VENUS on the Horizon

Neutron imaging to advance energy efficiency in industry and manufacturing

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

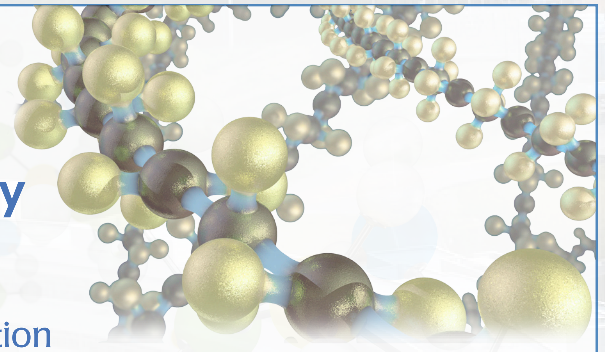
VENUS: Versatile Neutron Imaging Instrument at the Spallation Neutron Source

The world's brightest neutron source could soon shed light on new ways to improve energy efficiency and productivity of industrial and manufacturing applications. Neutron imaging can link directly the structures, properties, and function of complex materials and systems. The discovery, development, and deployment of next-generation vehicles, building technologies, manufacturing processes, geothermal systems, biofuels, and much more will be advanced through the ability to see systems and components under real-world conditions. Approved for construction at the Spallation Neutron Source at Oak Ridge National Laboratory, the VENUS instrument will harness the unique capabilities of neutron imaging to answer practical and fundamental questions about the performance of engineering materials and systems of materials.

Optimized for energy research

Neutron imaging is a non-invasive, non-destructive imaging technique that is complementary to other methods such as x-ray or gamma imaging. Considered an essential tool in many modern material sciences and engineering applications, neutron imaging facilities in the US will become much more capable for solving engineering problems with the addition of VENUS. The unique combination of the capabilities of VENUS and the intensity of the Spallation Neutron Source will improve conventional neutron imaging methods and offer novel energy-selective imaging techniques to better understand a wide range of materials, manufacturing, and production processes.

A Unique Source of Neutrons for the Engineering Community



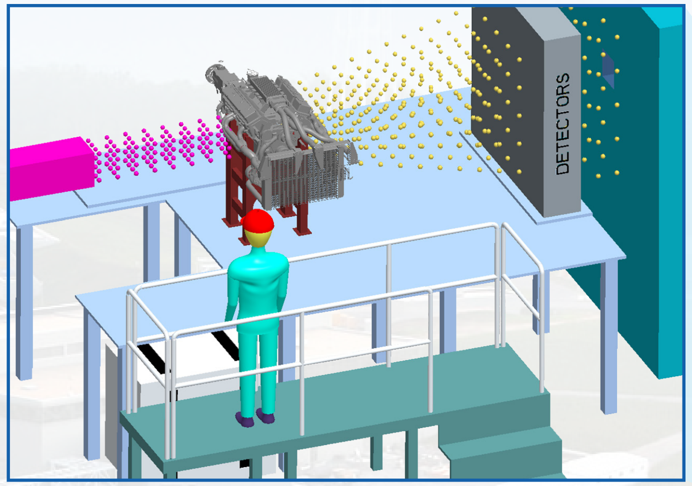
VENUS will provide the brightest source and highest energy resolution available for neutron imaging in the world. Time-of-flight neutrons that are produced from a spallation source provide a unique non-destructive look at materials and engineered material systems. For many engineered components, VENUS will provide three-dimensional residual stress and strain mapping and will reveal material and mechanical behaviors during operation and under exposure to extreme conditions such as heat and pressure. Time-of-flight neutrons provide a mechanism for neutron image analysis that is similar to hyperspectral imaging in the optical domain, enabling new ways to probe materials for engineering, manufacturing, geothermal, and biomass applications.

