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Repurposing coal assets for a decarbonized digital economy

Dale Sartor
Bo Shen
Arman Shehabi
Lawrence Berkeley National Laboratory

November 2023

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Repurposing Coal Assets for a Decarbonized Digital Economy

Prepared for the
DOE Office of Energy Efficiency and Renewable Energy (EERE), Office of Industrial Efficiency and Decarbonization Office (IEDO)
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Principal Authors
Dale Sartor
Bo Shen
Arman Shehabi

Ernest Orlando Lawrence Berkeley National Laboratory
1 Cyclotron Road, MS 90R4000
Berkeley CA 94720-8136

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Acronyms and Abbreviations

AACAES	Advanced Adiabatic Compressed Air Energy Storage
AML	Abandoned Mine Land
AMD	acid mine drainage
ARC	Appalachian Regional Commission
BES	battery energy storage
BLM	Bureau of Land Management
BTUS	Building Technology & Urban Systems
CAES	Compressed air energy storage
CAGR	compound annual growth rate
DOE	Department of Energy
EAEI	Energy Analysis and Environmental Impacts
EDA	U.S. Economic Development Administration
EIA	U.S. Energy Information Administration
EPA	Environmental Protection Agency
ESDR	Energy Storage and Distributed Resources
ETA	Energy Technologies Area
FERC	Federal Energy Regulatory Commission
GAO	U.S. Government Accountability Office
GBPS	billion of bits per second
GDP	gross domestic product
GWh	gigawatt-hours
IRA	Inflation Reduction Act
IRR	Internal Rate of Return
kVA	kilovolt-amps
kW	kilowatts
kWh	kilowatt-hours
MEP	mechanical, electrical and plumbing
MW	megawatts
MWh	megawatt-hours
NMTC	New Markets Tax Credit
NPV	Net Present Value
OSMRE	Office of Surface Mining Reclamation and Enforcement
PHES	pumped hydro energy storage
POP	Point of Presence
POWER	Partnerships for Opportunity and Workforce and Economic Revitalization
PPA	power purchase agreements
SGES	Solid gravity energy storage
SMCRA	Surface Mining Control and Reclamation Act
TBPS	trillion bits per second
TCO	Total cost of ownership
TNC	The Nature Conservancy

UPS	uninterruptible power supplies
USGS	U.S. Geological Survey
VRE	variable renewable energy
XaaS	everything-as-a-service

1. Introduction

Coal has long driven the U.S. economy, but in recent years, competition from natural gas and renewable energy technologies have led to a rapid decline in U.S. coal production. In 2020, coal production hit a record low of 535 million short tons, the lowest since 1965, with 11 of the 14 top coal-producing states experiencing a decline in production of over 40% in the last decade. Kentucky's coal production shrank by over 80% - the highest of any state. In line with that decline has been a downward employment trend in the industry; in fact, employment has more than halved in a decade. As the U.S. sets decarbonization targets in the power sector and across the economy, these transitions will accelerate.

While these changes are driving significant economic and cultural shifts in many coal-producing communities, they also present new opportunities. Because coal mines have large-scale power supply and transmission systems, as well as other beneficial infrastructure, they can potentially be repurposed to support the transition to a post-coal economy. For example, a significant amount of land in Appalachia and the Interior basins has been cleared for reuse after coal mine closure. With proper planning and investment, these lands can be repurposed for a variety of applications, such as renewable energy development, data center development, agriculture, and recreation, among others. Such efforts would benefit both local communities and contribute to the country's sustainable development goals, turning environmental liabilities into climate solutions and new economic drivers.

Much reclaimed mine land is being targeted for renewable energy projects. The Environmental Protection Agency (EPA), through the RE-Powering America's Land program, tracks hundreds of projects in the United States that installed renewable energy systems on current and formerly contaminated lands, landfills, and mine sites.[1] Many mine sites already offer the power infrastructure necessary to transmit renewable energy to population centers. That infrastructure, along with mines' many unique qualities, can make them excellent sites on which to develop various types of power storage, including pumped hydro, solid gravity, and compressed air energy storage.

The digital economy is an economic driver drawing considerable interest. Data centers are the engines of the digital economy, and their development, powered by renewable energy, on former mine sites is a focus of this study. Mines offer reclaimed land and the electrical infrastructure to support data center needs. Cooling is often a data center's second biggest electrical load, and significant quantities of water are used in the cooling process. Groundwater in mines and their adjacent aquifers offer an opportunity to save energy and water in data center cooling, providing a site-specific benefit not widely available at other sites. The ability to incorporate renewable energy into the project compounds the financial and climate benefits. Data centers use approximately 2% of our electricity and are a ready market for renewable energy. Moreover, data center waste heat can be recovered for activities such as indoor farming, further expanding community economic benefits and avoiding the carbon fuels that might otherwise be used for heating in those facilities.

Governments at all levels can partner in building a digital and circular economy in coal-reliant communities, through incentives and public policy. These take a variety of forms, from policy, institutional, and funding support for infrastructure development, to tax incentives and workforce training. Of course, dedicated internet access with fiber networks will be needed for the lightning-fast communications essential for a data center. Some of these efforts are already completed or under way; more are on the horizon.

This report discusses these issues in more detail. Chapter 2 outlines the state of the U.S. coal industry, Chapter 3 discusses repurposing coal assets for clean energy, Chapter 4 covers repurposing coal assets for data centers, Chapter 5 outlines government incentives, policies, and programs, and Chapter 6 offers conclusions and proposed next steps in this area.

2. Changes in the U.S. Coal Sector

2.1 Coal production and its changes over time

Coal as an energy source has helped propel the United States economy. Historically, the U.S. coal industry provided hundreds of thousands of jobs and supported a number of towns and communities. However, facing the competition from natural gas and the growth of renewable energy sources, coal production has been declining rapidly.

Figure 2-1 shows average annual coal production between 1950 and 2020. U.S. coal production had been growing and reached an all-time high of 1.17 billion short tons in 2008. However, U.S. coal production has declined since 2008. The U.S. coal production in 2020, 535 million short tons, is the lowest level of U.S. coal production since 1965.[2] Fourteen U.S. states produced coal exceeding or approaching 10 million short tons in 2020, and together accounted for 98% of the country's production that year. Changes in coal production over the decade 2010–2020 in these 14 coal-producing states are presented in Table 2-1. The coal industry has been in clear decline across the U.S. over the past decade, as seen in this table. Eleven of the 14 states have shrunk production by 38% or more over the past 10 years, and Kentucky's production has shrunk by more than 80%. This downward trend is related to the rapid expansion of gas production capacity in the early 2000s. The declining U.S. coal consumption and its shrinking share in the nation's total energy consumption relative to natural gas and renewable growth is shown in Figure 2-2.

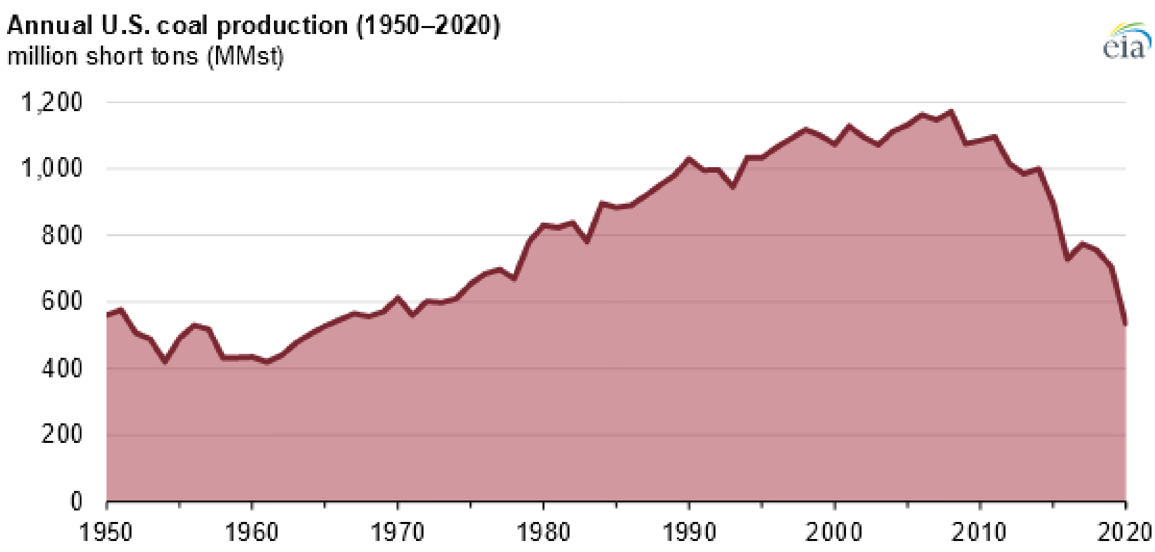


Figure 2-1. ANNUAL U.S. COAL PRODUCTION, 1950–2020

Source: EIA. 2021. Annual Coal Report 2020. October. ES-1. https://www.eia.gov/coal/annual/archive/0584_2020.pdf.

Table 2-1. CHANGE IN COAL PRODUCTION BY MAJOR COAL-PRODUCING STATES[3,4]

State	Production in 2010 (thousand short tons)	Production in 2020 (thousand short tons)	% Change
Alabama	19,915	12,151	-39
Colorado	25,163	10,056	-60
Illinois	33,241	31,578	-5
Indiana	34,950	19,942	-43
Kentucky	104,960	20,245	-81
Montana	44,732	26,422	-41
New Mexico	20,991	10,249	-51
North Dakota	28,949	26,438	-9
Pennsylvania	58,593	36,305	-38
Texas	40,982	19,682	-52
Utah	19,351	13,163	-32
Virginia	22,385	9,685	-57
West Virginia	135,220	67,228	-50
Wyoming	442,522	218,556	-51
Total of 14 states	1,031,954	521,700	-49
National Total	1,082,511	534,978	-51

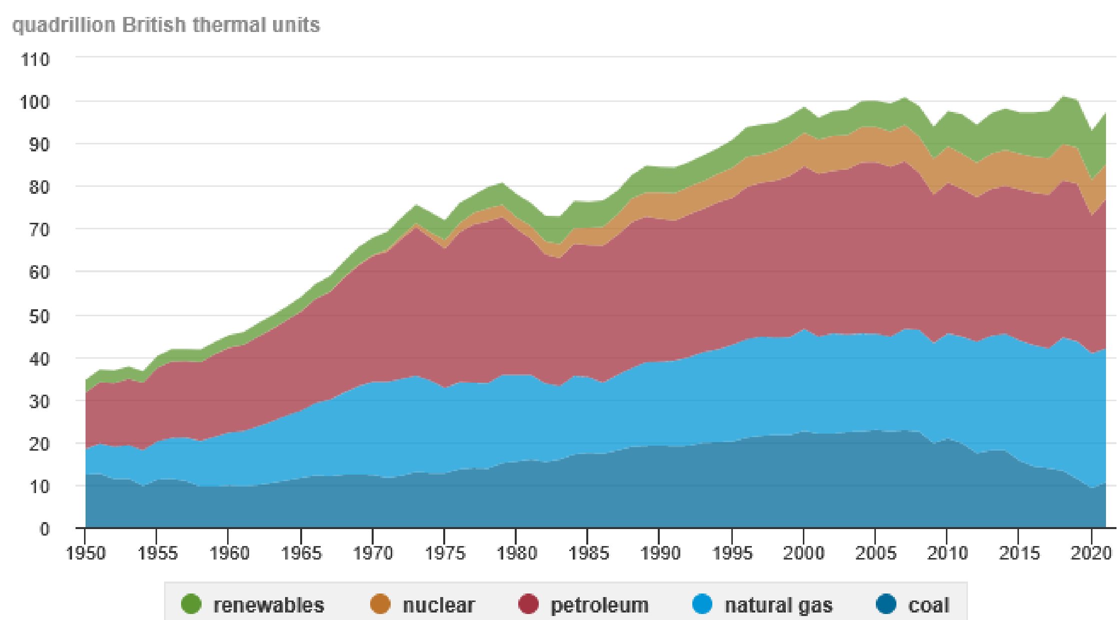


Figure 2-2. U.S. PRIMARY ENERGY CONSUMPTION BY MAJOR SOURCES, 1950–2021

Source: EIA. 2022. Monthly Energy Review, Table 1.3. April. Preliminary data for 2021.
Note: Petroleum is petroleum products excluding biofuels, which are included in renewables.

Coal consumption, especially in the power sector, will further shrink as the U.S. sets the goal of creating a carbon-free power sector by 2035, reducing net economy-wide greenhouse gas pollution by 50% from 2005 levels by 2030, and achieving net zero emissions by 2050.[5] Figure 2-3 highlights this trend, as well as the acceleration of renewable power production.

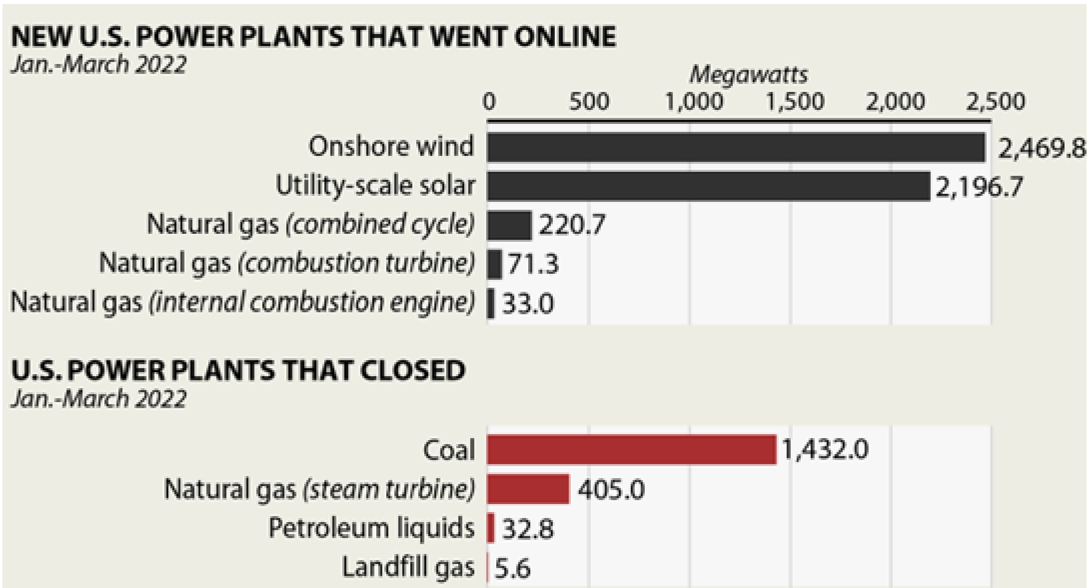


Figure 2-3. RECENT CHANGES IN U.S. POWER PLANTS

Source: Gearino, Dan. 2022. "Inside Clean Energy: The US's New Record in Renewables, Explained in Three Charts." *Inside Climate News* June 2. https://insideclimatenews.org/news/02062022/inside-clean-energy-renewables-2022/.

2.2 Geographical distribution of the coal industry

Knowing the number and types of coal mines in major coal-producing states and the capacity utilization of these mines will help stakeholders understand the distribution and characteristics of the U.S. coal mining industry. In 2020, there were 546 active coal mines in the U.S., including 350 surface coal mines and 196 underground coal mines, mainly distributed in the 14 major coal-producing states (see Table 2-2).

Table 2-2. also shows the average output per mine for the 14 states, which varies widely. This variation in coal output is due to several factors, including differences in the size of mines, coal seam geology, extraction technology, and coal types among different coal-producing regions.[6] For example, according to the U.S. Energy Information Administration (EIA), in 2017 the Appalachian and Illinois basins had 610 producing mines, mostly underground mines with average seam thicknesses of up to six feet. In contrast, the Powder River Basin had only 16 mines, but they produced 43% of the U.S. total coal output in the same year. The Powder River Basin mines are surface mines with an average seam thickness of 65 feet, which enables the use of larger mining equipment and results in higher production. While the Powder River Basin mines have higher productivity, the coal from Appalachian and Interior basins have their own advantages. Coal from these regions has higher energy content, and the mines are located closer to many power plants and industrial facilities that consume coal.

In 2020, 70% of underground coal production was produced from underground coal seams with coal beds between 4 and 7 feet thick, while 77% of surface coal production was produced from surface coal seams 10 feet and above.[7]

Table 2-2. DISTRIBUTION OF COAL MINES IN THE U.S. IN 2020[8]

State	# of mines	# of surface mines	# of underground mines	Average annual production per surface mine (thousand short tons)	Average annual production per underground mine (thousand short tons)
Alabama	26	20	6	85	1,742
Colorado	7	3	4	1,283	1,552
Illinois	14	5	9	399	3,287
Indiana	18	13	5	831	1,829
Kentucky	97	60	37	76	532
Montana	6	5	1	4,080	6,023
New Mexico	3	2	1	4,502	1,246
North Dakota	5	5	0	5,288	0
Pennsylvania	134	99	35	42	918
Texas	7	7	0	2,812	0
Utah	7	1	6	569	2,099
Virginia	41	24	17	104	423
West Virginia	135	68	67	170	831
Wyoming	16	15	1	14,409	2,424
Total of 14 states	516	327	189		
National Total or National Average	546	350	196	970	998

Capacity utilization is a ratio of actual annual production to productive capacity (the maximum amount of coal that can be produced annually). Capacity utilization is a useful indicator as it provides insights into how efficiently an asset is being used to generate output. A higher capacity utilization rate indicates that more coal is being produced with the available productive capacity. As shown in Table 2-3, at present, surface coal mines in Illinois, Kentucky, Montana, Pennsylvania, Utah, Virginia, West Virginia, and Wyoming are operating at relatively low capacity utilization rates, while the ratios are relatively low for underground mines in Colorado, Indiana, Montana, and New Mexico.

Although Wyoming mines produce a significant portion of U.S. coal, declining U.S. demand for coal in recent years has affected all regions of the U.S., including Wyoming, leading to year-over-year declines in capacity utilization (see Table 2-4).

Table 2-3. COAL MINE CAPACITY UTILIZATION STATUS IN THE 14 TOP COAL-PRODUCING STATES, 2020 AND 2021[9,10]

State	Capacity Utilization Ratio (surface mines) 2020/2021	Capacity Utilization Ratio (underground mines) 2020/2021
Alabama	0.81/0.59	0.75/0.61
Colorado	0.66/0.81	0.42/0.47
Illinois	0.58/0.33	0.55/0.84
Indiana	0.72/0.72	0.49.0.59
Kentucky	0.66/0.64	0.60/0.87
Montana	0.53/0.62	0.55/0.66
New Mexico	0.65/0.77	0.14/0.17
North Dakota	0.77/0.75	-
Pennsylvania	0.61/0.58	0.89/0.86
Texas	0.85/0.93	-
Utah	0.28/22	0.67/0.67
Virginia	0.38/0.66	0.76/0.95
West Virginia	0.61/0.66	0.70/0.77
Wyoming	0.49/0.58	1.00/0.94

Table 2-4. CHANGES IN WYOMING SURFACE MINING CAPACITY UTILIZATION, 2014–2021[11]

2014	2015	2016	2017	2018	2019	2020	2021
0.81	0.79	0.64	0.70	0.70	0.63	0.49	0.58

As coal demand declines and the industry faces economic pressures, the mines with less efficiency and lower productivity are usually the first ones to shut down.[6] As a result, states with these types of mines can expect more rapid closures. This trend highlights the need for policy makers to pay close attention to ensuring a just transition for states with lower productivity and higher costs, particularly those in the Appalachian and Interior basins.

2.3 Employment in the coal sector and energy transition impacts on coal industry jobs

Understanding the evolution of coal mining employment and the current employment status of the coal industry by state can illustrate the impact of the energy transition on coal industry jobs. As coal production has declined over the past decade, employment in the coal industry has also shown a clear downward trend (see Figure 2-4). From a high of over 90,000 total employees in 2011, employment in the coal industry fell by more than half in a decade. Figure 2-4 also shows underground and surface coal mines have the same trend of year-on-year job losses, however the underground mines employ ~50% more workers than the surface mines.

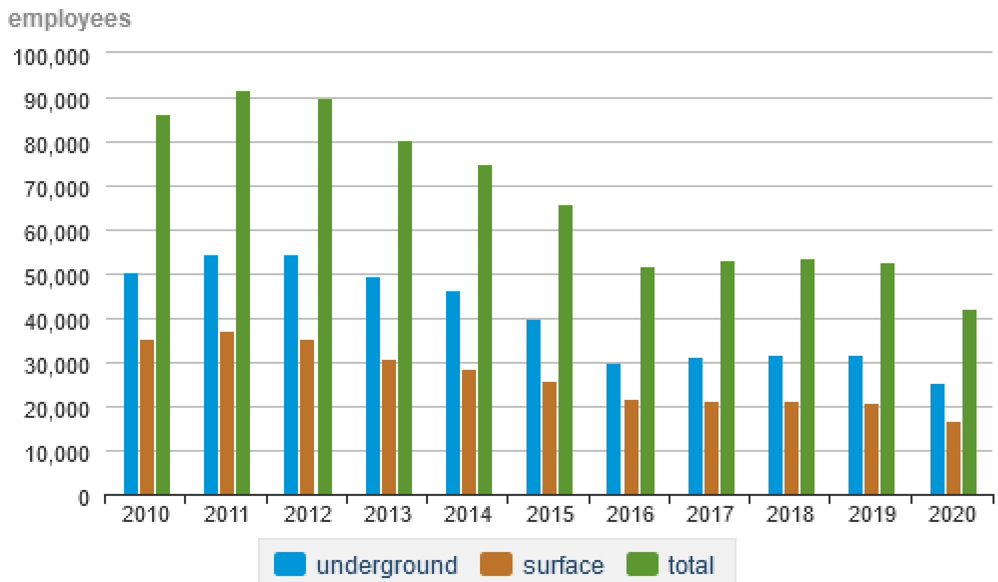


Figure 2-4. AVERAGE NUMBER OF EMPLOYEES BY MINE TYPE, 2010–2020

Source: EIA. Various years. Annual Coal Report (2010 through 2020). Table 18.

The employment and labor productivity of major coal-producing states in 2020 are listed in Table 2-5. While employment of underground mines is higher than that of surface mines, the coal mining productivity, measured by average short tons per employee hour, is often less. On a national level, labor productivity in underground mines is one third the productivity of surface mines (3.60 for underground mines versus 10.24 for surface mines in 2020). However, there is large variation among states, and states like Wyoming may be driving the national average. Irrespective of mine type, labor productivity is a factor in predicting mine closures.[12] Low-productivity mines and states with high coal mining employment are more likely vulnerable to the impacts of the energy transition.

Table 2-5. EMPLOYMENT AND PRODUCTIVITY BY STATE AND MINE TYPE, 2020[13]

State	# of Employees		Average Production per Employee Hour (short tons)	
	Surface	Underground	Surface	Underground
Alabama	384	2,146	1.99	1.96
Colorado	393	725	5.00	4.45
Illinois	192	1,983	4.31	7.12
Indiana	953	1,045	5.16	4.08
Kentucky	986	3,020	2.26	3.11
Montana	844	258	12.89	10.92
New Mexico	630	202	7.33	2.74
North Dakota	1,225	0	11.17	-
Pennsylvania	1,394	3,424	1.67	4.89
Texas	1,328	0	7.85	-
Utah	57	1,316	3.36	4.37
Virginia	642	1,452	1.91	2.40
West Virginia	2,289	9,129	2.42	2.79
Wyoming	4,728	139	23.83	7.70
Total or average of 14 states	16,045	24,839		
National Total or Average	16,761	25,356	10.24	3.60

There are many occupational types of employment in the coal industry, and the different occupational types are affected to different degrees by the energy transition. Understanding the occupational composition of coal workers can help to clarify the prospects for employment transition of coal industry employees, including which occupations can be easily transferred to other industries and which require reskilling. In terms of occupational classification of employees in the coal industry (see Table 2-6), coal extraction workers account for only 37% of the total coal mining employment, and the rest (63%) are occupations not directly involved in extraction. These workers (such as electricians, general equipment operators, construction workers, mechanics, etc.) have skills that can be used across industries, and are therefore less likely to be negatively affected by the transition. However, without local economic development and the creation of new jobs in coal communities, these workers would need to relocate, which would not generate tax revenue and bring prosperity for the local area.

Table 2-6. U.S. COAL MINING EMPLOYMENT AND WAGE BY OCCUPATION, MAY 2021[14]

Occupation	# of Jobs	% of Total Employment	Mean Hourly Wage ($)	Annual Mean Wage ($)
Construction and Extraction Occupations (a)	22,020	60	31.66	65,860
Extraction workers	13,640	37	28.07	58,380
Installation, Maintenance, and Repair Occupations (b)	5,340	15	35.16	73,120
Transportation and Material Moving Occupations	2,760	8	31.06	64,600
Management Occupations	1,870	5	78.80	163,900
Production Occupations (c)	1,500	6	34.02	70,770
Office and Administrative Support Occupations	1,020	3	22.38	46,550
Architecture and Engineering Occupations	880	2	44.14	91,800
Business and Financial Operations Occupations	590	2	43.32	90,110
Life, Physical, and Social Science Occupations	320	1	38.12	79,300
Building and Grounds Cleaning and Maintenance Occupations	60	0.17	23.19	48,240

Note: Occupations do not sum to the totals because the totals include occupations not shown separately. Estimates do not include self-employed workers.

(a) Includes, for example, construction trades workers, equipment operators, electricians, extraction workers, explosives workers, ordnance handling experts and blasters, and mining roof bolters.
(b) Includes, for example, electrical and electronic equipment mechanics, installers, and repairers, vehicle and mobile equipment mechanics, and other maintenance and repair workers.
(c) Includes, for example, metal workers and plastic workers; plant and system operators; inspectors; testers; sorters; samplers; and weighers, crushing, grinding, polishing, mixing, and blending workers.

