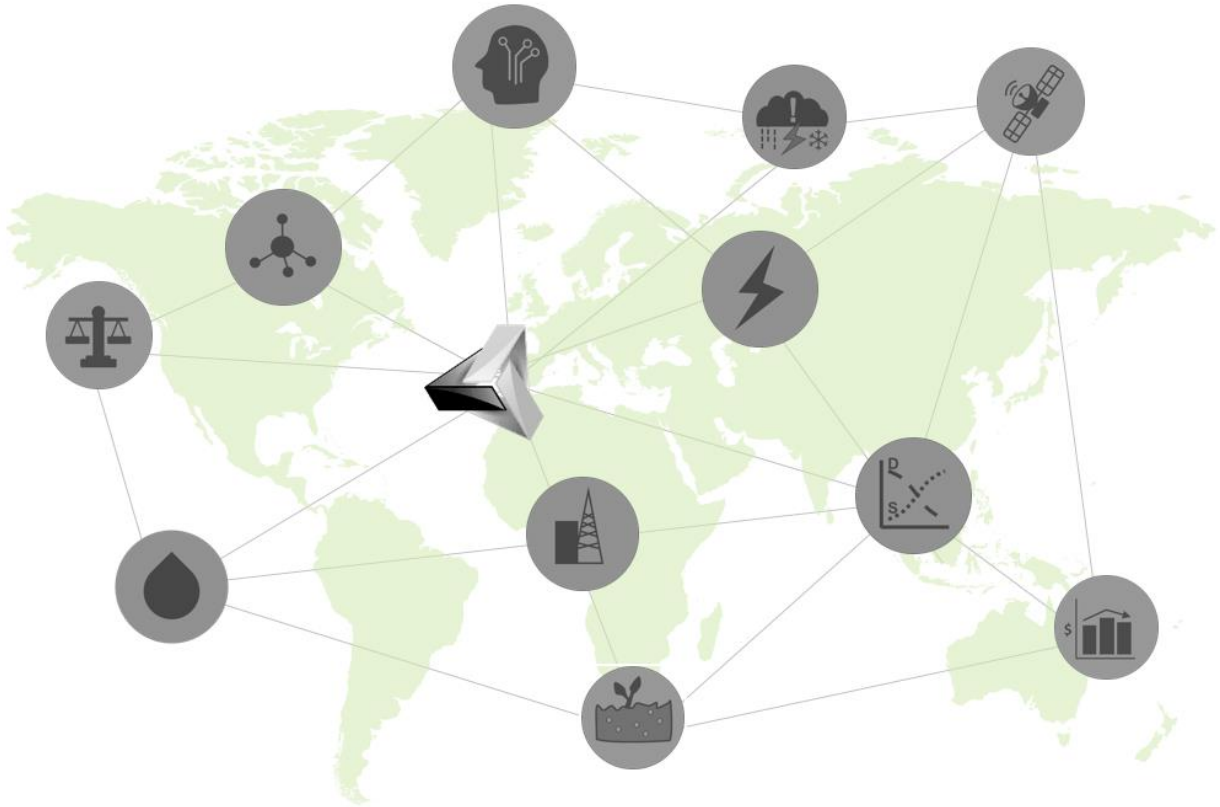


National Research Consortium (NRC) at Innovation Platform



The Oklahoma clean energy economy: A strategic initiative for
innovation leadership at the energy water nexus

April 2019

As a state blessed with the technical potential for four top ten energy resources - oil, natural gas, wind & solar - Oklahoma enjoys an enviable position as it begins to assert its leadership in the national clean energy economy through new market development strategies, collaborative industry-university R&D and partnerships throughout the public policy and regulatory space. Its two major cities - Oklahoma City and Tulsa - are uniquely and historically positioned to become advanced resource recovery hubs for smart cities and communities. These cities can set the pace and achieve major breakthroughs in the *grand disruption* of the energy, water and power sectors as the current digital innovation transformation quickens and expands into niche construction and new market creation. At scale, these breakthroughs can broaden the tax base through investment and job creation with technologies and services in new growth markets that have less price volatility and smoother tax revenue curves, and can serve as a hedge for the fiscal risks associated with declines in oil & gas prices.

