



SCHOOL OF ENERGY RESOURCES



ACADEMICS



RESEARCH



TECHNOLOGY



ENGAGEMENT

SEPTEMBER 28, 2018

ANNUAL REPORT



UNIVERSITY OF WYOMING

Please Note: This is a preliminary draft submitted for the purposes of the August 27th Joint Minerals and Economic Development Meeting. The final version will be submitted before the end of September.

**THE UNIVERSITY OF WYOMING SCHOOL OF ENERGY RESOURCES
ANNUAL REPORT FY 2018**

SEPTEMBER 28, 2018

Presented to:

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

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DRAFT

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. Through targeted engagement efforts, the bridges formed between academics and industry ensures programs are relevant, current and deliver impact and high value to stakeholders

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, 2017, through June 30, 2018, in the areas of research, academics, engagement and newly emerging areas of focus to keep UW and Wyoming at the forefront of the energy sector.

Fiscal year 2018 (FY18) was the first full year of activities guided by a new five-year strategic plan (provided as an Addendum to this report). 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 FY18.

Programmatic highlights over the period include:

1. The carbon engineering initiative, established in FY16, is moving aggressively from proving concepts in the laboratory to developing technology products. During FY18, funding consisting of \$500 thousand special appropriation for carbon engineering together with \$80 thousand of private funding and \$4.1 million from SER state funds has been expended. A significant patent portfolio is emerging. A dedicated carbon engineering laboratory has been established to accelerate program outcomes by providing a broader range of analytical equipment to all researchers and promoting collaborative discovery.
2. An influx of successful federal awards, \$9 million from DOE alone, has permitted existing activities on carbon capture, utilization and storage (CCUS) to flourish and new project

opportunities to begin. These funds will accelerate our activities related to developing solutions that could potentially secure future long-term operation of coal-fired energy generation facilities.

3. Further investment of \$0.865 million in nine energy related Centers of Excellence, has allowed some to now become financially independent of State funds and has resulted in faculty securing grants from external sources.
4. The graduation of 18 students from the Energy Resource Management and Development Bachelors of Science program with most successfully finding jobs.
5. SER's engagement program sustained a robust set of offerings by hosted four professional speakers, continuing an active SER Faculty Speaker Series and sponsoring 11 events held at UW and various locations around Wyoming

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 in attracting companies that want to operate in that arena to the state.

RESEARCH

Centers of Excellence

Center for Economic Geology Research (formerly Carbon Management Institute) – Kipp Coddington, Director

The Carbon Management Institute (CMI) formally rebranded itself as the Center for Economic Geology Research (CEGR) earlier this year to reflect an expanding portfolio of grant-funded applied geologic research for the benefit of the State of Wyoming. CEGR will continue to use the CMI brand to advance its ever-broadening work related to carbon dioxide (CO₂) geologic sequestration technologies. The expanding portfolio of grant-funded work includes research related to (1) the identification and characterization of rare earth elements (REE) in Wyoming coals and produced waters; and (2) energy policy studies. Nascent opportunities related to grid-scale energy storage and advanced geothermal drilling technologies are being pursued.

CEGR continues to expand its sources of funding too. 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 \$52M in grants. CEGR is currently entirely grant-funded in the approximate amount of \$22.8M (including cost share), with the result that 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 currently is now receiving direct (i.e., non-competitive) funding from DOE for applied research related to REEs. Potential funding opportunities from the private sector, including foundations, are also being pursued.

In another significant new development, CEGR was one of only three research teams in the United States to receive Phase 2 (feasibility) funding (\$12.2M, including cost share) under DOE's Carbon Storage Assurance and Facility Enterprise (CarbonSAFE) program. CarbonSAFE's goal is the siting and operation of several large-scale integrated carbon capture, utilization, and storage (CCUS) projects throughout the United States by the 2025 timeframe, with coal-fired power plants as the preferred CO₂ source. Each project site must eventually meet minimum CO₂ storage goals (at least 50M metric tons over 25 years) while putting forward business cases to make the projects economic to the extent feasible. CEGR's Phase 2 site is at Dry Fork Station (DFS) in Gillette. Separately under CarbonSAFE, CEGR continues its Phase 1

(prefeasibility) research at both DFS and the Rock Springs Uplift/Jim Bridger Plant and is supporting the related CCUS project in Kemper County, Mississippi.

CEGR also remains active in China under the DOE-funded Joint U.S.-China Clean Energy Research Center (CERC). Under the CERC initiative, CEGR researchers are working on a CO₂-enhanced oil recovery (EOR) storage project in the Ordos Basin, China. Over the years Wyoming and Chinese policymakers have built many bridges regarding CCUS policy and projects because of the two jurisdictions' shared interest in advancing coal usage and coal markets. CEGR is at the leading edge of these ongoing bilateral efforts.

CEGR concluded the DOE-funded work on REE concentration in produced and geothermal waters on June 30th. The funding was for approximately \$1 million over a two-year period. The research was conducted in collaboration with Idaho National Laboratory, the Center for Advanced Energy Studies in Idaho Falls, and the U.S. Geological Survey. The end result of this work is a first-of-its-kind national database of REEs in produced waters and REE predictions for nearly all geologic reservoirs across the US. Our presentations and publications of this work received national and international attention, including two invitations to deliver key-note presentations: the first at the Goldschmidt International Conference for Geochemistry in Paris, France and the second for the International Association for Mathematical Geoscience Meeting in Olomouc, Czech Republic. CEGR will continue to build upon this work through an additional year of funding provided by the University of Wyoming Water Research Program, which will focus on the remaining Wyoming geologic basins not previously addressed in prior investigations.

Center for Air Quality – Shane Murphy, Director

The aim of the Center for Air Quality (CAQ) is to better understand and mitigate air quality issues related to energy production. This allows for continued energy production while minimizing air quality impacts. This past year the Center has worked with energy companies (Jonah Energy), non-profits (Environmental Defense Fund, Clean Air Task Force, and Wyoming Outdoor Council), regulatory agencies (Wyoming DEQ, EPA Region 8), Federal agencies (BLM, NOAA), regional universities (Colorado State, University of Colorado) and Wyoming Schools (Saratoga High School) to accomplish this aim. Perhaps the most exciting news is the addition of new faculty to CAQ. Dr. Dana Caulton is a new assistant professor in the Department of Atmospheric Science from Princeton and she will become a critical new member of the Center. Dr. Caulton has extensive experience in quantifying fugitive emissions from energy development and other sources. Dr. Zach Lebo, also an assistant professor at the University, will be joining the CAQ to assist with the development of air quality models. Dr. Lebo has extensive

modeling experience having completed postdoctoral assignments at both the National Center for Atmospheric Research and the National Oceanic and Atmospheric Administration, and will significantly enhance the capabilities of the Center in the modeling domain.

Publications & Presentations

The data of CAQ's faculty and students were used as the foundation for two high profile articles. Specifically, CAQ's recent publication (Robertson et al., 2017) was used as a primary data source for a paper published in *Science* (Alvarez et al., 2018) that estimates methane emissions from oil/gas production based on observational data. The paper was widely reported in the popular press including an article in the *New York Times*.

