UTAH MINING 2016

by Taylor Boden, Ken Krahulec, Michael Vanden Berg, and Andrew Rupke

CIRCULAR 124
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
2018

UTAH MINING 2016

by Taylor Boden, Ken Krahulec, Michael Vanden Berg, and Andrew Rupke

ISBN: 978-1-55791-944-1

Cover photo: *Example of historical open-cut gilsonite mining in the Eocene-age Green River Formation, on the southeast end of the Cowboy vein, Uintah County.*

CIRCULAR 124
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
2018

Blank pages are intentional for printing purposes.

STATE OF UTAH
Gary R. Herbert, Governor

DEPARTMENT OF NATURAL RESOURCES
Michael Styler, Executive Director

UTAH GEOLOGICAL SURVEY
Richard G. Allis, Director

PUBLICATIONS
contact
Natural Resources Map & Bookstore
1594 W. North Temple
Salt Lake City, UT 84116
telephone: 801-537-3320
toll-free: 1-888-UTAH MAP
website: utahmapstore.com
email: geostore@utah.gov

UTAH GEOLOGICAL SURVEY
contact
1594 W. North Temple, Suite 3110
Salt Lake City, UT 84116
telephone: 801-537-3300
website: geology.utah.gov

Although this product represents the work of professional scientists, the Utah Department of Natural Resources, Utah Geological Survey, makes no warranty, express or implied, regarding its suitability for a particular use. The Utah Department of Natural Resources, Utah Geological Survey, shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this product.

CONTENTS

ABSTRACT 1
INTRODUCTION 1
Background 1
Historical Context 1
Industry Overview 2
BASE AND PRECIOUS METALS 4
Production and Values 7
Copper 7
Magnesium 9
Beryllium 9
Molybdenum 9
Gold 9
Silver 10
Exploration and Development Activity 10
Bingham Canyon 10
Lisbon Valley 12
Rocky Range 12
Spor Mountain 13
Gold Hill District 13
Goldstrike District 13
Gold Springs District 13
San Francisco District 14
Drum Mountains (Detroit District) 14
West Dip District 14
Tintic District 14
Confusion Range 14
INDUSTRIAL MINERALS 15
Production and Values 15
Sand and Gravel, Crushed Stone, and Dimension Stone 15
Potash, Salt, and Magnesium Chloride 15
Portland Cement, Lime, and Limestone 15
Sulfuric Acid 16
Phosphate 16
Gilsonite 16
Bentonite, Common Clay, and High-Alumina Clay 16
Expanded Shale 16
Gypsum 17
Exploration and Development Activity 17
URANIUM 17
COAL 20
Production and Values 20
Exploration and Development Activity 22
UtahAmerican Energy, Inc. – Murray Energy Corp. 22
Lila Canyon mine 22
West Ridge Resources, Inc. – West Ridge mine 22
Canyon Fuel Company – Bowie Resource Partners, LLC 22
Dugout Canyon mine 23
Skyline mine 23
Sufco mine 23
Fossil Rock Fuels – Bowie Resources Partners, LLC 23
Cottonwood tract 23
Bronco Utah Operations, LLC 23
Emery mine 23
Rhino Resource Partners, LP 23
Castle Valley mines 23

East Mountain Energy – PacifiCorp 23
Deer Creek mine 23
Alton Coal Development 24
Coal Hollow and Burton #1 mines 24
UNCONVENTIONAL FUELS – OIL SHALE AND OIL SAND 24
Exploration and Development Activity 24
Oil Shale 24
Company development activities 24
Oil Sand 25
Company development activities 25
NEW MINERALS INFORMATION 25
ACKNOWLEDGMENTS 26
REFERENCES 26

FIGURES

Figure 1. Annual value of Utah energy and mineral production, inflation adjusted to 2017 dollars, 1960–2017 3
Figure 2. Annual value of Utah minable mineral production in nominal dollars, by industry sector, 2007–2016 3
Figure 3. Utah annual coal production and value in nominal dollars, 2000–2017 4
Figure 4. Annual value of Utah mineral production (except coal and uranium) in nominal dollars, 2007–2016 6
Figure 5. Average annual mining employment and salary in Utah, for metal, industrial minerals, and coal mines and plants 6
Figure 6. Selected base and precious metals, industrial minerals, and coal production and development activity locations in Utah during 2016 8
Figure 7. View to the east of the Bingham Canyon open pit porphyry copper-gold-molybdenum mine 12
Figure 8. Licensed uranium mills and selected uranium exploration and development activity in Utah during 2016 19
Figure 9. Location and status of Utah coal mines and associated facilities 21
Figure 10. Distribution of Utah coal, 1970–2017 22

TABLES

Table 1. Coal production in Utah by coal mine, 2009–2017 5
Table 2. Summary of estimated 2016 world metal production value, U.S. net import reliance, main producing countries, and primary uses for select metals 7
Table 3. Select metal exploration and development projects in Utah, 2016 11
Table 4. Selected industrial mineral exploration and development projects in Utah, 2016 18
Table 5. Selected uranium exploration and development projects in Utah, 2016 20

UTAH MINING 2016

by Taylor Boden, Ken Krahulec, Michael Vanden Berg, and Andrew Rupke

ABSTRACT

During 2016, Utah mining produced mineral commodities with an estimated gross value of $3.3 billion. On an inflation-adjusted basis, this is a $200 million (7%) increase from 2015, but $2.4 billion (42%) less than the 2008 record high of $5.7 billion. Nonfuel mineral production was valued at $2.8 billion, including $1.4 billion from industrial mineral production, $1.2 billion from base metal production, and $200 million from precious metal production. Utah coal production was valued at $500 million. Projections for 2017 mineral commodities production values are expected to be slightly higher than 2016.

U.S. Geological Survey preliminary 2016 data ranked Utah 10th nationally in the value of nonfuel mineral production, accounting for approximately 3.3% of the United States total. In 2016, copper was the largest contributor to the value of nonfuel minerals in Utah, having an estimated value of $782 million, and is mostly produced from Kennecott Utah Copper Corporation's Bingham Canyon mine. The largest overall contributor to the value of industrial mineral production in Utah during 2016 was from the sand and gravel and crushed stone commodity group, which had an estimated value of $449 million. Notably, Utah remains the only state in the nation that produces magnesium metal, beryllium concentrate, potash as potassium sulfate, and gilsonite.

From 2015 to 2016, Utah coal production decreased 3.7% to 14.0 million tons and is expected to increase only slightly in 2017 to 14.3 million tons. Low uranium prices persisted in 2016, and production from uranium mining operations in Utah continues to be uneconomic. Similarly, the Iron Mountain mine remained closed due to low iron ore prices.

Overall, mineral exploration and development remained relatively depressed in 2016, with exploration focused primarily on lithium, potash, gold, and copper. Well over 5000 new unpatented mining claims were filed in Utah in 2016, increasing the total number of active unpatented mining claims on file with the U.S. Bureau of Land Management to 21,497 at year end. The number of new claims and the total number of active claims both increased during 2016, signaling a possible resurgence in activity in 2017.

INTRODUCTION

Background

Utah mineral activity summaries have been compiled annually by the Utah Geological Survey (UGS) since 1989. To maintain uniformity and continuity in reporting, the general style used in previous editions of this report will be continued. Final 2015 production and economic values became available in the fourth quarter of 2016, and for this report we used those numbers to update values published in *Utah's Extractive Resource Industries 2015* (Boden and others, 2016). Commodity production and values not included in base and precious metals and industrial minerals sections were not reported due to confidentiality. Note that mineral production values reported by the U.S. Geological Survey (USGS) may differ from those reported by the UGS due to different data sources and compilation methods. The 1996–2016 Utah mineral/mining summaries are available on the UGS website at https://geology.utah.gov/resources/mineral-resources/#tab-id-2.

Since 1993, Utah mineral industry summaries have categorized mineral production and economic value into four broad segments consisting of base metals, precious metals, industrial minerals, and energy minerals (coal and uranium). In 2011, the annual Utah coal report was combined with the mineral activities summary (Gwynn and others, 2011). More recently, sections were added discussing unconventional, but mined, fuels (oil shale and oil sands) (Boden and others, 2012). The USGS, U.S. Energy Information Administration (EIA), U.S. Bureau of Land Management (BLM), Office of Natural Resources Revenue (ONRR), and the Utah Division of Oil, Gas and Mining (DOGM) provided some of the data assembled for this report. Additional data were obtained by the UGS from annual operator surveys, company websites, trade industry publications, and personal correspondence.

Historical Context

Utah contains a remarkable variety of mineral resources. Development of these resources over the past 169 years has been important to Utah and the United States. Mining plays a vital role in Utah's economy and is the oldest nonagricultural industry in the state, employing thousands directly in mining, processing, and transportation, and indirectly in supporting occupations. The recorded mining history of Utah began in 1847. Soon after their arrival, Latter-day Saints pioneers began developing mineral resources. Their early efforts included recovering salt from Great Salt Lake, coal mining (near the

communities of Coalville, Wales, and Cedar City), quarrying building stone, and production of clay and lime products (Alexander, 2006).

With the arrival of the U.S. Third California Infantry under Colonel Patrick E. Connor in the 1860s came the discovery of significant base and precious metal deposits at Bingham Canyon and Stockton in the Oquirrh Mountains, as well as in Big and Little Cottonwood canyons and the Park City area in the Wasatch Range (Krahulec, 2006). After completion of the transcontinental railroad in 1869, branch lines were developed to access mining districts, and ore produced in Utah became more valuable, exceeding $100 million by 1917 (Stowe, 1975). The development of mine and transportation infrastructure allowed Utah to become one of the largest mining and smelting centers in the western U.S. by the early 1900s. Porphyry copper mining began in Bingham Canyon in 1904, and even today, the production of copper, gold, silver, and molybdenum makes it one of the most productive deposits in the U.S. Utah has also been the nation's only source of gilsonite since the late 1880s (Boden and Tripp, 2012), beryllium since 1969 (Alexander, 2006), and magnesium metal since 1972 (Krahulec, 2006). Demand for uranium for use in nuclear weapons and power plants resulted in the development of uranium deposits in southeastern Utah during the 1950s and 1960s. In 1952, Charlie Steen discovered one of the largest uranium deposits on the Colorado Plateau and developed the Mi Vida mine in the Big Indian Wash (Lisbon Valley) area of San Juan County.

In 1969, the annual value of minerals (excluding coal) produced in Utah had grown to $500 million (Stowe, 1975), and it surpassed $1 billion in 1988 (Walker and Smith, 1989). According to data compiled by the UGS, USGS, and other sources, the inflation-adjusted value of Utah's mined minerals reached a record high of $5.7 billion in 2008. The worldwide recession beginning in late 2008 is reflected in the decreased value of Utah's minerals mined in 2009. In 2013, a massive landslide in the Bingham Canyon mine resulted in lower base and precious metals production extending through 2016.

The contribution of mineral mining to the Utah Gross Domestic Product (GDP), compared to the value of all goods and services statewide, decreased from 6% in the 1960s to 1.3% in the early 2000s as the state economy grew and diversified. Over the past several years the contribution of the mining industry to the Utah GDP has ranged between 2% and 3% (U.S. Bureau of Economic Analysis, 2016). The demand and price for Utah mineral commodities extracted by mining will likely continue to rise, and the mining industry is expected to remain an important contributor to the Utah economy.

Industry Overview

The 2016 total value of Utah fossil fuel energy and nonfuel mineral production, inflation adjusted to 2016 dollars, was $5.5 billion (figure 1). Based on UGS data, the estimated gross value from mining of Utah mineral commodities during 2016 was $3.3 billion, a 5% increase from the 2015 inflation-adjusted value. Utah's minable mineral value of $3.3 billion includes: $1.4 billion from the industrial mineral sector, the largest contributor (41% of total); $1.2 billion from base metals (37% of total); $509 million from coal (15% of total), and $226 million from precious metals (7% of total) (figure 2). Compared to 2015, the 2016 values increased for industrial minerals by $76 million (6%), for base metals by $133 million (12%), for coal by $7.8 million (2%), and for precious metals by $44 million (24%). From 2015 to 2016, prices increased for gold, silver, and beryllium, while prices decreased for copper and molybdenum, and were flat for magnesium metal. Industrial mineral prices varied slightly from 2015, with notable decreases for both potassium chloride and potassium sulfate. From 2015 to 2016, Kennecott Utah Copper (KUC) gold, silver, and copper production increased significantly, and this together with magnesium metal production resulted in an increase in the overall value of the entire metals group. Industrial mineral values increased slightly from 2015 to 2016, due in large part to higher production and prices for sand and gravel and crushed stone. Industrial minerals have experienced fairly steady growth through the past decade, having been supported by Utah construction projects and increased production of potash and salt. The value of Utah coal increased only slightly in 2016 due to modestly higher prices (figure 3). However, demand for Utah coal continues to diminish as reflected by decreased production (table 1), especially as out-of-state power plants shut down or convert to natural gas. Energy Fuels Resources suspended production of uranium and vanadium from its Utah mines in 2013 because of low uranium prices. However, the company continues to operate its White Mesa mill near Blanding in San Juan County, mostly processing uranium ore from a mine in Arizona as well as stockpiled ore.

Preliminary USGS data show Utah ranked 10th nationally in 2016 for the value of nonfuel mineral production (excluding coal), accounting for about 3.3% of the United States total (USGS, 2017a). Utah remained among the top 10 nonfuel mineral-producing states during the past decade. The USGS data also show that Utah's nonfuel mineral production value decreased 14% in 2016 to an estimated $2.5 billion; however, UGS's estimate shows a slight increase to $2.8 billion (figure 4). Between 2007 and 2016, the value of Utah nonfuel mineral production has fluctuated between $2.6 and $4.5 billion (figure 4), with notable decreases in 2015 and 2016 because of significant decreases in base and precious metals production by KUC. Utah remains the only U.S. state to produce magnesium metal, beryllium concentrate, potassium sulfate, and gilsonite. In the 2016 Fraser Institute annual survey of mining companies, Utah was ranked as the 11th most favorable state/nation out of the 104 international jurisdictions included in the survey (89th percentile) in terms of overall investment attractiveness with regard to mining (Jackson and Green, 2017). The investment attractiveness index is a combination of a region's geologic favorability along with government policies toward exploration and development. Compared to other states, Utah ranked 10th in 2016 for coal production (U.S. EIA, 2017a).