This *grand disruption* has expanded to include investor types that pose imminent threats to the existing order in power and energy markets and they are growing in number and level of investment. Dynamic demand profiles coupled with advanced analytics that include innovative AI (artificial intelligence) technologies have dramatically shifted the balance of purchasing power toward consumer preference. Further disruption occurs via meaningful investments in the power sector by multiple oil & gas companies that now share center stage in the current transformation of the overall global energy system. Increasingly disruptive drivers are transforming the operational ecosystems of product and service providers in ways that were scarcely imagined just a few years ago.

The autonomy and optionality now available to residential, corporate and industrial consumers - with more purchasing and procurement options than ever before - will continue to disrupt and transform. Advanced buying and selling platforms that feature AI and graphical data architectures have forever altered the way consumers access their power sources and supply. Apple has built a complex and dynamic position in the clean energy economy through renewable energy purchase agreements that include retail stores, offices, data centers and co-located facilities in 43 countries. In terms of asset purchases, Apple currently owns installed generation capacity of 626 megawatts with 15 projects in construction for a total of 1.4 gigawatts installed across 11 countries.

Apple's Clean Energy Portal provides data for its suppliers to investigate their options for power and/or asset purchases with 23 companies making formal commitments and over 85 companies signing up for access to the portal. Microsoft, Intel, Google Inc. (Alphabet), and Bank of America join Apple in the top five of the EPA's Green Power Partnership Fortune 500 Partners List and all include growing percentages of onsite generation that allows any surplus to be sold to consumers through peer-to-peer transactions using sophisticated software based on localized networks using block chain technology.

A dominant presence is emerging in the form of innovative oil & gas majors that have begun in earnest to integrate renewable energy and advanced hydrocarbon technology investments into their portfolios. Royal Dutch Shell's (RDS) acquisition of First Utility, one of the UK's largest, is a savvy move that positions RDS to sell natural gas, electricity and the broadband and data services that optimize consumer choice. BP has invested \$200 million for a 43% stake in LightSource, Europe's largest solar development company, and has entered into an agreement to purchase Chargemaster which operates POLAR, the largest charging network in the UK with 6,500 charging stations. These moves by RDS and BP into financial, upstream, downstream and data assets are a clear signal that they're moving toward full vertical integration with clean energy portfolios.

In January 2019, BP Ventures invested \$5 million in Belmont Technology's Series A financing to further bolster BP's artificial intelligence (AI) and digital capabilities in its upstream business. The investment supports BP's ongoing work exploring opportunities to apply machine learning and cognitive computing in its global oil and gas business. The Houston technology start-up has developed a cloud-based geoscience platform using AI. The platform has a string of unique capabilities including specially-designed 'knowledge-graphs'. BP experts feed the platform geology, geophysics, reservoir and historic project information and it intuitively links that information together by identifying new connections and workflows and creating a robust knowledge-graph of BP's subsurface assets. Much like data searches available in the consumer domain, BP experts can then interrogate the data, asking the powerful knowledge-graph specific questions in natural language. The technology then uses AI neural networks to interpret results and perform rapid simulations. Aimed at accelerating project lifecycles, from exploration through to reservoir modeling, the technology is targeting a 90% time reduction in data collection, interpretation and simulation.

Also in January 2019, Greenlots, a US-based leader in electric vehicle (EV) charging and energy management software and solutions, signed an agreement to become a wholly owned subsidiary of Shell New Energies US LLC, a subsidiary of Royal Dutch Shell plc. With this deal, Greenlots' technology and team become the foundation for Shell's continued expansion of electric mobility solutions in North America. Together, the companies will offer best in class software and services that enable large-scale deployment of smart charging infrastructure and integrate with advanced energy resources like solar, wind and power storage. Greenlots is powering the future of electric transportation with industry-leading software and services that equip drivers, site hosts and network operators to efficiently deploy, manage, and leverage EV charging infrastructure at scale. Their technology brings together cutting-edge network management software, integrated charging optimization, grid balancing services and a driver-friendly mobile app - all in a single platform. Committed to advancing the promise of electrified transportation, Greenlots delivers new mobility infrastructure solutions designed to connect people to their destinations in safer, cleaner and smarter ways. Headquartered in Los Angeles, California, the company has deployed projects in 13 countries around the world.

