



SCHOOL OF ENERGY RESOURCES



ACADEMICS



RESEARCH



TECHNOLOGY



ENGAGEMENT

SEPTEMBER 15, 2020



UNIVERSITY OF WYOMING

ANNUAL REPORT

THE UNIVERSITY OF WYOMING SCHOOL OF ENERGY RESOURCES
ANNUAL REPORT FY 2020

SEPTEMBER 15, 2020

Presented to:

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

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LETTER FROM THE EXECUTIVE DIRECTOR

FY20 has been a year filled with change and unexpected challenges, but also major progress and resilience at the University of Wyoming School of Energy Resources (SER). After 13 years of service, the founding executive director, Dr. Mark Northam, retired at the end of June and handed over the reins. Much gratitude is due to Dr. Northam from the faculty, staff, and students that have been touched by his passion, dedication, and care throughout his tenure.

While I have begun my tenure as Executive Director of SER during a turbulent time, there is an abundance of reasons for optimism. SER's interdisciplinary faculty are engaged and supporting a review of our academic program, which has to date yielded more than 100 graduates. In addition, many of SER's faculty are focused on research programs that will ultimately benefit the state's natural resources and energy industries.

SER's research and technology development programs will continue to be, focused on delivering energy-driven economic development and diversification. This year, the Center for Economic Geology Research was awarded a Phase III CarbonSAFE grant to support a nearly \$20 million continuation of a CO₂ storage project, a \$1.6 million rare earth element project from Wyoming coal ash, and \$1.2M to participate in a regional carbon sequestration partnership led by the Energy and Environmental Research Center at the University of North Dakota. Under SER's Carbon Engineering Initiative, new technologies have been invented to use Wyoming coal in novel and sustainable ways, ranging from new clean combustion technologies to feedstock used to make non-energy and fuel products, such as agricultural, building and infrastructure, specialty materials, and petrochemical products. A new policy center, the Center for Energy Policy and Analysis has been stood up and is heavily engaged in supporting Wyoming stakeholders.

A special thank you is owed to SER's board, the Energy Resources Council, which oversees and provides guidance to SER. Without their support and engagement, SER could not be as successful as it is. We also welcome to UW's new leadership, President Seidel. His interdisciplinary and digital focus fits well with SER, but also challenge us.

Finally, on behalf of all those involved with SER, thank you to the Wyoming legislature for your continued support. SER is singularly focused on energy-driven economic development for the state of Wyoming. Despite unprecedented global challenges, the state of SER is strong and we are poised to deliver new technologies and policy analysis to and for the state of Wyoming.

Holly Krutka, PhD
Executive Director
University of Wyoming School of Energy Resources

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, 2019, through June 30, 2020, in academics, research, newly emerging areas of focus, and engagement to keep UW and Wyoming at the forefront of the energy sector.

The fiscal year 2020 (FY20) was the third 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 federal and private sector grants during FY20. The School of Energy Resources hired a new Executive Director, Dr. Holly Krutka to replace the inaugural director Dr. Mark Northam. Dr. Krutka began her appointment in March.

Programmatic highlights over the period:

Fifteen (15) students graduated from the Energy Resource Management and Development Bachelors of Science program, in total 103 students have graduated from SER programs since the fall of 2011. Ten of the 2019-2020 graduates found immediate employment and one has been accepted into law school.

Funds from the UW Foundation accounts continue to have a large impact on the energy research and academics at the University of Wyoming. Approximately \$1.4M was expended to enhance research and student experience at UW during the FY19-20 biennium. These include funds from the James E. Nielson Excellence Fund in the amount of \$0.9 million that supported student scholarships, faculty startup, fellowships, the Center for Global Studies, and the Undergraduate Science Initiative.

The Center of Economic Geology Research (CEGR) continued its leadership in the Department of Energy's Carbon Storage Assurance and Facility Enterprise (CarbonSAFE) program and was awarded funding (\$15.5M federal and \$1.5M private) to complete the Phase III site characterization study of the carbon capture and storage project at Dry Fork Station and the Wyoming Integrated Test Center. The three-year project will fully fund CEGR scientists beyond Y23.

The Center for Energy Regulation and Policy Analysis (CERPA) was formally launched in FY20. The mission of CERPA is to inform, educate, and develop pragmatic, reasonable, and effective low-carbon energy policy and regulation solutions for Wyoming, the Rocky Mountain Region. A key focus of the first year of CERPA has been to develop and use state of the art tools and interdisciplinary approaches, through scholarship and research that generates needed insight to guide and influence policy decisions whether at the federal, state, or industry and market levels.

The Carbon Engineering Initiative (CEI), established in FY16, is moving aggressively proving concepts in the laboratory to develop carbon-neutral process technology to manufacture valuable carbon products derived from Wyoming coal. A significant patent portfolio is emerging, while technologies are now being scaled-up, which will support the future development, demonstration, and commercialization of demonstration projects. In the area of coal to clean energy, as part of a \$#5 million funded project, the front end engineering design (FEED) study for a pre-commercial demonstration of flameless pressurized oxy-fuel (FPO) combustion technology is progressing well. FPO has the potential to be economically retrofitted to existing coal-fired utility schemes (as opposed to pre and post-carbon capture solutions), as well as serving new-build coal-fired plant constructions to ensure full compliance with the most stringent environmental and health regulations.

SER appreciates the continuing support of the Wyoming Legislature. In the face of tightening budgets, SER's commitment to providing funding for interdisciplinary 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 faculty and industry representatives are making significant progress in identifying and advancing toward commercialization new pathways to maintain a robust, healthy energy 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.

Challenges and Responses to COVID-19:

Like many in these unprecedented times, SER has been forced to navigate the continuing changing challenges related to COVID-19. In March 2020, the majority of SER administration and staff transitioned to remote work. As a result, the Energy Innovation Center was locked and building operations with the exception of research projects were suspended. Additional safety precautions allowed for critical path research to continue in the Energy Innovation Center. Reopening plans are in place for the Fall of 2021. Importantly, the safety and well being of faculty, staff, and students is of the highest priority and lower person densities are required in the Energy Innovation Center. Maintaining lower person density means priority is being given to researchers that must access laboratories to carry out their work.

Class Standing						
Semester	Freshmen	Sophomores	Juniors	Seniors	2nd Bachelors	Total
Spring 2020	7	11	7	18	1	44
Fall 2019	4	10	8	23		45
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

Table 1 SER Bachelors candidates sorted by class standing

Gender			
Semester	Female	Male	Total
Spring 2020	12	32	44
Fall 2019	10	35	45
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

Table 2 SER Bachelors Candidates sorted by gender.

Concentrations						
Semester	Energy Land & Water	Fossil Fuels	Professional Land Management	Renewable Energy	Undecided	Total
Spring 2020	13		29	2		44
Fall 2019	16		25	4		45
Spring 2019	20		27	4		51
Fall 2018	25		23	4	2	54
Spring 2018	23		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

Table 3. SER Bachelors Candidates classified by concentration.

Scholarships

Students received \$174,859 in scholarships for the academic year 2020.

Awarded Scholarships AY2020	Total Amount
Rocky Mountain Scholars	\$39,669
Nielson Scholarships	\$31,400
Hathaway Scholarships	\$30,836
ROTC	\$17,062
Western Undergraduate Exchange	\$10,485
Wyoming Association of Professional Landmen	\$ 8,500
American Association of Professional Landmen	\$ 5,000
GW Anderson Landman	\$ 2,500
Wyoming Scholars	\$ 3,000
Other Scholarships, Grants, and Loans	\$26,407

Table 4. Scholarships awarded during the 2020 academic year.

Honor Rolls

Undergraduate students who achieve high scholastic grades are recognized by placement on one of the honor rolls below. During the spring 2020 semester, 45.5% of our students were named to an honor roll, establishing the second-highest percentage since the program began in 2009.

- President's – 4.0 grade point average (GPA) and complete a minimum of 12 credit hours
- Dean's – 3.4 or better GPA, above a 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	Freshman	Provost	Total	% Students
Spring 2020	7	10	1	2	20	45.5%
Fall 2019	3	8	2	2	15	33.3%
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%

Table 5. Percent and category of Honor Rolls earned by SER students.

Graduation Statistics

Our graduating class consisted of fifteen students during the 2019-2020 academic year. Their job or graduate school placement as of July 1, 2020, is:

- 1 is attending law school at the University of Wyoming
- 1 is enrolled in the Atmospheric Science master's program at the University of Wyoming
- 1 is a second lieutenant in the U.S. Army
- 6 are working
 - Production Accountability – Bureau of Land Management – Pinedale WY
 - Co-owner – On the Hook Fish and Chips – Laramie WY
 - PacifiCorp – Glenrock WY
 - Title Landman – Rocking WW Minerals – Sheridan WY
 - LDAR Technician – Trihydro – Casper WY
 - Land Agent – Western States Land Services – Loveland CO

In total, 103 students have graduated from the program since fall 2011.

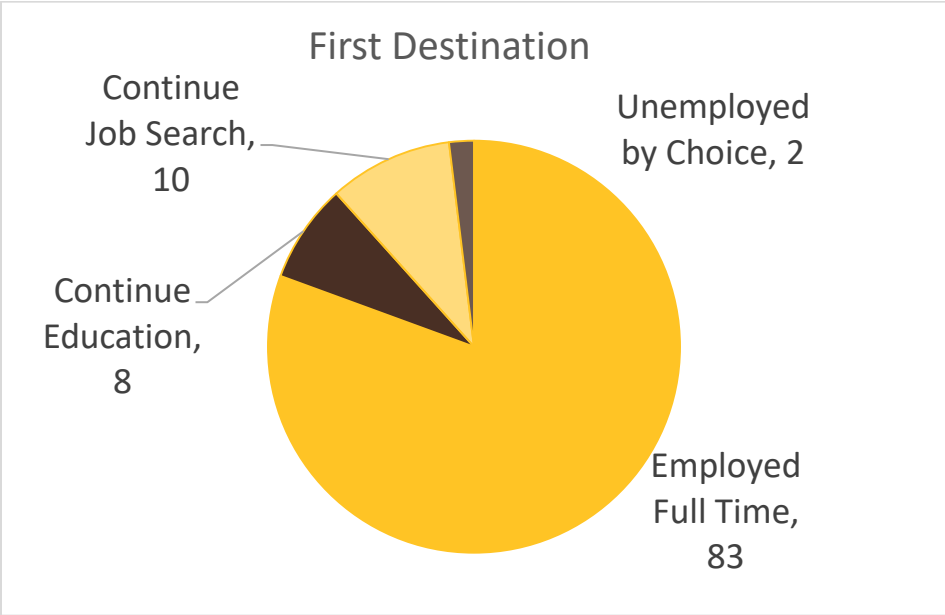


Figure 2. The first destination of 103 SER graduates.

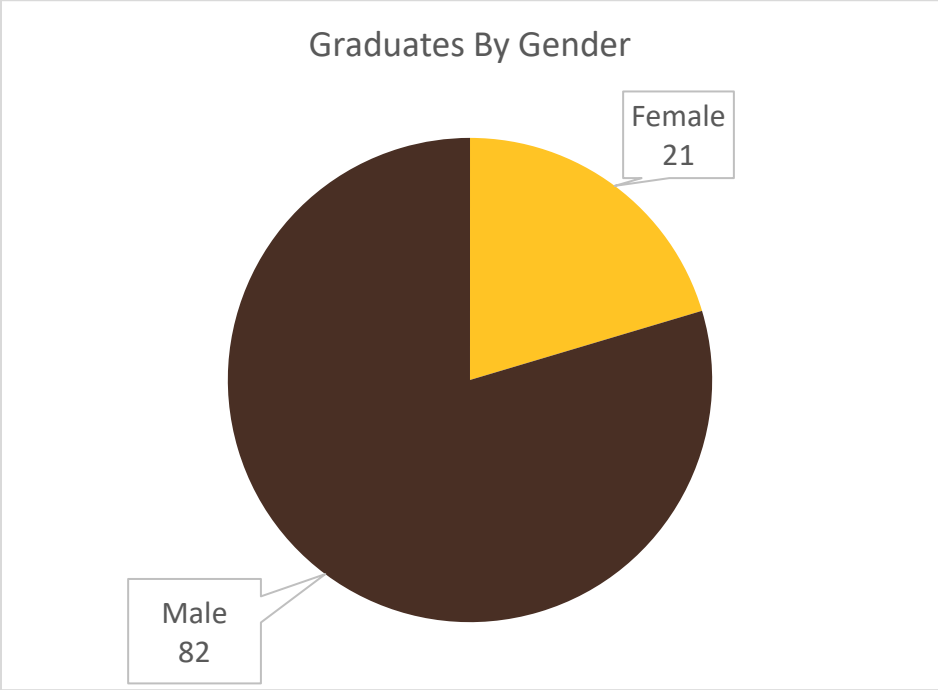


Figure 3. SER graduates sorted by gender since 2016.

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 (GPA) 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 2019, May 2020, and August 2020 are:

summa cum laude – 4.000

magna cum laude – 3.872

cum laude – 3.669

Degrees Awarded with Honors				
Semester	Summa Cum Laude	Magna Cum Laude	Cum Laude	Grand Total
Spring 2020			2	2
Fall 2019			1	1
Spring 2019		1		1
Summer 2018			1	1
Spring 2018	1			1
Spring 2017			1	1
Spring 2015			1	1
Total	1	1	6	8

Table 6. The number of degrees awarded with distinction 2016 to 2020.

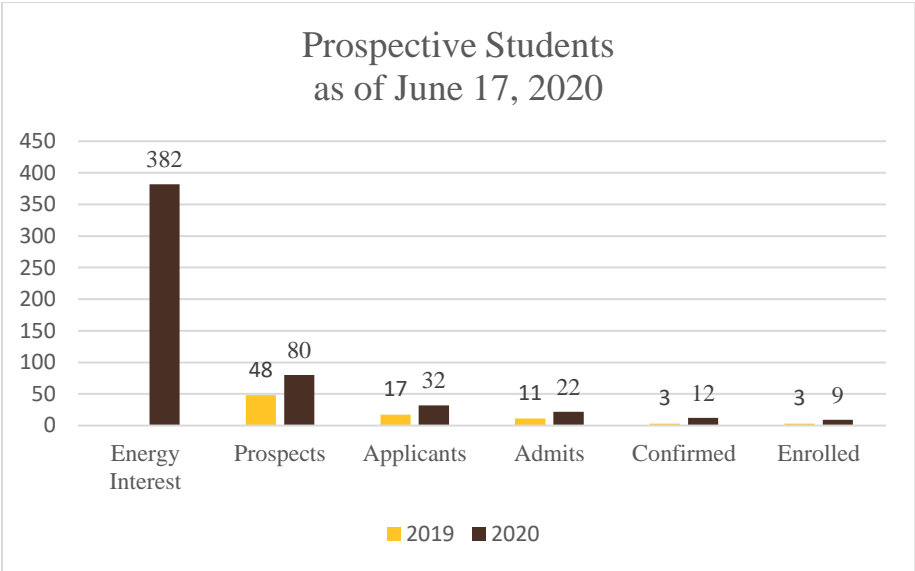


Figure 4. The number of prospective students for the 2021 academic year.