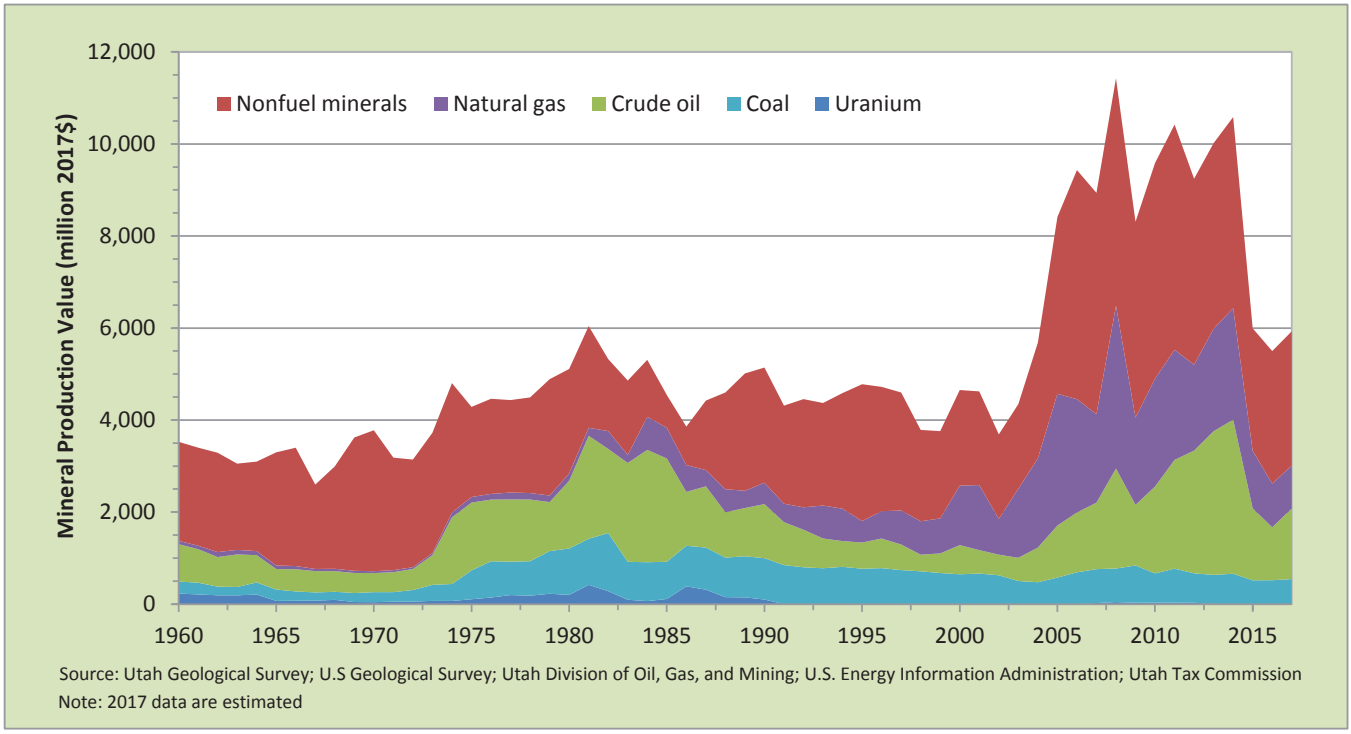

Figure 1. *Annual value of Utah energy and mineral production, inflation adjusted to 2017 dollars, 1960–2017.*

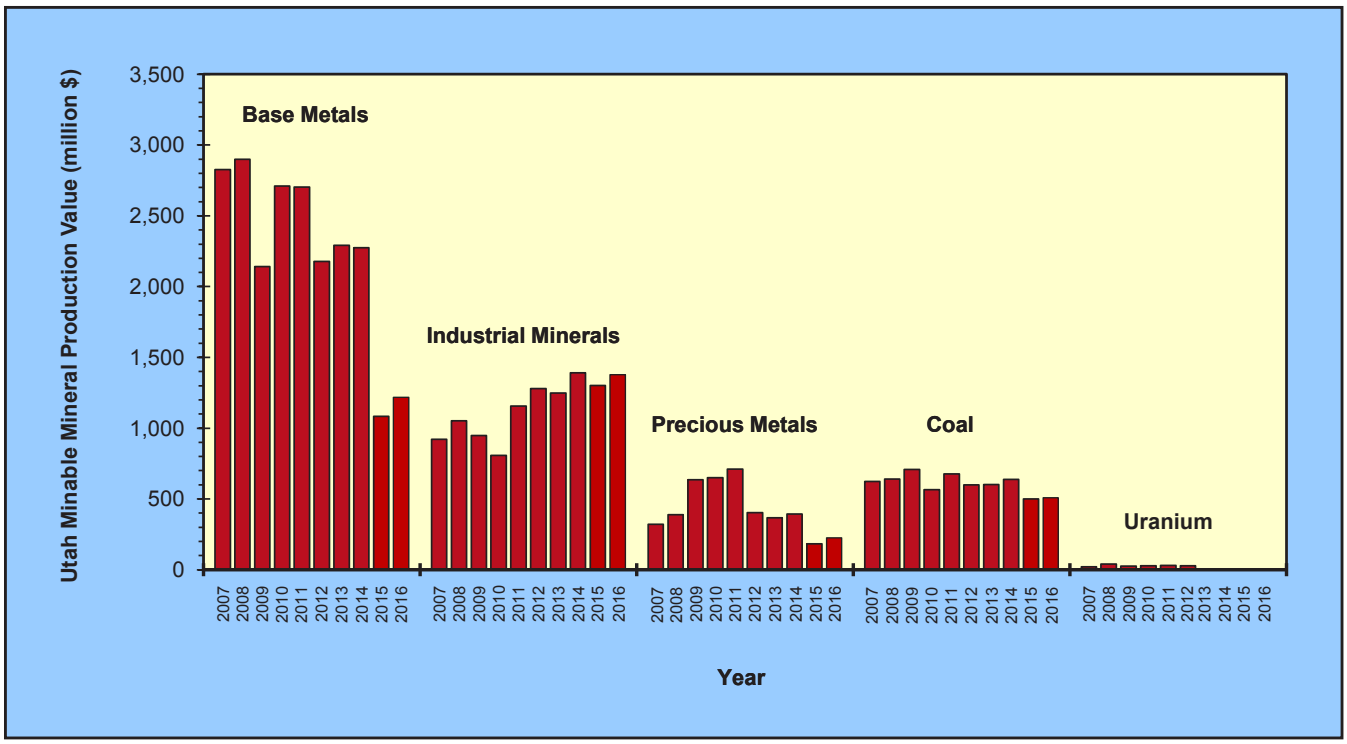

Figure 2. *Annual value of Utah minable mineral production in nominal dollars, by industry sector, 2007–2016. Source: Utah Geological Survey.*

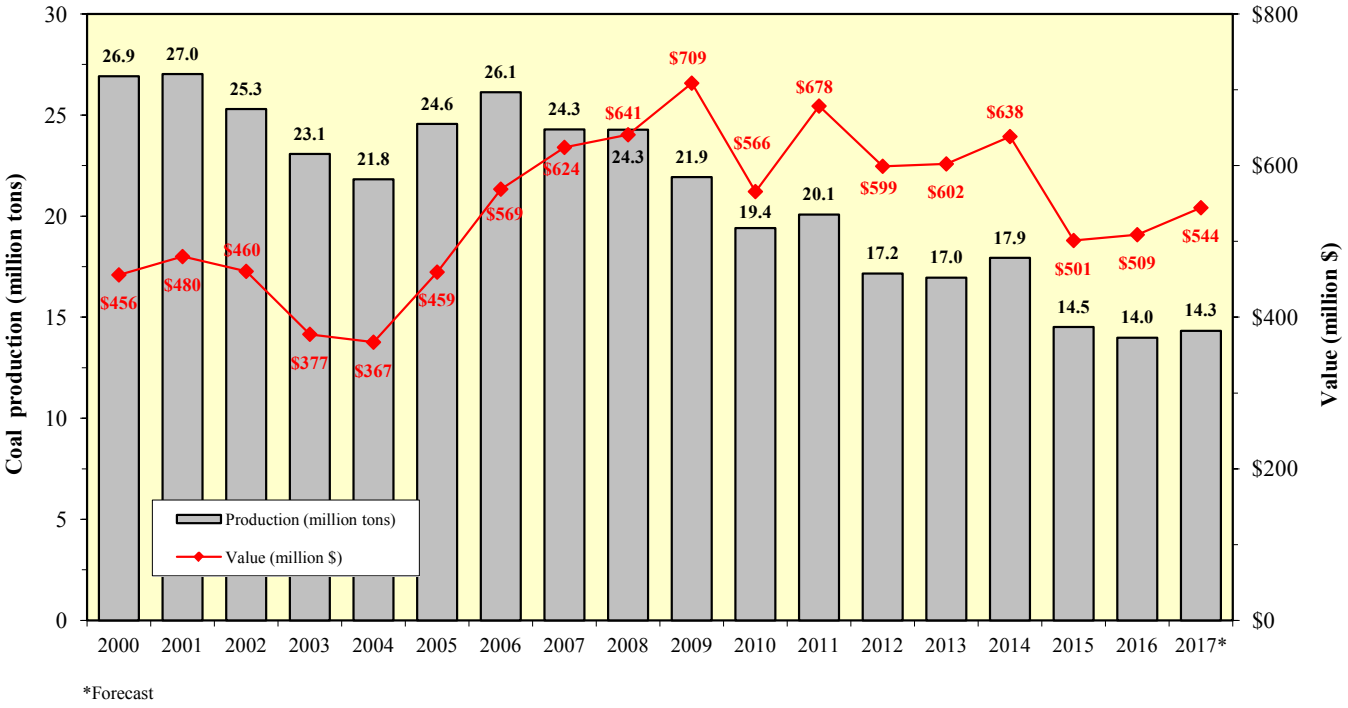

Figure 3. *Utah annual coal production and value in nominal dollars, 2000–2017.*

Utah mineral exploration, development, and production have generally all fluctuated with the commodity prices over the last 15 years. Commodity price indices were near record lows in 2002 only to rise dramatically from 2003 to 2008. The 2008 financial crisis resulted in a crash in the commodity markets that bottomed in 2009 and rose to new highs in 2011; copper reached $4.50 per pound in February 2011 and gold hit $1923 per ounce in September 2011. Subsequently, commodity prices declined steadily through 2015. This decline resulted in layoffs, closures, asset sales, and bankruptcies in the mining industry in Utah and around the world. These commodity price swings are mirrored in Utah's mining employment numbers, but in contrast, average mining salaries have steadily increased over the same timeframe (figure 5). Commodity prices stabilized in 2016 after bottoming out for iron ore in October 2015, molybdenum in November 2015, gold in December 2015, and copper and silver in January 2016.

In 2016, Utah's DOGM did not approve any new large mine permits and only seven small mine permits, of which six were for building stone, riprap, and other engineered materials, and one for humic shale. DOGM also approved 11 new exploration projects, six for precious metals, and one each for uranium, phosphate, gypsum, lithium, and humic shale. This is a decrease from two large mine permits in 2015, but an increase from five small mine permits and six exploration projects in 2015 (Paul Baker, DOGM, written communication, July 2017).

The Utah School and Institutional Trust Lands Administration (SITLA) manages about 4.4 million acres of state-owned lands in Utah. SITLA issued new leases and/or contracts on 53 mineral tracts in 2016, up 66% from 2015. These leases were issued for the following commodities: metalliferous minerals (24), sand and gravel (15), building stone (6), along with one each for potash, gilsonite, gypsum, coal, volcanic material, bituminous sand, gemstone/fossil, and humic shale (Jerry Mansfield, SITLA, written communication, July 2017).

A couple of unique factors have resulted in a dramatic increase in the number of new unpatented mining claims filed in Utah for 2016. Most notably, lithium prices increased 14% from 2015 to 2016 and construction commenced on a large lithium ion battery factory about 15 miles east of Sparks, Nevada. As a result, despite relatively flat traditional metal prices, strong interest in lithium has fostered a large increase in the number (5366) of new unpatented mining claims filed in Utah in 2016, up significantly (450%) from 2015. Grand (lithium), Tooele (lithium, gold, and copper), and Box Elder (lithium) Counties received the most activity, each having recorded over 650 newly filed claims in 2016. Garfield (lithium) and Beaver (copper and gold) Counties also experienced significant new claim staking. At the end of 2016, the BLM reported a total of 21,497 active unpatented mining claims in Utah, up (16%) from 2015 (Opie Abeyta, Utah BLM, written communication, July 2017).

BASE AND PRECIOUS METALS

Base metals are the more common, less valuable industrial metals, such as copper, molybdenum, and magnesium. Gold and silver are precious metals and have a significantly higher

Table 1. *Coal production in Utah by coal mine, 2009–2017.*

Company	Mine	County	Coalfield	2009	2010	2011	2012	2013	2014	2015	2016	2017*
				thousand short tons								
Canyon Fuel Company, LLC - Bowie Resources Partners, LLC[1]	Dugout Canyon	Carbon	Book Cliffs	3,291	2,307	2,395	1,588	561	676	763	650	626
	Skyline #3	Carbon	Wasatch Plateau	2,910	3,050	2,950	1,954	3,135	4,170	4,409	4,767	4,375
	SUFCO	Sevier	Wasatch Plateau	6,748	6,398	6,498	5,651	5,959	6,539	6,095	5,375	5,884
Bronco Utah Operations, LLC[2]	Emery	Emery	Emery	1,238	999	--	--	4	--	--	--	129
Castle Valley Mining, LLC - Rhino Resource Partners, LP[3]	Castle Valley #3	Emery	Wasatch Plateau	--	--	--	--	--	--	218	170	175
	Castle Valley #4	Emery	Wasatch Plateau	651	--	592	1,004	875	1,061	757	724	783
East Mountain Energy - PacifiCorp	Deer Creek	Emery	Wasatch Plateau	3,833	2,954	3,143	3,295	2,785	2,083	15	--	--
Hidden Splendor Resources, Inc. - America West Resources, Inc.	Horizon	Carbon	Wasatch Plateau	194	270	370	210	--	--	--	--	--
West Ridge Resources, Inc. - UtahAmerican Energy, Inc. - Murray Energy Corp.	West Ridge	Carbon	Book Cliffs	3,063	3,355	3,566	2,579	2,629	2,514	1,580	--	--
UtahAmerican Energy, Inc. - Murray Energy Corp.	Lila Canyon	Emery	Book Cliffs	--	72	157	304	257	335	350	1,587	1,629
Alton Coal Development, LLC	Coal Hollow	Kane	Alton	--	--	403	570	747	555	316	671	724
	Burton #1	Kane	Alton	--	--	--	--	--	--	11	34	--
Total				21,928	19,405	20,074	17,155	16,953	17,933	14,513	13,978	14,326

Source: UGS coal company questionnaires
*Preliminary
[1]Owned by Arch Coal until summer 2013
[2]Owned by CONSOL Energy until 2015
[3]Owned by C.W. Mining (Co-op) until summer 2010, mines formerly called Bear Canyon

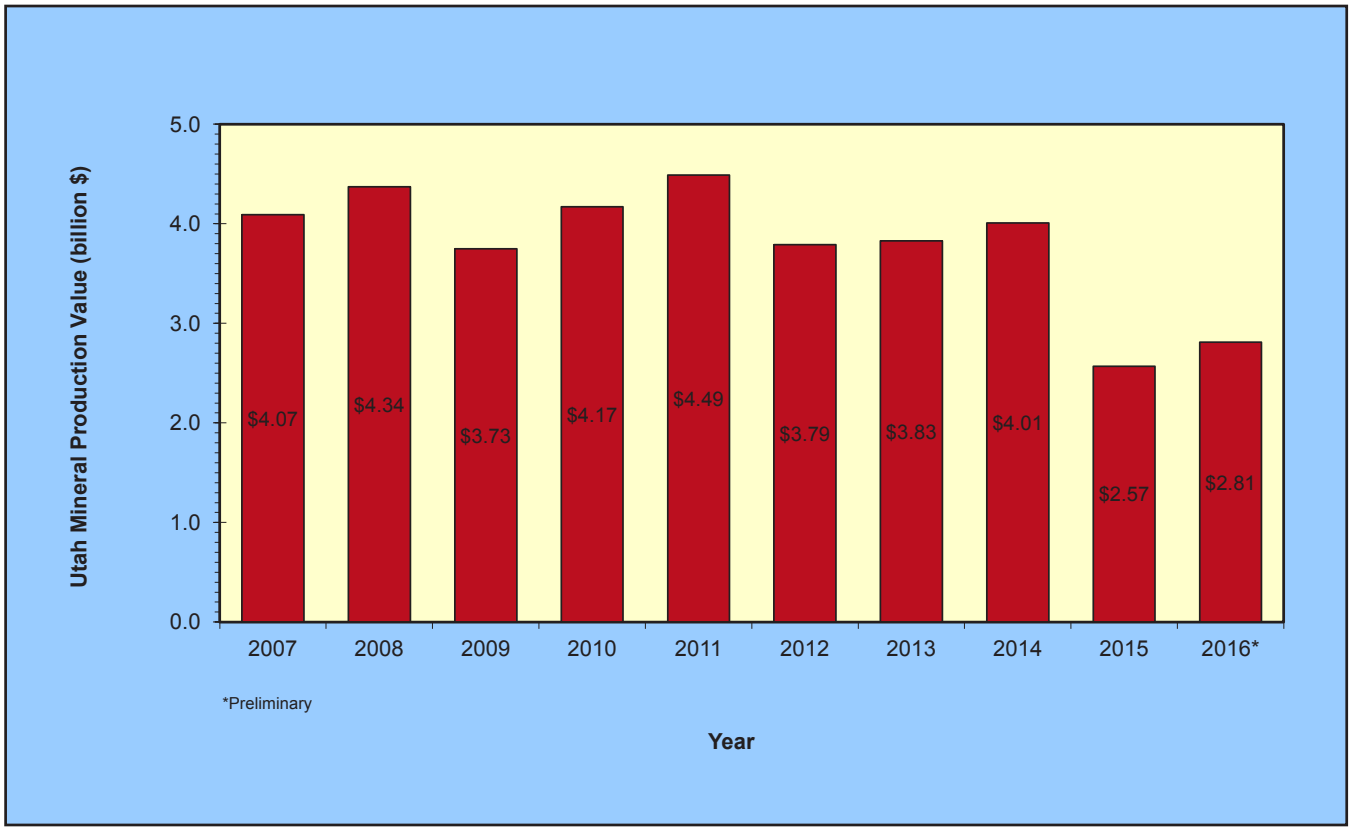

Figure 4. *Annual value of Utah mineral production (except coal and uranium) in nominal dollars, 2007–2016. Source: Utah Geological Survey.*

