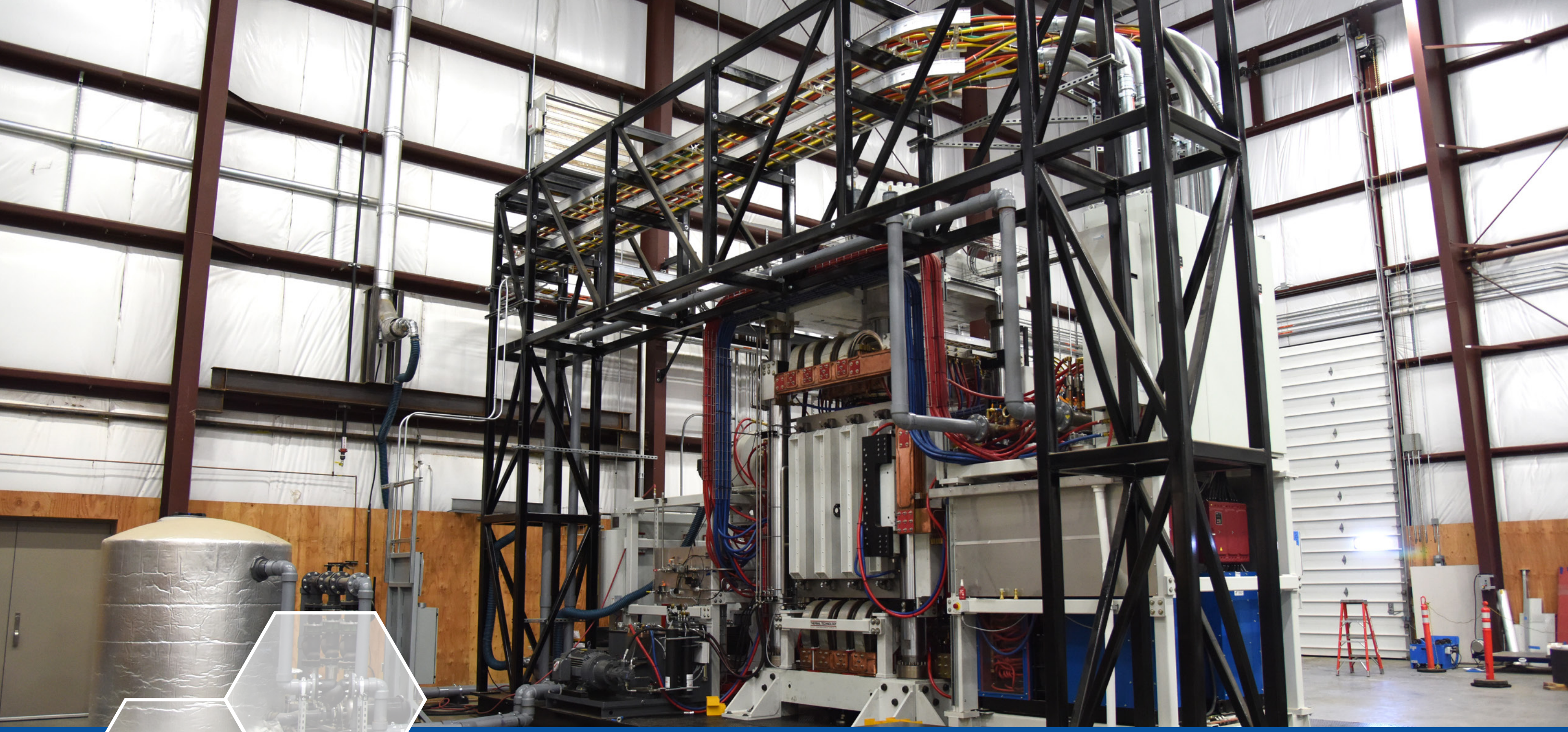


Electric Field Assisted Sintering

INL capabilities help industry optimize advanced materials manufacturing

Idaho National Laboratory has a long history of helping U.S. companies remain competitive in advanced manufacturing. Researchers are constantly innovating new processes and technologies to reduce the life cycle energy consumption of manufactured goods, and ensure critical material supplies meet high-performance standards.

As a result, INL has developed an array of core capabilities that are ideally suited to solve advanced manufacturing challenges. Over the past two decades, INL has expanded those capabilities to include Electric Field Assisted Sintering (EFAS), an approach that dramatically improves the manufacturing of high-performance components.

WHAT IS EFAS?

EFAS supports the decarbonization of metals, ceramics and composite material manufacturing through process electrification. EFAS enables distributed manufacturing activities that connect with regional supply chains and raw materials to deliver high-performance products.

