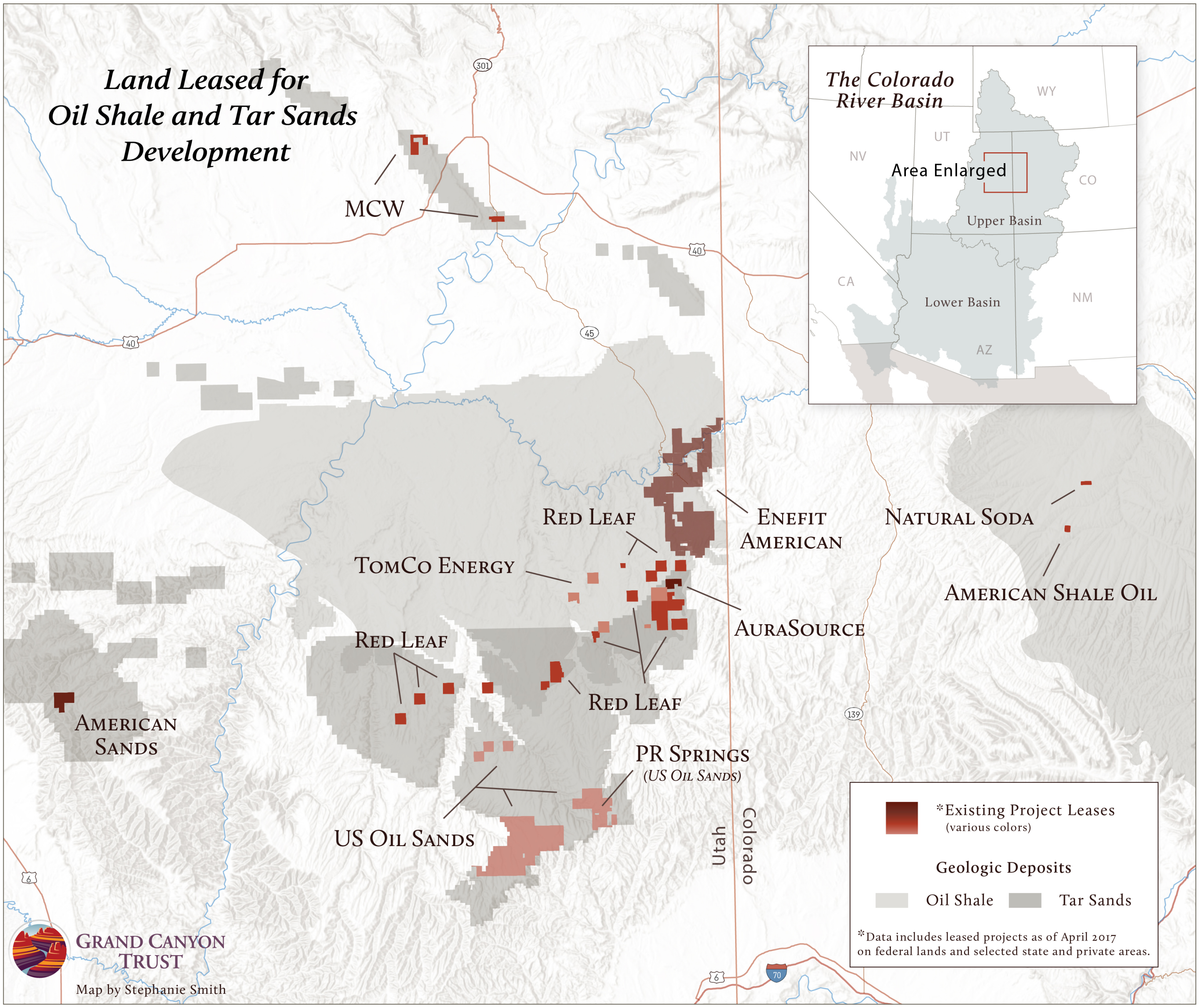
Land Leased for Oil Shale and Tar Sands Development
MCW
Red Leaf
TomCo Energy
Enefit American
Natural Soda
American Shale Oil
AuraSource
Red Leaf
Red Leaf
American Sands
PR Springs
(US Oil Sands)
US Oil Sands
Utah
Colorado
The Colorado River Basin
WY
UT
NV
Area Enlarged
CO
Upper Basin
CA
Lower Basin
NM
AZ
*Existing Project Leases
(various colors)
Geologic Deposits
Oil Shale
Tar Sands
*Data includes leased projects as of April 2017 on federal lands and selected state and private areas.
Grand Canyon Trust
Map by Stephanie Smith

Table 2 below lists the OS and TS projects that are included in the water- and GHG emissions footprint results presented in Table 3. Data for these projects were taken from RD&D leases and company documents.

Table 2. Oil shale (OS) and tar sands (TS) projects and project categories included in primary results

Project	Type	Project Category
American Shale Oil LLC RD&D Round 1 Lease - Rio Blanco County, CO[10]	Oil Shale	Federal
Enefit American Oil RD&D Round 1 Lease (includes BLM preferential lease) - Vernal, UT	Oil Shale	Federal
AuraSource RD&D Round 2 Lease - Vernal, UT	Oil Shale	Federal
Natural Soda Holdings RD&D Round 2 Lease - Rio Blanco County, CO	Oil Shale	Federal
Enefit SITLA (state leases - Utah Trust Lands Administration) - UT	Oil Shale	Non Federal
Enefit North - UT	Oil Shale	Non Federal
Enefit Orion Property - UT	Oil Shale	Non Federal
Enefit South - UT	Oil Shale	Non Federal
TomCoEnergy proposed oil shale developments	Oil Shale	Non Federal
Red Leaf proposed oil shale development (Seep Ridge, Holiday Block, Wyoming Holdings)	Oil Shale	Non Federal
PR Spring Special Tar Sands Area (STSA) - UT	Tar Sands	Federal
US Oil Sands proposed tar sands development	Tar Sands	Non Federal
American Sands Energy Corporation	Tar Sands	Non Federal
MCW - asphalt ridge	Tar Sands	Non Federal

The water footprint estimates are based on the water use efficiency of extracting OS & TS. Water use factors were taken from a review of prior research and are listed in Appendix A. Factors taken from project developers and companies were used when available. Developer proposed technologies report far lower water use factors than findings in the peer-reviewed research and based on prior experience and practice. Water use estimates based on developer claims should be treated with caution. Hence, this study evaluated several technology types to extract OS and TS, which would imply a range of water use estimates.[11] Developer water use estimates were only used to illustrate water use on a project-by-project basis, not the overall water use estimates. GHG emissions footprints for each project type are presented as low, median and high based on a range of GHG emissions factors and technology types. Water footprints for each project type are presented as minimum, maximum, median, 25th percentile and 75th percentile based on a range of water use factors.

[10] This project was withdrawn shortly before final publication of this report.

[11] In practice, the specifics of the formation and the resource can dictate which of the extraction technologies would be used. Further research could better refine this estimate by restricting some technology's use at some sites where the technology might be infeasible because of the underlying geology.

Table 3 below shows the water and GHG emissions footprints associated with developing existing RD&D development proposals for OS, Total Special Tar Sands Areas, and known proposed non-federal OS + TS projects. The resource volumes were estimated from RD&D documentation and company development documents.

Table 3. Range of GHG and water footprints for OS and TS projects under lease or proposed across federal and non-federal lands in the Colorado River Basin (across all technologies, emission factors and water use factors evaluated).

Resource type	**Resource Volume (MMbbls)**	**GHG emissions footprint (GT CO_{2e})**	**Water footprint (MMBbls Water)**
Oil shale (OS) RD&D Leases or project proposals	5,971	1.62 – 2.25	3,561 – 60,000
Tar sands (TS) non-federal + Utah STSA	4,304	1.37 – 1.50	2,152 – 114,000
Totals	**10,275**	**2.99 – 3.75**	**5,713 – 174,000**

To provide context for the magnitude of footprints presented in Table 3, we determined:

- The projected peak production of 140.5 MMBbls OS per year[12] could consume as much as 1.7 percent of the annual Colorado River flow, assuming the higher water use scenario.
- The maximum projected GHG emissions footprint from developing 10,275 MMbbls of OS and TS is about 50 percent of 2014 U.S. GHG emissions.

The area for all federal lands available for lease for OS (678,700 ac) and TS developments (132,200 ac) evaluated to determine water and GHG emissions footprints is approximately 0.11 percent of the Colorado River Basin area and 0.21 percent of the Upper Colorado River Basin area. The total acreages of the oil shale and tar sands developments studied in the context of the total acreage of the Colorado River basin are presented in table 4 below.

Table 4. Acreage of Oil Shale and Tar Sands developments as a proportion of total area of Colorado River Basin and Upper Colorado River Basin[13]

	Overall Acres	Proportion of area for all Federal + Non-federal OS and TS developments (176,636 ac) to overall CO River Basin / Upper CO River Basin	Proportion of area for all Federal OS (678,700)and TS developments (132,200 ac) to overall CO River Basin / Upper CO River Basin	Proportion of area for all Non-federal OS and TS developments (43,996 ac) to overall CO River Basin / Upper CO River Basin
Total Colorado River Basin	157,439,999	0.11%	0.08%	0.03%
Upper Colorado River Basin	83,200,000	0.21%	0.16%	0.05%

[12] Colorado, Yampa, and White River Basin Roundtables Energy Subcommittee, *Energy Development Water Needs Assessment (Phase 1 Report)*, September 2008.

[13] Appendix H contains the acreage of all oil shale and tar sands developments.

2. METHODOLOGY

2.1 Water footprint & system boundary

The system boundary for the estimates of water use for OS and TS projects is limited to the site of development. Other downstream water requirements needed to convert fossil fuels into final fuels, such water use at refineries, only fall into the system boundary if they occur at the site of extraction. Since water use onsite is directly related to regional water impacts, only the water use from onsite production phases are included. Appendix A shows the sources for the water use factors and describes whether the upgrading phase—where the resources are pre-prepared for feedstock at a petroleum refinery—is included. The following process was utilized to determine the water footprints:

1. Compiled inventory of OS and TS resources associated with a federal inventory of leasable land and of proposed and existing projects on federal and non- federal lands. These resources were further categorized as in place resources, resources available for lease, and projects under lease (or at some stage of development, if on private land).
2. Collected water use factors for OS and TS technologies from the literature and specific active applications/developments.
3. Generated low, high, median (50th percentile), 25th percentile, and 75th percentile values for water use factors and applied by technology and resource type to OS and TS production volumes.
4. Determined water footprints using low, high, 25th, median, and 75th percentile water use factors for OS and TS production values to estimate overall water use needed to extract OS and TS federal and non-federal resources.
5. Prepared tables and box and whisker plots to represent water footprint.