These investments by leading corporates combined with oil & gas companies that have tremendous expertise in the energy & technology sectors will compel increasing allocations for R&D as researchers and investors begin to understand the growth opportunities that AI offers for maximizing the performance of clean energy systems and infrastructure. As outlined by McKinsey in its September 2018 discussion paper, *Notes from the frontier: Modeling the impact of AI on the world economy*, advanced analytics & visualizations will provide long term growth opportunities for companies that learn how to capture and leverage the full potential of AI in the clean energy economy. The ability to truly understand and become fully invested in the value of AI and HPC (high performance computing) will be a key differentiator in the knowledge economy for states, companies and workers.

Energy Water Nexus Innovation Hub

NRC at Innovation Platform is a non-profit, meta-research lab that develops and directs technology to market research initiatives that deliver broad beneficial outcomes. NRC functions as a catalyst for university, industry, governmental and national lab partners and creates a vibrant connectivity that converts core competencies across multiple disciplines into high value collaborative efforts. These collaborative and investment partnerships drive innovation in the digital transformation of the energy, water, power and atmospheric sectors through technology to market research and demonstration projects with a quick and clear path to market and positive societal and environmental impact.

Advanced Resource Recovery Sites (ARRS) NRC's Advanced Resource Recovery Site (ARRS) designs can be configured for various technological requirements at the site, acreage and basin levels. These systems can integrate clean power & storage, recycled produced water and beneficial reuse, and atmospheric emissions monitoring and mitigation into an intelligent decision making and asset management platform. This platform can provide the proper metrics for greater environmental stewardship and increased profitability in the oil & gas sector through advanced analytics that provide anticipatory planning capabilities.

Advanced Resource Recovery & Asset Yields (ARRAY) the Advanced Resource Recovery & Asset Yields (ARRAY) digital innovation platform will be built to provide an array of asset valuations and complex decision making considerations for energy, power, water and atmospheric conditions. These variables offer an innovative, breakthrough approach to Field Development Planning (FDP) and ARRAY will support operational efficiency and technological functionality that achieves digital alpha or advanced value creation through sophisticated analytics and visualizations. ARRAY can ultimately be designed to accept any type of data input stream and can synthesize different classes and data types into a harmonized platform for a Full Context Analysis (FCA). This contextual assessment allows for scientific, financial, market, legal, regulatory, environmental and climate inputs into a single system that supports advanced strategic planning based on exposure profiles that include potential endogenous and exogenous shocks. The ability to capture, construct and display infinite digital streams, flows and reservoirs allows for technology, operations and discipline specific data saturation that creates an optimal decision making process. ARRAY will initially have the following flows and reservoirs:

Science & System Based Valuation Metrics

Hydrocarbons - Decline, Risk & Geophysics
 Water - Access, Impact & New Markets
 Renewables - Grid, Microgrid & Revenue
 Emissions - Mitigation, Reuse & Decarb

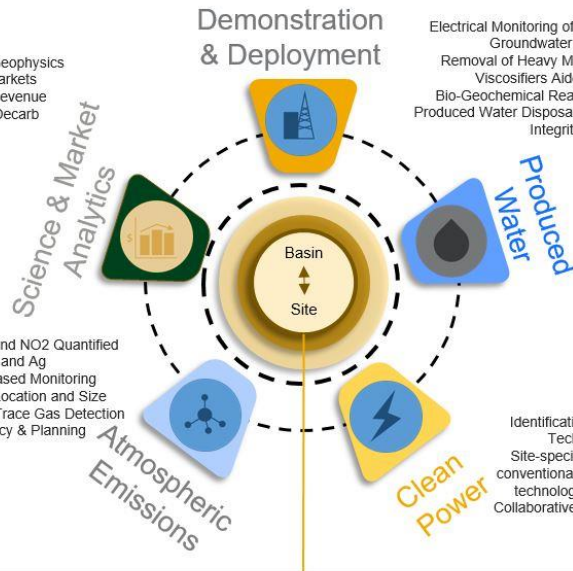
Tropospheric Monitoring of CH4 and NO2 Quantified
 CH4 fluxes from O&G and Ag
 Systems Analysis of Space-Based Monitoring
 Low-cost Sensor Networks for Location and Size
 Sensor-Based Measurements for Trace Gas Detection
 Atmospheric Emissions, Policy & Planning