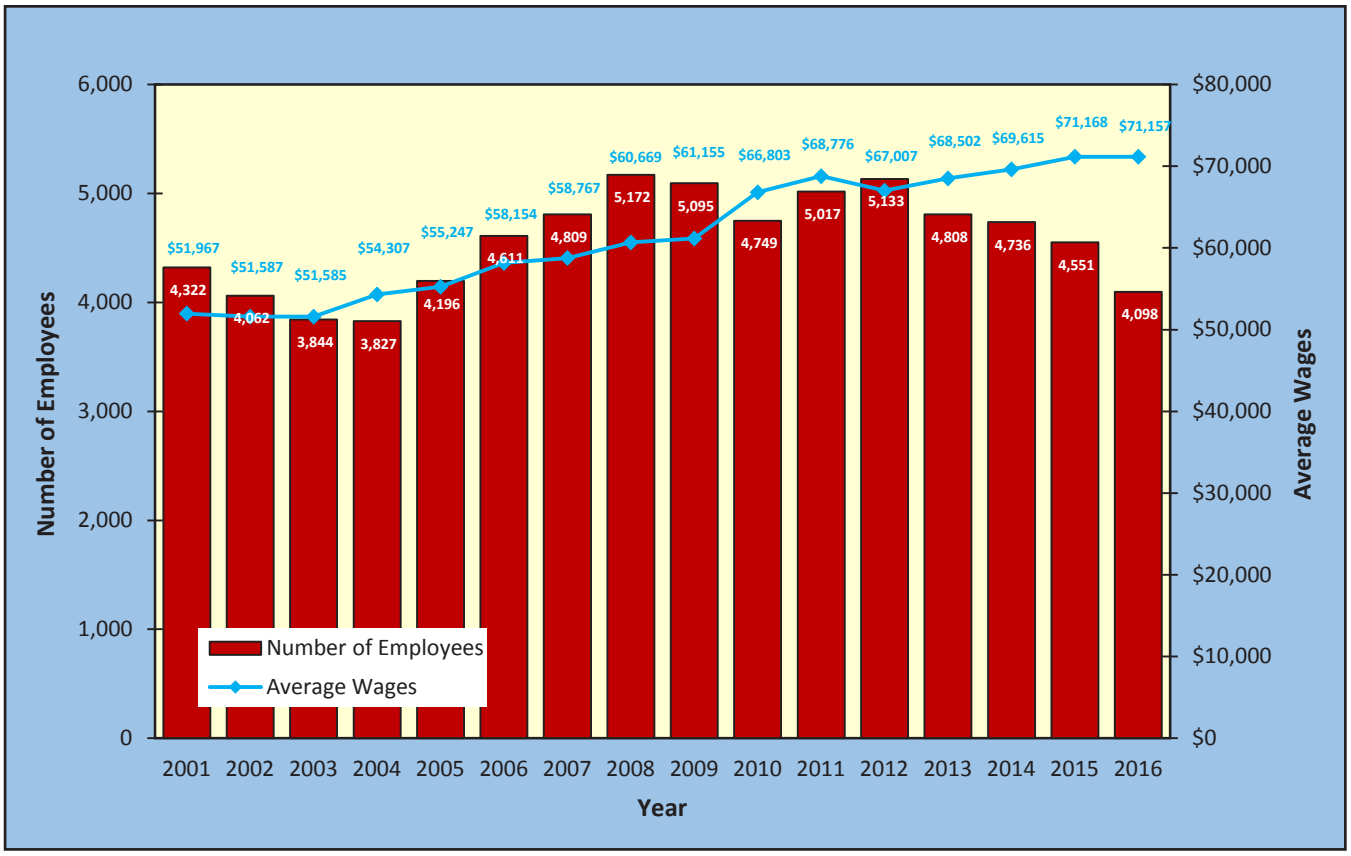

Figure 5. *Average annual mining employment and salary in Utah, for metal, industrial minerals, and coal mines and plants. Source: Utah Department of Workforce Services.*

unit price. Metal prices are affected by a variety of factors ranging from geology to government policies to the volatility of international trade. Historically, the U.S. was the leading or at least a major producer of many metals (copper, molybdenum, iron ore, rare earth elements [REE], and uranium), but U.S. production has declined over the last several decades, often displaced by Chinese production. Consequently, the United States' reliance on imports has increased significantly (table 2). Of particular note, the U.S. remains the world's leading producer of beryllium due to the Materion Natural Resources' Spor Mountain mines in Utah.

Production and Values

Utah's base metal production value totaled $1.2 billion in 2016, a 12% increase from 2015, and was mainly due to significant increases in copper and byproduct output by KUC (figure 2). Utah's base metal values are copper ($782 million, 64%), magnesium ($323 million, 27%), beryllium ($73.3 million, 6%), and molybdenum ($40.4 million, 3%).

Precious metal production value for Utah in 2016 is estimated at $226 million (figure 2) and is distributed between gold ($193 million, 85%) and silver ($33.3 million, 15%). Precious metal production value increased by 24% from 2015 to 2016 due to higher gold and silver production by KUC, as well as higher prices for both metals.

Most Utah copper, gold, and silver, and all of the molybdenum, is produced from the KUC Bingham Canyon mine, located about 20 miles southwest of Salt Lake City in Salt Lake County (figure 6). The combined value of metals produced by KUC in 2016 is estimated at $1.02 billion, a 27% increase from 2015. The Bingham Canyon mine was the second-largest copper, sixth-largest silver, seventh-largest molybdenum, and about the fourteenth-largest gold producer in the U.S. in 2016.

Copper

In 2016, copper was the most valuable metal, having an estimated value of $782 million, a 38% increase in value from 2015. The KUC Bingham Canyon open pit porphyry copper-gold-molybdenum mine produced most of this copper; their 2016 production amounted to 168,000 short tons (st), and is 67,000 st more than their production in 2015 (Rio Tinto, 2017). The 2016 average copper price decreased about 12% from 2015 to $2.25/lb. KUC production for 2016 at the average copper price has an estimated value of $757 million, an increase of about 46% from 2015.

Table 2. *Summary of estimated 2016 world metal production value, U.S. net import reliance, main producing countries, and primary uses for select metals; compiled primarily from USGS Mineral Commodity Summaries (USGS, 2017c).*

Commodity		Iron ore	Gold	Copper	Aluminum	Zinc	Silver	Magnesium
World production (billion)		$183.77	$126.57	$94.10	$46.08	$26.00	$17.03	$4.80
U.S. net import reliance		0%	0%	34%	52%	82%	67%	<30%
Main producers	**1**	Australia	China	Chile	China	China	Mexico	China
	2	Brazil	Australia	China	Russia	Australia	Peru	U.S.
	3	China	Russia	Peru	Canada	Peru	China	Russia
	4	India	U.S.	U.S.	India	U.S.	Chile	Israel
	5	Russia	Canada	Congo	U.A.E.	Mexico	Australia	Brazil
Primary use		Steel	Jewelry	Electrical	Transportation	Galvanized steel	Electronics Jewelry	Ti reducing agent

Commodity		Uranium*	Molybdenum	REE	Lithium	Vanadium	Beryllium	Rhenium
World production (billion)		$4.24[e]	$3.30	$0.95[e]	$0.26	$0.24	$0.11	$0.09
U.S. net import reliance		89%	0%	100%	>50%	100%	10%	81%
Main producers	**1**	Kazakhstan	China	China	Australia	China	U.S.	Chile
	2	Canada	Chile	Australia	Chile	Russia	China	U.S.
	3	Australia	U.S.	Russia	Argentina	South Africa	Madagascar	Poland
	4	Niger	Peru	India	China	Brazil	Other	China
	5	Namibia	Mexico	Brazil	Zimbabwe			Kazakhstan
Primary use		Power	Ferroalloys	Catalysts	Batteries	Ferroalloy	Electronics	Jet turbine blades

[e] Estimated

* Uranium information from the World Nuclear Association (http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/mining-of-uranium/world-uranium-mining-production.aspx)

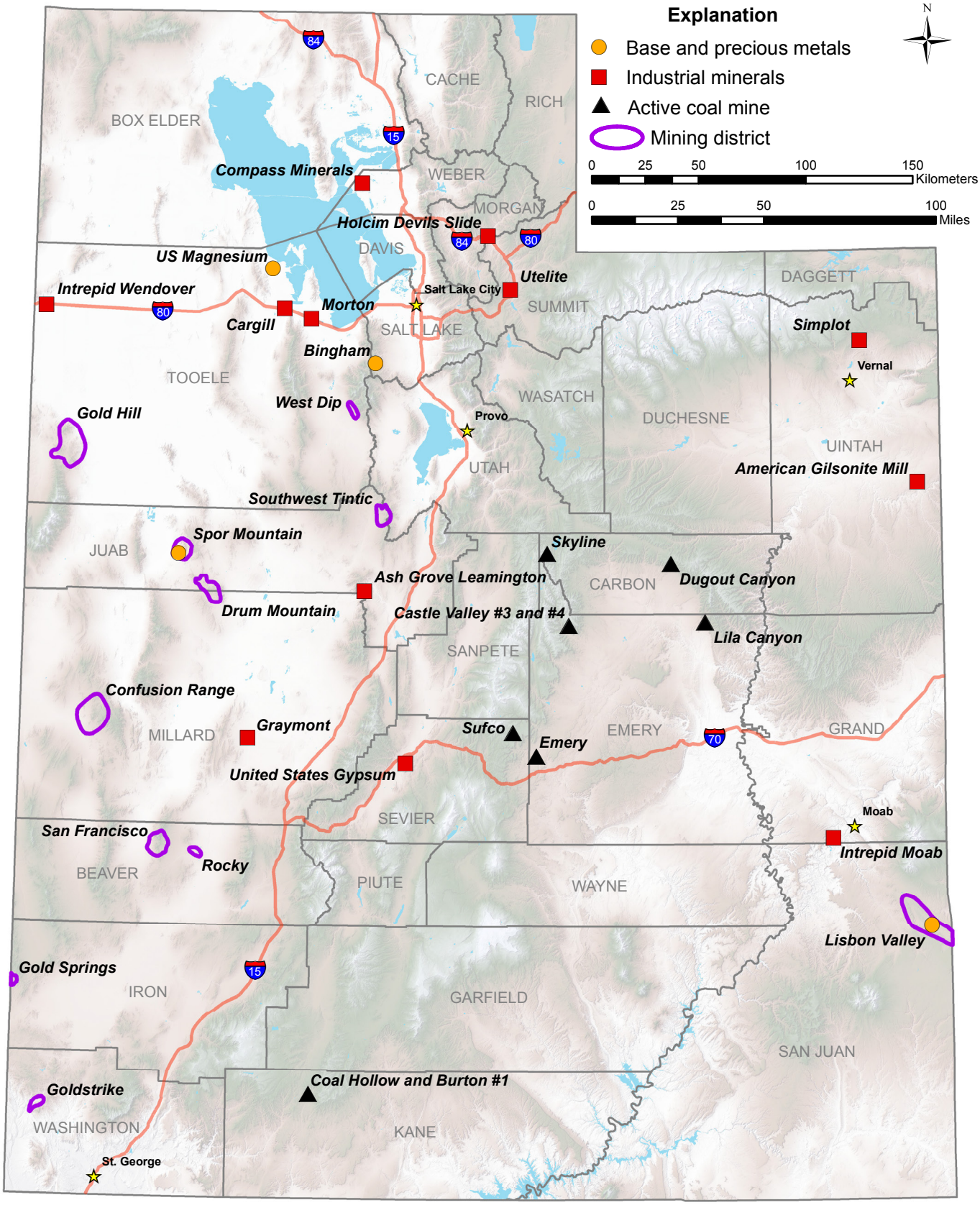

Figure 6. Selected base and precious metals, industrial minerals, and coal production and development activity locations in Utah during 2016.

Both Lisbon Valley Mining and CS Mining were negatively impacted by the low copper price in 2016. Lisbon Valley Mining Company operates a sediment-hosted copper mine and solvent extraction-electrowinning (SX-EW) processing facility about 30 miles southeast of Moab in San Juan County (figure 6). About 3800 st of copper was produced by the company in 2016, which is down from 2015. CS Mining, LLC's Rocky Range copper skarn production was down in 2016, although they completed construction of a new SX-EW plant early in the year that will be the primary metallurgical source for future production. Production for 2016 was principally derived from the SX-EW reprocessing of flotation tailings.

Copper is an internationally traded commodity and its price is determined by the world metal exchanges. Copper is combined with a number of metals to create alloys for a wide variety of applications and is used to produce a wide range of products including electrical wiring, electronic components, and pipe for plumbing, refrigeration, and heating systems.

Magnesium

US Magnesium, LLC is the only facility producing magnesium from a primary source in the United States and is located about 60 miles west of Salt Lake City at Rowley in Tooele County (figure 6). Magnesium chloride concentrate is produced from Great Salt Lake brines through evaporation and ultimately converted to magnesium metal by an electrolytic process. The annual magnesium production capacity at the US Magnesium plant is approximately 75,000 st. The price for magnesium metal remained flat from 2015, averaging $2.15/lb in 2016 (USGS, 2017a). Assuming plant operation at full capacity, Utah 2016 magnesium production has an estimated value of $323 million. Magnesium ranks second as a contributor to Utah base metal values in 2016. Significant quantities of US Magnesium's production are used by a nearby plant, operated by Allegheny Technologies Inc., to produce titanium sponge. However, this plant was idled at the end of 2016 because market conditions were unfavorable. Nationally, other markets for magnesium include use as a constituent of aluminum-based alloys, structural use in castings and wrought products, desulfurization of iron and steel, and other minor uses (USGS, 2017a). Lithium, which is also concentrated with magnesium in the US Magnesium solar evaporation ponds system, has been considered as a possible future byproduct from the operation (Tripp, 2009).

Beryllium

Utah remains the United States' sole producer of beryllium ore and the largest producer in the world. Materion Natural Resources, Inc. mines the mineral bertrandite [$Be_4Si_2O_7(OH)_2$] from the Spor Mountain area about 42 miles northwest of Delta in Juab County (figure 6). Materion operates a mill 11 miles north of Delta in Millard County. Bertrandite ore and imported beryl are processed at the mill into beryllium hydroxide. Materion's parent company (Materion Corporation) operates a refinery and finishing plant in Ohio where the beryllium hydroxide concentrate is shipped and converted to beryllium-copper master alloy, beryllium metal, and oxide (USGS, 2017a). About 119 st of bertrandite ore was mined in 2016 from the Topaz mine at Spor Mountain. The average beryllium price for 2016 was $231/lb, and was essentially unchanged from 2015 (USGS, 2017a). Contained beryllium metal from concentrate production was about 317,500 lbs, having an estimated value of $73.3 million at the 2016 average beryllium price. Beryllium ranks third as a contributor to Utah 2016 base metal values.

Beryllium is a specialty metal primarily used in alloys and specifically in copper-beryllium high conductivity alloy. Beryllium has applications in various telecommunications and consumer electronics products, defense-related applications, industrial components, commercial aerospace applications, appliances, automotive electronics, energy applications, medical devices, and other uses.

Molybdenum

Utah molybdenum production in 2016 came solely from the KUC Bingham Canyon mine and was recovered as a byproduct from the copper operation. Approximately 3100 st of molybdenum were produced in 2016, a 63% decrease from 2015 (Rio Tinto, 2017). During 2016, the average price of molybdenum decreased by 4% to $6.54/lb. At the 2016 average price, Utah molybdenum production has an estimated value of $40.4 million, a 65% decrease from 2015, reflecting the large decrease in production. This valuation makes molybdenum the fourth-most valuable base metal produced in Utah during 2016.