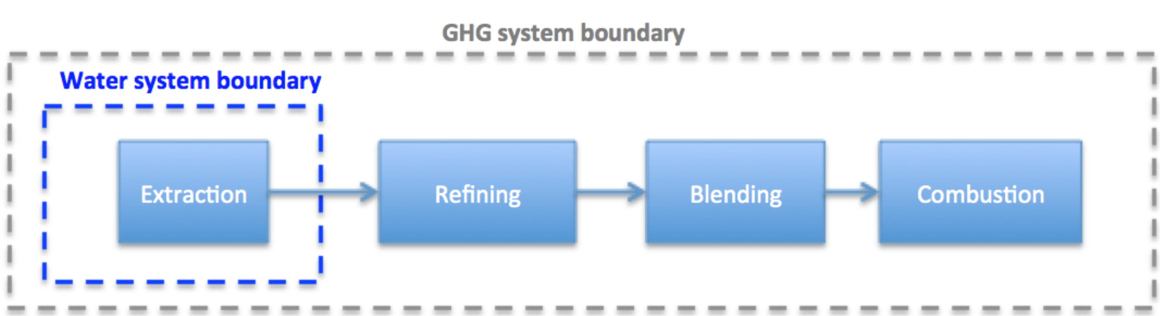

Figure 1: The system boundaries for water use and greenhouse gas emissions

2.2 Greenhouse gas emissions footprint

The system boundary for GHG emissions includes energy used at the site of production, but also embodied carbon in the fossil fuels, as well as all the energy and feedstock requirements to produce a final fuel product. The system boundary here is cast wider than the water use system boundary because most of the GHG emissions are embodied in the fuel itself or in downstream production. Since GHG emissions have global impacts, the entire fuel cycle is included in the system boundary. The following process steps determined the GHG emissions footprints:

1. Compiled inventory of OS and TS resources associated with projects on federal and non-federal lands. These resources were further categorized as in place resources, resources available for lease, and projects under lease or under development.
2. Compiled and applied emission factors for each technology and resource type to determine GHG emissions footprint.
3. Prepared tables to present GHG emissions footprint.

2.3 Data for Tar Sands and Oil Shale Resource Inventories

Three types of data were required to complete the analyses: (1) the total resource volume of OS and TS associated with leasable federal lands and individual development projects, (2) life cycle GHG emission factors for each OS and TS production technology type, and (3) water use factors for each OS and TS extraction technology, as cited in company development documents and the scientific literature.

2.4 Data for Water Use and Greenhouse Gas Emissions Factors

To quantify the volume of water required to develop OS and TS projects, we compiled water use factors from the literature quantified as barrels of water per barrel of oil produced and grouped them according to technology.[14] Because these ranges vary considerably even within OS and TS production technology categories, we present the water footprints in terms of minimum, maximum, medium, 25th percentile and 75th percentile under various OS and TS production technologies. Reporting ranges allows for extreme scenarios for water use to be evaluated.

Product-weighted life-cycle GHG emissions factors were developed to account for the various end products made from OS and TS. End products include finished motor gasoline, distillate fuel oil, kerosene, liquefied petroleum gases, petroleum coke, still gas, and residual fuel oil. Each end product has a different emissions factor to account for differences in refining processes, amounts of primary energy used to produce the end product. This approach accounts for the fact that some carbon is released as GHGs (combusted fuels), while some is embodied in other products (asphalt, plastics). Life-cycle GHG emissions factors were constructed for each type of OS and TS production technology in the study.

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[14] See Appendix A for the summary of these water use factors.

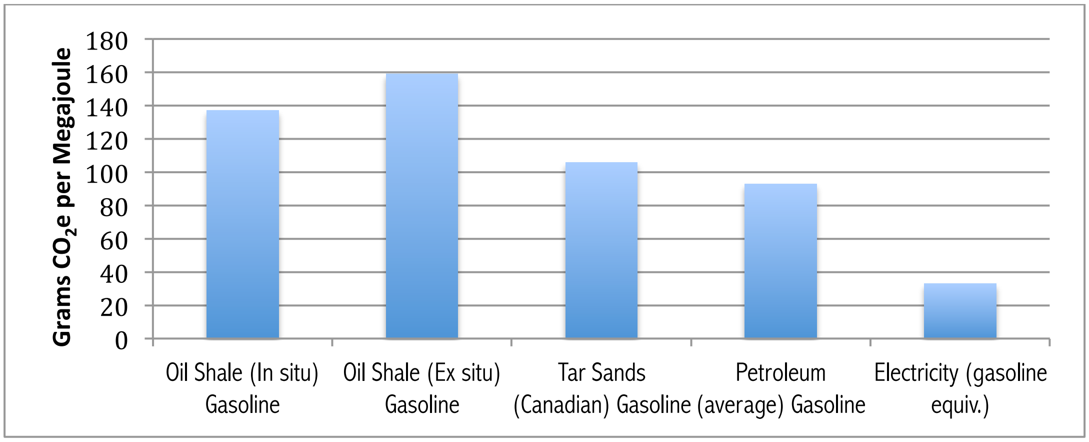

Figure 2: Carbon intensity differences between gasoline refined from various fossil fuel resources[15]

Table 5. Oil Shale GHG Emission Factors[16]

Life-cycle GHG emissions factor, in Gigatons CO_2e / million barrels			
Technology	Low	Median	High
Surface Retort - Based on Alberta Taciuk Processor (ATP)	0.000326	0.000349	0.000376
In Situ - Shell In Situ Conversion Process (ICP)	0.000271	0.000309	0.000351

Table 6. Tar Sands GHG Emission Factors[17]

Life-cycle GHG emission factor, in Gigatons CO_2e / million barrels			
Technology	Low	Median	High
In Situ SAGD (steam assisted gravity drainage) SCO (synthetic crude oil) - coker upgrader	0.000330	0.000334	0.000338
In Situ SAGD SCO - ebulated bed resid hydrocracking upgrader	0.000339	0.000343	0.000347
In Situ SAGD Bitumen	0.000321	0.000325	0.000329
Surface Mining SCO - coker	0.000326	0.000329	0.000334
Surface Mining Bitumen	0.000319	0.000323	0.000327

[15] From (1) NETL (2008), Development of Baseline Data and Analysis of Life Cycle Greenhouse Gas Emissions of Petroleum-Based Fuels, November 28, 2008, U.S. Department of Energy, DOE/NETL 2009/1346, (2) Brandt, A. R. (2009): Converting oil shale to liquid fuels with the Alberta Taciuk Processor: Energy inputs and greenhouse gas emissions. *Energy & Fuels*, 23(12), 6253–6258, (3) EPA EPA (2010), and (3) Renewable Fuel Standard Program (RFS2): Regulatory Impact Analysis. February 2010, EPA-420-R-10-006. Canadian TS are used for the GHG estimate because there are no commercial TS operations in the US.

[16] These end-use product weighted emissions factors were determined based on the emissions factors of two oil shale extraction technologies found in Brandt, A. R. (2009): Converting oil shale to liquid fuels with the Alberta Taciuk Processor: Energy inputs and greenhouse gas emissions. *Energy & Fuels*, *23*(12), 6253-6258; and Brandt, A. R. (2011). Greenhouse gas emissions from liquid fuels produced from Estonian oil shale. *A report prepared for the European Commission*.

[17] These end-use product weighted emissions factors were determined based on the emissions factors of various tar sands extraction technologies cited in Jacobs Consultancy Life Cycle Associates (2009). Life Cycle Assessment Comparison of North American and Imported Crudes. Chicago, IL.

3. RESULTS

Table 1 and 3 in the introduction shows the overall results of the GHG emissions- and water footprints of OS and TS development on federal and non-federal lands available for lease or under lease. The primary results presented in this section include the water use and GHG emissions footprints of OS and TS projects, which were either under lease or in some stage of active development. Projects that were confirmed as no longer under development were excluded from the inventory used to determine these primary results.[18] Projects included in the primary results were placed into project categories based on the ownership of the land in which they take place: federal and non-federal (whether on state or private) lands. Table 2 details the projects included in the primary water and GHG emissions footprints. Secondary results, i.e., the full results for the water and GHG emissions footprints (including in place resources) are available in the appendices.

3.1 Water Footprint of oil shale

The water requirements to bring 10,275 MMBbls of federal and non-federal OS and TS development projects (proposed and existing RD&D leases, STSAs available for lease, and private land) within the Colorado River Basin into production are presented in millions of barrels of water needed to produce the specified resource. Table 7a below describes the water use needed to produce 5,971 MMBbls of oil shale resources based on different technologies and a range of water use factors taken from the literature. We assumed that any of these technologies could be used to develop OS and TS projects.

Table 7a shows that surface retorting technologies require nearly three times the volume of water per unit energy extracted compared to other extraction technologies. In situ with technology advancements was considered to have the lowest water use in the published literature. The "All Technologies" category also includes estimates from project developers, which were lower on average (See Appendix A). Given the speculative nature of the water use estimates provided by industry (and not peer reviewed or based on industry practice), we grouped these water use factors into all technologies. Table 7b presents the water use per project based on developer estimates.

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[18] Staff from Grand Canyon Trust track these projects and determined status. Active projects as of 2016, were included.

Table 7a. Total water footprint to develop all federal and non-federal oil shale projects (5,971 MMBbls) based on the literature

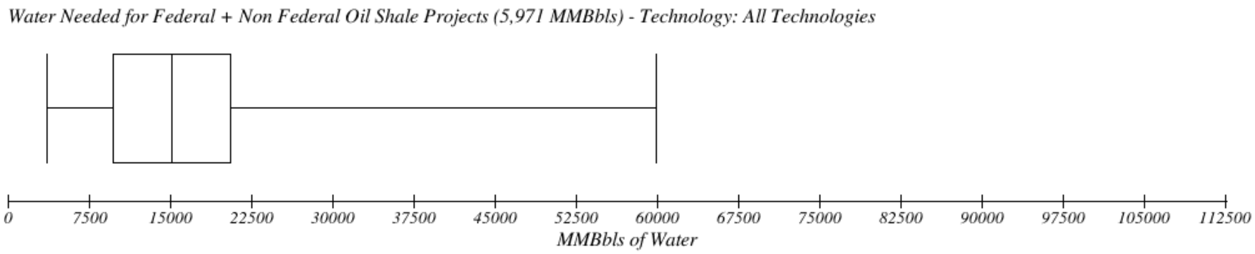
Millions of barrels of water to produce oil shale by extraction technology and range of water use factors						
Technology	*Description*	Min	Max	Median	25th Percentile	75th Percentile
ISA	In Situ With Technology Advancements	3,815	21,072	6,322	4,958	8,903
ALL	All Technologies	3,561	59,852	15,075	9,694	20,570
ISU	In Situ - Upgrading Confirmed Included	5,066	56,557	11,119	8,497	17,158
SRU	Surface Retort - Upgrading Confirmed Included	11,169	22,409	15,890	12,855	18,385

Table 7b. Total water footprint to develop each oil shale project based on developer estimates

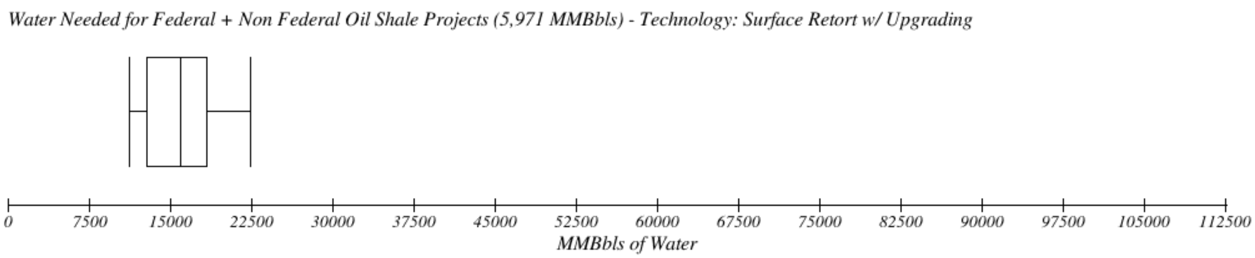
Millions of barrels of water to produce oil shale based on developer water use estimates		
Project	Energy (MMBbls)	Water (MMBbls)
American Shale Oil LLC	1,536	1,536
Enefit American Oil	545	1,455
AuraSource	47	47
Natural Soda Holdings	300	0.1
Enefit SITLA	415	1,108
Enefit North	321	857
Enefit Orion	132	352
Enefit South	1,200	3,204
Red Leaf	1,349	2,023
TomCoEnergy	126	189

Figures 2a through 2d present four "box and whisker" plots depicting the million barrels of water required for production of 5,971 MMBbls of oil shale from federal and non-federal developments under different production technologies. The line in the center of the box represents the median, the left and right sides of the box are the 25th and 75th percentiles, and the furthest extent of the whiskers represent the minimum and maximum water use factors found in the literature.

