Estimates of In-Place Oil Shale of Various Grades on Federal Lands, Piceance Basin, Colorado*

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Search and Discovery Article #10305 (2011)
Posted March 7, 2011

*Adapted from oral presentation at AAPG International Conference and Exhibition, Calgary, Alberta, Canada, September 12-15, 2010

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Abstract

The Eocene Green River Formation in the Piceance Basin of western Colorado contains the largest oil shale deposits in the world. The U.S. Geological Survey (USGS) recently completed a comprehensive assessment of in-place oil resources, regardless of richness, incorporating the considerable amount of oil-yield data collected since a 1989 USGS in-place assessment. The new estimate of in-place oil in the Piceance Basin is about 1.5 trillion barrels, an increase of 50 percent over the previous in-place assessment. Most of this increase is due to: (1) additional areas being assessed that previously had too little data for assessment purposes; and (2) new intervals being assessed.

The entire oil shale interval in the Piceance Basin is subdivided into seventeen “rich” and “lean” zones that were assessed separately. These zones are roughly time-stratigraphic units consisting of distinctive, laterally continuous sequences of oil shale beds that can be traced throughout much of the Piceance Basin. Several subtotals of the 1.5 trillion barrels total were calculated: (1) about 920 billion barrels (60 percent) exceed 15 gallons per ton (GPT); (2) about 352 billion barrels (23 percent) exceed 25 GPT; (3) more than one trillion barrels (70 percent) underlie Federally-managed lands; and (4) about 689 billion barrels (75 percent) of the 15 GPT total and about 284 billion barrels (19 percent) of the 25 GPT total are under Federal mineral (subsurface) ownership. These 15 and 25 GPT estimates include only those areas where the weighted average of an entire zone exceeds those minimum cutoffs. In areas where the entire zone does not meet the minimum criteria, some oil shale intervals of significant thicknesses could exist within the zone that exceed these minimum cutoffs. For example, a 30-ft interval within an oil shale zone might exceed 25 GPT but if the entire zone averages less than 25 GPT, these resources are not included in the 15 and 25 GPT subtotals, although they might be exploited in the future.
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By
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[Use of trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey]
• The USGS Piceance and Uinta Basin oil shale assessments are now available at the USGS oil shale web page.

• Type “oil shale usgs” in Google and the oil shale web page is first on the list. (It’s about 241 megabytes).

• It calculates in-place oil for 17 oil shale zones using a one-acre cell size.
Oil Shale Resources in the Green River Formation, Uinta Basin, Utah

By U.S. Geological Survey Oil Shale Assessment Team

USGS Digital Data Series DS-69-RR
2010

U.S. Department of the Interior
U.S. Geological Survey
## Piceance Basin assessment

- **ReadMeFile** (607 KB)
- **Chapter 1** (40.6 MB)
  An Assessment of In-Place Oil Shale Resources in the Green River Formation, Piceance Basin, Colorado
  By Ronald C. Johnson, Tracey J. Mercier, Michael E. Brownfield, Michael P. Pantea, and Jesse G. Self
- **Chapter 2** (12.6 MB)
  Nahcolite Resources in the Green River Formation, Piceance Basin, Colorado
  By Michael E. Brownfield, Tracey J. Mercier, Ronald C. Johnson, and Jesse G. Self
- **Chapter 3** (16.3 MB)
  Methodology for Calculating Oil Shale and Nahcolite Resources for the Piceance Basin
  By Tracey J. Mercier, Michael E. Brownfield, and Ronald C. Johnson
- **Chapter 4** (362 KB)
  The GIS Project for the Geologic Assessment of In-Place Oil Shale Resources of the Piceance Basin, Colorado
  By Tracey J. Mercier, Gregory L. Gunther, and Christopher C. Skinner
- **Chapter 5** (1.4 MB)
  Stratigraphic Cross Sections of the Eocene Green River Formation in the Piceance Basin, Northwestern Colorado
  By Jesse G. Self, Ronald C. Johnson, Michael E. Brownfield, and Tracey J. Mercier
- **Chapter 6** (6.9 MB)
  Calculation of Overburden Above the Mahogany Zone in the Piceance Basin, Colorado
  By Tracey J. Mercier
- **Chapter 7** (1.8 MB)
  Fischer Assay Histograms of Oil Shale Drill Cores and Cuttings from the Piceance Basin, Northwestern Colorado
  By Jesse G. Self, Michael E. Brownfield, Ronald C. Johnson, and Tracey J. Mercier

