



SCHOOL OF ENERGY RESOURCES



SEPTEMBER 15, 2019

ANNUAL REPORT



UNIVERSITY OF WYOMING

**THE UNIVERSITY OF WYOMING SCHOOL OF ENERGY RESOURCES
ANNUAL REPORT FY 2019**

SEPTEMBER 15, 2019

Presented to:

Joint Minerals, Business and Economic Development Interim Committee,
Joint Appropriations Interim Committee,
Joint Education Interim Committee

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EXECUTIVE SUMMARY

The University of Wyoming (UW) School of Energy Resources (SER) was created in 2006 to enhance the university's energy-related education, research, and engagement. SER directs and funds cutting-edge energy research and technology development, which integrates with the formulation and conduct of academic programs at UW and bridges academics and industry through targeted engagement efforts. The bridges formed between academics and industry ensure programs are relevant, current, and deliver impact and high value to stakeholders and the state.

Since its inception in 2006, SER has maintained flexibility in its focus and structure to meet the changing needs of Wyoming's energy industries and the state's economy—which is now more critical than ever. This report highlights SER's significant achievements, from July 1, 2018 through June 30, 2019, in academics, research, newly emerging areas of focus, and engagement to keep UW and Wyoming at the forefront of the energy sector.

Fiscal year 2019 (FY19) was the second full year of activities guided by a five-year strategic plan. Significantly, and in addition to our traditional leadership of academic, research, and engagement programs, that plan calls for increased focus in two new areas: growing our investment and guidance to commercialize the intellectual property that results from SER-funded research (**Technology Deployment & New Ventures** in the strategy) and increased effort in energy-related policy analysis (**Energy Regulation and Policy** in the strategy). Both areas received significant new funding from SER's budget and from federal and private sector grants during FY19.

Programmatic highlights over the period include:

The graduation of 9 students from the Energy Resource Management and Development Bachelor's of Science program with 100% of graduates receiving a job offer prior to graduation, establishing a new milestone in the history of the program.

Funds from the James E. Nielson Excellence Fund in the amount of \$0.5 million have supported student scholarships, faculty startup, fellowships, the Center for Global Studies, and the Undergraduate Science Initiative. The Nielson fund has one of the largest impacts of any fund at the University of Wyoming on students who are pursuing degrees in the energy sector.

Further investment of \$0.57 million in seven energy related Centers of Excellence has stimulated energy research in a broad range of disciplines. The Centers continue to evolve to respond to critical issues facing Wyoming's Energy Industries.

The Carbon Engineering Initiative (CEI), established in FY16, is moving aggressively (approximately \$3M in FY19) from proving concepts in the laboratory to developing technology products; a significant patent portfolio is emerging. CEI has identified and formed technology development relationships with two 3rd party technology companies to utilize their proprietary technology solutions on Powder River Basin (PRB) coal, and a dedicated carbon engineering laboratory has been established to accelerate program outcomes.

The Energy Regulation and Policy group developed a plan for the creation of a new research center, the Center for Energy Regulation and Policy (CERP). The mission of CERP is to inform, educate, and develop pragmatic, reasonable, and effective low-carbon energy policy and regulation solutions for Wyoming, the Rocky Mountain Region, federal and international policymakers using state of the art interdisciplinary approaches, and scholarship and analytical tools that draw upon economics, technology, and policy. CERP efforts began in earnest in Summer 2019.

The Center of Economic Geology Research (CEGR) received funding (\$9.7M) to complete the Phase II feasibility study of the carbon capture and storage project at Dry Fork Station and the Wyoming Integrated Test Center. CEGR will compete for Phase III funding during the next fiscal year.

SER's engagement program hosted 15 professional speakers as part of the SER Lunch & Learn Series. The SER speaker series serves as a platform from which to talk about multidisciplinary energy problems, and the series continued to gain interest and attendance throughout the year.

SER appreciates the continuing confidence of the Wyoming Legislature. In the face of tightening budgets, SER's commitment to providing funding support for energy education, targeted research, and engagement across multiple colleges at the University of Wyoming is more important and effective than ever. SER's partnerships with UW faculty and with industry representatives are making significant progress in keeping energy a viable industry in Wyoming. Importantly, great strides are being made to develop new uses for Wyoming's natural resources and attract companies that want to operate in that arena to the state.

ACADEMICS

The School of Energy Resources' academic mission is to develop innovative programs to meet the demands of the energy workforce and enhance societal literacy related to complex energy issues. Competitive success in the 21st-century energy sector requires deep foundational knowledge and enabling skills to adapt to rapidly changing technologies and an escalating knowledge base. Competency-based learning that integrates problem solving, critical analysis of uncertain and complex issues, and constant improvement in performance are overarching components of SER academic programs.

Energy Resource Management and Development Bachelor of Science

The Energy Resource Management and Development program (ERM&D) is an interdisciplinary Bachelor of Science (BS) degree program that integrates training in engineering, geology, policy, economics, business, law, and natural resources. This degree connects energy sector problem-solving experiences with classroom learning to prepare students for the workforce needs of the energy sector.

The program consists of two concentrations:

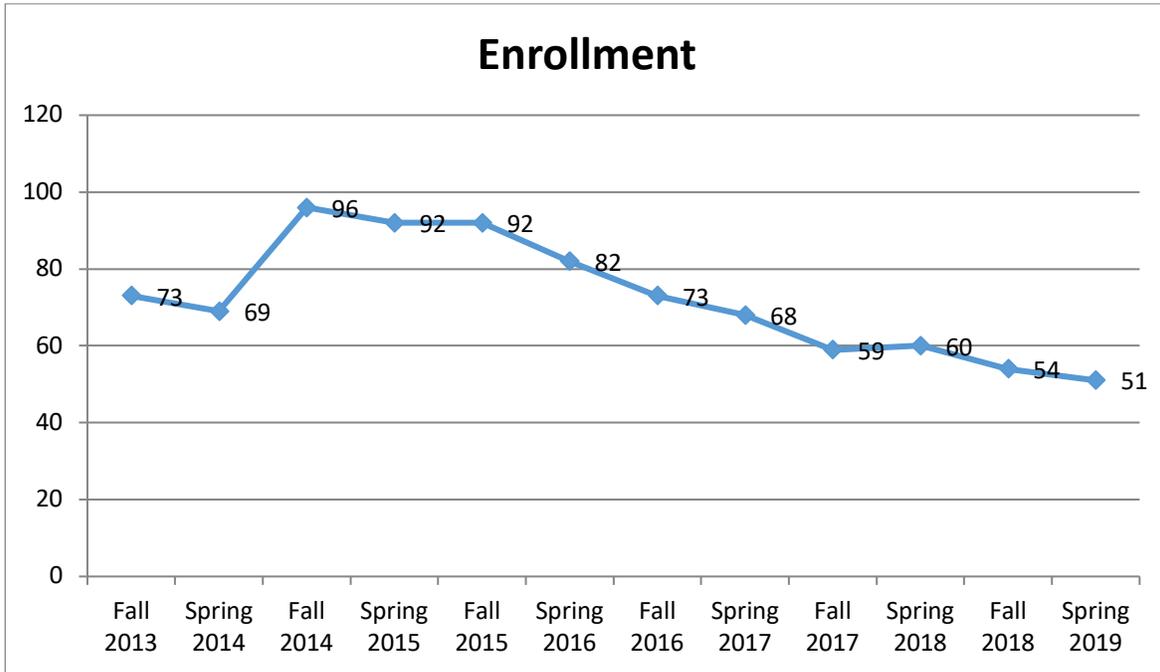
- Energy Air, Land and Water Management
- Professional Land Management (commonly shortened to Landman¹)

The American Association of Professional Landmen¹ (AAPL) accredits the Professional Land Management concentration.

Enrollment Statistics

The ERM&D program began the Fall 2018 semester with 54 enrolled students, including 9 freshmen, 12 sophomores, 14 juniors, and 19 seniors. Enrollment for the Spring 2019 semester declined to 51 students, including 8 freshmen, 11 sophomores, 8 juniors, and 24 seniors. Detailed information on student enrollment data and demographics for the 2018-2019 academic year is provided on the following pages.

¹ The terms Landman and Landmen are used by convention in industry and do not imply any gender reference.



Class Standing						
Semester	Freshmen	Sophomores	Juniors	Seniors	2 nd Bachelors	Total
Spring 2019	8	11	8	24		51
Fall 2018	9	12	14	19		54
Spring 2018	7	10	17	26		60
Fall 2017	8	10	18	22	1	59
Spring 2017	7	16	9	34	2	68
Fall 2016	12	15	15	29	2	73
Spring 2016	16	15	17	32	2	82
Fall 2015	22	22	15	30	3	92
Spring 2015	19	25	14	31	3	92
Fall 2014	36	14	18	25	3	96
Spring 2014	17	12	16	23	1	69
Fall 2013	26	15	11	20	1	73

Gender			
Semester	Female	Male	Total
Spring 2019	14	37	51
Fall 2018	17	37	54
Spring 2018	13	47	60
Fall 2017	14	45	59
Spring 2017	16	52	68
Fall 2016	18	55	73
Spring 2016	16	66	82
Fall 2015	18	74	92
Spring 2015	16	76	92
Fall 2014	19	77	96
Spring 2014	9	60	69
Fall 2013	10	63	73

Concentrations							
Semester	Energy Land & Water	Fossil Fuels	Professional Land Management	Renewable Energy	Undecided	Original Program	Total
Spring 2019	20	0	27	4	0		51
Fall 2018	25	0	23	4	2		54
Spring 2018	23	0	27	9	1		60
Fall 2017	24	1	23	8	3		59
Spring 2017	21	3	28	11	5		68
Fall 2016	26	3	25	10	9		73
Spring 2016	25	8	34	10	3		80
Fall 2015	23	10	34	12	8		87
Spring 2015	22	15	35	10	8	2	92
Fall 2014	21	16	36	11	9	3	96
Spring 2014	9	13	22	8	9	6	67
Fall 2013	8	13	19	6	17	9	72

Scholarships

Students received \$339,934 in scholarships and grants, an increase of \$63,620 over 2017-2018.