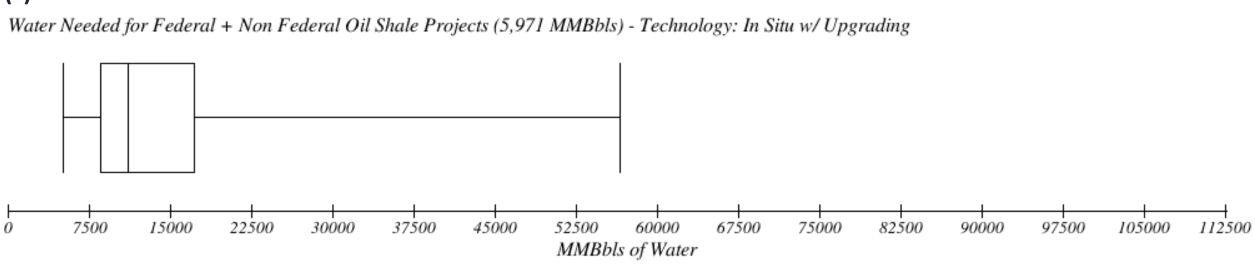
(a)



(b)



(c)



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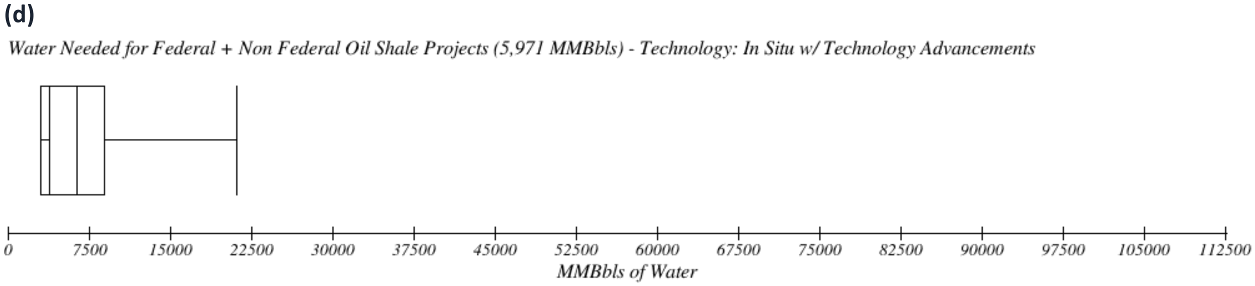

Figure 2 (a) Water required for oil shale development averaged across all technologies used in production, (b) Water required for oil shale development by surface retort production w/upgrading, (c) Water required for oil shale development by in situ production w/upgrading, (d) Water required for oil shale development by in situ production w/advancements.

3.2 Water Footprint of Tar Sands

Table 8a below describes the water requirements to produce 4,304 MMBbls of TS resources available on private land or through STSAs in the Colorado River watershed based on different technologies and a range of water use factors cited in the scientific literature. Table 8b presents specific project developments and the water use estimates provided by the project developers.

Table 8a. Tar sands water footprint range to produce 4,304 MMBls of federal and non-federal resources based on water use factors cited in scientific literature

Millions of barrels of water to produce tar sands by extraction technology and range of water use factors						
Technology Key	*Description*	Min	Max	Median	25th Percentile	75th Percentile
SV	Conventional mining and solvent extraction	4,907	114,072	20,641	8,943	51,763
ALL	All Technologies	2,368	5,596	3,982	3,175	4,789
SRU	Surface retort upgrading confirmed included	9,470	17,434	13,452	11,461	15,443
SAGDU	SAGD Upgrading confirmed included	2,152	15,066	8,394	3,444	13,452
CSSU	CSS upgrading confirmed included	13,344	13,344	13,344	13,344	13,344

Table 8b. Total water footprint to develop each oil shale project based on developer estimates

Millions of barrels of water to produce oil shale based on developer water use estimates		
Project	Energy (MMBbls)	Water (MMBbls)
US Oil Sands	9.6	14.4
American Sands Energy Corporation	150	NA
MCW	20	NA

Figures 3a through 3e presents five box and whisker plots depicting the million barrels of water required for production of 4,304 MMBbls of tar sands from federal and non-federal developments under different production technologies. The line in the center of the box represents the median, the left and right sides of the box are the 25th and 75th percentiles, and the furthest extend of the whiskers represent the minimum and maximum water use factors found in the literature. The "All Technologies" category is an average that includes data for water use factors not included in the other technologies, including some estimates for water use on existing and proposed TS projects. "All Technologies" is not an average of the other categories of technology.

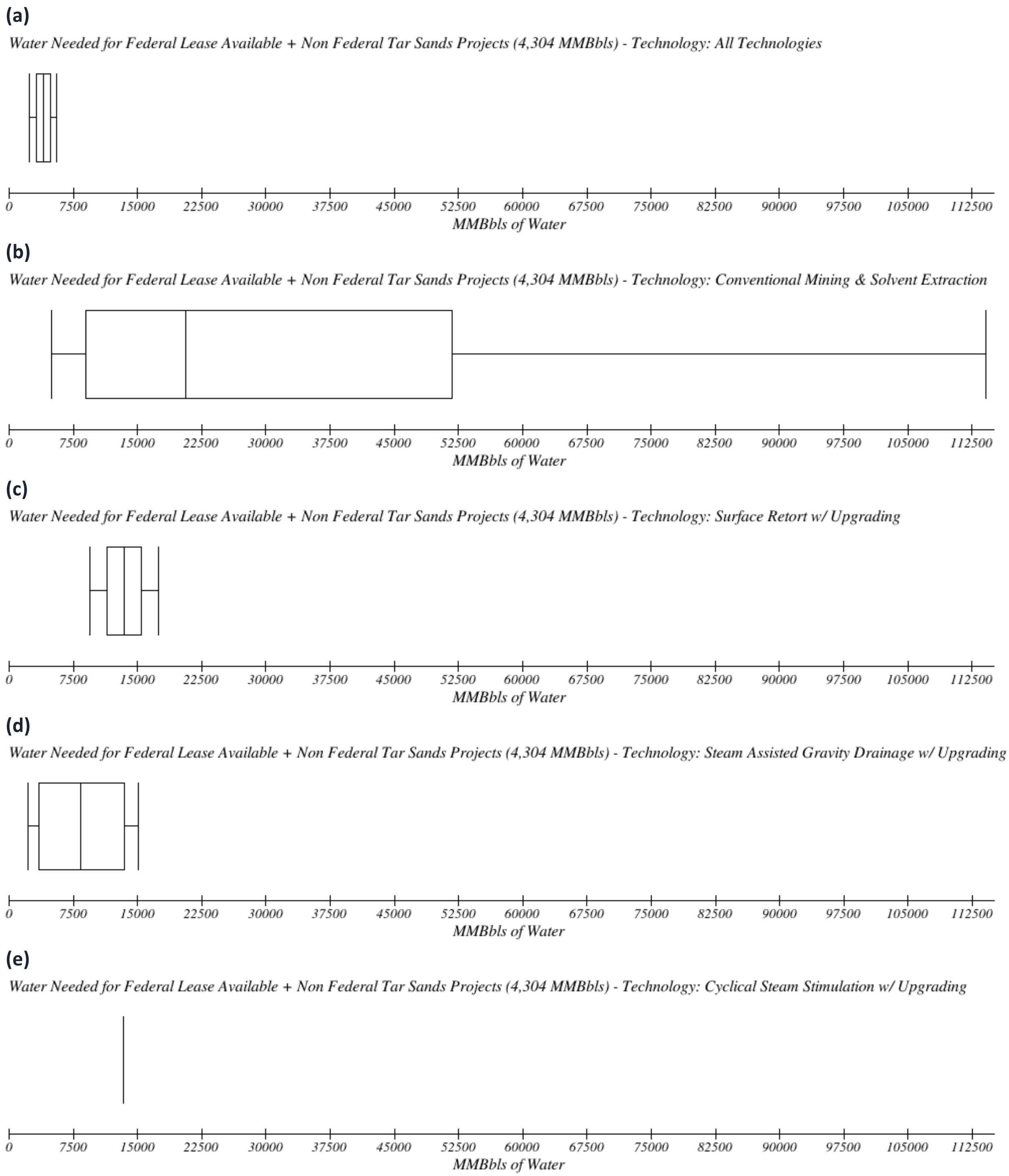

Figure 3. (a) Water required for tar sands production averaged across all technologies, (b) Water required for tar sands production of tar sands using conventional mining & solvents extraction, (c) Water required for tar sands production using surface retort with upgrading, (d) Water required for tar sands production using in situ steam assisted gravity drainage with upgrading, (e) Water required for tar sands production using in situ cyclical steam stimulation with upgrading.

3.3 Water Requirements to extract OS and TS in the Colorado River context

To help contextualize the water footprints, estimated volumes of water are compared to the annual flows of the Colorado River. The *Supplemental Streamflow Analysis* (SSFA) published by the Bureau of Reclamation in 2012 estimates that the annual water flow rate through the Colorado River is about 108,617 million barrels (14,000,000 acre-feet).[19] An optimistic industry estimate of peak production of 140.5 MMBbls of OS per year someday could use as much as 1.7 percent of the Colorado River flow annually based on this flow rate.[20]

Depletions throughout the upper Colorado River basin currently total approximately 48,352 million barrels (4.6 million acre-feet) of water, approximately 1/3 of the average seasonal flow[21]. For this analysis, it was not determined whether the water is available for development. This is important to consider in the context of the water that is available for use, especially in years of drought. The Bureau of Reclamation indicates that for the period from 2001 to 2008 there was a deficit of nearly 30,000,000 acre-feet in the Colorado River Basin.[22]

Importantly, annual runoff in the Colorado River basin appears to be declining, with significant consequences for reduced streamflow.[23] During 2001–2010, warm temperatures and dry conditions reduced average flows in the Colorado River (measured at Lees Ferry) to the second-lowest-flow decade since 1901, to12.6 million acre-feet per year compared to the 1901–2000 average of 15.0 million acre-feet per year.[24]

Moreover, modeling studies project that runoff and streamflow will continue to decrease substantially in the Colorado River basin during this century.[25] Scientists Barnett and Pierce

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[19] US Bureau of Reclamation. Supplemental Streamflow Analysis. (2012), http://www.usbr.gov/lc/region/programs/crbstudy/finalreport/Technical%20Report%20B%20-%20Water%20Supply%20Assessment/TR-B_Appendix5_FINAL.pdf

[20] Assuming oil shale projects have a 32 year production lifetime and production is equally distributed across all years, peak production = 140.5 MMBbls per year. Under the maximum water use factor used in this study (13.35 barrels water / barrel oil), this results in a peak water use of approximately 1,876 MMBbls per year. A production lifetime of 32 years is derived from Table 5.6 in Colorado, Yampa, and White River Basin Roundtables Energy Subcommittee, *Energy Development Water Needs Assessment (Phase 1 Report)*, September 2008

[21] This statement is drawn from a Grand Canyon Trust confidential memo and sources for the statistics cited could not be identified and verified by EcoShift.