Digital Innovation Platform

Electrical Monitoring of Hydrocarbon Production for Groundwater Monitoring Criteria
 Removal of Heavy Metals and NORMS through Viscosifiers Aided Dolomite Filtration
 Bio-Geochemical Reactive Transport Modeling of Produced Water Disposal and Long-Term Injectivity and Integrity Assurance

Quantification of Parent Organic Compounds & Transformation Products During Reuse
 AI Based Operating Platforms for Decentralized Water Management
 In-Situ Raman Sensors for Real-Time Detection

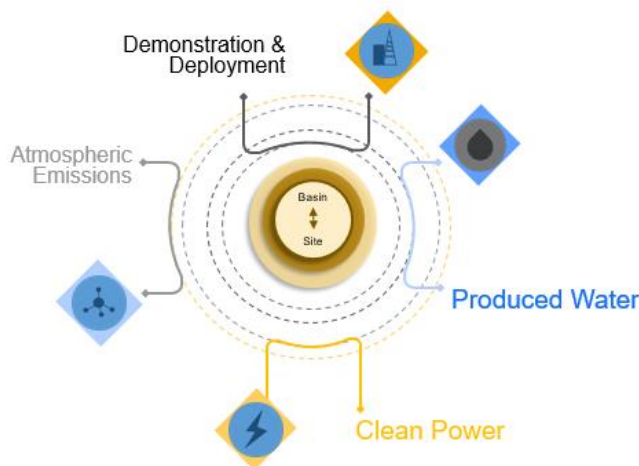
Identification, development and adaptation Technoeconomic-analysis and Site-specific optimizations of renewables & conventional generation, storage, dispatchable technologies and conservation measures
 Collaborative deployment with industry partners



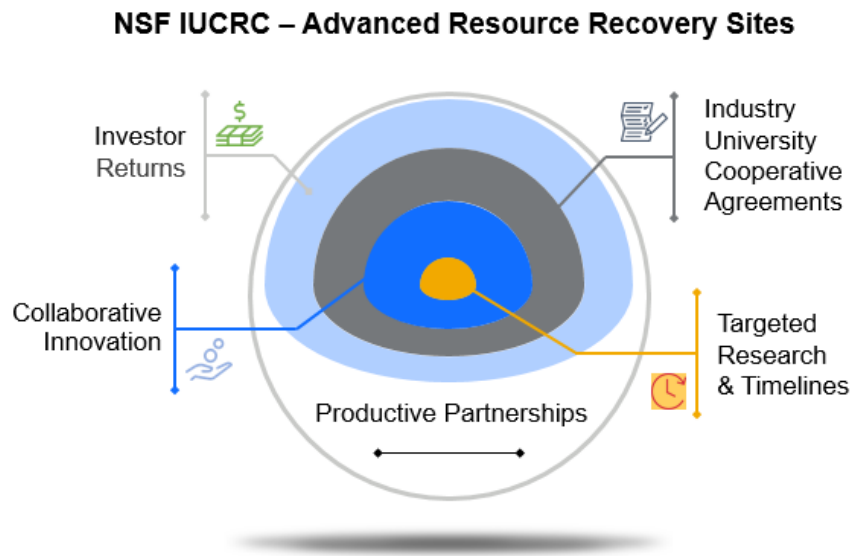
Advanced Resource Recovery & Asset Yields (ARRAY)