Designed for practical problems

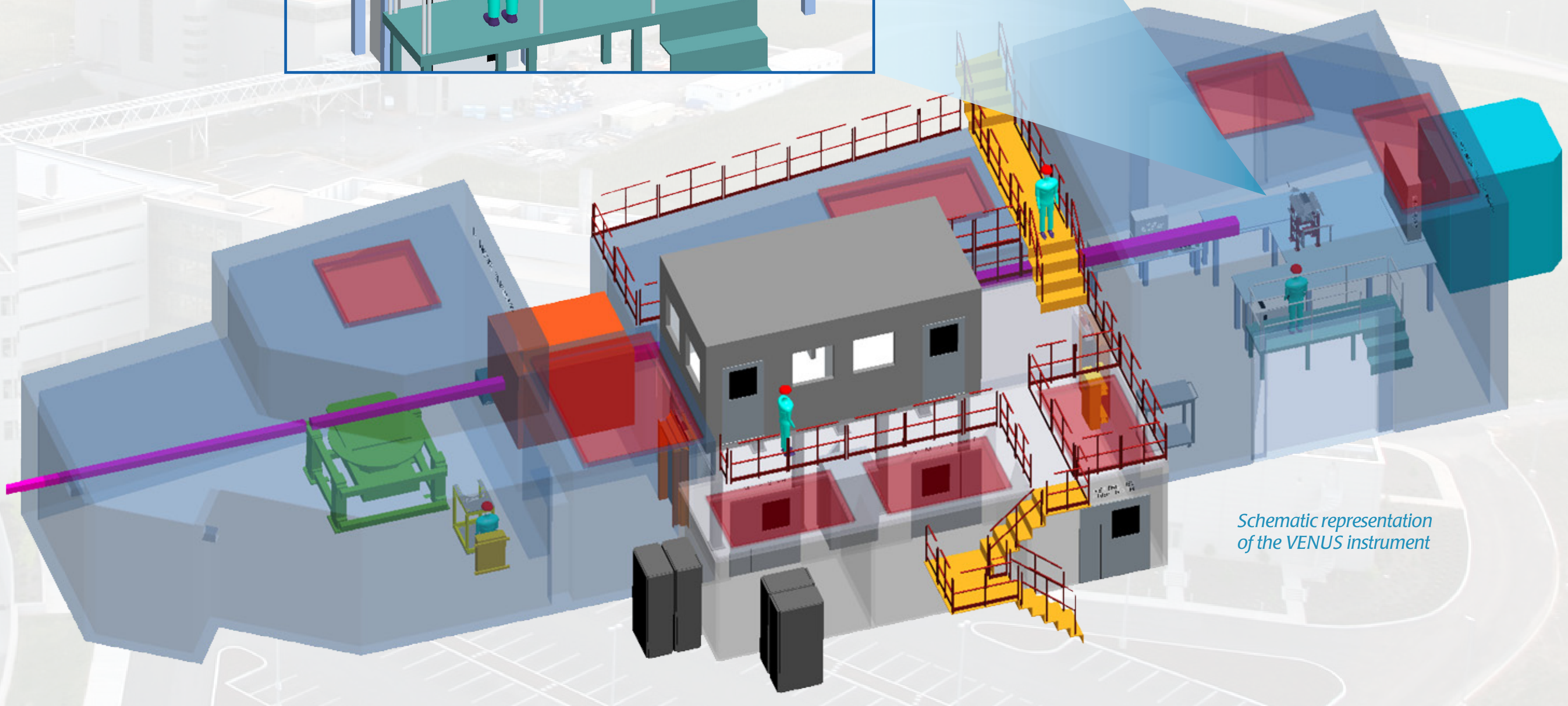
In late 2008, the VENUS Instrument Development Team (IDT) received provisional approval from the Neutron Scattering Science Advisory Committee to build VENUS at one of the three available beam lines at the Spallation Neutron Source. Approval followed three years of preparation, design, and preliminary testing by the team, whose representatives include researchers from various fields around the world. Throughout the process, The VENUS IDT has engaged the US Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE) in identifying science and engineering problems uniquely addressed by the capabilities of VENUS. Its design will enable direct studies of practical systems in energy production (including renewable, nuclear, and fossil sources), energy storage, fuel cells, hydrogen storage, vehicle technologies, building technologies, and industrial engineering component design.

VENUS will contribute to fundamental scientific understanding in areas important to the DOE Office of Science (OS) such as materials chemistry, physical and mechanical materials behavior, geosciences, plant biology and physiology, biofuel and energy production, and climate change. Advanced materials science and engineering programs such as DARPA and ARPA-E will benefit from the availability of VENUS, and the instrument will support additional studies in archaeological, biological, biomedical, forensic, and homeland security applications.

EERE-supported users will define a large part of the VENUS applied research user community, with OS supporting fundamental user research using VENUS.



Stroboscopic imaging set-up of an engine block showing neutrons transmitted through an engine, detected, and finally absorbed by beam stop.