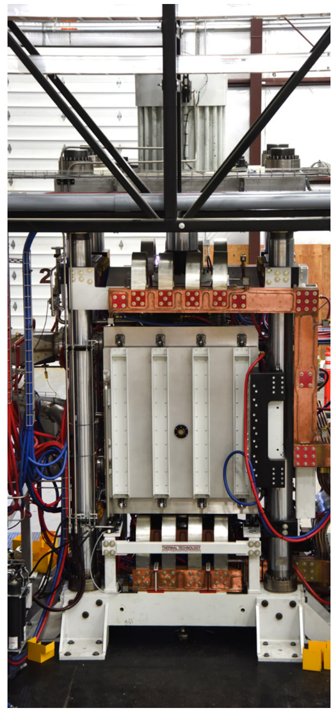
Many of today's high-performance technologies, including nuclear reactors, spacecraft, concentrated solar plants and hydrogen cells, require advanced materials made of metals and ceramics that can withstand extreme conditions or meet exacting specifications.

In the past, these advanced materials were typically manufactured from powder that was poured into a die, subjected to high pressure, and slowly heated in a process called hot pressing. However, hot pressing results in limited performance and wastes a lot of energy, contributing to high costs that have limited the widespread use of advanced materials in industries that manufacture more everyday items such as automobiles.

Advances in EFAS, including "brand specific" process names such as Spark Plasma Sintering, or Direct Current Sintering and Flash Sintering, now make it possible to

manufacture such materials on an industrially useful scale. EFAS is less expensive to run while being faster and more energy-efficient than traditional powder metallurgy and diffusion bonding methods. Energy savings, for example, can exceed 90%. In contrast to hot pressing, EFAS sends electricity through a die or the material itself, resulting in rapid heating.

EFAS reduces the costs of advanced materials. Instead of utilizing radiant heat, EFAS generates rapid joule heating. This process sends



DCS-800 located at INL's Energy Systems Laboratory

electricity through the die, and sometimes the material itself, to fuse the particles of powdered metals, ceramics or a mixture of both.

The EFAS process allows for more control of the product material properties.

INL is developing world-class capabilities–including a range of EFAS machines, modeling, analysis and testing tools–to help industry design efficient EFAS manufacturing processes.

These capabilities have broad applicability across research areas and industries including but not limited to renewable hydrogen, advanced heat exchanger technologies, nuclear fuels and systems components, fuel pellets, reactor components, and advanced moderator and reflector materials.

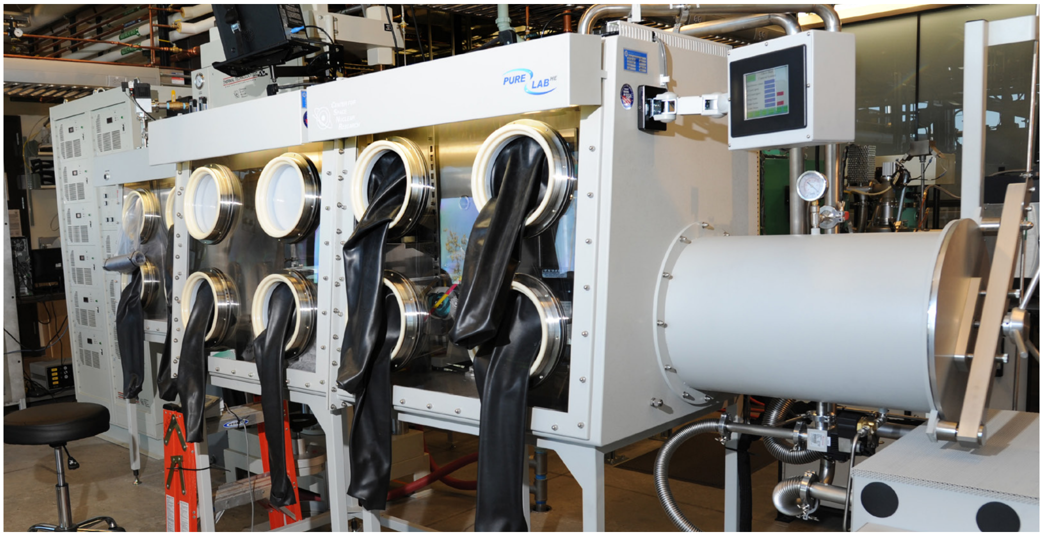
WHAT IS THE SCALE OF EFAS RESEARCH AT INL?

INL is developing four EFAS systems that range from micrometer and millimeter sized samples that support fundamental sintering science and bench scale experiments to industrially relevant, large-format systems capable of generating parts nearly half a meter in size.