Awarded Scholarships AY2019	Total Amount
Rocky Mountain Scholars	\$84,412
Nielson Scholarships	\$78,288
Hathaway Scholarships	\$65,015
ROTC	\$24,032
Western Undergraduate Exchange	\$21,168
American Association of Professional Landmen	\$ 5,000
GW Anderson Landman	\$ 5,000
Wyoming Scholars	\$ 4,000
Honors Program	\$ 2,000
Other Scholarships, Grants and Loans	\$51,019

Honor Rolls

Undergraduate students who achieve high scholastic grades are recognized by placement on one of the honor rolls below. During the Spring 2019 semester, 43% of our students were named to an honor roll, establishing the third highest percentage since the program began in 2009.

- President's – 4.0 GPA and complete a minimum of 12 credit hours
- Dean's – 3.4 or better GPA, above freshman standing and complete a minimum of 12 credit hours
- Dean's Freshman – 3.25 or better GPA and complete a minimum of 12 credit hours
- Provost's – 3.5 or better GPA and complete 6 to 11 credit hours

Honor Rolls						
Semester	President	Dean	Freshmen	Provost	Total	% Students
Spring 2019	2	16	2	2	22	43.1%
Fall 2018	4	10	2	1	17	31.5%
Spring 2018	5	16	3	2	26	43.3%
Fall 2017	5	14	4	1	24	40.7%
Spring 2017	5	17	4	8	34	50.0%
Fall 2016	4	14	5	7	30	41.1%
Spring 2016	5	17	5	1	28	34.1%
Fall 2015	4	15	4	1	24	26.1%
Spring 2015	5	14	4	4	27	29.3%
Fall 2014	3	6	6		15	15.6%
Spring 2014		15	3	1	19	27.5%
Fall 2013	3	8	4		15	20.5%

Graduation Statistics

Our graduating class consisted of nine students during the 2018-2019 academic year. In total, 88 students have graduated from the program since Fall 2011.

The 2018-2019 graduating class set a new record as each graduate received a job offer prior to graduation, establishing a new milestone in the history of the program.

Graduates by Gender			
Semester	Female	Male	Total
Spring 2019	3	5	8
Fall 2018		1	1
Summer 2018	1		1
Spring 2018	2	14	16
Fall 2017		1	1
Spring 2017	5	12	17
Fall 2016		1	1
Summer 2016		1	1
Spring 2016	1	9	10
Fall 2015		2	2
Spring 2015	1	8	9
Fall 2014		1	1
Spring 2014		3	3
Fall 2013	1	2	3
Summer 2013	1		1
Spring 2013	4	6	10

Graduates – First Destination					
Semester	Employed FT	Continue Education	Continue Job Search	Unemployed by Choice	Total
Spring 2019	8				8
Fall 2018	1				1
Summer 2018	1				1
Spring 2018	15	1			16
Fall 2017	1				1
Spring 2017	17				17
Fall 2016			1		1
Summer 2016	1				1

Spring 2016	6		4		10
Fall 2015	1			1	2
Spring 2015	7	2			9
Fall 2014	1				1
Spring 2014	3				3
Fall 2013	3				3

Degrees Awarded with Distinction

Designations of *summa cum laude*, *magna cum laude*, and *cum laude* are added to baccalaureate academic transcripts and diplomas of graduating students earning at least 48 University of Wyoming credit hours based on the following percentages:

- Top 1% *summa cum laude*
- Next 4% *magna cum laude*
- Next 5% *cum laude*

as computed from the grade point average of graduating students in each college or school. These graduates are identified by comparison to a 5-year rolling grade point distribution computed for each college or school and is recomputed each spring semester.

GPA's to be awarded with distinction for SER effective December 2018, May 2019, and August 2019 are:

- *summa cum laude* – 4.000
- *magna cum laude* – 3.694
- *cum laude* – 3.659

Degrees Awarded with Distinction				
Semester	<i>Summa Cum Laude</i>	<i>Magna Cum Laude</i>	<i>Cum Laude</i>	Total
Spring 2019		1		1
Summer 2018			1	1
Spring 2018	1			1
Spring 2017			1	1
Spring 2015			1	1
Total	1		3	5

First Destination Job Titles and Employers

SER would like to recognize and express gratitude to the employers of our graduating students. The employer, job title, and job location for our recent graduates include:

- Anadarko Petroleum Corporation – Surface Landman – Denver CO
- Down Hole Tools of Wyoming – Field Representative – Casper WY
- Kiewit – Field Engineer – Fort Worth TX
- Kiewit – Environmental Engineer – Seattle WA
- NextEra Energy Inc. – Land Services Representative – Juno Beach FL – Working out of Wyoming
- NorthStar Energy – Contract Landman – Denver CO
- Rocking WW Minerals – Title Landman – Sheridan WY
- Tri-State Generation and Transmission Association – Transmission Siting, Permitting and Environmental Planner – Westminster CO
- Ultra Petroleum – Land Technician – Denver CO

Accomplishments

- Mr. Jared Adams received the Outstanding Graduate Award from the AAPL for 2019 and is the second student from the University of Wyoming to be recognized for this prestigious honor.
- A group of Professional Land Management students attended the Rocky Mountain Mineral Law Foundation Due Diligence in Oil & Gas and Mining Transactions September 27-28, 2018 in Westminster, CO.
- SER students attended the Wyoming Oil and Gas Conservation Commission meeting in March 11-12, 2019 and met with representatives from the Wyoming AAPL.
- The AAPL recently formed a student leadership council with one representative from each of the accredited programs attending the annual meeting in Pittsburgh, PA on June 19-21, 2019. Mr. Colton Edwards represented the University of Wyoming and provided input to AAPL on how to better connect with students in the accredited programs.
- Several potential employers visited campus to meet with students, including Anadarko Petroleum Corporation, Black Hills Energy, and PetroValues.
- Twenty-one students accepted internships, undergraduate research, and job opportunities during summer 2019. Ten students enrolled in summer classes.
- After a two-year hiatus, the Energy Summer Institute is scheduled for July 14-19, 2019. Seventeen high school sophomores and juniors are invited to stay on campus to learn more about energy and the University of Wyoming.

RESEARCH

Center for Economic Geology Research (formerly Carbon Management Institute) – Scott Quillinan, Director

The Center for Economic Geology Research (CEGR) remains largely funded by competitive grants provided by the U.S. Department of Energy (DOE). Since its launch in 2010, CEGR has secured approximately \$52 million in grants. CEGR is currently entirely grant-funded with a total project portfolio of \$18.2 million (including cost share); as a result, the center's researchers are fully supported through 2020. Those dollars have not only supported CEGR's research staff, but they have percolated throughout the UW campus to support numerous graduate students and undergraduates over the years and have enabled the hiring of a variety of Wyoming industry partners through contracting services. Building off of this solid financial base of competitive grants, CEGR is currently receiving direct (i.e., non-competitive) funding from DOE for applied research related to rare earth elements (REEs).

Carbon Capture Utilization and Storage Projects:

CarbonSAFE (Carbon Storage Assurance and Facility Enterprise) Projects

Wyoming CarbonSAFE Phase II. Phase II of the Wyoming CarbonSAFE project at Dry Fork Station began September 1, 2018. The total award amount for this two-year project is \$12.2M (\$9.7 Federal and \$2.5M of in-kind cost share) with the objective to characterize the geology of storage reservoirs directly below Dry Fork Station. In order to collect the necessary data to perform the work, CEGR drilled a deep characterization well to collect geologic core, fluid, and geophysical logs, proximal to Dry Fork Station. A 12.5-mile 3D seismic survey will be collected in FY20. The stratigraphic test well was spud on April 12th and was drilled to a depth of 9,873 feet below land surface. The project team successfully collected 625 feet of geologic core from 9 different geologic formations and fluid samples from 6 geologic formations. High-resolution geophysical logs were also collected. The well was completed on May 11th.

Economic impact to the state. Federally sponsored research provides direct economic benefit to Wyoming communities. Benefits are realized as work for local contractors, jobs, and support for students. For example, the Wyoming CarbonSAFE project spent nearly \$3.5M in FY19 to permit, design, and drill the stratigraphic test well. Wyoming companies provided these services. The project will expend an estimated \$0.9M in FY20 to collect a 3D seismic survey, for total estimated expenditure of \$4.3M. In addition to the dollars spent in Wyoming communities, the project employs nine full time research scientists and provides support for six graduate students and three undergraduate students.

CEGR is separately teamed on the Phase II CarbonSAFE grant being administered by the Southern States Energy Board at the Kemper County Energy Facility in Mississippi. CEGR's share of that grant is \$517,854; the Kemper site runs through February, 2020.

Rare Earth Elements and Critical Materials Project:

Rare Earth Elements in Produced Water. CEGR's DOE-funded project to study rare earth elements (REEs) in produced and geothermal waters is complete, and the results can be found here: <https://gdr.openei.org/submissions/1125>. Continued investigation of REEs in produced water and extraction technologies will occur under CEGR's State-funded Wyoming Water Research Program (WRP2018) project that includes further sampling in two additional Wyoming geologic basins. The project will continue through June of 2020.

Rare Earth Elements in Coal and Coal By-Products. The project team is working with Peabody to obtain additional coal core samples to supplement the preliminary sample set. The goal is to increase the statistical relevance of the Powder River Basin (PRB) coal data set. Initial findings report that PRB coals contain elevated rare earth element concentration; further research is needed to understand the extent of the resource.

Rare Earth Elements in Unconventional Minerals and Uranium Roll Front Deposits. CEGR is mentoring a Geology student with SER Professor John Kaszuba. The student is funded through Marathon Interdisciplinary Fossil Fuel Laboratory Support Fund (see pg. 26), and his project is focused on quantifying rare earth element concentration in two unconventional sources: residual igneous melts and uranium roll-front deposits.

DISA LLC, Casper WY. CEGR concluded work with a Wyoming start-up business to validate materials separation technology. DISA technology uses mineral separation and density separation to perform clean-up in areas contaminated with uranium, traditional ore body mines, and hydrocarbons. CEGR research scientists tested and proved the efficiency of mineral separation through characterization of pre- and post-feed material.

Energy Storage. Idaho National Laboratories (INL) in Idaho Falls is leading the investigation of the potential for deep thermal energy storage in saline reservoirs near coal/wind plants owned by Rocky Mountain Power/PacifiCorp. The project is supported by non-competitive funding from the Geothermal Technologies Office. CEGR is providing the project team with subsurface targets and reservoir models and is investigating near and far-field pressure response and thermal response rates. INL views this as a first phase assessment and hopes to develop this into an expanded program with long-term funding.