[22] U.S. Bureau of Reclamation and Colorado River Basin Water Supply and Demand Study Team. 2011. Colorado River basin Water Supply and Demand Study: Technical Report B– Water Supply Assessment. Interim Report No.1.

[23] U.S. Bureau of Reclamation and Colorado River Basin Water Supply and Demand Study Team. 2011. Colorado River basin Water Supply and Demand Study: Technical Report B – Water Supply Assessment. Interim Report No. 1.

[24] Hoerling, M. P., M. Dettinger, K. Wolter, J. Lukas, J. Eischeid, R. Nemani, B. Liebmann, and K. E. Kunkel. 2013. Evolving weather and climate conditions of the Southwest United States. Pages 74–100 in G. Garfin, A. Jardine, M. Black, R. Merideth, J. Overpeck, and A. Ray, editors. Assessment of climate change in the Southwest United States: a report prepared for the National Climate Assessment. Island Press, Washington, D.C., USA.

[25] Ray, A.J., Barsugli, J.J., Averyt, K.B., Wolter, K., Hoerling, M., Doesken, N. Udall, B. and R.S. Webb. 2008. Climate change in Colorado: a synthesis to support water resources management and adaptation. Report for the Colorado Water Conservation Board. University of Colorado, Boulder; Das, T., Pierce, D.W., Cayan, D.R., Vano,

concluded that anthropogenic climate change is likely to reduce runoff in the Colorado River basin by 10-30 percent by 2050.[26] Projected reductions in runoff range from 6-7 percent[27] to 45 percent[28] depending on the models and methods used in each study[29] Hoerling and Eischeid predict streamflow to decrease by 25 percent during 2006-2030, and by 45 percent during 2035-2060.

Although there are both natural and human influences on these hydrologic trends, studies indicate that anthropogenic greenhouse gases began to impact snow-fed streamflow timing during 1950-1999.[30] Approximately half of the observed decline in snowpack in the western United States during 1950-1999 has been attributed to the effects of anthropogenic greenhouse gases, ozone and aerosols.[31] Modeling studies have projected that snowmelt, spring runoff, and streamflow timing will continue to shift earlier across much of the Southwest.[32]

J.A., and D.P. Lettenmaier. 2011. The importance of warm season warming to western US streamflow changes. Geophysical Research Letters 38(23); US Bureau of Reclamation and Colorado River Basin Water Supply and Demand Study Team. 2011. Colorado River basin Water Supply and Demand Study: Technical Report B – Water Supply Assessment. Interim Report No. 1; Cayan, D. et al. 2013. Future climate: projected average. Pages 101–125 in G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, editors. Assessment of climate change in the southwest United States: a report prepared for the National Climate Assessment. A report by the Southwest Climate Alliance. Island Press, Washington, D.C., USA; Georgakakos, A., P. Fleming, M. Dettinger, C. Peters-Lidard, T.C. Richmond, K. Reckhow, K. White, and D. Yates. 2014. Water resources. Pages 69–112 in J. M. Melillo, T. C. Richmond, and G. W. Yohe, editors. Climate change impacts in the United States: the third National Climate Assessment. U.S. Global Change Research Program, Washington, D.C., USA; Dettinger, M., B. Udall, and A. Georgakakos. 2015. Western water and climate change. Ecological Applications 25: 2069-2093.

[26] Barnett, T.P. and D.W. Pierce. 2009. Sustainable water deliveries from the Colorado River in a changing climate. PNAS 106: 7334-7338.

[27] Christensen, N.S. and D.P. Lettenmaier. 2007. A multimodel ensemble approach to assessment of climate change impacts on the hydrology and water resources of the Colorado River basin. Hydrology and Earth System Sciences 11: 417-1434.

[28] Hoerling, M. and J. Eischeid. 2007. Past peak water in the Southwest. Southwest Hydrology 35:18–19.

[29] See Barnett and Pierce, supra note 15 at Table 2.

[30] Barnett, T. P., et al. 2008. Human-induced changes in the hydrology of the western United States. Science 319: 1080–1083; Hidalgo, H. G., T. Das, M. D. Dettinger, D. Cayan, D.W. Pierce, T. P. Barnett, G. Bala, A. Mirin, A.W. Wood, C. Bonfils, B.D. Santer, and T. Nozawa. 2009 Detection and attribution of streamflow timing changes to climate change in the western United States. Journal of Climate 22: 3838-3855; Hoerling, M. P., M. Dettinger, K. Wolter, J. Lukas, J. Eischeid, R. Nemani, B. Liebmann, and K. E. Kunkel. 2013. Evolving weather and climate conditions of the Southwest United States. Pages 74–100 in G. Garfin, A. Jardine, M. Black, R. Merideth, J. Overpeck, and A. Ray, editors. Assessment of climate change in the Southwest United States: a report prepared for the National Climate Assessment. Island Press, Washington, D.C., USA.

[31] Pierce, D. W., T. P. Barnett, H. G. Hidalgo, T. Das, C. Bonfils, B. D. Santer, G. Bala, M. D. Dettinger, D. Cayan, A. Mirin, A. W. Wood, and T. Nozawa. 2008. Attribution of declining western U.S. snowpack to human effects. Journal of Climate 21: 6425-6444.

[32] Stewart, I. T., D. R. Cayan, and M. D. Dettinger. 2004. Changes in snowmelt runoff timing in western North America under a 'Business as Usual' climate change scenario. Climatic Change 62: 217-232; Rauscher, S. A., J. S. Pal, N. S. Diffenbaugh, and M. M. Benedetti. 2008. Future changes in snowmelt-driven runoff timing over the western US. Geophysical Research Letters 35: L16703, doi:10.1029/2008GL034424; Dettinger, M., B. Udall, and A. Georgakakos. 2015. Western water and climate change. Ecological Applications 25: 2069-2093.

See Appendix B for separate water footprint tables for OS and TS non-federal projects and federal RD&D projects. See Appendix C for separate water footprint tables for in place federal OS and TS resources available and those available for lease under PEIS and ROD[33] in the Piceance Basin (Colorado), Green River and Washakie Basins (Wyoming), and Uintah Basin (Utah). See Appendix D for separate water footprint tables for each OS and TS development lease.

3.4 Greenhouse Gas Emissions Footprint of Oil Shale

The life-cycle GHG emissions for the federal and non-federal development projects within the Colorado River Basin, if brought into production, range from 2.69 to 3.75 GT CO_2e. Tables 9 and 10 illustrate the estimated GHG emissions footprint range for each resource by technology type and for various emission factors.

Table 9. Life-cycle GHG emissions footprint from oil shale production

Life-cycle emissions, in Gigatons CO2e, of developing specific Oil Shale Resources Under Various Emissions Factors and Technologies Federal + Non-federal Projects – 5,971 MMBbls			
Technology	Low	Median	High
Surface Retort - Based on Alberta Taciuk Processor (ATP)	1.95	2.08	2.25
In Situ - Shell In Situ Conversion Process (ICP)	1.62	1.84	2.10

3.5 Greenhouse Gas Emissions Footprint of Tar Sands

Table 10. Life-cycle GHG emissions footprint from tar sands production

Life-cycle emissions, in Gigatons CO2e, of developing specific Tar Sands Resources Under Various Emissions Factors and Technologies Federal + Non-federal – 4,304 MMBbls			
Technology	Low	Median	High
In Situ SAGD (steam assisted gravity drainage) SCO (synthetic crude oil) - coker upgrader	1.42	1.44	1.46
In Situ SAGD SCO - ebulated bed resid hydrocracking upgrader	1.46	1.48	1.50
In Situ SAGD Bitumen	1.38	1.40	1.42
Surface Mining SCO - coker	1.40	1.42	1.44
Surface Mining Bitumen	1.37	1.39	1.41

These overall GHG emissions footprints are presented in a variety of other formats. See Appendix E for separate GHG emissions footprint tables for OS and TS non-federal projects and

[33] PEIS is the programmatic environmental impact statement; ROD is the record of decision in which the amount of federal resource available for lease is specified. Available from: http://ostseis.anl.gov/

federal RD&D projects. See Appendix F for separate GHG emissions footprint tables for in place federal OS and TS resources available and those available for lease under PEIS and ROD in the Piceance Basin (Colorado), Green River and Washakie Basins (Wyoming), and Uintah Basin (Utah). See Appendix G for separate GHG emissions footprint tables for each OS and TS development lease.

4. CONCLUSIONS

This technical memo reports the area for all federal lands available for lease for OS (678,700 ac) and TS developments (132,200 ac) and evaluated their water and GHG emissions footprints. The area available for lease is approximately 0.11 percent of the Colorado River Basin area and 0.21 percent of the Upper Colorado River Basin area. The maximum projected GHG emissions footprint from developing 69,667 MMbbls of federal OS and 4,125 MMbbls of TS is at least 20.19 GT CO_2e or over three times U.S. 2014 GHG emissions of 6.70 GT CO_2e, and as much as 26.63 GT CO_2e or over 4.5 times U.S. annual emissions. The amount of federal resource available for lease has a water footprint that equals one-fifth to eight times the flow of the Colorado River.

4.1 Water requirements for oil shale and tar sands development in the Colorado River Basin

The water use requirements for existing and proposed OS and TS development projects under lease equals 10,275 million barrels of water in the Colorado River Basin. The water footprint to develop 5,971 MMBbls of OS in existing and proposed projects across all technologies and water use factors ranges from 3,561 million barrels (459,000 acre-feet) to nearly 60,000 million barrels (77,334 acre-feet) of water.[34] The water footprint to develop 4,304 MMBbls of TS across all technologies and water use factors ranges from 2,152 million barrels (277,400 acre-feet) to over 114,000 million barrels (14,690,000 acre-feet) of water.

Previous estimates suggest that 2,933 million barrels (378,000 acre-feet) of water per year could be needed to develop oil shale alone at a production rate of 1.5 million barrels per day[35]. According to the Colorado River Water Conservation District, full-scale oil shale development (2 MMBbls per day) could require as much as 1,897,169 million barrels (244,532,000 acre-feet) of water to develop oil shale over the life of the developments.[36]

4.2 Greenhouse gas emissions from oil shale and tar sands development on Colorado Plateau

The life cycle GHG emissions for 10,275 MMBbls of oil shale and tar sands development on the Colorado River Basin are bulleted below.

[34] The barrel of water measurement used throughout equals 42 gallons or X acre-feet.

[35] This amount may be highly speculative. Colorado, Yampa, and White River Basin Roundtables Energy Subcommittee, *Energy Development Water Needs Assessment (Phase 1 Report)*, September 2008.

[36] Ibid., footnote 4.