Additionally, CAQ published papers detailing methane and volatile organic compound emissions related to energy production and distribution in Arkansas (Bell et al., 2017) and the United Kingdom (Derwent et al., 2017). Dr. Robert Field was a primary author for an EU report titled "Unconventional oil and gas development: Evaluation of selected hydrocarbons in the ambient air of three basins in the United States by means of diffusive sampling measurements." The report is one of the first EU reports on this topic and was presented at a seminar exploring recent advances in understanding oil and gas emissions at the Joint Research Center of the European Commission in Italy.

Two graduate students involved in the Center (Anna Robertson and Rachel Edie) gave presentations at the annual meeting of the American Geophysical Union in New Orleans, LA.

Projects and Activities

Over the past year CAQ continued renovation and upgrade of the Wyoming Air Quality Assessment Monitoring Laboratory (WAQAML), which included a new instrument for measuring ozone, a new ultra-pure zero air generator, and a new compressor for calibration. This on-going renovation was performed to support the deployment of the WAQAML to a new baseline monitoring site in Carbon County, Wyoming. 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*, (2016).

CAQ developed a proposal to create a functional photochemical model of the Upper Green River Basin (UGRB) of Wyoming. This model, based on the Weather Research and Forecasting Chemistry (WRF-Chem) model, will enable assessment of the air quality impacts of future energy development of the UGRB and evaluation of the impact of various control strategies. The

CAQ has secured two graduate fellowships for this project and has formed strong collaborations with NOAA, the University of Colorado, and the Environmental Defense Fund to pursue its completion over the next two years.

The CAQ Mobile Lab has been deployed twice this past year to the Front Range of Colorado in a collaborative project with the University of Colorado to measure levels of volatile organic compounds in urban areas near oil/gas development. CAQ is currently organizing additional field campaigns where measurements of methane fluxes will be made in several poorly characterized basins that are important to U.S. natural gas production.

Outreach

A new three-year program with Saratoga High School started with a series of classroom visits with students using personal air quality monitors. The CAQ also installed three particulate matter monitors in Wyoming: (1) BLM WAQAML site; (2) Saratoga High School and; 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 US.

Also this year CAQ launched a program for undergraduate research assistantships. The aim of the program is to provide a valuable experience for students while supporting core CAQ program goals including data management, air quality monitoring, and engagement events with the general public. In June 2018, CAQ provided a workshop for the Native American Institute and a weeklong workshop for the Engineering Summer Program entitled “How clean is the Air you breathe?” The workshop exposed participants to critical air quality concepts and calculations together with hands-on demonstrations with calibrating instruments and using personal air quality samplers.

Center for Biogenic Natural Gas Research – Michael Urynowicz, Director

The Center for Biogenic Natural Gas Research (CBNG) develops novel technologies that add value to Wyoming’s natural resources by bridging the gap between renewable energy and fossil fuels. CBNG has achieved financial self-sufficiency and will not receive operating funds from SER in the coming fiscal year.

The CBNG would like to highlight two projects from FY2017, one international and one domestic. Internationally, the Center has begun a project with the Vietnamese Government to investigate the feasibility of in situ biogasification in the Black River Basin. It is a one-year project that will involve two graduate students from the University of Wyoming.

Closer to home, the Center will be collecting several coal samples in the Powder River Basin outside of Gillette at three different depths within the Big George formation. The project is in collaboration with Vanguard Energy which is drilling the first coal bed methane wells in the Powder River Basin in nearly a decade.

The Center is collaborating with Emerald Energy to perform a field demonstration later this year for the production of low carbon renewable natural gas in the Powder River Basin. The field demonstration is the first-of-its-kind and will be using Emerald Energy's patent pending Gem Tool Technology which uses reverse osmosis to extract the biogas without the need for de-watering.

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 fiscal year 2018, CEEPP continued to assess and analyze Wyoming's tax structure and how it affects competitiveness in the wind industry. The most recent report is nearing completion and will be released early in fiscal year 2019.

The Center recently completed an annual effort to define the Wyoming's Prevailing Wages used in Federal and State-funded construction projects in 2018-19. CEEPP personnel annually conduct this survey of skilled occupations to determine prevailing market wages in the building, heavy and highway construction including energy projects. Center personnel have been involved in developing economic opportunities to diversify the state economy within and outside the energy sector. This effort is being conducted in conjunction with the state's Economically Needed Diversity Options for Wyoming (ENDOW) initiative.

CEEPP continued to be involved in federally-funded research projects, including an on-going \$5.2M 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. A second \$4.2M 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.

Other related projects include continued development of models of Wyoming's electricity grid, analysis of Wyoming's coal sector, and an analysis of the potential of coal ash remediation to produce REEs while reducing ash mitigation costs. 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

On October 2-3, 2017, CEEPP organized "*Wyoming's Wind Energy Future*", a 2-day public conference meant to stimulate statewide conversation regarding the opportunities and challenges of long-term wind energy development in the state. Over 300 participants and attendees, including public officials, policy-makers, and business interests, were at the conference. The event was hosted as a joint CEEPP/Haub School initiative.

During 2017-2018, CEEPP gave 18 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.

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

The Center of Excellence in Produced Water Management (CEPWM) was established in the College of Engineering and School of Energy Resources 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 2017-2018 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 (i.e., extremely difficult to wet). These superhydrophobic membranes are used for recovering free and dispersed hydrocarbons from produced waters. Successful development of these membranes will lead to reduced energy consumption during the desalination of produced waters and other brines. 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. Some biocides have been linked to a variety of negative outcomes, such as the development of biocide resistant microbes in the subsurface.

CEPWM is currently working with private and public partners in Oklahoma to design and build a research demonstration test bed in Stillwater, OK. Partners in this effort include Whitestar Petroleum, Oklahoma State University, the University of Oklahoma, the Central Electro Cooperative, and the National Research Consortium. This demonstration site will be capable of treating 1,000 barrels of produced water a day and provide facilities for the testing of advanced produced water treatment technologies. The site will also allow for the evaluation of using renewable energy resources, like solar and wind, to power distributed produced water treatment systems. CEPWM serves as the technical lead for this project.

SER funds were also used to support three undergraduate researchers and one doctoral student working on a variety of projects in Dr. Brant and Dr. Wawrousek's lab. These projects include developing nanofiltration processes for REEs from brines and evaluating ceramic microfiltration processes for solids and oil separation from produced waters.

Center for Photoconversion and Catalysis – Bruce Parkinson, Director and Carrick Eggleston, Associate Director

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.

The roof-top photovoltaics (PV) on the Energy Innovation Center (EIC) have been in full operation for just over two years. CPAC has closely monitored its performance. In the first year of operation, the system ran at a capacity factor of 22% and was often producing above its peak rating. When the performance is compared to standard operating systems in Germany, the EIC system produces approximately double the energy and performed well seasonally. The system output varied relatively little between winter and summer as well – speaking to the trade-off between longer days in summer but lower temperatures (that enhance the energy output of the silicon photovoltaics) during the winter.

CPAC continued its focus on hydrogen separation. This project involves solar-derived hydrogen from water to produce a liquid fuel (methanol) using synthesis gas derived from Wyoming coal. Over the last year, CPAC completed the design phase and purchased the necessary components. During the fall semester of 2018, engineering students will begin the assembly and initial testing of this system.