Molybdenum is primarily used in the production of stronger and/or more corrosion-resistant ferro-alloys. These uses are closely linked to oil, gas, and petrochemical uses, consequently molybdenum prices are strongly affected by the strength and weaknesses in these markets. Alloys account for about 76% of the molybdenum consumed (USGS, 2017a). Molybdenum prices have fallen nearly 80% from the record highs of 2005–08. This has resulted in mine closures or reductions in U.S. molybdenum operations at Mission and Sierrita, Arizona; Thompson Creek, Idaho; Questa, New Mexico; Mineral Park, Arizona; and Ashdown, Nevada. Moreover, Freeport-McMoRan announced that in about 2024 it plans to close its Henderson porphyry molybdenum mine in Colorado, which until recently was the largest molybdenum producer in the United States. The outlook for higher molybdenum production value in 2017 and beyond is very good.

Gold

In 2016, approximately 154,200 troy ounces (oz) of gold were produced in Utah, a 15% increase from 2015. Nearly all of this gold was from the KUC Bingham Canyon mine, where it was recovered as a byproduct from the copper ore (Rio

Tinto, 2017). Desert Hawk Gold Corp. also produced about a thousand oz of gold from their Kiewit gold-silver mine in the Gold Hill district in western Tooele County. The average gold price in 2016 was $1252.17/troy oz, an 8% increase from the 2015 average price. Utah's 2016 gold production had a value of $193 million, which is 24% more than the 2015 valuation. Small quantities of gold may have been produced by other small Utah mines, but this production is inconsistently reported and would not make a significant impact on the total amount or value of gold produced in Utah.

Gold is an internationally traded precious metal used primarily for jewelry, coinage, bullion for monetary purposes, and to a lesser extent a variety of industrial and electronic applications.

Silver

Most of the silver produced in Utah during 2016 came from the KUC Bingham Canyon mine and was recovered as a byproduct from the copper ore. Total silver production in 2016 was about 1,944,000 troy oz (Rio Tinto, 2017), a 14% increase from 2015. Nominal silver production also came from the Kiewit gold mine near Gold Hill. The average silver price in 2016 was $17.14/troy oz, a 9% increase from the 2015 average price. Utah's 2016 silver production from all reporting sources had a value of $33 million, 25% more than the 2015 valuation.

Silver is part precious metal and part industrial metal. Like gold, it is used for jewelry and coinage, but it is also heavily used for electronics, photography, and a wide variety of other industrial applications. Silver prices are determined by the world marketplace.

Exploration and Development Activity

The information in this section is largely compiled from a UGS annual industry survey of mine operators, mining company websites, press releases, and personal communications with government and operations staff. Exploration and development information was also obtained from the Utah DOGM website (http://ogm.utah.gov/minerals/MineralsPDO/angularminerals-filesbypermtiinfo.php). The locations of selected mining districts with exploration interest in 2016 are shown on figure 6.

Mineral exploration and development generally rises and falls with metal prices. The 2017 commodity prices generally remained too low to encourage serious new exploration and development. Utah, U.S., and world molybdenum production has fallen significantly with declining molybdenum prices over the last three years. Falling iron ore prices in 2014 caused CML Metals Inc. to close their Iron Mountain mine in late 2014 and the operation has remained closed with the generally depressed prices since. Gold and silver prices improved in 2016 as a result of the introduction of negative interest rates in some European and Asian countries.

Low metal prices have caused exploration activity to shift its focus from riskier greenfield work to more prospective brownfield exploration near current or recently active operations. Another sign of the risk averse attitudes in the industry is the proliferation of exploration joint ventures to spread the monetary risk among more players. Metallic mineral exploration and development activity in Utah remained low throughout 2016, except for some lithium excitement. Metal price forecasts predict modestly improved metal prices in the near term, 2017–18, hopefully resulting in increased exploration and production. Utah base and precious metal properties are shown on figure 6 and summarized in table 3.

Bingham Canyon

Bingham is the most productive mining district in the United States (Krahulec, 2015). The mine was developed on a giant, Eocene-age (~38 Ma) porphyry copper deposit. The Bingham Canyon open pit mine's 2016 production ranks it as the second largest copper, seventh largest molybdenum, fifth largest silver, and approximately fourteenth largest gold producer in the United States (figures 6 and 7). The mine, in production since 1903, became the world's first open pit porphyry copper mine in 1906 and is currently about 2.5 miles in diameter and 3830 feet deep. The Bingham Canyon open pit was designated a National Historic Landmark in 1966.

The massive Manefay pit-wall failures at the Bingham Canyon mine in April 2013 changed the face of the mine. All of the slide debris has been removed from the pit, but KUC had not completely recovered from the slide in 2016 and does not fully expect to do so until 2018. However, after a very difficult 2015, the total value of Bingham's production rebounded roughly 23% in 2016 despite very low molybdenum production. Three small pit wall failures occurred on March 11th, 15th, and April 5th, 2016, in the Main Hill area of the southwest corner of the pit. The slides are normal in the spring, were contained in a planned catchment basin, and no personnel or equipment was endangered.

Bingham is currently developing ore on the south side of the open pit, termed the south wall pushback (SPB). The SPB will open roughly 700 million st of ore and move the wall of the pit about 1000 feet farther south and the pit bottom 300 feet deeper. This reserve will extend the mine life through 2028. The open pit has proven and probable reserves of 736 million tons at 0.43% copper, 0.17 ppm gold, 0.033% molybdenum, and 2.06 ppm silver (Rio Tinto, 2017).

Bingham has developed two, horseshoe-shaped, underground drainage tunnels from deep in the pit, each with two portals into the pit. The first one, called the Highland Boy drainage gallery, was driven at an approximate elevation of 4740 feet under the southwest end of the pit to dewater the slide prone Main Hill area. The second, the Common Access Decline, is 200 to 300 feet deeper and was developed

Table 3. *Select metal exploration and development projects in Utah, 2016. District locations are shown on figure 6.*

Property	Commodity	District	County	Company	Progress
Bingham	Copper-Gold-Molybdenum	Bingham	Salt Lake	Kennecott Utah Copper Company	Ongoing underground deep development drilling
Cave Mine	Polymetallic	Bradshaw	Beaver	Grand Central Silver Mines, Inc.	Property has been dropped
Kings Canyon	Gold	Confusion Range	Millard	Pine Cliff Energy Ltd.	NI 43-101* completed, no work reported in 2016
Thompson Knoll	Polymetallic	Confusion Range	Millard	Inland Explorations Ltd. and BCM Resources	New NI 43-101* (Redfern, 2016), drilling planned
Southern Drum Mountains	Gold-Silver	Drum Mountains	Millard	Logan Resources Ltd., optioned from Pilot Gold	Mapping and sampling completed, 15 holes planned
Wildcat	Gold-Silver	Drum Mountains	Juab	TroyMet Exploration - Renaissance Gold Inc.	Ten holes completed, additional work planned
Dugway	Polymetallic	Dugway	Tooele	Bronco Creek Exploration, Inc.	Staked 154 unpatented lode claims in 2016
Burgin	Lead-Silver	East Tintic	Utah	Chief Consolidated Mining Company	Acquired by LeadFX, no work completed
Fraction	Tungsten	Gold Hill	Tooele	Scheelite Metals LLC	Produced 275 tons of ore
Gold Hill	Gold-Silver	Gold Hill	Tooele	Newmont USA Ltd.	Holds over 1500 unpatented claims and drilling ongoing
Kiewit	Gold-Silver	Gold Hill	Tooele	Desert Hawk Gold Corp.	Small open pit and heap leach; on standby over the winter
Jumbo	Gold-Silver	Gold Springs	Iron	TriMetals Mining, Inc.	Drilled 44 new holes totaling about 23,865 ft
Goldstrike	Gold-Silver	Goldstrike	Washington	Pilot Gold, Inc.	New NI 43-101* (Gustin and Smith, 2016) and 191 holes
Bromide Basin	Gold	Henry Mountain	Garfield	Bromide Mining LLC	Very small mill operating intermittently
Iron Mountain	Iron	Iron Springs	Iron	CML Metals Corp.	Iron ore mine closed in 2014; no new work announced
Copper Warrior	Copper	Lisbon Valley	San Juan	Eurasian Minerals Inc.	Staked 61 unpatented lode claims in 2016
Lisbon Valley Copper	Copper	Lisbon Valley	San Juan	Lisbon Valley Mining Company, LLC	Operating copper mine with ongoing exploration
East Canyon	Gold-Silver	Lucin	Box Elder	Tuvera Exploration, Inc.	NI 43-101* completed, no work done in 2016
North Lucin	Gold-Silver	Lucin	Box Elder	Newmont USA Ltd.	Property dropped
West Mercur	Gold	Mercur	Tooele	Ash-ley Woods LLC	Acquired 6300 acres of State sections and unpatented claims
Deer Trail	Polymetallic	Mount Baldy	Piute	Quintana WRP Holding Company	Property taken over by Quintana, no work completed
Bingham Orbit	Polymetallic	Oquirrh Range	Tooele	Kennecott Utah Copper Company	Ongoing deep exploration drilling in range
Milford Copper	Copper	Rocky Range	Beaver	CS Mining LLC	Open pit copper mines and agitation leach SX-EW
Frisco Project	Copper-Gold; Lead-Silver	San Francisco	Beaver	Alderan Resources Ltd.	Acquired large land package, four targets recognized
Speedway	Gold	Silver Island	Tooele	Emu NL - Genesis Gold Corp.	One core hole completed, no gold, and property dropped
SWT Porphyry	Copper-Molybdenum	Southwest Tintic	Juab	Freeport-McMoRan Exploration Corp.	Freeport-McMoRan purchased the property from Quaterra
TUG	Gold-Silver	Tecoma	Box Elder	Newmont Mining Corporation	Acquired from West Kirkland Mining

* An NI 43-101 is a formal Canadian National Instrument technical report prepared to a codified set of rules for public reporting of mineral exploration and development data on properties operated by companies listed on Canadian stock exchanges.

Figure 7. *View to the east of the Bingham Canyon open pit porphyry copper-gold-molybdenum mine. This 2017 photograph was taken by a Kennecott Utah Copper drone. Photograph courtesy of Rio Tinto Kennecott.*

under the northwest wall of the pit for drainage and to act as an exploration platform for the deep, underlying North Rim copper-gold skarn. The 3300-foot-deep North Ore Shoot shaft and associated workings have also been rehabilitated and dewatered to access these ores. The North Rim skarn has measured, indicated, and inferred resources of 22 million tons at 3.65% copper, 1.62 ppm gold, and 21 ppm silver (Rio Tinto, 2017).

In 2015, KUC began a significant $100 million, five-year project to reduce the current angle of repose mine dump slope angles to a lower gradient on the eastern waste dumps that face Salt Lake Valley. The project will also require building new toe drains and cutoff dams keyed into bedrock below the dumps to take in this newly enlarged dump footprint. The lower slope angle will help with surface-water management and facilitate revegetation efforts. In 2016, KUC repositioned the cutoff walls, installed new toe drains, and placed 89 million tons of base material in this program.

Less copper production from the pit in recent years leaves the KUC smelter at Magna with excess capacity, which has allowed for increased toll smelting of compatible outside copper concentrates. The smelter processed 348,000 st of outside concentrates in 2016. Kennecott Exploration Company continued their Bingham orbit exploration drilling program in the Oquirrh Mountains in 2016.

Lisbon Valley

The Lisbon Valley Mining Company operates a sediment-hosted, open pit, heap leach, SX-EW copper operation situated in the Lisbon Valley mining district of San Juan County (figure 6). The company began mine development in 2005 and plant construction was completed in 2006. Following some startup difficulties, Lisbon Valley Mining Company, LLC has been operating successfully since 2009. Total mine production in 2005–2016, inclusive, is estimated at 135 million pounds of copper. The 2016 copper cathode production is down from 2015.

Eurasian Minerals Inc. staked 61 lode claims on the northwest end of the Lisbon Valley anticline, about eight miles northwest of the Lisbon Valley copper operation. The target is a sediment-hosted copper deposit associated with a splay of mineralizing faults in the hanging wall of the large Lisbon Valley normal fault.

Rocky Range

CS Mining, LLC controls a group of small, Oligocene-age (~30 Ma) copper deposits in the Rocky Range, Beaver County (figure 6). These properties include several prograde, anhydrous, low sulfidation copper skarns. In 2009, a flotation mill was built and open pit mining began. The mill experienced poor copper recovery due to the mixed sulfide-oxide nature of the ore and

operations were halted. The mine and mill were successfully restarted in 2012, but continued to suffer from low copper recovery through 2015. CS Mining began construction of an agitation leach SX-EW plant in 2015 to more effectively process their copper oxide ore and reprocess the older flotation mill tailings to recover additional metal. Mining ceased in 2016 and the new SX-EX plant began operating on the tailings producing all of the operations' copper in 2016. CS Mining production from 2008 to 2016 (inclusive) is estimated at approximately 26 million pounds of copper. The 2016 production is down from 2015. CS Mining is currently in bankruptcy proceedings.

Spor Mountain

The Spor Mountain mining district lies on the west flank of the Thomas Range in west-central Juab County (figure 6) and is the world's premier beryllium producer. The beryllium occurs in epithermal, carbonate-replacement deposits in a basal Miocene-age tuffaceous sediment along northeast-trending, half-graben faults. Over 3.5 million st of ore with an average grade of greater than 0.2% beryllium has been mined from 10 small- to medium-sized pits since production began in the late 1960s. Total Spor Mountain district production is estimated at over 15.5 million pounds of beryllium. Materion Corporation has proven and probable reserves of about 9 million st at 0.25% beryllium, which at current production rates, would support well over 50 years of continued beryllium production.

Gold Hill District

In 2009, Clifton Mining Company agreed to jointly develop their Gold Hill district properties with Desert Hawk Gold Corp. Clifton's mineral properties lie in the northern Deep Creek Mountains of western Tooele County (figure 6). In April 2014, Desert Hawk received permits and started construction of a small open pit, heap leach operation at the Kiewit Miocene-age (~8 Ma) intrusive-hosted, low-sulfidation, quartz-carbonate-adularia stockwork gold-silver deposit (Robinson, 2016). Construction was completed and production began in September 2014. Desert Hawk commenced gold recovery in late 2014 and operations continued through fall 2016, having placed about 505,000 st on the heap leach pad. The Kiewit mine produced just over 1000 ounces of gold and slightly more silver in 2016.

Newmont Mining Corporation holds a large block of land including about 1500 unpatented claims and four SITLA sections interlaced with and surrounding the core patented mining claims in the district. Newmont has done considerable mapping and sampling, pursuing a variety of targets in 2015–16 with several drill holes completed and more planned.

Scheelite Metals, LLC attempted to reopen the old Fraction tungsten skarn in 2016. They rehabbed the mine and reportedly produced about 275 st of ore from underground workings. The primary ore mineral is scheelite [$Ca(WO_4)$], but powellite ($CaMoO_4$) is reported as well. The ore was then shipped and processed at the newly refurbished Callao gravity-circuit mill about 20 miles southeast of the mine. The mine halted operation by the end of 2016.

Goldstrike District

Pilot Gold acquired a 3800-acre land package encompassing the historical mining area of the Goldstrike Miocene-age sediment-hosted gold-silver mining district of Washington County in 2014 (figure 6). Production from Goldstrike in the late 1980s and early 1990s totaled approximately 210,000 oz of gold and 198,000 oz of silver from 12 small open pits along a 3.5-mile-long northeast-trend (Gustin and Smith, 2016).

Pilot assimilated and digitized the massive historical mine database, including over 1500 drill holes, some containing unmined oxide gold intercepts, and 100,000 blast holes. They used this data to produce a three-dimensional model of the geology and mineralization. They proceeded to drill 18 reverse circulation holes in 2015 and an additional 191 holes in 2016. Highlights from 2016 drilling included:

- 115 feet grading 2.10 ppm gold in drill hole PGS019,
- 100 feet grading 1.07 ppm gold in PGS020,
- 190 feet grading 1.19 ppm gold in PGS026,
- 155 feet grading 1.14 ppm gold in PGS027,
- 100 feet grading 1.85 ppm gold in PGS041C,
- 155 feet grading 1.06 ppm gold in PGS044C,
- 125 feet grading 3.28 ppm gold in PGS048,
- 135 feet grading 2.64 ppm gold in PGS051C,
- 193 feet grading 2.24 ppm gold in PGS054C,
- 150 feet grading 1.08 ppm gold in PGS097, and
- 95 feet grading 1.78 ppm gold in PGS179.

This drilling program included 10 core holes planned for metallurgical studies. Eight of the metallurgical holes returned an average of 88.4% gold recovery by cyanide. Pilot's plans are to complete a new Canadian National Instrument (NI) 43-101 resource estimate in the first quarter of 2018.