- The GHG emissions footprint associated with developing and using oil shale resources range from 1.62 to 2.25 GT CO_2e (Table 3).
- The GHG emissions footprint from tar sands development and use ranges from 1.37 to 1.50 GT CO_2e (Table 3).

To provide a sense of magnitude, the annual global fossil fuel and cement emissions were about 49.9 GT CO_2e in 2014.[37] Total U.S. emissions in 2014 were about 7.5 GT CO_2e.[38]

4.3 Limitations of Analysis

Our analysis is limited by the accuracy of the volumes of fossil fuels in the underlying data sources. For many projects, such as RedLeaf's projects in Utah, we have relied upon resource estimates provided by that company on their website. Further, both our water footprint and carbon footprint methodologies are top down calculations – rather than bottom-up engineering estimates from actual project specifications. Since lease durations were unavailable, we have assumed that the entirety of the resource (defined by a minimum thickness and yield) associated with the lease are extracted and combusted, which may or not be reflective of economic reality in the future. There was a wide range of water use factors in the literature, as well as clear consensus by other researchers in the literature that water use estimates from tar sands and oil shale product vary widely. We rectified this by providing a range of water use factors and water footprints. There are also conflicting data sources for GHG emission factors, which we rectified by providing ranges from the most recent meta-analyses prepared by the Department of Energy. Additionally, since the information containing the distribution of production over the lifetime of projects was sparse, we made a rough estimation of what peak production might look like, as described in footnote 10. Appendices A through H follow with tables detailing the water and carbon footprint estimates summarized in this Technical Memorandum.

[37] Le Quéré, C, R Moriarty, RM Andrew, JG Canadell, S Sitch, JI Korsbakken, P Friedlingstein, GP Peters, RJ Andres, TA Boden, RA Houghton, JI House, RF Keeling, P Tans, A Arneth, DCE Bakker, L Barbero, L Bopp, J Chang, F Chevallier, LP Chini, P Ciais, M Fader, RA Feely, T Gkritzalis, I Harris, J Hauck, T Ilyina, AK Jain, E Kato, V Kitidis, K Klein Goldewijk, C Koven, P Landschützer, SK Lauvset, N Lefèvre, A Lenton, ID Lima, N Metzl, F Millero, DR Munro, A Murata, JEMS Nabel, S Nakaoka, Y Nojiri, K O'Brien, A Olsen, T Ono, FF Pérez, B Pfeil, D Pierrot, B Poulter, G Rehder, C Rödenbeck, S Saito, U Schuster, J Schwinger, R Séférian, T Steinhoff, BD Stocker, AJ Sutton, T Takahashi, B Tilbrook, IT van der Laan-Luijkx, GR van der Werf, S van Heuven, D Vandemark, N Viovy, A Wiltshire, S Zaehle, and N Zeng 2015 Global Carbon Budget 2015 Earth System Science Data, 7, 349-396 doi:10.5194/essd-7-349-2015

[38] This estimate is derived by taking the CO2 emissions reported by the EIA and multiplying by 1.39 to convert to CO_2e. Energy Information Agency. 2015. *U.S. Energy-Related Carbon Dioxide Emissions, 2014*. http://www.eia.gov/environment/emissions/carbon/

APPENDIX A: WATER USE FACTORS BY TECHNOLOGY & PHASE

Barrels of Water / Barrel of Oil Produced					
Low	**Mean**	**High**	**Technology**	**Source**	**Upgrading Included?**
	2.52		M	Keiter 2010	Uncertain
0.7	4.5	11.5	IS	GAO 2010	Yes
1.5	2.5	3.6	SR	GAO 2010	Yes
	4.8		IS	NRDC 2011	Yes
	3		U	Rand 2005	Uncertain
	3.29		M	DOI 2008	Uncertain
	3.29		SR	DOI 2008	Uncertain
	2		IS	DOI 2008	Uncertain
	2.94		SR	URS 2008	Yes
	1.52		IS	URS 2008	Yes
	2		IS	Burian 2009	Uncertain
	0.75		ISA	Burian 2009	Uncertain
0.6		1.3	IS	AMEC 2014	Yes
2.4		2.6	IS	AMEC 2014	Yes
0.3		1	IS	AMEC 2014	Yes
1.4		1.6	IS	AMEC 2014	Yes
1	5	12	IS	GAO 2010	Uncertain
2		4	SR	GAO 2010	Uncertain
2.6		4	SR	OSTS PEIS	Yes
1		3	IS	OSTS PEIS	Yes
2.5		4	IS	Gleick 1994	
1.5		2	SR	Email from R. Dubuc	Yes
	0.47			Redleaf NOI	
Phased Water Use Factors[39]				**Source**	**Phase**
0	0.7	1	IS	GAO 2010	Extraction/Retort
0.6	0.9	1.6	IS	GAO 2010	Upgrading

39 Phased water use factors were used to estimate missing water use where certain steps like upgrading were known to be missing, but were not used in the water use profile.

0.1	1.5	3.4	IS	GAO 2010	Power Generation
0	1.4	5.5	IS	GAO 2010	Reclamation
0.9	1.5	1.9	SR	GAO 2010	Extraction/Retort/Upgrade
0	0.3	0.9	SR	GAO 2010	Power Generation
0.6	0.7	0.8	SR	GAO 2010	Reclamation
	0.19		SR	URS 2008	Mining and Crushing
	0.28		SR	URS 2008	Retorting
	0.777		SR	URS 2008	Upgrading
	1.54		SR	URS 2008	Processing Shale Disposal
	0.15		SR	URS 2008	Revegetation
	0.18		IS	URS 2008	Site Preparation
	0.25		IS	URS 2008	Subsurface Preparation
	0.57		IS	URS 2008	production/upgrading
	0.53		IS	URS 2008	reclamation and rinsing

Technology Key	Description	Min	Max	Median	25th Percentile	75th Percentile
IS	In Situ	0.3	12	2	1.075	3.75
SR	Surface Retort	1.5	4	2.6	2	3.445
M	Mix	2.52	3.29	2.905	2.7125	3.0975
U	Uncertain	3	3	3	3	3
ISA	In Situ With Technology Advancements	0.75	0.75	0.75	0.75	0.75
ALL	All Technologies – includes water use claims that have not been demonstrated, but that are included in project development proposals.	0.3	12	2.5	1.5	3.445
ISU	In Situ - Upgrading Confirmed Included	0.3	11.5	1.52	1	2.8
SRU	Surface Retort - Upgrading Confirmed Included	1.5	4	2.55	1.875	3.105

APPENDIX B: WATER FOOTPRINT TABLES FOR OS AND TS NON-FEDERAL PROJECTS AND FEDERAL RD&D PROJECTS

Table B.1. Water Footprints for Non Federal and Federal RD&D Oil Shale Projects

Millions of Barrels of Water needed to produce specified Oil Shale Resources by extraction technology and range of water use factors Non-federal Projects – 3,543 MMBbls						
Technology	*Description*	Min	Max	Median	25th Percentile	75th Percentile
ISA	In Situ With Technology Advancements	1,994	19,251	4,501	3,137	7,082
ALL	All Technologies	2,833	30,716	9,005	6,052	12,206
ISU	In Situ - Upgrading Confirmed Included	4,337	28,635	7,428	6,069	10,359
SRU	Surface Retort - Upgrading Confirmed Included	7,527	12,697	9,698	8,303	10,846
Millions of Barrels of Water needed to produce specified Oil Shale Resources by extraction technology and range of water use factors Federal RD&D Projects – 2,428 MMBbls						
Technology	*Description*	Min	Max	Median	25th Percentile	75th Percentile
ISA	In Situ With Technology Advancements	1,821	1,821	1,821	1,821	1,821
ALL	All Technologies	728	29,136	6,070	3,642	8,364
ISU	In Situ - Upgrading Confirmed Included	728	27,922	3,691	2,428	6,798
SRU	Surface Retort - Upgrading Confirmed Included	3,642	9,712	6,191	4,553	7,539

Table B.2. Water Footprints for Non Federal and Federal RD&D Tar Sands Projects

Millions of Barrels of Water needed to produce specified Tar Sands Resources by extraction technology and range of water use factors Non-federal Projects – 179.6 MMBbls						
Technology Key	*Description*	Min	Max	Median	25th Percentile	75th Percentile
SV	Conventional mining and solvent extraction	205	4,759	861	373	2,160
ALL	All Technologies	99	233	166	132	200
SRU	Surface retort upgrading confirmed included	395	727	561	478	644
SAGDU	SAGD Upgrading confirmed included	90	629	350	144	561
CSSU	CSS upgrading confirmed included	557	557	557	557	557
Millions of Barrels of Water needed to produce specified Tar Sands Resources by extraction technology and range of water use factors **Federal Resource Available for Lease – 4,125 MMBbls**						
Technology Key	*Description*	22	53	38	30	45
SV	Conventional mining and solvent extraction	4,703	109,313	19,779	8,570	49,603
ALL	All Technologies	2,269	5,363	3,816	3,042	4,589
SRU	Surface retort upgrading confirmed included	9,075	16,706	12,891	10,983	14,798
SAGDU	SAGD Upgrading confirmed included	2,063	14,438	8,044	3,300	12,891
CSSU	CSS upgrading confirmed included	12,788	12,788	12,788	12,788	12,788

APPENDIX C: WATER FOOTPRINT TABLES FOR ALL IN PLACE FEDERAL OS AND TS RESOURCES AVAILABLE AND THOSE AVAILABLE FOR LEASE UNDER PEIS AND ROD[40] IN THE PICEANCE BASIN (COLORADO), GREEN RIVER AND WASHAKIE BASINS (WYOMING), AND UINTAH BASIN (UTAH).

Table C.1. Water Footprints for In Place Federal Oil Shale Resources in CO, WY and UT[41]

Millions of Barrels of Water needed to produce specified Oil Shale Resources by extraction technology and range of water use factors In Place Federal Resources Available in Piceance Basin (yield > 25 GPT) 284,800 MMBbls – CO						
Technology	*Description*	Min	Max	Median	25th Percentile	75th Percentile
ISA	*In Situ With Technology Advancements*	213,600	213,600	213,600	213,600	213,600
ALL	*All Technologies*	85,440	3,417,600	712,000	427,200	981,136
ISU	*In Situ - Upgrading Confirmed Included*	85,440	3,275,200	432,896	284,800	797,440
SRU	*Surface Retort - Upgrading Confirmed Included*	427,200	1,139,200	726,240	534,000	884,304

Millions of Barrels of Water needed to produce specified Oil Shale Resources by extraction technology and range of water use factors In Place Federal Resources Available in Green River and Washakie Basins (yield > 15 GPT) – 72,179 MMBbls – WY						
Technology	*Description*	Min	Max	Median	25th Percentile	75th Percentile
ISA	*In Situ With Technology Advancements*	54,134	54,134	54,134	54,134	54,134
ALL	*All Technologies*	21,654	866,148	180,448	108,269	248,657
ISU	*In Situ - Upgrading Confirmed Included*	21,654	830,059	109,712	72,179	202,101
SRU	*Surface Retort - Upgrading Confirmed Included*	108,269	288,716	184,056	135,336	224,116

Millions of Barrels of Water needed to produce specified Oil Shale Resources by extraction technology and range of water use factors In Place Federal Resources Available in Uintah Basin (yield > 25 GPT) – 26,703 MMBbls - UT						
Technology	*Description*	Min	Max	Median	25th Percentile	75th Percentile
ISA	*In Situ With Technology Advancements*	20,027	20,027	20,027	20,027	20,027
ALL	*All Technologies*	8,011	320,437	66,758	40,055	91,992
ISU	*In Situ - Upgrading Confirmed Included*	8,011	307,086	40,589	26,703	74,769