- **GIS/Data/Metadata**
  - **Spatial Data**
Uinta Basin assessment

- **ReadMeFile** (918 KB)
- **Chapter 1** (53.3 MB)
  Assessment of In-Place Oil Shale Resources in the Eocene Green River Formation, Uinta Basin, Utah and Colorado
  By Ronald C. Johnson, Tracey J. Mercier, Michael E. Brownfield, and Jesse G. Self
- **Chapter 2** (8.8 MB)
  Sodium Carbonate Resources of the Eocene Green River Formation, Uinta Basin, Utah and Colorado
  By Michael E. Brownfield, Ronald C. Johnson, and John R. Dyni
- **Chapter 3** (39.1 MB)
  Methodology for Calculating Oil Shale Resources for the Uinta Basin, Utah and Colorado
  By Tracey J. Mercier, Michael E. Brownfield, and Ronald C. Johnson
- **Chapter 4** (489 KB)
  The GIS Project for the Geologic Assessment of In-Place Oil Shale Resources of the Uinta Basin, Utah and Colorado
  By Tracey J. Mercier, Gregory L. Gunther, and Christopher C. Skinner
- **Chapter 5** (2.1 MB)
  Fischer Assay Histograms of Oil Shale Drill Cores and Cuttings from the Uinta Basin, Utah and Colorado
  By Jesse G. Self, Michael E. Brownfield, Ronald C. Johnson, and Tracey J. Mercier
- **Chapter 6** (6.3 MB)
  Calculation of Overburden above the Mahogany Bed in the Uinta Basin, Utah and Colorado
  By Tracey J. Mercier
- **Chapter 7** (1.8 MB)
  Intertonguing of the Lower Part of the Uinta Formation with the Upper Part of the Green River Formation in the Piceance Creek Basin During the Late Stages of Lake Uinta
  By John R. Donnell

- **GIS/Data/Metadata**
  - **Spatial Data**
All data used were put into a single Access database

• The ability to create custom forms in Access was a crucial element in the assessment methodology as it allowed staff to write Visual Basic scripts and SQL statements to filter subsets of the data and perform the necessary calculations using Access form controls.

• The Radial Basis Function method was used to generate maps and resource numbers. (Kriging and the Inverse Distance Weighted methods were also tried).
• The public benefits from this process as the original forms used to calculate resources also serve as an end-user interface to view the raw data in a more simplified and meaningful manner.
• After resources were calculated for each core hole, the resultant Access tables were linked with ESRI's ArcGIS software to model, extrapolate, and quantify the data spatially.
• The end product is a database of tables (spreadsheets), forms to view the data, and a series of GIS maps quantifying the results of those calculations.
Piceance Basin: 1,335 square miles (3,458 square kilometers).  
**In-place resource: 1.52 trillion barrels.**

Uinta Basin: 3,834 square miles (9,930 square kilometers).  
**In-place resource: 1.32 trillion barrels.**
Saline Lake Uinta was created when two smaller fresh-water lakes expanded to cover the Douglas Creek arch and form one large lake.

Prior to this, the arch acted as a hinge line between two subsiding basins with little to no sediments accumulating on the crest.

Low subsidence rates continued over the arch throughout Green River Fm. deposition.

Stratigraphic cross section showing Cretaceous and lower Tertiary rocks, and oil, gas and water occurrence in selected wells in the Uinta and Piceance Basins, Utah and Colorado
Cross section showing stages of Lake Uinta:

1) Freshwater
2) Illitic oil shale
3) Carbonate oil shale and saline mineral
4) Infilling

North-south cross section of Tertiary rocks, Piceance Basin, Colorado
Rich oil shale is only exposed around the basin margins. The central part of the basin is largely covered by volcaniclastic sandstones of the Uinta Formation.

Oblique photo of the oil shale deposits of the Piceance Basin with an overburden map showing cubic miles of overburden per square mile.
Typical outcrop of Uinta Formation sandstones. Note back-rotated slump block.
Rich oil shale units are persistent around the basin margins. Bradley (1931) traced the richest oil shale interval around the entire margin of the Piceance Basin and into the eastern Uinta Basin to the west.
Mahogany ledge 20 miles southwest of Anvil Points. Note Mahogany ledge in background (arrows).
Mahogany ledge (top of ridge, arrow) along lower Piceance Creek in northern part of Piceance Basin.
Mahogany ledge (arrow) along Evacuation Creek in eastern Uinta Basin.
The oil shale interval in the Piceance and Uinta Basins was subdivided by Cashion and Donnell (1972) into 18 rich and lean oil shale zones.