Accomplishments

- Jenifer Paintin was hired as a college relations representative to focus on student recruitment efforts. SER's prospective students' pipeline, along with enrollment, increased compared to recent years due to Ms. Paintin's efforts.
- After a 2-year hiatus, SER hosted the Energy Summer Institute designed to recruit students to the Energy Resource Management and Development program long with the University of Wyoming. The program was attended by 16 high school juniors and seniors. Out of the 7 seniors, 5 were admitted to UW and 4 enrolled including 1 student in the Energy Resource Management and Development program.
- An Energy Resource Management minor program under development to attract students to take SER classes. 382 students who applied to UW for the Fall 2020 semester indicated an interest in studying energy.
- Rock Springs High School Energy Academy visited campus on September 11, 2019, and Cheyenne East High visited on December 11, 2019. Visits were made by SER staff to Wyoming Indian High School, Casper College, Northwest College, Western Wyoming Community College, and Community College of Denver throughout the fall semester.
- Due to the COVID-19 pandemic, SER academic staff continued to support prospective and current students remotely.

Revitalizing and Refreshing SER's Academic Program

SER's academic program has experienced a significant downward trend in enrollment in recent years. There are likely many reasons behind the decline in enrollment and SER is actively taking steps to reduce that trend and grow the program. For example, SER hired Jennifer Paintin to recruit – this step seems to have helped to stem the decline with a flattening of the downward curve observed during Ms. Paintin's tenure. Improved recruiting resources is only the first step in revitalizing and refreshing SER's academic program. SER also hired an Academic Director, Dr. Tim Considine, on an interim basis to lead faculty and be responsive to UW Academic Affairs, which has allowed the advising staff to focus more on their core responsibilities.

In addition to declining enrollment, the energy industry is rapidly evolving – meaning that the academic program should be regularly reviewed to ensure that students are prepared to be highly successful in their careers and lives. Thus, a strategic academic review was launched in August 2020. To lead this academic review, the former Associate Dean of the College of Engineering and Applied Sciences, David Whitman, was hired on a part-time basis. Dr. Whitman spent about 35 years at the University of Wyoming and is well versed in many of the programs with which SER often collaborates. Dr. Whitman is interviewing all SER faculty, deans of several relevant colleges, current students, alum, industry partners, and more. Preliminary findings from the strategic academic review will be presented in the November joint meeting of the UW Board of Trustees and Energy Resources Council.

Beyond the SER degree program, it is also important to evaluate how to impact students that have an interest in energy but are not enrolled in the degree program. This may encompass a second phase of the academic strategic review

RESEARCH

Center for Economic Geology Research— 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) and project partners. CEGR research scientists are entirely grant-funded and have a total project portfolio of \$33.5M million (including cost share); as a result, the Center's researchers are fully supported through the fall of 2023. Of the \$33.5M, approximately 83% of the total is spent in Wyoming, including 30% of the total spent at UW. Thus the majority of the grant-funded dollars are spent in Wyoming communities using Wyoming-based contractors. Those dollars have not only supported CEGR's research staff, but they have percolated throughout the UW campus to support 26 graduate and undergraduate students and have enabled the hiring of a variety of Wyoming industry partners through contracting services.

Carbon Capture Utilization and Storage (CCUS) Projects:

SER has long been engaged in applied technical and policy research focused on CCUS. The benefit of this work to the State of Wyoming are several-fold, such as enabling the use of Wyoming coal and natural gas in a carbon-constrained world. In addition, by positioning itself as a leader in the CCUS field, Wyoming may ultimately be in a position to accept CO₂ from outside the state and build a new industry on storing CO₂. Current assessments indicate that Wyoming has the potential to store billions of tons of CO₂.

Wyoming CarbonSAFE (Carbon Storage Assurance and Facility Enterprise)

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 cost-share) to characterize the geology of storage reservoirs directly below Dry Fork Station near Gillette, WY. During FY20, CEGR and team partners used the data and samples collected from the stratigraphic test well drilled in FY19 to develop the geologic models and interpretation needed to address the feasibility of geologic storage of carbon

dioxide at Dry Fork Station. In addition to the analytical work, the project generated economic models, model contract agreements, and conducted public outreach. These results were used to prepare the successful Phase III application. Phase II continues through January 31, 2021, and will include additional field-scale data acquisition. Planned for FY21, the project team will collect 9-square miles of 3D seismic data surrounding Dry Fork Station.

Wyoming CarbonSAFE Phase III.

Wyoming CarbonSAFE (Figure 1) is one of five selected projects to move onto Phase III. The \$19.1M (\$15.2M federal, \$1.5M private, and \$2.4M cost share) will begin on October 1, 2020, and run for three years. The private contribution is provided by site host Basin Electric Power Cooperative and is comprised of \$1.2M cash and \$300k in-kind. The cost-share distribution includes an in-kind donation from Schlumberger (\$1.1M), SER (\$407k in-kind and \$150k cash), Energy and Environmental & Energy Research Center, University of North Dakota (\$625k in-kind), Denbury Resources (\$99k in-kind), and Occidental Low Carbon Ventures (\$85k in-kind).

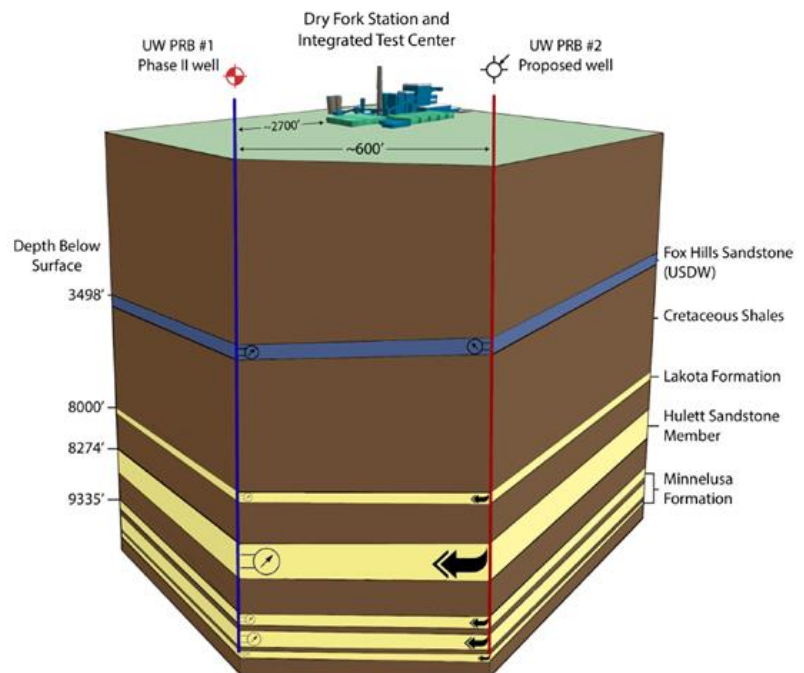


Figure 5 Schematic of proposed Phase III subsurface field activities. Drilled in Phase II, UW PRB#1 will be re-entered and gauged for monitoring. UW PRB#2 will be drilled in Phase III for data collection and injection tests.

In Phase III, the project team will: (1) complete the characterization of the commercial-scale CO2 storage complex using rigorous commercial-scale surface and subsurface testing, data assessment, and modeling; (2) prepare and file Class VI permits with the Wyoming Department of Environmental Quality (DEQ) under the Underground Injection Control (UIC) Program; (3) integrate Membrane Technology Research’s separately funded CO2 capture study at Dry Fork

Station; and (4) conduct required National Environmental Policy Act (NEPA) analyses in support of eventual commercialization of the site.

Plains CO₂ Reduction (PCOR) Partnership

CEGR is teamed with the Energy and Environmental Research Center, at the University of North Dakota in the PCOR Partnership, a Regional Carbon Sequestration Partnership (regional area included shown in Figure 2). The 5-year project began May 1st of 2020 and aims to develop a regional deployment of carbon capture and storage. The PCOR Partnership includes over 120 stakeholders from industry, regulatory, and academia.

Other CCUS projects

In FY20 CEGR also participated in other CCUS projects. For example, CEGR was a project team member of the CarbonSAFE project administered by the Southern States Energy Board at the Kemper County Energy Facility in Mississippi. That project concluded on February 28, 2020.

Rare Earth Elements (REE) and Critical Materials Projects:

Wyoming's mineral wealth is significant, including rare earth and critical minerals, although further characterization needs to be completed to fully understand the resources. SER's work on REEs and critical minerals is focused on building a new, revenue and job-creating industry based on mineral wealth and using skillsets widely available in the state. The rare earth element projects are funded by the SER standard budget except for the REE extraction pilot and the REE in produced waters projects. The SER investment to date for each project has been less than \$50k. As the projects mature SER anticipates that each of the projects may attract significant federal dollars.

Rare Earth Elements in Produced Water.

CEGR continued investigation of REEs in produced water and extraction technologies under the Wyoming Water Research Program. This study included sampling in two additional Wyoming

geologic basins. The project concluded in June 2020. Researchers are preparing the final report for release in early FY21.

Rare Earth Elements in Coal and Coal By-Products.

The project team continued to work with industry partners to obtain additional coal core and coal ash samples to supplement the preliminary sample set. Characterization work is ongoing.

Rare Earth Element Extraction Pilot.

SER is teamed with the National Energy Technology Laboratory (NETL), the city of Gillette, and Campbell County on a \$1.6M rare earth element (REE) pilot project. The project team will complete the REE characterization of PRB fly-ash and economically demonstrate the NETL extraction technology. The 3-yr project will utilize lab space at the University of Wyoming and NETL in years 1 and 2 of the project and deploy a field demonstration in year three at the Wyoming Innovation Center located in Gillette, Wyoming (formerly known as the Advanced Carbon Products Innovation Center).

Rare Earth Elements in Unconventional Minerals and Uranium Roll Front Deposits.

A UW Geology student, Garrett Gay, supervised by SER Professor John Kaszuba, in conjunction with CEGR is developing methodologies for REE separation, processing, and analyses of the Red Mountain Pluton, and hopes to lay the groundwork for other rock types. In addition, Gay is working with a Wyoming Uranium Company to complete an REE mobility assessment of the roll front. The project is funded by the UW Foundation Marathon Interdisciplinary Fossil Fuel Research Laboratory and will be completed in the fall of 2020.

Critical Minerals in the Phosphoria Rock Complex.

CEGR is working with Dr. Simone Runyon, UW Geology assistant professor, to evaluate the REE potential of the Phosphoria Formation. Researchers collected and analyzed samples during FY20. Initial concentrations indicate that REE concentrations occur above 1,500 parts per million and correlate with phosphoric oxide concentration. This formation is worth studying in

greater depth because the extraction of REEs may be easier and less costly. More work is scheduled to continue next fiscal year.

Oil and Gas Research Projects:

Oil and gas research projects undertaken by SER are focused on driving incremental production, and thus revenue, of these important domestic energy resources.

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 Wyoming Powder River Basin. Ongoing on this project is compiling the background data needed to foster a development strategy for the Mowry fairway. In FY20, SER student interns compiled a database of the core intervals available at the USGS core repository, and completion reports from the Wyoming Oil and Gas Commission and had success digitizing logs to examine the play. These data will allow CEGR researchers to develop a basin-wide understanding of the play. Similar to the REE projects the Mowry Shale project is seed funded from the SER standard budget.

Center for Air Quality – Shane Murphy, Director

The School of Energy Resources Center of Excellence for Air Quality (CAQ) continues to conduct fieldwork and modeling projects to better understand and mitigate air quality issues related to energy production. It is envisioned that this work can help Wyoming companies meet environmental requirements more cost-effective and/or provide a differentiator to Wyoming producers that can demonstrate a significantly lower environmental impact than their non-Wyoming counterparts. During FY20, CAQ has worked with energy companies (Jonah Energy), monitoring companies (Project Canary), non-profits (Environmental Defense Fund), regulatory agencies (Wyoming DEQ, Utah DEQ, Colorado Department of Public Health and Environment (CDPHE)), Federal agencies (BLM, NOAA), regional universities (Colorado State, University of Colorado, University of Utah, Utah State), and Wyoming schools (Saratoga High School). In

FY20, CAQ added a new faculty member, Dr. Lars Kotthoff from the Computer Science Department. The center now has the following members:

- **Dr. Shane Murphy** (Director, Associate Professor of Atmospheric Science): Coordinates center activities for both field and modeling efforts.
- **Dr. Robert Field** (Assistant Director, Senior Research Scientist): Leads BLM field project and CAQ outreach efforts.
- **Dr. Zach Lebo** (Assistant Professor of Atmospheric Science): Leads photochemical modeling efforts.
- **Dr. Dana Caulton** (Assistant Professor of Atmospheric Science): Leads field research of greenhouse gas (GHG) and volatile organic compound (VOC) emissions.
- **Dr. Lars Kotthoff** (Assistant Professor of Computer Science): Leads efforts related to machine learning and advanced statistical analysis of distributed sensors.
- **Matt Burkhart** (Senior Research Scientist): Lead electrical and data engineer for CAQ.
- **Dr. Anna Robertson** (Postdoc): Leads field research of GHG and VOC emissions.

Students: Kristen Pozsonyi (1st year Ph.D. student in atmospheric science), Shreta Ghimire (2nd year Ph.D. student in atmospheric science), Jeff Nivitanont (Incoming Ph.D. student in atmospheric science), Joseph Klebba (Undergraduate researcher in computer science).

Publications & Presentations

Provided below are the peer-reviewed papers either published or submitted in FY20 by CAQ.