2.4 Coal mining electricity use and electrical capacity

Significant electricity is consumed in coal extraction (drilling, digging, ventilation, and dewatering pumping), materials transport and handling (load-haul-dump machines, hoists, conveyor belt systems, and pipelines for pumping slurries), and beneficiation and processing (crushing, grinding, and separations).[15]

According to the U.S. Department of the Interior's Information Circular *Mine Power Systems*, the main substations in coal mining facilities have a capacity ranging from 500 kilovolt-amps (kVA) (for pumps and conveyors only) to 50,000 kVA (for large mining operations and preparation facilities), where electricity is then distributed to the various load centers in operation.[16] Note that real power (kilowatts [kW]) will be slightly lower after accounting for power factor.[17,18]

The estimates of electricity use per ton of coal production is in the range of 18–37 kilowatt-hours (kWh) per ton for surface coal mines and 26–55 kWh/ton for underground mines.[19] Looking at two large coal mine examples (one the largest surface mine and the other the largest underground mine), the magnitude of power capacity is a good fit for data center power needs. The first example is the North Antelope Rochelle Mine in Wyoming, which produced 66 million short tons in 2020. Using the USGS range of electrical energy use per ton would result in 1,188 to 2,442 gigawatt-hours (GWh), which represents an average power draw over the year of 136 to 279 megawatts (MW). The second example is the River View Mine in Kentucky, which produced 9.4 million short tons in 2020. Again, using the USGS range, but this time for underground mines, would result in 244 to 517 GWh per year, or an average power draw over the year of 28 to 59 MW. The scale of electricity consumption in these two mines with an estimated average hourly power consumption ranging from 28 to 279 MW is similar to the operation of large (hyperscale) data centers.

Since coal mine production consumes a significant amount of electricity and the mines have built large-scale power supply and transmission systems, this infrastructure may potentially be repurposed to support the transition to a post-coal economy.

2.5 Retired coal mines and coal mine lands

2.5.1 Coal mine retirement

Changes in the U.S. coal industry have resulted in the closure of a significant number of coal mines and idled coal assets. The contraction of coal mine capacity and the reduction of the number of coal mines can be used as indicators to judge the scale of coal mine closure. Over the last decade (2010 to 2020), coal productive capacity (i.e., the maximum amount of coal that can be produced each year) fell by 30% (see Figure 2-5). During the 10-year period between 2010 and 2020, the number of coal mines in the United States decreased from 1,296 to 546, indicating that nearly 60% of coal mines were closed (see Figure 2-6). The four states with the most coal mine closures over the past decade were Kentucky (down 295), West Virginia (down 117), Pennsylvania (down 106), and Virginia (down 65).[20] Combined, these four states accounted for 77% of all mine closures nationwide.

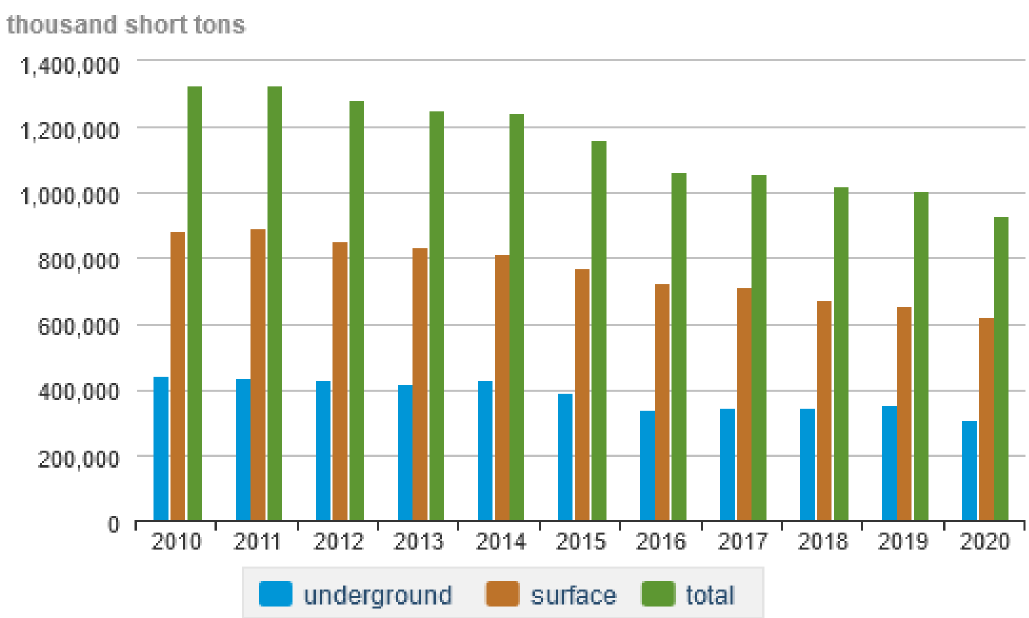


Figure 2-5. PRODUCTIVE CAPACITY OF COAL MINES BY MINE TYPE, 2010–2020

Source: EIA. 2021. Annual Coal Report 2021. October. Table 11. https://www.eia.gov/coal/annual/pdf/acr.pdf.

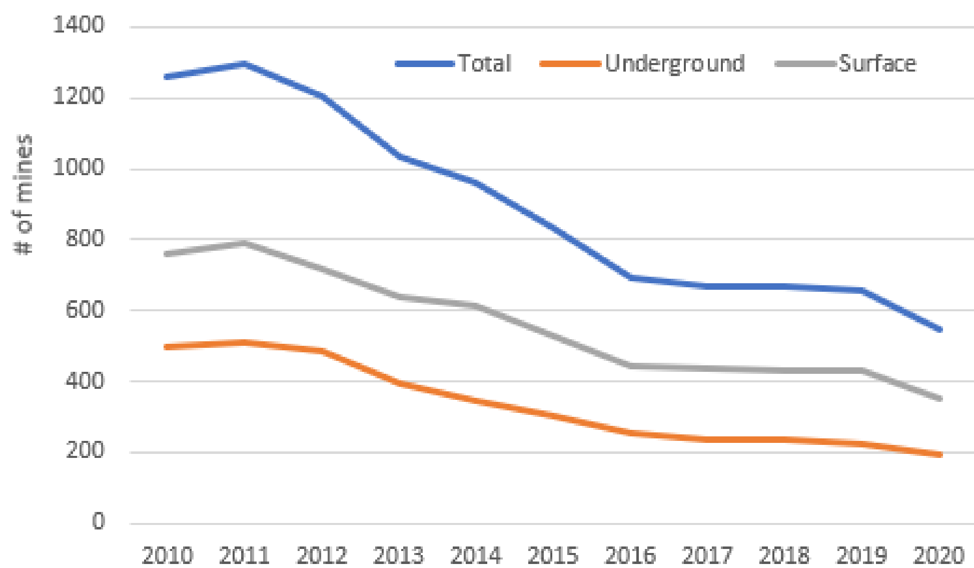


Figure 2-6. U.S. COAL MINE CLOSURE TRENDS, 2010–2020

Source: EIA, Annual Coal Report, various years

The continuous shrinking of coal mine production capacity and decreasing number of active coal mines shows the extent of retirement in recent years. Retired coal mines can provide redevelopment opportunities for clean energy and economic diversification (see the next two chapters for details) if the infrastructure is effectively repurposed. Repurposing is more urgent for states with large-scale retirement. It is likely that the more severe the coal mine retirements, the greater the need for transition programs and policies.

2.5.2 Coal mine lands

Coal mining requires a lot of land. Both the land occupied by retired coal mines and the land still in operation have potential value for redevelopment. The scale of reusable coal mine land can be determined from three measures: (1) the total permitted acreage that determines the land area of existing coal mine production, (2) the amount of disturbed land that is restored after coal production is completed (post 1977), and (3) the number of acres of abandoned coal mine land that has been cleaned up for reuse (prior to 1977). The Surface Mining Control and Reclamation Act (SMCRA), which came into effect in 1977, has had a profound impact on coal mining and the land involved in coal mining.

2.5.2.1 Surface Mining Control and Reclamation Act

SMCRA is "the primary federal law that regulates the environmental effects of coal mining in the United States."[21] The law addresses many aspects of coal mining's impacts, including post-mining land use, hydrological concerns, land restoration and revegetation, and subsidence. SMCRA consists of two distinct components, one aimed at reclaiming abandoned mine lands to restore the environment, and the other aimed at regulating coal mining to protect the environment. Title IV of the Act establishes a program to reclaim land used for mining prior to 1977 and abandoned mines that have not been reclaimed. Title V creates a regulatory and permitting process requiring active coal mining operations to comply with required environmental performance standards and reclamation directives.

2.5.2.2 Land used by coal mines in operation

The relevant data on the size of coal mine lands used by active coal mines in the U.S. is the "total acreage permitted" in each state, which is reported annually by the U.S. Department of the Interior's Office of Surface Mining Reclamation and Enforcement (OSMRE). Each year, states report respective new permitted acreage. The "total acreage permitted" represents the total area of land with coal mining permits in each state at the end of each fiscal year. Under the SMCRA, permits are required for coal mining. The permit processes for underground and surface mines contain similar components. For underground mines, surface facilities such as mine portals, refuse disposal areas, and access roads must be included in the permitting and bonding.[22] Permits have an expiration date, but can be renewed as long as the permit holder continues mining operations.

In a recent report with 2018 data,[23] the U.S. total acreage permitted as of FY 2018 was close to 4.3 million acres. About 10% of the total permitted acreage is on leased federal land managed by the Department of the Interior's Bureau of Land Management (BLM).[24] The 14 major coal-producing states have a national share of 93% of the total permitted acreage. Of these 14 states, Kentucky, Wyoming, West Virginia, and Texas are the top four with the largest number of permitted acres, which together account for two-thirds of the national total permitted land acreage (see Table 2-7).

In terms of land use intensity (permitted acres per thousand short tons of coal produced), the highest and lowest states were Kentucky and Wyoming, respectively. As mentioned above, this is influenced by the coal seams in Kentucky being much thinner than those in Wyoming, and highlights that coal mining footprint is not directly proportional to production output.

Table 2-7. TOTAL ACREAGE PERMITTED AND LAND INTENSITY IN THE TOP 14 COAL-PRODUCING STATES AS OF FY 2018

State	Total Acreage Permitted	Share of National Total (%)	Production (thousand short tons)	Land Use Intensity (acres per thousand short tons)
Alabama	77,452	2	14,783	5
Colorado	167,079	4	14,026	12
Illinois	80,727	2	49,563	2
Indiana	168,846	4	34,598	5
Kentucky	1,719,961	40	39,567	43
Montana	7,5219	2	38,610	2
New Mexico	79,782	2	10,792	7
North Dakota	132,174	3	29,643	4
Pennsylvania	297,629	7	49,883	6
Texas	320,167	7	24,823	13
Utah	2,850	0	13,619	0
Virginia	73,761	2	12,715	6
West Virginia	342,430	8	95,365	4
Wyoming	434,523	10	304,188	1
Total for 14 states	3,972,600	93	732,175	5
National total or average	**4,282,976**	**100**	**755,442**	**6**

Source: U.S. Department of the Interior. n.d. FY 2018 Highlights. The Office of Surface Mining Reclamation and Enforcement. https://www.osmre.gov/sites/default/files/inline-files/OSMRE%20FY%202018%20Annual%20Report_0.pdf.

2.5.2.3 Reclaimed land

Ensuring that mined land is reclaimed to pre-mining conditions or to beneficial post-mining uses is one of the most important goals of the SMCRA. Performance bonds are posted during the permitting for the purpose of ensuring sufficient funds to pay for the reclamation of disturbed lands if coal mine operators fail to comply with the terms of the permit, thus becoming the primary means of enforcing land reclamation. The number of acres that meet the bond release criteria and receive a bond release is a measure of reclamation success. The release of the bond relieves the operator of liability under SMCRA for damage caused by the mining operations.

Performance bonds are released in three phases: Phase 1 - backfill and grading, Phase 2 - revegetation, and Phase 3 - full reclamation under SMCRA standards.[25] While underground mines do not do as much damage to the surface land as surface mines, the operators of underground mines do have reclamation responsibilities. These include stabilizing tailing ponds while mining, reclaiming the area after mining is complete, addressing any subsidence issues, and protecting surface and groundwater from drainage and the effect of metal composition above ambient water levels.[26] Table 2-8 provides the 15-year cumulative acreage of bond released land in each of three phases between 2000 and 2019 (there are no data available for five years). Only the land that has completed the Phase 3 reclamation task can be redeveloped, since Phase 3 meets the full reclamation SMCRA standards and thus releases the bond holder from legal responsibility.

From the available 15 years of data over the past 20 years, among the 14 major coal-producing states Kentucky, West Virginia, Indiana, Pennsylvania, and Illinois are the five that have completed the most acres of Phase 3 reclamation. Together they account for nearly two-thirds of the national total (see Table 2-8). Figure 2-7 Shows the Peabody Energy Seneca II West Mine in Routt County, Colorado, before and after reclamation.

Table 2-8. CUMULATIVE ACREAGE OF BOND-RELEASED LAND BY STATE AND PHASE, 15 YEARS OVER 2000–2019[27]

State	Acreage of Phase 1 Bond Release Lands	Acreage of Phase 2 Bond Release Lands	Acreage of Phase 3 Bond Release Lands
Alabama	35,974	29,146	46,630
Colorado	6,609	11,123	12,419
Illinois	66,420	68,031	72,320
Indiana	68,502	76,070	80,785
Kentucky	182,196	104,920	178,945
Montana	13,912	8,904	1,820
New Mexico	9,142	7,111	4,710
North Dakota	13,478	12,259	15,676
Pennsylvania	75,043	72,211	79,472
Texas	50,997	25,172	26,020
Utah	542	388	277
Virginia	17,398	20,592	29,139
West Virginia	58,175	60,205	88,499
Wyoming	57,544	32,488	8,233
Total of 14 states	655,932	528,620	644,945
National Total	759,332	637,245	772,266

Figure 2-7. PEABODY ENERGY SENECA II WEST MINE, COLORADO BEFORE AND AFTER RECLAMATION

Source: Office of Surface Mining Reclamation and Enforcement. 2006. Annual Report 2006. October 1. https://www.osmre.gov/resources/annual-reports

Abandoned land

By 1977, more than 1 million acres of land in the United States had been disturbed by past coal mining, creating a wide-range of environmental, public health, and safety hazards, including open or poorly sealed mine shafts and slopes, gas leaks, mine fires, acid mine drainage, refuse piles, and spoil ridges, as well as subsidence problems. Concerns about these issues led to the passage of the SMCRA, which established detailed mining and reclamation standards and regulations for coal mining activities.[28] The law gives OSMRE the authority to impose a fee on each ton of coal produced at active coal mines and established an Abandoned Mine Land (AML) program under which states and tribes can use collected fees to eliminate environmental, public health, and safety hazards posed by past mining activities. Legacy land that has been cleaned up and restored to meet SMCRA's environmental and safety requirements can be redeveloped.

OSMRE's annual reports on the environmental restoration and safety risk mitigation of abandoned coal mines only include related clean-up projects in each state, without data on the restored land area. However, a research report pointed out that since the establishment of the AML program and funding, the cumulative area of reclaimed abandoned mine land has reached 330,000 acres nationwide.[29] These lands, freed from environmental and safety risks, can be used for redevelopment.

As coal demand falls and the coal industry comes under economic pressure, less productive and efficient coal mines are often the first to close. This highlights the need for policy makers to pay close attention to ensuring a just transition, particularly in lower-productivity states like those in Appalachia and the Interior basins. There is a significant amount of land in Appalachia and the Interior basins that has been cleared for reuse after coal mine closures. With proper planning and investment, these lands can be repurposed for a variety of purposes, such as renewable energy development, agriculture, and recreation, among others. This would not only benefit local communities but also contribute to the country's sustainable development goals.

3. Repurposing Coal Assets for Energy Decarbonization

Immediately after his inauguration, President Biden signed Executive Order 14008, "Tackling the Climate Crisis at Home and Abroad," proposing a series of measures, including the creation of an Interagency Working Group on Coal and Power Plant Communities and Economic Revitalization to support the economic revitalization in America's energy communities immediately and over the long term. One of the opportunities that the Interagency Working Group promotes for energy communities is the repurposing of fossil energy assets.[30] In June 2022, the Biden administration announced the launch of a $500 million plan to convert mine lands into new clean energy hubs as part of an effort to implement the Bipartisan Infrastructure Law.[31] These initiatives present potential opportunities for repurposing coal assets to develop energy systems that do not rely on fossil fuels, as well as to develop new post-coal economies in energy communities.

3.1 Current use of retired coal mine lands

Information on land utilization after mine closures in the U.S. shows most of the reclaimed land is relatively unproductive (see Figure 3-1). This represents a potential for using these lands to develop new economic infrastructure powered by carbon-free energy. This section discusses possibilities for coal communities to repurpose the existing coal assets.

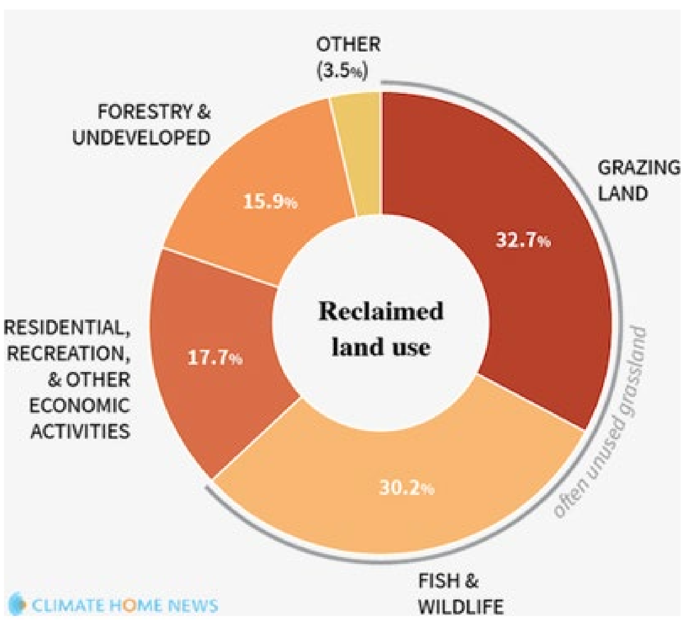


Figure 3-1. CURRENT USE OF RECLAIMED MINE LAND

Source: Olalde, M. 2018. Reclaiming coal: US mines' clean-up cash – all our data. March 15. https://www.climatechangenews.com/2018/03/15/us-coal-mines-clean-up-bonds-database/.

3.2 Mine water as a geothermal resource to provide energy efficient cooling

Water typically collects in mines. During mining operations this water must be pumped out, however, what once was a liability may become an asset post reclamation if the mine water can be utilized. Estimates from various state geological surveys show that the amount of groundwater filling the voids in abandoned mines is large. In Indiana, for example, underneath the nearly 200,000 acres of mine land are mostly abandoned room-and-pillar underground coal mines. The amount of groundwater filling the voids of these abandoned mines could contain 170 billion gallons or more of groundwater.[32] In West Virginia, 69 of 73 mineable coal seams have undergone significant underground mining, with the water now stored in these mines potentially exceeding one trillion gallons.[33]

With the demand for water resources increasing, mine water collection has the potential to be exploited for various purposes, including cooling.[34] Typically, the temperature of the mine water is not affected by changes in ambient temperature and remains within a relatively stable range throughout the year.[35] Therefore mine water has the potential to be used as a geothermal resource to provide highly efficient compressor free cooling for industries such as data centers. Cooling systems can use the mine water as a heat sink without depleting the volume of water. Cool water would be drawn from the pool and returned slightly warmer. In the case of mine water that flows out or is pumped out, it too can be used as a heat sink. In both cases the mine water can be used to replace cooling towers, thereby eliminating the need for large amounts of water that is normally required and lost to evaporation. Also, using mine water as a heat sink may allow warmer (above the dew point) cooling applications such as data centers to be cooled directly with the mine water without compressor cooling (chillers). Even in cases where a chiller is used, it will run much more efficiently being cooled by the mine water rather than by cooling towers or the ambient air. Using mine water to cool data centers is a large potential energy saver, as cooling is typically the second largest energy load in data centers (accounting for 40% of data center total energy use[36]) after IT equipment energy consumption.

An example of using mine water for cooling a data center is Iron Mountain's National Data Center located in Pennsylvania. The facility provides compressor-free cooling for data center servers by using water at temperatures around 50°F from an underground lake as the cooling source. Energy-efficiency initiatives like the use of mine water for cooling and the use of 100% renewable energy have made Iron Mountain one of the DOE's Better Buildings Challenge models. They have surpassed their original Better Buildings Challenge goals aimed at trimming non-IT energy intensity by 25%.[37]

As the example of Iron Mountain shows, using mine water as a heat sink for cooling has multiple advantages: (1) improving cooling energy efficiency and potentially even replacing electric compressor based cooling, thereby reducing energy consumption and the climate impact and environmental pollution of generating the required energy, and (2) reducing water consumption in conventional cooling towers. Both lead to significant climate and cost benefits.[38]

A detailed study to assess the feasibility of developing a data center on abandoned coal mine land in Southwest Virginia has suggested that mine water at a constant temperature of approximately 51°F could provide billions of gallons of water, providing data center operators with a sustainable and cost-effective cooling solution. Mine water cooling systems could reduce the electricity needed to cool the data center by 90%, while also eliminating the need to purchase large volumes of municipal water that would be evaporated through the cooling towers in traditional mechanical cooling systems, saving over $1 million per year in water purchases and electricity costs.[39]

A potential problem with mine water that needs to be addressed is water quality and contamination. While water in some mines is of good quality, it is not in others. For example, some mines can produce a toxic sludge known as acid mine drainage (AMD), an overflow of highly acidic water from underground mines that occurs when groundwater comes into contact with exposed mining rock. AMD is seen as a serious long-term environmental impact of mining.[40] In Ohio, for example, AMD affects 1,300 miles of streams.[41] Poor mine water quality is not necessarily a showstopper for its use to cool data centers. The mine water is not being consumed; it is merely being used as a heat sink. Where the mine water is being treated, cooling water can be drawn downstream of the treatment plant. In all cases, the mine water will be separated from the water used to cool the data centers with a heat exchanger. The design of the heat exchanger can be tailored to the chemistry of the water.

3.3 Using mine lands for renewable energy development

3.3.1 Coal mine land for renewable energy development as a low-conflict land use

Developing renewable energy has the potential to create jobs and provide local investment while tackling climate change. However, the large amount of land this type of development requires could have impacts on agriculture, afforestation, and wildlife. Renewable energy projects require a land footprint 3 to 12 times larger than coal-powered energy generation because the power density—a measure of energy production per unit of land area—is much smaller, as illustrated in Figure 3-2.