Schematic representation of the VENUS instrument

Accelerating opportunities

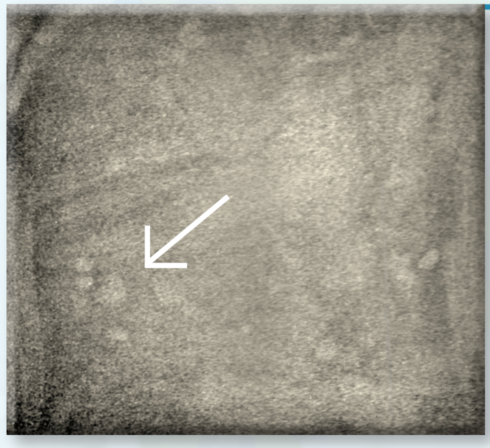
EERE program support of VENUS conceptual designs and early testing at a prototype beam line at ORNL's High Flux Isotope Reactor have shown the importance and the potential impact of forefront neutron imaging capabilities. In less than one year and with a fraction of the capabilities planned for VENUS, the prototype beam line addressed an influx of user projects with major manufacturers and industry leaders including Ford, GM, Chrysler, Toyota, United Technologies Research Center, Cummins Engines, Detroit Diesel, Mack, Delphi, Navistar, PACCAR, John Deere, Caterpillar, Volvo, GE, Whirlpool, DuPont, Thermacore, Mars, and Bush. The overwhelming response to the prototype beam line confirmed industry's demand for energy-selective neutron imaging and validated an array of potential new research and development areas and opportunities identified by the development team during project planning and design.

Aluminum/steel

VENUS will be used to evaluate materials at different stages of manufacturing to improve process design and prevent future waste. For example, understanding the composition of alloys and the impact of impurities on material properties can be achieved through neutron imaging to determine the spatial distributions of alloying materials, magnetic properties, stress/strain, and the distribution, sizing and identification of inclusions and impurities.

Carbon fiber

VENUS will enable the development of stronger carbon fiber composites for industrial and other purposes. Neutron tomography (3D) of carbon fiber polymer composites can be used to identify and measure voids that may be prone to failure under stress. ORNL researchers have applied neutron imaging to compare unidirectional and randomly chopped fiber samples and found the resin distribution more even in the unidirectional sample.



Voids inside the resin of the sample are expected to impact the structural integrity of the final composite.

Concrete

Advancing the construction of more protective and durable infrastructure, VENUS will enable the study and development of concrete and composite materials with superior mechanical strength. ORNL researchers in collaboration with the Department of Homeland Security used neutron computed tomography to quantify the hydrous and anhydrous phases of ultra-high performance concretes for improved understanding of composite behaviors under normal and extreme environments, such as impacts and fires.

Neutron radiographs outline the different hydrous phases of four unique ultra-high performance concrete samples.

Forest products

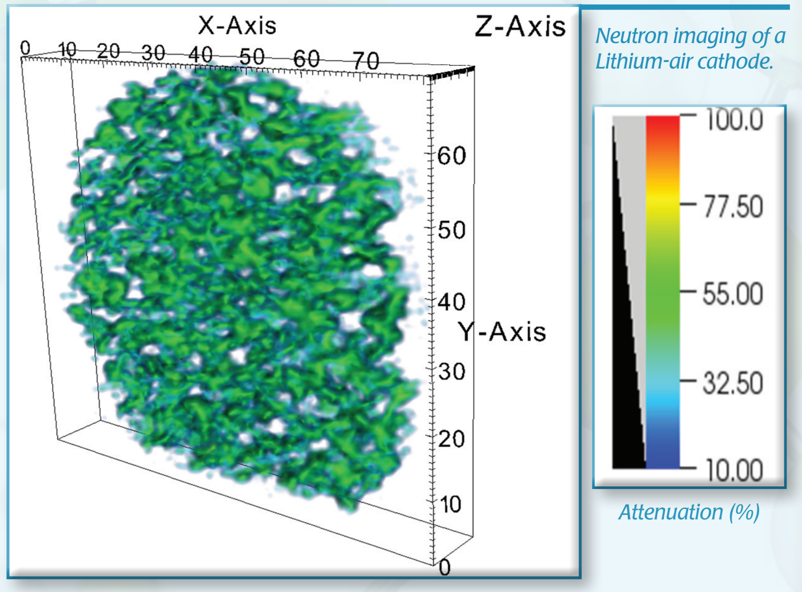
In situ characterization of lignin removal and cellulose fiber production from wood will be possible through neutron imaging at VENUS, as well as improved understanding of the pyrolysis process to produce energy (fuels), fertilizers, and other byproducts.