Robertson, Anna; Edie, Rachel; Field, Robert; Lyon, David; McVay, Renee; Omara, Mark; Zavala-Araiza, Daniel; Murphy, Shane, "*New Mexico Permian Basin Well Pad Methane Emissions are a Factor of 6 – 13 Times Higher Than US EPA Estimates*" Environmental Science and Technology, In Review.

Edie, R., Robertson, A. M., Field, R. A., Soltis, J., Snare, D. A., Zimmerle, D., Bell, C. S., Vaughn, T. L., and Murphy, S. M., "*Constraining the Accuracy of Flux Estimates Using OTM 33A*" Atmospheric Measurement Techniques, 13, 341–353, 2020, <https://doi.org/10.5194/amt-13-341-2020>

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Student Accomplishments

Graduate student Shreta Ghimire is preparing a manuscript describing her successful simulation of ozone formation in the Upper Green River Basin of Wyoming to be submitted in fall 2020.

Postdoc Anna Robertson is preparing a paper summarizing airborne measurements of methane flux from the Upper Green River Basin and Dr. Rachel Edie (now at the Utah Department of Environmental Quality) is drafting a manuscript summarizing emission measurements, made during her Ph.D., from produced water injection facilities in Colorado.

Two graduate students supported by CAQ, Anna Robertson and Rachel Edie, received their Ph.D.'s in FY20.

Projects and Activities

Air Quality Monitoring Continental Divide-Creston Natural Gas Development Area.

Dr. Robert Field of CAQ continued to upgrade and operate the Wyoming Air Quality Assessment Monitoring Laboratory (WAQAML) west of Saratoga in Carbon County. 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 model efforts related to the National Environmental Policy Act (NEPA) NEPA Record of Decision for the Continental Divide-Creston Natural Gas Development Project.

Permian Basin Methane Emissions.

CAQ members Murphy, Caulton, Robertson, Burkhart, and Pozsonyi deployed the UW Atmospheric Science Mobile Laboratory to New Mexico and Texas in January 2020 to support an ongoing project funded by the Environmental Defense Fund (EDF) that began with a deployment in August of 2018. The project aims to refine estimates of methane emissions from the Permian Basin and define best practices to reduce leakage. Data from these deployments have been integrated into the New Mexico emissions inventory and has been submitted for publication. CAQ is planning a third deployment in support of this project in September 2020.

Upper Green River Basin Ozone Modeling.

Shreta Ghimire, a 2nd year Ph.D. student under the advisement of CAQ members Lebo and Murphy, has developed a functional photochemical model for the Upper Green River Basin using the weather research and forecasting chemistry (WRF-Chem) model. Shreta has run the model and demonstrated ozone formation in reasonable agreement with ambient observations from the Wyoming Department of Environmental Quality (DEQ) monitoring stations. Ozone formation depends both on the emissions inventory (NEI 2014) utilized and on the chemistry scheme (MOZART and RACM). Shreta is currently writing this work up for publication. CAQ has developed a strong working partnership with Utah State University to simulate ozone formation in the Upper Green Basin in Wyoming and the Uintah Basin of Utah. CAQ has leveraged Utah State's extensive experience in ozone modeling and the collaborative team is utilizing a recently awarded large allocation of time on the NCAR-Wyoming Cheyenne Supercomputer.

Low-Cost Approaches to Reduce Methane Emissions.

CAQ members Murphy, Kotthoff, Klebba, Caulton, Robertson, Burkhart, and Pozsonyi are working with Jonah Energy and Project Canary to assess the ability of low-cost detection systems in combination with supervisory control and data acquisition (SCADA) data to reduce methane and VOC emissions in Wyoming oil and gas basins. CAQ recently signed an NDA for the project and is collecting data to begin the advanced statistics/machine learning portion of the project. CAQ plans a field deployment of its mobile laboratory to support this project in the fall of 2020.

Outreach

CAQ's program with Saratoga High School continues, and 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.

CAQ planned to again provide workshops for the Native American Institute (lead by Dr. Murphy and Dr. Caulton) and the weeklong Engineering Summer Program (lead by Dr. Murphy) but was unable to do these programs this year because of the Covid-19 pandemic. The programs focus on air quality and climate, with hands-on experiences using personal air quality samplers and launching a weather balloon. CAQ plans to continue to lead these workshops in future years.

Also in FY20, Dr. Murphy gave an invited talk at the NOAA Earth System Research Lab summarizing CAQ research activities. Dr. Robertson, who is now a postdoc in CAQ, gave an invited talk at the American Geophysical Union Fall Conference in San Francisco.

Proposals and Future Work

Several proposals were submitted during FY20 and the project titles, agency, and amount requested is noted below. All proposals below are currently pending, these proposals are in addition to the already funded and ongoing projects in the Permian Basin (\$80k received, additional \$50k requested from EDF), modeling ozone formation in the Upper Green River Basin (supercomputer large allocation awarded), and with Jonah Energy/Project Canary. In addition to the projects noted below, we plan to pursue additional external funding for the project with Jonah Energy/Project Canary assessing the utility of low-cost sensors for methane mitigation.

- Invited joint proposal with Colorado State University to Colorado Department of Public Health and Environment (UW share \$130K) to quantify emissions in the DJ Basin.
- Wyoming Air Quality Assessment and Outreach program (2020-21); Wyoming BLM, \$165K. This is year 4 out of 5 of our second cooperative agreement.

- Installing PM_{2.5} sensors to provide real-time indicative air quality data for the Greater Yellowstone Area (2021); Greater Yellowstone Coordinating Committee \$25k (with additional \$5k support from ORD Crossing Divides funds). Invited submission.
- Building community air quality networks to engage, educate, and inform (2020-2023); NSF; \$334k. Collaboration between Colleges of Engineering and Education.

Center for Biogenic Natural Gas Research – Michael Urynowicz, Director

The Center for Biogenic Natural Gas Research (CBNG) is dedicated to developing next-generation renewable energy technologies that add value to Wyoming's vast energy resources by bridging the gap between renewable energy and fossil fuels.

Commercialization Activities

Cowboy Clean Fuels, LLC (CCF) is a University of Wyoming technology holding company that has the exclusive rights to commercialize technologies patented through the CBNG. The company was formed in 2020 to commercialize the University of Wyoming patent (13/437,689 *Biomass-Enhanced Natural Gas from Coal*), held by the Center. The technology represents an innovative approach for producing low-carbon renewable natural gas from depleted coalbed methane (CBM) wells through microbial enhancement using sugar beet molasses; a large source of waste carbon generated from Wyoming's 2nd largest agricultural crop behind alfalfa. CCF is working with Huron River Ventures to secure venture capital funding (~\$2M) to complete Phase II field demonstration activities at a University of Wyoming experimental research station located within the Powder River Basin.

Research and Development Activities

For the foreseeable future, all research and development activities at the CBNG will focus exclusively on supporting commercial efforts devoted to transforming Wyoming's depleted CBM and natural gas assets within the PRB into a large producer of low carbon natural gas.

Center for Produced Water Management – Jonathan Brant, Director

The Center of Excellence for Produced Water Management (CEPWM) was established by the College of Engineering and Applied Science 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, to maximize water recovery and beneficial use as well as 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 FY20, CEPWM leveraged funds provided by SER to advance two research areas in the pursuit of external funding. One Ph.D. student was supported by the SER funds during the past fiscal year, while the remainder of the research funds were used to acquire materials and supplies for the subsequently described research efforts. The first area involved the development of electrospun PVDF membranes for selectively recovering hydrocarbons from produced waters. These membranes are characterized as having superhydrophobic/oleophilic properties and thus permeate non-aqueous phases (hydrocarbons) while rejecting polar phases (water). Data from SER funded efforts were used to successfully apply for research funds from the DOE. The DOE-sponsored project focuses on developing two membrane prototypes that will be tested in the field for hydrocarbon recovery from produced waters generated in Wyoming's Greater Green River Basin (GGRB). The project duration is 2-years and involves carrying out a techno-economic assessment of the hydrocarbon recovery process in addition to developing the membrane prototypes.

The second research area involved supporting an active research grant from Strategic Environmental Solution, Inc. (Pensacola, FL). The overall objective of this effort is to develop and evaluate a new produced water treatment system that relies on magnetic fields to alter the characteristics of water and its constituents. During this fiscal year, we produced a peer-

reviewed publication on this technology and described how it alters the proton concentration and electrical conductivity of water through the manipulation of hydrogen bonds. We are currently testing how the aligned magnetic field affects the characteristics, like size, dissolution rate, etc., of silver nanoparticles. The purpose of these tests to describe how the process enhances the disinfection effectiveness of the nano-silver. The intended application for this arrangement is the disinfection of produced water during rejection while reducing, or avoiding, the usage of biocides like glutaraldehyde. Data collected over the past year indicates that the magnetic field increases the ionic fraction of the nano-silver, thus enhancing the impact that it has on bacteria. Further, we have found that the molecular structure of the glutaraldehyde is altered upon exposure to the magnetic field. All these outcomes are a function of flow velocity through the magnetic field. This finding has provided a starting point for optimizing process performance and design.

Center of Innovation for Flow through Porous Media—Mohammed Piri, Director

The Center of Innovation for Flow through Porous Media (COIFPM) is located at the High Bay Research Facility (HBRF) of the University of Wyoming (UW). The HBRF contains more than 90,000 square feet of high-bay and traditional laboratory space, and affiliated office and meeting areas (<https://coifpm.com>). It is, to the best of our knowledge, the world's largest experimental research facility focused on flow through porous media problems with applications primarily in oil and gas recovery and carbon utilization and storage. It is developed using more than \$100 million investment from the State of Wyoming and corporate sponsors. The Center provides imaging and flow capabilities at the atomic, nano, micro, and macro scales. Furthermore, it establishes an unparalleled capacity for scientists to conduct numerous studies in parallel. COIFPM is a world-class research entity with a distinguished track record in scholarly activity, technology development, commercialization, and fundraising. Technologies developed at this center of excellence have applications not only in oil and gas recovery problems but also in many other areas of science and engineering, thereby establishing a remarkable potential for future growth with appropriate investment and planning.

Team members

The following list provides some basic information and statistics regarding the teams at COIFPM:

- Twenty-three (23) PhD & one (1) MSc students
- Wight (8) post-doctoral research associates & senior research scientists
- Five (5) staff members and
- Three (3) faculty members
- Five (5) full-time professionals (technical services branch)
- Graduated seventeen (17) PhD & eight (8) MSc students
- New graduate students and research associates are currently being recruited to join the program
- A highly international composition (from more than 20 countries)
- One of the largest research groups on the UW campus

Research – Unconventional Reservoirs

The following list presents examples of technologies being developed under the research division of COIFPM in connection to the exploitation of unconventional reservoirs:

- *Foam-assisted hydrocarbon gas injection (FAGI) in unconventional reservoirs:* This is an initiative that is funded by the Department of Energy and focused on pilot testing of this enhanced oil recovery scheme in Bakken. The project includes significant experimental and modeling components as well. It is a collaborative program between UW, Dow Chemical Company, and Hess Corporation. Prof. Piri is the PI of the project.
- *Confined Fluid Phase Behavior:* Using state-of-the-art experimental techniques developed at COIFPM, we probe the effect of confinement on the phase behavior of fluids stored in nanometer-sized pores. The data are then used to develop an Equation of State to model the confined fluid phase behavior. When fully developed, the model can be used with, for instance, reservoir simulation platforms to account for the effect of confinement in reservoir performance evaluations.

- **Advanced Well Stimulation Chemicals:** Design and evaluation of the next generation stimulation chemicals to enhance the productivity of unconventional oil and gas wells.
- *Multiphase Flow in Propped and Unpropped Fractures:* Characterization of multiphase flow behavior in rough-walled propped and unpropped fractures under a wide range of flow conditions.
- *Proppant Wettability and Fracture Conductivity:* Investigation of the effect of proppant size, wettability, and geometry on fracture conductivity. Evaluation of the impact of proppant wettability reversal on fracture conductivity.

Research - Conventional Reservoirs

Examples of technologies being developed at COIFPM for applications in oil and gas recovery from conventional reservoirs include:

- *Digital Rock Technology (DRT):* Development of state-of-the-art DRT platforms capable of modeling complex multiphase flow and transport physics at the pore scale in large three-dimensional digital domains faithfully representing the disordered pore space in man-made and naturally-occurring porous media. The platforms will produce physically-based predictions of key multiphase flow and transport properties (e.g., relative permeabilities) that are then used to, for instance, significantly reduce the uncertainty associated with predictions of, for instance, recovery from oil and gas reservoirs, CO₂ storage capacity in geologic formations, and NAPL transport behavior in contaminated aquifers.
- *Enhanced Oil Recovery (EOR):* Investigations of efficacies of different EOR agents (e.g., surfactants, polymers, and engineered low salinity brine solutions), displacement physics, and recovery trends in non-water-wet sandstone and carbonate samples.
- *Nanofluids:* COIFPM scientists design/evaluate nanofluids (solutions of nanoparticles with/without surfactants) as EOR agents for different conventional reservoirs. For example, novel Wyoming coal-derived carbonaceous nanoparticles are being proposed for enhanced oil recovery applications. These environmentally-friendly nanoparticles have remarkable physicochemical properties such as nanometer size, chemical inertness, and ability to modify IFT and/or wettability that makes them potentially suitable as EOR agents. These studies provide novel insights into the structure-function

relationship of nanofluids and pave the way for the development of more engineered nanoparticles via chemical functionalization.

Commercialization

Members of COIFPM work diligently to capture and commercialize IP as they are conceived under the research branch of the Center. Examples of the activities in this category include:

- Piri Technologies, LLC: (i) Piri Technologies is a spin-off company located at COIFPM that is partly owned by UW. It commercializes technologies developed in Prof. Piri's research group at UW in the broad area of Flow through Porous Media; (ii) Since the start of its operation in September 2017; it has developed projects with large national and international corporations. This indicates that its business model and the technologies that it commercializes are globally relevant; (iii) It currently employs five (5) highly-talented professionals with advanced degrees. Four (4) of these employees are UW graduates, and (iv) Piri Technologies is capable of significantly contributing to the development of effective solutions to some of the technical challenges that the oil and gas producers in Wyoming encounter in enhancing hydrocarbon recovery. An initiative of this kind is listed in the next section.
- Revenue Generation: Consistent with the formal framework that governs the relationship between UW and Piri Technologies, Piri Technologies provides UW with revenues for royalty on the licensed IP and rent on the utilized instruments.
- Capturing, Protecting, and Licensing IP: Members of COIFPM work closely with UW's General Counsel and Wyoming Technology Transfer and Research Products Center on IP capture. To this end, COIFPM submits to UW completed Invention Disclosure Forms for IPs conceived in the Center. Subsequently, we work on the development of appropriate strategies to protect and license them (e.g., filing patents, maintaining IP in the form of trade secrets, etc.).
- Over the last fourteen years, Prof. Piri's research program has developed and filed more than ten (10) Invention Disclosure Forms and 3-5 patents.