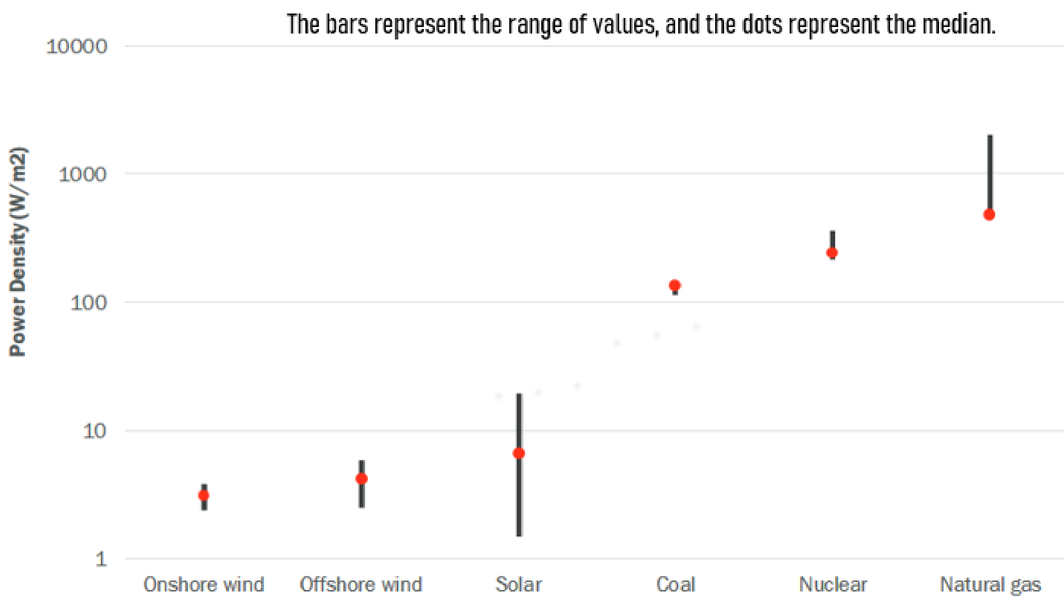


Figure 3-2. LAND IMPLICATIONS OF DIFFERENT FORMS OF ENERGY

Source: Gross, S. 2020. Renewables, Land Use, and Local Opposition in the United States. https://www.brookings.edu/wp-content/uploads/2020/01/FP_20200113_renewables_land_use_local_opposition_gross.pdf

Repurposing post-mining land for new energy sources including wind power, solar power, and biomass energy, can reduce the impact of renewable energy development on agricultural and natural (e.g., forested) land. Large tracts of relatively undesirable and underutilized land are available. Additionally, existing open pit mines can possibly utilize their large earth moving machines to contour the topography to fit solar (or other) use, thereby reducing development costs.[42] Further, the development of renewable energy on mine land could benefit from the existence of electrical transmission and distribution infrastructure.[43]

The use of mapping tools can aid in the identification of low-conflict sites, such as post-mining land, for wind and solar development. This has the potential to reduce the likelihood of social, land management, and ecological conflicts that may arise during renewable energy project siting. The Nature Conservancy (TNC), a U.S.-based conservation organization, has developed mapping tools, including the Wyoming Brightfields Energy Siting Tool, and SiteRight adopted in India, with the aim of assisting in the identification of low-conflict sites for renewable energy projects.[44]

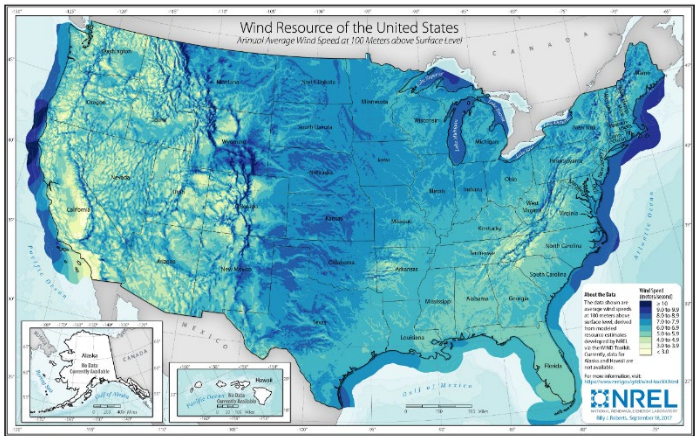
3.3.2 Matching of renewable energy resources and coal mine land

The use of post-mining coal land for renewable energy development ideally matches renewable energy resources to the coal mining areas. An understanding of geographic distribution of renewable energy resource availability can help determine where coal mine land is most suitable for renewable energy development. Figure 3-3 presents the geographic distribution of U.S. wind and solar resources and the distribution of coal basins. The wind and solar resources as well as the percent of power produced from renewable energy in the 14 major coal-producing states, are compared in Table 3-1. The following observations can be made from this comparison:

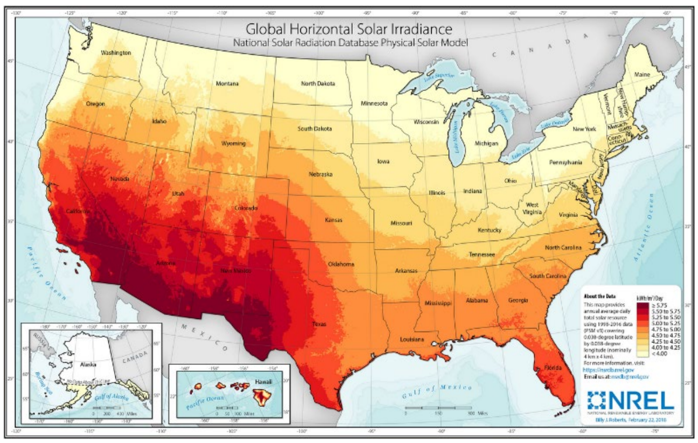
- Colorado, Illinois, Indiana, Montana, New Mexico, North Dakota, Texas, and Wyoming have superior wind energy resources.[45]
- Colorado, New Mexico, Texas, and Utah have superior solar energy resources.[46]
- Although Kentucky, West Virginia, and Pennsylvania have large amounts of coal mining land, the wind and solar resources are no more than average, these states so far have a low percentage of power consumption coming from renewable energy (1%–3%). Likewise, Alabama has under 3% renewable power.[47]
- Of the 14 coal states, those with a high percent of renewable power in 2022 were Colorado (34%), Illinois (13%), Indiana (11%), Montana (15%), New Mexico (41%), North Dakota (37%), Texas (27%), Utah (13%), and Wyoming (24%).[48]

Table 3-1. WIND AND SOLAR RESOURCES OF 14 MAJOR COAL-PRODUCING STATES[49,50,51,52]

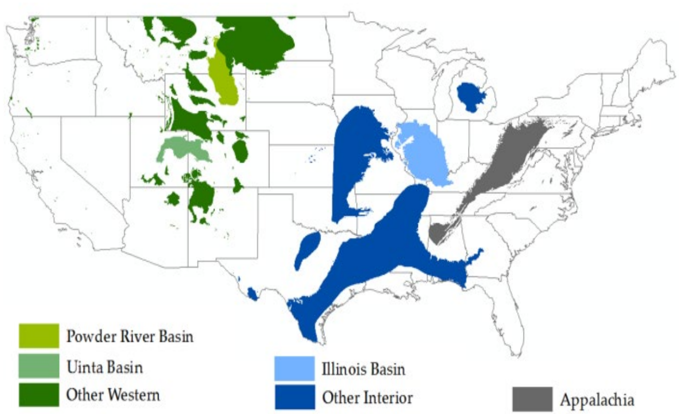
State	Total Acreage Permitted as of 2019	# of Surface/Underground Mines (2020)	2020 Coal Production (thousand short tons)/ranking	Coal Basin	Wind Resource (average wind speed - m/sec at 100 m)	Solar Resource (irradiance - $kWh/m^2/day$)	% of Power Produced by Renewable Energy[53]
Alabama	77,141	20 | 6	12,151 / 11	Appalachia/Other Interior	4–6.9	4.5–5	2.7
Colorado	165,618	3 | 4	10,056 / 13	Uinta Basin/Other Western	3–8.9	4.75–5.25	33.8
Illinois	86,435	5 | 9	31,578 / 4	Illinois Basin	6–8.9	4–4.5	13.0
Indiana	157,595	13 | 5	19,942 / 8	Illinois Basin	6–8.9	4–4.5	11.4
Kentucky	1,432,703	60 | 37	24,245 / 7	Appalachia	5–7.9	4–4.5	0.7
Montana	80,927	5 | 1	26,422 / 6	Powder River Basin/Other Western	3–8.9	below 4–4.25	14.9
New Mexico	79,748	2 | 1	10,249 / 12	Other Western	4–8.9	5.25–5.75 above	40.5
North Dakota	134,168	5 | 0	26,438 / 5	Other Western	7–8.9	below 4–4.25	37.2
Pennsylvania	288,866	99 | 35	36,305 / 3	Appalachia	5–7.9	below 4–4.25	2.4
Texas	318,061	7 | 0	19,682 / 9	Other Interior	5–8.9	4.75–5.75 above	26.6
Utah	2,830	1 | 6	13,163 / 10	Uinta Basin/Other Western	3–5.9	4.5–5.5	12.7
Virginia	74,113	24 | 17	9,685 / 14	Appalachia	4–7.9	4.25–4.75	9.0
West Virginia	357,896	68 | 67	67,228 / 2	Appalachia	4–7.9	4–4.25	3.4
Wyoming	416,586	15 | 1	218,556 / 1	Powder River Basin/Other Western	4–9.9	4.25–5	23.6
Share of National Total	92.86%	93.43% | 96.43%	98%				



Source: NREL. 2017. Wind Resource of the United States. https://upload.wikimedia.org/wikipedia/commons/5/53/U.S._Wind_Power_Resource_at_100-meter_Hub_Height.pdf.



Source: NREL. 2018. Global Horizontal Solar Irradiance. https://www.nrel.gov/gis/assets/images/solar-annual-ghi-2018-usa-scale-01.jpg.



Source: Popa, Adriana, Ajith Das Menon, Bartłomiej Walentyński, John Rudoph Young, Hing Yee Ching, Lia Cairone, Miguel Barros Brito, and Wilson Ying Kit Yung. 2016. The challenges of the US coal industry and lessons for Europe. Columbia University. May. https://unece.org/fileadmin/DAM/energy/se/pdfs/cmm/pub/Challengs_US.Coal.Ind_LessonsEurope.pdf.

Figure 3-3. DISTRIBUTION OF WIND AND SOLAR RESOURCES, AND SPATIAL DISTRIBUTION OF COAL BASINS IN THE U.S.

3.3.3 Examples of developing renewable energy projects at former coal mines or coal power plant sites

In 2019 TNC completed one of the largest land acquisitions in the United States—acquiring 253,000 acres of forest land in the Appalachians in southwestern Virginia, eastern Tennessee, and eastern Kentucky. While much of the land will be preserved and restored, former coal mines in the area will be used to develop utility-scale solar projects with a total capacity of 120 MW. By directing solar development towards former coal mine land, it will "help conserve the region's intact forests for wood products, carbon storage, wildlife habitats, outdoor recreation and tourism." As part of kicking off the work, TNC and Dominion Energy, Virginia's largest electric utility, announced they will convert approximately 1,200 acres of the former Red Onion open pit mine in Southwest Virginia into a 50 MW solar project (equivalent to powering 12,500 homes at peak output). TNC plans to use this project to generate a model that can be replicated in other coal mining regions across the country.[54,55]

Through its RE-Powering America's Land program, EPA tracks 417 installations in 45 states and territories with a combined capacity of 1.8 gigawatts (GW). From these tracked projects, a small number have been developed using both former coal mine and coal-fired power plant sites. These are summarized in Table 3-2, which shows the type, scale, and footprint of renewable energy projects that have been built on these abandoned coal sites. It can be seen that the scale of projects utilizing power plant sites is much smaller than that utilizing coal mine sites. This may be because the land area associated with coal power plants is limited compared to that of coal mines. Coal power plants may be better suited for conversion to more power-dense alternatives, such as nuclear. DOE's Office of Nuclear Energy recently reported that hundreds of retiring coal plant sites could be converted to nuclear at a 35% savings in small modular reactor development costs.[56]

Table 3-2. RENEWABLE ENERGY PROJECTS DEVELOPED USING FORMER COAL MINE OR COAL-FIRED POWER PLANT SITES

1. Site Description	Multiple installations on a single site (location)							2. Renewable Energy Info				3. Project Implementation		
Site/Project Name	**State**	**City**	**Type of Site**	**Site Owner**	**Site Ownership Type**	**Property Acreage**	**Former Use Description**	**RE Type**	**Project Capacity (MW)**	**Project Acreage**	**Primary RE Developer Name**	**Completion Date**	**Project Type**	MW/Acre
Mount Tom Station	MA	Holyoke	State Brownfields	ENGIE North America	Private	128	Coal Plant	Solar PV	5.7600	30.0	GDF SUEZ	2017	Wholesale Electricity	0.19
Silver Lake Solar Photovoltaic Facility	MA	Pittsfield	Superfund	Western Massachusetts Electric Company	Private	8	Former GE site and former steam generating site	Solar PV	1.8000	8.0	Western Massachusetts Electric Company (WMECO)	2010	Wholesale Electricity	0.23
Casselman Wind Power Project	PA	Traverses Summit, Black, and Addison	Mine Lands	Iberdrola Renewables, LLC	Private	2,000	Surface coal mine and adjacent land	Wind	34.5000	165.0	Iberdrola Renewables LLC	2008	Wholesale Electricity	0.21
Highland North Wind	PA	Cambria County	Mine Lands	Various	Various	3,500	Strip Mine	Wind	75.0000	3,500.0	Everpower	2012	Wholesale Electricity	0.02
Highland Wind	PA	Cambria County	Mine Lands	Everpower	Private	4,000	Strip Mine	Wind	62.5000	4,000.0	Everpower	2009	Wholesale Electricity	0.02
Paseo Verde South Apartments	PA	Philadelphia	Brownfields	Paseo Verde	Private	2	Coal Yard	Solar PV	-	-	Unknown	2013	Onsite Use - General	
Savannah River's Biomass Steam Plant	SC	Aiken	Superfund	U.S. DOE	Federal	34	1950s Vintage Coal-fired Steam Plant	Biomass	20.0000	34.0	Ameresco	2008	Onsite Use - General	0.59
Beloit Coal Ash Landfill	WI	Beloit	Landfill	Alliant Energy	Private	20	Coal Ash Landfill	Solar PV	2.3000	17.0	Hanwha Q CELLS USA	2016	Wholesale Electricity	0.14
Chevron Questa Project	NM	Questa	Superfund	Chevron Mining	Private	-	Mining Site	Solar PV	1.0000	20.0	Chevron Technology	2011	Wholesale Electricity	0.05
Oronogo-Duenweg Mining Belt Superfund Solar Site	MO	Web	Superfund	Private	Private	60	Mine Waste Repository	Solar PV	2.2000	12.0	Liberty Utilities	2021	Community Owned / Subscription	0.18
Dave Johnston Mine / Glenrock Wind I	WY	Glenrock	Mine Lands	PacificCorp	Private	14,000	Surface Coal Mine	Wind	118.5000	300.0	PacifiCorp	2008	Wholesale Electricity	0.40
Dave Johnston Mine / Glenrock Wind III	WY	Glenrock	Mine Lands	PacificCorp	Private	14,000	Surface Coal Mine	Wind	39.0000	300.0	PacifiCorp	2009	Wholesale Electricity	0.13
Dave Johnston Mine / Rolling Hills	WY	Glenrock	Mine Lands	PacificCorp	Private	14,000	Surface Coal Mine	Wind	118.5000	300.0	PacifiCorp	2009	Wholesale Electricity	0.40
Ajo Solar Project	AZ	Ajo	Mine Lands	Freeport-McMoRan Copper & Gold Inc.	Private	38	Adjacent to mining	Solar PV	5.0000	38.0	Recurrent Energy	2011	Wholesale Electricity	0.13

Source: EPA. 2022. RE-Powering Tracking Matrix. October. https://www.epa.gov/re-powering/re-powering-tracking-matrix.

3.4 Advancing energy storage using retired coal mining facilities

Energy storage is a key to building a zero-carbon energy system centered on variable renewable energy (VRE).[57,58] Coal assets can be repurposed to build energy storage systems. Abandoned coal mines in different U.S. regions have different geological structures and asset characteristics, presenting different opportunities for the adoption of energy storage solutions. Some potential solutions are described below.

3.4.1 Pumped hydro energy storage

Developing pumped hydro energy storage (PHES) using abandoned mines is a potential way to repurpose closed coal facilities to facilitate zero-carbon on-demand energy. Utilizing closed coal mine sites to develop PHES may achieve lower construction costs than conventional PHES projects due to the potential use of existing land and changes in elevation, utilization of established mine structures such as mine voids as a low reservoir, availability of reliable mine water sources, and mine sites already connected to the grid with existing transmission access.[59,60]

Further, converting retired coal mines for use as PHES may have reduced environmental and regulatory concerns associated with developing pumped storage plants, including permitting and zoning. Reuse of mine assets may facilitate compliance with environmental regulations, while bringing opportunities for new jobs and economic development to the coal community.[61] Development of PHES using closed coal mines—both surface and underground—has been initiated, but appears mostly in early stages. For example, a 200 MW PHES project has been planned on a former surface coal mine in Kentucky, and it is under permitting from the Federal Energy Regulatory Commission (FERC).[62] In Indiana, a legislative effort is underway to develop underground PHES using abandoned coal mines and other suitable sites.[63] Indiana's terrain is relatively flat and does not provide the steep land contouring required for pumped storage, but mines typically have depth that can be used for such systems.[64]

And in Southwest Virginia, Project Energizer is a public/private development team looking at new technology for PHES.[65] They are investigating smaller scale, modular, and less disruptive approaches pairing PHES with wind and solar power generation. The system will incorporate containment bladders that will be used as upper and lower reservoirs. The team feels Southwest Virginia's topography can take advantage of this technology, which requires 700 feet of drop, or head, to create the necessary force to generate power. The team specifically targets the region's inventory of reclaimed surface mine land to host such integrated power generation and storage systems. Figure 3-4 illustrates the Project Energizer energy storage concept.

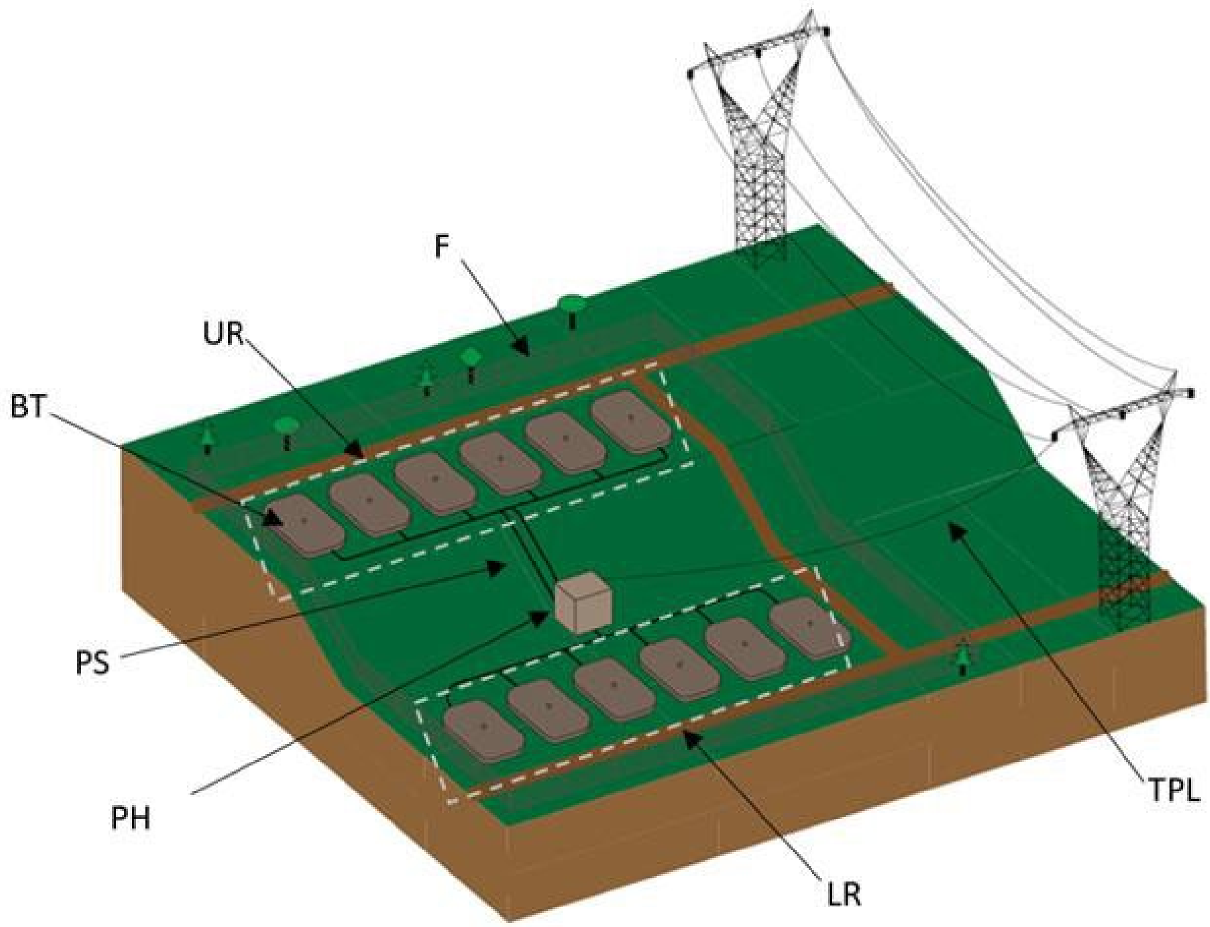


Figure 3-4. PROJECT ENERGIZER'S CONCEPT FOR PUMPED HYDRO ENERGY STORAGE USING BLADDERS.

Source: Invest SWVA. 2022. Project Energizer. https://www.investswva.org/project-energizer

Internationally, there have been efforts to build PHES on abandoned coal mine land. These include the upcoming construction of a 250 MW, eight-hour PHES facility at an abandoned surface coal mine in eastern Australia[66] and a project sponsored by the Australian Government to explore the repurposing of a former underground coal mine for a 600 MW PHES in New South Wales.[67] China is also looking at developing pumped-hydro storage sited at former coal mines, both using underground reservoirs[68,69,70] and in surface mines.[71]

3.4.2 Solid gravity energy storage

Solid gravity energy storage (SGES) can use excess renewable energy to lift heavy weights from a lower point to a higher point, and when electricity is needed, the system drops those weights to convert kinetic energy into electricity using a regenerative electrical motor.

3.4.2.1 Gravity energy storage applications in retired coal mines

SGES may be well suited for abandoned mining facilities due to the inherent depth of the mines (topography). For example, most underground coal mines in the United States are within 1,000 feet of the ground. Some can reach depths of 2,000 feet.[72]

Slope mines and shaft mines are the two main types of underground coal mines. Typically slope mines are located in hilly areas and use a sloping tunnel through the ground to the coal seam. Coal is transported out of the mine on either shuttle cars or conveyor belts. Shaft mines are those used to get to the coal beds that are usually located at a deeper underground depth than those reached by slope mines. A shaft is dug down to the coal bed location.[73] The existing architecture of vertical shafts and downward slopes may be repurposed for the development of gravity energy storage. Surface mines also have sloped architectures[74] that may be used for the development of SGES. Figure 3-5 illustrates these three different coal mine structures that may be used to build SGES systems.

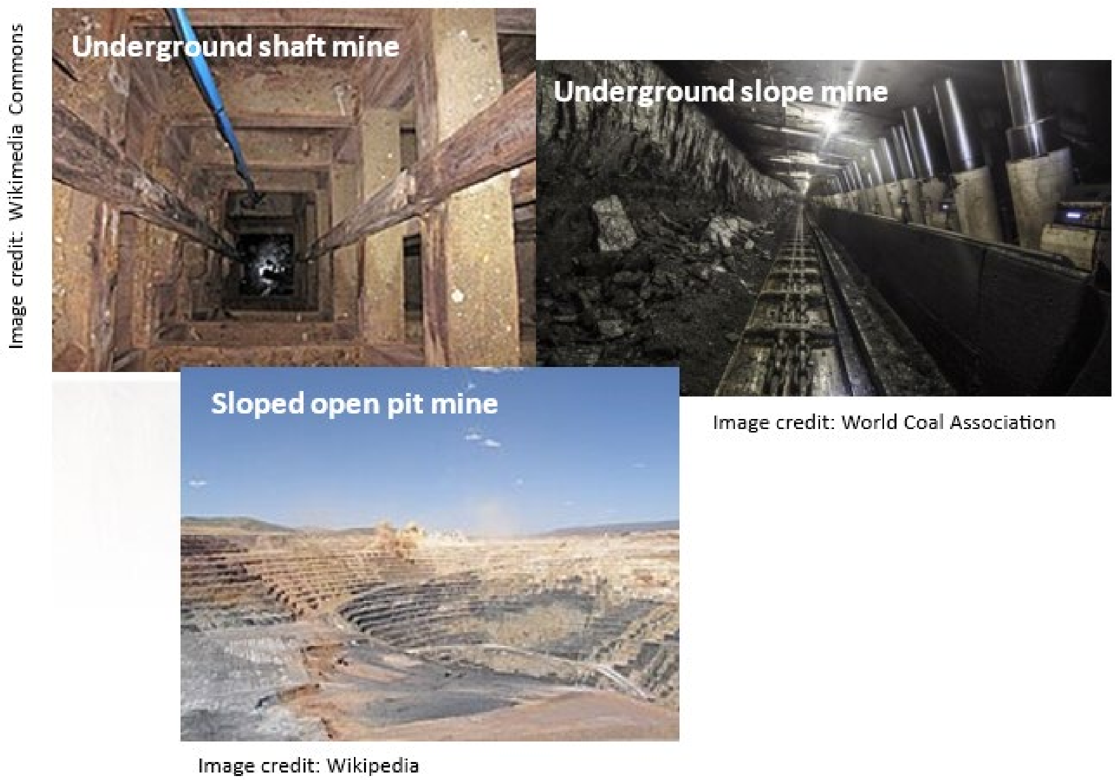


Figure 3-5. ABANDONED MINE STRUCTURES FOR SGES

Compared with PHES, SGES may have better geographical adaptability, higher energy density, and greater cycle efficiency.[75] The energy released in an SGES system is proportional to the acceleration.[76] This makes SGES both a regular power source when operating at a constant speed and a fast-response power supply when accelerating, making it valuable to electric grids integrating VRE.[77]

3.4.2.2 Examples of SGES projects

In recent years, several international companies have carried out small-scale demonstration projects or started small-scale commercial projects. These projects show that SGES can be built both on the surface and underground.

Surface SGES projects include railcar and tower-based storage systems. Both surface systems require large areas of land, and coal mine land may provide low-conflict land for such development. The American company ARES is building a railcar SGES facility in Nevada. The project, which broke ground in October 2020, will provide 50 MW for 15 minutes, yielding 12.5 megawatt-hours (MWh) of regulation services for the California Electric System Operator. The project will construct a set of 10 closed tracks to allow a fleet of 210 heavy mass cars to run in parallel up and down a sloped open-pit gravel mine of 20 acres.[78] According to ARES, the company provides a variety of SGES solutions, ranging in size from 5 MW to 1 GW, with storage times ranging from 15 minutes to 24 hours, depending on factors such as the weight and number of mass cars, the slope of the site, and the distance of the tracks.[79] A rendering of the ARES' gravity storage system is shown in Figure 3-6.

Figure 3-6. SCHEMATIC DIAGRAM OF RAIL-BASED SGES

Image credit: Weed, Russ. 2021. Advanced Rail Energy Storage (ARES): Market Needs and Technology Overview. Presentation at Thermal-Mechanical-Chemical Energy Storage Workshop. August 11. https://netl.doe.gov/sites/default/files/netl-file/21TMCES_Weed.pdf.

The energy storage company Energy Vault operates tower-based SGES facilities using a tower crane design. Energy Vault has projects underway in Australia, Brazil, China, India, South Korea, and the United States—the largest of which is a 2 GWh system planned to be built in China.[80,81] In the U.S., Energy Vault announced three projects totaling 2.2 GWh of gravity storage capacity for the production of hydrogen for aviation fuel, the first of which is a system of nearly 1.2 GWh in Louisiana (up to 73 MW for 16 hours).[82] Illustrations of tower based SGES systems are shown in Figure 3-7.