CPAC began an economic analysis to investigate utility-scale solar installations in Wyoming. This is a collaborative work with SER students and faculty from the business school. Preliminary results suggest that solar photovoltaics at the utility scale could benefit the state with both sales and property tax revenues. We estimate that depending on the size of a project, revenues could be on the order of a hundred(s) million dollars. Obstacles to solar include the capacity of available power transmission to target markets. Therefore, future work will investigate promising solar energy install sites that have access to the electrical grid including the concept of co-location of solar arrays with wind farms.

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 experimental services to industry.

The Viz Center has seen some exciting advances this year regarding use and increased capacity. These advances were realized through an additional SER investment of \$75,000 for procurement of new technologies. The additional investment allowed the Viz Center to establish its first portable Virtual Reality set up, purchase a ground-based 3D laser scanner, and purchase a variety of 3D 360 cameras and video cameras. Since the procurement in June, portable VIVE head-mounted display technology has been taken on the road to support the Department of Civil and Architectural Engineering, 360^o cameras have been taken for an experiment to capture poverty housing in Europe by the Department of Political Science, and the Department of Anthropology has added the ground-based LIDAR scanner into several pending grant applications.

Developed and approved last year, the fee model was utilized in two external contracts this year. Each contract is with a Croatia museum. The focus of these projects is to create a 3D virtual reality installation and to present research from the Department of Anthropology regarding bat caves. The goal of this work is to recreate a 3D version of a bat cave, which will allow researchers to examine attributes of the field site, such as animal tracks, in high detail. The Viz Center was awarded additional funding through a competitive internal grant process through a UW Arts & Sciences Award. This project is developing a Life Science Augmented Learning Tool in collaboration with the College of Education and the Department of Molecular Biology.

The Viz Center would like to highlight a few additional projects that were launched this year, including:

- Fossil Viz – Funded and in collaboration with the UW Geology museum this project aims to depict a timeline of prehistoric environments and fossil data accessible via the web on a desktop device as well as in 3D virtual reality. This is to support teaching and outreach for the museum.
- Soil Sim – Utilizing 3D virtual reality, this project aims to depict how vegetation drives soil formation.
- Volcano Sim – A collaboration with CEGR, to create a 3D virtual reality simulation of a volcano to support K-12 science curriculum.

A collaboration was formed with the Department of Civil and Architectural Engineering to use virtual reality technology to improve communication between architects and their clients. A highlight of this work is an ongoing student independent study over the summer that utilizes VIVE head-mounted displays in the Viz Center. The promising preliminary results of this work suggest that the technology allows the clients to have a more engaging and useful review of their home design thus substantiating the use of the technology.

The Viz Center has successfully adopted the Agile Scrum methodology. Agile Scrum provides a methodology to manage a project using a flexible framework, and promotes close communication between the client and developers. It is highly visible how this methodology positively impacts the development of tools supporting teaching and research, and how it brings together the clients and developers in a highly productive and creative way.

Contributions, Presentations, and Professional Service.

The Viz Center remains an active contributor to professional meetings and workshops. Viz Center staff and students have had multiple abstracts accepted to the Rocky Mountain Advanced Computing Consortia (RMACC) in August 2018; Viz Center Virtual Reality Developer, Kyle Summerfield, will be presenting two papers, *Real-time Rendering in VR with Unity 3D* and *Designing in the Dark-guiding research-driven software with visualization*.

Alexander's project, *3D Future Form* was a qualifying finalist in the UW Wyoming Technology Business Center's *Fischer Innovation Challenge* in November. The project put forth a business concept that specializes in Virtual Reality tools to support the treatment of obesity.

Alexander remains the current president and founding member of The Higher Education Campus Alliance for Advanced Visualization (THE CAAV). The group now has 188 members. Non-profit status has been filed, and all documentation is with counsel to finalize the process. The 2nd annual conference was held in October 2017; Alexander chaired the 2-day event which was well received by the attending members. In addition to THE CAAV, Alexander was invited to be a technical reviewer of a special track at the 13th International Symposium on Visual Computing (ISVC'18). The papers are regarding Artificial Intelligence in Immersive Environments.

Intern and Student engagement

The Viz Center is benefiting from a particularly engaging and talented group of student interns this summer, most of which have worked or volunteered in the facility for at least two semesters. They are leading projects with real-world clients and are taking on the roles of developers using the Agile Scrum methodology.

To widen access further to K-12 students this summer, the Viz Center is supporting a forward-thinking group of high school students taking part in the UW Summer Apprenticeship Program. The program allows Virtual Reality content development to create an interactive visualization component for their final project presentation.

Wyoming Restoration and Reclamation Center – Pete Stahl, Director

The Wyoming Reclamation and Restoration Center (WRRC) helps to maintain and protect Wyoming's land, air, water and wildlife by promoting restoration of the complex components and functions of disturbed ecosystems. With a special emphasis on energy and natural resource development activities in the arid west, WRRC a) educates new professionals, b) provides information about ecological restoration and land reclamation, c) creates new knowledge, and d) addresses the concerns of industry, government, and the public.

WRRC continues to conduct research on restoring sage grouse habitat, developing reclamation mapping tools, efficient monitoring methods for restoration, and use of pyrolyzed coal (coal char) as a soil amendment. Sage grouse habitat restoration research was conducted in cooperation with the Douglas Core Area Restoration Team. This work has been expanded to include new methodologies and land areas. One focus of this work is examining the potential to recruit and transplant new sagebrush from those the restoration team has previously planted. In regard to improved monitoring methods, the Bureau of Land Management (BLM) has approved use of WRRC proposed methods by a number of monitoring contractors at both the local and national levels. In addition, BLM has given initial approval for use of our disturbance and reclamation database by operators in Wyoming. Coal char and coal residue research has moved from initial greenhouse studies to field trials which are being conducted at the Sustainable Agriculture Research and Extension Center near Lingle, WY. Research on recovery of ecosystem services in a restored gas field (Jonah Field) is also ongoing. WRRC has also been collaborating on research investigating restoration of sagebrush grassland habitat in Grand Teton National Park that was impacted by homestead farmers near Mormon Row.

The WRRC again organized and participated in a number of Outreach Events during FY2018. A number of talks were presented by students and faculty at the Wyoming Petroleum Association Annual Reclamation Meeting in Casper, WY. WRRC organized a workshop held in Douglas, WY to discuss and work on a database design for disturbed lands and includes their reclamation status for Wyoming. Representatives of a number of oil and gas producers in Wyoming along with several reclamation monitoring contractors and representatives of the BLM from both the state office in Cheyenne, WY as well as the national office in Washington D.C. were in attendance. The

director of WRRC, Pete Stahl, was invited to participate and be a panelist at a National Academy of Sciences Workshop held in Aurora, CO on legacies of unconventional hydrocarbon development in the western U.S. WRRC organized a Pub Talk held in Pinedale, WY to engage the local community regarding benefits of gas field restoration. Dr. Doug Smith gave a talk about the benefits of well pad restoration to pollinators in the Jonah Field. Pete Stahl completed a term as the president of the American Society of Mining and Reclamation just in time to be elected chair of the High Altitude Revegetation Committee. Stahl is also a member of the executive committee organizing the 2019 Reclamation and Restoration Conference to be held in Fort Collins, CO at Colorado State University. Stahl is chair of the Vendors and Sponsorship Committee for the conference.