Contributions to the State of Wyoming

The following list provides examples of COIFPM's contributions to the State of Wyoming:

- COIFPM attracts some of the world's best talents to work on critical flow through porous media problems in Wyoming. This is the most important factor that controls our ability to innovate and develop key technologies.
- Engagement of COIFPM's Technical Services branch (Piri Technologies) with the Enhanced Oil Recovery Institute (EORI) in a project titled 'Unlocking the Tight Oil Reservoirs of the Powder River Basin, Wyoming'. This initiative is funded by the Department of Energy.
- COIFPM is capable of providing leading-edge scientific support for programs focused on the effective development of Wyoming's significant hydrocarbon resources (conventional and unconventional). Prof. Piri is currently working closely with the new Executive Director of the School of Energy Resources (SER), Dr. Holly Krutka, and Dr. Steven M Carpenter, Director of the EORI, on the development of an initiative to directly assist oil and gas producers in Wyoming using COIFPM technologies.
- Development and evaluation of novel Wyoming coal-derived carbonaceous nanoparticles for enhanced oil recovery applications.
- COIFPM significantly increases external funding for research initiatives in Wyoming through competitive and innovative research and unparalleled reputation (more than \$70 million in external funding since 2005).
- COIFPM has indisputably enhanced UW's reputation and visibility, both nationally and internationally in the area of flow through porous media and EOR. This has significantly contributed to the successful realization of SER's vision as well as that of UW's Tier-I initiative. Furthermore, it has established a successful example of how technology conceived at UW can be commercialized to create jobs in the State of Wyoming, and thereby contribute to the development of a diverse, technology-based economy.
- COIFPM has established a truly unique set of integrated experimental capabilities that are equally important to studies in non-oil-and-gas domains such as Materials Science and Engineering, Rare Earth Elements, Geologic Sequestration of CO₂, Carbon Engineering, etc. Examples of these capabilities include Environmental Transmission Electron Microscopy and imaging of multiphase flow through porous materials at the

micro-scale. Therefore, as the State of Wyoming moves toward diversifying its economy, COIFPM will be able to play a key role in supporting some of the scientific initiatives focused on developing IPs needed for such economic diversification.

Updates and Highlights

In this section, we present highlights and updates regarding COIFPM's recent accomplishments as well as current/upcoming developments and activities. COIFPM is continually engaged in new technology development initiatives, collaborative research endeavors, and fundraising efforts, and here we list several related updates:

- Prof. Piri is working closely with the Executive Director of the School of Energy Resources, Dr. Holly Krutka, on the development of an initiative to directly assist oil and gas producers in Wyoming using COIFPM technologies. To this end, Dr. Piri held two meetings with Rob Hurless and Lon Whitman of the Enhanced Oil Recovery Institute (EORI) to discuss the technical needs of the oil and gas producers in the State of Wyoming and to determine how COIFPM can assist them. Subsequently, Dr. Krutka and Dr. Piri held a meeting with Dr. Carpenter and Mr. Scott Austin Quillinan to further advance this initiative. We are in the process of coordinating various elements of this effort with UW General Counsel and other administrators. In collaboration with EORI, Prof. Piri has been in communication with two companies regarding the technical needs of their operations in Wyoming.
- We are proud that, for the last five years, a member of the COIFPM research team was placed first in the regional SPE Student Paper Contest. Furthermore, for the past two years, Prof. Piri's PhD students, Elizabeth Barsotti (2019) and Vahideh Mirchi (2018), won the first place in the International Student Paper Contest hosted by SPE. In Fall 2020, one of Prof. Piri's PhD students, Mr. Abdelhalim Mohamed, will compete at the international contest against the winners of the other SPE regions from around the world. The competition will be held in Denver as part of the SPE Annual Technical Conference and Exhibition.
- During the time period between January 2019 and August 2020, twenty-three (23) papers from Prof. Piri's research group have been published (or accepted for publication) in high-quality, peer-reviewed journals. Furthermore, the team has more than 15 manuscripts either submitted for publication or in preparation.

- After a presentation by Prof. Piri to UW Board of Trustees Budget Committee in May 2020, COIFPM has received support for two staff positions, i.e., IT and IP specialists.
- During the time period between January 2019 and July 2020, COIFPM held six preliminary exams and eight final thesis defense sessions for its PhD students. This brings the total number of PhD students graduated from the group to seventeen (17).
- In January 2020, for the fifth year in a row, COIFPM wins the performance award granted annually by Hess Corporation after their careful evaluation of COIFPM's contributions and accomplishments.
- Prof. Piri has initiated the development of a visual chart that shows the connection between different COIFPM technologies to key reservoir engineering and oil recovery challenges encountered by the producers in Wyoming. This effort was commenced after helpful interactions between Mr. Carl Bauer of ERC and Prof. Piri.
- Since Fall 2017, Prof. Piri and scientists at ADNOC have been interacting regarding the establishment of a research collaboration initiative between COIFPM and the company. It is an initiative focused on the development of the next generation of DRT platforms and is titled 'Multi-scale Investigations of Two- and Three-Phase Flow in Porous Media of varying Wettability using Experimental and Digital Rock Technologies'. In April 2020, ADNOC sent to Prof. Piri a contract for this collaboration. Since then, Prof. Piri has worked with UW General Counsel to negotiate the contract details, including the IP rights.
- COIFPM has recruited two high-caliber research scientists for its DRT team: (1) Dr. Amin Amooie from Massachusetts Institute of Technology, and (2) Dr. Samuel Fagbemi from UW.
- One (1) visiting Professor from France has spent his sabbatical leave at COIFPM using a Fulbright scholarship.
- In year 2020, COIFPM recruited a Microcopy Laboratory Manager from Harvard University (Dr. Zhenyuan Zhang) and a general Laboratory Manager who had previously joined COIFPM from the University of Utah (Dr. Wattana Chaisoontornytin).
- In the year 2019, Prof. Piri secured \$20 million in external funding to support the technology development activities under COIFPM's research division. Over the last fourteen years, the funding granted by various external entities to Prof. Piri's research program on flow through porous media at the University of Wyoming has exceeded \$70 million. This amount does not include State matching funds.

- Earlier this year, Prof. Piri had initiated engagement with UW IT to develop an effective solution for the storage and management of large volumes of data that is being generated at COIFPM. This will play a key role in supporting the development of COIFPM's DRT platforms that are mentioned earlier in this document. COIFPM has now acquired a 1.9 PB data storage unit and UW IT is in the process of installing it.
- Shell and Petrobras companies have been in commutation with Prof. Piri to create a JIP focused on oil recovery from oil-wet carbonates. Prof. Piri had previously submitted a proposal upon their request. Representatives from Shell and Petrobras visited COIFPM in December 2019.
- In connection to enhanced oil recovery from unconventional oil reservoirs (specifically foam-assisted hydrocarbon gas injection in Bakken), Prof. Piri and members of his team designed a massive foam testing experimental platform. This is a HPHT apparatus that allows us to test the impacts of a large number of parameters (e.g., different foaming chemicals, concentration of foaming agent, the ratio of gas and aqueous solution flow rates (HC gas and surfactant solution), proppant wettability, proppant pack properties, etc.) on foam properties. It incorporates 6 modules (each with 3 proppant packs; a total of 18 packs), thereby establishing a significant capacity. Each of these packs will be replaced frequently as we change test parameters. This will allow us to conduct a large number of foam experiments with proppant packs at reservoir conditions. This three fluid phase system is made from Hastelloy to prevent corrosion of components and contamination of fluids. The research team is in the process of commissioning different system modules in a staged manner.
- Prof. Piri recruited three new PhD students who plan on joining COIFPM in Fall 2020 or Spring 2021. Their arrival will most likely be delayed due to COVID-19 pandemic.
- Prof. Piri developed and presented a chart to Dr. Holly Krutka, Dean Cameron Wright, Prof. Dennis Coon (Head of Petroleum Engineering Department), and Interim Provost Anne Alexander showing detailed organizational structure that he has established over the years to support the operations at COIFPM. He has recruited high-caliber staff, with appropriate job descriptions, to support the research program. The chart shows that Prof. Piri has also planned for additional positions to further strengthen the robustness of the operations at COIFPM and to prepare for expected growth.
- Prof. Piri continues to facilitate and support high-resolution imaging services as well as other equipment utilization needs of UW campus members.

- COIFPM installed a state-of-the-art x-ray microcomputed tomography system. This apparatus enables high-resolution imaging of samples during, for instance, high-pressure, high-temperature flow experiments.

Shell 3D Visualization Center – Emma Jane Alexander, Manager

The Shell 3D Visualization Center is a service provided by SER to the University of Wyoming and across the state. This technology platform is particularly valuable for viewing of large datasets.

The 3D Viz Center has seen significant growth in the last 12 months, which is a direct result of implementing the ReVision. Staffing, accommodation, and services provided have all been positively impacted. The 3D Viz Center has now expanded into what a larger working area called the SimSuite (previously the Drilling Simulator) on the 2nd floor of the Energy Innovation Center. The east side of the room will provide office space for two members of the team and a dedicated space for augmented reality exploration. The west side will become the Short Course and Technology Associate Program (TAP) Laboratory. Two new members of staff were welcomed onto the team, and one was promoted from a previous role in the 3D Viz Center. Early 2020 brought P. Black and P. O'Toole as the Digital 3D Asset Developer and the Lead Scientific Virtual Reality Developer. Late 2019 saw K. Summerfield promoted as the Lead Creative Virtual Reality Developer. Finally, the most celebrated achievement of the year is the award of a contract worth \$84,000 for the provision of professional services to Gillette's Northern Wyoming Community College District (NWCCD) for the development of a tool called 'Virtual Reality 4 Teaching - Surface Mine Exploration' (VR4T SME) for use with the Mining Safety and Health Administration safety training course.

Mission Statement: "To help bring digital innovation technologies to the heart of the UW academic, professional and entrepreneurial communities; enabling communication through visualization, while raising teaching and research aspiration and achievement".

Service Center Activity

The contract with NWCCD was officially kicked off in April 2020. It was through careful relationship nurturing that the opportunity to provide professional services developed. The 3D Viz Center attended, upon invitation, the launch of the Area 59 innovation facility at Gillette College in 2018 and subsequently provided two short courses in close succession for their staff. The digital knowledge transfer that was designed and delivered in the short courses by K. Summerfield, enabled the staff to begin creating their VR tools for teaching, which were recognized with a national innovation award. Swiftly following the short courses, a further business opportunity was identified to enhance the method, quality, and mode of teaching mining students about hazards and safety. Ms. E. Alexander turned that business need from the College into an \$84,000 contract for services for the 3D Viz Center.

Contributions, Presentations, and Professional Service

The 3D Viz Center continues to be a well-recognized, proactive contributor to meetings, workshops, and conferences. After founding THE CAAV (Higher Education Campus Alliance for Advanced Visualization) Ms. Alexander completed a 4-year term as the president in January 2019. The 3D Viz Center will continue to support and participate in THE CAAV. The international group of visualization practitioners has grown to over 200 members worldwide. Ms. Alexander chaired the 4th annual 3-day conference in October 2019 at Indiana University and secured a \$20,000 donation to support the event. K. Summerfield presented (upon invitation) at an event called PokeBot2.0 hosted by the Coe Student Innovation Center where he engaged the audience with his experience of participating in and leading game jams. For four consecutive years, the 3D Viz Center has had a proposal accepted to the UW Ellbogen Center for Teaching with Technology Impact (TnT) Invited Presenters Series in collaboration with a faculty member. This year's success was found with Dr. Lynch (Dept. of Anthropology) on a session called '3D Visualization: Engaging 1st-year Students in USP Physical and Natural World Classes'.

Teaching and Research

The 3D Viz Center has provided letters of support for funded research proposals including:

- Dr. Lynch (Dept. of Anthropology) for the ‘Hell Gap National Historical Landmark Consultation: Developing a Sustainable Virtual Museum to Preserve Wyoming Culture Heritage’ to the Wyoming Cultural Trust Fund.
- Dr. Matt Fox (College of Business) for the ‘University of Wyoming, Breaking through Innovations’ proposal to the US Economic Development Administration.
- Dr. Stephen Santoro (Dept. of Zoology & Physiology) for the ‘Olfactory experience-dependent regulation of the neuron types born in the nose’ to the National Science Foundation.
- Dr. Pejman Tahmasebi (Dept. of Petroleum Engineering) for the ‘An Open-Source Platform for Porous Media Analysis’ to the National Science Foundation.

The 3D Viz Center supported the human participant experiments for the 3D Future Form research project with Ms. E. Alexander in collaboration with Dr. Picorelli (Dept. Political Science) in December 2019 as scheduled, following the successful IRB (Institutional Review Board) application earlier in the year. The research question underpinning this work is “Can oneself experience healthy weight in VR and can that experience impact autonomy in motivation concerning real-world eating habits?” Subsequently, a research paper is now in development with Dr. Picorelli., K. Summerfield developed the 3D Future Form prototype VR software experience used in the experiments.

An exciting animation project was completed supporting a Ph.D. candidate in the Dept. of Petroleum Engineering, this required a complex animation sequence to be developed depicting various movements of fluid through porous rock networks (Fig 6). The output has been received with glowing praise from the client.