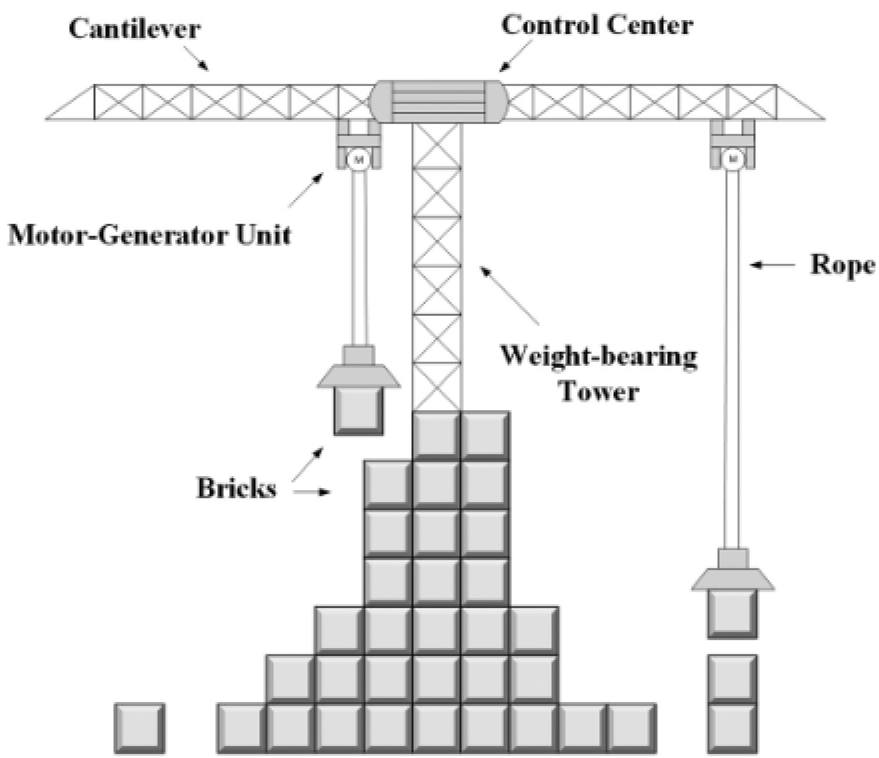


Figure 3-7. SCHEMATIC DIAGRAM OF A TOWER SGES SYSTEM AND PHOTO OF ENERGY VAULT'S SGES

Image credits: Tong, Wenxuan, Zhengang Lu, Weijiang Chen, Minxiao Han, Guoliang Zhao, Xifan Wang, and Zhanfeng Deng. 2022. "Solid gravity energy storage: A review." *Journal of Energy Storage* 53. https://doi.org/10.1016/j.est.2022.105226 and Energy Vault. https://www.energyvault.com/newsroom/energy-vault-announces-commercial-availability-of-transformative-utility-scale-energy-storage-technology.

An example of an underground SGES is being developed by the UK startup Gravitricity, which has built a 250 kW SGES demonstration project on an industrial site in Scotland. Gravitricity plans to deploy its gravity energy storage system in an abandoned coal mine in Czechia that has six shafts with depths of 150–1,500 meters. This is part of Gravitricity's plan for a full-scale, 4–8 MW renewable-powered SGES prototype program in abandoned mine shafts.[83] Gravitricity estimates that about 14,000 mines around the world may be suitable for its gravity energy storage system.[84] Figure 3-8 is a rendering of an underground SGES system.

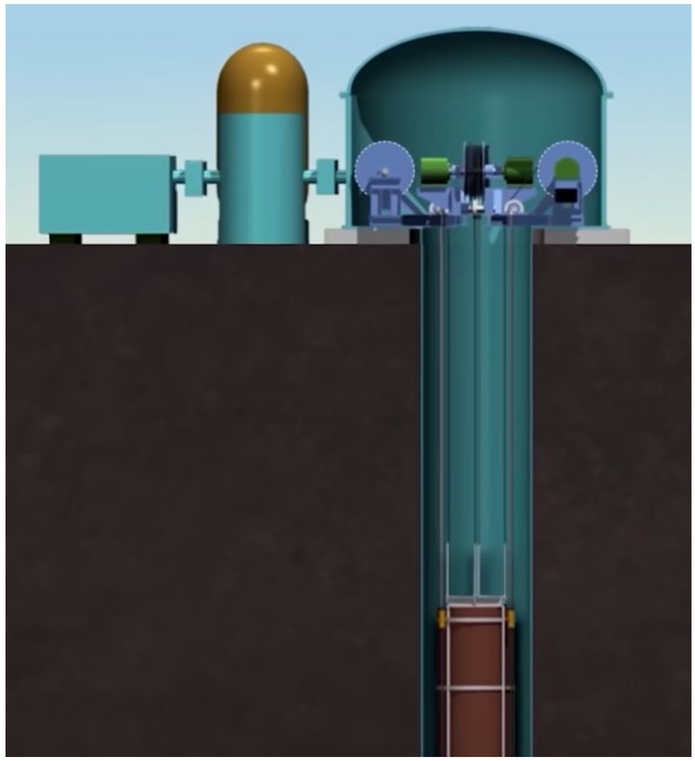


Figure 3-8. SCHEMATIC DIAGRAM OF UNDERGROUND SGES

Image credit: Just Have a Think. Gravity Energy Storage. Who's right and who's wrong? https://www.youtube.com/watch?v=lz6ZB23tfg0.

3.4.3 Compressed air energy storage

3.4.3.1 Compressed air energy storage (CAES) and its application in retired coal mines

CAES is another potential energy storage option to address the intermittency of renewable electricity. The technology converts electrical energy into potential energy by compressing air and storing it under pressure in different types of storage volumes, such as caverns, voids, and porous structures. When electricity is needed, the compressed air is released to drive turbine generators.

Two compressed air power plants have been operating for many years: the 321 MW Huntorf plant (with a discharging time of 2 hours at full load) in Germany, and the 110 MW plant (with a discharging time of 24 hours at full load) in McIntosh, Alabama. Both facilities use underground salt caverns for air storage.[85] In the United States, however, salt caverns are mainly used for natural gas storage, which accounts for 23% of U.S. underground natural gas storage deliverability.[86] The limited availability of salt caverns could hinder a scale-up of compressed air energy storage. Abandoned underground coal mines may be a potential opportunity for using CAES. Coal mines may have advantages over salt cavern systems or above-ground storage in tanks:

- Abandoned mines outnumber salt caverns, providing more opportunities for CAES.
- Closed coal mines already have available space and certain infrastructure, and the cost of developing CAES may be reduced.
- Since the energy storage system is located underground, it is more protected from external factors such as extreme weather and terrorist attacks.[87]

Converting an abandoned coal mine into a CAES requires several key issues to be addressed, including isolating the compressed air from the coal seam to prevent possible fires, preventing water infiltration into the compressed air storage space, and ensuring the robustness and integrity of the storage facility so that it can withstand high pressure without structural failure or air leakages. Typically, liners are used on the mine surfaces that are in contact with the compressed air to prevent leakages.[88] A study[89] that focused on using underground coal mines for a CAES system suggested that air leakage in the mine can be minimized by both grouting and lining the surrounding rock with concrete and installing flexible bags that are less expensive than steel storage tanks to store compressed air. A schematic diagram of compressed air energy storage in an abandoned coal mine is shown in Figure 3-9.

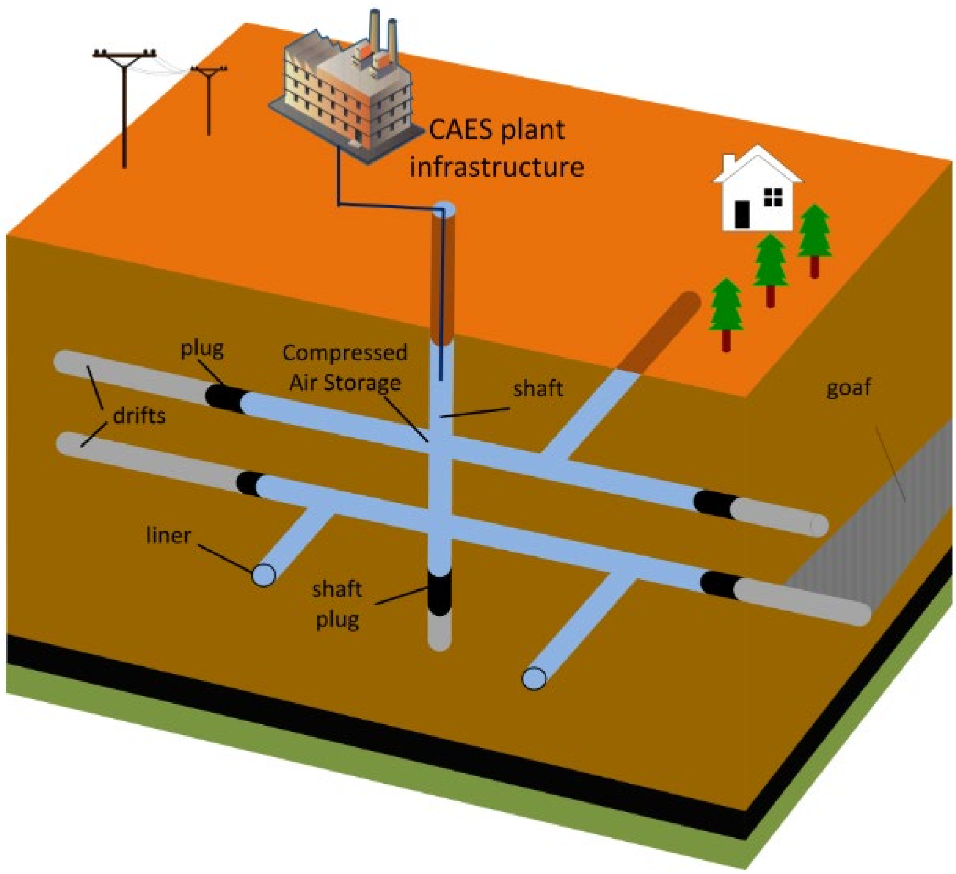


Figure 3-9. SCHEMATIC DIAGRAM OF CAES IN ABANDONED COAL MINE

Source: Lutyński, Marcin. 2017. "An overview of potential benefits and limitations of Compressed Air Energy Storage in abandoned coal mines." IOP Conf. Ser.: Mater. Sci. Eng. 268 012006. https://iopscience.iop.org/article/10.1088/1757-899X/268/1/012006.

The use of abandoned coal mines to develop CAES has been promoted in China in recent years. The Chinese government's 14th Five-Year Plan for the Development of New Energy Storage promotes CAES as one of the new energy storage technologies and requires development of pilots using abandoned coal mines,[90] and the Sichuan province recently called for the development of 100 MW-level CAES in abandoned coal mines.[91]

Shanxi Province is currently building the world's first CAES that utilizes abandoned underground coal mines as energy storage space. The first phase of the project, with a planned capacity of 60 MW out of a total capacity of 100 MW, was launched in 2020. Once the entire project is completed, with a daily charging and discharging cycle, electricity will be delivered from the CAES for approximately 1,300 hours for a total annual storage of 130 GWh. At the same time, the heat recovered from the CAES system can provide heating for residential buildings with an area of approximately 11 million square feet (ft^2).[92]

Hydrostor, a Canadian company, has been developing underground CAES projects and has been targeting coal communities—both looking to site projects at coal plants and using coal miners to construct the necessary subterranean tunnels and caverns. Hydrostor's Advanced Adiabatic Compressed Air Energy Storage (AACAES) uses thermal energy storage to capture waste heat during compression and reheat the air when it is released, significantly increasing efficiency and eliminating the use of natural gas which is usually used for heating. Further, a water reservoir is utilized to maintain a constant air pressure.[93] They have a 1 MW-scale system operating in Toronto that serves as a peaking power plant for transmission decongestion and renewable energy integration. Hydrostor plans to build three CAES systems with approximately a 9 GWh storage capacity in total; two in California and one in Australia. California's Willow Rock Energy Storage Center in Kern County is the largest, offering 500 MW of energy storage for up to eight hours. In January 2023, Central Coast Community Energy, an aggregator with over 440,000 customers in Kern County, agreed to buy 200 MW (1.6 GWh) of electrical energy storage from the Willow Rock Energy Storage Center.[94,95] Figure 3-10 shows schematically the hybrid system concept of Willow Rock Energy Storage Center.

Figure 3-10. SCHEMATIC DIAGRAM OF THE HYBRID SYSTEM CONCEPT OF THE WILLOW ROCK ENERGY STORAGE CENTER

Source: Jones, Jeffrey. 2023. "Hydrostor signs offtake agreement for energy storage project in California." *The Global and Mail* January 13. https://www.theglobeandmail.com/business/article-hydrostor-energy-storage-california-deal/.

3.4.4 Comparison of different energy storage technologies

Each energy storage technology has its place in an integrated approach to mine land redevelopment. As described, some are particularly well suited to take advantage of existing coal mine assets, including topography. Tong et al. compared the technical characteristics of various energy storage technologies, including battery energy storage (BES), PHES, SGES, CAES, and AACAES systems. Figure 3-11 shows their comparison of these energy storage technologies with three indicators: rated energy capacity, response time, and levelized cost of energy.[96]

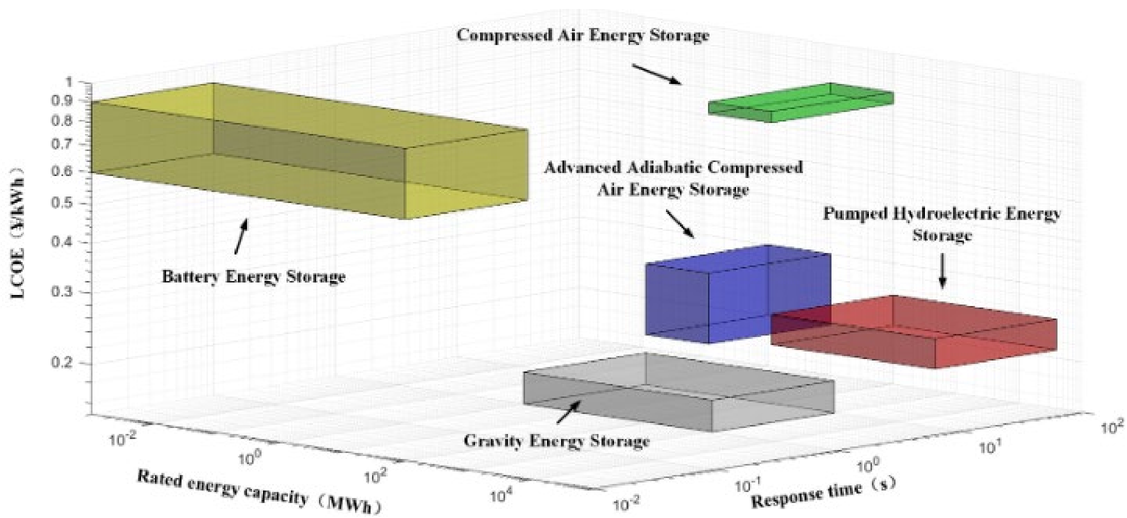


Figure 3-11. COMPARISON OF DIFFERENT ENERGY STORAGE TECHNOLOGIES

Source: Tong, Wenxuan, Zhengang Lu, Weijiang Chen, Minxiao Han, Guoliang Zhao, Xifan Wang, and Zhanfeng Deng. 2022. "Solid gravity energy storage: A review." *Journal of Energy Storage* 53. https://doi.org/10.1016/j.est.2022.105226.

Pumped hydro energy storage, which has cost and scale advantages, is often limited by geographical conditions. However, utilizing coal mine sites and existing power systems can unlock new possibilities for PHES. Gravity energy storage, with its potential for fast response time, may also be a viable solution in coal mine facilities due to their structural characteristics. Traditional compressed air energy storage using salt caverns can be constrained by geographical conditions. Repurposed abandoned coal mines for CAES, potentially with containers within the mine caverns, opens up additional opportunities. The use of these traditional and new storage technologies in defunct coal mines is still in the early stages of deployment, and requires technical development, policy support, and investment for wider adoption. Repurposing coal mine facilities for energy storage allows existing coal mining infrastructure to support clean and sustainable energy systems, reducing the need for new infrastructure development and land use. Large-scale energy storage is crucial for integrating intermittent renewable energy sources into the grid and ensuring grid stability.

4. Building a Digital Economy in Coal Communities through Data Center Expansion

There are different pathways to repurpose abandoned coal facilities. One application that has not received much attention but could have significant technical, economic, and social value is to build data center hubs in coal-reliant regions/communities. Repurposing abandoned coal sites to support data center expansion brings social, economic, and resource benefits to both coal communities and the data center industry, helping to achieve an equitable transition away from reliance on coal while advancing the digital economy in the United States.

4.1 Growth of the digital economy and expansion of data centers in the U.S.

With rapid development of the 5G network, big data analytics, artificial intelligence, and the Internet of Things, a new digital economy is being created. The output value of the U.S. digital economy in 2019 reached $2.1 trillion, accounting for 9.6% of U.S. gross domestic product (GDP). From 2005 to 2019, the digital economy grew at an average annual rate of 6.5%, much faster than overall U.S. economic growth of 1.8%.[97] Data centers are key to supporting the rapid expansion of this new economy, and thus the digital economy is a sector with great development prospects. The United States data center market was valued at $ 8.4 billion in 2020, and it is expected to reach $13.9 billion by 2026, with a compound annual growth rate (CAGR) of 8.6% during this period.[98]

While most data center demand comes from cloud providers and social media companies, new demand drivers emerge, including self-driving car technology, 5G infrastructure, virtual reality communities, and blockchain technology.[99] The COVID-19 pandemic has made more companies rely on virtual collaboration and work-from-anywhere models, and demand for “everything-as-a-service” (XaaS) demand is surging, growing 42% year-over-year in the first half of 2022.[100] As more and more companies turn to XaaS, the amount of data created, used, and stored has grown exponentially, greatly increasing the need for data center facilities.

CBRE’s data center market data indicates that in the first half of 2022, total inventory across U.S. primary data center markets rose 20% year over year to 3,711 MW. Total inventory in the secondary markets rose 11% year over year to 1,055 MW. More than 1,600 megawatts of new capacity were under construction in the first half of 2022, more than double what it was the year before. More than half of that new capacity is in Northern Virginia.[101]

In addition to the increase in total inventory, the low vacancy rate of data centers reflects the high demand in the data center market. CBRE’s semi-annual report shows that the overall vacancy rate in the primary market hit a record low of 3.8% in the first half of 2022. Vacancy rates in all primary markets are down from the year before, with Silicon Valley having the lowest at 1.3%.[102]

As for the regional distribution of data centers, Figure 4-1 shows the regional distribution of the primary and secondary markets of data centers in 2022. Northern Virginia dominates the data center market, with Dallas/Fort Worth, Silicon Valley, Phoenix, Chicago, Atlanta, and New York serving as additional major markets.

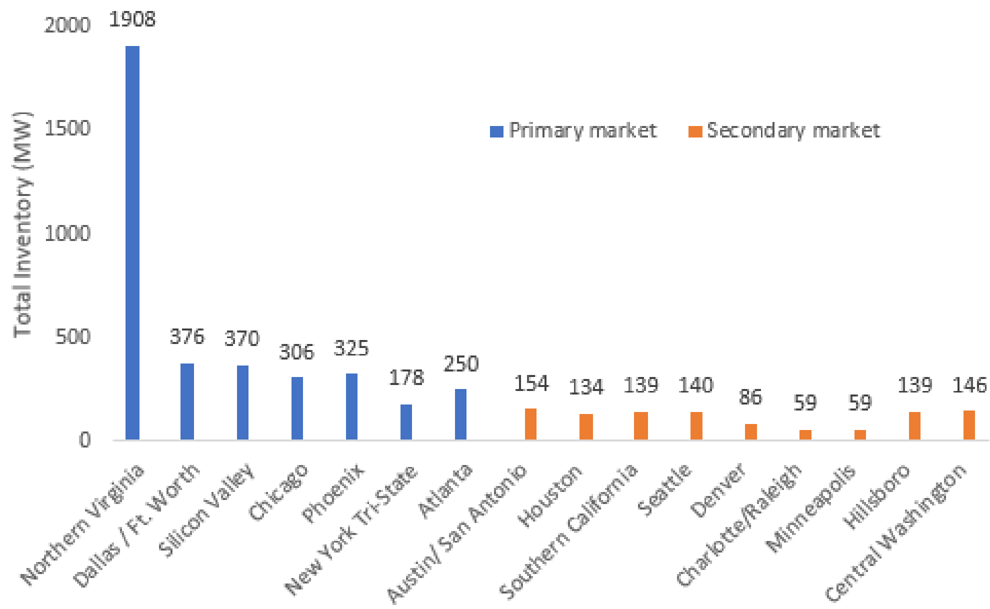


Figure 4-1. GEOGRAPHIC DISTRIBUTION OF DATA CENTER INVENTORY, H1 2022

Source: CBRE. North America Data Center Trends H2 2022. September 29. https://www.cbre.com/insights/reports/north-america-data-center-trends-h1-2022

Data center market data from CBRE shows that limited land space and electric power constraints have increased costs in supply-constrained markets like Northern Virginia and Silicon Valley. Industry insights point to two trends in U.S. data centers:[103] first, migration to secondary and tertiary markets will increase as land and power constraints affect data center expansion in key primary markets; second, investment in edge data centers (distributed computing closer to the end use) will increase, as latency and bandwidth become more important as end users need to access large amounts of data faster from more locations. Edge data centers help reduce latency and optimize bandwidth by bringing data closer to end users and devices. The increase in edge deployments has been facilitated by vendors opening smaller facilities in markets outside of primary markets.

Table 4-1 identifies the size of data centers in terawatt-hours (TWh) in each of the 14 top coal mining states. The top states in order of data center presence are Virginia and Texas, followed by Illinois, Pennsylvania, Alabama, and Colorado.

Table 4-1. DATA CENTER ENERGY USE BY STATE

State	Total annual data center energy in 2018 (TWh)
Alabama	1.3
Colorado	1.1
Illinois	3.4
Indiana	0.6
Kentucky	0.4
Montana	0.1
New Mexico	0.5
North Dakota	0.1
Pennsylvania	1.4
Texas	7.3
Utah	0.7
Virginia	9.3
West Virginia	0.1
Wyoming	0.3
Total of 14 "coal" states	26.6
National Total	72.1

Source: Siddik, M.A.B., A. Shehabi, and L. Marston. 2021. "The environmental footprint of data centers in the United States." *Environmental Research Letters* 16(6), 064017.

4.2 Beneficial use of coal community resources for data centers

A benefit of expanding data centers in coal communities is that auxiliary infrastructure that no longer plays an economic role at abandoned coal sites can provide needed resources and infrastructures for data centers. These resources include land, power infrastructure, and mine water cooling.

Land resources are needed for development. Unused reclaimed land, as described in Chapter 2, can provide the necessary land for the construction of data centers and auxiliary infrastructure.

Data centers require a lot of power. Data centers therefore need reliable power supply infrastructure (such as nearby transmission lines and substations). This type of infrastructure has already been built at abandoned mines and power plants, potentially saving new investments in such facilities. In addition to the existence of the electricity supply infrastructure, coal regions often have more competitive electricity prices. The top five coal-producing states (Wyoming, West Virginia, Pennsylvania, Illinois, and Kentucky), which accounted for over 70% of total U.S. coal production in 2019, are among the states that have the lowest average retail electricity prices in the country.[104]

Besides the land and infrastructure, many abandoned coal mines are flooded with mine water. This water can be used for cooling data centers. For example, a report from the Indiana Geological Survey on the characterization of groundwater in the coal mine aquifers estimated that there are more than 194,000 acres of underground coal mines in Indiana, most of which are abandoned room and pillar mines. The amount of groundwater in the voids of these mines may be as high as 172 billion gallons. The report points out that these potentially high-yielding coal-mine aquifers may represent resources that can be used for a variety of purposes, including geothermal heat pump systems, energy storage, and cooling water.[105]

4.3 Economic development, job opportunities, and other local benefits from data center expansion

Repurposing abandoned coal facilities for data centers is a potential answer to the call from coal communities across the United States for creating a more diverse and sustainable local economy in the post-coal era. Such a transition could bring job opportunities to distressed coal-reliant regions where workers face difficulty finding work that allows them to maintain their current quality of life after the coal phaseout.[106]

Prior to new development, the restoration of coal facilities also creates job opportunities. The Sierra Club estimates that in Appalachia alone, the federal government's support for the restoration of abandoned coal mines can create more than 13,000 jobs.[107] The new data center job opportunities are in addition to jobs to rehabilitate and clean up decommissioned coal sites.

Considering the high growth of the digital economy, job opportunities are expected to increase in this sector. A recent Uptime Institute report indicated "the headcount for extra staffing requirements will reach 300,000 by 2025. With a rapidly ageing workforce and talent poaching rife, there are legitimate concerns that the industry is sleepwalking into an early grave."[108] A recent Uptime Institute survey identified staffing as data center operators' biggest management and operations need.[109]

A study focusing on Southwest Virginia found that locating a large 36 MW data center in a former coal mining area can bring more than 2,000 construction jobs and almost 100 permanent jobs to the local community. The construction would generate $233 million in local economic activity during construction, and the operation would bring more than $50 million in annual revenue.[110]

Econsult Solutions, Inc. (ESI) analyzed the potential growth of the data center industry in Pennsylvania. The ESI analyses indicate that Pennsylvania would gain the following if a full data center sales and use tax exemption existed:

- Over 33,000 additional total jobs, including 10,000 more jobs in data center sector.
- Over $6 billion more in total output (direct, indirect and induced sales/revenue).
- Over $2 billion more in total wages.
- $110 million more in annual net tax revenues, after accounting for the sales tax exemption.
- Increased county, municipal, and school district property tax revenue.