Student numbers in restoration classes continue to be relatively low due to impact from the current low amount of oil and gas activity in Wyoming, but still have respectable enrollment. Graduate students working on reclamation/restoration related degrees are making progress towards completion. Amanda Penino, who completed a M.S. project examining soil redevelopment on a mine site reclaimed using geomorphic reclamation techniques won the best student presentation award at the American Society of Mining and Reclamation Conference in St. Louis this summer. Michael Curran, a PhD student working with WRRC, was invited to Washington D.C. this past spring to present his work to BLM officials. Ramesh Sapkota won a fellowship from the School of Energy Resources and the International Studies Center at UW for his research on restoration of tropical forests in Nepal impacted by energy resource collection.

Enhanced Oil Recovery Institute – Steve Carpenter, Director

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

Other Research Programs

US China Clean Energy Research Center – Advanced Conversion Technology Center (CERC-ACTC)

The School of Energy Resources continues its work with the Joint US-China Clean Energy Research Center – Advanced Coal Technology Consortium (CERC-ACTC), a joint research effort between the United States and China. The US 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, \$5.5M contract to UW for two CERC Phase II projects has just completed its second 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 (former Carbon Management Institute), and a project on a novel catalyzed carbon capture technology led by SER Professor Dr. Maohong Fan in the Department of Chemical Engineering. In the first two years of work, researchers on the CCUS project evaluated 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 second 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.

Functional Materials

Led by Dr. John Hoberg and SER Professor Dr. Bruce Parkinson from the Chemistry Department, the Functional Materials project continues to develop materials that can be modified for a desired use. Specifically, the work supported by the initiative involves the synthesis of two-dimensional honeycomb-like structures with ordered hexagonal nanopores termed Covalent Organic Frameworks (COF) that can be modified with almost any functional group to impart desired properties.

The applications for these materials include:

- Gas phase catalysis – gas permeable and catalyst binding
- Gas separation membranes – gas binding and variable pore size
- Hydrogen storage
- Ion size selectivity in membranes.
- Bipolar membranes – desalinization (testing to begin shortly)

Results from the National Renewable Energy Lab (NREL) on hydrogen storage found that our materials were selective for only hydrogen, loaded the hydrogen at room temperature (vs the usual 77 kelvin), and have a binding energy of 25-28kj/mole, which according to NREL is “awesome”. In a recent milestone report for NREL’s AOP (Annual Operation Plan), our material was highlighted as one of the top performers. Our separation studies have shown the material to significantly outperform graphene oxide (GO).

Patent No. *PCT/US2017/20000* was filed as a provisional on February 2017 and was published internationally as WO 2017/151643. This patent covers a very broad composition of matter for the materials. We are in the process of composing three additional patents that will cover applications of the materials.

Research funded from UW Foundation Accounts

Center for Global Studies-SER Nielsen Awards

The Center for Global Studies and School of Energy Resources partnership through the Nielson Opportunity Funding Program has supported a variety of faculty and student international research projects, a graduate and undergraduate scholarship, as well as programming and outreach focusing on energy and natural resources. Faculty award recipients in 2018 include Jeff Hamerlinck from WyGISC and the Department of Geography, and Brandon McElroy from the Department of Geology and Geophysics. Faculty award recipients from 2017, Carrick Eggleston (Geology and Geophysics) and Sarah Strauss (Anthropology), hosted visiting scholar Andrew Hurst from the University of Aberdeen on campus in April and May for a number of meetings to enhance a UW-Aberdeen exchange and as a result of their Nielson grant taught two faculty-led study abroad courses in Scotland with a significant focus on energy in summer 2018. The 2018 Nielson Graduate Excellence Fellowship went to Ramesh Sapkota who received his PhD in Ecology in May. Sapkota’s PhD research focused on resource management and conservation in Nepal’s forests; he submitted four articles for review in scholarly journals, and is now an Assistant Professor of Environmental Science at Tribhuvan University Nepal.

At the undergraduate level two students received the Nielson undergraduate tuition scholarship. Makenzie Beck (Lovell, WY; Senior in Political Science) and Calvin Chalstrom (Cherokee, Iowa; Junior in Political Science and ENR) are looking into how to balance resource extraction with environmental and social concerns while meeting energy needs. Three students received the Nielson International Fieldwork Grants: Thomas Ashley (Laramie, WY), PhD program in Geology; Anne Reed (Cheyenne, WY), MS program in Rangeland Ecology and Watershed Management; and Cristian Maldonado (Santiago, Chile), PhD program in

Management and Marketing for research fieldwork in The Netherlands, India, and Chile, respectively.

Finally, the CGS-Nielson partnership supported campus and statewide symposia. These included forums and discussions in Sheridan and Laramie on global energy markets with Dr. Robert Ichord, Non-Resident Senior Fellow with the Atlantic Council Global Energy Center and former Deputy Assistant Secretary of State for Energy Innovation. We also hosted Dr. Andreas Goldthau, Professor in International Relations at Royal Holloway University of London, for his discussion on “Russian Energy and European Security: Challenges and Policy Implications: A Presentation.” Both Ichord and Goldthau stayed on campus for a week and visited classes and met with various faculty and students. The statewide “What in the World?” series also included presentations by students on their fieldwork projects on campus and in Jackson, Cody, and Powell.

Anadarko Fellowship

Funds from the Anadarko Fellowship partially supported the thesis project of Kara Hoppes within the Department of Geology and Geophysics. Hoppes has successfully defended her thesis titled, "Sediment flux and sand thickness mass conservation analysis of the Parkman Sandstone Member, Mesa Verde Formation, Powder River basin, Wyoming, USA." She will graduate in August 2018.

Specifically, the funds were used to help Hoppes conduct field work and laboratory analyses. The research consisted of measured stratigraphic sections with particular attention to the record of sediment transport contained within fluvial portions of the Parkman Member. The project results include a new method for estimating distributions of sand in marginal marine deposits like those of the Cretaceous Interior Seaway that are preserved in the Powder River basin. This work was presented at the annual meeting of the American Association of Petroleum Geologists in May 2018 in Salt Lake City, UT.

In January 2018, an agreement was reached with Anadarko Petroleum to convert the funds that have been used to award fellowships into a new faculty chair. The title of the new chair is “The Anadarko Petroleum Corporation Chair in Energy and Environmental Technologies”. At the request of Anadarko, SER and the College of Engineering and Applied Science are collaborating on recruiting an individual with research interests in the area of fugitive emissions (natural gas) to be the first holder of the new chair.

Ultra Petroleum Endowment

Close to \$77,000 of Ultra funds were leveraged against a similar amount provided by the State of Wyoming appropriation afforded to the School Energy Resources to establish a reservoir core-flooding benchmark apparatus and capability. These assets focused upon providing technical support in the area of improving oil productivity to independent operators in Wyoming. The focus of future work will be to understand the performance of different enhanced oil recovery (EOR) strategies in the laboratory. The stimulus for the work program addresses challenges in Wyoming Cretaceous reservoirs in which clay swelling impedes secondary recovery.