Unconventional Hydrocarbon Assessment of the Mowry Shale within the Powder River Basin (PRB). The Mowry Shale is an organic-rich source rock that has provided the oil to many of the lower cretaceous reservoirs in the PRB. Wyoming operators showed increased interest in Mowry in 2018; however, not many successful wells have been drilled. CEGR is taking a first order look at the Mowry Petroleum System, hopefully to match geologic attributes with production trends.

Center for Air Quality – Shane Murphy, Director

The Center for Air Quality (CAQ) continues to pursue its goals of better understanding and mitigating air quality issues related to energy production. During FY19, CAQ has continued to work with some of the same entities as previous years and has also expanded its reach. This year, the CAQ worked with energy companies (Jonah Energy), non-profits (Environmental Defense Fund), regulatory agencies (Wyoming DEQ, Utah DEQ, Colorado Department of Public Health and Environment (CDPHE), EPA Region 8), Federal agencies (BLM, NOAA), regional universities (Colorado State, University of Colorado, University of Utah, Utah State), and Wyoming Schools/Programs (Saratoga High School, UW Native American Institute, UW Engineering Summer Program). The new members of the CAQ, Dr. Dana Caulton and Dr. Zach Lebo, have become active members of the center. Dr. Lebo is co-advising (along with Dr. Murphy) Ph.D. student Shreta Ghimire in a project to model ozone formation in the Upper Green River Basin using the weather research and forecasting chemistry (WRF-CHEM) model. In addition to establishing her research lab, Dr. Caulton has published important articles on methane emissions and participated in proposal development.

Publications & Presentations

The peer-reviewed papers either published or submitted in FY19 include:

- Edie, R; Robertson, A.M.; Soltis, J; Field, R.A.; Burkhart, M.D.; Murphy, S.M., “Measuring volatile organic compound fluxes from oil and gas production facilities via real-time, off-site measurements” *Environmental Science & Technology*, Submitted, 2019.
- Caulton, D.R., Lu, J.M., Lane, H.M., Buchholz, B., Fitts, J.P., Golston, L.M., Guo, X., Li, Q., McSpiritt, J., Pan, D. and Wendt, L., “Importance of Superemitter Natural Gas Well Pads in the Marcellus Shale” *Environmental Science & Technology*, 53(9), pp.4747-4754, 2019.
- Caulton, D. R., Li, Q., Bou-Zeid, E., Fitts, J. P., Golston, L. M., Pan, D., Lu, J., Lane, H. M., Buchholz, B., Guo, X., McSpiritt, J., Wendt, L., and Zondlo, M. A., “Quantifying uncertainties from mobile-laboratory-derived emissions of well pads using inverse Gaussian methods” *Atmospheric Chemistry and Physics*, 18, 15145-15168, 2018.

Additionally, CAQ has three papers in review; the topical areas include: (1) demonstrating the accuracy of the OTM-33a flux technique for quantifying emissions from oil and gas production facilities, (2) a first-ever estimate of methane emissions in the Permian Basin, and (3) an investigation of volatile organic compound (VOC) emissions from produced water injection facilities in the Colorado Front Range.

Two graduate students involved in the Center (Anna Robertson and Rachel Edie) both presented their research (one oral presentation, one poster presentation) at the annual meeting of the American Geophysical Union in Washington D.C. Rachel also gave an oral presentation at the 2019 NOAA ESRL Global Monitoring Annual Conference. Both Rachel and Anna are scheduled to defend their Ph.D. dissertations by September, 2019.

Projects and Activities

Air Quality Monitoring Continental Divide-Creston Natural Gas Development Area. Dr. Robert Field of the CAQ continued to upgrade and operate the Wyoming Air Quality Assessment Monitoring Laboratory (WAQAML). The data generated from this facility supports a cooperative agreement with the Bureau of Land Management (BLM) that runs from August 2017 to September 2022. Ongoing baseline monitoring is required to inform modeling efforts related to the EPA Record of Decision for the Continental Divide-Creston Natural Gas Development Project.

Permian Basin Methane Emissions. The CAQ deployed the UW Atmospheric Science Mobile Laboratory to New Mexico and Texas in FY 2019 to estimate methane emissions from the Permian Basin in a project funded by the Environmental Defense Fund (EDF). Data from this deployment has already been integrated into the New Mexico emissions inventory, and a publication will be submitted by the end of August. The CAQ is currently in discussions with EDF about a follow up deployment to be conducted in FY 2020 that would be part of a much larger, multi-million-dollar effort by EDF to fully quantify emissions from the Permian.

Upper Green River Basin Modeling. Shreta Ghimire, a Ph.D. candidate, is developing a functional photochemical model for the Upper Green River Basin. Shreta has successfully run the model and demonstrated good performance of the meteorology compared to ambient observations from the Wyoming Department of Environmental Quality (DEQ) monitoring stations. She is building the chemistry portion of the model and then will integrate the DEQ emissions inventory into the model. The aim is to have model results in FY 2020. The project has recently received significantly increased attention from the State of Wyoming, and a

preliminary meeting with the Wyoming DEQ was held at the end of June 2019 to begin a more formal collaboration between the DEQ and the CAQ.

Drone-Based Detection. CAQ pursued funding—to evaluate cutting-edge methane and VOC emissions detection via drones—from the Alfred P. Sloan foundation in FY 2019. Unfortunately, the project was not funded, but there remains strong interest in this effort from industry collaborators, and we continue towards a project involving drone-based detection in FY 2020.

Uintah Basin Ozone Modeling. CAQ was invited to meetings involving both the Utah DEQ and the Colorado Department of Public Health and Environment (CDPHE) in FY 2019. We are actively involved with a consortium of research, industry, and government representatives lead by Utah State University to assist in reducing ozone exceedances in the Uintah Basin. We are currently preparing a proposal for CDPHE to quantify emissions from produced water injection facilities in Colorado.

Outreach

The CAQ's program with Saratoga High School continues, and the CAQ continues to operate three particulate matter monitors in Wyoming: (1) BLM WAQAML site; (2) Saratoga High School; and (3) UW. These were the first monitors installed in Wyoming as part of the Purple Air network that launched in 2018, which has nearly 200 sites in the U.S. The CAQ is collaborating with Wyoming DEQ to install a real-time particulate monitor in Laramie in FY 2020.

The CAQ again provided workshops for the Native American Institute (lead by Dr. Murphy and Dr. Caulton) and the weeklong Engineering Summer Program (lead by Dr. Murphy). Both programs focused on air quality and climate with hands-on experiences using personal air quality samplers and launching a weather balloon. The CAQ plans to continue to lead these workshops every year.

Center for Biogenic Natural Gas Research – Michael Urynowicz, Director

The Center for Biogenic Natural Gas Research (CBNG) develops next generation renewable energy platforms that add value to Wyoming's vast energy resources by bridging the gap between renewable energy and fossil fuels. Some of the Center's more recent projects are highlighted below.

Microbial Communities in Produced Water. The Center is collaborating with SER in FY19-20 to study microbial communities present in produced water (PW) from unconventional oil and gas

wells in five production basins in Wyoming. DNA extraction and analysis of 16S rRNA gene sequencing data will be performed to assess microbial community structure and diversity in PW and compare the data across different wells and geologic basins. The results of this work have both practical implications—such as guiding management strategies for PW—and research implications by providing insights into the environmental factors that predict life’s survival in extreme environments.

The Center’s ongoing work with SER includes three projects also studying the microbial communities present in PW from unconventional oil and gas wells. In the first project, 16S rRNA gene sequencing was performed to assess microbial communities present in PW from the Powder River, Wind River, and Washakie Basins. The data collected in this study supplements SER’s Rare Earth Elements in PW project and looks for correlations between microorganisms, water chemistry, and isotopes. Publication of the results of this work is underway. The follow-up work to this project includes a time series analysis of PW from Powder River Basin unconventional wells to evaluate microbial community changes over time. Another project studies microbial communities present in both PW and oil from production wells in Quealy Dome, to look for correlations between microorganisms present in each phase.

Low Carbon Natural Gas. The CBNG is currently working on a joint venture with Emerald Energy to perform a low-carbon renewable natural gas field demonstration in the Powder River Basin. The field demonstration is the first-of-its-kind to demonstrate the BIOGEM Process™, a novel approach for producing low-carbon renewable natural gas from depleted coalbed methane (CBM) wells. The process combines several UW patented technologies developed through the Center with Emerald’s patent pending Gem Tool, a down-hole gas collection device that uses membrane technology and the reservoir’s hydrostatic pressure to recover CBM without producing water.

Center for Energy Economics and Public Policy – Robert Godby, Director

The Center for Energy Economics and Public Policy (CEEPP) provides objective information, research, and analysis to support public policy-making at the local, state, national, and international levels. The goals of CEEPP are to evaluate the economic costs and benefits of developing state, regional, and national energy and public resources and integrating them into society. The Center builds and maintains a research infrastructure to solve pressing economic challenges in energy and natural resource development and to develop objective policy-making to improve human capital and economic development relevant to Wyoming, the region, and the nation. These goals are accomplished through research studies and programs sponsored and

initiated by the Center and through ongoing and active engagement with policy-makers, industry, and academia.

Projects and Activities

During FY19, CEEPP continued to assess and analyze Wyoming's tax structure and how it affects competitiveness in the wind industry. The most recent report on the relative costs of wind development across the eleven western states of the western electricity grid was completed in March 2019.

Wind Tax Assessment. The Center also completed its annual effort to define the Wyoming's Prevailing Wages used in Federal and State-funded construction projects for 2019-20 and has been contracted by the State of Wyoming to continue its survey efforts and compute estimates for prevailing wages in 2020-21 (http://www.uwyo.edu/ser/_files/docs/research/wind-energy/estimatingtheimpactofstatetaxationpoliciesonthecostofwinddevelopmentinthewest-3-7-2019.pdf). CEEPP personnel annually conduct this survey of skilled occupations to determine prevailing market wages in the building, heavy industry, and highway construction including energy projects. Center personnel have also been involved in developing economic opportunities to diversify the state economy within and outside the energy sector. This effort has been conducted in conjunction with the state's Economically Needed Diversity Options for Wyoming (ENDOW) initiative and continues in conjunction with various state agencies and the Governor's Office.