Glass

Visualization and characterization of air compressor performance *in situ* is possible through neutron imaging and can contribute to improving the formation of containers and other glass products. VENUS will also identify opportunities for improving energy efficiency in industrial steam and hot water systems used in glass factories.

Energy storage

Optimizing lithium-ion transport is a key to improving the power, capacity, and lifetime of batteries. In advanced battery research, the change in lithium concentration in both cathodes and anodes as a function of charge and discharge can be visualized and quantified using neutron imaging techniques that will be available at VENUS.



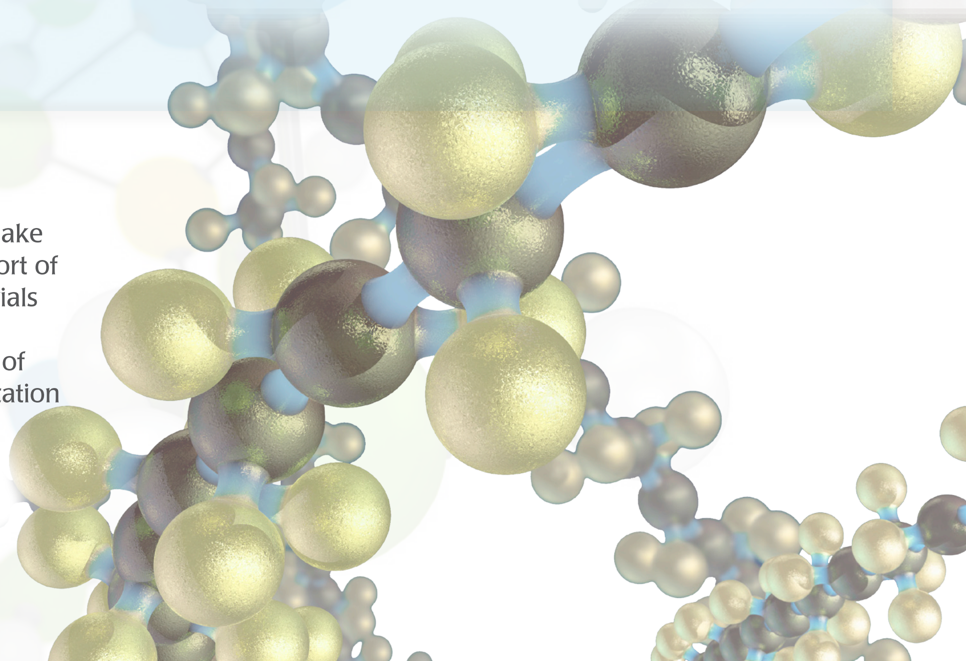
Neutron imaging of a Lithium-air cathode.

> *"Proof-of-concept measurements at ORNL of the Li distribution in Li-air battery cathodes clearly showed a non-uniform distribution of Li discharge product through the electrode which may have implications for the electrode/catalyst system design. These preliminary results also have us thinking of further measurements that would help our understanding of advanced Li-ion batteries. With its predicted higher spatial resolution VENUS could deliver the capability to quickly construct 3D maps that not only show the lithium distribution inside of a real battery electrode at a fixed state of charge, but the higher flux available on the SNS could also enable studies of dynamic behavior in batteries and other vehicle components."*