Each zone was assessed separately here.

Some oil shale zones can be traced over a lateral distance of more than 200 miles (322 km).
Four maps were generated for each of the 17 oil shale zones.
Variations in barrels of oil per acre (BPA)

Total oil per 36 square mile township
The oil shale resources under any given area can be calculated using the ArcGIS project. A one-acre cell size is used.

Generalized map showing Federal subsurface ownership, Piceance Basin.

Figure 1. Map showing Federal surface management and Federal mineral rights of oil shale resources in the Eocene Green River Formation, Piceance Basin, Colorado.
Area with maximum in-place oil shale resources is largely Federally owned.
Cross section shown in next slide
Estimates of 15 gallon per ton shale and 25 gallon per ton shale is done by oil shale zone. The entire zone must exceed these values.
The R-1 zone in the first well would easily exceed 15 gallons per ton if the mudstone wedge were removed. An attempt was made to subdivide the R-1 zone into two parts above and below the mudstone, but it was discovered that several mudstone units occur at various stratigraphic positions in the R-1.
<table>
<thead>
<tr>
<th>Oil shale zone</th>
<th>Total Oil in-place</th>
<th>Federal Mineral</th>
<th>Federal Surface</th>
<th>Oil yield of 15 gallons per ton or greater</th>
<th>Oil yield of 25 gallons per ton or greater</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>in-place as % of total in-place</td>
<td>in-place as % of total in-place</td>
<td>in-place as % of total in-place</td>
<td>in-place as % of total in-place</td>
<td>in-place as % of total in-place</td>
</tr>
<tr>
<td>Bed 44</td>
<td>185,500</td>
<td>109,900</td>
<td>59%</td>
<td>103,000</td>
<td>55%</td>
</tr>
<tr>
<td>A-groove</td>
<td>6,283</td>
<td>4,394</td>
<td>70%</td>
<td>4,178</td>
<td>66%</td>
</tr>
<tr>
<td>Mahogany zone</td>
<td>191,700</td>
<td>129,600</td>
<td>68%</td>
<td>124,200</td>
<td>65%</td>
</tr>
<tr>
<td>B-groove</td>
<td>7,819</td>
<td>5,463</td>
<td>70%</td>
<td>5,256</td>
<td>67%</td>
</tr>
<tr>
<td>R-6</td>
<td>185,400</td>
<td>127,400</td>
<td>69%</td>
<td>122,300</td>
<td>66%</td>
</tr>
<tr>
<td>L-5</td>
<td>66,060</td>
<td>46,900</td>
<td>71%</td>
<td>46,520</td>
<td>71%</td>
</tr>
<tr>
<td>R-5</td>
<td>198,200</td>
<td>147,600</td>
<td>74%</td>
<td>142,200</td>
<td>72%</td>
</tr>
<tr>
<td>L-4</td>
<td>69,130</td>
<td>54,530</td>
<td>79%</td>
<td>52,920</td>
<td>77%</td>
</tr>
<tr>
<td>R-4</td>
<td>127,200</td>
<td>97,840</td>
<td>77%</td>
<td>94,600</td>
<td>74%</td>
</tr>
<tr>
<td>L-3</td>
<td>22,500</td>
<td>17,580</td>
<td>78%</td>
<td>17,070</td>
<td>77%</td>
</tr>
<tr>
<td>R-3</td>
<td>68,080</td>
<td>56,480</td>
<td>83%</td>
<td>55,040</td>
<td>81%</td>
</tr>
<tr>
<td>L-2</td>
<td>24,220</td>
<td>19,860</td>
<td>82%</td>
<td>19,290</td>
<td>80%</td>
</tr>
<tr>
<td>R-2</td>
<td>66,770</td>
<td>52,350</td>
<td>78%</td>
<td>50,700</td>
<td>70%</td>
</tr>
<tr>
<td>L-1</td>
<td>15,070</td>
<td>10,790</td>
<td>72%</td>
<td>10,310</td>
<td>68%</td>
</tr>
<tr>
<td>R-1</td>
<td>186,410</td>
<td>124,900</td>
<td>64%</td>
<td>118,300</td>
<td>61%</td>
</tr>
<tr>
<td>L-0</td>
<td>8,265</td>
<td>6,023</td>
<td>73%</td>
<td>5,799</td>
<td>70%</td>
</tr>
<tr>
<td>R-0</td>
<td>83,420</td>
<td>58,240</td>
<td>70%</td>
<td>55,600</td>
<td>67%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,522,000</strong></td>
<td><strong>1,070,000</strong></td>
<td><strong>70%</strong></td>
<td><strong>1,027,000</strong></td>
<td><strong>67%</strong></td>
</tr>
</tbody>
</table>