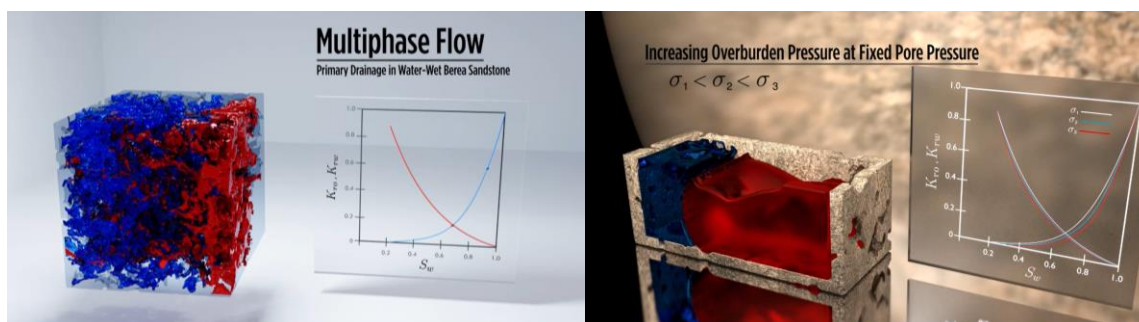


Figure 6 Animation to support research visualization in multiscale fluid-solid interaction in porous media prepared by the 3D Visualization Center.

In other research activities, K. Summerfield is the second author on a paper in collaboration with Dr. Bruce Parkinson (SER Professor in Chemistry) for his contributions in illustrating the chemical process. K. Summerfield utilized the game development engine Unity to create an interactive application to support Dr. Parkinson's hypothesis; rather than the intended visualization provision simply performing the role of illustrating the work, it subsequently led the research thinking underpinning the work. This was a transformation of the role the 3D Viz Center played, and K. Summerfield is to be highly commended for his efforts. K. Summerfield and E. Alexander were also cited as being contributing authors to a paper submitted to the *Land* journal called 'Use of 3-dimensional videography as a non-lethal way to improve visual insect sampling' by Mike Curran (Dept. of Ecosystems & Science Management). The support included a 360-degree camera for data capture at a field site, and to then host experiments where the users re-counted the insects in virtual reality. An Invention Disclosure has been submitted to the Wyoming Technology Transfer and Research Products Center to aid the consideration of commercial potential.

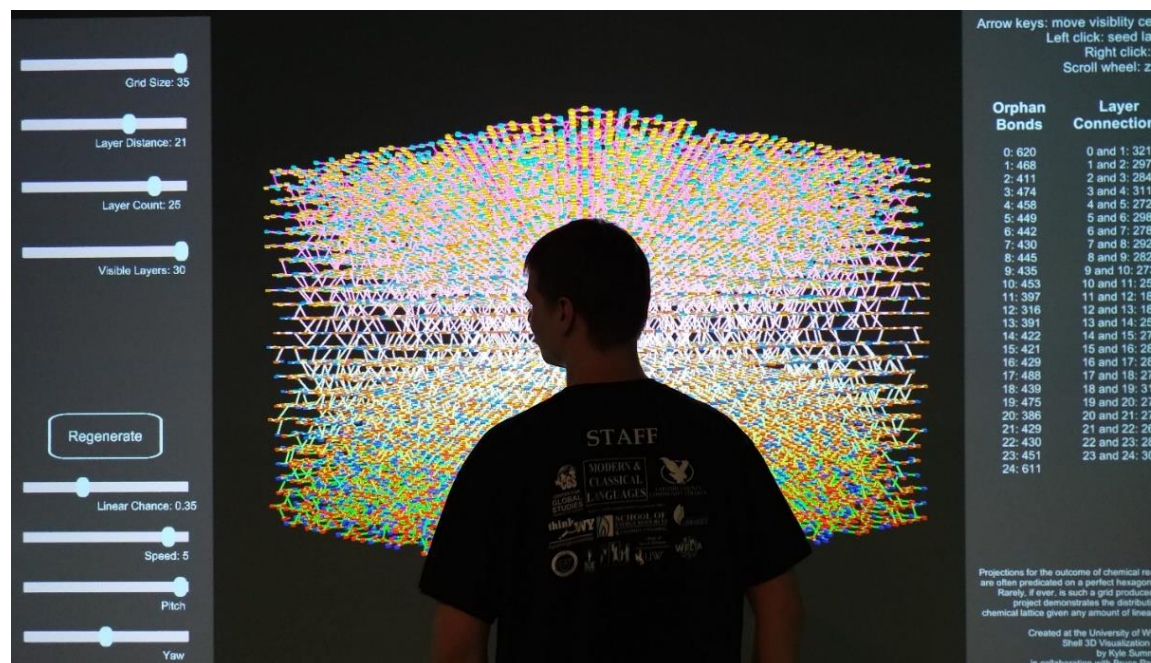


Figure 7 D Viz Center collaboration with the Dept. of Chemistry synthesizing new two-dimensional polymer systems that have many applications in energy technology.

Development also continues for 1. The Dept. of Molecular Biology on a 2D video game for community engagement (targeted at 8-14 year-olds on a mobile device; Fig. 7), 2. The Dept. of Ecosystem & Science and Management on the SoilSim 2.0 teaching tool (funded by the U.S

Department of Agriculture; Fig 8), and 3. The Dept. of Anthropology and the Virtual Reality (VR) Linguistic Elicitation Applications research application (funded by the National Science Foundation).

K. Summerfield was invited to provide technical guidance and professional leadership of the University of Calgary Cumming School of Medicine's first Brain-computer Interface (BCI) Game Jam; the goal of the game jam was to promote accessibility in gaming for children who have severe physical disabilities due to early life injury, such as perinatal stroke. K. Summerfield also hosted the annual Wyoming Game Jam 2019 in Casper.

A collaboration with Cleveland State University saw E. Alexander accepted into a round table discussion session on Human Fusions at the Society for Neuroscience in October 2019, she presented a piece on Personalized Virtual Reality Experiences, focusing on the roles of health, risk, and education at the international conference.

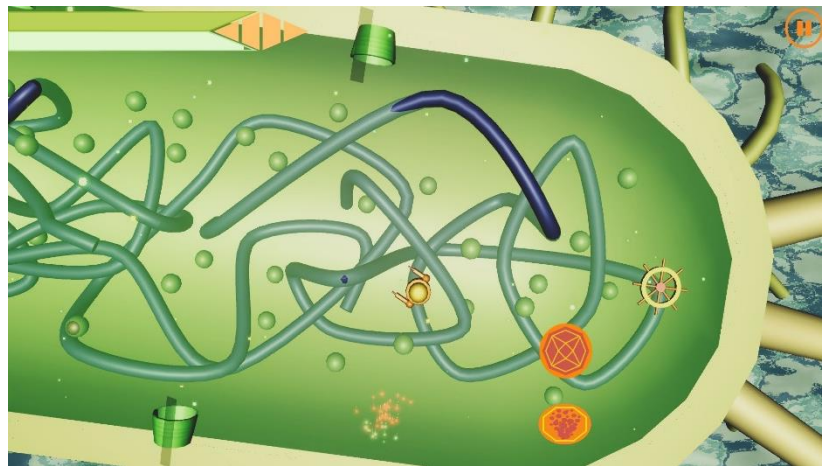


Figure 8. Interactive 2D Cell mobile game for the Dept. Ecosystem & Science Management

Technology Associate Program (TAP) Internships

The TAP intern team grew from four to six during FY20. The 3D Viz Center has started the process of engaging with other UW entities this year to gauge interest and potential cross-campus benefits of



Figure 9. SoilSim 2.0 virtual reality interactive tool supporting innovations in undergraduate teaching for the Dept. of Ecosystem & Science Management

whether it would strengthen students' experience of technology-oriented internships if they could experience the TAP program elsewhere on campus. Both the Makerspaces and the Dept. of Computer Science were receptive to exploring this further. This would expand the brand and on-campus impact of the 3D Viz Center TAP experience. To enable the wider adoption of TAP, a prototype mobile app is in development by K. Summerfield that would allow students to sign up for projects and manage their commitments and deliverables in a game-like application. Testimonials from previous TAP interns have led to the formation of the TAP Graduate Speaker Series. Interns are invited to speak about their careers to date, and the impact of their education and internship experience.

Exciting real world real-world projects and client opportunities are continually being proactively sought for TAP interns. For example 1. The Minotaur Mazes museum in Seattle is providing an augmented reality project regarding a pollinator exhibition, and 2. An architect in Denver is providing a collaborative 2D floorplan layout project, both projects will see the external business acting as the client, and the 3D Viz Center will support the students in using Agile Scrum techniques to manage the technical aspects of development. Other TAP intern projects this year include 1. Stop-Mo-Dino, this project which sees the recreation of the triceratops model from the 1933 King Kong movie (the client is the UW Art Museum), 2. Digital Badge development for 360-degree data capture technology.

UW Collaborations and Opportunities

It has already been highlighted that in the interests of sharing good practice the 3D Viz Center is reaching out across UW to offer its TAP program to other entities, in contrast to this and in the interest of adopting good practice elsewhere on campus, the 3D Viz Center has reached out to the Engineering Education and Research Building's makerspace to learn from its Digital Badge program. The Digital Badge program is a fantastic way to compartmentalize learning for users (staff or students). Subsequently, the 3D Viz Center is creating Digital Badges for 1. LiDAR scanning, 2. Mobile application development, and 3. 360 camera usage.

During December 2019 visiting artists to UW who had an exhibition in progress at the UW Art Museum were invited to the 3D Viz Center. Much lively creative conversation ensued, along with an invitation for a reciprocal visit for the 3D Viz Center team to experience the

Re(Evolution) exhibit. During the reciprocal visit, Ms. E. Alexander highlighted the prospect that 360-degree data capture and LiDAR laser scan of their work could enable future collaboration. The artists were delighted with the prospect and within the week K. Summerfield returned to perform the 360-degree data capture. It was agreed with the artists that there would be a pause on the collaborative discussion because this wasn't a scheduled project, and all staff and students were occupied for the semester. During the COVID-19 pandemic, the UW Art Museum enquired if the 3D Viz Center had any creative data that might be of interest to them to host online, we suggested these very data. Thus, development is underway of an appendix to the existing Research Agreement to allow the various parties to maintain their rights; the 3D Viz Center to the digital data, and the artists to their original work. The goal of this work is to create a digital experience of the sculpture exhibition and make it available online for the public to access. Further goals include plans to have the TAP interns collaborate with the artists, to create digital interactive landscapes for the mythical animals, or augmented reality experiences of the animals. The online experience of Re(Evolution) can be used on a desktop, mobile phone, or VR device. Users can navigate between various points of interest marked throughout the exhibit on their mobile phones or desktops by touching the blue sphere.

In response to the call for proposals, the 3D Viz Center submitted to the UW Heywood Trust Fund. The proposal was entitled '3D Viz Center MoVR (Mobile Virtual Reality)' and focused on establishing a mobile virtual reality facility that will enhance core UW facilities. Specific focus was afforded to 1. Teaching, research, entrepreneurship, and community engagement using VR technology, and 2. The advancement of high-impact distance learning. The outcome remains pending at the submission of this report.

Marketing

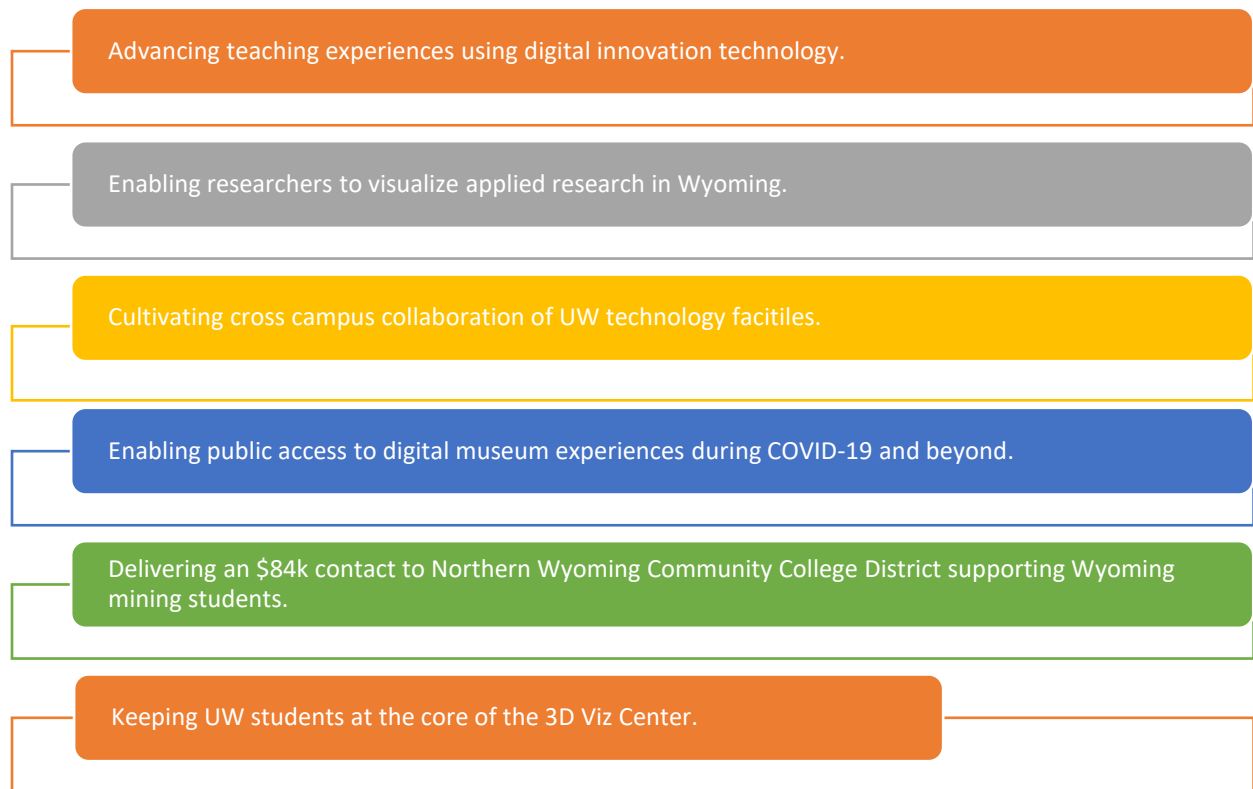
Planning and implementation by K. Summerfield have been undertaken on the development of the VizAbility App, a downloadable mobile application that allows users to read and watch extensive content about a variety of 3D Viz Center projects. Version 1 will be launched before the fall semester of 2020.

Impact of COVID-19

COVID-19 resulted in 3D Viz Center staff (and TAP students) transitioning to working remotely from home. The team (10 individuals) had a preexisting high level of routine digital communication already part of their daily practice, and the continued effective usage of Microsoft Teams, combined with the morning daily Team Meet (at 8:45 am) was soon mirrored with a daily Wrap Up (at 4:40 pm) helped to strengthen the sense of community not only by beginning each day as a team but by bringing it to a close and reflecting upon it as well. This has kept team relationships strong and helped to integrate the new members of the team who have joined during this challenging time.