Andy Drews
Ford Research & Advanced Engineering

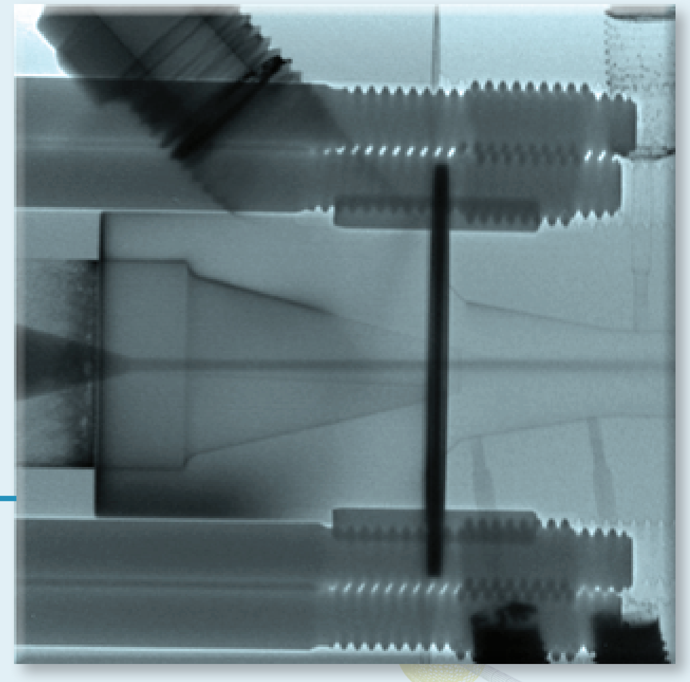
Geothermal

Its unique, time-resolved imaging capability will make VENUS ideal for investigating the flow and transport of water and CO_2-rich fluids, including organic materials within the complex heterogeneous rock matrix. Combined neutron and x-ray imaging capabilities of VENUS will also enable visualization and quantification of multi-phase fluid distributions in porous media.



Industry and buildings

VENUS will support ongoing worldwide efforts to optimize heat exchangers for reduced energy consumption. It will enable optimal selection of energy to enhance contrast and also allow use of multiple energies for material identification in experiments related to buildup in the heat exchanger system. Stroboscopic imaging will capture brief events for a better understanding of boiling and condensation processes.



Neutron image of internal ejector nozzle flow to validate physical models needed for improving heat pump ejector design and system efficiency.

Metals casting

Spatial and temporal information collected by VENUS during casting solidification will provide valuable modeling and verification of the dynamic process using computational fluid dynamic codes. Data can be used to develop suitable engineered solutions to achieve near net-shaped castings with lower scrap rates.

Mining

Neutron imaging at VENUS will lead to better ways to break and crush ore while using less energy, and help identify unique characteristics of minerals that can increase efficiencies in separating minerals from wastes. Fundamental understanding of ore processing and neutron characterization of ores and core samples can also lead to mining hard-to-exploit ore bodies.

Petroleum science and technology

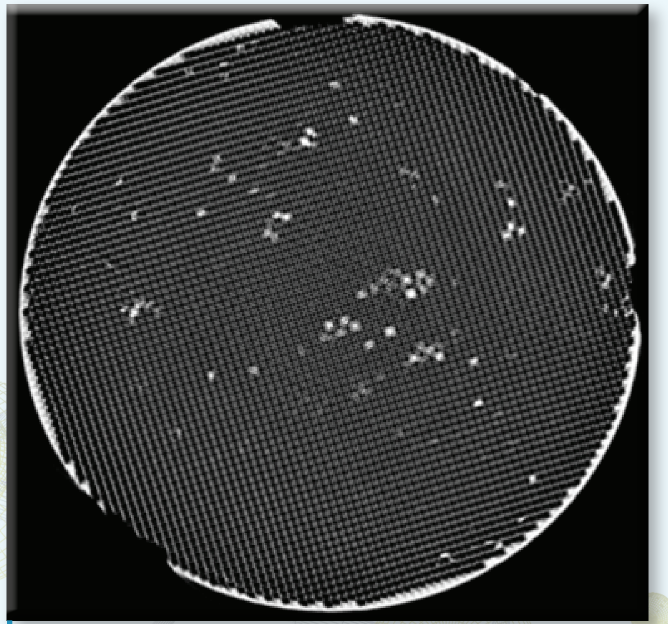
In situ neutron imaging at VENUS is expected to significantly improve our understanding of the production and extraction processes of hydrocarbons from oil, shale, and other deposits. It will also be used to investigate and optimize the process of CO_2 enhanced oil and gas recovery from unmineable coal deposits.

Vehicle technologies

VENUS will help predict system behavior and maximize energy efficiency of next-generation vehicles. Its neutron imaging capabilities will lead to development of better spray models and fuel injection systems. Non-invasive energy selective capabilities will allow internal viewing of diesel exhaust systems, while stroboscopic imaging will enable advanced *in situ* engine experiments and diagnostic research.

"Non-destructive analyses of soot and ash distribution accumulated in diesel particulate filters are issues for future and further improvements for emission aftertreatment system management. Neutron imaging is one of the technologies that has potential to solve the issues."

Shawn Fujii
NGK Ceramics USA, Inc.