[40] PEIS is the programmatic environmental impact statement; ROD is the record of decision in which the amount of federal resource available for lease is specified. Available from: http://ostseis.anl.gov/

[41] Different thresholds were used by USGS to account for Wyoming oil shale deposits to account for the extensive resources, but

SRU	*Surface Retort - Upgrading Confirmed Included*	40,055	106,812	68,093	50,068	82,913

Table C.2. Water Footprints for In Place Federal Oil Shale Resources Available for Lease under PEIS and ROD in CO and WY and UT

Millions of Barrels of Water needed to produce specified Oil Shale Resources by extraction technology and range of water use factors In Place Federal Resources Available for Lease Under PEIS and ROD UT - Uintah Basin – 26,703 MMBbls						
Technology	*Description*	Min	Max	Median	25th Percentile	75th Percentile
ISA	*In Situ With Technology Advancements*	20,027	20,027	20,027	20,027	20,027
ALL	*All Technologies*	8,011	320,437	66,758	40,055	91,992
ISU	*In Situ - Upgrading Confirmed Included*	8,011	307,086	40,589	26,703	74,769
SRU	*Surface Retort - Upgrading Confirmed Included*	40,055	106,812	68,093	50,068	82,913

Millions of Barrels of Water needed to produce specified Oil Shale Resources by extraction technology and range of water use factors In Place Federal Resources Available for Lease Under PEIS and ROD CO - Piceance Basin – 7,890 MMBbls						
Technology	*Description*	Min	Max	Median	25th Percentile	75th Percentile
ISA	*In Situ With Technology Advancements*	1,152	1,152	1,152	1,152	1,152
ALL	*All Technologies*	461	18,432	3,840	2,304	5,292
ISU	*In Situ - Upgrading Confirmed Included*	461	17,664	2,335	1,536	4,301
SRU	*Surface Retort - Upgrading Confirmed Included*	2,304	6,144	3,917	2,880	4,769

Millions of Barrels of Water needed to produce specified Oil Shale Resources by extraction technology and range of water use factors In Place Federal Resources Available for Lease Under PEIS and ROD WY – 35,074 MMBbls						
Technology	*Description*	Min	Max	Median	25th Percentile	75th Percentile
ISA	*In Situ With Technology Advancements*	26,306	26,306	26,306	26,306	26,306
ALL	*All Technologies*	10,522	420,889	87,685	52,611	120,830
ISU	*In Situ - Upgrading Confirmed Included*	10,522	403,352	53,313	35,074	98,207
SRU	*Surface Retort - Upgrading Confirmed Included*	52,611	140,296	89,439	65,764	108,905

Table C.3. Water Footprints for All In Place Federal Tar Sands Resources in WY and UT

Millions of Barrels of Water needed to produce specified Tar Sands Resources by extraction technology and range of water use factors Federal In Place Tar Sands – 10,834 MMBbls - UT						
Technology Key	Description	Min	Max	Median	25th Percentile	75th Percentile
SV	Conventional mining and solvent extraction	12,351	287,112	51,951	22,508	130,284
SAGD	In situ steam assisted gravity drainage	5,959	14,085	10,022	7,990	12,053
CSS	In situ cyclical steam stimulation	23,836	43,879	33,858	28,847	38,868
IS	In situ (un specified)	5,417	37,920	21,127	8,668	33,858
M	Mixed technology types	33,587	33,587	33,587	33,587	33,587
ALL	All Technologies	5,417	287,112	32,503	16,522	43,744
SRU	Surface retort upgrading confirmed included	24,919	43,338	62,298	34,128	52,818
SAGDU	SAGD Upgrading confirmed included	14,085	14,085	14,085	14,085	14,085
CSSU	CSS upgrading confirmed included	23,836	23,836	23,836	23,836	23,836

Millions of Barrels of Water needed to produce specified Tar Sands Resources by extraction technology and range of water use factors Federal In Place Tar Sands - 40.60 MMBbls - WY						
Technology Key	Description	Min	Max	Median	25th Percentile	75th Percentile
SV	Conventional mining and solvent extraction	46	1,076	195	84	488
SAGD	In situ steam assisted gravity drainage	22	53	38	30	45
CSS	In situ cyclical steam stimulation	89	164	127	108	146
IS	In situ (un specified)	20	142	79	32	127
M	Mixed technology types	126	126	126	126	126
ALL	All Technologies	20	1,076	122	62	164
SRU	Surface retort upgrading confirmed included	93	162	233	128	198
SAGDU	SAGD Upgrading confirmed included	53	53	53	53	53
CSSU	CSS upgrading confirmed included	89	89	89	89	89

APPENDIX D: WATER FOOTPRINT TABLES FOR EACH OS AND TS DEVELOPMENT LEASE

Table D.1. Water Footprints for Oil Shale Leases in CO, WY and UT

	Millions of Barrels of Water needed to produce specified Oil Shale Resources by extraction technology and range of water use factors American Shale Oil LLC[42] RD&D Round 1 Lease - 1,536 MMBbls - Rio Blanco County, CO						
Developer Estimate	*Technology*	*Description*	Min	Max	Median	25th Percentile	75th Percentile
1,536[43]	*ISA*	*In Situ With Technology Advancements*	1,152	1,152	1,152	1,152	1,152
	ALL	*All Technologies*	461	18,432	3,840	2,304	5,292
	ISU	*In Situ - Upgrading Confirmed Included*	461	17,664	2,335	1,536	4,301
	SRU	*Surface Retort - Upgrading Confirmed Included*	2,304	6,144	3,917	2,880	4,769

	Millions of Barrels of Water needed to produce specified Oil Shale Resources by extraction technology and range of water use factors Enefit American Oil RD&D Round 1 Lease (includes BLM preferential lease) 545 MMBbls – Vernal, UT						
Developer Estimate	*Technology*	*Description*	Min	Max	Median	25th Percentile	75th Percentile
1,455[44]	*ISA*	*In Situ With Technology Advancements*	409	409	409	409	409
	ALL	*All Technologies*	164	6,540	1,363	818	1,878
	ISU	*In Situ - Upgrading Confirmed Included*	164	6,268	828	545	1,526
	SRU	*Surface Retort - Upgrading Confirmed Included*	818	2,180	1,390	1,022	1,692

	Millions of Barrels of Water needed to produce specified Oil Shale Resources by extraction technology and range of water use factors AuraSource RD&D Round 2 Lease – 47 MMBbls - Vernal, UT						
Developer Estimate	*Technology*	*Description*	Min	Max	Median	25th Percentile	75th Percentile

42 This project was withdrawn after the analysis.

43 http://amso.net/our-commitment/environment/. *AMSO* states it's goal is to use less than 1 barrel of water per barrel of shale oil; however we assume the process uses 1 barrel of water per barrel of oil since the company literature does not specify water use except to say it uses less than one gallon.

44 http://enefitutah.com/project/low-water-use/. Enefit cites Harvard University and the National Shale Oil Associating and indicates oil shale uses .06 gallons / 1000 kcal of energy produced, which is (1,400,000 kcal / 1 barrel of oil) x (.06 gallons of water / 1,000 kcal) x (1 barrel of water (US) / 31.5 gallons of water) = 2.67 barrels of water per barrel of oil.

47[45]	*ISA*	*In Situ With Technology Advancements*	35	35	35	35	35
	ALL	*All Technologies*	14	564	118	71	162
	ISU	*In Situ - Upgrading Confirmed Included*	14	541	71	47	132
	SRU	*Surface Retort - Upgrading Confirmed Included*	71	188	120	88	146

	Millions of Barrels of Water needed to produce specified Oil Shale Resources by extraction technology and range of water use factors Natural Soda Holdings RD&D Round 2 Lease - MMBbls - Rio Blanco County, CO – 300 MMBbls						
Developer Estimate	*Technology*	*Description*	Min	Max	Median	25th Percentile	75th Percentile
0.1198 [46]	*ISA*	*In Situ With Technology Advancements*	225	225	225	225	225
	ALL	*All Technologies*	90	3,600	750	450	1,034
	ISU	*In Situ - Upgrading Confirmed Included*	90	3,450	456	300	840
	SRU	*Surface Retort - Upgrading Confirmed Included*	450	1,200	765	563	932

	Millions of Barrels of Water needed to produce specified Oil Shale Resources by extraction technology and range of water use factors Enefit SITLA (state leases - Utah Trust Lands Administration) – 415 MMBbls - UT						
Developer Estimate	*Technology*	*Description*	Min	Max	Median	25th Percentile	75th Percentile
1,108[47]	*ISA*	*In Situ With Technology Advancements*	311	311	311	311	311
	ALL	*All Technologies*	125	4,980	1,038	623	1,430
	ISU	*In Situ - Upgrading Confirmed Included*	125	4,773	631	415	1,162
	SRU	*Surface Retort - Upgrading Confirmed*	623	1,660	1,058	778	1,289

[45] http://www.aurasourceinc.com/n12.html. We assume the process uses the maximum scenario of 1 barrel of water per barrel of oil since the company literature says that the amount of water use is less than 1, but does not specify.

[46] From Table 2.3 in http://www.blm.gov/style/medialib/blm/co/field_offices/white_river_field/oil_shale/Round_2_-_POO_and_Map.Par.73287.File.dat/doiblmco11020110177ea_final.pdf. Assuming 32 year project lifetime, total water use is (100 barrels x 30 days) + (365 days x 32 years x 10 barrels per day) = 119,800 barrels of water.

[47] See footnote 28.