Prevailing wage assessment of the Energy Sector. CEEPP continued to be involved in federally-funded research projects, including an on-going \$5.2 million research collaboration among the Departments of Electrical Engineering, Mechanical Engineering, Economics, and Agricultural and Applied Economics to develop additional productivity in wind generation and transmission facilities. This project is funded by the U.S. DOE. This funding will end in November 2019. A second \$4.2 million project, funded by the National Science Foundation, also continued with researchers from CEEPP and others from the University of Wyoming, Montana State, and South Dakota State. This project attempts to determine the feasibility of using bio-energy carbon capture and storage (BECCS) to reduce carbon emissions consistent with limiting global temperature increases to 2°C by the year 2050. This funding will continue for another year.

Other related projects include continued development of models of Wyoming's electricity grid and an analysis of Wyoming's coal sector. A new project for 2019 was a project to develop a survey tool to determine Wyoming residents' preferences regarding wind development. While wind development creates new opportunities to diversify the state's economy and revenue

streams, it also creates costs with respect to the intensive use of land in the state, watershed changes, and habitat change for state wildlife. This survey will attempt to determine state residents' preferences with respect to these tradeoffs and their willingness to allow additional wind development in the state. The preparation for the survey begun in 2019-20, and the survey will be conducted in late 2020.

Additional projects and ongoing activities monitor the state of the Wyoming economy; CEEPP personnel are studying a range of socio-economic issues, including health care, worker health, and economic development.

Outreach and Engagement

During FY19, CEEPP gave 10 public presentations at national and regional research and policy meetings and public events, and CEEPP research and analysis were provided to the media in over 150 interviews. Additionally, CEEPP research results were presented in testimony to the State of Wyoming Public Service Commission and to the State's Joint Revenue Committee. CEEPP has also been involved informally with the Governor's Office to help develop state revenue and energy transition policy.

CEEPP Changes Going Forward

At the direction of Dr. Mark Northam, CEEPP director Rob Godby began planning a new policy center initiative with Kipp Coddington, Director of Energy Policy and Economics. These efforts have resulted in the creation of a new research center, the Center for Energy Regulation and Policy (CERP). This Center will effectively combine CEEPP with a wider interdisciplinary effort led by the SER. The new initiative plans to utilize resources and personnel from across the University of Wyoming and in collaboration with new partnerships to conduct research regarding the ongoing energy transition in Wyoming. Research efforts will also identify and maximize economic benefits for the State of Wyoming in light of: (1) international drivers, such as climate change and energy poverty; and (2) national, regional, and state policies related to reducing greenhouse gas emissions from fossil fuels and expanding the utilization of renewable energy systems.

The mission of CERP is to inform, educate, and develop pragmatic, reasonable, and effective low-carbon energy policy and regulation solutions for Wyoming, the Rocky Mountain Region, federal and international policymakers using state of the art interdisciplinary approaches, and scholarship and analytical tools that draw upon economics, technology, and policy. CERP efforts will begin in Summer 2019, and research will be focused in three areas:

- Collecting baseline socio-economic, environmental, and demographic data to inform policymakers of policy drivers and the context of the ongoing energy transition.
- Developing pragmatic and sustainable (ecologically, economically, and politically sustainable) policies to address climate change by identifying and evaluating potential pathways to achieving various realistic low-carbon outcomes in the energy sector.
- Communicating policy and technical strategies that pursue cost-effective low-carbon goals while minimizing the socio-economic costs.

To accomplish these efforts, Godby and Coddington will develop research plans and identify key personnel to complete the research described above and will utilize the former resources of CEEPP along with new resources being provided to the Center.

Center of Excellence for Produced Water Management – Jonathan Brant, Director

The Center of Excellence for Produced Water Management (CEPWM) was established in the College of Engineering and SER as part of the Tier I Engineering Initiative in 2015. The CEPWM vision promotes the management of waters produced during industrial processes (such as oil and gas production), with the goal of maximizing water recovery and beneficial use and mineral recovery. This vision is structured around reducing costs, permitting issues, and waste disposal volumes during resource extraction and utilization. Our mission is thus: to develop knowledge and technologies for recovering resources of value leading to sustainable management strategies for produced waters. CEPWM collaborates with many disciplines that have a stake in produced water management, such as petroleum, chemical, civil, economic, and environmental. We emphasize research and development of technologies and approaches for reducing the economic and environmental burdens of produced water management. Of particular interest is increasing revenue generation—adding new income streams and enhancing existing ones—from byproducts of oil/gas extraction, such as produced waters.

During the 2018-2019 reporting year, CEPWM leveraged funds provided by SER to advance two research areas. The first area involved the development of novel nanocomposite membranes, made using imogolite nanotubes, for produced water desalination applications. Imogolite is a clay mineral generally found in soils that are rich in volcanic ash. Specifically, these membranes are designed for use in membrane distillation and forward osmosis systems, as well as for a newly developed process based on the concept of superhydrophobicity/oleophilicity. These superhydrophobic membranes are being used for recovering BTEX/oil from produced waters originating from the Greater Green River Basin. Successful development of these membranes will lead to reduced energy consumption during desalination of produced waters and improved

treatment economics through the generation of a revenue stream (BTEX/oil). A second research area involves a grant from Strategic Environmental Solution (Pensacola, FL) to develop and evaluate a new produced water treatment system. This novel system uses aligned magnetic fields and silver nanoparticles to disinfect produced waters prior to reinjection. This technology avoids the need for biocides, like glutaraldehyde. Data collected over the past year indicates that the magnetic fields destroy the molecular structure of the glutaraldehyde, without the need to add expensive oxidants, like ozone. Testing is now commencing where the magnetic system is integrated into a pilot-scale membrane filtration/desalination system to evaluate process improvements (reduced membrane fouling).

Center for Photoconversion and Catalysis – Bruce Parkinson & Carrick Eggleston, Directors

The Center for Photoconversion and Catalysis (CPAC) promotes collaboration and experimentation in the fields of solar energy conversion, energy storage, and catalyst optimization—all with the aim of helping Wyoming and the world develop a more sustainable and efficient portfolio of both renewable and conventional energy resources. CPAC faculty and students work together to find new ways of generating and using energy, emphasizing conversion of light into both electrical and chemical energy as well as the closely related catalytic chemistry needed to use new and conventional energy forms more cleanly and efficiently.

This fiscal year, CPAC funded student research for two undergraduate student researchers, Mr. Alan Halverson and Ms. Veronica Spaulding. The award amount for each project was \$3,500 and was used for laboratory consumables and instrument time.

Shell 3D Visualization Center – Emma Jane Alexander, Manager

The mission of the Shell 3D Visualization Center (Viz Center) is to support and further leverage increased adoption of visualization technology first at the University of Wyoming, and second, to the wider community in the form of services to industry.

Technology

The School of Energy Resources provided the Viz Center additional funds in June 2018, and this investment in data capture technology has since born spectacular fruit. Investments were made in 360 cameras and ground based LiDAR scanning technology. Faculty have embraced the new methods of data capture and have been utilizing them both for teaching and research. For example, the Dept. of Anthropology has multiple members of faculty/PhD students who are using the 360 cameras: (1) to capture areas of anthropological interest, including the national

Historic Landmark called Hell Gap in Wyoming for research and teaching purposes, and (2) to capture the interior of an Arapaho Tipi in combination with a number of sacred sites for use in a language preservation research project. The Dept. of Civil and Architectural Engineering is utilizing 360 camera technology on a 1-month summer study abroad program to engage students in new methods of data capture rapidly emerging as standard practice in industry. These immediate and productive uptakes of the newly acquired technology are excellent examples of the thirst for innovation that UW faculty present.

Service Center Progress

The fee model for services has been further developed this year to accommodate the rising need for short courses. Multiple contracts have been developed this year for external entities, such as Gillette College (short courses in virtual reality and Unity game engine programming), The Albright Institute for Archaeological Research in Jerusalem (point cloud optimized VR viewing software development), and Third Element Design (collaborative design review for commercial architects).

Contributions, Presentations, and Professional Service

The Viz Center continues to be a well-recognized, proactive contributor to meetings, workshops, and conferences. Mr. K. Summerfield (Viz Center VR developer) had an abstract selected for delivery at the Rocky Mountain Advanced Computing Consortium (RMAACC) in Boulder in May 2019. The conference presentation was titled “Stereo 360 Photography for Virtual Reality.”

Ms. E. Alexander remains the current president and founding member of the Higher Education Campus Alliance for Advanced Visualization. The international group has grown to 194, and non-profit status as a 503(c) was established in March 2019. Ms. Alexander chaired the 3rd annual 3-day conference hosted this year at the University of Villanova. The invited keynote speaker was Dr. Carolina Cruze (Inventor of the CAVE), and the conference saw 50 members from across the globe present on virtual reality topics, computing architecture, and strategic issues relating to how academic entities invest in and support their high-end technology installations. The Viz Center has provided letters of support for NSF research grants this year for the Departments of Atmospheric Sciences, Zoology and Physiology, Anthropology, Ecosystem Science and Management, Psychology, Program in Neuroscience, and the Biodiversity Institute.

The Viz Center (facility and staffing) was noted as a contributor on various research documents this year, such as “Hellgap in 3D poster at the Society for American Archaeology,” “3D Visualization of a rock art panel poster at the Wyoming Archaeology Society,” and “The Public

Administration Theory Network (PAT-Net),” in collaboration with the Dept. of Public Affairs and International Studies.

A collaboration with Cleveland State University has seen Ms. E. Alexander accepted into a round table discussion session on Human Fusions at the Society for Neuroscience in October 2019. Ms. E. Alexander also attended professional development at the Stern New York School of Business on “Breakthrough Technologies” and “Innovation: How to take your moonshot” in May 2019. The high-quality courses provided great insight into how to prepare a workplace for digital innovations.

Intern and Student Engagement

The Viz Center continues to benefit from an established group of student interns, who are all actively contributing towards real world projects. The newly established Technology Associate Program is providing them with a framework for their internships with a focus on skills development, Agile client interaction, and collaborative throughput. The Viz Center supports the UW program of summer activities and has this summer alone seen over 300 K12 students pass through the doors.

