Argonne NATIONAL LABORATORY

Energy to Renew Our World

At Argonne National Laboratory, we passionately pursue energy-efficient technologies and renewable energy innovations that contribute to a better, cleaner future for all.

Argonne's Research in Energy Efficiency and Renewable Energy

As we begin our journey into the 21st century, the U.S. Department of Energy's (DOE) Argonne National Laboratory continues to make significant contributions to the nation's health and well being by delivering achievements in energy technology development and deployment.

We are working toward technological innovations that will reduce greenhouse gas emissions and create clean energy solutions — fueling new economies and creating the jobs of the future.

Argonne's research supports DOE's mission to ***enhance our nation's energy efficiency and productivity***.

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Argonne's mission is to apply a unique mix of world-class science, engineering and facilities to deliver innovative research and technologies. Two of the Lab's user facilities – Advanced Photon Source and Center for Nanoscale Materials – are pictured below.

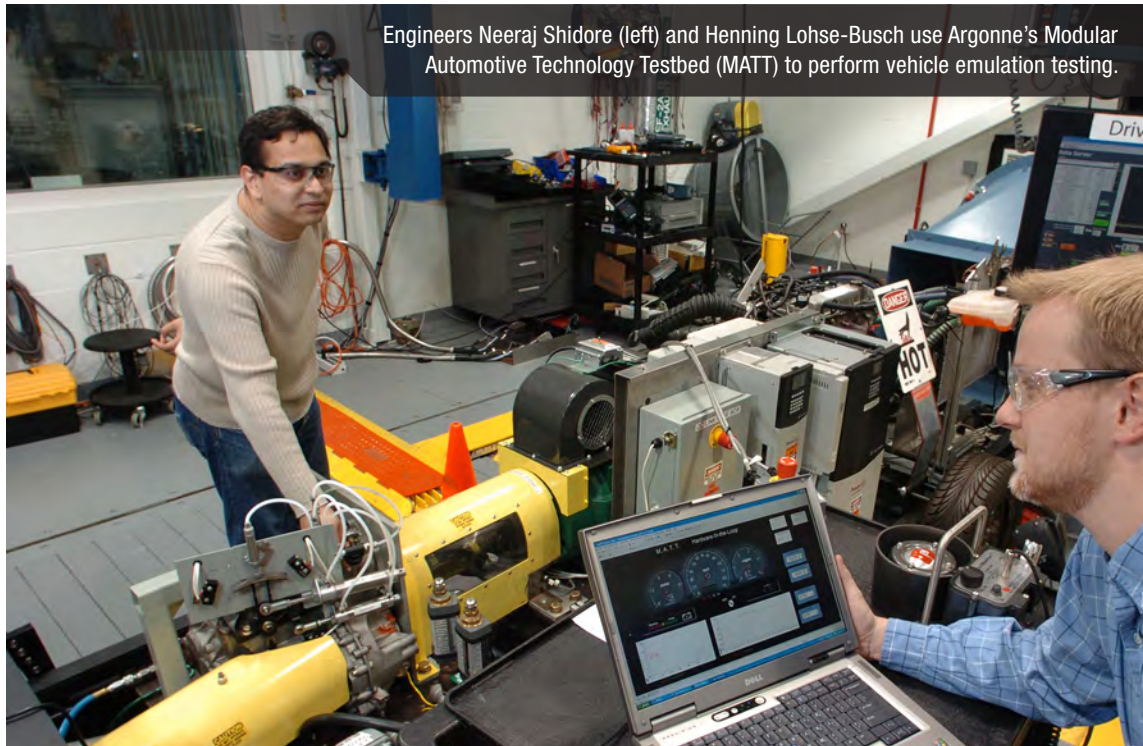
Vehicle Technologies

Driving U.S. Transportation Forward

Argonne's comprehensive transportation research program is developing technologies for hybrid powertrains, advanced batteries, improved combustion systems and fuel-efficient vehicles. These technologies will reduce the consumption of imported oil, minimize consumers' vulnerability to oil price shocks and reduce emissions.

Our research spans fuel production through end-of-life vehicle recycling to enable a sustainable transportation future. Research areas include:

- **Batteries** – Developing advanced battery and capacitor technology to support cost-effective electrification of vehicles; working with industry to improve manufacturing capabilities to support the production of these new technologies
- **Fuel Cells** – Investigating ways to decrease costs and improve performance of fuel cells for vehicles
- **Vehicle Systems** – Simulating and measuring the performance of advanced vehicle systems to identify optimal technologies, configurations and engine control strategies for new technology options



Engineers Neeraj Shidore (left) and Henning Lohse-Busch use Argonne's Modular Automotive Technology Testbed (MATT) to perform vehicle emulation testing.