Of equal paramount relevance here is the 3D Viz Center's firmly-held mindset that 'content is king'; without meaningful digital content to visualize and interact with, having software or tools for doing so is worth little. Business cases for projects always come down to the digital content that is at the heart (the 'what are building and why' question); the particular display technology being used is secondary in most cases. This has ensured that all staff and students were already occupied with creating content for existing users, and the only physical transition required was to provide laptops and VR headsets to students to enable summer collaborative projects to progress. Staff was encouraged to take their workstations home to ensure that they could capitalize upon the hardware, and not have to compromise via remote working experience. Since working remotely, all projects have met the expected rate of development, and safe working practices have been incorporated when in-office participation was required. A return-to-work plan has been developed by Ms. E. Alexander in collaboration with the team, and confidence is high that if demand is present, safe visits can be offered to those wishing to visit the 3D Viz Center. The 3D Viz Center has created a sub-team to explore and evaluate virtual reality (or non-immersive) collaborative digital workspaces; the team is reviewing open-source and fee-based services, establishing what features existing tools have, and how they can be capitalized up for the benefit of teaching and research. The results will be shared with UW interested parties.

3D Viz Center Key Achievements



Other SER Research Projects

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

The CERC-ACTC program is a long-standing research collaboration that further enhances SER’s work in carbon capture, use and storage.

The School of Energy Resources continues its work with the U.S.-China Clean Energy Research Center – Advanced Coal Technology Consortium (CERC-ACTC), a joint clean energy technology research effort between the United States and China. The U.S. membership consists of federal, private, and public sector entities 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 fourth year. The Phase II projects include a joint study to develop a commercial-scale integrated CCUS demonstration project and a novel catalyst for carbon capture project.

Ordos Basin Carbon Capture Utilization and Storage.

Dr. Zunsheng Jiao, in CEGR, leads the CCUS Ordos Basin Project. In the first four years of Phase II work, researchers on the CCUS project evaluated and validated existing technical and preliminary injection and production data for CO₂ utilization (enhanced oil recovery using CO₂ flooding) and CO₂ storage in stacked reservoirs of the Ordos Basin. The CEGR team has assisted the Yanchang Petroleum Group to implement a CO₂/storage pilot project in the Ordos Basin. A pilot CO₂ EOR/storage project in the Yanchang Field is in the process with over 60,000 tonnes of anthropogenic CO₂ injected. The project is now focusing on scale-up. The lesson learned from the Ordos CO₂ EOR/storage demonstration project would benefit Wyoming and other United States CCUS locations by sharing know-how on validated technologies, identifying most critical risk components, and optimizing an implementation strategy on CO₂ storage and utilization with tight, unconventional reservoirs.

Novel catalyst development for CO₂ Capture.

A second project is on a novel catalyzed carbon capture technology led by SER Professor Dr. Maohong Fan in the Departments of Chemical and Petroleum Engineering. The fourth year of work on the CO₂ capture project has consisted of 3rd party manufacturing and testing of the UW catalysts. The 3rd party testing of the performance of the catalysts has shown measured efficiency increases over other commercial catalysts. The final testing will occur over FY21 with the hope of demonstration testing at the National Carbon Capture Center later in the year.

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

This project was focused on the development of engineered techniques to address problems inherent to Powder River Basin reservoir rock. 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. During FY20, in collaboration with Mid-Con Energy, a comprehensive study was performed to support an upcoming cyclic water injection pilot in Culp Draw Unit. The results identified a chemical that significantly improves production efficiency.

Enhanced Oil Recovery Institute – Steve Carpenter, Director

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

Center for Energy Regulation and Policy Analysis – Director, Kipp Coddington

A new SER Center of Excellence focused on interdisciplinary energy policy assessments, known as the Center for Energy Regulation and Policy Analysis (CERPA) was stood up during FY20 and has been highly active in outreach as well as forming a robust, Wyoming-focused business plan, including providing policy support for research projects, including those funded by the U.S. Department of Energy (DOE). This center is focused on research analysis as well as real-time support of Wyoming elected and appointed officials.

CERPA-Related Activities

CERPA Administration and Outreach

- Coddington was appointed to the UW President's Engagement Council
- Coddington was appointed and served as co-chair of a National Coal Council study regarding energy policies to support advanced coal generation technologies

- Coddington was appointed the policy chair of Governor Gordon's Power Wyoming initiative
- Coddington was appointed policy fellow at: (1) the Colorado School of Mines; and (2) Boise State University
- CERPA leadership: (1) engaged a consultant to build-out a new web site; (2) started the process of hiring a federally funded energy policy fellow; and (3) completed a business plan with many specific projects to be launched over FY20 and FY21

Published Papers & Articles

- Bazilian, M., Coddington, K. "CCUS Under the Paris Agreement," The Hill (May 4, 2020) (available at <https://thehill.com/opinion/energy-environment/492990-carbon-capture-utilization-and-storage-under-the-paris-agreement>)
- Pettit, A., Koski, K., Coddington, K. "Secure Geologic Storage: 45Q, The ISO, and State Regulation," Energy Law Advisor, The Center for American and International Law, Vol. 14, No. 1 (2019) (available at <https://www.cailaw.org/media/files/IEL/Publications/2020/apettit-vol14-no1.pdf>).
- Coddington, K., Terrell, C. "Low-Carbon Energy Law & Policy: What Wyoming Lawyers Need to Know." White Paper for Presentation at the Wyoming State Bar 2019 Annual Meeting & Judicial Conference (Oct. 2, 2019; Moran, Wyoming)
- Guo, F., Aryana, S., Wang, Y., McLaughlin, F., Coddington, K. "Enhancement of Storage Capacity of CO₂ in Saline Aquifers Using Nanoparticle Stabilized CO₂ Form," Int'l J. of Greenhouse Gas Control, vol. 87, pp. 134-141 (Aug. 2019) (available at <https://www.sciencedirect.com/science/article/abs/pii/S1750583619301859>)
- Coddington, K., Righetti, T. "Why Current Regulation of Commercial CO₂-EOR Operations, Coupled With Documenting Storage under the International Organization for Standardization's New CO₂-EOR Standard, Can Be Used to Demonstrate 'Secure Geologic Storage' Under Amended 45Q of the Internal Revenue Code" (June 2019) (available at https://www.researchgate.net/publication/333825695_Current_Regulation_of_Commercial_CO2EOR_Operations_Coupled_with_Documenting_Storage_under_the_International_Organization_for_Standardization's_New_CO2-EOR_Standard_Can_Be_Used_to_Demonstrate_Secure_G)

Speaking Engagements

- May 28, 2020: Cohost, “Energy Policy Workshop” (Center for Advanced Energy Studies; webinar)
- April 7, 2020: Panelist, “Solve Climate by 2030” (Center for Advanced Energy Studies; webinar)
- April 1, 2020: “Update on Wyoming’s New CCUS Policies” (United States Energy Association; webinar)
- March 16, 2020 (postponed): “Climate Law & Policy Update” (The Jackson Hole Center for Global Affairs; Jackson, WY)
- March 3, 2020: “CCUS Roundtable Discussion” (Colorado School of Mines; Golden, CO)
- February 25, 2020: “Low-Carbon Fossil Update: The View from Wyoming” (IEA Coal Industry Advisory Board; Washington, D.C.)
- February 14, 2020: “Wyoming’s Energy Outlook” (Wyoming County Commissioners Association 2020 Legislative Conference; Cheyenne, WY)
- January 25, 2020: “Overview of UW’s Center for Energy Regulation & Policy” (University of Wyoming’s “Saturday University” Program; Rock Springs, WY)
- January 23, 2020: “Overview of UW’s Center for Energy Regulation & Policy” (University of Wyoming’s “Saturday University” Program; Pinedale, WY)
- December 18, 2019: Panelist, “Energizing Our Future” (Albany County Public Library; Laramie, WY)
- November 13, 2019: “Wyoming Energy Outlook” (Governor’s Business Forum; Cheyenne, WY)
- November 11, 2019: “Low-Carbon Policy Considerations” (Testimony before the Revenue Committee of the Wyoming Legislature; Cheyenne, WY)
- November 8, 2019: “Is the Green New Deal Poised to Become Federal Law?: A Federal Climate Policy Update” (University of Wyoming’s School of Energy Resources Lecture Series; Laramie, WY)
- October 25, 2019: Moderator, a panel discussion on “The Energy Transition: The Disparate Roles, Impacts and Influences of Federal & State Law and Regulation” (2019 Landscape Discussion on Energy Law & Policy in the Rockies; University of Wyoming; Laramie, WY)

- October 2, 2019: “Low-Carbon Energy Law & Policy: What Wyoming Lawyers Need to Know” (Wyoming State Bar, 2019 Annual Meeting & Judicial Conference; Moran, WY)
- September 20, 2019: Panelist, a panel discussion on “Amazon Rainforest Fires” (Center for Advanced Energy Studies; Idaho Falls, ID)
- September 6, 2019: Moderator, a panel discussion on the “The Future of Coal and Other Fossil Fuels” (The U.S. Future Leaders Topical Seminar on Energy and Natural Resources, University of Wyoming, Laramie, WY) (<http://www.uwyo.edu/globalcenter/upcoming-conferences.html>)
- August 30, 2019: Testimony regarding the section 45Q tax credit before the Wyoming Legislature’s Committee on Minerals, Business & Economic Development (<https://www.wyoleg.gov/Committees/2019/J09>)
- August 29, 2019: “Energy Policy Update” (The Jackson Hole Center for Global Affairs; Jackson, WY)
- August 26-27, 2019: “Powering the Future: Energy in the West Conference”; speaker and emcee (Boise, Idaho) (<https://westernenergyconference.com/>)
- August 14, 2019: “Update on University of Wyoming Research Projects” (Gillette College; Gillette, WY)
- July 22, 2019: “The Evolution of CCUS Policy and CCUS in Wyoming” (Research Experience in Carbon Sequestration; Laramie, WY)
- June 28, 2019: “So You’ve Captured CO₂. Now What?; Thoughts Regarding Utilization” (Carbon Dioxide Removal Panel, AAAS “Beyond Electricity” Symposium, Washington, D.C.)

Student Engagement & Teaching

- April 2, 2020: “Energy Policy & Climate” Guest Lecturer, John Hopkins University (online)
- January 30, 2020: Environment & Natural Resources in Practice for ENR 4900; Panelist; University of Wyoming; Laramie, Wyoming
- December 5, 2019: “Energy & Climate Problem Solving” for ENR 5000 (“Approaches to Environmental Problem Solving”); Guest Lecturer; University of Wyoming; Laramie, Wyoming

Activities & Related Research Support

Many of SER's grant-funded research projects include policy components revolving around the law, regulation, economics, and policy. Indeed, these components generally are critical aspects of the research, arising to Principal Investigator-level (PI) status. For Wyoming CarbonSAFE, for example, these components remain a significant aspect of the funded grant because DOE is driving towards an eventual commercial project.

Key achievements:

- Coddington, Co-Principal Investigator (co-PI). "Wyoming CarbonSAFE Phase 3."
- Coddington, Co-PI. "Carbon Dioxide Transportation and Enhanced Oil Recovery Policy Review" (private foundation(s), 2018-2019, circa \$36k) (completed)
- Coddington, 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) (completed)
- Coddington, 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)
- Coddington, Co-PI. "Integrated Commercial Carbon Capture and Storage (CCS) Prefeasibility Study at Dry Fork Station, Wyoming" (DOE/NETL, DE-FE0029375, 2017-2019, circa \$1M) (completed)
- Coddington, 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) (completed)

Emerging Technology – Director, Richard Horner

The primary focus of the Emerging Technology program remains to expedite two strategies that support the future of Wyoming coal and create economic development and diversification opportunities for the state, namely:

1. Invest in original research and technology development, producing solutions that have a high impact potential to advantage the future of Wyoming coal
2. Work with 3rd party providers on bringing their proprietary technology solutions to Wyoming and operate them on Wyoming coal

The primary business focuses on technology solution development are to:

1. Support continued use of Wyoming coal in thermal applications
2. Grow opportunities for Wyoming coal sales in foreign markets
3. Develop new uses for Wyoming coal to non-energy and fuel product markets

Support Continued use of Wyoming Coal in Thermal Applications

In support of continued Wyoming coal use in existing thermal markets, SER continues to actively support the further development, demonstration, and commercialization of a novel combustion technology called flameless pressurized oxy-fuel (FPO) combustion.

FPO has the potential to be economically retrofitted in some existing coal-fired utility schemes (e.g., reuse existing turbine and electricity infrastructure), and as well as serving new-build coal-fired plant constructions to ensure full compliance with the most stringent environmental regulations. This technology combusts coal in an oxygen-rich environment producing energy, a pure water stream, and a gaseous high-quality CO₂ stream that can be directly utilized in enhanced oil recovery (EOR) applications and for the supply of feedstock in chemicals manufacture.

SER is part of a consortium—led by Southwest Research Institute (SwRI), and including GE, Sargent and Lundy and the Electric Power Research Institute (EPRI) as partners—that completed the basic engineering design for a demonstration project producing 25MW_{th} energy, which is slated for construction in Wyoming in the 2022-2023 time frame. The consortium is progressing a US Department of Energy (DOE) grant as part of their large-pilot program, which was successfully awarded in October 2019, with the next phase front end engineering design (FEED) for the demonstration project due for completion and submitted to US DOE by mid-January 2021.

The Wyoming Legislature, in its March 2020 biennial budget review, approved the appropriation of \$12M as cost-share for the DOE project focused on the FPO demonstration.

Supporting this initiative, SER and its UW collaborators continue to develop the computational fluid dynamics (CFD) model for FPO, in collaboration with the technology owner Itea spa, which has provided experimental data from wide-ranging pilot plant studies to permit the simulation model to be developed. The model is a critical component of technology development that, once fully developed, can be used to confidently design the combustor for the demonstration and support the future when the technology becomes available commercially.