Here are some examples of projects that student interns are working on this year:

- Dept. of Theater - prop scanning, allowing digital props to be utilized in teaching.
- Dept. of Ecosystem Science and Management - K12 game promoting microbiology.
- Viz Center - 3D Future Form (VR obesity treatment tool).

Other SER Research Projects

U.S. China Clean Energy Research Center – Advanced Conversion Technology Center (CERC-ACTC)

The School of Energy Resources continues its work with the Joint U.S.-China Clean Energy Research Center – Advanced Coal Technology Consortium (CERC-ACTC), a joint research effort between the United States and China. The U.S. membership consists of federal, private, and public sectors and is managed for the DOE by West Virginia University. The first 5-year phase of the CERC-ACTC was completed in December 2015. A second 5-year, \$5.5 million contract to UW for two CERC Phase II projects has just completed its third year. The Phase II projects include a joint study to develop a commercial-scale integrated CCUS demonstration project, including CO₂ capture, transportation, utilization, and storage in the Ordos Basin of China, conducted by Dr.

Zunsheng Jiao in the Center for Economic Geology Research (formerly the Carbon Management Institute). The lesson learned from the Ordos CO₂ EOR/storage demonstration project would benefit Wyoming and U.S. CCUS projects by providing validated technologies on CO₂ storage and utilization with tight, unconventional reservoirs (i.e., Muddy Sandstone in the Powder River Basin, Lance Formation in the Great Green River Basin of Wyoming, and Bakken Formation in the Williston Basin). A second project is on a novel catalyzed carbon capture technology led by SER Professor Dr. Maohong Fan in the Department of Chemical Engineering. In the first three years of Phase II work, researchers on the CCUS project evaluated and validated existing technical and preliminary economic data for CO₂ utilization (enhanced oil recovery using CO₂ flooding) and CO₂ storage in stacked reservoirs of the Ordos Basin. The UW team has assisted the Yanchang Petroleum Group to implement a CO₂/storage pilot project in the Ordos Basin. The third year of work on the CO₂ capture project has consisted of bench-scale testing of a novel catalyst to improve the absorption/desorption efficiency of CO₂ in an amine system using simulated coal combustion flue gas.

Engineered Water and Gas Flooding Approaches for Improved Oil Recovery in Wyoming's Powder River Basin, Dr. Soheil Saraji

This project seeks to develop engineered techniques to address problems inherent to Powder River Basin reservoir rock. To begin the project, an experimental core flooding apparatus was modified to specifically test the reservoir types under this project. During FY19, Dr. Saraji worked with EORI and CEGR staff to identify representative reservoir samples from the United States Geological Survey Core Repository in Denver for experimentation. The project has been able to leverage additional funds from private industry and grant funds to supplement the project.

Enhanced Oil Recovery Institute – Steve Carpenter, Director

The report for the Enhanced Oil Recovery Institute (EORI) will be submitted under separate cover.

UW FOUNDATION ACCOUNTS THAT FUND RESEARCH AND SCHOLARSHIP

SER Nielson Awards

The very generous James E. Nielson Excellence Fund for the School of Energy Resources has one of the largest impacts of any fund at the University of Wyoming on students who are pursuing degrees in the energy sector. The nation is experiencing a growing demand for these new workers—and the University of Wyoming School of Energy Resources is answering that

call by continuing to increase the competitiveness of our students in critical thinking about energy transition and experience in energy research and development. The school focuses on the critical technologies and processes of this vital industry, as well as the impact to our future world. Thanks to the Nielson Fund, UW students come away with technical and commercial tools to become effective employees—and future leaders—in the highly complex world of energy. In turn, the energy industry plays a crucial role in the future of mankind, supporting governmental goals of doubling energy productivity by 2030 and developing the nation’s energy workforce while strengthening U.S. energy security, environmental quality, and economic vitality. The James E. Nielson Excellence Fund for the School of Energy Resources supports unique opportunities for UW students and faculty in the energy disciplines. This fund has a big impact on the School of Energy Resources and its students and researchers, and we wish to thank the donors for their great generosity.

Highlights include:

- *Nielson Energy Scholarship for Women and Minorities*, which promotes recruitment of highly talented women and minority students in the energy sector;
- *Nielson Scholars Award* is for first-time entering freshmen seeking their first bachelor’s degree;
- *James C. Nielson Transfer Student Scholarship* is offered to entering transfer students with an associate’s degree from a Wyoming community college;
- *Nielson Professional Land Management Scholarship* for students in the Professional Land Management program;
- *Nielson Experiential Learning Travel Support* is for students traveling to a professional conference for travel support;
- *Nielson Excellence Fellowship in Energy Studies* to recognize superior performance among faculty that participate in energy programs.

Anadarko Petroleum Corporation Chair in Energy and Environmental Technologies

The Anadarko Petroleum Corporation Chair in Energy and Environmental Technologies is a recent evolution of an endowment made by Anadarko Petroleum Corporation in 2009. The title of that endowment was “The Anadarko Fellowships for Excellence in Energy Scholarship,” and funds were used to provide support for UW undergraduate students, graduate students, and young faculty engaged in key energy disciplines. In recent discussions, an agreement was reached to create the Anadarko Petroleum Corporation Chair in Energy and Environmental Technologies. It is SER’s hope to fill this chair in the coming academic year. We are deeply grateful for Anadarko Petroleum Corporation's support.

Marathon Interdisciplinary Fossil Fuel Research Laboratory Support Fund

The Marathon Fund provided a stipend, tuition, and fees for one Geology graduate student, Garrett Gay. Mr. Gay’s project seeks to identify rare earth element bearing minerals in the Red Mountain Pluton of the Laramie Mountains and uranium roll front deposits in the Powder River Basin. Working closely with a Wyoming uranium company, Mr. Gay is developing a methodology for separating, dissolving, and analyzing mineral grains that can all be done in-house on the University campus. The methodologies will be used to assess potential REE resources of the field areas.

John and Jane Wold Centennial Chair in Energy

John and Jane Wold established the John and Jane Wold Centennial Chair in Energy at UW in 1990. This fund traditionally supports a research professor with “teaching ability as well as research” who has an international reputation. The chair has not been refilled since the retirement of Dr. Norman Morrow in 2015. For the 2020 academic year, expendable funds from the endowment will facilitate the addition of Dr. Brian M. Kelley to the faculty of the Geology department at UW. Dr. Kelly is an early career outstanding carbonate geologist who earned his PhD from Stanford and has been employed by ExxonMobil for the last five years. The expendable funds from the endowment will provide the first year of Dr. Kelley’s salary and partial startup funding. We plan to identify the next recipient of the Wold Chair during the coming academic year.

ENERGY POLICY & ECONOMICS

In 2018, SER formalized a new operating unit—the Center for Energy Regulation & Policy—that was tasked with laying the groundwork, including preparing a business plan, for the formal launch of an interdisciplinary energy focus, effective July 1, 2019 (see pg. 19). In 2018, those tasks were successfully accomplished, along with the following:

Published Policy-related Papers

Two LinkedIn articles were published on U.S. perspectives on international carbon trading and climate policy following a new EU agreement (the Electricity Regulation and Electricity Directive) that would impose a carbon dioxide emission limit on new coal-fired power plants and following a concluding session of the Paris Agreement COP24 meetings. The third publication, by the National Coal Council, assesses the value of the existing coal fleet and examines how to retain its continued operation, reform the regulatory environment, and renew investment in coal generation.

- Coddington, K. “Climate Policies in Flux for Coal-Fired Power Plants: EU Agrees on A CO₂ Emission Rate That Differs from U.S. Policy; Implications for CCS, Renewables.” LinkedIn Article (December 20, 2018) (available at <https://www.linkedin.com/pulse/climate-policies-flux-coal-fired-power-plants-eu-co2-rate-coddington/>)
- Coddington, K. “International Carbon Markets: Initial Observations from Yesterday’s Conclusion of the Paris Agreement COP24 Meetings.” LinkedIn Article (December 16, 2018) (available at <https://www.linkedin.com/pulse/international-carbon-markets-initial-observations-from-coddington/>)
- Contributing Author. “Power Reset: Optimizing the Existing Coal Fleet to Ensure a Reliable and Resilient Grid.” National Coal Council (October 2018) (available at <https://www.nationalcoalouncil.org/studies/2018/NCC-Power-Reset-2018.pdf>)

Engagement

Mr. Coddington attended various speaking engagements to update and present on topics in energy security, low-emission coal research, tax incentives, and the role of policy, law, and economics in the research impact of energy research and development. Speaking engagements included a CCS panel discussion at the DOE/NETL & Coal Utilization Research Council Technology Showcase, an update on the amended section of 45Q CCS Tax Incentive at the Wyoming Oil & Gas Fair in Casper, WY, and an update on low-carbon research at SER on the UW campus.

Student Education

- Fall 2018, "Energy Security"; Guest Lecturer; University of Wyoming, Global Energy Sustainability & Development

Speaking Engagements

- October 25, 2018: American Association for the Advancement of Science peer-review panel, which was convening for a review of an unrelated project on campus (Laramie, WY)
- October 25, 2018: “Update on Low-Emission Coal Research at the University of Wyoming” (Rotary Club of Laramie; Laramie, WY)
- October 4, 2018: CCS Panel Discussions (DOE/NETL & Coal Utilization Research Council Technology Showcase; Washington, D.C.)
- September 13, 2018: “Update on the Amended Section 45Q CCS Tax Incentive” (Wyoming Oil & Gas Fair; Casper, WY)
- May 30, 2018: “In Search of Research Impact in Energy R&D: The Role of Policy, Law & Economics” (Presentation to Idaho National Laboratory; Idaho Falls, ID)
- March 28, 2018: “Update on SER Low-Carbon Research” (School of Energy Resources, University of Wyoming; Laramie, WY)

Ongoing Grant Support

Ongoing research out of SER on Energy Policy & Economics includes CCS Policy Assessment, Dynamic Earth Energy Storage, Carbon Dioxide Transportation and Enhanced Oil Recovery Policy, and the examination of prefeasibility of commercial-scale carbon storage at Dry Fork Station and Rock Springs Uplift in Wyoming.