The McKinsey Global Institute attempts to simulate the outcomes of emerging digital technologies and they identify five main AI categories 1) computer vision: acquiring, processing, analyzing and understanding data and digital images 2) natural language: interaction of computer and human words and images 3) virtual assistants: skilled, home-based professionals 4) robotic process automation: software robots or AI workers; and 5) advanced machine learning: algorithm creation and selection with an emphasis on concept over code. The relevant types of AI and HPC will be central to achieving unprecedented speed and literacy in the data capture and construct processes for scientific and system performance. The following data streams create the flows and reservoirs listed in ARRAY and include the following inputs from university research teams, national labs and industry partners:

ARRAY – Infinite Data Streams & Scientific Inputs



NRC's planning for the demonstration sites includes collaborative research and industry partnerships as part of a National Science Foundation (NSF) Industry University Cooperative Research Centers (IUCRC) effort. The IUCRC program was initiated in 1973 to develop long-term partnerships among industry, academe and government.



NSF invests in these partnerships to promote research programs of mutual interest, contribute to the nation's research infrastructure base, enhance the intellectual capacity of the engineering or science workforce through the integration of research and education, and facilitate technology transfer. As appropriate, NSF encourages international collaborations that advance these goals within the global context.

The following universities are currently participating in the NSF effort and will demonstrate their technologies at the Oklahoma site(s):

University of Colorado Boulder: Renewable and Sustainable Energy Institute (RASEI), Department of Civil, Environmental and Architectural Engineering, Earth Lab, Department of Chemistry, Department of Earth Sciences

The CU Boulder team leads the NSF effort and has brought multiple high value corporate investment partners into the process to plan and create research to market demonstration sites in Oklahoma. CU has secured member commitments from oil & gas majors, a global satellite company and a non-profit organization. Their research focus is on atmospheric emissions with TropOMI observations of methane and nitrogen oxides from oil and gas production; quantifying CH₄ emission fluxes from oil & natural gas and agriculture sources; a systems analysis of space-based methane monitoring; top-down CH₄ emissions estimates using mixed observing platforms and novel dimension reduction techniques; coupled modeling for fugitive release source reconstruction and sensor network design; airborne low-cost sensor networks for determining the location and size of renegade gas sources; smart planning to reduce methane emissions; and, water-energy sustainability in the oil & gas industry: scaling and demonstration of bench scale technologies for recycling flowback and produced wastewater.

Oklahoma State University: Boone Pickens School Geology, Department of Microbiology

OSU will be the host university for the first demonstration site and field lab. The OSU site will feature various technologies being developed by their researchers including - but not limited to - electrical monitoring of hydrocarbon production to meet groundwater monitoring criteria; beneficial use of produced water and carbon dioxide in depleted oil reservoirs: in-situ crude oil conversion to methane gas; removal of heavy metals and

NORMS through viscosifiers aided dolomite filtration; bio-geochemical reactive transport modeling of produced water disposal: long-term well injectivity and integrity assurance; and, aseismic production approaches in USGS PISAs.

University of Oklahoma: Mewbourne College of Earth and Energy, Gallogly College of Engineering, the National Weather Center (NWC) and the College of Atmospheric and Geographic Sciences

OU will develop in-situ raman sensors for real-time detection of oxidized and reduced sulfur compounds for the assessment of corrosion in energy infrastructure; an online dissolved oxygen sensor for challenging environments; in-situ raman sensors for real-time detection of dissolved organic and inorganic compounds in produced water; and, in-situ raman sensors for real-time detection of fugitive emissions including light hydrocarbons and hazardous air pollution. OU has partnered with NASA, Lockheed Martin Advanced Technology Center and SES Government Solutions to develop the Geostationary Carbon Cycle Observatory (GeoCarb), a first-of-its-kind space Earth science mission that is scheduled for launch in 2022. GeoCarb will be observing changes in concentrations of three key carbon gases - carbon dioxide, carbon monoxide and methane - from day to day and year to year. This will help researchers make a major leap forward in better understanding the carbon cycle. GeoCarb will also be measuring solar-induced-fluorescence throughout the Americas, a direct indicator of plant health and vegetation stress. The GeoCarb team collaborates with Colorado State University on field testing for their emissions research. NASA's goal of using satellite data to improve our understanding of energy and water resources can provide a significant boost to our understanding of our impacts and opportunities at the energy water nexus.