Achievements during the year included the successful commissioning of the apparatus and establishing a formal working relationship with Wyoming independent operators. The plan forward is to replicate existing strategies in recently recovered cores and offer advice to independent operators of how they might improve (oil) productivity.

Koch, Charles and Double 4

Led by SER Professor Dr. Tim Considine and with funding from the Charles Koch Foundation (\$200K) and the Double 4 Foundation (\$18K), SER faculty are implementing an interdisciplinary initiative involving peer-reviewed studies in energy regulatory economics and law. This project initially is focusing on the following five topical areas: (1) greenhouse gas emission regulations; (2) international trade in refined petroleum products; (3) production of oil and natural gas on federal lands; (4) natural gas markets and trade; and (5) oil and natural gas pipelines. These studies are advancing scientific knowledge of the costs and benefits of regulations affecting energy production and consumption, and identifying strategies to improve regulatory efficiency with direct relevance to the U.S. economy, regional economies in the Intermountain West, and Wyoming specifically.

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:

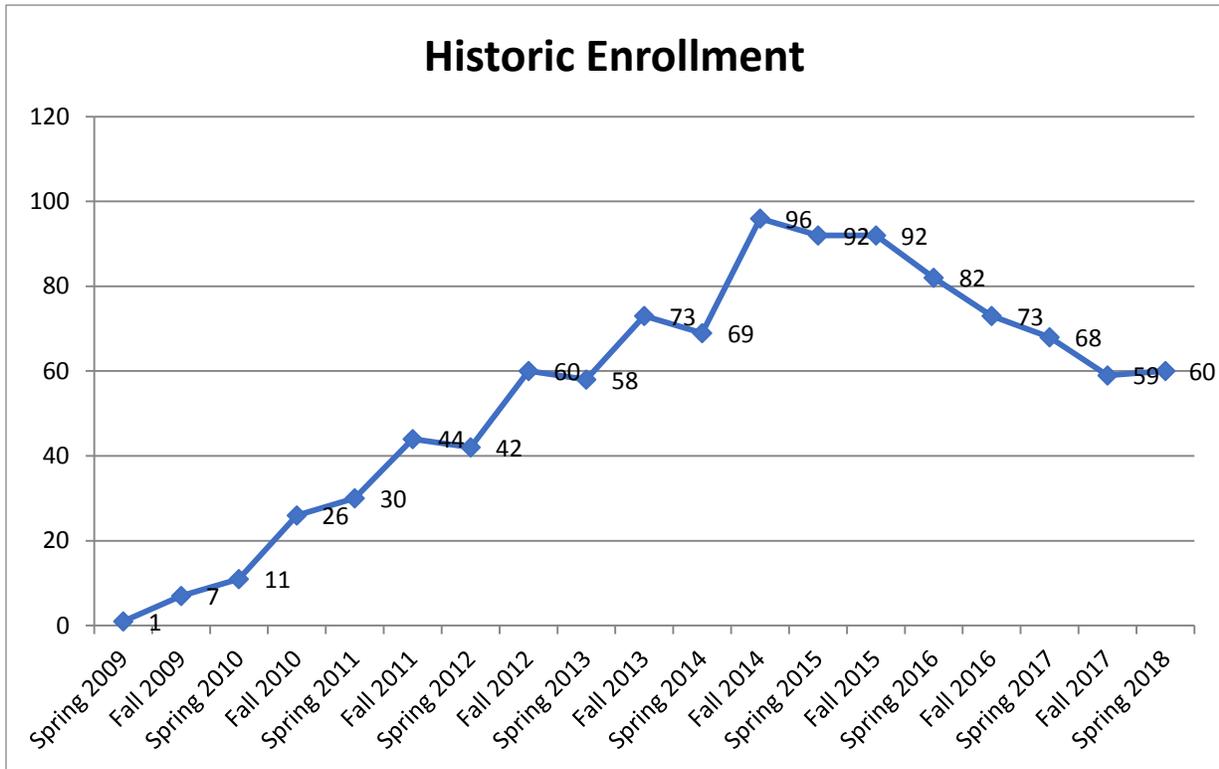
- Energy Air, Land and Water Management
- Professional Land Management (Landman)

Beginning in academic year 2018, students are not being accepted into the Fossil Fuels and Renewable Energy concentrations due to no or low enrollment.

The Professional Land Management concentration is accredited by the American Association of Professional Landmen.

Enrollment Statistics

The ERM&D program began the fall 2017 semester with 59 enrolled students including 8 freshmen, 10 sophomores, 18 juniors, 22 seniors, and 1 second bachelors' candidate. Enrollment for the spring 2018 semester improved to 60 students including 7 freshmen, 10 sophomores, 17 juniors, and 26 seniors. Detailed information on student enrollment data and demographics for the 2017-2018 academic year is provided on the following pages.



Class Standing						
Semester	Freshmen	Sophomores	Juniors	Seniors	2 nd Bachelors	Total
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
Spring 2013	13	12	9	23	1	58
Fall 2012	16	10	17	17		60

Gender			
Semester	Female	Male	Total
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
Spring 2013	10	48	58
Fall 2012	9	51	60

Concentrations							
Semester	Energy Land & Water	Fossil Fuels	Professional Land Management	Renewable Energy	Undecided	Original Program	Total
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
Spring 2013	1	12	11	3	7	25	59
Fall 2012	1	8	6	2		37	54

Scholarships

Students received \$276,314 in scholarships and grants.

Awarded Scholarships AY2018	Total Amount
Nielson Scholarships	\$83,840
Hathaway Scholarships	\$54,056
Rocky Mountain Scholars	\$54,350
Western Undergraduate Exchange	\$19,350
Trustees Scholars Award	\$12,952
Wyoming Association of Professional Landmen	\$8,000
Wyoming Scholars	\$7,000
American Association of Professional Landmen	\$10,000
Denver Association of Professional Landmen	\$1,000
York Future of Energy	\$2,446
Other Scholarships, Grants and Loans	\$23,320

Honor Rolls

Undergraduate students who achieve high scholastic grades are honored by being placed on one of these honor rolls. During the spring 2018 semester, 43% of our students were named to an honor roll establishing the second 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 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%
Spring 2013	2	8	1	1	12	20.7%
Fall 2012		13	3		16	26.7%

Graduation Statistics

Our graduating class consisted of eighteen students during the 2017-2018 academic year.

Graduates by Gender			
Semester	Female	Male	Total
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
Summer 2018	1				1
Spring 2018	12		4		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
Summer 2013	1				1
Spring 2013	8	1		1	10

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. Beginning fall 2017, SER graduates are awarded these honors based on GPAs within the school rather than the College of Engineering and Applied Science. These graduates are identified by comparison to a 5-year rolling grade point distribution computed for each college and is recomputed each spring semester.