		Included					

	Millions of Barrels of Water needed to produce specified Oil Shale Resources by extraction technology and range of water use factors Enefit North - 321 MMBbls - UT						
Developer Estimate	*Technology*	*Description*	Min	Max	Median	25th Percentile	75th Percentile
857[48]	*ISA*	*In Situ With Technology Advancements*	241	241	241	241	241
	ALL	*All Technologies*	96	3,852	803	482	1,106
	ISU	*In Situ - Upgrading Confirmed Included*	96	3,692	488	321	899
	SRU	*Surface Retort - Upgrading Confirmed Included*	482	1,284	819	602	997

	Millions of Barrels of Water needed to produce specified Oil Shale Resources by extraction technology and range of water use factors Enefit Orion Property - 132 MMBbls - UT						
Developer Estimate	*Technology*	*Description*	Min	Max	Median	25th Percentile	75th Percentile
352[49]	*ISA*	*In Situ With Technology Advancements*	99	99	99	99	99
	ALL	*All Technologies*	40	1,584	330	198	455
	ISU	*In Situ - Upgrading Confirmed Included*	40	1,518	201	132	370
	SRU	*Surface Retort - Upgrading Confirmed Included*	198	528	337	248	410

	Millions of Barrels of Water needed to produce specified Oil Shale Resources by extraction technology and range of water use factors Enefit South – 1,200 MMBbls - UT						
Developer Estimate	*Technology*	*Description*	Min	Max	Median	25th Percentile	75th Percentile
3,204[50]	*ISA*	*In Situ With Technology Advancements*	900	900	900	900	900
	ALL	*All Technologies*	360	14,400	3,000	1,800	4,134
	ISU	*In Situ - Upgrading Confirmed Included*	360	13,800	1,824	1,200	3,360
	SRU	*Surface Retort - Upgrading Confirmed Included*	1,800	4,800	3,060	2,250	3,726

	Millions of Barrels of Water needed to produce specified Oil Shale Resources by extraction technology and range of water use factors

48 See footnote 28.
49 See footnote 28.
50 See footnote 28.

	Red Leaf proposed oil shale development (Seep Ridge, Holiday Block, Wyoming Holdings) – 1,349 MMBbls						
Developer Estimate	Technology Key	Description	Min	Max	Median	25th Percentile	75th Percentile
2,023[51]	IS	In Situ	405	16,188	2,698	1,450	5,059
	SR	Surface Retort	2,024	5,396	3,507	2,698	4,647
	M	Mix	3,399	4,438	3,919	3,659	4,179
	U	Uncertain	4,047	4,047	4,047	4,047	4,047
	ISA	In Situ With Technology Advancements	1,012	1,012	1,012	1,012	1,012
	ALL	All Technologies	405	16,188	3,373	2,024	4,647
	ISU	In Situ - Upgrading Confirmed Included	405	15,514	2,050	1,349	3,777
	SRU	Surface Retort - Upgrading Confirmed Included	2,024	5,396	3,440	2,529	4,189

	Millions of Barrels of Water needed to produce specified Oil Shale Resources by extraction technology and range of water use factors TomCoEnergy proposed oil shale developments – 126 MMBbls						
	Technology Key	Description	Min	Max	Median	25th Percentile	75th Percentile
189[52]	IS	In Situ	38	1,512	252	135	473
	SR	Surface Retort	189	504	328	252	434
	M	Mix	318	415	366	342	390
	U	Uncertain	378	378	378	378	378
	ISA	In Situ With Technology Advancements	95	95	95	95	95
	ALL	All Technologies	38	1,512	315	189	434
	ISU	In Situ - Upgrading Confirmed Included	38	1,449	192	126	353
	SRU	Surface Retort - Upgrading Confirmed Included	189	504	321	236	391

[51] http://www.riversimulator.org/Pubs/OSTS/Ref/Presentations4RedLeaf.pdf. Pg 28. 1.5 barrels of water / barrel of oil

[52] Since this project uses the same technology as Red Leaf, and water use data for TomCoEnergy could not be found, we apply the same 1.5 barrels of water / barrel of oil that Red Leaf cites.

Table D.2. Water Footprints for Tar Sands Leases in CO, WY and UT

Millions of Barrels of Water needed to produce specified Tar Sands Resources by extraction technology and range of water use factors PR Spring Special Tar Sands Area (STSA) – 4,125 MMBbls - UT						
Technology Key	Description	Min	Max	Median	25th Percentile	75th Percentile
SV	Conventional mining and solvent extraction	4,703	109,313	19,779	8,570	49,603
SAGD	In situ steam assisted gravity drainage	2,269	5,363	3,816	3,042	4,589
CSS	In situ cyclical steam stimulation	9,075	16,706	12,891	10,983	14,798
IS	In situ (un specified)	2,063	14,438	8,044	3,300	12,891
M	Mixed technology types	12,788	12,788	12,788	12,788	12,788
ALL	All Technologies	2,063	109,313	12,375	6,291	16,655
SRU	Surface retort upgrading confirmed included	9,488	16,500	23,719	12,994	20,109
SAGDU	SAGD Upgrading confirmed included	5,363	5,363	5,363	5,363	5,363
CSSU	CSS upgrading confirmed included	9,075	9,075	9,075	9,075	9,075

	Millions of Barrels of Water needed to produce specified Tar Sands Resources by extraction technology and range of water use factors US Oil Sands proposed tar sands development – 9.6 MMBbls						
Developer Estimate	Technology Key	Description	Min	Max	Median	25th Percentile	75th Percentile
14.4[53]	SV	Conventional mining and solvent extraction	11	254	46	20	115
	ALL	All Technologies	5	254	29	15	39
	SRU	Surface retort upgrading confirmed included	22	38	55	30	47
	SAGDU	SAGD Upgrading confirmed included	12	12	12	12	12
	CSSU	CSS upgrading confirmed included	21	21	21	21	21

	Millions of Barrels of Water needed to produce specified Tar Sands Resources by extraction technology and range of water use factors American Sands Energy Corporation – 150 MMBbls						
Developer Estimate	Technology Key	Description	Min	Max	Median	25th Percentile	75th Percentile
NA[54]	SV	Conventional mining and	171	3,975	719	312	1,804

53 http://www.usoilsandsinc.com/index.php/operations/environmental-leadership/water-conservation. 1.5 barrels of water / barrel of oil

54 This company seems to have gone out of business and its website is no longer accessible. No information found.

		solvent extraction					
	ALL	All Technologies	75	3,975	450	229	606
	SRU	Surface retort upgrading confirmed included	345	600	863	473	731
	SAGDU	SAGD Upgrading confirmed included	195	195	195	195	195
	CSSU	CSS upgrading confirmed included	330	330	330	330	330

	Millions of Barrels of Water needed to produce specified Tar Sands Resources by extraction technology and range of water use factors MCW - asphalt ridge – 20 MMBbls						
Developer Estimate	Technology Key	Description	Min	Max	Median	25th Percentile	75th Percentile
NA[55]	SV	Conventional mining and solvent extraction	23	530	96	42	241
	ALL	All Technologies	10	530	60	31	81
	SRU	Surface retort upgrading confirmed included	46	80	115	63	98
	SAGDU	SAGD Upgrading confirmed included	26	26	26	26	26
	CSSU	CSS upgrading confirmed included	44	44	44	44	44

[55] http://www.mcwenergygroup.com/technology/overview. It appears MCW's technology is an effort to use solvents on a pile of oil sands tailing on a liner above ground. No mention of water use, only water discharge, which may be from separation.

APPENDIX E: GHG EMISSIONS FOOTPRINT TABLES FOR TS & OS NON-FEDERAL PROJECTS & FEDERAL RD&D PROJECTS

Table E.1. GHG emissions footprints for Non Federal and Federal RD&D Oil Shale Projects

Life-cycle emissions, in Gigatons CO2e, of developing specific Oil Shale Resources Under Various Emissions Factors and Technologies Non-federal Projects – 3,543 MMBbls			
Technology	Low	Median	High
Surface Retort - Based on Alberta Taciuk Processor (ATP)	1.16	1.23	1.33
In Situ - Shell In Situ Conversion Process (ICP)	0.96	1.09	1.24
Life-cycle emissions, in Gigatons CO2e, of developing specific Oil Shale Resources Under Various Emissions Factors and Technologies Federal RD&D Projects – 2,428 MMBbls			
Technology	Low	Median	High
Surface Retort - Based on Alberta Taciuk Processor (ATP)	0.79	0.85	0.91
In Situ - Shell In Situ Conversion Process (ICP)	0.66	0.75	0.85

Table E.2. GHG emissions footprints for Non-Federal and Federal RD&D Tar Sands Projects

Life-cycle emissions, in Gigatons CO2e, of developing specific Tar Sands Resources Under Various Emissions Factors and Technologies Federal + Non-federal – 4,304.6 MMBbls			
Technology	Low	Median	High
In Situ SAGD (steam assisted gravity drainage) SCO (synthetic crude oil) - coker upgrader	1.42	1.44	1.46
In Situ SAGD SCO - ebulated bed resid hydrocracking upgrader	1.46	1.48	1.50
In Situ SAGD Bitumen	1.38	1.40	1.42
Surface Mining SCO - coker	1.40	1.42	1.44
Surface Mining Bitumen	1.37	1.39	1.41
Life-cycle emissions, in Gigatons CO2e, of developing specific Tar Sands Resources Under Various Emissions Factors and Technologies Non-federal Projects – 179.6 MMBbls			
Technology	Low	Median	High
In Situ SAGD (steam assisted gravity drainage) SCO (synthetic crude oil) - coker upgrader	0.06	0.06	0.06
In Situ SAGD SCO - ebulated bed resid hydrocracking upgrader	0.06	0.06	0.06
In Situ SAGD Bitumen	0.06	0.06	0.06
Surface Mining SCO - coker	0.06	0.06	0.06

Surface Mining Bitumen	0.06	0.06	0.06
Life-cycle emissions, in Gigatons CO2e, of developing specific Tar Sands Resources Under Various Emissions Factors and Technologies Federal Resource Available for Lease – 4,125 MMBbls			
Technology	Low	Median	High
In Situ SAGD (steam assisted gravity drainage) SCO (synthetic crude oil) - coker upgrader	1.36	1.38	1.40
In Situ SAGD SCO - ebulated bed resid hydrocracking upgrader	1.40	1.41	1.43
In Situ SAGD Bitumen	1.33	1.34	1.36
Surface Mining SCO - coker	1.34	1.36	1.38
Surface Mining Bitumen	1.32	1.33	1.35

APPENDIX F: GHG EMISSIONS FOOTPRINT TABLES FOR IN PLACE FEDERAL OS & TS RESOURCES AVAILABLE IN CO, WY AND UT AND THOSE OS RESOURCES AVAILABLE FOR LEASE UNDER PEIS & ROD[56] IN CO, WY AND UT

Table F.1. GHG emissions footprints for In Place Federal Oil Shale Resources in CO, WY and UT

Life-cycle emissions, in Gigatons CO2e, of developing specific Oil Shale Resources Under Various Emissions Factors and Technologies In Place Federal Resources Available in Piceance Basin (yield > 25 GPT) – 284,800 MMBbls - CO			
Technology	Low	Median	High
Surface Retort - Based on Alberta Taciuk Processor (ATP)	92.87	99.27	107.11
In Situ - Shell In Situ Conversion Process (ICP)	77.15	87.93	99.97

Life-cycle emissions, in Gigatons CO2e, of developing specific Oil Shale Resources Under Various Emissions Factors and Technologies In Place Federal Resources Available in Green River and Washakie Basins (yield > 15 GPT) – 72,179 MMBbls - WY			
Technology	Low	Median	High
Surface Retort - Based on Alberta Taciuk Processor (ATP)	23.54	25.16	27.15
In Situ - Shell In Situ Conversion Process (ICP)	19.55	22.28	25.34

Life-cycle emissions, in Gigatons CO2e, of developing specific Oil Shale Resources Under Various Emissions Factors and Technologies In Place Federal Resources Available in Uintah Basin (yield > 25 GPT) – 26,703 MMBbls - UT			
Technology	Low	Median	High
Surface Retort - Based on Alberta Taciuk Processor (ATP)	8.71	9.31	10.04
In Situ - Shell In Situ Conversion Process (ICP)	7.23	8.24	9.37

Table F.2. GHG emissions footprints for In Place Federal Oil Shale Resources Available for lease under PEIS and ROD in CO and WY and UT

Life-cycle emissions, in Gigatons CO2e, of developing specific Oil Shale Resources Under Various Emissions Factors and Technologies In Place Federal Resources Available for Lease Under PEIS and ROD - CO - Piceance Basin – 7,890 MMBbls:			
Technology	Low	Median	High
Surface Retort - Based on Alberta Taciuk Processor (ATP)	2.57	2.75	2.97
In Situ - Shell In Situ Conversion Process (ICP)	2.14	2.44	2.77
Life-cycle emissions, in Gigatons CO2e, of developing specific Oil Shale Resources Under Various Emissions			