University of Wyoming: Center for Excellence in Produced Water Management (CEPWM), Department of Chemical Engineering

The CEPWM and H2O Systems, Inc. have written: *Treatability Proof of Concept for High Salinity Produced Water* based on initial treatment and testing of the waters from the Clary Advanced Resource Recovery Site (CARRS) in Stillwater, Oklahoma. Their preliminary investigation suggests the water treatment technology total cost of ownership to be less than \$2/bbl, which may be reduced to under \$1/bbl if products and markets can be defined for resalable products arising from the treatment process. Additional research includes: the identification and quantification of parent organic compounds and their transformation products during produced water treatment and reuse; deploying artificial intelligence based operating platforms for decentralized produced water management systems; and, quantification and life-cycle assessment of CO2 storage sequestration by grasslands supplemented with treated produced water.

Collaborative Partners and Major Stakeholders

Purdue University: Purdue Agile Strategy Lab

The Agile Strategy Lab at Purdue has created and mastered a collaboration platform for cross disciplinary research teams that optimizes research through strategic focus areas, core functions, multidisciplinary research projects, external partner networks and funding sources. This platform creates a robust, dynamic and resilient foundation for developing complex research proposals and expanding university research portfolios. The leadership at the Lab was part of the 1993 launch of Forward Oklahoma City which was established to create quality jobs, increase capital investment, retain existing business and improve per capita income. Through four five-year cycles, this dynamic economic development effort has produced results far exceeding expectations, repositioning Oklahoma City as one of the top economic development site locations in the country. NRC will collaborate on a strategy with the Purdue team to develop the Smart Cities Innovation Ecosystem and the Energy Water Nexus Innovation Hub that will leverage the talent and assets in Oklahoma City, Tulsa and throughout the state.

Oklahoma Water Resources Board: Water for 2060 Produced Water Working Group (PWWG)

NRC began its university research recruitment efforts in produced water treatment and management as a follow-up and continuation of the work done by the Produced Water Working Group and the Oklahoma Water for 2060 Act. Early research and testing results from the CARRS site indicate favorable outcomes that dramatically decrease the cost per barrel with a potential for 85% beneficial reuse. NRC has begun a discussion with the Noble Research Institute, OSU and Duke University regarding an agricultural beneficial reuse test bed based on the results from Duke's work with the USDA's National Institute of Food and Agriculture (NIFA) on a multi-year project evaluating the potential human health impacts and sustainability of using produced water from oilfields to irrigate crops on agricultural land in the California Central Valley. Duke will publish its findings this year that clearly demonstrate viable agricultural reuse options that benefit farming and ranching communities.

Oklahoma Office of Energy & Environment

NRC has worked closely with the Oklahoma Office of Energy & Environment in joining 30 other states in declaring a National Clean Energy Week Proclamation. This D.C. based initiative has given Oklahoma a very favorable media presence as we continue to build out our clean energy economy in 2019. There is also a clear opportunity to further develop produced water research to market solutions through the EPA's Water Reuse Action Plan and the Energy and Water Research Integration Act of 2019. NRC's work has been structured to create significant alignment with and support for the mission of this office to advance policies that encourage energy exploration and production, responsible environmental stewardship and the development of natural resources throughout Oklahoma. NRC's Energy Water Nexus Innovation Hub and Smart Cities Innovation Ecosystem will extend this mission into new technologies, markets and job creation in the clean energy economy throughout the state.

Environmental Defense Fund (EDF): Oil & Gas Division

NRC works with the oil & gas division of EDF to track developments and progress in produced water recycling and reuse with specific attention given to the details in *Oil and Natural Gas Produced Water Governance in the State of New Mexico – Draft White Paper* from November 2018. EDF is currently compiling a database that can provide critical inputs for ARRAY of the chemical profiles of produced water as it is transformed through various treatment methods. This particular data stream will be fundamental to understanding the suitability of certain waters for beneficial reuse in industrial and agricultural applications and is an excellent example of the scientific inputs that will be captured and constructed in ARRAY.