GPAs to be awarded with distinction for the School of Energy Resources effective December 2017, May 2018, and August 2018 are:

- Summa Cum Laude – 3.883
- Magna Cum Laude – 3.694
- Cum Laude – 3.611

Degrees Awarded with Distinction				
Semester	Summa Cum Laude	Magna Cum Laude	Cum Laude	Total
Summer 2018			1	1
Spring 2018	1			1
Spring 2017			1	1
Spring 2015			1	1
Total	1		3	4

First Destination Job Titles and Employers

- Crestone Energy – EHS&R Field Technician – Firestone CO
- Electrical Solutions LLC – Apprentice Electrician – Laramie WY
- FDL Energy – Environmental Engineer – Casper WY
- NorthStar Energy – Independent Contract Landman – Denver CO – two graduates hired
- Pacer Energy – Landman – Casper WY
- Royal Dutch Shell – Land Representative – Houston TX
- SWCA Environmental Consulting – Biological Field Technician – Sheridan WY
- U.S. Senate Budget Committee – Intern – Washington DC

- USDA/NRCS – Soil Conservation – Manitowoc WI
- Wyoming Conservation Corps – Crew Member – Laramie WY
- Wyoming State Engineers Office – Natural Resource Analyst – Cheyenne WY

Student Accomplishments

- Samuel Mallory was a finalist for the Tobin Award for Outstanding Male Graduate. He also received the Outstanding Graduate Award from the American Association of Professional Landmen for 2018 and is the first student from the University of Wyoming to be recognized for this prestigious honor.
- Under the supervision of Associate Lecturer Kristopher Koski, our Landman students are working on a project to remove outdated covenants from title in the Armor subdivision in Cheyenne. The covenants state that only Caucasian people can live in the subdivision within the city of Cheyenne. The U.S. Supreme Court declared such covenants as unconstitutional, but they remain on title. Students are acquiring signatures from homeowners and have sent letters to property owners regarding the covenant. Plans are to connect with homeowners during the fall semester to continue working on receiving the required number of signatures.
- The Wyoming Student Chapter of Professional Land Managers held a You Fund project to raise money to attend the American Association of Professional Landmen annual meeting in Denver CO. They raised \$1,826.00.
- School of Energy Resources students now have representation on the ASUW Senate due to the efforts of Paige Trent. Previously, our students did not have representation and Trent worked with the ASUW administration so that our students, along with Haub School students, are represented in student government. She is serving as the first ASUW senator for our school.
- Joe Icenogle, Land Manager with Wave Petroleum, worked with the Enhanced Oil Recovery Institute on their outcropping core analysis and logging project. He included three seniors from our program on the project.
- Twenty-five students accepted internships, undergraduate research, and job opportunities during summer 2018.

Faculty Accomplishments

- Kristopher Koski accepted the Associate Lecturer position beginning in August 2017. Mr. Koski received his J.D. from the University of Wyoming College of Law in 2008, graduating at the top of his class with honors and Order of the Coif. He is licensed to practice law in Colorado and Wyoming. He developed courses in the Professional Land Management concentration focusing on the introductory land management course and law courses in property, contracts, and federal public lands.

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

During FY 2018, SER hosted four professional speakers and the SER Faculty Speaker Series featuring each of the nine Centers of Excellence, bringing together students, faculty, researchers, and the public to learn about a wide range of advanced energy technologies and industry trends.

Events

In FY 2018 SER hosted and sponsored 11 events held at UW and various locations around Wyoming. A few of the key events are listed below:

- *Wyoming-JCOAL Workshop: The Future of Coal*, September 20-22, 2017, Gillette, WY. As follow up to the July 25, 2016 MOU between the State of Wyoming and the Japan Coal Energy Center (JCOAL), the SER workshop was designed as a forum to get acquainted and discuss areas of potential collaboration; knowledge sharing and partnership in the areas of coal trade and exports; economic development; clean coal solutions and carbon capture, utilization, and storage. Wyoming Governor Matt Mead attended and provided opening remarks for the workshop. The conference also featured opening comments by Mr. Osamu Tsukamoto, President of JCOAL. Since the workshop, a restricted website has been created to display presentations from the workshop and share future ideas and next steps among participants.
- *5th Annual Energy Day Celebration*, September 30, 2017, Laramie, WY. As part of the 5th Annual Energy Day, SER sponsored a booth at the Texas State-UW football game pre-game festivities. SER staff and two SER student ambassadors handed out mini-footballs and talked to people about SER's academic and research programs. During the football game, Executive Director Mark Northam was acknowledged along with visitors from the energy industry.
- *Western States Section – Combustion Institute Annual Meeting*, October 1-3, 2017, Laramie, WY. Dr. Erica Belmont, University of Wyoming Assistant Professor in Mechanical Engineering, served as the chair and organizer for this year's Western State Section – Combustion Institute (WSSCI) Fall Technical Meeting in Laramie, WY. WSSCI is a non-profit educational and scientific society that promotes the science and application of combustion technologies for the benefit of society. The conference featured invited technical presentations

on innovative and emerging concepts in combustion. SER provided event planning support and sponsorship funding for food at the event.

- *Wyoming's Wind Energy Future Conference*, October 2-3, 2017, Laramie, WY. SER provided event planning staff for this two-day conference that talked about the economic, social and environmental impacts of impending wind energy development in Wyoming. The conference was convened by the SER Center for Energy Economics and Public Policy and the Haub School of Environment and Natural Resources. The presentations from the forum can be viewed at the following website: <http://www.uwyo.edu/haub/ruckelshaus-institute/forums/wind/presentations.html>
- *Energy Law Conference*, October 13, 2017, Laramie, WY. SER and the UW College of Law's Center for Law and Energy Resources in the Rockies teamed together again for a one-day conference focused on energy and natural resource law issues in the West under a new federal administration. The conference featured a welcome address from Governor Matt Mead and was moderated by former Governor Dave Freudenthal.
- *SER Centers of Excellence Open House*, April 26, 2018, 2nd floor lobby, Energy Innovation Center (EIC), Laramie, WY. The 2018 Centers of Excellence (COE) Open House was a stand-alone event this year. The event highlighted the COE in an open house exhibition of demonstrations and interactive displays throughout the second-floor lobby of the EIC. In addition, the adjacent Encana Auditorium was used to show the recently completed COE promotional videos that highlight the achievements and missions of each COE. The event was free and open to the public.

EMERGING TECHNOLOGY

The Carbon Engineering Initiative (CEI) focuses on supporting existing markets and creating new markets for Wyoming coal. It primarily seeks to develop original patentable intellectual property to process and make value added products that can be deployed as standalone solutions or used to augment technology developed by others. A second initiative is to identify potentially commercially viable clean-coal solutions in the market, support their further development to operate with Wyoming coal, and encourage transfer of these technologies to sites in Wyoming.

The overall mission of the CEI is to develop technologies that have potential to benefit Wyoming coal. To accomplish this mission CEI focuses in two areas: (1) sustaining demand for coal as an energy fuel by developing and supporting technologies that permit clean high efficiency combustion with integrated CO₂ capture that are technically and economically viable and fully compliant and (2) growing the demand for coal as a feedstock that can be converted into chemical and high-performance engineered products that have greater value than that of the Btu component of the coal itself.

FY 2017-18 Achievements and Progress

In the 2015 budget session, the Wyoming State Legislature provided a special \$2M appropriation to fund carbon engineering research and technology development. During the first year of the biennium, starting July 2016, \$1.5M of this Special Appropriation was expended on 15 carbon engineering projects led by faculty in the Colleges of Engineering and Applied Sciences (CEAS) and Arts and Sciences (A&S). For FY 2018, the remaining \$0.5M available through the appropriation was expended on continuing the 15 carbon engineering research and technology projects.