The study also notes the expansion of data centers in Pennsylvania would have additional community and economic impacts, including:

- Diversification of local economies.
- Investments in human capital with high-wage jobs.
- Improvements to the electric grid, including in rural areas.
- Innovations in energy efficiency.
- Increased broadband access, including in rural areas.

According to a report[111] by the U.S. Chamber Technology Engagement Center (C_TEC), the average data center adds $32.5 million in economic activity to its local community each year. Tim Day, senior vice president of C_TEC said "When communities support data centers, those data centers in turn create jobs, improve local public infrastructure, and encourage skills training for workers and businesses." The report shows that during construction, data centers on average employ 1,688 local workers, provide $77.7 million in wages for those workers, produce $243.5 million in output along the local economy's supply chain, and generate $9.9 million in revenue for state and local governments. Additionally, during its yearly operation, a typical large data center supports another 157 direct and indirect local jobs and $7.8 million in wages.

In interviews with industry experts, many noted that tax revenue is a large benefit to local communities, even those that provide tax concessions to attract data center development. Industry experts also pointed out that data centers are a low burden on local community services. They reported that local communities can benefit with millions of dollars in tax revenue. According to John Sasser, Chief Technical Officer for Sabey Data Centers (pers. comm. April and May 2023), data centers can be the highest or close to the highest taxpayers in some communities (especially rural ones); residents receive a much higher tax benefit for a much lower tax burden due to the presence of data centers in the community. In one example, KC Mares of MegaWatt Consulting reported (pers. comm. April and May 2023) property tax values went up tenfold in three to four years of data center development in Quincy, Washington. While the city did increase overall tax revenue and increase services, they were also able to significantly reduce the tax rate for everyone. Therefore, with the added data center tax revenue, residents of Quincy saw an increase in municipal services and a decrease in their individual property taxes. In addition to the property tax benefits, local communities can see benefits from sales tax collections, both on the initial equipment as well as "refreshes" that typically occur every few years.

However, while industry touts the economic and tax benefits of data center development—for example, Facebook has commissioned studies and promotes the economic impacts of their data centers[112,113]—there is controversy. For example, in his article on *Facebook's Data Center Fluff*, Pat Garofalo argues Facebook is "subsidized by taxpayers to the tune of hundreds of millions of dollars."[114] Some argue that local and state governments are wasting money incentivizing data centers to locate in their communities.[115,116,117] They note that the primary drivers for locating data centers is low-cost electricity (see Section 4.6 for an extensive discussion of location criteria) and find that data center developers are playing states and localities against each other in bidding wars. One study reported that for 11 mega data center deals, over $2 billion in subsidies were provided, costing $1.95 million per job created.[118] As noted in Chapter 6, more independent study of the cost/benefits of public incentives for development is needed.

Another potential local community benefit of data center development is improved access to the internet with higher speeds and bandwidth via fiber networks. Data centers generally require high speed and bandwidth via dedicated internet access from multiple carriers. These networks can potentially be shared with other companies and institutions that require such service. Carriers often share fiber capacity with each other, opening up access to others, and data centers are often the hub (Point of Presence [POP]) where such interconnections occur. Hospitals, schools, and office complexes are among the potential users of dedicated internet access. A recent GAO report[119] found that small-sized and rural health care providers struggle to modernize their IT systems. The report stated that a lack of broadband connectivity and trained staff are main barriers for less populated and more isolated communities. The federal government is pursuing an aggressive national broadband plan. Its goal is to influence the U.S. broadband ecosystem through specific measures, such as supporting the deployment of broadband in high-cost areas, ensuring that low-income Americans can afford broadband, and promoting adoption and utilization of broadband, among others.[120]

4.4 Synergistic opportunities from data center expansion

While it is possible to develop data centers on mine land as stand-alone projects, complementary development can make the undertaking even more compelling. Synergistic developments of renewable energy power production, energy storage, and mine water cooling were explored in Section 3. Such integrated multifaceted developments will be attractive to data centers and will provide additional economic benefits to the community. The integration of data centers with renewable power generation and energy storage can be further enhanced with smart microgrids that would allow the data center and other critical facilities within the microgrid to "island" and operate independently of the utility grid. The U.S. Department of Energy supports the development of microgrids.[121] Further, such an integrated electrical system can provide "grid services"[122] that support the utility grid and nearby communities by reducing their load at critical times, helping to maintain grid stability, and sharing renewable and stored power when the utility grid is under stress. Many data center loads (e.g., cryptocurrency mining, AI learning, animation rendering) can be strategically curtailed or moved via the network to other data centers not experiencing utility grid issues. Hence an integrated data center development can improve the power reliability in a community.

Taking this integrated approach one step further would involve a "circular economy" that keeps materials, products, and services in circulation for as long as possible.[123] This could involve waste heat recovery from the data center (see next section) as well as enterprises that facilitate repair, recycling, and reuse of IT equipment and materials. Figure 4-2 illustrates a fully integrated approach.

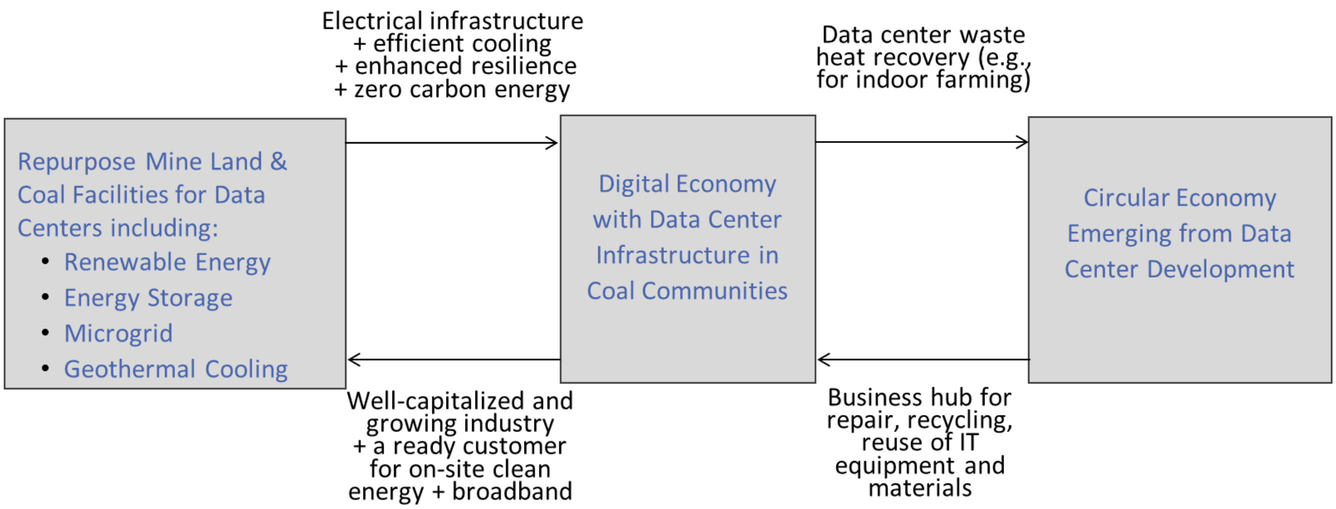


Figure 4-2. A FULLY INTEGRATED APPROACH TO DATA CENTER EXPANSION

4.4.1 Productive use of heat recovered from data centers

A large synergic opportunity with data centers is the availability of waste heat 24/7 all year round. All the power going to a data center – often many megawatts – is converted to heat and must be removed from the data center. Normally that heat would be wasted, however it can be considered "free" for someone to use, or a commodity that can be sold to add economic value to the project. For example, the heat can be recovered and used for district heating. Amazon uses heat recycled from a data center to warm its Seattle campus.[124,125,126] Data center integration with district heating systems is more common in Europe; for example, the Stockholm district heating system.[127]

Where the temperature of district heating systems exceeds the temperature available from the data center, heat pump technology can be used to efficiently increase the temperature. That technology is being used at the Meta data center in Odense Denmark where 100,000 MWh are recovered.[128] See Figure 4-3.

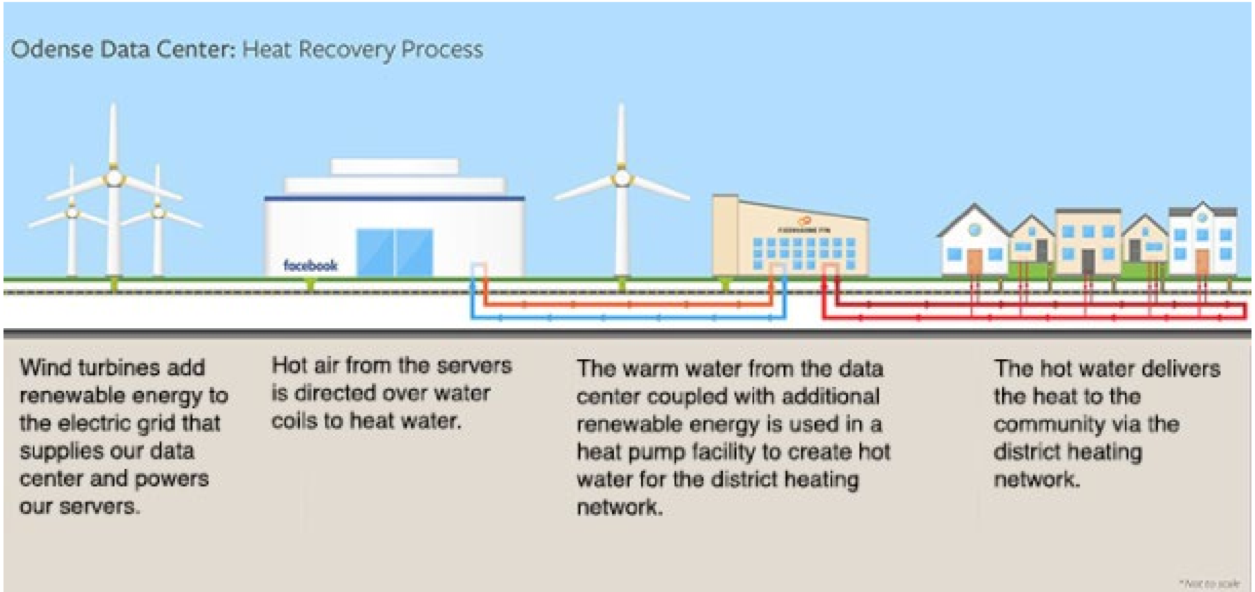


Figure 4-3. HEAT RECOVERY AT META'S ODENSE DATA CENTER

Source: Meta

But perhaps more applicable to remote locations would be the use of recovered heat for food production, including plants in greenhouses[129] or fish in aquatic ponds or tanks.

Several U.S. data centers are being designed in conjunction with heat recovery and large-scale greenhouses for indoor farming. These include the Wyoming Hyperscale Whitebox,[130,131,132] and GeoBitmine[133] in Idaho. The first phase of Wyoming Hyperscale involves 30 MW of data center (out of a planned 120 MW) and 30 acres of greenhouses. Figure 4-4 is a rendering of the Wyoming Hyperscale White Box data center and adjacent indoor farms. GeoBitmine's white paper[134] describes 1 MW crypto mining pods each capable of heating approximately one acre of greenhouse. The white paper describes a 15 pod (15 MW) data center with 15 acres of greenhouse space creating over 100 full-time jobs mostly on the food production side.

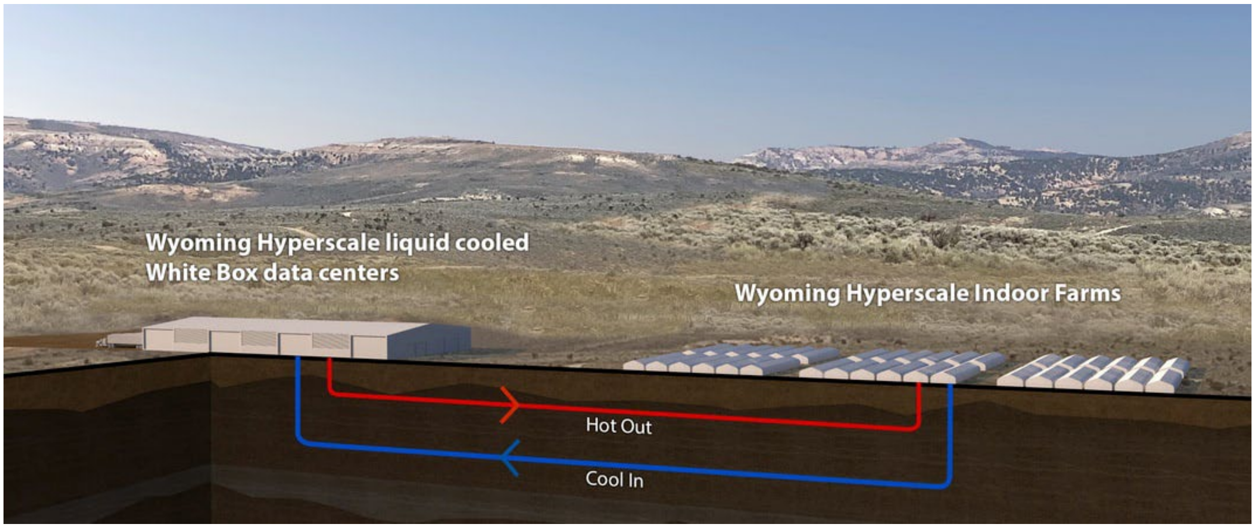


Figure 4-4. WYOMING HYPERSCALE WHITE BOX DATA CENTER WITH ADJACENT INDOOR FARMS.

Source: https://wyominghyperscalewhitebox.com/project.html

Fish farming is a form of aquaculture in which fish are raised in enclosures to be sold as food. It is the fastest growing area of animal food production.[135] Many species require warm water. The U.S. Department of Agriculture maintains the Warmwater Aquaculture Research Unit whose mission is to develop technologies that improve the efficiency, profitability, and sustainability of fish farming in the United States.[136] There are examples of data centers providing heat to fish farms in Europe.[137] And Green Mountain, a data center owner and developer in Norway is planning to use waste heat from one of their data centers for a land-based trout farm.[138,139,140] They also have developed a concept for a more elaborate integrated “eco system” as shown in Figure 4-5.

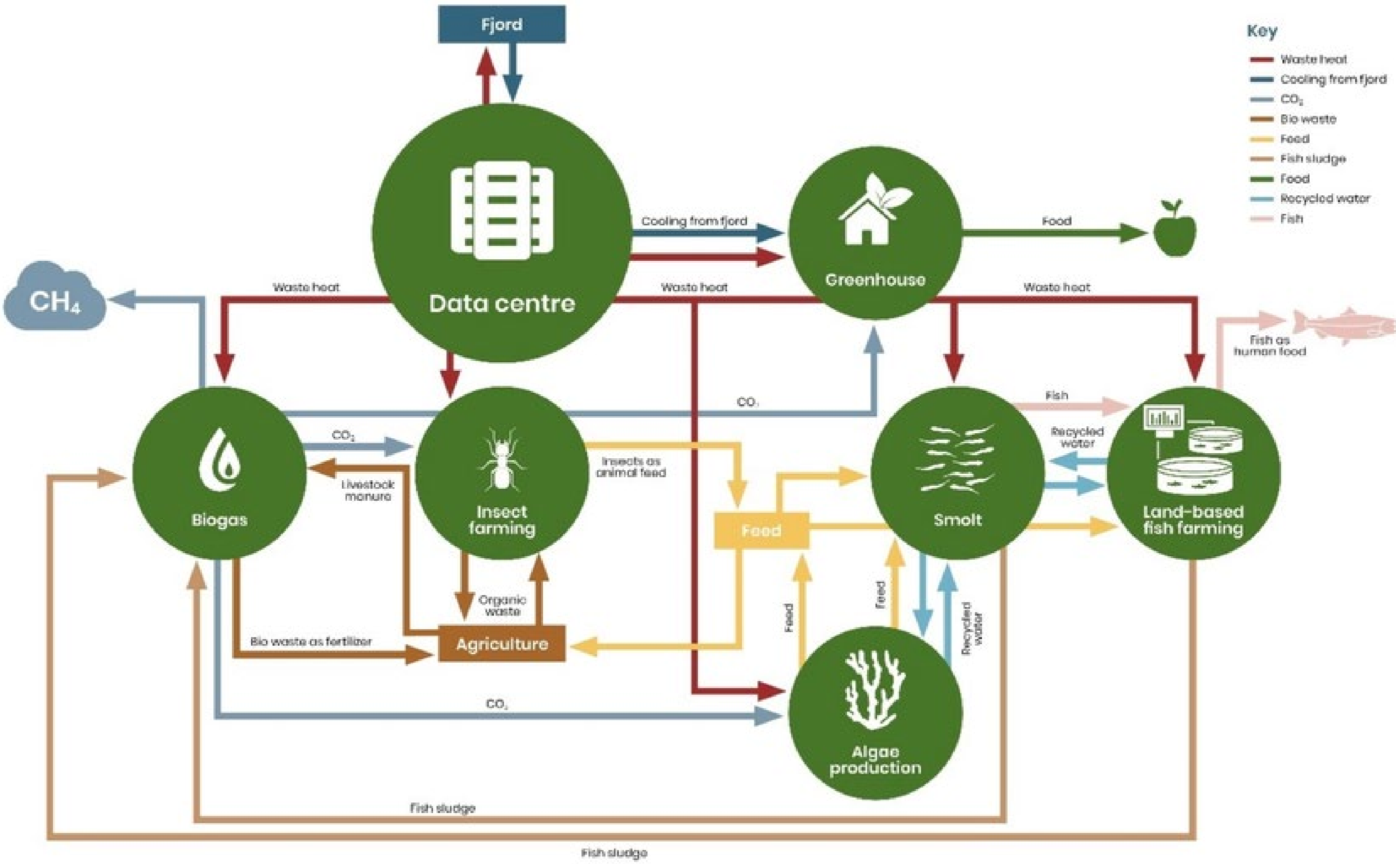


Figure 4-5. GREEN MOUNTAIN DATA CENTER INTEGRATED HEAT RECOVERY CONCEPT

Source: Tor Kristian Gyland, CEO Green Mountain, presentation at the Data Center Forum, October 5, 2021. https://www.datacenter-forum.com/green-mountain-data-centre/how-green-mountain-tackled-the-many-challenges-of-data-center-heat-re-use-and-what-they-learned-along-the-way.

There are additional options for using data center heat in other industrial processes. Intel commissioned a study[141] from David Gardiner and Associates to evaluate the opportunity for data center waste heat use, and they found the top five uses are:

1. Pharmaceutical Heating and Cooling
2. Food and Beverage Pasteurization
3. Other Food and Beverage
4. Commercial Process Cooling and Refrigeration
5. General Water Pre-heat

The Open Compute Project is a data center industry organization that has established a working group addressing the opportunities for data center heat reuse.[142] They are developing resources on the opportunity, and have a global map describing data center heat reuse projects.[143]

While technically recovery and use of data center heat is viable, there are barriers. First, there is the cost associated with a potentially complex system involving many players. Second is proximity. The heat-supplying data center must be close to the heat-using "thermal host." Third, it is not easy getting all the parties together, as they are typically in completely unrelated businesses, and neither the heat producer nor the heat user is in the business of distributing and selling heat. And fourth, there can be legal/regulatory issues associated with transferring the heat (in essence a utility) from one entity/property to another. However, in the case of mine land redevelopment where the community organizers or land developers are targeting an integrated approach, putting the right entities and technologies together may be feasible and could add to the overall economic viability of the project, as well as the community economic development and jobs created.

4.5 Examples of using mines and coal assets for data centers

There are a number of examples of data centers built in mines, on mind land, or on closed coal power plant sites, and they have demonstrated a number of advantages.

4.5.1 Iron Mountain

Iron Mountain is an owner and developer of data centers. They have developed two data centers in retired limestone mines. Their primary underground data center is in Boyers, Pennsylvania. It is 300 feet deep and includes an underground lake (mine water) that is used for data center cooling. Originally our study considered placing data centers in coal mines, however their structure is significantly different than limestone mines and the study has instead focused on reusing the land associated with coal mines (mine land) while still using mine water and mining infrastructure assets. Jim Henry, Senior Manager of Global Risk, Compliance, and Quality Management at Iron Mountain has provided valuable advice and support to our project. The Boyers data center is a U.S. Department of Energy Better Buildings' partner and the following information is drawn from the Better Buildings solutions website.[144]

Iron Mountain uses mine water as a heat sink for cooling, yielding multiple advantages: (1) improving cooling energy efficiency and potentially even replacing electric compressor-based cooling, thereby reducing energy consumption and the climate impact and environmental pollution of generating the required energy, and (2) reducing water consumption that is normally used in cooling towers. Both lead to significant climate and cost benefits.

Since 2017, Iron Mountain has operated all of its data centers on 100% renewable energy. In the same effort, every data center location in their enterprise is ISO50001 Energy Management System (EnMS) certified, ensuring continuous improvement of energy efficiency practices across their portfolio.[145] A virtual tour is available.[146] Figure 4-6 shows data center infrastructure and the underground lake at the Boyers data center.

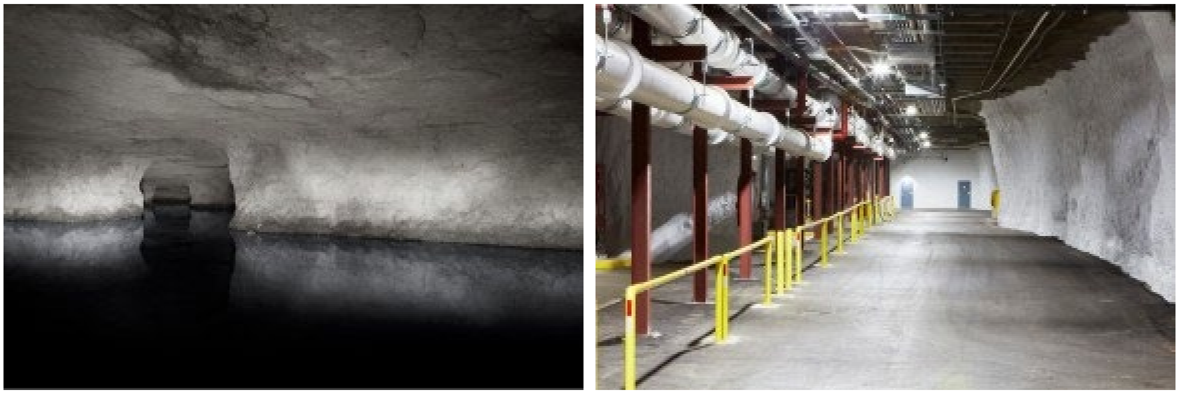


Figure 4-6. MINE WATER LAKE USED FOR COOLING AND UNDERGROUND DATA CENTER INFRASTRUCTURE.

Source: Iron Mountain

4.5.2 Other data centers repurposing limestone mines or other underground structures

Other data centers have located in previous limestone mines. The Bluebird Data Center in Springfield, Missouri, is located 85 feet underground with two square miles of honeycombed limestone passages providing over 5 million $ft^2$of galleries for data center expansion (the current data center is 80,000 ft^2).[147] And the Lefdal Mine in Norway which was used as a military installation,[148] is now being converted to a data center. It draws on “free cooling” from an adjacent fjord, and is supplied with renewable energy.[149] The proximity to the fjord ensures access to unlimited 8°C (46°F) seawater year around. The facility covers 120,000 square meters, spread over six levels, with a potential capacity of 200 MW. The first stage of the build-out involves a single level of the mine and 30 MW capacity. Figure 4-7 illustrates the multi-level configuration with central access road and 75 perpendicular galleries where containerized data centers are stacked.

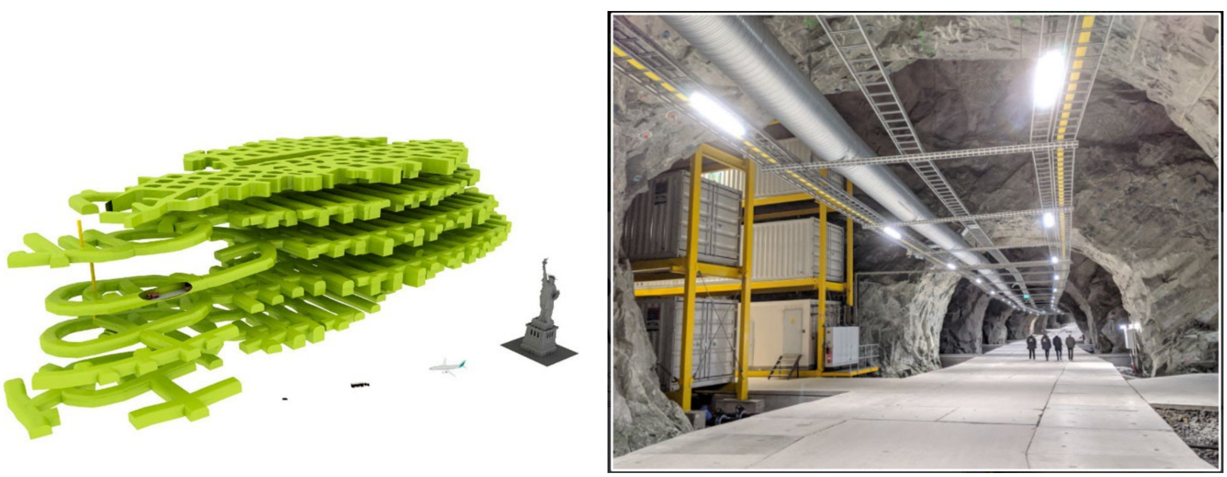


Figure 4-7. MULTILEVEL LIMESTONE MINE CONVERTING TO DATA CENTER

Source: Lefdal Mine Datacenter. https://www.lefdalmine.com/.