Gold Springs District

The Gold Springs mining district is located along the Nevada border in Iron County (figure 6). The district contains a Miocene-age low-sulfidation, epithermal, gold-silver quartz-adularia-calcite vein/stockwork deposit. TriMetals Mining, Inc. acquired a 6000-acre block of ground in the district in 2014. A NI 43-101 preliminary economic assessment (PEA) was released in 2015 on the Gold Springs property. This 2015 PEA shows a measured and indicated resource on the Jumbo gold-silver stockwork of 13,591,000 st at 0.53 ppm gold and 13.6 ppm silver at a 0.3 ppm gold cutoff. The PEA calls for

a 15,000 ton per day, open pit, heap leach operation with a 2:1 stripping ratio (Lane and others, 2015). In 2016, TriMetals drilled an additional 44 reverse circulation holes totaling 23,865 feet (average 542 feet per hole). This drilling includes encouraging results like:

- 155 feet at 23.7 ppm silver and 0.69 ppm gold in J-16-006,
- 100 feet at 32.6 ppm silver and 0.50 ppm gold in J-16-004 in the Jumbo zone,
- 145 feet at 15.1 ppm silver and 1.93 ppm gold in E-16-005,
- 100 feet at 15.6 ppm silver and 1.10 ppm gold in E-16-008 in the Etna zone.

San Francisco District

Alderan Resources Pty. acquired a very large block of land in mid-2016 covering most of the San Francisco district, Beaver County (figure 6). This property consists of two large blocks of patented claims totaling an estimated 4000 acres and a block of 253 unpatented claims. Alderan spent considerable time assimilating the historical mining and exploration data, mapped and sampled the district, and flew a very detailed aeromagnetic survey. They used this data to define four primary targets: Cactus Canyon porphyry copper, Cactus copper breccia pipe, Accrington (Imperial) copper-zinc skarn, and Horn (Horn Silver) zinc-lead-silver replacement.

Drum Mountains (Detroit District)

The Drum Mountains has one of the most complex land ownership positions in the state (figure 6). Freeport-McMoRan Exploration Corporation acquired 1020 acres of SITLA land, about 1000 acres of patented mining claims, and staked an additional 400 unpatented lode claims in and around the central copper-gold area of the old mining district in the last few years. They drilled two deep core holes to at least 2500 feet, one on the patented claims and the other well to the north. Freeport-McMoRan then dropped the patented claim block but not their unpatented claims. No information is available on their other deep hole drilled several miles to the north near the eastern margin of the Eocene-age Thomas caldera.

Logan Resources Ltd. agreed to an option on Pilot Gold Inc. prospects in the southern Drum Mountains, Millard County. The property is 1 to 2 miles southeast of the old Drum sediment-hosted gold mines which unearthed about 3.7 million st at 1.23 ppm gold from 1983 to 1989, inclusive (Krahulec, 2011). Rock-chip samples of jasperoid breccias in the Lower Cambrian-age carbonates on Logan's claims typically run from 0.1 to 1.0 ppm gold with a high of 5.2 ppm gold. Mapping and sampling has defined three principal target areas: PDS, GD1, and BAJ. Logan plans a 15-hole, 7000-foot drilling program for 2017.

TroyMet Exploration Corp. signed an earn-in agreement with Renaissance Gold Inc. in 2015 for their Wildcat sediment-hosted gold-silver target northwest of the main Drum Mountain district, Juab County. TroyMet drilled 10 holes totaling 4334 feet in 2016. While the analytical results were generally not encouraging, one hole (WC 16-09) encountered lost circulation and had some select chips from the bottom of the hole running up to 1.56 ppm gold. TroyMet plans additional work for 2017.

West Dip District

Ashley Woods, LLC has assembled a 6300-acre land position at its West Mercur project in Tooele County (figure 6). The project is located three miles west of the Mercur gold mine, which produced nearly 3.5 million ounces of gold between 1890 and 1997 (Mako, 1999). The Carlin-type gold deposits at West Mercur occur in west-dipping Mississippian-age Great Blue Limestone, the same host as at Mercur, but on the opposite limb of the Ophir anticline. The project area includes several historical prospects and small mines that worked gold deposits between 1895 and 1917.

Tintic District

In 2007, Quaterra Resources, Inc. acquired about 3200 acres of patented and unpatented mining claims encompassing the Southwest Tintic porphyry copper system in Juab County (figure 6). The property includes a known historical resource of about 400 million st with 0.33% copper and 0.01% molybdenum (Krahulec and Briggs, 2006; Krahulec, 2015). In a 2009 joint venture with Quaterra, Freeport-McMoRan Exploration Corporation began an integrated program of geological mapping, geochemical sampling, and geophysical surveying; seven exploration holes were drilled in 2010 and 2011. Freeport-McMoRan acquired the property from Quaterra outright in 2015, but no additional drilling has been undertaken.

Confusion Range

Inland Explorations' Thompson Knolls property lies on the west slope of the Confusion Range in west-central Millard County (figure 6). The Thompson Knolls targets include porphyry/skarn associated with a covered magnetic high and sediment-hosted gold-silver. This property may be similar in size to that at the Kings Canyon deposit, about 7.9 million st at 0.93 ppm gold and 3.7 ppm silver (Krahulec, 2011), a few miles to the northeast. In 2015, a 51% interest in the Thompson Knolls project was optioned to BCM Resources Corporation. BCM assimilated the previously generated exploration information, staked 25 new unpatented lode claims, completed two additional geophysical surveys, and produced a NI 43-101 technical report on the property (Redfern, 2016). The most notable previous result at Thomson Knolls is a 1996 exploration hole drilled by Centurion Mining Company (CKC-96-10), which intersected 30 feet

of 8.31 ppm gold and 26.9 ppm silver from 250 to 280 feet (Redfern, 2016). One or two deep holes are planned for 2017.

INDUSTRIAL MINERALS

Production and Values

Industrial mineral production in Utah during 2016 had an estimated value of $1.4 billion (figure 2), which was an increase of 6% from 2015. The largest overall contributor to the 2016 value of Utah industrial minerals production was the sand and gravel, crushed stone (including limestone and dolomite), and dimension stone commodity groups. These products had a combined value of $449 million, a 30% increase in value from 2015, and account for 33% of total value of Utah's industrial mineral production in 2016. The second-largest contributors to the value of industrial minerals production were the brine- and evaporite-derived products including potash, salt, and magnesium chloride. These products had a combined value of $359 million, a 6% decrease in value from 2015, and accounted for 26% of total value of Utah's industrial mineral production in 2016. The third-largest contribution to the value of industrial minerals production came from the Portland cement and lime product group, which had a combined value of $232 million and accounted for 17% of total industrial mineral value in 2016; this was a slight decrease in value from 2015. These three commodity groups contributed 76% of the total value of industrial minerals produced in Utah during 2016. The remaining value came from, in decreasing order, sulfuric acid, phosphate, gilsonite, clay, expanded shale, and gypsum.

Sand and Gravel, Crushed Stone, and Dimension Stone

Sand and gravel, crushed stone, and dimension stone are produced by many private, county, state, and federal entities. Given the numerous producers of this commodity group, it was impractical for the UGS to send annual production surveys to all of the operations. However, the UGS does compile data from selected operators to track these commodities and uses USGS data for production and value estimates. During 2016, approximately 50 million st of sand and gravel worth $379 million was produced in Utah (USGS, 2017b). About 10 million st of crushed stone worth $70 million was also produced (USGS, 2017b), as well as several thousand st of dimension stone. The 2016 total production value for this commodity group increased by 30% to approximately $449 million. The increased value resulted from moderate increases in production and slight increases in prices for sand and gravel and crushed stone.

Potash, Salt, and Magnesium Chloride

The brine-derived commodities produced from Great Salt Lake include, in descending order of production, salt, magnesium chloride, and potash (in the form of potassium sulfate). Potash, in the form of potassium chloride, along with significant amounts of magnesium chloride and lesser amounts of salt, were also produced by operations in other parts of the state.

Potash production in Utah was about 392,000 st in 2016 and was the largest contributor to the value of the brine-derived commodity group. The 2016 value of potash produced in Utah was approximately $188 million, a decrease of 5% from 2015. The lower value was due primarily to a large decrease in the price of potassium chloride, as well as a moderate decrease in production. Potassium sulfate experienced an increase in production and value, despite a slightly lower price than in 2015. Potassium sulfate has a significantly higher market value than potassium chloride. Compass Minerals Ogden, Inc. produces potassium sulfate, whereas Intrepid Potash-Wendover and Intrepid Potash-Moab produce potassium chloride (figure 6). In 2016, Compass Minerals used some purchased potassium chloride to supplement their potassium sulfate production.

Utah salt production in 2016 amounted to approximately 2.7 million st and had a production value estimated at $147 million. Some 75% of the salt was produced from Great Salt Lake brine by three operators: Compass Minerals Ogden, Inc., Cargill Salt Co., and Morton International (in descending production order) (figure 6). The remaining 25% came from Redmond Minerals, Inc. near Redmond in Sanpete County, Intrepid Potash-Wendover near Wendover in Tooele County, and Intrepid Potash-Moab near Moab in Grand County.

In 2016, magnesium chloride production in Utah slightly increased to 769,000 st and had a production value of about $24 million (ONRR, 2017). The magnesium chloride brine was produced by Intrepid Potash-Wendover and Compass Minerals Ogden, Inc.; the latter also produces small amounts of magnesium chloride flake.

The most significant source of brine-derived products in Utah is Great Salt Lake. An estimated 2.5 million st of total solids was produced from Great Salt Lake in 2016, including salt, potash, magnesium chloride, and magnesium metal; this is slightly down from the 2015 estimate of 2.6 million st. This estimate does not account for all byproducts so the actual solids production is likely higher. The 2016 value of mineral and brine production from Great Salt Lake is estimated at $610 million, which is an increase of about 3.5% from 2015.

Portland Cement, Lime, and Limestone

Together, Ash Grove Cement Co. and Holcim, Inc., produced about 1.6 million st of Portland cement in Utah during 2016, having an estimated value of $161 million. Ash Grove Cement Co. operates the Leamington quarry and plant east of Leamington in Juab County, while Holcim, Inc. operates the Devil's Slide quarry and plant east of Morgan in Morgan County (figure 6). Portland cement production was steady in 2016, but production value increased about 5% due to an increase in

the price of cement (USGS, 2017a). Besides limestone, the Ash Grove and Holcim mines also produce small amounts of sandstone, clay, and shale, which are minor feedstock for their cement plants.

During 2016, Graymont Western U.S., Inc. was the sole producer of lime in Utah. In the past, Lhoist North America produced dolomitic lime, but their quarry and plant in Tooele County have been idle since 2008. Lime production decreased approximately 13% in 2016. Graymont Western U.S. produces high-calcium quicklime and dolomitic quicklime from their quarry and plant in the Cricket Mountains about 35 miles southwest of Delta in Millard County (figure 6). The annual production capacity of their plant is about 1.5 million st.

During 2016, about 3.3 million st of limestone was produced in Utah for uses other than crushed stone. More than half of the production was chemical-grade limestone from Graymont Western U.S. Inc., while Ash Grove Cement Co. and Holcim, Inc. produced most of the remainder for cement. The Cotter Corp. in San Juan County produced about 26,000 st of limestone for flue-gas desulfurization at coal-fired power plants. Limestone is primarily used in the manufacture of cement and lime products, for flue-gas desulfurization, and as a safety product for the coal mining industry as "rock dust."

Sulfuric Acid

In 2016, the KUC Bingham Canyon mine produced an estimated 920,000 st of sulfuric acid (H_2SO_4). Sulfuric acid is a byproduct of the KUC copper-gold-silver smelting process. The UGS estimates sulfuric acid prices average about $140/st, giving Utah's production an approximate value of $129 million. Although sulfuric acid has been recovered at the Bingham copper smelter since 1917, the commodity has only recently been included in the UGS production survey. Currently, sulfuric acid is the fourth-most valuable industrial mineral commodity produced in Utah. Sulfuric acid is used in the production of fertilizer and by some gold, copper, uranium, and beryllium producers, as well as in chemical manufacturing, power plants, steel companies, farming, and water treatment.

Phosphate

Simplot Phosphates continues to be the only active phosphate producer in Utah. The phosphate operation is located 12 miles north of Vernal in Uintah County (figure 6). In 2016, the mine produced approximately 3.7 million st of ore, which was about equal to 2015 production. The ore yields about 1.4 million st of phosphate concentrate (P_2O_5) after processing. The concentrate is transported in slurry through a 96-mile underground pipeline to the Simplot fertilizer plant near Rock Springs, Wyoming. More than 95% of the phosphate rock mined in the United States was used to manufacture phosphoric acids to make ammonium phosphate fertilizers and animal feed supplements (USGS, 2017a).

Gilsonite

Gilsonite is a shiny, black, solid hydrocarbon that occurs in a swarm of laterally and vertically extensive veins in the Uinta Basin. It has been mined since the late 1880s in Utah and Colorado. In 2016, American Gilsonite Company was the only significant producer, mining and processing gilsonite at their operation in southeastern Uintah County (figure 6). Over the past decade, gilsonite production from the Uinta Basin has ranged between 60,000 and 85,000 st per year. Production for American Gilsonite was significantly reduced in 2016 as the company underwent Chapter 11 bankruptcy reorganization. Small quantities of gilsonite may have been produced by other small Utah mines, but this production is inconsistently reported and would not make a significant impact on the total amount of gilsonite produced in Utah. Utah is the only place in the world that contains large deposits of gilsonite, and it has been shipped worldwide for use in numerous and diverse products including asphalt paving mixes, coatings, inks, paints, and oil and gas well drilling additives (Boden and Tripp, 2012).

Bentonite, Common Clay, and High-Alumina Clay

Production of bentonite, common clay, and high-alumina clay in Utah during 2016 was about 234,000 st, a 23% increase from 2015 production. These commodities were produced by many small and large mines, often on an intermittent basis. Consequently, production and value estimates are subject to significant change on a year-to-year basis. Bentonite was produced by Western Clay Co. and Redmond Minerals, Inc. Uses for bentonite include well drilling and foundry operations, various civil engineering applications, and as litter-box filler. The largest producers of common clay and high-alumina clay were Interstate Brick Co., and Holcim, Inc. Common clay is largely used to make bricks, whereas high-alumina clay is used to make Portland cement.

Expanded Shale

Expanded shale in Utah is produced by Utelite at their quarry and plant near Wanship in Summit County (figure 6). The company produced approximately 175,000 st of raw shale in 2016, which was used as the feedstock to produce expanded shale. Expanded shale is a lightweight aggregate, sometimes called "bloated shale," and is mainly used by the construction industry. It is produced by rapidly heating high-purity shale from the Cretaceous-age Frontier Formation to about 2000°F, causing it to expand and vitrify. The resulting aggregate is durable, inert, uniform in size, and lightweight, with a density about one-half that of conventional aggregates. The material is used in roof tile, concrete block, structural concrete, and horticulture additives, as well as for highway construction and geotechnical fill. About half of Utelite's production is used locally along the Wasatch Front and the rest is shipped out of state.

Gypsum

Four operators reported combined Utah gypsum production of about 290,000 st in 2016, a 5% decrease from 2015 production. The 2016 production had an estimated value of $3.9 million, similar to the 2015 value. Higher value calcined gypsum production was up slightly in 2016, while lower value crude gypsum production was moderately down. The four Utah gypsum producers were Sunroc Corp., United States Gypsum Co., Diamond K Gypsum, Inc., and Nephi Gypsum (in descending production order). Two gypsum wallboard plants are located near Sigurd in Sevier County. The plant operated by United States Gypsum was active in 2016 (figure 6), but the plant operated by Georgia Pacific remains idle due to economic considerations. Utah gypsum is primarily used in raw or crude form by regional cement companies as an additive to retard the setting time of cement and by the agriculture industry as a soil conditioner. Lesser amounts of the higher value calcined gypsum are used to make wallboard.

Exploration and Development Activity

Industrial minerals exploration and development in Utah varies according to the commodity. The development of high-value, internationally traded commodities, like potash, are relatively immune to fluctuating shipping costs and vary with international demand and the global economy. In contrast, the development of low-value commodities, like sand and gravel, are constrained by shipping costs and consequently are sensitive to regional economic conditions. Similar to the metals exploration and development activity section, the information presented in this section is derived primarily from company websites, press releases, the UGS annual industry survey, and DOGM records. Industrial mineral exploration developments are summarized in table 4.