- Co-Principal Investigator (co-PI). “Carbon Dioxide Transportation and Enhanced Oil Recovery Policy Review” (private foundation(s), 2018-2019, circa \$36K) (underway)
- Co-PI. “Dynamic Earth Energy Storage: Terrawatt-Year, Grid-Scale Energy Storage Using Planet Earth as a Thermal Battery” (Idaho National Laboratory; U.S Department of Energy (DOE), Geothermal Technologies Office grant, 2018-2019, circa \$46K) (underway)
- Co-PI. “Commercial-Scale Carbon Storage Complex Feasibility Study at Dry Fork Station, Wyoming” (DOE/National Energy Technology Laboratory (NETL), DE-FE0031624, 2018-2020, circa \$10M) (underway)
- Co-PI. “Integrated Commercial Carbon Capture and Storage (CCS) Prefeasibility Study at Dry Fork Station, Wyoming” (DOE/NETL, DE-FE0029375, 2017-2019, circa \$1M) (underway)
- Co-PI. “Integrated Pre-Feasibility Study of a Commercial-Scale CCS Project in Formations of the Rock Springs Uplift, Wyoming” (DOE/NETL, DE-FE0029302, 2017-2019, circa \$1M) (underway)
- Lead Author. “CCS Policy Assessment” (private foundation(s), 2017-2019, circa \$20K) (underway)

EMERGING TECHNOLOGY

The Carbon Engineering Initiative (CEI) has, over the last three years, focused upon researching and proving processes and products that can be manufactured from Wyoming Powder River Basin (PRB) coal. The focus of these endeavors has been to:

1. Support and develop compelling clean-coal beneficiation and combustion solutions that have potential to sustain Wyoming coal as a competitive energy resource.
2. Develop new uses of Wyoming Powder River Basin (PRB) coal beyond combusting this abundant natural resource to produce energy and fuel.

A two-pronged strategy has been developed to achieve these objectives: (1) to organically develop new technology solutions within the University of Wyoming (UW) that have potential to have marked impact on existing and potential coal demand and markets and (2) to work with third party companies to understand the performance of their own proprietary technology on Wyoming coal, and if sufficiently compelling, attract and promote the further development and commercialization of these solutions in Wyoming itself.

FY19 Achievements, Progress, & Financial Outlook

Since 2016 and up to June 2019, the State of Wyoming will have invested in total \$13.2 million in CEI (FY17 = \$2.7 million, FY18 = \$4.7 million, FY19 = \$3.5 million, and for the forthcoming FY20, a nominal funding level of \$2.3 million has been appropriated). Further discretionary funds to support the salaries of 8 graduate (PhD level) students has been set aside from the College of Engineering and Applied Sciences (CEAS) Tier 1 Engineering initiative for FY19-20.

Research and Development

During FY 2018-19, the focus of CEI has been to: (1) appraise the techno-economic sensibility of proven coal conversion concepts and coal-based products that demonstrate an increased value for Wyoming coal and (2) understand the coal-based product qualities and match these to markets and business opportunities.

Highlights of the value-added research and development for Wyoming coal include:

- *Intellectual property.* A patent has been awarded for a novel thermo-chemical process to convert coal to make value-added products. Six further invention disclosures have been filed, which cover the transformation of the intermediate products made from this thermo-chemical process into carbon fiber products for electrical applications, green building materials, polymers, and asphalt materials. A further patent application was filed for the conversion of CO₂ produced from coal pyrolysis with natural gas into a rich petrochemical feedstock (syngas) using a dry reforming catalyst.
- *Market analysis.* CEI continues to conduct detailed process model analyses to better understand the economics surrounding a coal refinery and to realize market specifications of coal-based products.
- *Coal-based soil amendments.* A demonstration of soil amendment products made from PRB coal was completed at the University's Agricultural test site near Wheatland in conjunction with the SER Wyoming Restoration and Reclamation Center (WRRC). The tests involved the manufacturing of approximately six tons of coal-char carbon that was enriched with nitrogen (a crop nutrient). The one-year trial was able to optimize the soil amendment chemistry, which generated significant interest from agricultural and farming industry. For example, the project is pursuing a potential collaboration with the local sugar beet cooperatives, whom it is expected will be a collaborating partner(s) in the next planned demonstration field trials.
- *Coal-based asphalt and paving additives.* Broad formulations for coal-based asphalt road paving and additives were successfully proven in the laboratory and will now be demonstrated and benchmarked against standard oil-based paving materials over the coming year.
- *High temperature coal-based composites.* High-temperature resin systems, based upon polyurethane-phenolic together with polyamide chemistry, have been developed and product qualities have been quantified. The scale up of the resins into master batches for industrial evaluation is scheduled for the coming year.
- *Coal-based nano-products.* The manufacture of graphene oxide (GO) from Wyoming PRB coal successfully passed techno-economic appraisal, and following the filing of a patent, will now be scaled up. Samples will be sent to industry partners for their evaluation and appraisal.

- *Coal-based building products.* New coal-based bricks and wall plaster materials have been made from residual coal products, and the technology development phase has been completed. They have been proven to have robust properties and the potential to provide a substitute for cheap construction materials. In concert with a Denver-based brick manufacturing company, demonstration buildings will be constructed this year, and the thermal and weathering properties of the new coal-based construction materials will be measured.
- *Carbon fiber development.* Improvements have been made to the properties of carbon fiber made from PRB coal for electric utilities such as energy storage. The focus is now to complete benchmarking the properties of these products with those commercially available and to work with a technology company to investigate use in supercapacitor applications and products.
- *Coal to petrochemicals.* Further development work has been successfully completed on a dry reforming catalyst to convert CO₂ produced when pyrolyzing coal into a valuable cheap petrochemical feedstock (CO₂ + CH₄ = CO + H). The catalyst successfully passed continuous use in a small laboratory recirculating loop without showing coking tendency and reduced activity and exhibited superior performance to commercial variants available today. Steps are now being taken to complete kinetic studies and to evaluate the scale up of the catalyst in a large pilot plant facility. Use of this technology means that the products made from Wyoming coal mentioned above possess essentially a zero carbon footprint.
- *Coal-to-high-value chemicals.* The construction of a continuous thermo-chemical process pilot plant to demonstrate the advantage of flash-pyrolysis of coal merged with solvent extraction is near completion and will be used to produce sizable quantities of intermediate products that will be used by other CEI projects to make finished products, such as carbon fibers, resins, polymers, and asphalt materials.

Technology Transfer

Three technology transfer opportunities, related to bringing promising technologies to Wyoming, have developed. These studies relate to understanding the performance of Wyoming PRB coal in promising technologies developed by others. The end goal is to attract the technology provider to conduct business at a location in Wyoming.

Entities who have signed agreements to work with the CEI include:

- *Clean Coal Technologies Incorporated (CCTI)* – The CCTI technology seeks to beneficiate PRB coal and increase the Btu value. The company recently announced it will move its pilot plant to Gillette, Wyoming to further develop and showcase the technology and has signed a formal technology development agreement in which they will provide \$1 million, and SER will provide \$0.5 million in matching funds, to validate the long-term performance of the technology.
- *Itea SpA* – CEI continues to work with the company to develop a combustion model, a prerequisite to commercialization and scale up of the technology. The University of Wyoming Central Energy Plant, which burns coal, has been selected as the preferred location to demonstrate the flameless pressurized oxy-fuel (FPO) solution as part of a pending submission for a DOE award. Separately, SER has entered into an exclusive technology development framework agreement with the owner of FPO technology, which is currently being negotiated and subject to due diligence.
- *Carbon Fuels, LLC.* – Based upon an existing 16 tons a day pilot plant owned by Carbon Fuels, LLC., SER was one of the successful partners in a recent DOE award to evaluate and develop the technology on Wyoming PRB Coal. The technology claims to produce high yields of chemical liquids from coal through the rapid and deliberate addition of hydrogen, thereby upgrading the easily recovered coal liquids to higher value hydrocarbons.

A further non-exclusive technology transfer agreement is currently being negotiated with a South Dakota-based technology company. The parties have agreed to explore technology development opportunities that leverage both parties' proprietary technology solutions and to further investigate commercial business opportunities based upon processing Wyoming PRB coal in the State.

Finally, the CEI review committee recently met to conduct end of year project reviews and decided to fund only 9 of the 13 projects funded during FY19, favoring those where the solutions were fully proven and economically feasible and ready for technology scale up and/or demonstration. Those not funded, as they are still in the fundamental research stage, were offered cost share funding that permits them to find funding from other sources, such as federal awarded initiatives offered by the DOE.

Funding proposals that will be funded by CEI in FY20 relate to:

- Thermo-chemical processing of Wyoming coal to make valuable carbon-based materials
- Solvent extraction characterization of PRB coal intermediates from which to make finished products
- Green Building Materials
- Carbon fiber mats from PRB coal for electrical applications
- Coal-based soil amendment and nutrient products for poor quality soils in Wyoming
- Development of a dry reforming catalyst to manage CO₂ emitted during the pyrolysis processing of PRB coal
- Development of a combustion model and experimental demonstration of flameless oxy-fuel combustion (FPO) technology
- Asphalt products from Wyoming PRB coal
- Manufacture of coal-based resins and coatings from Wyoming PRB coal

ENGAGEMENT

SER seeks to engage broadly with experts in all sectors to disseminate knowledge that improves understanding and decision-making about issues currently facing Wyoming's and the nation's energy activities. Collaboration with UW colleges and local, national, and international industry and government leaders results in the convening of a dynamic selection of symposia, conferences, workshops, and speakers.