Importantly, an additional \$4.1M from the School of Energy Resources and other available funds were expended on these same projects, bringing the total expenditures to \$4.6M for the second year of the biennium. Adding the \$2.6M spent during the first year, CEI has spent \$7.2M, which includes \$6.6M of state based funding and \$0.6M of private funding over the biennium.

Research and Development

During FY 2018, the focus of CEI has been to: (1) prove and develop coal conversion concepts and coal based products that demonstrate an increased value for Wyoming coal, (2) enhance the understanding of flameless pressurized oxy-fuel (FPO) combustion as a viable technology, and (3) continue to invest in equipment and human capital to establish a dedicated carbon engineering laboratory in the Energy Innovation Center.

CEI continues market and process modeling analyses to better understand the economics surrounding a coal refinery and to realize market specifications of coal based products. As a result, a full patent filing has been prepared for the coal refinery concept. A further 11 patents will be filed that relate to the processes or product manufacturing routes described in the overarching coal refinery patent. Securing intellectual property rights is considered vital to leverage and create businesses and diversification opportunities in Wyoming.

CEI continues further development of three focus areas for value added development of Wyoming coal: (1) advanced composite materials, fibers, and polymers; (2) construction and agricultural products; and (3) performance liquid chemicals including those for oil and gas production.

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

- *Coal-based soil amendments.* A demonstration of soil amendment products made from PRB coal started at the University's Agricultural test site near Wheatland in conjunction with the WRRC (pg. 16, above). The tests involved manufacturing of approximately six tons of activated carbon that has been enriched with nitrogen (a crop nutrient). The one year trial has created significant interest, for example the project is pursuing a potential collaboration with the local sugar beet cooperatives.
- *Coal-based asphalt and paving additives.* Formulations for asphalt road paving and additives were successfully proven in the laboratory and will now be demonstrated at a field location - to be decided next year.
- *High temperature coal-based composites.* High-temperature resin systems based upon polyurethane-phenolic chemistry have been developed. They exhibit superior temperature resistance to similar oil-derived products presently on the market. Plans are underway to further develop the resin as a composite material and to scale up the resin manufacturing process.
- *Coal-based nano-products.* Dispersion additives involving carbon from coal nano-products appear to exhibit properties that can be utilized to improve the productivity of oil and gas in Wyoming reservoirs. While in the preliminary stages of research, early results are promising and next year, core flood studies will be started to better understand the relationship between additive formulation and performance.

- *Coal-based Building Products.* Many new-building products have been made from residual coal products. They have been proven to have robust properties and the potential to provide a substitute for cheap construction materials. This project will now move into the product development phase.
- *Carbon Fiber Development.* Improvements have been made to the properties of carbon fiber made from PRB coal (both mechanical and electrical). The focus is now to benchmark the properties of these products with those commercially available and to better understand the relationship between finished properties and coal chemistry. This is needed so that the best routes for scaling up the processes can be developed (melt spinning and electro-spinning), the target markets assessed (automotive and construction fascia materials are the current choices), and the economics better understood.
- *Coal to petrochemicals.* Further development work has been successfully completed on a dry reforming catalyst ($\text{CO}_2 + \text{CH}_4 = \text{CO} + \text{H}$). The catalyst has proven to exhibit superior performance to commercial variants known today for taking CO_2 and methane and converting it to syngas – a valuable feedstock to make petrochemicals. The ability to convert the small amounts of CO_2 liberated when pyrolyzing coal is a crucial technology for the coal refining process to be carbon-competitive with traditional petrochemicals.
- *Coal-to-high-value chemicals.* A pilot plant to demonstrate the advantage of flash-pyrolysis of coal to generate high yields of valuable chemicals is nearing completion and will be used to validate earlier promising laboratory results and the techno-economics of the process. The pilot plant will be commissioned soon.

Technology Transfer

Three technology transfer opportunities have been pursued, related to bringing promising technologies to Wyoming. 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:

- *Clean Coal Technologies Incorporated* – A technology 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 after generating promising results that show the economics of the technology are sound when using PRB coal.

- *Itea SpA* - An integrated CO₂ capture combustion system that benefits coal. 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, will be the location to demonstrate the flameless pressurized oxy-fuel (FPO) solution as part of a pending submission for a DOE award, which includes a consortium of Southwest Research Institute, Electric Power Research Institute, Jacobs Engineering, and Sargent & Lundy.
- *Carbon Fuels LLC.* - Based upon an existing 16 tons a day pilot plant owned by Carbon Fuels LLC., a framework agreement to evaluate the performance of the technology on Wyoming PRB coal has been established. 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.

Capital Investments

A dedicated carbon engineering laboratory is being designed in the Energy Innovation Center. The laboratory will provide a collaborative space to facilitate interaction between the various CEI projects. A full time laboratory coordinator has been hired to accelerate the development and creation of the laboratory. The movement of research from dedicated singular College domains into the carbon engineering laboratory space will facilitate and enhance collaboration across projects.

Finally, the CEI review committee recently met to measure progress and to assess projects. Some projects were deemed worthy of accelerated support, while others were encouraged to refocus efforts in different directions to maximize potential positive outcomes; other projects faced reduced or elimination of funding based upon a lack of promise to ultimately develop technology solutions that benefit the State economy – the primary goal of the carbon engineering initiative.

FY 2019-20 Outlook

A further \$1M special appropriations for the CEI was approved by the Wyoming State Legislature for the 2019-20 biennium starting July 2018. In all likelihood the full amount will be spent over the first year of the biennium during FY 2019 and used to accelerate progress of those projects that have demonstrated early promise and require support to further develop technology solutions. The expectation is that a further investment of up to \$2.5M million will be provided from the standard appropriation afforded to the School of Energy Resources by the Wyoming Legislature. The focus of this funding will be to accelerate technology development from the bench scale experiments towards scale-up, pilot plant testing and eventually leading to full demonstration and field trial. Efforts will also be made to procure key full patents for the coal

refinery and related process and product manufacturing patents. During the upcoming year increased collaboration among CEI projects should be realized with the establishment of the dedicated carbon engineering laboratory.