Green Mountain's SVG1-Rennesøy data center is built in a former underground NATO ammunition storage facility.[150] Like the Lefdal Mine it is in Norway and is cooled by an adjacent fjord. It will support up to 2 x 26 MW in 230,000 ft^2. Figure 4-8 illustrates the entrance to the mine and the underground structure.

Figure 4-8. GREEN MOUNTAIN DATA CENTER BUILT IN MOUNTAIN

Source: Business Norway. n.d. Green Mountain's carbon-neutral data centres have natural cooling. https://businessnorway.com/solutions/green-mountain-carbon-neutral-data-centres-have-natural-cooling

4.5.3 Project Oasis

The State of Virginia and local officials feel Southwest Virginia could be an attractive data center destination and have developed Project Oasis with many of the concepts outlined in this report on repurposing coal assets.[151,152] U.S. Sen. Mark Warner (D) said "Southwest Virginia is primed to become the next hot spot for data centers." And Congressman Morgan Griffith (R), noted "Reinventing our economy can include reusing our existing infrastructure. The water pooled in abandoned mine sites could serve industrial operations requiring substantial water use, such as data centers. This innovation would be a way to draw economic opportunities to Southwest Virginia. Just like the potential to use our abandoned mines for closed-loop hydropower, the possibilities presented by Project Oasis are exciting, and I stand ready to assist its progress to benefit our region."

The Project Oasis study[153] found the region could become a data center location of choice. The use of geothermal cooling technology with billions of gallons of water collected in underground mines was found as a significant energy and cost-savings tool that could drive modernization and bring 21st century jobs to the region. The study provides an in-depth look at how to attract data centers to Southwest Virginia, including key investments in infrastructure. Further the study found that Southwest Virginia is well-positioned for data centers because of land availability, geothermal cooling opportunities unique to the region, and workforce readiness and development.

Highlights from the study include the following:[154]

Economic Impact:
The economic and fiscal impact analysis estimated that a large data center (36 MW) locating in the region would result in over 2,000 jobs created during construction, 40 direct and 59 additional permanent jobs, $233 million in economic activity during construction, and over $50 million in economic activity annually once operations begin.

Land and Geothermal Cooling:
As data center suitable real estate becomes increasingly scarce and extremely expensive in Northern Virginia, other parts of the state with abundant power and fiber infrastructure have seen increased interest from data center developers. Data centers have unique site and infrastructure requirements. Six sites were identified for large data centers, and four additional sites for smaller data centers of up to 10 MW. Two of the sites have opportunities for geothermal cooling through utilization of 51-degree mine water contained in vast pools below the surface of previously mined properties. The annual savings for a geothermal cooling system would be over $1 million annually in reduced electric costs and municipal water purchases. Factoring in savings for avoided maintenance and other costs for a conventional system, the mine water system would provide a favorable return on investment.

Renewable Energy:
Most new renewable energy projects for data centers in the current market utilize solar energy, which requires large land area (6-10 acres per MW). Southwest Virginia has ample previously mined properties suitable for solar development. The availability of solar development potential, cost-effective geothermal cooling, and the region's desire to transform itself from a coal producing area to an innovative renewable energy hub provides a compelling case for data centers who are increasingly mandating new facility locations that allow sustainability goals to be met.

Workforce:
There is a reasonable pool of workers in the region with skills and training that are potentially transferrable to a data center environment. Wages for IT workers such as network architects and information security analysts are 17% less in the region than the national average. IT training programs and resources exist with the community colleges and the University of Virginia at Wise.

State and Local Incentives:
While the state already has data center incentives in place, the study called for lowering data center equipment property tax rates to make the region more competitive with other Virginia counties. Since the study was published, five Southwest Virginia localities agreed to lower the regional property tax on data center equipment to Virginia's lowest.[155] Also in an effort to attract data center development to distressed localities (like coal communities), the state reduced the requirements to qualify for sales and use tax exemptions.[156]

4.5.4 DP Mineral Gap Data Center

DP Mineral Gap is the first data center in Southwest Virginia that is supplied with power from an adjacent 3.5 MW solar farm built on an abandoned coal mine.[157,158] See Figure 4-9 for an image of the project. The data center company pair with the solar power provider to propose the solar farm be built in a coal region that was last mined in 1957. While the data center is connected to the local electrical grid, the solar farm is proposed to reduce peak-load demands on the local distribution grid.

Figure 4-9. SOLAR POWERED DP MINERAL GAP DATA CENTER

Source: McGowan, Elizabeth. 2019. Federal funds to help turn Virginia coal mine into solar farm. Energy News Network. March 8. https://energynews.us/2019/03/08/virginia-solar-farm-among-10-projects-to-receive-mineland-reuse-funds/.

4.5.5 Google

Besides locating data centers in mines and on mine land, it also is possible to repurpose other fossil fuel facilities including coal fired power plants. Google recently opened a $600 million data center in Jackson County, Alabama, that created over 100 local jobs.159 The project is on the grounds of Widows Creek, a shuttered TVA coal power plant. According to Google "there's a lot of potential in redeveloping large industrial sites like former coal power plants [for data centers]… At Widows Creek, we can use the plants' many electric transmission lines to bring in renewable energy to power our new data center."160 See Figure 4-10 for an image of the Widows Creek power plant, now the home of a Google data center.

Figure 4-10. TVA'S WIDOWS CREEK COAL POWER PLANT

Sources: Gammons, Patrick. 2015. A power plant for the Internet: our newest data center in Alabama. Google. June 24. https://blog.google/inside-google/infrastructure/a-power-plant-for-internet-our-newest/

The Google data center will be powered with renewable energy from the 100 MW Skyhawk Solar project in Tennessee under a long-term power purchase agreement, thus contributing to Google's goal of carbon free operation by 2030. Google has purchased 413 MW of power generated by multiple solar farms within the TVA territory to power its campuses in the Southeastern U.S.[161]

4.6 Factors affecting data center expansion into coal communities

Discussions were held with 15 data center industry experts from 10 companies to get their input on the concept of reusing coal mine land for renewably powered data center development and specifically location criteria. Prior to the discussion they were sent a short presentation (Appendix A) to brief them on the concept. The experts included:

- Suresh Pichai, P.E., Director, Innovation, Global Design & Construction, Equinix
- John Gross, Owner, Mechanical Engineer, J. M. Gross Engineering
- Aaron Binkley, VP, Sustainability, and Dave Craft, VP of Acquisitions and Investments, Digital Realty
- Brian J. DeLeon, PE, Senior Associate, Lead Mission Critical Practice, and Mark Flickinger, ME Principal at Burdette, Koehler, Murphy (BKM)
- KC Mares, MegaWatt Consulting
- Troy Isbell, Account Director, Zayo Group
- John Sasser, Chief Technical Officer, and Bobby Robbins, VP of Sales, Sabey Data Centers

- Jim Henry, Senior Manager, Global Risk, Compliance, and Quality Management, Iron Mountain
- Oren Wool, VP of Sustainability, Quantum Loophole (QL)
- Eric Yang, Principal Mechanical Engineer, and Tyler Smith, Vice President, Market Development, and Mark Egan, New Site Development, Vantage Data Centers North America.

4.6.1 Data center development/location criteria

The discussions with industry experts focused on location selection criteria. Often there was not a full consensus on the priority of the criteria, and there are many nuances. Some variations in priorities can be explained by differences in:

- Size of the project.
- Time frame for the project (short term being a 1- to 2-year development cycle, while long term may have up to a 10-year planning horizon)
- The developer's business model (e.g., land developer, colocation [colo] developer, cloud or social network provider).
- Nature of the development company (e.g., risk tolerance for innovation).

There are differences in priority for criteria such as power reliability based on the criticality of the compute load and the options the user has to move the load to other data centers. Another example of differences is the need for high bandwidth—important to social media companies, but not important to crypto currency miners.

In general, the highest priorities relative to site selection for data center development included:

1. Readiness for development: land reclaimed, infrastructure in place, local support strong, minimal planning and environmental concerns (e.g., approvals have been obtained), and due diligence studies have been completed. Customer interest is also needed for colos, which lease capacity within their data centers to customers that operate their own IT equipment.
2. Power: low electric prices, ample capacity, reliable (typically from two sources), and clean.
3. Dedicated Internet Access (fiber networks) available (capacity, latency).
4. Secure: safe from natural disasters (e.g., floods, earthquakes) and human-made threats.
5. Low total cost of ownership (TCO) (capital plus operating costs): this relates to many of the selection criteria including local/state incentives (e.g., sales, property, and income tax), and expedited approval/permitting.

Other lower priorities include:

6. Renewable energy resources available.
7. Mine water or other "free" cooling.
8. Structurally sound building sites.
9. Simple and clear land ownership.

10. Infrastructure in place.
11. Proximity to skilled workforce and availability of job training programs.
12. Demonstrated success of concept.
13. Proximity to peers (hub, campus).

In many cases, even the high priority criteria are fungible. For example, with priorities relating to cost, low-cost elements can balance out high-cost ones. And even the TCO is fungible if there is a particularly desirable location (e.g., near a hub like Silicon Valley). The purpose of developing these criteria is to assist policy makers and community organizations (e.g., economic development offices) in assessing their potential ability to attract such projects, and to provide guidance on what needs to be available and how best to position redevelopment opportunities relative to the market.

A detailed discussion of site selection criteria generally follows the priorities listed above; however, some reorganization was done for clarity (e.g., grouping of related criteria).

1. Readiness **(high priority)**

The more ready for development a project is, the less risky it is for project developers. This is especially true for data center developers, while land developers take on these risks and provide buildable sites to their (data center) customers.

a) Reclaimed land is ready for development **(high priority)**
For many data center developers, the time frame for development is short, so any risk that could delay the project is to be avoided. The more ready the better. Mine land that is clean and buildable, with at least some useful infrastructure in place, is the ideal. Required action, such as that needed by the EPA, can be a show stopper. While mine land remediation is an issue, tax and other incentives can mitigate that concern, especially for long-term land developers. Some of the largest developers have longer time horizons for large projects – up to 10 years—and will take on more responsibility. But all developers will be concerned about existing liabilities that might be associated with coal mining (e.g., contamination, land stability).

b) Local support **(high priority)**
Data center developers look for receptive communities – the community at large and the local government agencies. Many developers consider local support a high priority. Anything the community can do to reduce development risk and cost and expedite the project will demonstrate that support and help facilitate the project(s). See Planning and environmental concerns below.

c) Planning and environmental concerns minimal (e.g., approvals have been obtained) **(high priority)**
Ideally planning and environmental concerns should be minimal, i.e., pre-approvals are in hand (e.g., zoning, clear land ownership free of leans, water rights, permits for emergency generation). Outstanding issues such as wetlands, contamination, and protected species can be showstoppers. Water rights and permitting for consumption is

a common issue but can be mitigated if mine water use is feasible and approved. Local requirements (e.g., who can tap in and for how much) must be resolved. Jurisdictions treat water rights differently even when the user is not removing water (e.g., returning it to the mine or aquifer). Land often does not come with water and mineral rights, but data center developers do not want someone else to have the rights that could impact the site. While some of these concerns may be showstoppers for short and midterm project development, land developers noted they would just need to "lawyer up."

d) Due diligence studies have been completed **(high priority)**
If studies are done, then there is less risk. Some communities have sponsored such studies to fast-track projects, such as characterizing the mine water resource, identifying the location of supply and return wells, and more. Air quality is a concern – both gaseous contaminants that can corrode electronics and dust (which is less important if the data center is liquid cooled).

e) Infrastructure in place
While existing infrastructure is a plus, its size, age, and capacity are issues. Use of existing infrastructure factors into the project's implementation time frame and capital cost. Fast implementation is appealing especially for developers with short time horizons (e.g., colos with a customer ready to move), while building infrastructure is "part of the job" for land developers and others with longer time horizons. Power and high-speed dedicated internet access are the most important infrastructure needs, and are covered separately below. Other infrastructure needs include roads (usually not an issue), and water (perhaps not an issue if mine water quality and availability are proven).

f) Access
Good access to data centers is desired for employees, first responders, and customers. Developers suggested that the data center site needs to be no more than 1 to 2 hours from a small city/metro area, and no more than 1 to 2.5 hours from an airport. It was noted that the commute is likely against the normal traffic.

g) Customer interest (colos)
Colo investors want to make sure there will be (or better, are) customers, and customers want to make sure a colo project is certain and will be completed on schedule. If the data center is near a Tier 1 hub (large metro market), then identifying a customer is less important, however mine land is generally not found near these cities. The first customer is the hardest to attract; once the first customer is committed, it is easier to attract others.

2. Power **(high priority)**

Available nearby electrical transmission capacity is very important. Hundreds of megawatts or even gigawatts are needed. Data center developers can build new substations, but the transmission capacity needs to be available. Typical projects can max out at 200–300 MW, while larger multiphase campus projects can be much more. A rule of thumb was suggested that 3+ GW of power is needed 5–10 miles from the project, developable within two to three years (for rapid access). Other power attributes, including cost, reliability, and renewable sourcing are covered later.

3. Dedicated Internet Access **(high priority)**

Dedicated internet access is provided to data centers via high bandwidth fiber networks. Long-haul optical fiber networks connect cities and countries throughout the world. Capacity, latency, and reliability are all important. Generally, redundancy and reserved capacity is needed. Access should come from at least two directions/routes and be provided by multiple carriers – with more carriers better (e.g., two is minimum, and four or more is better, especially for colos). Fiber is often shared among carriers and given the requirement for multiple carriers; they often have networks serving the same markets. Suggested rules of thumb include the following:

- A high-speed long-haul network with dark fiber (unused) capacity is needed less than 100 miles from site. Closer is better (e.g., 40–50 miles to major connections were mentioned), and the feasible distance depends on the ease of laying the cable/fiber.
- One expert suggested ~1 billion of bits per second (GBPS)/server. Assuming server power of ~1 kW, then the rough bandwidth required is 1 trillion bits per second (TBPS) per MW.
- Ideally, latency to each coast should be less than 20 milliseconds.
- 100 G is desirable, but high traffic networks are now migrating to 400 G.
- Long-haul fiber (generally required for large data centers), are spliced every 50–60 miles, often in a data center. In some cases, a data center may be located very close to a fiber line but needs to run its own fiber to a splice point.
- There are also medium-haul networks, and in metro areas there will be denser local or metro networks.
- Interstate highways often have fiber networks running alongside them.
- Transcontinental cable landings are hard to replicate, therefore data center hubs are often built around them. This explains why most internet traffic passes through northern Virginia and results in the highest density of data centers nationwide.

See Figure 4-11 for the network map from a major carrier. As noted above, multiple carriers typically serve the same markets. Tools are available from the carriers and consultants for analyzing fiber networks at specific locations. This should be an early step in the assessment process. Note however that not all data centers require high bandwidth. For example, crypto currency mining can be done with lower bandwidths. If adequate fiber capacity is not available, carriers may be willing to bring it in if the market is deemed large enough. There may be opportunities for partnering, including public/private partnerships for such development. High-capacity fiber networks may bring other opportunities to coal communities to attract organizations such as hospitals, schools, and large businesses, including multi-tenant offices, that need dedicated internet access.

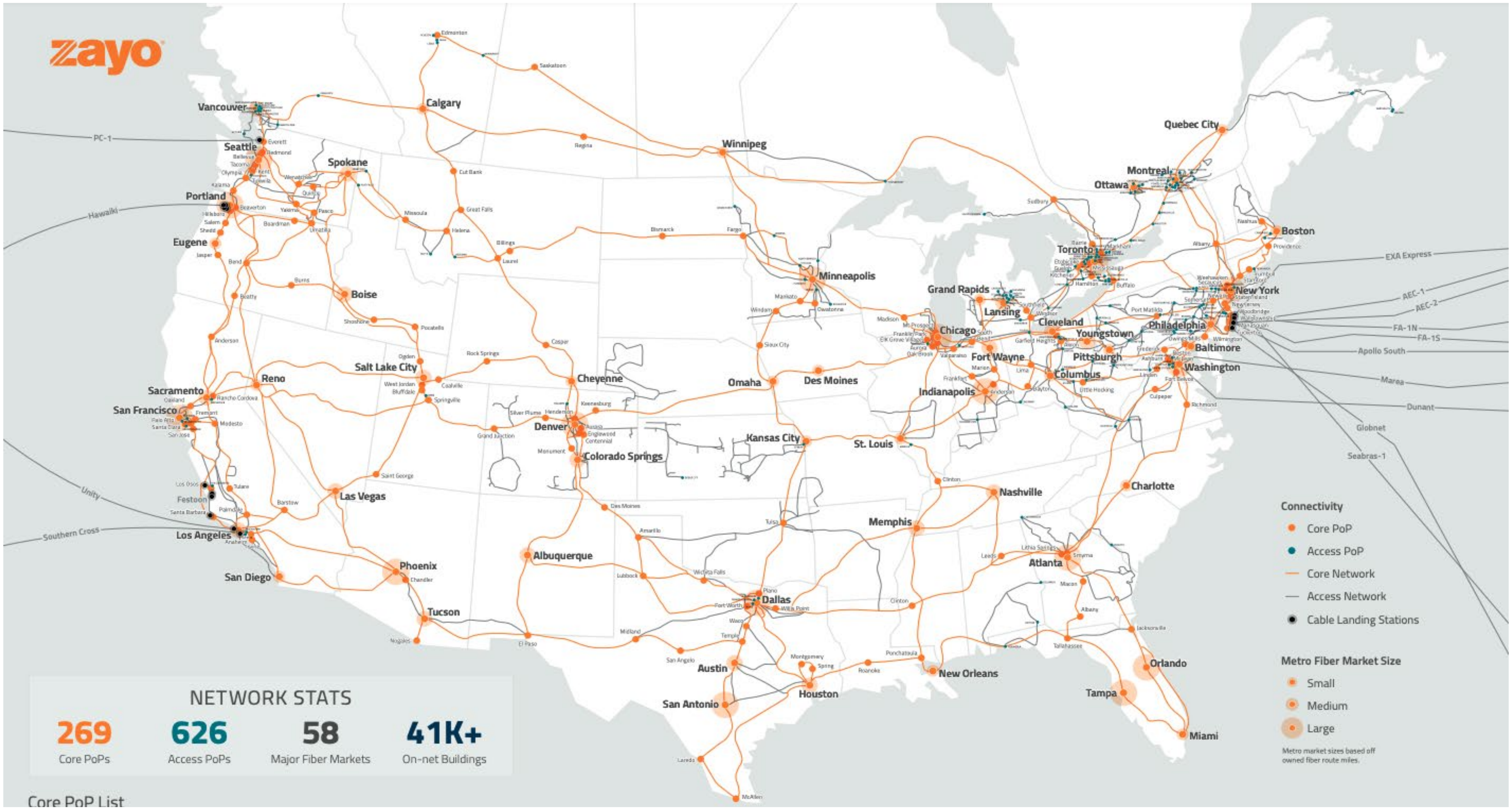


Figure 4-11. TYPICAL FIBER NETWORK MAP FROM A LONG-HAUL CARRIER

Source: Zayo. n.d. Expansive, Global Network Capabilities. https://www.zayo.com/network/

4. Secure: Low risks during operation **(high priority)**

While many of the readiness factors described above mitigate the risks for developing a data center project, risks in this section focus on physical risks or risks associated with the infrastructure during operation.

a) Power reliability **(high priority)**
Most data centers require highly reliable power. For that reason, they often need two diverse feeds from two substations. Both sources of power must be reliable and come to the site via different routes. Further, grid supplied power is typically backed up with on-site generation and fuel storage. Data centers typically must be able to island power and be self-sufficient for days at a time. The co-development of renewable energy power generation, on-site energy storage, and a microgrid configuration are elements that will likely be attractive to data center developers to increase their power reliability and resiliency. Such systems may be trade-offs for components in a conventional configuration. Significant capital costs can be spent on back-up systems that are undesirable to operate (expensive and polluting). Despite the availability of uninterruptible power supplies (UPSs) and on-site generators (generally diesel), developers will be interested in the number and duration of annual outages at the specific data center location. They also will want a strong maintenance program (e.g., tree removal) of transmission and distribution systems serving the data center(s). A growing number of data centers take advantage of redundancy in their IT network rather than overly redundant infrastructure onsite, but power reliability remains a high priority.

b) Safe from natural disasters (e.g., floods, earthquakes) and human-made threats **(high priority)**
Threats, including those from natural disasters, can be mitigated, but at a cost. Given options, data center developers will avoid such threats; for example, not locating in a flood zone, or even a flight pattern. Several experts noted the criterion is nuanced, with some threats being showstoppers while others can be managed. The remote nature of mine land will likely facilitate protection from human-made threats. But the response time for other threats may be a challenge. Good reliable access (e.g., roads) is needed for critical employees and emergency responders.

5. Low total cost of ownership (TCO) **(high priority)**

The bottom line is the TCO. Many of the criteria described above relate to cost, e.g., the cost of mitigating a risk or providing infrastructure that does not already exist. There will be trade-offs between various capital costs as well as between capital costs and operating costs. TCO will be a major driver in the location selection.

a) Electricity **(high priority)**
The capital cost of electric infrastructure as well as the operating cost of energy are major TCO drivers. Data center developers expect to build new substations and other electric infrastructure. They will give preference for locations with low-cost, reliable, clean, and plentiful electricity. They will pay a premium for long-term renewable power

to stabilize their operating costs. And many data center developers are committing to renewable energy (zero carbon) for environmental reasons, and in some cases, it is the lowest cost option. As one expert put it "it is becoming more essential." Further it was reported that a growing number of players are committing to 24/7 renewables, making storage even more valuable. The renewable energy typically needs to be from local sources – at least on the same grid. Mine land offers the opportunity to develop renewable power options "onsite" and integrate it into a microgrid with energy storage options. This integrated approach creates an attractive premium package for data center developers.

b) Incentives and policies to mitigate risks and/or costs, and encourage development (high **priority)**
Local/state tax incentives (e.g., sales, property, and income tax), utility rebates and demand response programs, and grants (e.g., Austin, Texas[162,163]) can reduce TCO. Expedited approvals and permitting can reduce risks and costs. And coal communities can partner in other ways to encourage successful development. Other incentives can include amenities (access, housing, parks, schools) and infrastructure (utilities, roads, airports). Disincentive can be even more critical; for example, a digital advertising tax can be detrimental to some data center applications. More details on incentives and public policies to attract data center development are covered in the next section.

c) "Free" cooling
Cooling is often the second highest energy consumer in a data center (second to the IT equipment). Tapping the relatively cool and constant temperature mine water for data center cooling offers an opportunity to dramatically reduce costs. Some developers may require a redundant conventional cooling system, but it is possible to reduce capital cost as well as operating cost by using mine water cooling. Experts reported "free cooling potential is important to customers."

d) Cost of labor
The cost of labor plays a role in TCO (both in the construction and operations phases). Rural coal communities may have lower-cost labor due to the lower cost of living; however, the unavailability of skilled workers or travel time may drive the price up.

6. Renewable energy

As discussed above, the data center industry typically wants renewable energy. Few data centers have onsite renewable power generation, as the loads are so large, but the data center industry is the biggest purchaser of renewable energy in the U.S. generally via power purchase agreements (PPAs). Many data centers require their renewable power generation to be on the same grid. But given the space likely available on mine land, locally produced power at a reasonable fixed price would be very attractive. Since a growing number of IT companies are committing to renewable energy 24/7, local energy storage would be another big plus.

7. Mine water or other free cooling

   As noted above, being able to utilize the cool and constant-temperature mine water for data center cooling could provide a competitive advantage. Issues that must be addressed in assessing this potential include: water rights, contamination, and water volume and refresh rate (to avoid heating the mine water to the point where it is less useful). If mine water is not available, other "free" sources of cooling should be pursued, such as using outside air (in which case air quality is even more important). See the discussion under Low TCO (#5 above) and Planning and Environmental Concerns (#1c above).

8. Structurally sound building site

   It was reported by experts that one of the first studies would be to find buildable sites (geo/tech study). Typical problems are solvable, but can be costly. Unique issues would include contamination (pad site versus risks over the entire site) and unstable conditions due to underground construction and/or fill. Perception issues (fear) surrounding land stability around mines could also play a role. Data centers are heavy buildings, and there may be concerns regarding ground stability after land restoration (e.g., fill to the original grade). The potential for sinkholes could be a showstopper. Developers would likely avoid sites with structural problems.

9. Simple and clear ownership

   Land, mineral, and water rights are issues that need to be addressed, especially if they can affect the schedule or budget. Outstanding liens can be an issue. While a data center does not utilize mineral rights as a business, developers do not want someone else having the rights that could impact the site. Ideally mineral rights are obtained for more control and to reduce risk. Some developers require clarity going in, while others (e.g., longer term land developers) would "lawyer up" if the site is otherwise attractive. Also see the discussion under Readiness (#1 above).

10. Infrastructure in place

    The extent and condition of existing infrastructure can affect schedule and budget. Power and fiber networks are the two most important infrastructure components that must be existing or developable quickly (one to two years). The issues of time are likely more important than cost. A number of infrastructure improvements are or can be the responsibility of the municipality. The community's ability to act quickly will be an issue. Data center developers expect to do some level of infrastructure development, and that will factor into their evaluation of TCO. Land developers see infrastructure as part of their business, while other data center developers will want the site ready in a matter of months rather than years. The more infrastructure in place and in good condition, the more attractive the location will be. See Readiness for development (#1 above).