Compass Minerals, an active potash producer in Utah, is upgrading its solar evaporation ponds and plant to increase efficiency and capacity at their operation. Solar ponds are being sealed to prevent loss of brine, and plant upgrades are focused on increasing capacity to convert purchased potassium chloride to potassium sulfate. Overall, the improvements are expected to increase their annual potassium sulfate capacity from 400,000 to 550,000 tons.

Over the past several years much of the industrial mineral exploration and development in Utah has focused on potash, but for 2016 interest in Utah potash waned. Projects reporting progress include Crystal Peak Minerals Inc.'s (CPM) Sevier Lake project and Potash Ridge Corporation's Blawn Mountain project. During 2016, Crystal Peak Minerals Inc. made progress on their feasibility study and coordinated with state and federal agencies to advance their EIS. Potash Ridge Corporation is re-evaluating project economics at Blawn Mountain and is considering a lower production rate than initially planned. Both of these projects intend to produce potassium sulfate, the more valuable form of potash. Other potash projects still exist, but no substantive activity was reported in 2016. Similar to 2015, activity at Utah's undeveloped phosphate projects was limited. Utah Phosphate Company (Agrium) conducted water monitoring at their Ashley Creek project, which is west of Simplot, while continuing to evaluate metallurgy and economics.

Following substantial recent increases in lithium demand and pricing, several lithium projects were staked in Utah in 2016. Projects targeted lithium brines and several areas were claimed or leased across the state. Projects are located in the Paradox Basin, Pilot Valley, Tule Valley, and the Black Rock Desert. Beyond claim staking and lease acquisition, exploration activities were limited to some sediment and shallow brine analytical testing.

URANIUM

Historically, Utah is the third largest uranium-producing state, the vast majority of this production came from sandstone-hosted uranium deposits of the Colorado Plateau (Gloyn and others, 2005). Utah also has two of the three licensed conventional uranium mills in the United States—Energy Fuels' White Mesa mill near Blanding and Anfield Resources' Shootaring mill near Ticaboo (figure 8). Only the White Mesa mill is currently operating, intermittently using high-grade uranium ore from Energy Fuels' breccia pipe deposits in Arizona and alternate feed material from out of state.

The spot price of U_3O_8 has been especially volatile over the last decade with a huge price spike up to $136/lb in June 2007 and lows of less than $45/lb in 2009–2010. The spot price rebounded to $73/lb in early 2011, but fell back below $50/lb after the March 2011 Fukushima nuclear power plant disaster in Japan. Uranium spot prices have remained below $40/lb throughout 2012–14, only to fall below $35/lb in 2015 and $30/lb in 2016. Spot U_3O_8 prices finally seemed to have bottomed out at $18/lb in December 2016. However, unlike the volatile spot price, long-term contract U_3O_8 prices have declined fairly gradually to about $31/lb at the end of 2016. Uranium exploration and development in Utah has varied directly with the U_3O_8 spot price fluctuations.

The continuing low uranium prices resulted in a halt to all of Utah's uranium mining operations in late 2012. All Energy Fuels Inc.'s Utah mines were closed because they could purchase U_3O_8 on the spot market for less than their production cost. This business strategy has the added corporate benefit of preserving their existing ore reserves for times of higher prices. Energy Fuels' Daneros, Pandora-Snowball, and Whirlwind mines all remain on standby (figure 8). Utah's uranium mines will likely remain uneconomic until U_3O_8 prices surpass at least $50/lb. No Utah uranium production is anticipated in 2017.

Table 4. *Selected industrial mineral exploration and development projects in Utah, 2016.*

Property	Commodity; Deposit	Location	County	Company	Progress
Ashley Creek	Phosphate; Meade Peak Mbr. of Phosphoria Fm.	Uinta Basin, Ashley Creek	Uintah	Utah Phosphate Company (Agrium)	Limited activities in 2016 included metallurgical and economic evaluations and water monitoring.
Blawn Mountain	Potash; alunite alteration	Blawn Mountain; Wah Wah Mtns.	Beaver	Potash Ridge Corporation	Minimal reported activity in 2016; continued to evaluate a reduced initial production rate for startup; completed preliminary feasibility study in 2013
Crescent Junction	Potash; Paradox Fm. evaporites	Paradox Basin	Grand	Pinnacle Potash International	No reported activity in 2016
Dragon Mine	Halloysite specialty clay and iron oxide	Tintic Mtns.	Juab	Applied Minerals Inc.	Mine is in production with a combined capacity of 50,000 tons; continuing to develop product lines for both commodities
Green Energy Lithium	Lithium; brine	Paradox Basin	Grand	Voltaic Minerals	Acquired claims totaling 4160 acres
Green River	Potash; Paradox Fm. evaporites	Paradox Basin	Grand	American Potash Corp.	No potash activity in 2016; added 6160 acres of lithium claims to their potash land holdings during 2016
Monument	Potash; Paradox Fm. evaporites	Paradox Basin	San Juan	Sennen Potash Corp.	No reported activity in 2016
North Paradox	Lithium; brine	Paradox Basin	Grand	Liberty One Lithium	Acquired claims totaling 4,480 acres
Paradox Basin Lithium	Lithium; brine	Paradox Basin	Grand	US Cobalt Inc. (formerly Scientific Metals Corp.)	Acquired claims totaling 2220 acres
Red Valley	Lithium; brine	Black Rock Desert, west of Fillmore	Millard	Red Mountain Mining, Ltd.	Partial stake in lithium project
Sal Rica	Lithium; shallow brine	Pilot Valley	Box Elder	Uranium Resources, Inc. (URI)	Acquired and staked claims totaling 13,260 acres at Pilot Valley; prior to acquisition by URI, some sediment and brine sampling was conducted
Sevier Lake	Potash; shallow brine	Sevier (Dry) Lake	Millard	Crystal Peak Minerals Inc. (EPM Mining Ventures Inc.)	Continued work on feasibility study and worked with state and federal agencies on EIS during 2016; completed preliminary feasibility study in 2013
Tule Valley Lithium	Lithium; brine	Tule Valley	Millard, Juab	Umbral Energy Corp.	Acquired claims totaling 4800 acres; collected and analyzed some sediment and brine samples

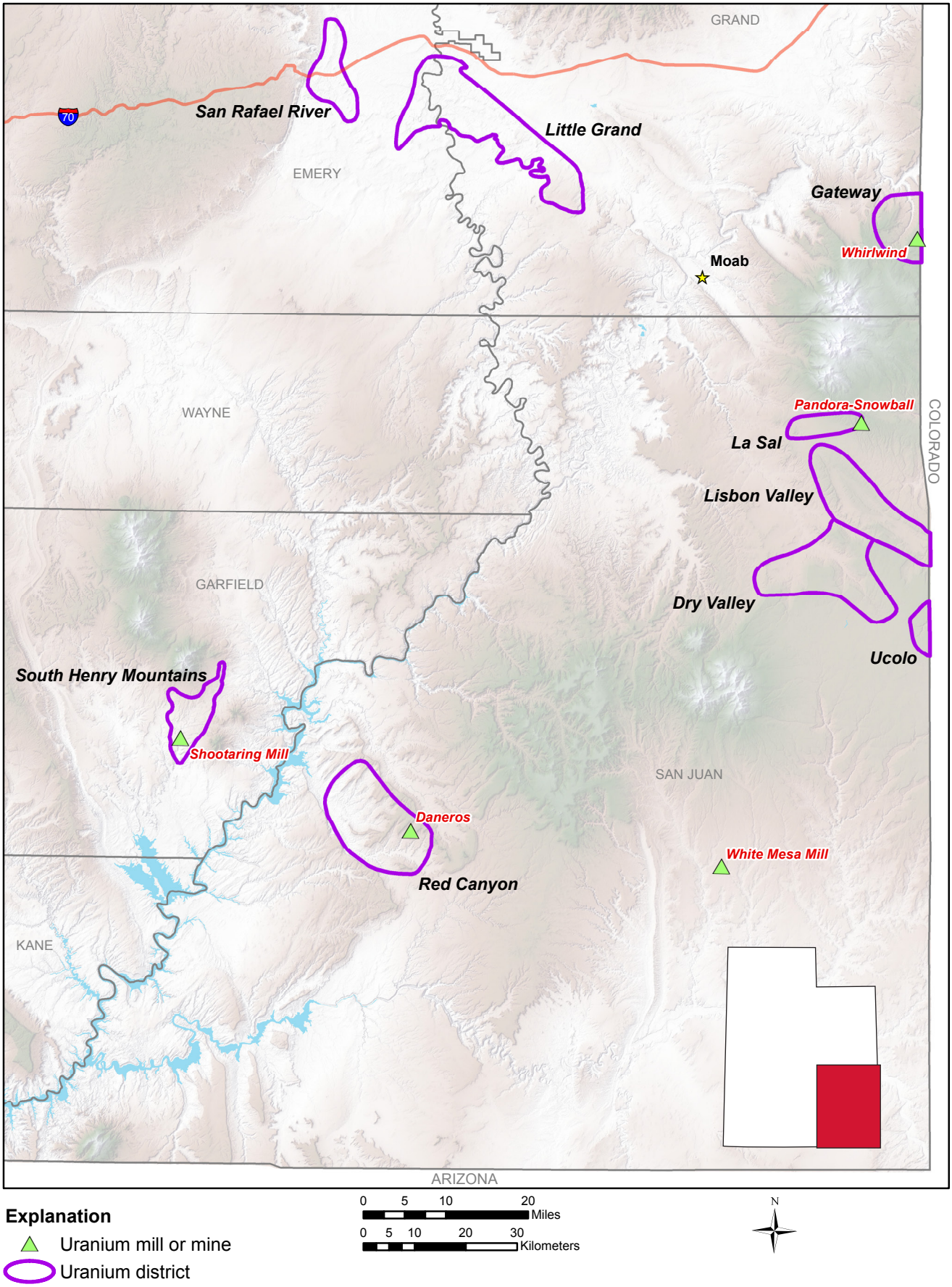

Figure 8. *Licensed uranium mills and selected uranium exploration and development activity in Utah during 2016.*

In the past few years of low spot prices, the uranium industry in Utah was consolidated by Energy Fuels and Anfield Resources, as they acquired most of the promising uranium mines and prospects. The most significant known Utah uranium properties are listed in table 5 and shown on figure 8. Anfield Resources completed a preliminary economic assessment in 2016 on their Velvet-Wood underground uranium project using a U_3O_8 price of $65 per pound (Beahm and McNulty, 2016).

Weak uranium prices discourage revitalization of Utah's uranium industry. However, the upswing in the demand for vanadium redox batteries (VRB) may add some renewed interest to the exploration and development of the vanadium-uranium mines to feed the existing White Mesa dual circuit mill.

COAL

Production and Values

Four Utah coal operators produced 14.0 million st of coal valued at $509 million from seven underground mines and one surface mine in 2016 (figures 3 and 9). Overall production was 3.7% lower than in 2015, mainly due to the closing of the Deer Creek and West Ridge mines. No new mines opened in 2016, however, the longwall mining machine used at West Ridge was shifted to the Lila Canyon mine, increasing production there to make up for the closure at West Ridge. The Emery mine, which has been idle since 2010, was sold to Bronco Energy at the end of 2015; plans are to open new portals and resume production in late 2017 to early 2018. Even with relatively steady demand from Utah's large coal-fired power plants, fuel switching or closure at other U.S. coal-fired power plants outside of Utah has reduced demand for Utah coal to near historical lows. Utah coal production is expected to total about 14.3 million tons in 2017.

In 2016, the majority of Utah coal, 11.0 million st, was produced from the Wasatch Plateau coalfield, with 2.2 million st coming from mines in the Book Cliffs coalfield and 0.7 million st from the Alton coalfield. The majority of Utah coal in 2016, 88% (12.3 million st) was produced from federal land, while only 2.6% (0.4 million st) was from state-owned land. Federal coal production has dominated in Utah since July 2011, when the Deer Creek mine's state-owned Mill Fork coal tract reverted back to federal ownership after a 22.3 million st coal production threshold was reached. This reversion dramatically increased the amount of coal produced on federal land in 2012, from 48.0% in 2011 to 84.2% in 2012. Utah's 2016 coal production also came from private lands (7.6%, 1.1 million st) at the Castle Valley, Skyline, and Coal Hollow mines, and county lands at the Skyline mine (1.7%, 0.2 million st).

Utah coal mines face steady reserve depletion and difficult mining conditions. In addition, the demand for Utah coal has

Table 5. *Selected uranium exploration and development projects in Utah, 2016. District locations are shown on figure 8.*

Property	District	County	Company	Progress
Whirlwind	Beaver Mesa	Grand	Energy Fuels, Inc.	Permitted resource: 656,000 lb U_3O_8; on standby
Rim-Columbus	Dry Valley	San Juan	Energy Fuels, Inc.	Permitted resource: 660,000 lb U_3O_8
Energy Queen	La Sal	San Juan	Energy Fuels, Inc.	Permitted resource: 1.2 M lb U_3O_8
Pandora-Snowball-Beaver	La Sal	San Juan	Energy Fuels, Inc.	Permitted resource: 1.2 M lb U_3O_8 reserve; on standby
La Sal #2	Lisbon Valley	San Juan	Laramide Resources Ltd.	Resource: 808,000 tons at 0.167% U_3O_8
Velvet-Wood	Lisbon Valley	San Juan	Anfield Resources Inc.	New PEA** NI 43-101* completed (Beahm and McNulty, 2016)
Daneros	Red Canyon	San Juan	Energy Fuels, Inc.	Permitted 740,000 lb U_3O_8 inferred resource; on standby
San Rafael	San Rafael River	Emery	Baobab Asset Management LLC.	Indicated resource: 758,050 tons at 0.23% U_3O_8
Frank M	South Henry Mountains	Garfield	Anfield Resources Inc.	Resource: 1.1 M tons at 0.1% U_3O_8
Tony M-Bullfrog	South Henry Mountains	Garfield	Energy Fuels, Inc.	Permitted resource: 1.684 M tons at 0.24% U_3O_8
Highlands	Ten Mile Canyon	Grand	Highlands Natural Resources Plc.	Staked 67 claims based on high gamma (3000 to 8000 API units) in oil well log
Sage Plain	Ucolo	San Juan	Energy Fuels, Inc.	NI 43-101* completed (Peters, 2015)

* An NI 43-101 is a formal Canadian National Instrument technical report prepared to a codified set of rules for public reporting of mineral exploration and development data on properties operated by companies listed on Canadian stock exchanges.