The small sample **Nano-Spark Plasma Sintering** machine will be able to fuse nanometer-sized powder grains of metals or ceramics to form parts on the nano to micrometer scale. This experimental machine helps researchers directly observe samples at the nanostructure and microstructure scales. For example, X-ray and neutron diffraction experiments, using the Nano-Spark Plasma Sintering setup within beamline facilities, provide real-time, in-situ data about chemical and microstructure evolution during the Nano-Spark Plasma Sintering process.

The **Micro-Spark Plasma Sintering System**, or DCS-5, is a bench-scale machine custom designed for smaller millimeter to centimeter sized specimens and in-situ analysis. It is useful in understanding microstructural evolution during the production of new materials.

The Micro-Spark Plasma Sintering system provides insight into the bulk sintering behavior of materials during EFAS processing. This real-time active interrogation of materials utilizes X-ray radiography, allowing researchers to generate bulk material sintering kinetics



Radiological Spark Plasma Sintering System located at INL's Materials and Fuels Complex

Manufacturing Methods Cost/Energy Comparison

	Energy use	Cost for 5,000 parts
Hot pressing	1.83 kW/g	$5.7M
Spark Plasma Sintering	0.1 kW/g	$520K
Savings via Spark Plasma Sintering	1.82 kW/g	$5.2M

data and master sintering curves for given materials.

EFAS is also an emerging technology for advanced nuclear fuels fabrication. The **Radiological Spark Plasma Sintering System**, located at INL's Material and Fuels Complex, is purposefully engineered and integrated within a radiological work glovebox. This unique system facilitates nuclear fuel fabrication and other highly air-sensitive work.

A recent demonstration of the Radiological Spark Plasma System was performed at INL's Transient Reactor Test Facility. In this demonstration, accident tolerant fuels and nuclear fuels, fabricated for nuclear thermal propulsion applications, were irradiated at a temperature of almost 3,000 degrees Kelvin.

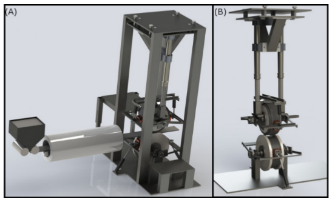
A larger EFAS machine can make parts up to half a meter in size. INL's **Direct Current Sintering-800** is the largest machine of its kind in the world, with an operating power supply of 150,000 amperes (<12 volts DC) and allowing compaction with up to 800 tons of force. The Direct Current Sintering-800 operates at high power, high temperature, and high pressure. This infrastructure allows materials that have been discovered on the bench-scale to be demonstrated at industrially relevant scales.

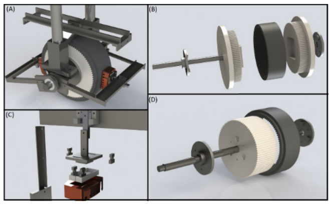
Finally, the **Continuous Electric Field Assisted Sintering (CEFAS)** machine changes the form factor of traditional EFAS systems, moving away from samples batch processed in graphite die and plunger assemblies to being fed continuously through Joule heated carbon-based rollers. It will allow INL researchers to make contiguous sheets of material that can be joined together to make parts of unlimited size or of multiple layers while further decreasing the energy use and time of manufacture.

HOW DO ANALYSIS AND MODELING HELP?

INL is developing advanced modeling and simulation tools, that couple with data analytics and machine learning methodologies. These tools will provide a scientific foundation to optimize EFAS process behavioral predictions and material processing parameters.

Microscopy helps researchers peer at the microstructure of components so they can understand how products made by EFAS evolve from metal and ceramic





Roller EFAS system design and development at INL

powders under different process parameters such as temperature, pressure, current, voltage and time. This data is then used to create models using tools such as INL's Multiphysics Object-Oriented Simulation Environment (MOOSE) framework. Though INL's computer scientists originally designed MOOSE to model nuclear fuel performance in a reactor, the open-source software is flexible enough to simulate various physics problems, ranging from the movement of fluids through shale to electromagnetic wave propagation. These MOOSE models allow EFAS users to engage in process-informed design of production components and systems for service in extreme environments.

HOW IS INL DIFFERENT?

INL has a rich history of developing manufacturing techniques and testing materials performance. Our capabilities, from modeling and characterization to testing, allow for a comprehensive approach to EFAS research and development. INL's EFAS efforts stand out due to our ability to bridge bench-scale with industrially relevant demonstration.

Furthermore, INL's expertise in handling high-consequence, harsh environment materials is unique. We can help industry partners move from research to commercial use for industries such as mining, where it is crucial to improve the efficiency of manufacturing materials for (or in) harsh environments.

With EFAS, making products from high-temperature materials can reduce the cost of materials and energy. EFAS can reduce temperatures by as much as 50%, reducing the energy cost by an order of magnitude.

FOR MORE INFORMATION

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