Speakers

SER Lunch & Learn Speaker Series – On Fridays during the noon hour, SER hosted 15 speakers as part of the SER Lunch & Learn Series. The speaker series provides a platform from which to talk about multidisciplinary energy problems. The SER speaker series continued to gain interest and attendance throughout the year. The speakers and titles from the FY19 academic year were as follows:

- Dr. Lisa Stright, Colorado St. University, *Impact of Bed-to-Geobody Architecture on Subsurface Reservoir Modeling: Testing Hypotheses Based on Deep-Water Channel Outcrops.*
- Dr. Bob Bradley, University of Oxford, *Carbon Materials for the 21st Century: Energy, Environment & Engineering.*
- Dr. David Bell, University of Wyoming, Chemical and Petroleum Engineering, *Fractionation of Coal as the First Step in Coal Refinery.*
- Mr. Hosokawa and Dr. Boisnier Etienne, CoalinQ, *Opportunities and Challenges for PRB Coal in Japan: a Changing Market.*
- Dr. J. Fred McLaughlin, School of Energy Resources, Center of Economic Geology Research, *Advancing Wyoming's Carbon Management Programs.*
- Dr. Soheil Saraji, University of Wyoming, Petroleum Engineering, *Complex Fluids for Enhanced Oil Recovery.*
- Dr. Richard Middleton, Los Alamos National Laboratory, *SimCCS: Helping to Make CO₂ Capture and Storage a Reality.*
- Dr. Mark Engle, United States Geological Survey, *Predicting Rare Earth Element Potential in Produced and Geothermal Waters of the United States: Application of Emergent Self-Organizing Maps, Subject: USGS Oil and Gas Produced Waters Research.*

- Dr. Roe-Hoan Yoon, Center for Advanced Separation Technologies, Virginia Tech, *Hydrophobic Force: True or False*.
- Mr. Alec Nettleton, Schlumberger-Wellbore Integrity North America, *An Overview of Wellbore Integrity and the Tools Available to Aide in Cement Placement and Casting Integrity*.
- Dr. John Hoberg, Dr. Bruce Parkinson, and Dr. Katie Li, University of Wyoming, Chemistry and Chemical Engineering, *Fully modifiable, highly ordered, nanoporous, two-dimensional covalent organic frameworks: synthesis, characterization and applications*.
- Dr. Llewelyn Hughes, Associate Dean of Research, College of Asia & the Pacific, *Japan and Australia: Contrasting Energy Transitions*.
- Dr. Lars Kotthff, Associate Professor of Computer Science, University of Wyoming, *An Introduction to Machine Learning, with Applications in Engineering*.
- Dr. Ben Cook, Sr. Energy Economist for the Enhanced Oil Recovery Institute, *An Economic Introduction to Integrated Resource Planning (IRP), Coal's Heavy Lift, and Tax-Equity Financing for Capture*.
- Dr. Pejman Tahmasebi, Assistant Professor of Mechanical and Civil Engineering, University of Wyoming, *Multiscale and Multiphysics Subsurface Modeling: High Order Statistics and Machine Learning*.

Events

- *Rocky Mountain Rendezvous* – The Rocky Mountain Rendezvous (RMR) is co-hosted by the University of Wyoming Geology and Geophysics and SER. The RMR is a three-day event that includes field trips, a networking lunch, a venter expo, and onsite interviews that connect geoscience students with recruiters. This year, the event attracted 224 geoscience students from 84 universities and 35 recruiters from 20 companies.
- *Energy Law & Policy in the Rockies* – The Energy Law & Public Policy in the Rockies conference is co-hosted by SER and the College of Law's Center for Law and Energy Resources in the Rockies. The event brings together stakeholders with collaborative interests to engage in a thought-provoking discussion on key energy topics currently at play in Wyoming, the region, and the nation. The one-day conference had an attendance of 186, up from 160 people in 2017.
- *Saturday U* – SER had a successful community outreach meeting in Gillette and Sheridan for the Wyoming CarbonSAFE project. The meeting in Gillette took place on February 21st, utilizing the University of Wyoming Saturday U program (https://www.gillettenewsrecord.com/news/local/article_e0a1a0b8-4ae8-5ea1-8101-

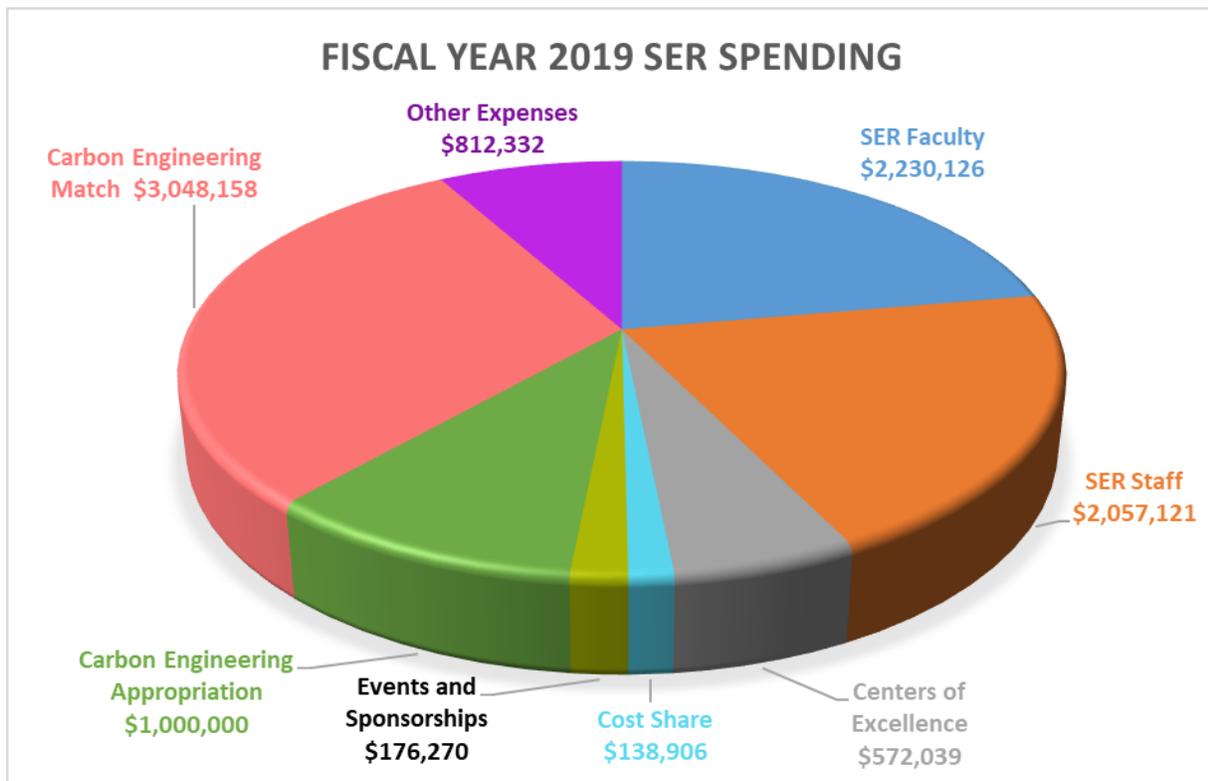
[15b203a9da4f.html](#)). There was a record attendance of roughly 130 people. Likely, the most valuable part was a 1-hour discussion with the community; the contents of the discussion was *Gaining a social license to operate*, moderated by Dr. Jessica Western (https://www.gillette newsrecord.com/news/local/article_e1beeefc-3c94-55bb-984c-83c6c1eb5271.html). The same program was then given two days later in Sheridan, WY (https://trib.com/news/state-and-regional/researchers-argue-for-low-carbon-future-for-state/article_a862170d-6879-5280-a151-7f16e3bc6062.html).

FINANCIAL SUMMARY

The Wyoming State Legislature provided funding for the School of Energy Resources over the 2019-20 biennium in the State of Wyoming 2018 Budget Session in the amount of \$19,303,167. Of this, \$1,000,000 was a one-time appropriation for the Carbon Engineering Initiative.

In Fiscal Year 2019, \$10,034,952 was spent. The remaining \$9,268,215 will be spent in Fiscal Year 2020.

FY19 State Appropriations Spent



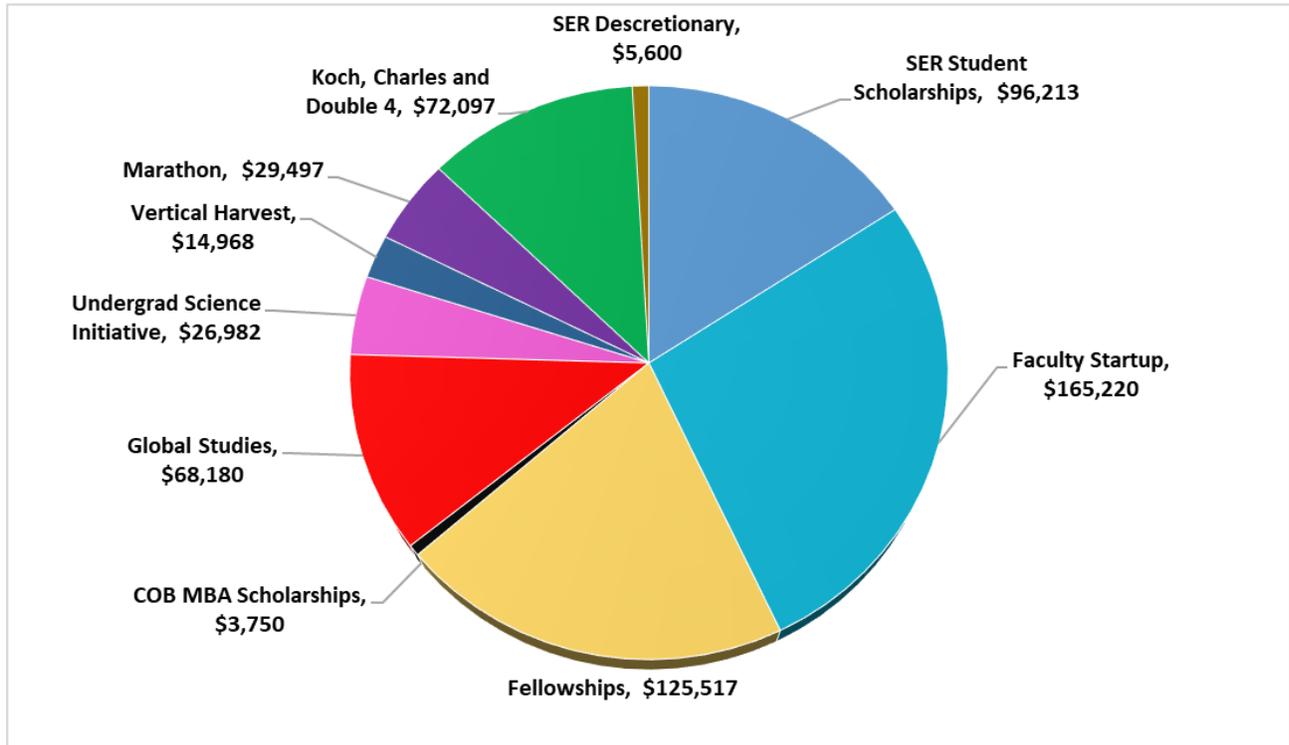
In FY19 SER spent:

- \$2,230,126 for salaries and benefits for SER faculty
- \$2,057,121 for salaries and benefits for SER staff
- \$572,039 to support research activities for the Centers of Excellence
- \$138,906 in cost share support for state and federal research grants
- \$176,270 for events and sponsorships
- \$1,000,000 from the one-time appropriation for carbon engineering research
- \$3,048,158 from SER's standard budget to support carbon engineering research
- \$812,332 in remaining expenses that include graduate assistantships, recruiting, travel, publications, office support, etc.