Grow Opportunities for Wyoming Coal Sales in Foreign Markets

In 2017, SER signed a collaborative research agreement with a technology provider Clean Coal Technologies Inc. (CCTI), to support the development of a coal beneficiation technology. A previously developed demonstration facility capable of processing up to 15 tons of coal per day in batch production mode has been moved to an industrial facility (Fort Union) on the outskirts of Gillette, WY. The facility is now being reconfigured and reengineered to evaluate the beneficiation performance on Wyoming mined Powder River Basin (PRB) coal. The facility has been re-engineered so that it can operate in continuous operating mode and is expected to be recommissioned and operational in Spring on 2021.

Laboratory tests have confirmed the capabilities of the technology to beneficiate Wyoming PRB coal. The acquired data will be used to set the operating parameters for the full-scale testing campaign, which will first establish the optimum process conditions for beneficiating Wyoming PRB coal in practice. Once operational, upgraded coal will be evaluated for its ability to withstand weathering and long-term stability. These are identified requirements of foreign customers who might consider purchasing imported beneficiated coal in the Asian Pacific region, which is the target primary growth market sector.

Separately, following the completion of a market study for the sale of Wyoming PRB coal, as-mined and beneficiated, to meet the growing demand for imported coal in Japan, a similar

study for the Indian market was completed. Both markets hold important growth potential opportunities for international sales of Wyoming PRB coal in the future.

Develop New Non-energy and Fuel Product Markets

The Carbon Engineering Initiative achieved important milestones in FY20, with a strong focus upon scaling up technology solutions that had been proven in the laboratory and preparing them for demonstrating in the field.

Since 2016 and through June 2020, the State of Wyoming has invested in a total of \$14.1 million on the Carbon Engineering Initiative projects (FY17 = \$2.7M, FY18 = \$4.7M, FY19 = \$3.2M, FY20 = 3.5M). The Wyoming Legislature in its FY21-22 biennial budget appropriated \$7.0 million to support the scale-up of carbon engineering technology over the biennium.

The next significant goal of the carbon engineering initiative is to have completed, by the end of FY23, the outline engineering design and scope for the construction of a 50 to 100-ton throughput field demonstration of the UW-invented integrated pyrolysis and solvent extraction process coupled with CO₂ management. This process has the advantage of using less energy than its competitors and producing valuable engineered intermediate and derivative products with virtually zero CO₂ footprint. An important milestone was reached when this unique and novel process was awarded a provisional patent (WO 2019/ 055529).

The Carbon Engineering Initiative continues to support the research groups of 9 faculty members in the College of Engineering and Applied Sciences, College of Arts and Sciences, and College of Agriculture and Natural Resources, demonstrating the interdisciplinary approach and contributions from across UW.

At the program and project level, while significant achievements have been made, the unfortunate onset of the current COVID-19 pandemic has affected the level of progress and attainment since early March 2020.

Coal to Products Process Development

Coal-to-high-value chemicals.

The construction of two continuous operation process pilot plants to demonstrate the thermal pyrolysis and solvent extraction deliberate decomposition of the coal process is near completion. A third pilot plant to demonstrate the dry methane reforming of CO₂ produced during coal processing and converting this into a valuable synthesis gas petrochemical feedstock has been commissioned and is now being used to further understand the long-term performance of the catalyst under development that is used to convert CO₂ and CH₄ into 2CO+2H₂. The pyrolysis and solvent extraction pilot plants are expected to be commissioned this summer and will be able to produce intermediate products that can be used in other projects investigating the manufacture of finished derivative products described below.

The focus of the pilot plants during FY21 will be to optimize the process conditions by which properties and yields of desirable products can be made. The continued collection of the information and its analysis will be used to input into the required study for deciding upon the outline engineering requirements for the field demonstration of the integrated process targeted for the end of FY23.

Coal Derived Products Development

Coal-based soil amendments.

A demonstration of soil amendment products started in FY18 and made from 100% PRB coal continues at the UW's agricultural test site near Wheatland in conjunction with the SER Wyoming Restoration and Reclamation Center (WRRC). Crop yield and soil fertility measurements continue to show the benefits of adding such treatments to agricultural land to improve economic returns. A pilot facility has been designed and constructed for the production of a Wyoming produced nutrient that supplements the soil amendment product. The 60-ton soil amendment and soil nutrient field studies planned for FY20 and scheduled to start at the beginning of the growing season (March 2020) had to be suspended due to COVID-

19. Both the local agricultural and sugar beet cooperative communities continue to take an interest in the field demonstrations ongoing.

Coal-based asphalt and paving additives.

Broad formulations for coal-based asphalt road paving and additives, previously proven in the laboratory have been further developed to a point where there is now both paving and roofing industry interest in supporting the ongoing product development activities.

High-temperature coal-based composites.

High-temperature resin and coating systems, based upon polyurethane-phenolic and epoxy and polyamide chemistry, have been developed and product development continues. The resin and coating systems have been formulated from intermediate materials that possess very low toxicity and, in this regard, offer advantages over the coal tar materials commercially available and which are being used as benchmarks to determine performance advantages. The product formulation determination and scale-up of the resins into masterbatches for industrial evaluation is scheduled for the coming year. This was planned for this year, however, the work to scale up was canceled because of the COVID-19 pandemic.

Coal-based nano-products.

After previously confirming that graphene oxide (GO) from Wyoming PRB coal can successfully be techno-economic made from Wyoming PRB coal, the process of manufacture has been scaled up and the parameter's and engineering of the production scheme to ensure product quality meets current commercial specifications have been validated, including benchmarking for properties against commercial products. Samples have been provided to industry partners for their characterization evaluation and appraisal.

Coal-based building products.

After completing the technology development phase to make char-bricks and insulation panels from Wyoming PRB coal, the focus has been to scale up the manufacture of both products and

to further design and develop the demonstration building to showcase the developed coal-derived product qualities. Other building materials such as geo-polymers and thermal insulation products have also been developed and are subject to ongoing testing and evaluation. Unfortunately, the Denver-based building material manufacturing company, who were scheduled to manufacture products to construct the demonstration building this summer, were badly impacted by COVID-19, and the manufacture and subsequent building demonstration construction had to be delayed.

Carbon fiber mat development.

Improvements have been made to the electrical properties of the carbon fiber mats derived from Wyoming PRB coal for electric utility energy; it is now possible to tune and customize properties to suit applications. The carbon fiber mats have been benchmarked against current commercially available supercapacitor products and show superior charging, storage capacity, and discharge characteristics. The focus is now to complete benchmarking the properties. A recent technology application agreement has been formalized with a Denver based technology company interested in using these products for utility, residential, and commercial energy storage applications.

Forward Plan (FY21)

The primary focus for FY21 is to continue scale-up and demonstration activity of already proven technologies. Supporting these thrusts with applied research on expanding product applications, motivated by the 3-year goal to develop an outline engineering scheme to field demonstrate and highlight the UW invented coal to products process by the end of FY23.

The field demonstration will allow the display of the co-production of multiple products under development to industry, allowing the manufacture of pre-commercial quantities of products for their evaluation and; inform potential investors of the potential to negotiate a transfer of Wyoming homegrown technology and commercialize a coal-to-products manufacturing complex in Wyoming.

ENGAGEMENT

Speakers

SER Lunch & Learn Speaker Series

On Fridays during the noon hour, SER hosts distinguished energy speakers as part of The SER Lunch & Learn Series. The speaker series provides a platform from which to discuss multidisciplinary energy problems. Unfortunately, the distinguished Speaker's Series was cut short in the spring semester due to the COVID-19 campus closure. The speakers and titles include:

Mr. James Sorensen, Energy & Environmental Research Center, University of North Dakota, Assistant Director for Subsurface Strategies, ***“Overview of Two Enhanced Oil Recovery Pilots in the Bakken”***

Dr. Edith Wilson, Rock Whisperer LLC Owner/CEO, John Hopkins University, “Exploring New Energy Frontiers with Petroleum Geoscience Talent and Technology”

Dr. Brian Rand, University of Manchester, “Engineering Carbon and Graphite Materials from Aromatic Precursors”

Dr. Sue Horvorka, Gulf Coast Carbon Center, Bureau of Economic Geology, the University of Texas at Austin, ***“Technical Progress Toward Making Carbon Capture and Storage Commercial”***

Mr. Nick Jones, Enhanced Oil Recovery Institute, University of Wyoming “Application of Sequence Stratigraphy in the Minnelusa Formation: a Method to Optimize Production”

Dr. Craig Hart, Atlantic Council Global Energy Center, John Hopkins University, ***“Energy Transition and its Implications for Competitiveness and Communities”***

Dr. Jonathan Matthews, Penn State University, “Atomistic Representations of Coal, Char, Coke, Soot, and Their Use”

Kipp Coddington, Esq., Center for Energy Regulation & Policy Director, University of Wyoming, “Update on the U.S. House of Representatives’ Efforts to Enact a Climate Bill in Advance of the 2020 Elections: Risks and Opportunities for Wyoming”

Tara Righetti, Esq., College of Law, University of Wyoming, “***The Indomitable Surface Estate***”

Dr. Rick Honaker, Department of Mining Engineering, University of Kentucky “Developments toward an Economical Viable Process Flowsheet for Rare Earth Element Recovery and Concentration from Pre-Combustion Bituminous Coal Sources”

Dr. Michael Woodhouse, Researcher IV-Economic/Financial Analysis, Strategy Energy Analysis Center, National Renewable Energy Laboratory (NREL) “**The International Supply Chain and Manufacturing Costs for Photovoltaic Modules, and Project Economics of Systems Including Storage**”

Events

Carbon Day

SER teamed up with the Wyoming Infrastructure Authority on the inaugural Carbon Day event on February 14 at the Wyoming State Capitol during the legislative session. The purpose of the event was to provide information on SER’s academic program and updates on projects within the Center for Economic Geology Research and the Carbon Engineering Initiative.

Saturday University

SER participated in Saturday University in Pinedale and Rock Springs (Jan. 25) to discuss a low-carbon future for fossil fuels. The University of Wyoming, Wyoming Community Colleges, and Wyoming Communities sponsor Saturday U.

Energy Day

SER joined with Learfield Sports to sponsor Energy Day on Saturday, Sept. 28, 2019, at the UW football game vs. the University of Nevada-Las Vegas. This is the seventh year SER has sponsored Energy Day. As part of the celebration, SER hosted a kick-off reception on Friday, hosted tours of the new Engineering Education and Research building drilling simulator, and set up a booth inside the Indoor Practice Arena before the game. In addition to SER, Energy Day 2019 sponsors include Devon Energy, Ciner, JCA Companies, True Oil, Junction Energy, Tri-State, Wyoming Mining Association, and Tata Chemicals.

U.S. Future Leaders Seminar in Energy and Natural Resources

SER hosted the U.S. Future Leaders Seminar in Energy and Natural Resources on Thursday, Sept. 5, 2019, in the Energy Innovation Center. The U.S. State Department-sponsored the seminar. Participants learned from and engaged with departments across UW, researchers at SER, the State Department, and private industry experts to leave the seminar with both the cross-cultural skills and industry knowledge they need to launch or further build careers in energy and natural resources.



Figure 10 U.S. Future Leaders carbon capture and storage (CCUS) workshop, sponsored by the U.S. State Department. The geologic core from the Wyoming CarbonSAFE project was used to demonstrate CCUS concepts.

Research Experience in Carbon Storage (RECS)

SER was asked to host the 2019 RECS program. Funded by the U.S. DOE's Office of Fossil Energy (FE), the RECS program invites graduate students and early-career professionals to learn more carbon capture, utilization, and storage (CCUS). The program offers graduate students and individuals starting in their careers the opportunity to gain hands-on field research experience in areas related to CCUS. The program has been hosted by the Southern States Energy Board in Alabama for the last seven years.

Energy Law & Policy in the Rockies

The Energy Law & 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 214, up from 186 people in 2018. The conference continues to show substantial attendance growing every year. However, in 2020 due to complications with COVID 19, the conference will be postponed until the fall of 2021.

Rocky Mountain Rendezvous

The Rocky Mountain Rendezvous (RMR) geoscience student job fair is hosted by the University of Wyoming Department of Geology and Geophysics. SER is proud to be a perennial sponsor of the event. The RMR is a 3-day event that includes field trips, a networking lunch, a vendor expo, and onsite interviews to connect geoscience students with recruiters. In 2019, the event attracted 103 geoscience students from 37 universities and 37 recruiters from 8 companies. Additionally, in 2019, RMR partnered with the AAPG Rocky Mountain Section annual meeting (coincident in Cheyenne last year) to promote cross-attendance for student attendees. This was achieved thru a specific RMR student poster session and social "ice-breaker" event. The 2020 event, will take place virtually and expects to reach even a wider group of job-seeking students.

FINANCIAL SUMMARY

State Appropriations

The Wyoming Legislature provided funding for the School of Energy Resources over the FY19-20 biennium in the State of Wyoming 2018 Budget Session of \$19,303,167. Of this, \$1,000,000 was a one-time appropriation for the Carbon Engineering Initiative.

In FY19, \$10,034,952 was spent. The remaining \$9,268,215 was spent in FY20.