11. Proximity to skilled workforce and availability of job training programs

    Finding and retaining qualified employees is a challenge for data centers, but it is generally considered solvable. The construction of data centers involves the employment of many tradespeople, while the operation involves facility operations and maintenance personnel as well as IT technicians (e.g., server administration and network technicians). Often data centers are developed in clusters on large campuses or industrial parks. In these cases, construction can span many years. Facility trades such as mechanical, electrical and plumbing (MEP) are in greatest demand. It was noted that there are likely good opportunities for transferring skills from the trades supporting mining operations (e.g., electrical and mechanical technicians) to the new data centers. Mitigating factors in attracting workers to coal communities include a potential low cost of living, and the likelihood that coal mine land would be a reverse (easy) commute. It was suggested that the data center should be no further than 1 or 2 hours from a metropolis or small suburb/town (e.g., 50,000 population). This is for both employee recruitment as well as access by clients, contractors, and service providers. Several data center developers noted the need for the surrounding community to be a pleasant place to live to attract and retain skilled workers. They suggested, “a nice place to raise a family,” and “the data center should be an appealing place to work.” As previously mentioned, several developers noted the importance of proximity to an airport (1–2.5 hours). There are numerous successful data centers located up to two hours away from a metropolis.

Several industry experts noted that training for data center staff (facilities and IT technicians) can often be accomplished in a two-year community college program (versus IT professionals who can work remote from the data center). Some community college programs offer data center technician-specific training. Northern Virginia has pioneered data center job training (a two-year degree). And in some cases, data center owners partner with community colleges to ensure a pipeline of qualified labor. For example, TJ Ciccone, the Vice President of Critical Operations for STACK Infrastructure is active in such training.[164] Availability of qualified staff and training programs in a community, or a willingness to develop such programs, would be a plus for data center developers. Other potential training programs include union training or retraining programs, as well as military veteran’s programs. It was reported that veterans offer good diversity and they are “process and procedures oriented” (important to the operation of mission critical data centers). Communities anxious to attract data centers should inventory such resources.

12. Demonstration of concept

The concept of using mine land for a data center development has not been demonstrated, and there is some fear of being first. Given that many data centers are “critical facilities” the industry is conservative, and there is fear of unknown unknowns. However, there were differences of opinion on this concern, depending on the type of the company (e.g., colo versus owner/occupied) and their risk tolerances. Some needed certainties of the feasibility but were not afraid of being first (“not a problem if all other factors are positive/resolved”).

13. Proximity to peers (hub or campus)

    Proximity to peers was another criterion with mixed responses. It was pointed out that some of the largest hyperscalers are located remotely (100–200 miles away) from others. And size is a factor with the benefit of proximity to peers higher for smaller data centers. It was noted that being located in a regional hub/community/campus with other data centers offers advantages; for example, ease of staffing and the ability to attract long-haul fiber network carriers. Once there is an anchor or first data center, it is also easier to attract others. They may benefit from infrastructure (e.g., fiber) developed for the first.

4.6.2 Additional input

Besides addressing site selection criteria, a number of general questions were discussed with the industry experts. Excerpts from their responses follow:

1. What do you see as the concepts most compelling attributes?

   Land/infrastructure reuse; green local power; energy storage associated with renewable energy and arbitrage; free cooling of the data center; waste heat reuse.

2. What are your greatest concerns with the concept, what barriers do you envision?

   Development costs; initial resistance to new ideas; latency considerations (location-specific).

3. Have you considered such a project or are you aware of examples of data center development in mines or on mine land?

   No. However, there is openness to consider, especially locations not too far from existing Tier 1 node campuses. Tier 1 are the largest metro markets. For example, if we can find a site in West Virginia (which is not far from Ashburn, Virginia), it is likely that we can start a discussion. (This was from the perspective of a colo provider).

4. What benefits do data centers bring to the community (for example, high speed Internet access, use of waste heat and other synergistic development, etc.)?

   All that you mention. Lower cost green sites can primarily target large capacity backend compute needs with less emphasis on latency – this can help attract new data centers away from more populated urban areas. Local employment and training opportunities could benefit. Target compute intensive applications that don't have back and forth traffic e.g., AI training. Financial customers may be good targets (data processing). Local communities benefit with millions of dollars in taxes (even those that provide tax concessions), and data centers are a low burden on local community services. It was reported that they are the highest or close to highest taxpayers in some communities.

In one example, property tax revenues went up ten times in three to four years of data center development.

While it was reported that local governments like fiber availability and several industry experts felt local communities could benefit from new fiber bandwidth brought in for data center development, one did not, so this is an area needing greater analysis on a case-by-case basis. It likely depends on who is paying for the fiber, and what their business relationships are. Carriers often share fiber capacity with each other, opening up access to others.

5. What additional information/tools/technology do you feel is needed/desirable to facilitate moving forward?

   Schematic designs; reasonably accurate cost estimates; partnership plans; funding mechanisms; high-capacity fiber connectivity; turnkey capabilities of design/build teams; transportation enhancements including air transport, etc., will all help. Of course, good incentives for the first few instances!

   Also mentioned was facilitating partnerships (bringing stakeholders together). Assistance in setting up consortia for various connected interests such as data centers, investors (e.g., pension funds), utilities, green power producers, energy storage providers, etc. would be great to fully exploit the possible synergies.

4.7 Attracting data centers to coal communities

Communities have numerous opportunities to mitigate risks and/or reduce development costs to encourage data center development. Ideally each of the location criteria described above can be addressed, but it will be especially important for the community to address the highest priorities:

1. Readiness for development.
2. Ample, reliable, and low-cost electricity, and availability of renewable energy.
3. Dedicated internet access (fiber networks).
4. Safe from natural disasters (e.g., floods, earthquakes) and human-made threats.
5. Low total cost of ownership (capital plus operating costs).

Measures that local communities, regions, and states can take to attract data center development are included in Chapter 5 which describes incentives and public policies attractive to data center development.

5. Government Incentives, Policies, and Programs

5.1 Federal actions

The federal government is taking action to help communities in the transition from fossil fuels. These include:

1. Policy, institutional, and funding support
2. Tax credits
3. Technical and workforce training

5.1.1 Policy, institutional, and funding support

Executive Order 14008 was issued by the Biden-Harris administration. It calls for federal leadership in fostering economic revitalization of and investment in hard-hit energy communities and turning them into healthy, thriving communities as the nation transitions to a clean energy economy. The Order requires the federal government to initiate projects that reduce emissions of toxic substances and greenhouse gases from existing and abandoned fossil energy infrastructure, that:

- prevent environmental damage from harming communities,
- plug leaks in oil and gas wells and reclaim abandoned mine land, and
- turn properties idled in these communities into new hubs for economic growth.

The Biden-Harris administration also has created the Interagency Working Group on Coal and Power Plant Communities and Economic Revitalization to develop strategies and coordinate the identification and delivery of federal resources for revitalizing fossil-energy communities and supporting affected workers.[165] Repurposing of fossil energy assets is one of the opportunities that the Working Group promotes for the energy community. As part of the implementation of bipartisan infrastructure laws, the federal government launched a $450 million funding program to support the transformation of mine lands into new clean energy hubs.

In addition, the U.S. Economic Development Administration (EDA) has a Coal Communities Revitalization Initiative, which provides funding to support economic diversification and revitalization efforts in communities affected by the decline of the coal industry. This initiative includes funding opportunities for infrastructure development, workforce training, and business development.

Incentives and assistance to redevelop mine land for renewably powered data centers can come from the federal government as well. Many of the industry experts consulted are from multinational companies, and it was noted that the European Union provides grants up to $2.5 million for the use of Euro technologies. It was also suggested that proof of concept demonstrations should be funded at the national level.

5.1.2 Tax credit support

The New Markets Tax Credit (NMTC) program is a federal tax incentive that encourages private investment to revitalize underserved communities and promote economic opportunity for businesses and individuals in these areas. As of the end of Fiscal Year 2021, the NMTC Program has been successful in driving community development and economic growth through the use of tax credits to attract private investment to distressed communities. The program has demonstrated impressive outcomes, including generating $8 of private investment for every $1 of federal funding, creating nearly 239 million ft^2 of manufacturing, office, and retail space, and financing over 10,800 businesses.[166]

In 2022, the Inflation Reduction Act (IRA) passed provisions for a 30% tax credit for wind, solar, and other green energy projects. Additionally, the IRA provides an extra 10% bonus tax credit for investments made in designated "energy communities." To qualify, the area must meet specific criteria, including having or recently having at least 0.17% direct employment, or at least 25% local tax revenues related to the extraction, processing, transport, or storage of coal, oil, or natural gas. The community must also have an unemployment rate at or above the national average unemployment rate for the previous year.

5.1.3 Technical and workforce training support

The Partnerships for Opportunity and Workforce and Economic Revitalization (POWER) Initiative is a multi-agency effort led by the Appalachian Regional Commission (ARC) and the U.S. Economic Development Administration (EDA) that aims to invest in coal-impacted communities and support economic diversification. The POWER Initiative provides funding for projects that promote workforce training, entrepreneurial development, and technical assistance to help coal communities transition to new industries.

The DOE Industrial Efficiency and Decarbonization Office provides technical assistance and develops partnerships with industry to supports workforce training that prepares existing workers to future industrial jobs. The office's efforts focus specifically on increasing the adoption of energy efficient practices, decarbonization technologies, energy management programs, and water and waste reduction strategies across the industrial sector. The program also has a specific focus around industrial facilities and other large energy users to increase the adoption of onsite clean energy technologies. With the expected growth in data center infrastructure, workforce training around implementing and operating the next generation of efficient data centers paired with renewable electricity in existing coal communities in an area of growing opportunity for the office.

The Labor Department's implementation of the Workforce Innovation and Opportunity Act (WIOA) provides funding for workforce development programs that can be tailored to meet the specific needs of coal communities. The DOL also offers apprenticeship programs, on-the-job training, and other initiatives to help individuals in coal communities acquire new skills and find employment in emerging industries.

5.1.4 Other federal policy opportunities

Additional potential federal actions include the following:

- Consider adjusting reclamation procedures under SMCRA to allow land topography not to be restored to original conditions if it is more advantageous to contour land for optimum renewable and energy storage projects.
- Develop demonstration projects under the IRA to showcase viable energy alternatives and economic diversification models.
- Develop transition implementation pathways and provide technical support:
    - Enhance cross-industry exchanges with data center, coal, and clean energy industries, as well as coal communities.
    - Conduct technical exchanges between national labs, universities, and industry stakeholders to share emerging technologies and applications and understand industries' technical challenges and needs.
    - Conduct in-depth techno-economic analysis to assess adopting various clean energy technologies and economic diversification models and quantify job and economic development benefits and justice gains of different pathways.
    - Carry out collaborative R&D and provide technical and economic assistance for adopting recommended pathways.
    - Promote workforce readiness training on information technology and clean energy
- Consider tax credits, IRA funding, or loans to encourage integrated data center developments on mine land.
- IT Networks: Encourage and invest in expanding high speed dedicated internet access to coal communities with high-speed fiber networks to ensure all communities have access to fast, reliable, and affordable connectivity for data centers and other uses. This will increase the appeal of coal communities as a location for data centers and attract more investment to these locations.

Relative to the action on IT networks, the federal efforts to promote an equitable energy transition can be integrated with the promotion of internet access in economically stagnant areas so the infrastructure needs to build a digital economy can be met. Such integration will not only help expand internet access to distressed coal communities, but can also provide the infrastructure needed for the expansion of the data center industry to coal communities. Expanding internet access infrastructure to coal regions could promote data center hubs, promoting the transformation of the coal-reliant region from a coal economy to a new digital economy.

5.2 Local Incentives and public policies to encourage data center development

Communities have numerous opportunities to mitigate risks and/or reduce development costs to encourage data center development. As noted under location selection criteria, incentives offered by state and local governments can play a significant role and may include:

- Sales tax incentives
- Property (land and IT equipment) tax incentives
- Income tax incentives
- Grants
- Infrastructure development (e.g., internet access, power, roads)
- Completed due diligence studies
- Expedited approvals or pre-approvals including development zones
- Job training programs
- Other opportunities, including facilitating partnerships and marketing.

5.2.1 Local/regional financial incentives

Data center developers expand to where they get the best deals, and the industry experts generally agreed that tax (and other) incentives influence their location decisions. Offsets to capital costs are generally considered most desirable. IT equipment and its corresponding sales tax is a significant expense and occurs initially and with every refresh (every three to five years). Therefore, sales tax breaks are considered desirable. For example, Wyoming has a popular sales tax incentive. In some cases, the data center developer will not be buying the IT equipment (e.g., land developers and colos); however, several experts noted the marketing benefits of sales and property tax relief in attracting tenants/customers. According to one expert, while sales and property tax incentives are important, income tax is playing a growing role, and states like Nevada that do not have an income tax are at an advantage. The absence of taxes or low taxes can substitute for special tax incentives; for example, Oregon does not have a sales tax. Conversely, abnormally high taxes, e.g., property taxes in Texas, or special/unique taxes such new digital advertising taxes,[167] can have the opposite effect (a disincentive to developing data centers). The wrong policies can be detrimental. All taxes and tax incentives go into the project's economic evaluation (TCO/net present value [NPV]/ internal rate of return [IRR]), which drives many decisions. For land and colo developers, incentives can help attract customers. These incentives would include: lower rent/operating cost as well as lower taxes (e.g., sales, equipment property, and income taxes).

There is a wide range of state incentives offered to encourage data center development. The Montrose Group compiled a summary of state incentives for data center development and concluded[168] few industries are as sensitive to tax policy and incentives as data centers. According to Montrose, data centers pay substantial sales and property taxes. There are 11 states that automatically do not assess property taxes on equipment and furniture. These states include Delaware, Illinois, Iowa, Kansas, Minnesota, New Jersey, New York, North Dakota, Ohio, Pennsylvania, and South Dakota. Nineteen states offer some form of property tax abatements data centers can attempt to gain. Sales tax is another substantial cost center for both the operation and construction of data centers, and many states offer aggressive economic development incentives to address their high sales tax costs, which often provide revenue for local and state governments. Texas and Florida's very high sales and property tax illustrates the downside of not having a state or local income tax. This sales and property tax burden highlights the need for data center economic development incentives.

Some communities establish special economic or enterprise zones to attract businesses. These zones can offer tax incentives such as reductions or exemptions on local taxes, and can offer other incentives including infrastructure covered in the next section. There may be a potential for tax free municipal bond financing of needed infrastructure, such as using Industrial Revenue Bonds.[169] Other communities such as Austin, Texas are offering grants to incentivize development.[170,171]

While the use of tax and other financial incentives reduces the benefits of data center development to the local community at least in the short run, numerous industry experts noted the additional tax revenues to the local jurisdictions are substantial, and the level of services provided by the municipality is relatively low. A key question is whether or not the data center development or other business development would happen anyway in the absence of the incentives. The net benefit needs to be evaluated and confirmed independently. Competition between communities to attract data centers has created situations where they have been in “bidding wars” with each other.[172] This has led to some agreements among jurisdictions to set more uniform policies and incentives. For example, five Southwest Virginia localities agreed to lower the tax on data center equipment in their region.[173]

5.2.2 Other local actions to encourage data center development

Besides the direct financial and tax incentives, communities can offer other incentives for development. The data center industry experts interviewed agreed that local community support, both from the public and within the local governments, is very important. Anything the community can do to reduce risks and expedite projects will be seen as positive. This can include:

Infrastructure development: If needed infrastructure such as internet access, power and other utilities, and roads are in place, project development will be faster and the risk reduced. Establishing needed rights-of-way for utilities such as dedicated internet access, distribution of waste heat, and access to mine water for cooling will help reduce the risk, time, and cost to potential developers.

Complete due diligence studies: Studies and permitting can take significant time and resources and represent risks to the developer. Several industry experts indicated that planning and approval processes that take over a year or two are a problem. Developers must complete many due diligence studies before a project can move forward. Each represents a risk. Therefore, communities and redevelopment organizations that have done at least some of the groundwork will make the location more attractive. These studies could include assessments of existing and needed infrastructure; assessments (and mitigation studies) of hazards such as flood, seismic, and other natural disasters; environmental impact studies; and mine water use feasibility (including well placement, design, and sizing).

Expedited approvals and development zones: Communities that have expedited development approval processes and/or have pre-approvals, and/or special development zones already in place will be considered favorable by developers.

> Processes that facilitate zoning, planning, permitting, architectural/design review, environmental studies, environmental impact reports, and other approvals will be attractive. Rezoning and other approvals can affect schedule and budget. Project approval is needed within months, not years, according to some industry experts.

Very large hyperscalers and land developers have longer planning time horizons (up to 10 years), but they are still interested in community support and the ability to move projects forward quickly with low risks once a decision has been made to do so.

Besides government incentives and policies, the utility company can play a major role in attracting or deterring data center development. Available, reliable, and low-cost power are important site selection criteria. But developers were also interested in the availability of renewable energy and energy efficiency programs (e.g., rebates), and to a lesser degree demand response programs. There is a trend in the IT industry towards a 24/7 commitment to zero carbon, thus increasing interest in energy storage and demand management. While utility companies can be a great project partner helping to meet the project demands, some are not supportive of interconnecting customer-provided renewable energy and/or microgrids that may only infrequently utilize the utility's grid and other resources.

Also mentioned by industry experts is the need to facilitate partnerships (bringing stakeholders together). This could be done at the local, state, or national level. Assistance in setting up consortia for various connected interests such as data centers, investors (e.g., pension funds), utilities, green power producers, energy storage providers, and others would be great to fully exploit the possible synergies.

Data centers will also be attracted to communities that are nice to be in and provide good amenities for their employees. These amenities can include: easy access, housing, shopping, restaurants, parks, schools, and other infrastructure. An attractive community to live and work in will help data centers recruit the workforce they need.

Growth in the data center industry has spurred concerns relative to maintaining an adequately trained workforce. See the "Proximity to Skilled Workforce and Availability of Job Training Programs" section above. This concern is heightened with data centers located away from metro areas. For coal communities this may be a barrier to attracting data center development, but it can also be an opportunity for training or retraining local workers for the digital economy. Many of the jobs associated with data centers arise during the construction phase and involve the trades—some of the same trades required for mines. For example, several industry experts specifically mentioned the need for electricians. During data center operations there is a continued need for facility tradespeople, such as electrical and mechanical technicians, as well as IT technicians (e.g., server and network technicians). Communities can partner with others to offer the training the industry needs. The following ideas were offered by industry experts:

- Union training programs
- Community colleges (two-year programs were mentioned by several industry experts)

- Veterans' programs
- Data center developers themselves (and their staff) often participate in training programs

Availability of qualified staff and training programs in a community, or a willingness to develop such programs, would be a plus for data center developers.

Other opportunities to encourage data center development can include the following:

- Public-private partnerships: Build public-private partnerships between local governments, data center operators, and other stakeholders through joint investment, resource sharing, and other collaborative efforts.
- Marketing: Develop promotional campaigns to showcase the advantages of locating data centers in coal communities, such as the availability of affordable land, existing infrastructure, free cooling, available renewable energy, and a skilled workforce (as appropriate). For example, Project Oasis is marketing itself as a data center location of choice in Southwest Virginia based on power and broadband infrastructure, along with the use of geothermal cooling technology using water collected in underground mines as a significant energy and cost-savings tool.[174]

6. Conclusions and Recommendations

6.1 Conclusions

6.1.1 The Challenge

Reclaimed coal mine sites offer a variety of opportunities for energy decarbonization and community economic vitality in former mining communities. In 2020, U.S. coal production was at its lowest level since 1965, and coal consumption continues to shrink, as do mining jobs.

Coal industry employment is on a clear downward trend; falling by more than half in a decade. Workers with skills in other industries are less likely to be negatively affected by this transition, but the livelihoods of extraction workers, who account for 37% of the total coal mining employment, are at risk. Without local economic development and the creation of new jobs in coal communities, these workers will need to relocate, disrupting communities and hindering local prosperity.

The four states with the most coal mine closures over the past decade were Kentucky, West Virginia, Pennsylvania, and Virginia. Combined, these four states accounted for 77% of all mine closures nationwide. As coal demand declines and the industry faces economic pressures, less-efficient, lower-productivity mines can expect more rapid closures. Policy makers should pay close attention to ensuring a just transition for such states, particularly those in already disadvantaged communities in the Appalachian and Interior basins.

In 2020, 98% of coal mine output was produced in 14 states.[1] Currently, most active mines (350 out of 546) are surface mines; however, underground mines employ approximately 50% more workers in the U.S.

6.1.2 Repurposing Coal Mines

Reclamation and repurposing of closed mines offers development opportunities. The Surface Mining Control and Reclamation Act (SMCRA) of 1977 addresses reclamation of mine lands. There are three phases of reclamation under SMCRA: backfill and grading, revegetation, and full reclamation. Fifteen years of available data shows that 772,266 acres have completed all three phases. Kentucky, West Virginia, Indiana, Pennsylvania, and Illinois have completed the most acres of Phase 3 reclamation requirements. Together they account for nearly two-thirds of the national total. A significant amount of additional land is currently in the reclamation process.

SMCRA requires permits for active mines, and in 2018 there was close to 4.3 million acres permitted, with about 10% of that on leased federal land. Five states—Kentucky, Wyoming, West Virginia, Pennsylvania, and Texas—account for 72% of the permitted acres.

[1] Alabama, Colorado, Illinois, Indiana, Kentucky, Montana, New Mexico, North Dakota, Pennsylvania, Texas, Utah, Virginia, West Virginia, and Wyoming.

Land abandoned prior to 1977 adds another million acres of mine land, of which approximately one-third has been reclaimed under the SMCRA's AML program. The AML program allows states and tribes to use collected fees to eliminate environmental, public health, and safety hazards posed by past mining activities.

In total, there appears to be about 7 million acres of coal mine land, either abandoned, being reclaimed, reclaimed, or active. Reclaimed land that has been cleaned up and restored to meet SMCRA's environmental and safety requirements can be repurposed and developed for a variety of purposes.

This study targeted renewably powered data centers for repurposing mine land. Coal communities can often offer data centers the benefits of land, power infrastructure, mine water cooling, and low electricity rates. The top five coal-producing states offer some of the lowest average retail electricity prices in the country. Conversely, data center and renewable development offers jobs both during and after the mine reclamation and construction processes. Additional impacts may include: diversification of the local economy, electric grid improvements, energy efficiency improvements, and increased internet access. Tax revenues from the development can further benefit local communities.

Mine water can provide highly efficient cooling for industries such as data centers—where cooling is typically those facilities' second largest energy load—saving energy and alleviating the need to use local potable water supplies. While water quality and contamination must be addressed when using mine water for cooling, these factors can be managed.

In many mine locations, the magnitude of power capacity is a good fit for data center power needs. Many have large-scale power supply and transmission systems, and this infrastructure could be repurposed to support the transition to a post-coal economy.

Initiatives such as the Biden administration's $500 million plan to convert mine lands into new clean energy hubs can help open potential opportunities to repurpose coal assets to develop energy systems that do not rely on fossil fuels and develop post-coal economies in energy communities. Information on land utilization after mine closures in the U.S. shows most of the reclaimed land currently is relatively unproductive, so opportunities abound.

6.1.3 Renewable Energy

Renewable energy projects require significant land resources, and there is growing concern regarding potential conflicts; for example, taking up prime agricultural or forest land. Coal mine lands offer large tracts of low conflict developable land that can be used for renewable energy facilities. Developing renewable energy has the potential to create jobs and provide local investment while tackling climate change. Mapping tools can aid in the identification of low-conflict sites for wind and solar development, reducing the likelihood of social, land management, and ecological conflicts that may arise during renewable energy project siting.

The EPA, through its RE-Powering America's Land program, runs a database that tracks hundreds of projects in the United States that installed renewable energy systems on current and formerly contaminated lands, landfills, and mine sites. Through this initiative, EPA tracks 417 installations in 45 states and territories with a combined capacity of 1.8 gigawatts (GW). From these tracked projects, a small number have been developed using both former coal mine and coal-fired power plant sites.

Some states in particular offer promising repurposing opportunities for renewable energy development on mining sites:

- Colorado, Illinois, Indiana, Montana, New Mexico, North Dakota, Texas, and Wyoming have superior wind energy resources.
- Colorado, New Mexico, Texas, and Utah have superior solar energy resources.
- Some coal states already have a track record of using renewable energy, with significant percentages of renewable energy contributing to their total energy mix: Colorado (34%), Illinois (13%), Indiana (11%), Montana (15%), New Mexico (41%), North Dakota (37%), Texas (27%), Utah (13%), and Wyoming (24%).
- Although Kentucky, West Virginia, and Pennsylvania have large amounts of coal mining land, the wind and solar resources are no more than average, and these states so far have a low percentage of power consumption coming from renewable energy (1%–3%). Likewise, Alabama has under 3% renewable power.

6.1.4 Energy Storage

Retired coal sites also can be repurposed to develop energy storage systems. Abandoned coal mines in different U.S. regions have different geological structures and asset characteristics, which present a variety of opportunities for the adoption of energy storage solutions. This includes pumped hydro energy storage (PHES), solid gravity energy storage (SGES), and compressed air energy storage (CAES). All of these options can be combined with renewable generation options to address the intermittency of those technologies. Some energy storage technologies have been deployed for many years, while others are in the development and demonstration phase, especially those that might utilize mine shafts or pits. Utilizing coal mine sites and existing power systems can unlock new possibilities for energy storage.

6.1.5 Data Centers

Repurposing abandoned coal sites to support data center expansion could bring benefits to both coal communities and the data center industry, helping to achieve an equitable transition away from reliance on coal while advancing the digital economy in the United States.

Data center development in coal communities will provide economic development, job opportunities, and other local benefits:

- Growth in data centers is creating job opportunities, and there are staffing shortages. The jobs are mostly construction and facilities oriented, although there are some IT jobs, such as server and network technician, at data centers.

- Large data centers involve hundreds of millions of dollars of construction activity, employing thousands of workers. Data centers are often developed in phases, creating construction jobs for years.
- A large operating data center yields tens of millions of dollars of annual economic activity.
- Tax revenue can increase significantly due to data center development. Taxes include property taxes on the equipment and real estate, sales tax on the IT equipment (which is often “refreshed” every few years), and income tax. The burden on municipal services is low.
- Industry representatives report that data center property taxes in small communities can significantly increase tax revenue and municipal services, while the local property tax rate can be reduced (lowering taxes for the existing residents and businesses).
- Many data centers require significant networking capability, involving high speed and high-capacity fiber optic networks. Such networks are often shared in a community. Hence, other enterprises and institutions could share the benefits of the network resources.