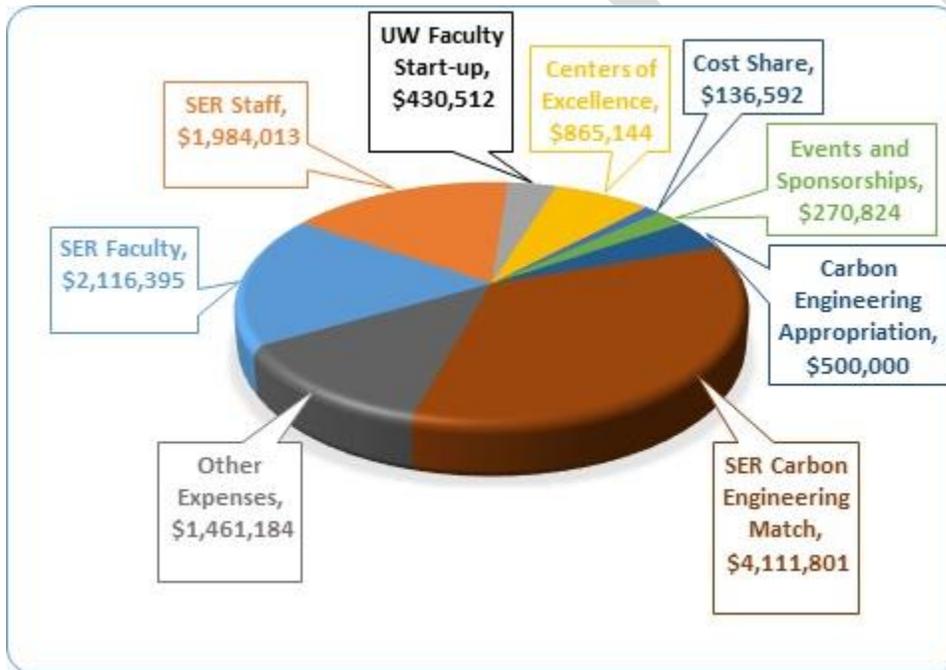
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FINANCIAL SUMMARY

The Wyoming State Legislature provided funding for the School of Energy Resources over the 2017-18 biennium in the 2015 Legislative Budget Session in the amount of \$21,874,188. Of this, \$2,000,000 was a one-time appropriation for the Carbon Engineering Initiative. \$1,500,000 of this one-time appropriation was utilized in Fiscal Year 2017 and the remaining \$500,000 was utilized in Fiscal Year 2018. After adjustments for retirement, health insurance, EORI salary shifts, and mandated state budget cuts, SER was left with \$20,953,176.

In Fiscal Year 2017, \$9,076,711 was spent. In Fiscal Year 2018 the remaining \$11,876,465 was spent.

FY18 State Appropriations Spent



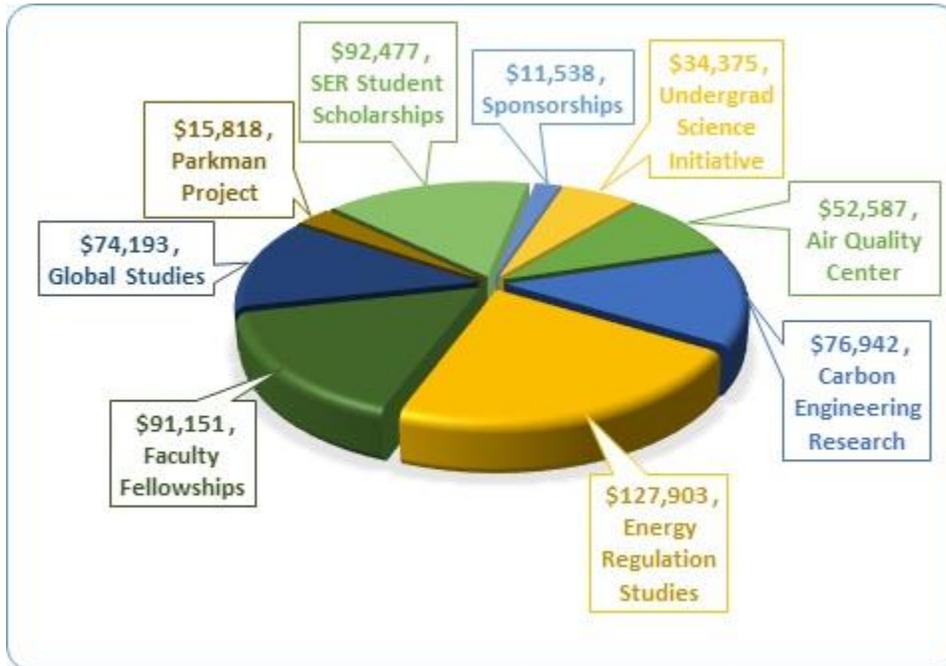
In FY18 SER disbursed:

- \$2,116,395 for salaries and benefits for SER faculty
- \$1,984,013 for salaries and benefits for SER staff
- \$430,512 for UW faculty start-up commitments
- \$865,144 to support research activities for the Centers of Excellence
- \$136,592 in cost share support for state and federal research grants
- \$270,824 for events and sponsorships
- \$500,000 from the one-time appropriation for carbon engineering research
- \$4,111,801 from SER's standard budget to support carbon engineering research

- \$1,461,184 in remaining expenses that include graduate assistantships, recruiting, travel, publications, office support, etc.

In Fiscal Year 2018 SER utilized \$576,984 of private gift funds held at the UW Foundation.

FY18 Foundation Spent



- \$92,477 for SER student scholarships - Nielson, James E. Excellence Fund
- \$15,818 to minimize pre-seismic risk through process stratigraphy of potential Parkman reservoirs - Anadarko Petroleum Corporation
- \$127,903 for energy regulation studies on oil and gas production on Federal lands - Koch, Charles and Double 4 Foundation
- \$76,942 to support Carbon Engineering studies on chemical flooding and miscible gas flooding - Ultra Petroleum Endowment
- \$34,375 for the Undergraduate Science Initiative Wyoming Research Scholars Program - Nielson, James E. Excellence Fund
- \$52,587 to support the Center of Excellence in Air Quality to better understand emissions from the oil and gas sector in the Rocky Mountain region - Jonah Energy LLC Fund
- \$74,193 to Global Studies for student scholarships, faculty fieldwork, visiting fellows, and outreach programs - Nielson, James E. Excellence Fund
- \$91,151 for Faculty Fellowships in the College of Arts & Sciences and the College of Business - Nielson, James E. Excellence Fund
- \$11,538 for sponsorships, networking, etc.-Multiple accounts

CONCLUSION

Fiscal Year 2018 was one of new successes for SER. Guided by our five-year strategic plan, we shifted a significant portion of SER's budget to advancing our portfolio of technologies that exploit the non-Btu value of coal, 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:

- SER leadership and the ERC finalized the five-year strategic plan that advances the mission of SER, aligns with that of UW, and focusses heavily on workforce and technology development that will aid Wyoming's efforts to diversify and stabilize its economy.
- SER continued implementation of a broad scope of Carbon Engineering research activities. Significant outcomes include inventions and patents, and the design of a dedicated Carbon Engineering Laboratory.
- Addition of new grant dollars to continue investigating CCUS technologies suited to Wyoming's coal-fired energy generation facilities. Including, roughly 9M in funding from DOE's flagship program for CCUS research.
- Nine diverse Centers of Excellence are active. Some have achieved financial independence, and others are successfully competing for grants.
- The procurement of new technologies has allowed the 3D Visualization Center to broaden the scope of services and attract an increased number of users.
- Graduation of 18 students for the Energy Resource Management and Development. Most of the graduates successfully found jobs.
- A successful year of knowledge transfer and engagement through domestic and international events, and hosting of distinguished speakers.

Looking forward, we anticipate continued delivery of important outcomes in FY 2019. These include the establishment of a Carbon Engineering Laboratory in the Energy Innovation Center, movement toward commercial deployment of non-Btu coal product technologies, important decisions about installation of the Flameless Pressurized Oxy-Combustion power plant, the start of large CCUS feasibility project near Gillette, and a plan for significant growth and commercialization of the 3D Visualization Center.

DRAFT

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, the 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.

Disciplinarity 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,
 - 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 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.