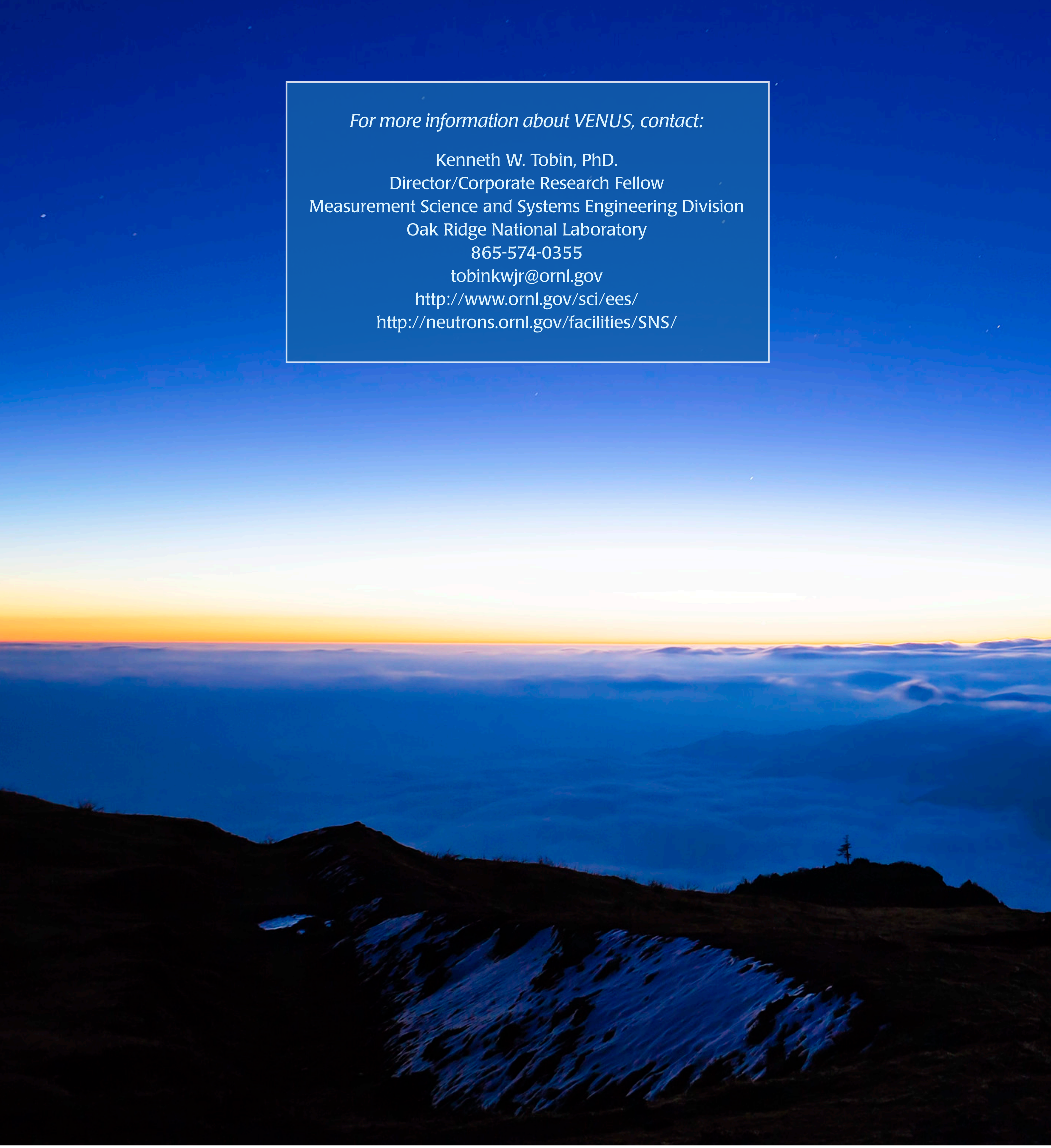
Neutron tomography (3D) slice of diesel particulate filter enables in situ study of particulate matter and ash during steady state and regenerative cycling.

"Modine is using the results of ORNL neutron imaging of soot-covered exhaust gas recirculation (EGR) coolers to improve fin designs for next generation products with the overall goal being to reduce fouling, maintaining design performance, in order to meet diesel emission requirements with compact, cost-effective EGR coolers."

Joseph R. Stevenson
Modine Manufacturing Company

Neutron CT of EGR cooler measured at the High Flux Isotope Reactor prototype beam line.

VENUS will require approximately $20 million over the next five years to finalize construction and instrumentation within the Spallation Neutron Source. This necessary support will enable unprecedented neutron imaging capabilities at Oak Ridge National Laboratory and open new doors to industry and a broader user community.



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U.S. DEPARTMENT OF ENERGY

VENUS research will directly support the DOE Office of Energy Efficiency and Renewable Energy, as well as the DOE Office of Science. The research will also support other DOE offices and programs, other government agencies, research organizations in the private sector, and private industry.

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