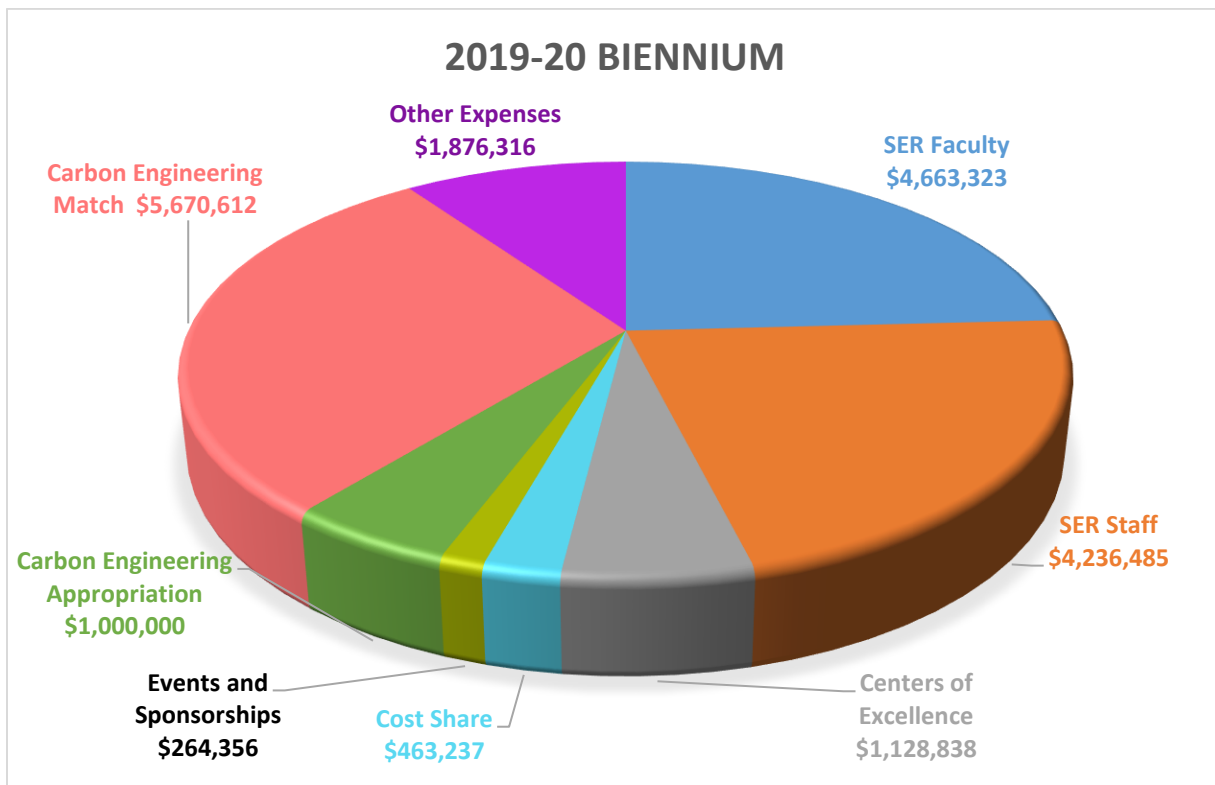


Figure 11. FY19/20 State Appropriations Spent

Throughout the 2019-20 biennium, SER spent:

- \$4,663,323 for salaries and benefits for SER faculty
- \$4,236,485 for salaries and benefits for SER staff
- \$1,128,838 to support research activities for the Centers of Excellence
- \$463,237 in cost-share support for state and federal research grants

- \$264,356 for events and sponsorships
- \$1,000,000 from the one-time appropriation for carbon engineering research
- \$5,670,612 from SER's standard budget to support carbon engineering research
- \$1,876,316 in remaining expenses that include graduate assistantships, summer camp, recruiting, travel, publications, office support, etc.
- 115 different undergrad and graduate students were funded by SER's standard budget.

UW Foundation Accounts Funding Research and Scholarship

The following section reports biennial spending from UW Foundation accounts for FY19 and FY20. SER utilized \$1,407, 017 of private gift funds held at the UW Foundation.

Anadarko Petroleum Corporation Chair in Energy and Environmental Technologies

The Anadarko Petroleum Corporation Chair in Energy and Environmental Technologies is an 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 have been used to provide support for UW undergraduate students, graduate students, and young faculty engaged in key energy disciplines. As part of the acquisition of Anadarko by Occidental Petroleum Corporation (OCP) in 2019, the name of the endowment was also transferred to OCP. During FY19 and FY20, the endowment was used to fund a post-doctoral researcher and the purchase of supplies in the SER Center of Excellence for Air Quality.

Given the size of the endowment, which stood at approximately \$4.3 million at the close of 2019, it was decided to split the endowment to support two endowed chairs. The process of splitting these chairs remains underway. One endowed chair will be jointly administered by SER and the Haub School of Environment and Natural Resources (ENR) and will be focused on energy and environmental policies. The second endowed chair will be administered by SER and focused on energy and environmental technology. SER has created position descriptions for both chairs and is working with the UW Provosts' Office, the UW Foundation, the Haub School, and OPC to finalize the documentation required to formally split the chairs. SER, in

collaboration with the Haub Schol ENR for one chair, aims to fill the two chairs as soon as possible.

Arch Clean Coal Technology

The Arch Clean Coal Technology commercialization fund was developed to support students and faculty dedicated to the development of improved technologies for the extraction of energy from coal and to drive effective and economical disturbed lands reclamation. The account was created to support undergraduate and graduate students, fellowships and to help the University of Wyoming recruit and retain the next generation of the most promising young scientists and engineers. The fund advances excellence in the topics of coal utilization and carbon sequestration.

In FY20, the generous Arch Clean Coal Technology Fund provided helped to purchase data sets for SER's newly created Center for Energy Regulation and Policy to help drive policy analysis focused on domestic power plants that consume Wyoming coal. In addition, these funds helped support SER's Emerging Technologies research program, which is focused on identifying novel, large-scale uses for Wyoming coal as well as a new type of coal-fired power plant based on pressurized oxy-combustion, which can operate flexibility with a pipeline-ready CO₂ stream as the only exhaust.

Charles Koch Foundation UW Energy Policy Fund

The Charles Koch Foundation UW Energy Policy Fund provides support to academic research projects under the supervision of the University of Wyoming Foundation and Direction of Dr. Timothy Considine. During FY19 and FY20, funds were used to support the salary of an academic researcher and to help support the annual license and maintenance fees of the REMI software for the University of Wyoming College of Business, which is used, among other activities, to support SER and UW faculty participation in the Power Wyoming initiative.

Dominion Energy

The Dominion Energy fund was developed to support the University of Wyoming School of Energy Resources Center of Excellence in Produced Water Management. The mission of CEPW is to perform research to industry, government, and stakeholders with an interest in the management of water produced alongside oil and gas.

James E. Nielson Excellence Fund

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 on 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.

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
- *Nielson Faculty Start-up* to provide laboratory and student funding for incoming faculty.
- *Neilson Scholars in the College of Business* to provide scholarships to the University of Wyoming Energy MBA program

In addition to these highlights the James E. Nielson Excellence Fund provided support for the University Undergraduate Science Initiative in the form of undergraduate research support and publications fees, provided graduate student stipend, travel, and equipment purchases to support the Vertical Harvest Project, and provided support for the International Standards Organization meeting to develop international standards for the storage of carbon dioxide during enhanced oil recovery operations.

Jonah Energy, LLC

The Jonah Energy, LLC fund was created to support the efforts of the University of Wyoming School of Energy Resources Center of Excellence in Air Quality. The goal of the Center is to develop a better understanding of emissions from the oil and gas sector in the Rocky Mountain region.

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, although it has leveraged to temporarily support faculty. For example, during FY20 the endowment provided funding for Dr. Brian Kelley in the department of Geology & Geophysics.

This endowment was increased this year with a commitment from the Wold Foundation, matched by the State of Wyoming, to contribute a total incremental of \$750,000. This brings

the value of the Wold Chair to approximately \$3.0 million and makes it a premier endowed chair at the University of Wyoming. SER met with the Wold Foundation and prepared a position description, currently under review by the Provost. SER aims to identify the next recipient of the Wold Chair during the coming academic year.

Marathon Interdisciplinary Fossil Fuel Research Laboratory Support Fund

The Marathon Interdisciplinary Fossil Fuel Research Laboratory Support fund was developed to support the on-going needs and activities in the Marathon Interdisciplinary Fossil fuel Research Lab. During FY19 and FY20, the Marathon Fund provided a stipend, tuition, and fees for one Geology graduate student, Garrett Gay. 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, Gay is developing a methodology for separating, dissolving, and analyzing mineral grains that can all be done in-house on the UW campus. The methodologies will be used to assess potential REE resources of the field areas.

SER Reservoir Characterization Collaboratory Fund

The SER Reservoir Characterization Collaboratory Fund was created to support technology in the Energy Innovation Center. During the FY19 and FY20, this fund provided for the purchase of technology for the 3D Visualization Center housed in the Energy Innovation Center.

School of Energy Resources Support Fund for Students and Faculty

The SER Support Fund for Students and Faculty was created to support students and faculty including but not limited to travel to professional energy conferences. During the FY19-20 biennium, this fund supported travel expenditures for SER student travel.

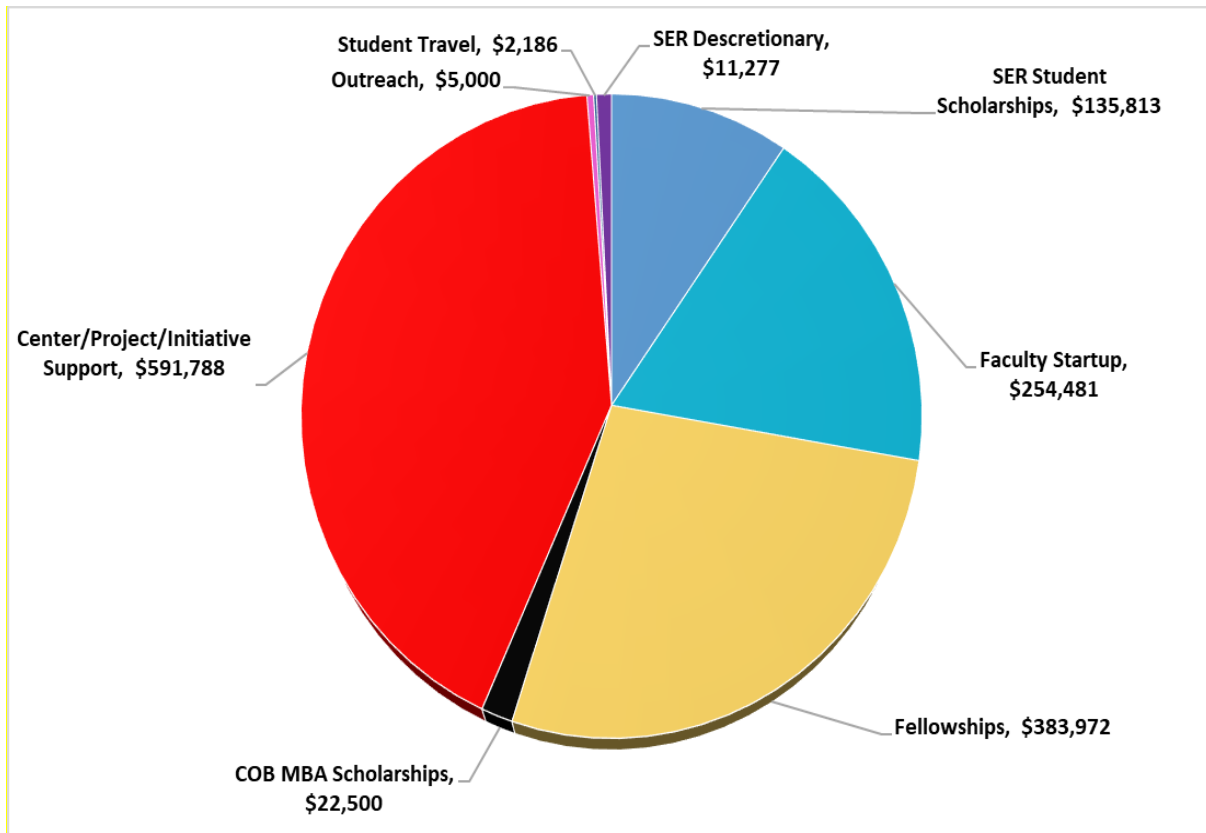


Figure 12. FY19/20 Foundation Spent

- \$18,850 – Anadarko Petroleum
 - Energy & Air Quality Center
- \$138,884– Arch Clean Coal Technology
 - \$26,000 Energy Regulation & Policy Analysis Center
 - \$112,884 Carbon Engineering Project
- \$18,257 – Dominion Energy
 - Center for Excellence in Produced Water Management
- \$7,269 – Jonah Energy
 - Energy & Air Quality Center
- \$151,352 – Koch, Charles, and Double 4 Foundation
 - Energy Regulation & Policy Analysis Center
- \$58,384 – Marathon Interdisciplinary Fossil Fuel Research Lab
 - Economic Geology Research Center

- \$887,004 - Nielson, James E. Excellence Fund
 - \$135,813 SER student scholarships
 - \$165,220 Faculty startup
 - \$383,972 Fellowships
 - \$22,500 COB MBA scholarships
 - \$68,496 Global Studies Center
 - \$64,708 Undergrad Science Initiative
 - \$41,295 Vertical Harvest Project
 - \$5,000 Outreach Support
- \$24,293 – SER Reservoir Characterization Collaboratory
 - 3D Visualization Center
- \$2,186 – SER Support Fund
 - Student Travel
- \$89,261 – Wold, John & Jane Chair Energy
 - Faculty Start-up
- \$11,277 – SER Discretionary

CONCLUSION

FY20, though interrupted by a global pandemic, was truly a successful one 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 an 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 graduation of 15 students from the Energy Resource Management and Development of the Bachelor of Science program.
- The Center of Economic Geology Research (CEGR) maintained its international recognition in the field of CO₂ storage and received funding (\$15.5M federal and \$1.5M private) to complete the Phase III site characterization study of the carbon capture and storage project at Dry Fork Station and the Wyoming Integrated Test Center, to participate in the Plains CO₂ Reduction Partnership (\$1M), and to develop a rare earth element extraction facility in Gillette (\$1.6M).
- The Center of Air Quality is partnered with Utah State to simulate Ozone formation in the Upper Green River Basin.
- The Center for Biogenic Natural Gas is seeking Phase II financing to complete the demonstration of creating renewable natural gas from Wyoming coalbed methane fields.
- The Center of Excellence for Produced Water Management leveraged SER funds to obtain a Department of Energy sponsored project to develop membranes to remove hydrocarbons from oil and gas produced water.
- The 3D Viz Center saw significant growth during FY20 due to the implementation of the ReVision. The growth included two new staff members, expansion into a new

visualization suite, the development of a fee schedule, and significant growth in the Technology Associate Program.

- The Center for Energy Regulation and Policy Analysis (CERPA) was formally launched in FY20. The mission of CERPA 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.
- The Carbon Engineering Initiative (CEI), established in FY16, is moving aggressively from proving concepts in the laboratory to developing technology products; a significant patent portfolio is emerging. CEI is making progress in the following strategic areas; continued use of thermal coal in existing and new stationary energy applications, identification of growth opportunities for Wyoming coal in foreign energy markets, development of new non-energy and fuel product markets, and conversion of Wyoming coal into valuable coal-derived products on which new industry can be founded.
- SER's engagement program hosted 11 distinguished 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.

Looking forward, we anticipate the continued delivery of important outcomes in FY21. These include continued investment and growth in private sector involvement 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, growing interdisciplinary engagement across UW and beyond, execution of the CERPA business

plan, 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.