**A PEA is a preliminary economic assessment.

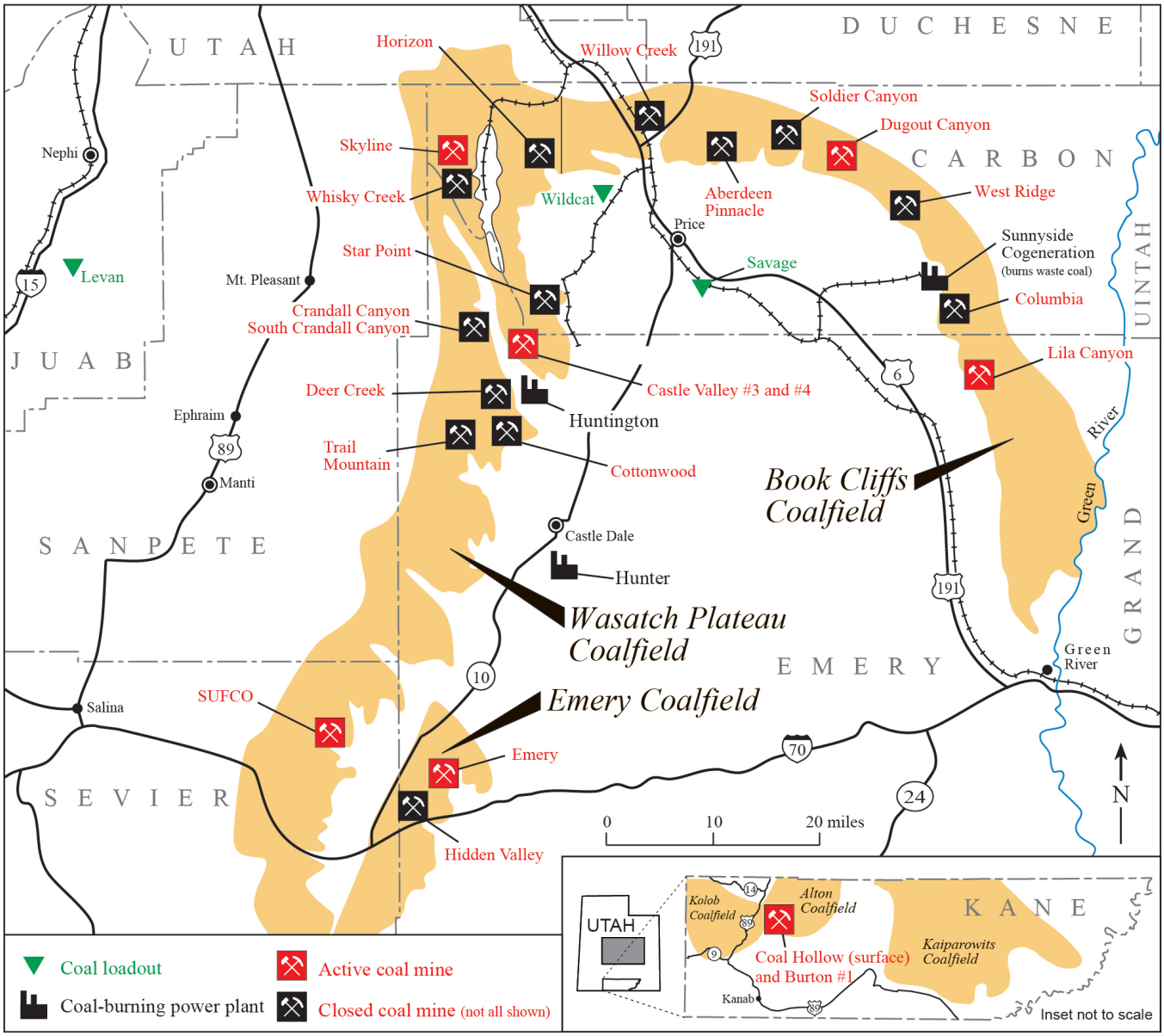

Figure 9. *Location and status (at time of publication) of Utah coal mines and associated facilities.*

sharply decreased over the past few years as coal-fired power plants have closed or switched to natural-gas-fired generation. Gas overtook coal as the leading fuel for U.S. power plants in 2016, while coal used to produce electricity fell to the lowest level since 1982 according to federal data. Within Utah, the Carbon coal-fired power plant outside Helper, Utah, closed in April 2015 because it was cost prohibitive to retrofit the old plant with new EPA-mandated emission-reducing technology. This removed about 600,000 st of coal from the Utah market. In 2016, KUC permanently converted units 1, 2, and 3 at its Salt Lake City smelter power plant from coal to gas. In California and Nevada, both significant past markets for Utah coal, several coal-fired generation plants are closing or converting to natural gas to comply with stricter air-quality standards. In Nevada, the Reid Gardner coal-fired power plant shut down units 1 through 3 in 2014, and unit 4, 257 MW, is scheduled for shutdown in 2017. In California, several co-generation plants that formerly used Utah coal have shut down or converted to natural gas in recent years. Most importantly, the City of Los Angeles, which is the majority owner of the Intermountain Power Plant (IPP) north of Delta, Utah, has stated that it will no longer purchase power from IPP after its current power purchase agreement expires in 2027, unless IPP converts to natural gas or implements carbon capture and storage technology. Thus, annual Utah coal production will likely be in the 13 to 15 million st range until, or possibly before, 2027 when there could be a loss of another 4–5 million tons of annual coal demand.

Excluding overseas exports, the total amount of Utah coal distributed to the U.S. market in 2016 was 13.6 million st. As recently as 2002, nearly 13.2 million st of Utah coal was exported to other states, while 10.1 million st was used in state (figure 10). In 2016, only 1.9 million st of Utah coal was shipped to other states, while 11.7 million st was used locally.

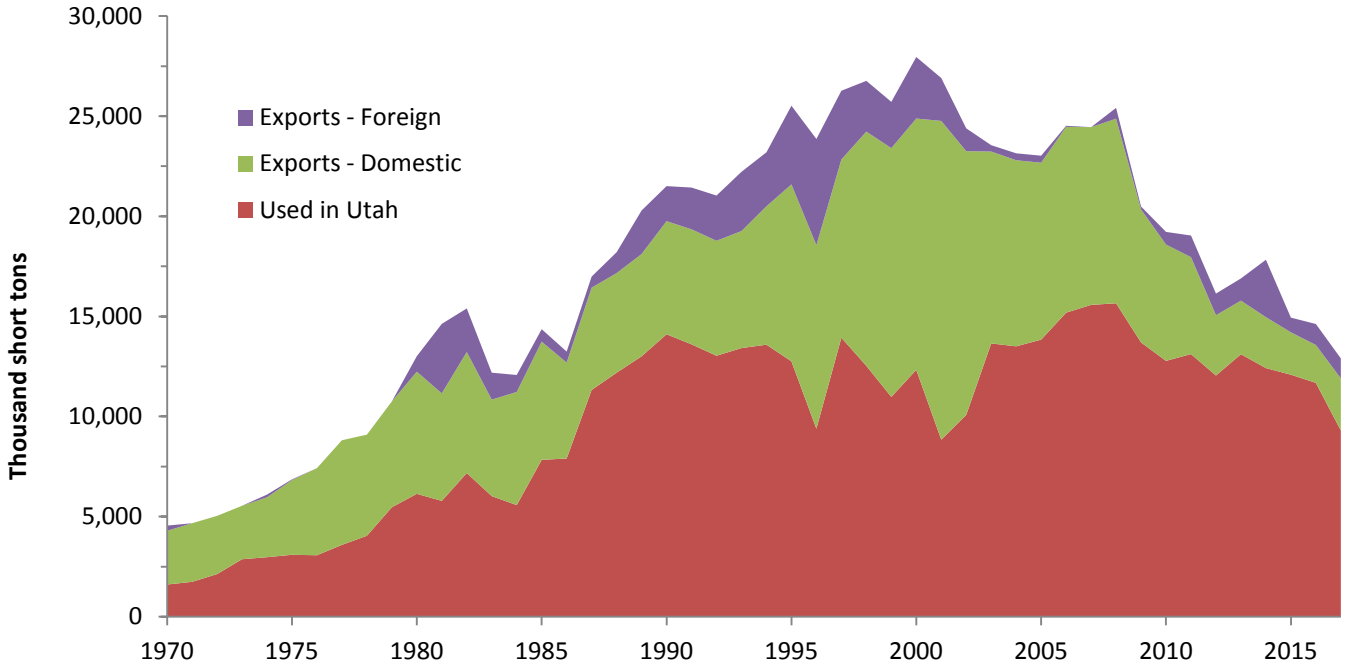

Figure 10. *Distribution of Utah coal, 1970–2017 (2017 data are estimated).*

The vast majority of Utah coal, about 83% (11.3 million st), went to the electric utility market mainly within the state. A slowly growing economy since the recession of 2009 and low natural gas prices have greatly diminished demand for Utah coal in the industrial sector where deliveries totaled 2.3 million st in 2016, which was significantly less than peak deliveries of 4.4 million st in 2003. Total annual deliveries of Utah coal in 2017 are expected to remain in the 12 to 14 million st range, reflecting low overall demand.

Foreign exports of Utah coal averaged about 3.0 million st per year in the 1990s, peaking at 5.3 million st in 1996 (figure 10). Beginning in the early 2000s, foreign exports dropped dramatically, with no exports reported in 2007. Starting in 2008, Utah coal exports revived, reaching 2.9 million st in 2014, before dropping again in 2015 to only about 0.7 million st, and 1.1 million st in 2016. Demand for coal in Asia exists, but Utah operators need increased access to port facilities on the West Coast to allow this market to grow and offset decreasing domestic demand.

For detailed statistics on Utah's coal industry (including information previously published in the annual Utah coal report), refer to extensive data tables located on the UGS's Utah Energy and Mineral Statistics website: http://geology.utah.gov/resources/energy/utah-energy-and-mineral-statistics/.

Exploration and Development Activity

UtahAmerican Energy, Inc. – Murray Energy Corp.

Lila Canyon mine: The Lila Canyon mine is located south of Horse Canyon in the Book Cliffs coalfield in Emery County. In spring of 2010, the company finished construction on 1200-foot-long rock slopes and began development work in the Sunnyside coal bed, producing 72,000 st of coal in 2010. Mine development work continued from 2011 through 2015, and total coal production reached 157,000 st, 304,000 st, 257,000 st, 335,000 st, and 350,000 st, respectively. Coal production increased substantially in 2016, up to 1.6 million st, after the now-closed West Ridge mine's refurbished longwall mining equipment was installed in February. At full capacity, the mine could employ up to 200 people and produce up to 4.5 million st of coal per year. However, the exact timing of reaching that level of production depends on the coal market. Coal is presently mined from federal leases where the merged upper and lower Sunnyside bed is about 13 feet thick.

West Ridge Resources, Inc. – West Ridge mine: The West Ridge mine began operation in 1999 in the Book Cliffs coalfield with production from the lower Sunnyside bed. Production at West Ridge has averaged 2.6 million st between 2012 and 2014, but production in 2015 decreased to about 1.6 million st as UtahAmerican depleted the remaining recoverable coal under lease and shut down operations in late November 2015. Total production from the mine's 17 years of operation was about 43.7 million st.

Canyon Fuel Company – Bowie Resource Partners, LLC

Bowie Resource Partners, LLC bought Canyon Fuel Company (the Dugout, Sufco, and Skyline mines) from Arch Coal in summer 2013. Bowie, based in Louisville, Kentucky, owns

the mines in a joint venture with Galena Private Equity Resources Fund, a unit of the Amsterdam-based commodity trader Trafigura Beheer BV. Trafigura sells the venture's coal production. In late 2017, it was announced that Canyon Fuel would be sold to Canyon Consolidated Resources, a partnership formed largely by Murray Energy with several other minor investors; however, the sale fell through less than a month after the announcement.

Dugout Canyon mine: In 2012, Dugout Canyon in the Book Cliffs coalfield completed mining the longwall panels in its current mine plan and now operates as a room-and-pillar operation with the option to resume longwall mining in the future in an adjacent reserve block. Thus, in 2013 coal production consisted of only 561,000 st from the Rock Canyon bed, down significantly from the 1.6 million st produced in 2012. A second continuous miner section was added in 2015 and the Dugout mine produced 650,208 st in 2016. The two continuous miners could increase production if more working shifts were added in response to improved coal market conditions, but 2017 production is expected to remain near 625,000 st.

Skyline mine: Canyon Fuel Company's Skyline mine, located in the Wasatch Plateau coalfield, is currently mining in the Lower O'Connor "A" bed on their Winter Quarters lease in Carbon County. Production from this bed increased slightly in 2016 to 4.8 million st, but is expected to dip to 4.4 million st in 2017. Production on the Winter Quarters lease will be completed in 2018, after which mining will shift to the recently leased Flat Canyon federal coal tract in Sanpete County, near the border with Emery County. The Flat Canyon tract is estimated to contain up to 42 million st of recoverable coal reserves in the Lower O'Connor "B" and Flat Canyon beds.

Sufco mine: Sufco is Utah's largest coal producer and the 13th largest producing underground coal mine in the United States (2016 data). Located in the Wasatch Plateau coalfield, Sufco is also the only active mine in Sevier County. Sufco produced nearly 5.4 million st of coal in 2016 from the upper Hiawatha bed, 11.8% less than in 2015, but 32% less than record high production of 7.9 million st achieved during 2006. Production at Sufco is expected to increase to 5.9 million st in 2017 and production on current leases will last about another year before operations shift to the Greens Hollow tract, containing an estimated 55.7 million st of recoverable coal. The Greens Hollow federal coal lease was leased to the sole bidder, Canyon Fuels Company, in January 2017 for $23 million, or $0.41 per ton of recoverable coal.

Fossil Rock Fuels – Bowie Resources Partners, LLC

Cottonwood tract: On December 31, 2007, SITLA held a sale of the Cottonwood Competitive Coal Leasing Unit. The tract was awarded to Ark Land Company, a subsidiary of Arch Coal, Inc., also the former owner of Canyon Fuel Company. Two coal leases were issued, one for 8204 acres covering lands within the 1998 land exchange Cottonwood Coal Tract and the other for 600 acres within an adjacent SITLA section. In mid-2011, the Cottonwood lease was transferred to Fossil Rock Resources, a subsidiary of PacifiCorp and Rocky Mountain Power, as part of a settlement of litigation between the two companies. The Cottonwood tract is adjacent to PacifiCorp's existing, but inactive, Train Mountain federal lease. Total recoverable coal in the Hiawatha bed for the combined leases is estimated to equal 49 million st. Following the announcement of the closure of the Deer Creek mine in early 2015, Fossil Rock Resources along with its coal reserves was sold to Bowie Resources.

Bronco Utah Operations, LLC

Emery mine: Bronco Utah Operations bought the Emery mine from CONSOL Energy in December 2015. The Emery mine produced about 1 million st annually from the Ferron Sandstone I bed from 2005 through 2010, then CONSOL idled the mine due to low coal demand. Bronco developed new portals into the I bed in early 2017, producing about 130,000 st of coal while readying the mine for full production. At full capacity, the Emery mine could produce from 1.0 to 1.5 million st per year using up to three continuous miner sections.

Rhino Resource Partners, LP

Castle Valley mines: Rhino purchased the Bear Canyon mines from C.W. Mining in 2010 and changed their name to Castle Valley. Full-scale production using two continuous miners produced 1.1 million st from the Tank bed (#4 mine) in 2014. Total production in 2015 was about 975,000 st, split between the reactivated Castle Valley #3 mine (218,000 st; Bear bed) and the #4 mine (757,000 st; Tank bed). Rhino reported that its western mines produced 894,190 st of coal from the Castle Valley #3 (169,899 st) and Castle Valley #4 (724,291 st) mines in 2016 with an average sales price of $38.56 per ton. As of December 31, 2016, the Castle Valley mining complex included an estimated 17.9 million tons of proven and probable coal reserves. For 2017, Rhino Western operations reported to its shareholders it has contracted about 950,000 st of coal sales at an average price per ton of about $37.

East Mountain Energy – PacifiCorp

Deer Creek mine: Production at the Deer Creek mine was 2.1 million st in 2014, and the mine closed in early January 2015 after negligible production (15,000 st). During most of 2015, the Deer Creek mine began removing mining equipment and preparing the mine for permanent closure and reclamation. No production was reported for the mine in 2016 while closure activities continued.

Alton Coal Development

Coal Hollow and Burton #1 mines: In 2011, Alton Coal Development began production at a new coal mine in the Alton coalfield in southern Utah's Kane County. The Coal Hollow mine produces subbituminous Dakota Formation coal from the Smirl bed, which averages about 10,000 Btu/ lb, about 1% sulfur, and 8% ash. Surface-mining production at the company's Coal Hollow mine on private property peaked in 2013 at 747,000 st before decreasing to 316,000 st in 2015 as the reserves on the southern property were depleted. In the spring of 2014, highwall mining began in the mine's open pits in an effort to recover coal with less surface disturbance. Also during this time, permitting was underway to begin mining the northern fee tract, which commenced production in 2016. The Coal Hollow surface mining operations produced about 669,000 st during 2016. After experiencing difficulty producing coal using the highwall mining machine, Alton Coal commenced underground room and pillar mining in late 2015 at the Burton #1 mine. Total production from the underground mine in 2015 was only 11,000 st. Production was increased to about 34,000 st in the first half of 2016 before problems establishing an approved roof control program shut down the underground mine in the second half of 2016. Alton Coal Development's application to acquire an adjacent federal coal lease, a process begun in 2004, was affected when a federal coal leasing moratorium was declared in January 2016 by the BLM. Under a new administration, the BLM lifted the coal leasing moratorium in March 2017, providing a new opportunity for Alton Coal to receive a lease on federal coal adjacent to its private leases before the private coal is exhausted. If a new federal lease is acquired, the Alton Coal operation would likely continue to be a combination of surface and underground mines.