Total Federal ownership and total oil shale that exceeds 15 gallons per ton (GPT) and 25 GPT for each of the 17 oil shale zones. The entire zone must exceed these cutoffs to be counted.
About 1 trillion barrels or 70% of the 1.5 trillion barrels total is on Federal lands.

60% of total oil shale exceeds 15 gallons per ton (GPT), whereas only 23% exceeds 25 GPT.

75% of 15 GPT or greater and 81% of 25 GPT or greater is on Federal lands.
Oil shale contains nahcolite (NaHCO₃) in the “saline depocenter.” We also assessed the amount of nahcolite on Federal land.
Most common saline minerals found in the Green River Formation, Piceance Basin:

- Nahcolite: $\text{NaHCO}_3$
- Dawsonite: $\text{NaAl(OH)}_2\text{CO}_3$
- Halite: $\text{NaCl}$
Nahcolite occurs as thick beds associated with halite, as aggregates in oil shale, and disseminated in oil shale.
Cross section shown in next slide.
Nahcolite is currently being leached out by groundwater movement and once extended to near the limits of dawsonite occurrence.
• Nahcolite occurs in the richest part of the oil shale in the north-central part of the Piceance Basin.

• The presence of nahcolite is a concern for in-situ oil shale processes because nahcolite decomposes to natrite \((\text{Na}_2\text{CO}_3)\) or soda ash, carbon dioxide, and water at temperatures near 100°C during the recovery processes.

• Dawsonite thermally breaks down at a temperature of 200° to 370°C into soda ash, \(\text{AL}_2\text{O}_3\), water, and \(\text{CO}_2\).

• In addition, nahcolite is considered a leasable mineral and cannot be discarded during processes used to recover oil from oil shale.
• 40.5 billion tons out of a total of 43.3 billion tons or 94% of the nahcolite is under Federal land.
More oil shale was once under public lands.

In 1986, 82,000 acres of the oil shale area was allowed to go to patent under the 1872 Mining Claims law.
The Federal Government used to control even more of the oil shale in the Piceance Basin.

- The General Mining Act of 1872 is a United States federal law that authorizes and governs prospecting and mining for economic minerals, such as gold, platinum, and silver, on federal public lands. This law, approved on May 10, 1872, codified the informal system of acquiring and protecting mining claims on public land, formed by prospectors in California and Nevada from the late 1840s through the 1860s. (Wikipedia)
• The **Mineral Leasing Act of 1920** made certain nonmetallic minerals, such as **petroleum** and **oil shale**, not open to claim staking.

• Large parts of the Piceance Basin were staked for oil shale just prior to the act taking effect.

• Interest in oil shale declined in the 1920s, and these claims languished for many decades.

• In the 1970s and 1980s there were attempts to bring many of these old claims to patent.
The areas allowed to go to patent in 1986 even though there are no outcrops of rich oil shale in the claims.
Volcaniclastic sandstones of the Uinta Formation cover the central part of the basin, but marlstone tongues of the Green River Formation are present as well. The white band is the Thirteenmile Creek Tongue of the Green River Formation at Horse Draw. These tongues contain thin beds of oil shale that were claimed under the 1872 Mining Act.
White marlstone tongue (arrow) of the Green River Formation in Uinta Formation sandstone. Some of these tongues have been mapped for many tens of miles and include thin oil shale beds.
Thin oil shale beds in marlstone tongue of Green River Formation (arrow) were staked under the 1872 Mining Act.
Reasonable Man Hypothesis

• Would a reasonable man in 1920 be able to deduce that rich oil shale lay beneath the surface based on thin oil shale exposed on the surface? The government’s mineral examiner went into the field to examine the claims as part of the patenting process. He needed to be convinced that a reasonable person could expect to find oil shale under the claims based on nearby outcrops of shale.