The need for data center development is great: more than 1,600 megawatts of new data center capacity were under construction in the first half of 2022, more than double what it was the year before. Moreover, the low vacancy rates in these facilities and increasing need for data centers outside their traditional locations indicates a strong need for new facilities. As noted above, coal facilities have assets valuable to data centers including:

- Inexpensive and relatively secure land
- Power infrastructure and often low-cost electricity
- Stable temperature mine water available for potential “free” cooling (without actually consuming the water)

Data centers on mine sites are already in operation. Iron Mountain currently has two data centers in retired limestone mines and uses mine water as a heat sink for cooling and to reduce water consumption. Other examples of mines used for data centers are the Bluebird Data Center in Springfield, Missouri, and the Lefdal Mine in Norway, which draws on “free cooling” from an adjacent fjord and is supplied with renewable energy. Green Mountain’s SVG1-Rennesøy data center is built in a former underground NATO ammunition storage facility, and is also cooled by an adjacent fjord.

The Project Oasis study, conducted for Southwest Virginia, found the region could become a data center location of choice by using the billions of gallons of water collected in underground mines for cooling to significantly reduce energy and costs and bring modernization and twenty-first century jobs to the region. Also cited in the project study was land availability and geothermal cooling opportunities unique to the region, as well as workforce readiness and development. DP Mineral Gap is the first data center in Southwest Virginia that is supplied with power from an adjacent 3.5 MW solar farm built on an abandoned coal mine.

This study included discussions with 15 data center industry experts from 10 companies to get input on the concept of reusing coal mine land for renewably powered data center development, as well as their data center location criteria. They identified five factors as high priority for this type of development. These are the factors likely to draw a data center to a community:

1. Readiness for development: land reclaimed, infrastructure in place, local support strong, minimal planning and environmental concerns (e.g., approvals have been obtained), and due diligence studies have been completed. Customer interest is also needed for colos, which lease capacity within their data centers to customers that operate their own IT equipment.
2. Power: ample, reliable power capacity from a clean source and at a low price.
3. Dedicated internet access (fiber networks) available (capacity, latency).
4. Secure: safe from natural disasters (e.g., floods, earthquakes), human-made threats.
5. Total cost of ownership (TCO) (capital plus operating costs): TCO relates to many of the selection criteria including local/state incentives (e.g., sales, property, and income tax), and expedited approval/permitting.

Lower, but still important, priorities included: (1) renewable energy resources available, (2) mine water or other "free" cooling, (3) structurally sound building sites, (4) simple, clear land ownership, (5) infrastructure in place, (6) proximity to a skilled workforce and availability of job training programs, (7) demonstrated success of concept, and (8) proximity to peers (a hub or campus).

Policy makers and community organizations (e.g., economic development offices) can use the criteria described to assess their potential ability to attract data center projects, what needs to be put into place, and how best to position redevelopment opportunities relative to the market. Communities have numerous opportunities to mitigate risks and/or reduce development costs to encourage data center development. Ideally each of the location criteria can be addressed, but it will be especially important for communities to address the highest priority criteria.

6.1.6 Synergies and an Integrated Approach

Developing synergistic projects with data centers on mine land will make the undertaking more compelling. Such an integrated approach can include the following:

- Renewable power and energy storage configured into microgrids. The data center industry is perhaps the largest consumer of renewable power, and the opportunity to have such power, with storage, on site will be attractive. A microgrid can provide improved resiliency, and the integrated system can provide "grid services" to improve power reliability in the community.
- While data centers can benefit from the "free cooling" associated with mine water, they also produce heat that can be productively used but is normally wasted. The waste heat could be used for district heating, indoor farming, warm water aquaculture, or other applications of low-grade heat.
- Other "circular economy" opportunities at data center hubs include IT equipment repair, refurbishment, and recycling.

An integrated approach can bolster the economic and environmental benefits for both the data center and the community.

Summary Data

Table 6-1 provides key attributes of the top 14 coal states. Descriptions of each attribute are provided in chapters 2 through 5.

Table 6-1. SUMMARY OF KEY DATA POINTS

State	Production in 2020 (thousand short tons)	% Change since 2010	Number of Mines			Average annual production per mine (thousand short tons)		Capacity Utilization Ratio 2020/2021		Number of Employees		Average Production per Employee Hour (short tons)		Total Acreage Permitted 2018	Land Use Intensity (Acres per thousand short tons) 2018	Acreage of Phase 1 Bond Release Lands	Acreage of Phase 3 Bond Release Lands	% of power produced by renewable energy	Estimated total annual data center energy (2018)* (TWh) *Siddik et al. 2020
			Surface	Under-ground		Surface	Under-ground	Surface	Under-ground	Surface	Under-ground	Surface	Under-ground						
Alabama	12,151	-39	20	6		85	1,742	0.81/0.59	0.75/0.61	384	2,146	1.99	1.96	77,452	5	35,974	46,630	2.7	1.3
Colorado	10,056	-60	3	4		1,283	1,552	0.66/0.81	0.42/0.47	393	725	5.00	4.45	167,079	12	6,609	12,419	33.8	1.1
Illinois	31,578	-5	5	9		399	3,287	0.58/0.33	0.55/0.84	192	1,983	4.31	7.12	80,727	2	66,420	72,320	13.0	3.4
Indiana	19,942	-43	13	5		831	1,829	0.72/0.72	0.49/0.59	953	1,045	5.16	4.08	168,846	5	68,502	80,785	11.4	0.6
Kentucky	20,245	-81	60	37		76	532	0.66/0.64	0.60/0.87	986	3,020	2.26	3.11	1,719,961	43	182,196	178,945	0.7	0.4
Montana	26,422	-41	5	1		4,080	6,023	0.53/0.62	0.55/0.66	844	258	12.89	10.92	7,5219	2	13,912	1,820	14.9	0.1
New Mexico	10,249	-51	2	1		4,502	1,246	0.65/0.77	0.14/0.17	630	202	7.33	2.74	79,782	7	9,142	4,710	40.5	0.5
North Dakota	26,438	-9	5	0		5,288	0	0.77/0.75	-	1,225	0	11.17	-	132,174	4	13,478	15,676	37.2	0.1
Pennsylvania	36,305	-38	99	35		42	918	0.61/0.58	0.89/0.86	1,394	3,424	1.67	4.89	297,629	6	75,043	79,472	2.4	1.4
Texas	19,682	-52	7	0		2,812	0	0.85/0.93	-	1,328	0	7.85	-	320,167	13	50,997	26,020	26.6	7.3
Utah	13,163	-32	1	6		569	2,099	0.28/22	0.67/0.67	57	1,316	3.36	4.37	2,850	0	542	277	12.7	0.7
Virginia	9,685	-57	24	17		104	423	0.38/0.66	0.76/0.95	642	1,452	1.91	2.40	73,761	6	17,398	29,139	9.0	9.3
West Virginia	67,228	-50	68	67		170	831	0.61/0.66	0.70/0.77	2,289	9,129	2.42	2.79	342,430	4	58,175	88,499	3.4	0.1
Wyoming	218,556	-51	15	1		14,409	2,424	0.49/0.58	1.00/0.94	4,728	139	23.83	7.70	434,523	1	57,544	8,233	23.6	0.3
Total 14states	521,700	-49	327	189						16,045	24,839			3,972,600	5	655,932	644,945		26.6
National Total	534,978	-51	350	196		970	998			16,761	25,356	10.24	3.60	4,282,976	6	759,332	772,266		72.1

Table values were compiled from data presented in tables included in chapters 2 through 5, except for the final column, which is from Siddik et al. 2020.

6.1.7 Government Incentives, Policies, and Programs

Federal, state, and local governments can attract data center development and assist the redevelopment of former mine sites with incentives and public policies.

On the federal level, the government is taking action to help communities transition from fossil fuels through policy, institutional, and funding support; tax credits; and technical and workforce training:

- Executive Order 14008: Tackling the Climate Crisis at Home and Abroad, to foster economic revitalization of and investment in hard-hit energy communities, requiring federal projects to reduce emissions of toxic substances and greenhouse gases from existing and abandoned fossil energy infrastructure.
- The newly created Interagency Working Group on Coal and Power Plant Communities and Economic Revitalization has launched a $450 million funding program to support the transformation of mine lands into new clean energy hubs.
- The U.S. Economic Development Administration (EDA)'s Coal Communities Revitalization Initiative provides funding to support economic diversification and revitalization efforts in communities affected by the decline of the coal industry. This initiative includes funding opportunities for infrastructure development, workforce training, and business development.
- The POWER Initiative provides funding for projects that promote workforce training, entrepreneurial development, and technical assistance to help coal communities transition to new industries.
- DOE Industrial Efficiency and Decarbonization Office provides technical assistance and workforce training that could support implementing and operating the next generation of efficient data centers paired with renewable electricity in existing coal communities.
- The New Markets Tax Credit (NMTC) program encourages private investment to revitalize underserved communities and promote economic opportunity for businesses and individuals in these areas.
- The Inflation Reduction Act (IRA) includes provisions for a 30% tax credit for wind, solar, and other green energy projects and provides an extra 10% bonus tax credit for investments made in designated "energy communities."
- The Labor Department's Workforce Innovation and Opportunity Act (WIOA) provides funding for workforce development programs that can be tailored to meet the specific needs of coal communities. The DOL also offers apprenticeship programs, on-the-job training, and other initiatives to help individuals in coal communities acquire new skills and find employment in emerging industries.

The federal government can provide incentives and assistance to redevelop mine land for renewably powered data centers. Some respondents interviewed for the study suggested that proof of concept demonstrations should be funded at the national level, and pointed to the European Union, which provides grants up to $2.5 million for the use of Euro technologies.

States and local communities can also offer a variety of incentives and public policies to encourage data center development, mitigate risks, and/or reduce development costs. Such incentives can play a significant role, and may include: sales tax incentives, property (land and IT equipment) tax incentives, income tax incentives, grants, infrastructure development, completed due diligence studies, expedited approvals or pre-approvals, job training programs, and others, including facilitating partnerships and marketing.

Data center industry experts generally agreed that tax (and other) incentives influence their location decisions. Offsets to capital costs are generally considered most desirable. Sales and property tax incentives are important, but also states that have no income tax are at an advantage. The absence of taxes or low taxes can substitute for special tax incentives. For land and colo developers, some incentives that lower operating costs such as lower sales, equipment property, and income taxes don't benefit them directly but can help attract customers.

Few industries are as sensitive to tax policy and incentives as data centers—they pay substantial sales and property taxes based on very large investments. Eleven states automatically do not assess property taxes on equipment and furniture, and nineteen offer some form of property tax abatement. Sales and property tax burdens heighten the need for data center economic development incentives.

Communities can offer non-tax incentives for development as well, such as infrastructure development, complete due diligence studies, expedited approvals and development zones, and facilitation of partnerships to bring stakeholders together. Utilities can support such efforts by helping to ensure available, renewable, reliable, and low-cost power. And of course, an attractive community to live and work in will help data centers recruit the workforce they need.

To help promote development of local jobs, communities can partner with others to offer the training the industry needs, both in constructing and operating the facility. Industry experts suggested union training programs, two-year community college programs, and having data center developers themselves (and their staff) participate in training programs. Availability of qualified staff and training programs in a community, or a willingness to develop such programs, would be a plus for data center developers. Public-private partnerships and marketing can support these efforts.

There is significant competition between communities to attract data center development, and they often provide subsidies of tens to hundreds of millions of dollars generally in the form of tax relief. Some argue that communities are over-subsidizing data centers, but such subsidies will likely be required to attract development.

6.2 Recommendations for further work

Recommendations for further work are based on this study and discussions with industry stakeholders to identify their top-priority considerations.

1. Better connect data center siting criteria with mine lands and their specific attributes.
The location, configuration, and existing infrastructure of each mine site offers unique opportunities for repurposing. Selection and development of these sites will be facilitated by identifying each mine's characteristics through the following activities:

a. Identify and characterize large mine land parcels (including those restored, in progress, and still in use).
b. For major mine sites, collect data on attributes relating to data center location criteria.
c. Refine data and develop a database and inventory of coal mine land. At a minimum, data should include:
   - mine land area
   - location (including jurisdiction)
   - existing use
   - ownership
   - topography
   - electrical capacity, condition, reliability, cost, and renewable resources
   - available fiber network resources and distance from site
   - Suitability of restored coal mine land for building construction and renewable energy development
d. Conduct a preliminary assessment of the top sites relative to high priority siting criteria.
e. Perform a more detailed evaluation/feasibility study of typical coal assets/infrastructure sites for reuse.
   - Based on a handful of case studies and lessons learned, develop a guide for evaluating existing coal mine assets for reuse.

2. Conduct techno-economic analyses.
Techno-economic analyses help to make sure projects are feasible , and because repurposing coal mines is a relatively new process, these analyses are especially important. Further socio/economic studies of coal regions will help stakeholders better understand the economic health of the area and priorities for action (both present and future). In-depth techno-economic analyses can assess the adoption of various clean energy technologies and economic diversification models.

Because the economics in many mining communities are tied to the mine(s), it is important to independently quantify the job and economic development benefits and justice gains to local communities and states of different pathways. Documenting incentives already available in "coal" states will identify ready assistance for projects. It also will be important to evaluate the cost effectiveness of incentives put in place to attract data center development (e.g., tax revenue impacts)—as well as to evaluate the effectiveness of incentives to impact development decisions.

To help ensure a just transition of displaced coal workers to a clean digital economy, it is essential to assess data center workforce needs. This can be accomplished by assessing jobs in the data center industry (skills/trades) and workforce needs. Which jobs are hard to fill?

Further evaluation of coal industry employment (number and types of jobs), and transferability to other jobs (e.g., construction and operation of renewable energy and data center projects) will help stakeholders identify jobs and skills that could transfer to a repurposed mine site. Assess the alignment of data center jobs with displaced workers in coal communities, and identify the job training needs to fill the gap. Also identify and showcase existing job (re)training best practices in coal communities and the data center industry. Finally, develop national, state, and local job training plans to promote workforce readiness training on information technology and clean energy.

Assessments of new technologies and of existing technologies in new applications also can help stakeholders identify operational and economic viability. Perform more detailed studies of the technologies identified for applications to specific sites. For example, more robust feasibility analysis and engineering guidance is needed on the use of mine water for data center cooling (technical study). Based on a handful of case studies and lessons learned, develop a guide for evaluating mine water as a cooling resource.

For renewable energy, further study is needed on the suitability of coal assets for development of projects. For example, evaluate the required land (MW and MWh per acre) in coal regions and compare it to the mine land available. Also consider the topology and constructability on mine land. Likewise for energy storage, conduct further evaluation of mine land for suitability of energy storage technologies (and pairing with renewable energy systems and data centers).

3. Facilitate partnerships (bring stakeholders together) at the local, state, and national levels.

Facilitating partnerships will establish synergies that can spark economic development and cooperation. Assist in setting up a consortium of connected interests, including coal miners, coal communities, data centers, investors (e.g., pension funds), utilities, green power producers, energy storage providers, and others. Host cross-industry exchanges.

Such partnerships could be key to identifying and analyzing potential issues such as existing laws governing coal assets, including mine land, ownership rights, zoning, policy, technology, markets, and infrastructure that hinder the use of coal assets for clean energy and data center development. This process will be essential for identifying issues early in the process, to ensure barriers are cleared for development.

4. Provide technical assistance.

When integrating technologies from different sectors, it is important that all stakeholders understand the advantages and potential challenges of that process, and such discussions can identify opportunities that would otherwise not be considered. Providing technical assistance to, and facilitating exchanges with, coal communities and other stakeholders will equip them with the tools they need to understand the full range of needs, challenges, and opportunities. Projects can also benefit from conducting technical exchanges between national labs, universities, and industry stakeholders to share emerging technologies and applications. Share information to understand the technical challenges and needs of industry players including coal mining, renewable energy, energy storage, electric utilities, data centers, and indoor farming.

Conduct outreach on results to encourage successful initiation and replication of technical assistance. Broad outreach of successful projects can help boost interest in coal mine repurposing.

5. Perform collaborative Research Development and Demonstrations (RD&D)

Working with industry and communities, develop, evaluate, and document solutions for addressing technical and business challenges. Conduct research, development, and implementation of proof of concept demonstrations. These demonstrations, including case studies, can help decision makers determine whether to go ahead with a project or change their approach. Identify and initiate pilot projects for demonstrating technical concepts and economic models for adoption. Such RD&D brings stakeholders together, spurs brainstorming, and can help identify challenges and solutions. The technology areas described in this report should be targeted. Also conduct R&D on economic/business models for development of integrated renewable energy, energy storage, and industrial (e.g., data centers and indoor farming) projects utilizing coal assets. Finally, conduct outreach to disseminate RD&D results to encourage initiation and replication of projects. Broad outreach of successful RD&D can help boost interest in coal mine repurposing by illustrating the multiple benefits such projects can achieve.

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Appendix A. Presentation on Leveraging Coal Infrastructure for a Digital Economy

Leveraging Coal Infrastructure for a Digital Economy

Concept for Discussion:
Repurposing Mines and Mine Land for
Development of Renewably Powered Data Centers

Lawrence Berkeley National Laboratory
January 11, 2023

ENERGY TECHNOLOGIES AREA

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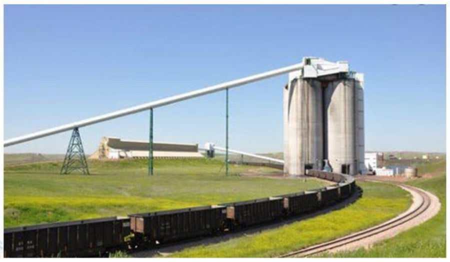
LEVERAGING COAL COMMUNITIES ASSETS

As we transition away from fossil fuels, coal communities offer challenges and opportunities:

- Mines and mine land offer valuable resources (reclaimed land, electrical infrastructure, efficient cooling/heating, rights-of-way).
- Turn environmental liabilities into climate solutions and new economic drivers.
- Communities generally receptive, and mine land is conducive to renewable energy and other development.



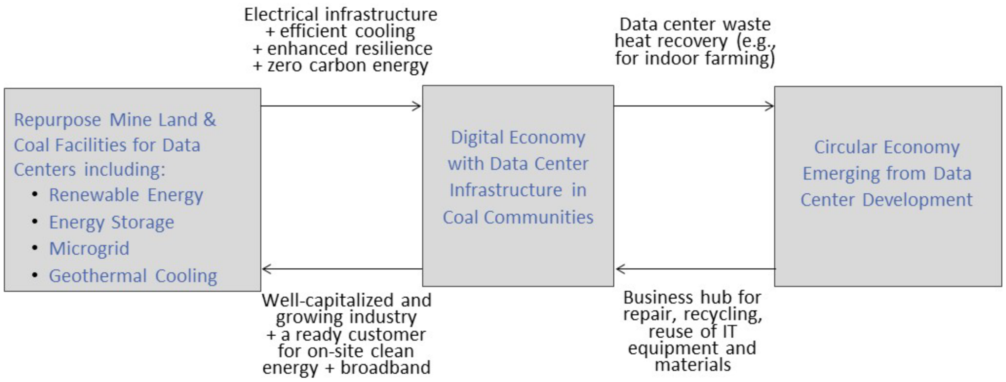
Dry Fork and Cordero Rojo surface Mines, WY

ENERGY TECHNOLOGIES AREA

2

BERKELEY LAB

A REVITALIZATION MODEL FOR COAL COMMUNITIES



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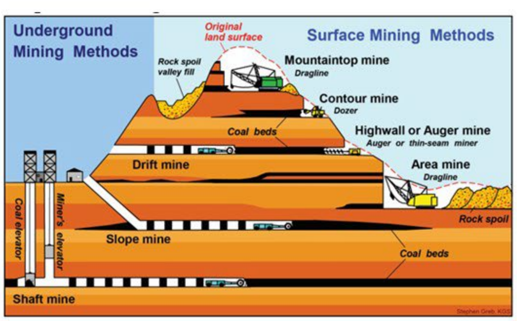
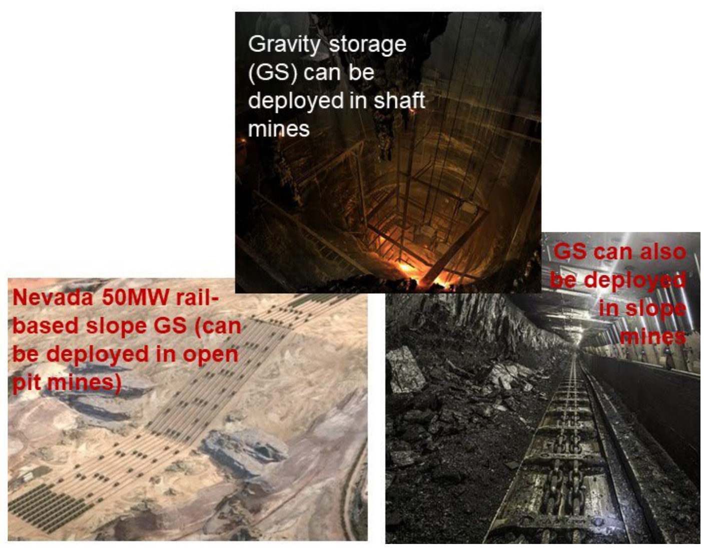
LEVERAGING COAL COMMUNITY ASSETS - ENERGY STORAGE

- Use existing infrastructure for deploying energy storage.





ENERGY TECHNOLOGIES AREA

LEVERAGING COAL COMMUNITY ASSETS FOR DATA CENTERS

- Data centers use approximately 2% of our electricity and are a ready market for renewable energy.
- The 2nd biggest load is typically cooling (2nd only to the IT equipment itself).
- significant quantities of water are often used in the cooling process.
- Groundwater in mines and adjacent aquifers can be used for energy- and water-saving data center cooling.

LBNL SuperComputer

LBNL Compressorless Cooling

Iron Mountain Cold Sink Mine Lake

ENERGY TECHNOLOGIES AREA

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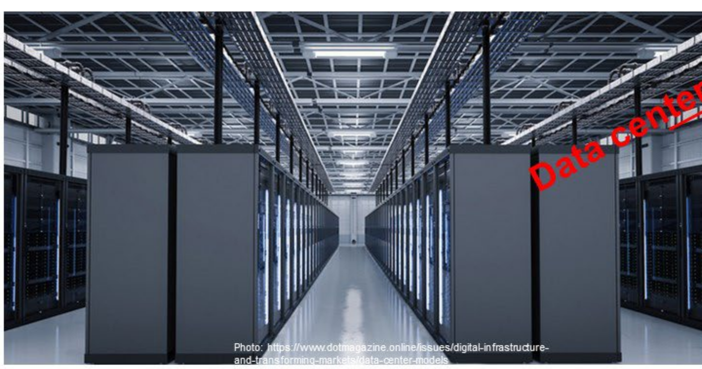
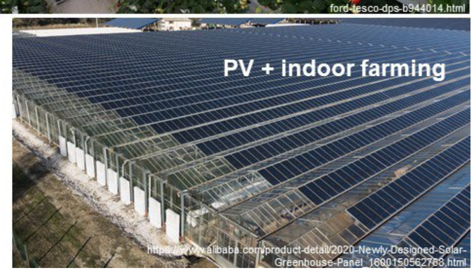
LEVERAGING ASSETS

- Heat recovered from data centers can be put to productive use, avoiding carbon fuels for heating.



Data center waste heat



ENERGY TECHNOLOGIES AREA

COMPREHENSIVE PROGRAM VISION

PARTNERSHIP IN BUILDING A DIGITAL AND CIRCULAR ECONOMY IN COAL-RELIANT COMMUNITIES

REPURPOSE COAL ASSETS FOR DIGITAL INFRASTRUCTURE AND ALTERNATIVE ECONOMIC DEVELOPMENT

Establishment of Partnership

- Carry out effective cross-industry exchanges with data center, coal, and clean energy industries, and coal communities.
- Categorize legacy coal assets and their geographic distribution.
- Analyze drivers of location and desired infrastructure for data centers, and how they overlay with the locations and infrastructure available in coal-reliant communities.

Technical support and R&D Collaboration

- Provide technical support to industries and communities with the resources and expertise of national labs and universities.
- Conduct technical exchanges to understand industries' technical challenges and needs.
- Identify specific areas for collaborative research and development with national labs, universities and industries.
- Carry out R&D collaboration and provide technical assistance to develop solutions for addressing technical and business challenges.

Feasibility and Techno-economic Assessment

- Evaluate various options for utilizing coal assets for data centers and clean energy.
- Conduct techno-economic analysis to assess the feasibility of adopting certain solutions.
- Evaluate job skill requirements for repurposing coal assets and their match with existing skills.

Barriers Identification and Policy Recommendations

- Work with the coal communities to identify potential issues such as laws, ownership, zoning, policy, technology, markets, and infrastructure that hinder the use of coal assets for clean energy and data center development.
- Make recommendations on local, state, and national policy changes needed to overcome barriers.

Demonstration Pilots

- Identify and initiate pilot projects for demonstrating concepts of repurposing coal assets for clean energy and data centers and adoption of models for economic growth.
- Outreach on results to encourage replication.

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CONTACTS

Dale Sartor (DASartor@LBL.gov)
Arman Shehabi (AShehabi@lbl.gov)
Bo Shen (BoShen@lbl.gov)

Energy Analysis & Environmental Impacts Division:
https://energyanalysis.lbl.gov/

Center of Expertise for Energy Efficiency in Data Centers:
https://datacenters.lbl.gov/

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8

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