- 74 different undergrad and graduate students were funded by SER's standard budget.

In Fiscal Year 2019, SER utilized \$608,024 of private gift funds held at the UW Foundation.

FY19 Foundation Spent



- \$500,830 - Nielson, James E. Excellence Fund
 - \$96,213 SER Student scholarships
 - \$165,220 Faculty startup
 - \$125,517 Fellowships
 - \$3,750 COB MBA Scholarships
 - \$68,180 Center for Global Studies
 - \$26,982 Undergrad Science Initiative
 - \$14,968 Vertical Harvest
- \$29,497 – Marathon Interdisciplinary Fossil Fuel Research Lab
 - \$29,497 Geology G.A.
- \$72,097 – Koch, Charles and Double 4 Foundation
 - Materials and supplies, Salaries and Fringe
- \$5,600 – SER Discretionary

CONCLUSION

Fiscal Year 2019 was one of new successes for SER. Guided by our five-year strategic plan, we utilized a significant portion of SER's budget to advance our portfolio of technologies that exploit the non-Btu value of coal in the direction of commercialization with a strong focus on collaboration with the private sector to develop economic value for the state. That latter focus has permeated much of SER programmatic support. Our previous reputation-building research in carbon management was leveraged to capture significant new grant funding that promises to create a globally significant integrated technology demonstration presence in Wyoming. Also, our academic program has become more focused on air, land, and water management, and student success is growing as a result.

Chief among our accomplishments this year are:

- The Carbon Engineering Initiative (CEI) developed a patent for a novel thermo-chemical process to convert coal to make value-added products, and six further invention disclosures have been filed.
- The establishment of a Carbon Engineering Laboratory in the Energy Innovation Center
- The University of Wyoming Central Energy Plant has been selected as the preferred location to demonstrate the flameless pressurized oxy-fuel solution (FPO) as part of a pending submission for a DOE award. SER has entered into an exclusive technology development framework agreement with the owner of FPO technology.
- Three companies have signed agreements to work with the CEI, including Clean Coal Technologies Incorporated, Itea SpA, and Carbon Fuels, LLC., to utilize their proprietary technology solutions on Wyoming PRB coal.
- Investigation of geological CO₂ storage potential in Phase II of the Wyoming CarbonSAFE project at Dry Fork Station commenced. The project is supported by roughly \$12.2 million in grant funding from DOE's Carbon Storage Program.
- The 3D Visualization Center has shown significant growth. A fee model for services has been further developed this year to accommodate the rising need for short courses, and multiple contracts have been developed this year for external entities.
- Seven diverse Centers of Excellence are active. Some have achieved financial independence, and others are successfully competing for grants.
- Graduation of 9 students from the Energy Resource Management and Development program. 100% of the graduates successfully found jobs.

- A successful year of knowledge transfer and engagement through domestic and international events and hosting of distinguished speakers.
- SER formalized a new operating unit—the Center for Energy Regulation and Policy—with a prepared business plan.

Looking forward, we anticipate continued delivery of important outcomes in FY 2020. These include continued investment in the Carbon Engineering Initiative, successful completion of the feasibility study of the carbon capture and storage project at Dry Fork Station, successful placement of SER students in the workforce, demonstration of technology, continued significant growth of the 3D Visualization Center, continued development of new uses for Wyoming's natural resources, and future growth of the outreach program.

ADDENDUM

Strategic Plan of the School of Energy Resources at the University of Wyoming 2017-2022

Preamble

The School of Energy Resources (SER) partners with the University of Wyoming (UW) colleges, with the state government, and with the energy sector to develop solutions to energy challenges in Wyoming and elsewhere and to strengthen and diversify Wyoming's economy and UW's energy brand.

Vision

SER pursues the creation, sharing, and implementation of technology and knowledge for sustainable economic production of Wyoming's natural resources to generate additional employment and revenue opportunities for the state that include supply of clean energy and materials and products.

Mission

SER develops and deploys expertise to solve critical energy challenges, add value to the Wyoming energy sector, and position UW as a primary provider for energy innovation at the national level. In pursuit of this mission, SER facilitates internal and external interdisciplinary coalitions and builds institutional capacity in energy education, research, and outreach.

SER distinguishes its programs in areas of strategic importance to Wyoming's economy by focusing technology development and academic activities primarily in four strategic areas of concentration:

- Maximizing the economic recovery of fossil energy and mineral resources;
- Protecting existing markets for fossil fuels;
- Creating new markets – traditional and value-added – from Wyoming energy and mineral resources; and

- Educating the workforce and stakeholders to facilitate diversification of the energy sector through addition of value-added activities.

We seek to develop and deploy new technologies and to educate the workforce and stakeholders in these areas to deliver broad and significant benefits to the state and the energy industry. Chief among these benefits are:

- Growth in energy-based revenue streams for Wyoming
- A hedge against boom and bust economic cycles
- A well-trained, homegrown workforce
- Enhanced competitiveness at UW for student and faculty recruiting, corporate partnerships, and funding
- Mutual gain for UW and industry from cooperative relationships
- Improved performance in monetizing Wyoming's most valuable energy assets

Values

Leadership

Sharing a clear vision for the future of Wyoming's energy and mineral resources guides our provision of technology, knowledge, and processes for stakeholders to create value in new and innovative ways.

Innovation and Application

Motivating collaborative, creative thinking leads to new knowledge, inspires student and faculty achievement, and brings practical, innovative solutions to challenges in the energy sector.

Focus on Commercial Outcomes

An eye towards eventual benefits to growth, diversification, and sustainability of Wyoming's economy guides our investment of resources.

Engagement and Partnership

Engagement with local, state, national, and global constituencies inspires and informs our work. We seek to collaborate broadly with experts in all sectors to bring together the skills and knowledge required to solve problems.

Thinking Locally, Acting Globally

SER recognizes that solutions for Wyoming's challenges are not unique and may have their genesis in foreign settings. We seek global partnerships in pursuit of our mission.

Disciplinary and Interdisciplinarity

Knowledge advances through intense and focused study, and also, in the intersection of ideas and disciplines. SER supports both in pursuit of solutions.

Goals and Objectives

SER has four focus areas, as described below.

Education

1. Develop the workforce for a more diverse energy economy. Work with deans and faculty in the UW colleges to:
 - a. Motivate development of energy curricula consistent with the needs of the state.
 - b. Keep energy curricula relevant to the needs of employers.
 - c. Design new curricula in carbon engineering, manufacturing, and material science.
 - d. Grow enrollment in energy degree programs by recruiting and graduating a diverse community of students.
 - e. Graduate creative thinkers capable of meeting the unpredictable and complex challenges of our future energy needs.
 - f. Achieve improved employment outcomes for graduates.
2. Advance energy literacy in Wyoming and beyond
 - a. Disseminate knowledge that improves understanding and decision-making about issues currently facing Wyoming's energy activities.
 - b. Become a reliable resource for information about potential solutions to energy issues.

Research

1. Continue to support a strong culture of relevant, innovative research that fosters innovation in line with the needs of the energy sector in Wyoming.
2. Partner with the energy industry to ensure relevance and to address critical issues.
3. Motivate and support Centers of Excellence that bring together interdisciplinary research teams to address critical issues in the energy arena.
4. Provide seed funding for faculty research on key topics and financial support for graduate and undergraduate student research.
5. Distinguish energy programs at UW over the next five years by concentrating research funding in three strategic areas:
 - A. Maximizing the economic recovery of fossil energy and mineral resources
 - i. Improving recovery of oil and gas from unconventional and mature reservoirs through fundamental knowledge of flow through porous media;
 - ii. Developing process and materials to enhance recovery of oil, gas, and minerals; and
 - iii. Reducing cost of producing oil, gas, and minerals through geomechanical, petrophysical, and modeling studies.
 - B. Protecting existing markets for coal, oil, gas, and other energy resources
 - i. Carbon dioxide capture, utilization, and geologic storage technology innovation, improvement, and implementation,
 - ii. Air and water quality studies,
 - iii. Efficiency improvements in energy production (fossil and renewable),
 - iv. Assessment of how energy regulation and policy impacts Wyoming resources.
 - C. Creating new markets—traditional and value-added—for Wyoming energy and mineral resources
 - i. New export markets for Wyoming energy and mineral resources.
 - ii. Carbon engineering value-added products from coal and low-value petroleum.
 - iii. Rare Earth Element recovery and separations.

- iv. Exploitation of oil shales for silica-based materials production.
- v. Explore new markets and applications for renewable energy resources.

Energy Regulation and Policy

1. Develop a plan of operations for SER and UW in this important new area. The overriding premise is that better informed policy-making will reduce the occurrence of unintended consequences for the energy sector, the economy, and the environment.
2. Develop a research protocol for generation and analysis of policy options.
3. Convene an annual forum for discussion among global experts in this area that will result in a proceedings publication.
4. Over time, engage directly with policy makers through briefings and/or formal testimony.

Technology Deployment & New Ventures

This new enterprise will be undertaken in collaboration with:

- UW Vice President for Research and Economic Development
 - Wyoming Technology Business Center
 - Director of Economic Diversification Strategy and Initiative
 - CEO of Wyoming Business Council
1. Motivate and enable researchers to develop their energy technologies to higher levels of readiness, to the point where they are attractive for commercialization;
 2. Identify and engage with individuals, companies, and agencies that may invest in, license, and otherwise support development and commercialization of said technologies;
 3. Work with the inventors to strategically publicize and otherwise increase the awareness of the most promising energy technologies; and
 4. Collaborate with the above-mentioned entities to evaluate ways that these technologies can be exploited for diversification of Wyoming's economy.