Gary Aho (written communication, 2010)
This was a lawyer’s dream come true.
South to north cross section across the Piceance Basin showing intertonguing relationship between the Uinta Formation and the Green River Formation (from Johnson, 1981).

This cross section showing that these marl tongues merge with the main oil shale section to the south was used in the court case. Would a reasonable man in 1920 have known this? Highly unlikely.
Woodruff and Day (USGS Bulletin 581, 1913, published in 1915) outlined area underlain by bituminous shale (yellow) in the southern part of the Piceance Basin.
In 1916, Winchester (USGS Bulletin 641-F) published a more detailed outline of the Green River Formation in the Piceance Basin and described it as “Contains beds of oil shale in most places.”
<table>
<thead>
<tr>
<th>Oil shale zone</th>
<th>Lost barrels</th>
<th>Total oil in place</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bed 44</td>
<td>24,684</td>
<td>186,500</td>
</tr>
<tr>
<td>A-groove</td>
<td>680</td>
<td>6,283</td>
</tr>
<tr>
<td>Mahogany zone</td>
<td>22,199</td>
<td>191,700</td>
</tr>
<tr>
<td>B-groove</td>
<td>804</td>
<td>7,819</td>
</tr>
<tr>
<td>R-6</td>
<td>22,390</td>
<td>185,400</td>
</tr>
<tr>
<td>L-5</td>
<td>6,727</td>
<td>66,060</td>
</tr>
<tr>
<td>R-5</td>
<td>19,051</td>
<td>198,200</td>
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<td>L-4</td>
<td>5,804</td>
<td>69,130</td>
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<td>R-4</td>
<td>10,633</td>
<td>127,200</td>
</tr>
<tr>
<td>L-3</td>
<td>1,719</td>
<td>22,500</td>
</tr>
<tr>
<td>R-3</td>
<td>4,508</td>
<td>68,080</td>
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<tr>
<td>L-2</td>
<td>1,892</td>
<td>24,220</td>
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<td>6,371</td>
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<td>L-1</td>
<td>1,692</td>
<td>15,070</td>
</tr>
<tr>
<td>R-1</td>
<td>24,970</td>
<td>195,400</td>
</tr>
<tr>
<td>L-0</td>
<td>813</td>
<td>8,265</td>
</tr>
<tr>
<td>R-0</td>
<td>9,539</td>
<td>83,420</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>164,475</strong></td>
<td><strong>1,522,000</strong></td>
</tr>
</tbody>
</table>

In 1986 the Federal Government allowed over 164 billion barrels or 11 percent of the total oil in place to go to patent under the 1872 mining law.

Numbers are in millions of barrels.
Ongoing projects

- Variations in water content of oil shale.
- Redoing the resource maps depicting weight percent oil instead of gallons per ton of oil.
- Combining Uinta and Piceance Basins.
- Weight percent is more meaningful in countries that use metric.
- Variations in specific gravity of oil shale.
We recently used our Fischer assay database to calculate water content in oil shale

**Fischer Assay**

ASTM: D 3904-90

Products Collected
- condensed oil
- condensed water
- spent rock

Reported Values
- wt% oil
- wt% water
- wt% loss (gases)
- oil density
- coking tendency

95 g of <8 mesh rock is heated from 25 to 500°C in 40 min. and held at 500°C for an additional 40 min.

The Fischer assay method measures water content as well as oil content.
The Piceance Basin is a high semi-arid plateau with limited water resources. Water in the major rivers in the area is largely over-allocated. It has been suggested that water from retorting oil shale could provide a significant amount of the water needed for an oil shale industry.
Recent estimates of water requirements vary from 1-10 barrels of water per barrel of oil produced, depending on the type of retort process used.

Alberta Taciuk Retort

Adapted from material provided by Shell Exploration and Development Company.
As a result, we can use the same methodology used to calculate oil shale resources. Gallons of water per ton (GPT) instead of gallons of oil per ton. Gallons of water per acre (GPA) instead of barrels of oil per acre (nobody uses barrels of water).
GPT of water decreases from about 4 to 6 around the basin margins to less than 2 in the central part of the basin. GPA water also decreases from as much as 5 million to less than one million in this same central basin area. **Water increases towards basin margins due to an increase in clay?** Water-to-oil ratios are significantly less than one.
Variations in gallons per ton oil in the R-6 zone, Uinta and Piceance Basins.
Average weight percent oil in the Mahogany zone. The richest oil shale zone never exceeds 13%.
References Cited


Thank You

http://energy.usgs.gov