NREL: Joint Institute for Strategic Energy Analysis (JISEA)

NRC will continue its work with JISEA as it conducts cross-cutting objective energy analysis and manages programs at the intersection of renewable energy and traditional energy for consortiums of industry partners. JISEA is co-located at the National Renewable Energy Laboratory, enabling access to engineers, scientists, and business managers across the entire spectrum of energy technologies. By drawing on the skills and resources of its founding institutions - Colorado School of Mines, Colorado State University, Massachusetts Institute of Technology, National Renewable Energy Laboratory, Stanford University, and the University of Colorado - JISEA offers research and analytical capabilities that exceed those of any single institution. JISEA will support the identification, development, and adaptation of highly reliable, cost effective clean energy solutions for oil and gas operations; perform techno-economic analysis and site-specific optimization of combinations of renewable and conventional generation, energy storage, dispatchable technologies, and energy conservation measures; and deploy (with the collaboration of industry partners) the most promising technologies for validation of performance in a variety of field environments, while simultaneously analyzing optimization scenarios to determine return on investment and impact on environmental and social issues.

NREL: Energy-Water Modeling and Analysis

NREL's Energy & Water Group provides expertise in modeling and analysis for system co-evolution and performance with a focus on resilience and efficiency that can provide modeling expertise for NRC and ARRAY. Their models include water and grid integration with renewable-integrated and zero-emission flexible desalination technologies and co-optimizing flexibility of water systems for electric systems benefits. NREL collaborates on advanced water treatment including new water filter elements and membranes using computational process design to functionalize for selective separations and low-cost roll-to-roll manufacturing. They also provide technology validation through hardware-in-the-loop simulation, validation at scale and field and pilot demonstration. Their decision science and support team provides business intelligence through policy, finance and economic technical assistance as well as innovative system designs.

Oklahoma Leadership at the Energy Water Nexus

NRC's work to date has focused on building a team of university colleagues and collaborative partners that can position Oklahoma as a top ten state in advanced resource recovery through leading edge research to market initiatives that demonstrate the achievements of the state's top universities and the expertise of our colleagues. Using the Purdue model, these initiatives can be designed to create innovation ecosystems that can feature any school in the state - including K12 - that has a desire and the capacity to participate in this crucial and exciting space. By establishing Smart Cities Innovation Ecosystems in Oklahoma City and Tulsa, the state can begin the educational and job training programs required to lead in this space for decades to come. These new, innovative clean energy technologies will continue to mature and the Oklahoma workforce can be a regional driver with national and global influence.

The technologies and research included in this strategic initiative are foundational and have the potential to create countless opportunities for next generation enhancements and improved performance through AI and HPC, and can lead to the expansion and sophistication of Oklahoma's oil & gas industry. In addition to our abundant energy resources, Oklahoma benefits from a dedicated and aspirational work force that can maximize the job creation and economic growth opportunities embedded in a multitude of technologies that an Energy Water Nexus Innovation Hub can develop, deploy and scale.

The investments made to date by leading corporations and the oil & gas majors in this space are the opening sequence in the ongoing and inevitable convergence of the hydrocarbons and renewables sectors. The hybridization of energy and power companies is made possible through sophisticated digital platforms, and these new business models will be adaptive, anticipatory and hypercompetitive. Their data platforms will become part of a much larger digital solutions stack that will inform the crucial decision making processes for cities and communities as they begin to develop and operate in increasingly efficient and cost effective ways. Oklahoma City and Tulsa have an extraordinary opportunity at an ideal moment to grow into cities of the future that can benefit citizens and communities throughout the state. The opportunities in this space are tailor-made for Oklahoma to achieve an entirely new level of legacy based leadership that will endure for generations. Our heritage requires us to answer this call and the time to act is now, without delay or ambivalence.