UNCONVENTIONAL FUELS – OIL SHALE AND OIL SAND

Exploration and Development Activity

Oil Shale

The upper Green River Formation in the Uinta Basin of Utah contains one of the largest deposits of oil shale in the world. The oil shale deposit contains an estimated in-place resource of 1.3 trillion bbls (USGS Oil Shale Assessment Team, 2011) and a potential economic resource of 77 billion bbls (Vanden Berg, 2008). The richest Green River oil shale horizon is the Mahogany zone, where individual beds can yield 80 gallons of oil per ton of rock. The Mahogany zone is 70 to 120 feet thick and is accessible via extensive outcrops along the eastern and southern flanks of the basin.

Company development activities: The outcrop accessibility, low dip, and shallow cover of Utah oil shale deposits make surface/underground mining and surface retort the preferred technology to recover oil from the shale. Currently, three companies are pursuing oil shale development in Utah: Enefit American Oil, Red Leaf Resources, and TomCo Energy.

Enefit American Oil is an Estonian company that acquired 100% of OSEC (Oil Shale Exploration Company), including their private land (the Skyline property, 21,000 acres), state leases (4000 acres), and a U.S. BLM Research, Development, and Demonstration oil shale lease (5000 acres), for which Enefit recently received a lease extension through 2022 from the BLM. On the southern, private portion of its property, Enefit seeks to develop a full-scale oil shale operation consisting of a surface and/or underground mine, surface retorts and circulating fluidized bed combustion units, and a shale oil upgrader. Recent work has focused on drilling several wells and recovering core to prove up the resource and provide fresh mining-horizon samples for testing the company's specific retort technology. In addition, several water monitoring wells have been drilled. Although the project will begin on private land, a utility corridor that crosses BLM land is needed to support the development. A draft Environmental Impact Statement for the corridor was released in April 2016 and a final decision is expected in early 2018.

Red Leaf Resources is a Utah company having several state oil shale leases on the southeastern side of the Uinta Basin. Red Leaf has developed a modified in-situ retort process called EcoShale technology. The process involves surface mining oil shale from a pit, lining the pit with an impermeable clay layer, placing the oil shale back in the pit with a series of pipes, and covering the filled pit (capsule) with clay and top soil. Shale in the capsule is retorted by hot air circulating through the pipes. Reclamation can commence while the capsule is still retorting the shale. This process was tested on a pilot scale at the Seep Ridge lease and the company has acquired a large-mine permit to build a near-commercial-scale capsule. During 2016, Red Leaf completed a feasibility study on a 30,000 bbl/day project that indicated costs of $35/bbl. Red Leaf is continuing engineering studies and is currently evaluating the possible benefits of reusable capsules that may significantly improve costs per barrel of oil. In March 2012, Red Leaf announced a joint venture with Total E&P USA Oil Shale (a U.S. affiliate of Total USA). Total intended to fund an 80% share of the EPS expenses, which were estimated at approximately $200 million. However, in March 2017 Total announced its withdrawal from the Utah joint venture. A favorable settlement was reached with Total and Red Leaf is considering its options for both continued development of its Seep Ridge project and other opportunities to further advance its EcoShale technology.

TomCo Energy is a United Kingdom-based company with 2919 acres of SITLA leases in the Uinta Basin. The company has drilled nine exploratory wells to define their resource and has begun work to acquire the necessary development per-

mits. SRK Consulting Limited reviewed the drilling and geological work over the Holliday Block and issued an updated mineral resource statement upgrading the resource from 123 million bbls of oil in the "indicated" category to 126 million bbls of oil in the "measured" category. The company originally planned to use the Red Leaf Ecoshale technology on their Holliday block property. However, as a result of the sharp drop in oil prices in 2015, TomCo announced in March 2017 that it has set up TurboShale Inc, an oil shale technology company that will, subject to funding, seek to develop a less expensive, radio-frequency-heating, oil-shale technology as an alternative to Red Leaf's technology.

Oil Sand

North America has the greatest oil sand resources in the world, most of which are in Canada. Utah oil sands, though small compared to Canadian resources, are the largest resource in the United States. Utah oil sand deposits contain 14 to 15 billion bbls of in-place oil and have an additional inferred resource of 23 to 28 billion bbls. Twenty-four individual deposits exist in the Uinta Basin, mainly around its periphery, and an additional 50 deposits are scattered throughout the southeastern part of the state. Utah's major oil sand deposits individually have areal extents ranging from 20 to over 250 square miles, as many as 13 pay zones, gross thickness ranging from 10 to more than 1000 feet, and overburden thickness ranging from zero to over 500 feet.

With the current glut of conventional crude oil and the attendant low price, there is less incentive for new drilling or the employment of bitumen extraction and upgrading techniques to move Utah's oil sands toward successful and sustainable development. Meanwhile, investment and investigation should continue into factors such as permitting, process efficiency, site accessibility, adequate infrastructure, water availability, environmental concerns, and greater understanding of the problems associated with the heterogeneity of reservoir sands to reduce investment risk and improve the economic viability of oil sand development in Utah when market conditions improve in the future.

Company development activities: US Oil Sands holds 32,005 acres of bitumen extraction rights on leases within the PR Springs oil sand deposit in the southern Uinta Basin. In the summer of 2011, the company drilled more than 180 wells on their leases to define the resource. These assets contain approximately 184 million barrels of discovered resource, as described in a NI 51-101 report, and represent the largest oil sands holdings in the United States. All lands are leased from SITLA and US Oil Sands owns 100% of the bitumen rights to these lands. US Oil Sands has two project areas: PR Springs and the Cedar Camp-NW. The Cedar Camp-NW project area holds 26,075 acres of exploration land, which will be assessed for future development. The primary area of development is the PR Spring project area, which consists of 5930 contiguous acres. Within a portion of this lease, the company has acquired all the necessary permits for development of a surface mine/solvent extraction project on which work commenced in the second half of 2013. The initial development was targeted to produce 2000 bbl/d of bitumen. The significant drop in crude oil prices in 2015 delayed financing and construction of the mining and bitumen extraction operations. The company completed some project advancements during 2016, including an updated NI 51-101 report that projected lower future commodity prices. In early 2017, the company continued to work towards initial production, but ongoing financial challenges caused the company to go into receivership (similar to bankruptcy) later in the year.

Another of Utah's oil sand deposits that consistently generates interest is Asphalt Ridge near Vernal, Utah. Several companies have tried to develop oil sand operations in the area in the past, but limited commercial activity occurred during 2016. One company, Petroteq Energy Incorporated (formerly MCW Energy Group until mid-2017), has pilot-scale tested operations on the northern side of Asphalt Ridge, also using a solvent-based extraction technique. Prior to the decline of oil prices during 2015 and early 2016, predecessor MCW Energy produced approximately 10,000 bbls of oil from its 250 bbl/day pilot plant. During the latter part of 2016, the company began relocation of its plant to their mine site, Temple Mountain, which is on the southeast end of Asphalt Ridge. The new plant will be scaled up to 1,000 bbl/day.

NEW MINERALS INFORMATION

The following publications released in 2016 provide new information on the energy and mineral resources of Utah. Boden and others (2016) compiled production, values, and exploration and development activity for Utah's extractive resource industries for 2015. This and other UGS and Utah Geological Association publications are available through the Utah Department of Natural Resources Map and Bookstore (utahmapstore.com).

Utah Geological Association Publication 45 (Comer and others, 2016) focuses on resources and geology of Utah's West Desert and includes 16 papers. Several papers have economic overtones including significant papers on the deep Pine Grove Climax-type porphyry molybdenum deposit, Beaver County (Stegen, 2016) and the Kiewit gold deposit, Gold Hill district, Tooele County (Robinson, 2016).

Three new NI 43-101 technical reports were completed on properties in Utah, including Goldstrike (Gustin and Smith, 2016), Velvet-Wood uranium deposit (Beahm and McNulty, 2016), and Thompson Knolls (Redfern, 2016). An interactive map to download Canadian National Instrument Technical Reports for Utah mineral properties is available on the UGS website at geology.utah.gov/apps/reportviewer/index.html.

The UGS website has added features to use and/or download the Utah Mineral Occurrence System (UMOS) at geology.utah.gov/resources/data-databases/utah-mineral-occurrence-system/ and production and shapefile information on Utah mining districts at geology.utah.gov/resources/data-databases/utah-mining-districts/. The UGS also maintains a repository for Utah energy and mineral data at geology.utah.gov/emp/energydata/index.htm, which contains over 130 tables and 50 figures (in both Excel and PDF formats) in nine chapters that are continuously updated as new data become available. Additional geographic information system (GIS) data on Utah is available for free download at http://agrc.utah.gov and geology.utah.gov/resources/.

ACKNOWLEDGMENTS

This report has been compiled from a wide assortment of both published and unpublished sources. In addition, we particularly appreciate the cooperation and assistance of Alton Coal Development (Larry Johnson), BLM (Opie Abeyta and Ed Ginouves), Bowie Resources (Mark Bunnell, David Spillman, and Craig Brown), CS Mining (Dave Hartshorn), DOE (Donald Metzler and Chris Banghart), East Mountain Energy (Ken Fleck), Geomineinfo (David Briggs), Kennecott Exploration Company (Russ Franklin), Kennecott Utah Copper (Kyle Bennett), Lisbon Valley Mining (Lantz Indergard), Materion Corporation (Greg Gregory), Rhino Resource Partners (Dennis Gibson), SITLA (Jerry Mansfield), USGS (Désirée Polyak and Micheal George), UtahAmerican Energy (David Hibbs), Utah DOGM (Paul Baker and Leslie Heppler), and David Tabet (UGS, retired).

REFERENCES

Alexander, T.G., 2006, Generating wealth from the earth 1847–2000, *in* Whitley, C., editor, From the ground up—the history of mining in Utah: Logan, Utah State University Press, p. 37–57.

Beahm, D.L., and McNulty, T.P., 2016, Velvet-Wood uranium project, preliminary economic assessment, National Instrument 43-101, Utah, USA: unpublished Canadian National Instrument (NI) 43-101 technical report prepared for Anfield Resources, Inc., 122 p.

Boden, T., Krahulec, K., Vanden Berg, M., and Rupke, A., 2016, Utah's extractive resource industries 2015: Utah Geological Survey Circular 123, 33 p.

Boden, T., and Tripp, B.T., 2012, Gilsonite veins of the Uinta Basin, Utah: Utah Geological Survey Special Study 141, 50 p., 1 plate, CD.

Boden, T., Vanden Berg, M.D., Krahulec, K., Tabet, D., and Gwynn, M., 2012, Utah's extractive resource industries 2011: Utah Geological Survey Circular 115, 27 p.

Comer, J.B., Inkenbrandt, P.C., Krahulec, K.A., and Pinnell, M.L., 2016, Resources and geology of Utah's West Desert: Utah Geological Association Publication 45, p. 377.

Gloyn, R.W., Bon, R.L., Wakefield, S., and Krahulec, K., 2005, Uranium and vanadium in Utah: Utah Geological Survey Map 215 DM, scale 1:750,000.

Gustin, M.M., and Smith, M.T., 2016, Technical report on the Goldstrike project, Washington County, Utah, U.S.A.: unpublished Canadian National Instrument (NI) 43-101 technical report prepared for Pilot Gold Inc., 77 p.

Gwynn, M., Krahulec, K., and Vanden Berg, M.D., 2011, Utah mining 2010: Utah Geological Survey Circular 114, 21 p.

Jackson, T., and Green, K.P., 2017, Fraser Institute annual survey of mining companies, 2016, Fraser Institute: Online, https://www.fraserinstitute.org/sites/default/files/survey-of-mining-companies-2016.pdf, accessed July 2017.

Krahulec, K., 2006, Utah mining timeline, *in* Bon, R.L., Gloyn, R.W., and Park, G.M, editors, Mining districts of Utah: Utah Geological Association Publication 32, p. 1–5.

Krahulec, K., 2011, Sedimentary rock-hosted gold and silver deposits of the northeastern Basin and Range, Utah, *in* Steininger, R., and Pennell, B., editors, Great Basin evolution and metallogeny: Geological Society of Nevada 2010 Symposium Volume I, p. 31–62.

Krahulec, K., 2015, Tertiary intrusion-related copper, molybdenum, and tungsten mining districts of the eastern Great Basin, *in* Pennell, W.M., and Garside, L.J., editors, New concepts and discoveries: Geological Society of Nevada 2015 Symposium CD, p. 219–250.

Krahulec, K., and Briggs, D.F., 2006, History, geology, and production of the Tintic mining district, Juab, Utah, and Tooele Counties, Utah, *in* Bon, R.L., Gloyn, R.W., and Park, G.M., editors, Mining districts of Utah: Utah Geological Association Publication 32, p. 121–150.

Lane, T., Moritz, R., and Katsura, K., 2015, Preliminary economic assessment update, Gold Springs property, Utah/Nevada, USA: unpublished Canadian National Instrument (NI) 43-101 technical report prepared for TriMetals Mining Inc., 194 p.

Mako, D.A., 1999, A post-mining view of the Mercur gold district, Tooele County, Utah: Geological Society of Nevada Special Publication 30, 44 p.

Office of Natural Resources Revenue, 2017, Office of Natural Resources Revenue statistical information: Online, http://statistics.onrr.gov/ReportTool.aspx, accessed March 2017.

Peters, D.C., 2015, Updated technical report on Sage Plain project, San Juan County, Utah, USA: unpublished Canadian National Instrument (NI) 43-101 technical report prepared for Energy Fuels Inc., 73 p.

Redfern, R.R., 2016, Technical report on Thomson Knolls property, Millard County, Utah, USA: unpublished Canadian National Instrument (NI) 43-101 technical report prepared for BCM Resources Corporation, 89 p.

Rio Tinto, 2017, Rio Tinto 2016 annual report: Online, http://www.riotinto.com/documents/RT_2016_Annual_report.pdf, accessed March 2017.

Robinson, J.P., 2016, The Kiewit gold deposit—A late Miocene (?) low-sulfidation gold-quartz stockwork, Gold Hill mining district, Tooele County, Utah, *in* Comer, J.B., Inkenbrandt, P.C., Krahulec, K., and Pinnell, M.L., editors, Resources and geology of Utah's West Desert: Utah Geological Association Publication 45, p. 43–58.

Stegen, R.J., 2016, Mineralization and alteration characteristics of the Pine Grove porphyry molybdenum deposit, Beaver County, Utah, *in* Comer, J.B., Inkenbrandt, P.C., Krahulec, K., and Pinnell, M.L., editors, Resources and geology of Utah's West Desert: Utah Geological Association Publication 45, p. 59–72.

Stowe, C.H., 1975, Utah mineral industry statistics through 1973: Utah Geological and Mineral Survey Bulletin 106, 121 p.

Tripp, T.G., 2009, Production of magnesium from Great Salt Lake, Utah, USA: Natural Resources and Environmental Issues, v. 15, Article 10, p. 55–61.

U.S. Bureau of Economic Analysis, 2016, Gross domestic product by state: Online, http://www.bea.gov/regional/index.htm, accessed April 2017.

U.S. Energy Information Administration, 2017, Annual Coal Distribution Report, 2016: Online, http://www.eia.gov/coal/distribution/annual/, accessed December 2017.

U.S. Geological Survey, 2017a, U.S. Geological Survey minerals information: Online, http://minerals.usgs.gov/minerals/pubs/commodity/index.html, accessed February 2017.

U.S. Geological Survey, 2017b, Crushed stone and sand and gravel in the fourth quarter 2016: Online, http://minerals.usgs.gov/minerals/pubs/commodity/stone_crushed/mis-2016q4-stonc.pdf, accessed March, 2017.

U.S. Geological Survey, 2017c, Mineral commodity summaries 2017: Online, https://doi.org/10.3133/70180197, accessed March 2017.

U.S. Geological Survey Oil Shale Assessment Team, 2011, Oil shale resources in the Eocene Green River Formation, greater Green River Basin, Wyoming, Colorado, and Utah: U.S. Geological Survey Data Series 69-DD, no pagination.

Utah Department of Workforce Services, 2016: Online, https://jobs.utah.gov/jsp/utalmis/#/industry/212/Mining%20(except%20Oil%20and%20Gas)/000049/Statewide//detail.

Vanden Berg, M.D., 2008, Basin-wide evaluation of the uppermost Green River Formation's oil-shale resource, Uinta Basin, Utah and Colorado: Utah Geological Survey Special Study 128, 19 p., 8 plates, CD.

Walker, G.L., and Smith, S.D., 1989, Survey methods and statistical summary of nonfuel minerals: U.S. Bureau of Mines Minerals Yearbook 1988, v. 2, p. 1–44.