[56] PEIS is the programmatic environmental impact statement; ROD is the record of decision in which the amount of federal resource available for lease is specified. Available from: http://ostseis.anl.gov/

Factors and Technologies In Place Federal Resources Available for Lease Under PEIS and ROD - WY – 35,074 MMBbls			
Technology	Low	Median	High
Surface Retort - Based on Alberta Taciuk Processor (ATP)	11.44	12.23	13.19
In Situ - Shell In Situ Conversion Process (ICP)	9.50	10.83	12.31

Life-cycle emissions, in Gigatons CO2e, of developing specific Oil Shale Resources Under Various Emissions Factors and Technologies In Place Federal Resources Available for Lease Under PEIS and ROD - UT - Uintah Basin – 26,703 MMBbls:			
Technology	Low	Median	High
Surface Retort - Based on Alberta Taciuk Processor (ATP)	8.71	9.31	10.04
In Situ - Shell In Situ Conversion Process (ICP)	7.23	8.24	9.37

Table F.3. GHG emissions footprints for In Place Federal Tar Sands Resources in WY and UT

Life-cycle emissions, in Gigatons CO2e, of developing specific Tar Sands Resources Under Various Emissions Factors and Technologies Federal In Place Tar Sands – 10,834 MMBbls - UT			
Technology	Low	Median	High
In Situ SAGD (steam assisted gravity drainage) SCO (synthetic crude oil) - coker upgrader	3.58	3.62	3.67
In Situ SAGD SCO - ebulated bed resid hydrocracking upgrader	3.68	3.71	3.76
In Situ SAGD Bitumen	3.48	3.52	3.57
Surface Mining SCO - coker	3.53	3.57	3.62
Surface Mining Bitumen	3.46	3.50	3.55
Life-cycle emissions, in Gigatons CO2e, of developing specific Tar Sands Resources Under Various Emissions Factors and Technologies Federal In Place Tar Sands – 40.6 MMBbls - WY			
Technology	Low	Median	High
In Situ SAGD (steam assisted gravity drainage) SCO (synthetic crude oil) - coker upgrader	0.01	0.01	0.01
In Situ SAGD SCO - ebulated bed resid hydrocracking upgrader	0.01	0.01	0.01
In Situ SAGD Bitumen	0.01	0.01	0.01
Surface Mining SCO - coker	0.01	0.01	0.01
Surface Mining Bitumen	0.01	0.01	0.01

APPENDIX G: GHG EMISSIONS FOOTPRINT TABLES FOR EACH TS & OS DEVELOPMENT LEASE IN CO, WY AND UT

Table G.1. GHG emissions footprints for Oil Shale Leases in CO, WY and UT

Life-cycle emissions, in Gigatons CO2e, of developing specific Oil Shale Resources Under Various Emissions Factors and Technologies American Shale Oil LLC RD&D Round 1 Lease - MMBbls - Rio Blanco County, CO – 1,536 MMBbls			
Technology	Low	Median	High
Surface Retort - Based on Alberta Taciuk Processor (ATP)	0.50	0.54	0.58
In Situ - Shell In Situ Conversion Process (ICP)	0.42	0.47	0.54
Life-cycle emissions, in Gigatons CO2e, of developing specific Oil Shale Resources Under Various Emissions Factors and Technologies Enefit American Oil RD&D Round 1 Lease (includes BLM preferential lease) – 545 MMBbls - Vernal, UT			
Technology	Low	Median	High
Surface Retort - Based on Alberta Taciuk Processor (ATP)	0.18	0.19	0.20
In Situ - Shell In Situ Conversion Process (ICP)	0.15	0.17	0.19
Life-cycle emissions, in Gigatons CO_2e, of developing specific Oil Shale Resources Under Various Emissions Factors and Technologies AuraSource RD&D Round 2 Lease – 47 MMBbls - Vernal, UT			
Technology	Low	Median	High
Surface Retort - Based on Alberta Taciuk Processor (ATP)	0.02	0.02	0.02
In Situ - Shell In Situ Conversion Process (ICP)	0.01	0.01	0.02
Life-cycle emissions, in Gigatons CO_2e, of developing specific Oil Shale Resources Under Various Emissions Factors and Technologies Natural Soda Holdings RD&D Round 2 Lease - MMBbls - Rio Blanco County, CO – 300 MMBbls			
Technology	Low	Median	High
Surface Retort - Based on Alberta Taciuk Processor (ATP)	0.10	0.10	0.11
In Situ - Shell In Situ Conversion Process (ICP)	0.08	0.09	0.11
Life-cycle emissions, in Gigatons CO_2e, of developing specific Oil Shale Resources Under Various Emissions Factors and Technologies Enefit SITLA (state leases - Utah Trust Lands Administration) - MMBbls – UT – 415 MMBbls			
Technology	Low	Median	High
Surface Retort - Based on Alberta Taciuk Processor (ATP)	0.14	0.14	0.16
In Situ - Shell In Situ Conversion Process (ICP)	0.11	0.13	0.15
Life-cycle emissions, in Gigatons CO_2e, of developing specific Oil Shale Resources Under Various Emissions Factors and Technologies			

Enefit North - MMBbls – UT – 321 MMBbls			
Technology	Low	Median	High
Surface Retort - Based on Alberta Taciuk Processor (ATP)	0.10	0.11	0.12
In Situ - Shell In Situ Conversion Process (ICP)	0.09	0.10	0.11
Life-cycle emissions, in Gigatons CO_2e, of developing specific Oil Shale Resources Under Various Emissions Factors and Technologies Enefit Orion Property - MMBbls – UT – 132 MMBbls			
Technology	Low	Median	High
Surface Retort - Based on Alberta Taciuk Processor (ATP)	0.04	0.05	0.05
In Situ - Shell In Situ Conversion Process (ICP)	0.04	0.04	0.05
Life-cycle emissions, in Gigatons CO_2e, of developing specific Oil Shale Resources Under Various Emissions Factors and Technologies Enefit South - MMBbls – UT – 1,200 MMBbls			
Technology	Low	Median	High
Surface Retort - Based on Alberta Taciuk Processor (ATP)	0.39	0.42	0.45
In Situ - Shell In Situ Conversion Process (ICP)	0.33	0.37	0.42
Life-cycle emissions, in Gigatons CO_2e, of developing specific Oil Shale Resources Under Various Emissions Factors and Technologies TomCoEnergy proposed oil shale developments 126 MMBbls			
Technology	Low	Median	High
Surface Retort - Based on Alberta Taciuk Processor (ATP)	0.04	0.04	0.05
In Situ - Shell In Situ Conversion Process (ICP)	0.03	0.04	0.04
Life-cycle emissions, in Gigatons CO_2e, of developing specific Oil Shale Resources Under Various Emissions Factors and Technologies Red Leaf proposed oil shale development (Seep Ridge, Holiday Block, Wyoming Holdings) – 1,349 MMBbls			
Technology	Low	Median	High
Surface Retort - Based on Alberta Taciuk Processor (ATP)	0.44	0.47	0.51
In Situ - Shell In Situ Conversion Process (ICP)	0.37	0.42	0.47

Table G.2. GHG emissions footprints for Tar Sands Leases in CO, WY and UT

Life-cycle emissions, in Gigatons CO_2e, of developing specific Tar Sands Resources Under Various Emissions Factors and Technologies PR Spring Special Tar Sands Area (STSA) – 4,125 MMBbls - UT			
Technology	Low	Median	High

In Situ SAGD (steam assisted gravity drainage) SCO (synthetic crude oil) - coker upgrader	1.36	1.38	1.40
In Situ SAGD SCO - ebulated bed resid hydrocracking upgrader	1.40	1.41	1.43
In Situ SAGD Bitumen	1.33	1.34	1.36
Surface Mining SCO - coker	1.34	1.36	1.38
Surface Mining Bitumen	1.32	1.33	1.35

Life-cycle emissions, in Gigatons CO_2e, of developing specific Tar Sands Resources Under Various Emissions Factors and Technologies
US Oil Sands proposed tar sands development –- 9.6 MMBbls

Technology	Low	Median	High
In Situ SAGD (steam assisted gravity drainage) SCO (synthetic crude oil) - coker upgrader	0.003	0.003	0.003
In Situ SAGD SCO - ebulated bed resid hydrocracking upgrader	0.003	0.003	0.003
In Situ SAGD Bitumen	0.003	0.003	0.003
Surface Mining SCO - coker	0.003	0.003	0.003
Surface Mining Bitumen	0.003	0.003	0.003

Life-cycle emissions, in Gigatons CO_2e, of developing specific Tar Sands Resources Under Various Emissions Factors and Technologies
American Sands Energy Corporation – 150 MMBbls

Technology	Low	Median	High
In Situ SAGD (steam assisted gravity drainage) SCO (synthetic crude oil) - coker upgrader	0.05	0.05	0.05
In Situ SAGD SCO - ebulated bed resid hydrocracking upgrader	0.05	0.05	0.05
In Situ SAGD Bitumen	0.05	0.05	0.05
Surface Mining SCO - coker	0.05	0.05	0.05
Surface Mining Bitumen	0.05	0.05	0.05

Life-cycle emissions, in Gigatons CO_2e, of developing specific Tar Sands Resources Under Various Emissions Factors and Technologies
MCW – Asphalt Ridge – 20 MMBbls

Technology	Low	Median	High
In Situ SAGD (steam assisted gravity drainage) SCO (synthetic crude oil) - coker upgrader	0.01	0.01	0.01
In Situ SAGD SCO - ebulated bed resid hydrocracking upgrader	0.01	0.01	0.01
In Situ SAGD Bitumen	0.01	0.01	0.01

Surface Mining SCO - coker	0.01	0.01	0.01
Surface Mining Bitumen	0.01	0.01	0.01

APPENDIX H: ACREASE OF EACH TS & OS DEVELOPMENT LEASE IN CO, WY AND UT

Table H.1. Acreage of Oil Shale and Tar Sands developments

Project	Type	Acres
American Shale Oil LLC RD&D Round 1 Lease - MMBbls - Rio Blanco County, CO	Oil Shale	160[a]
Enefit American Oil RD&D Round 1 Lease (includes BLM preferential lease) - MMBbls - Vernal, UT	Oil Shale	160[a]
AuraSource RD&D Round 2 Lease - MMBbls - Vernal, UT	Oil Shale	160[a]
Natural Soda Holdings RD&D Round 2 Lease - MMBbls - Rio Blanco County, CO	Oil Shale	160[a]
Enefit SITLA (state leases - Utah Trust Lands Administration) - MMBbls - UT	Oil Shale	4,051
Enefit North - MMBbls - UT	Oil Shale	4,592
Enefit Orion Property - MMBbls - UT	Oil Shale	3,070
Enefit South - MMBbls - UT	Oil Shale	13,441
TomCoEnergy proposed oil shale developments	Oil Shale	2,919
Red Leaf proposed oil shale development (Seep Ridge, Holiday Block, Wyoming Holdings)	Oil Shale	12,720
US Oil Sands proposed tar sands development in PR Spring STSA - MMBbls - UT	Tar Sands	6,017
US Oil Sands proposed tar sands development (private land)	Tar Sands	315
American Sands Energy Corporation	Tar Sands	1,760
MCW - asphalt ridge	Tar Sands	1,128

a – excludes preference area

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