Mechanical engineer Thomas Wallner adjusts Argonne's "omnivorous engine," an automobile engine tailored to run at optimal efficiency on blends of gasoline, ethanol and butanol.

- **Emissions Control** – Developing technologies to improve the fuel economy and overall performance of combustion engines, while at the same time reducing emissions
- **Applied Materials Research** – Developing ceramic and lightweight materials, advanced coatings and lubricants, thermal management systems and manufacturing processes to further improve the fuel economy and reduce the costs of advanced vehicles
- **Materials Recovery and Recycling** – Developing end-of-life materials recovery technologies to minimize environmental impact and to ensure cost-effective availability of materials

Engineer Ted Bohn checks levels on a plug-in hybrid electric vehicle (PHEV) battery using the Lab's Through-the-Road PHEV development platform.

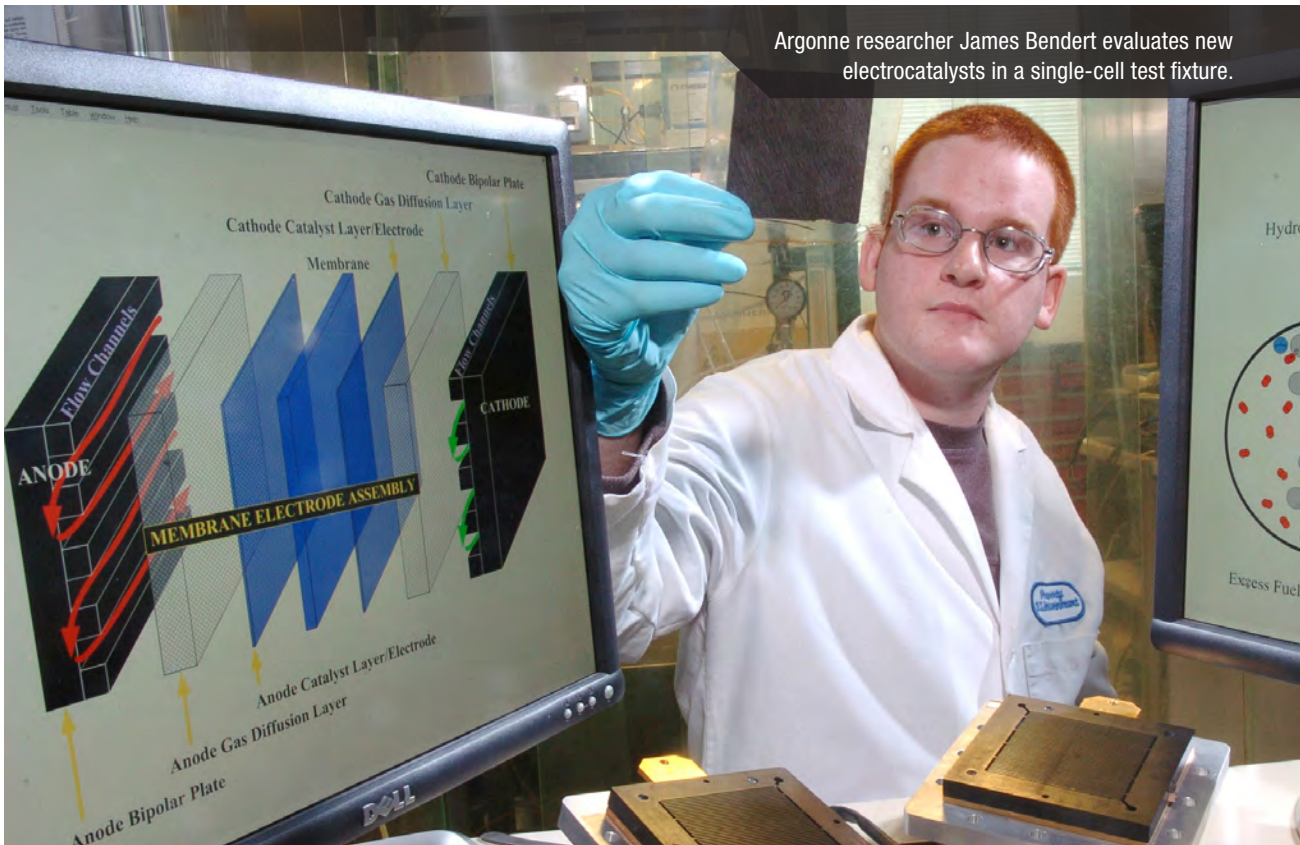
Fuel Cell Technologies

Providing Clean and Efficient Energy with a Low Carbon Footprint

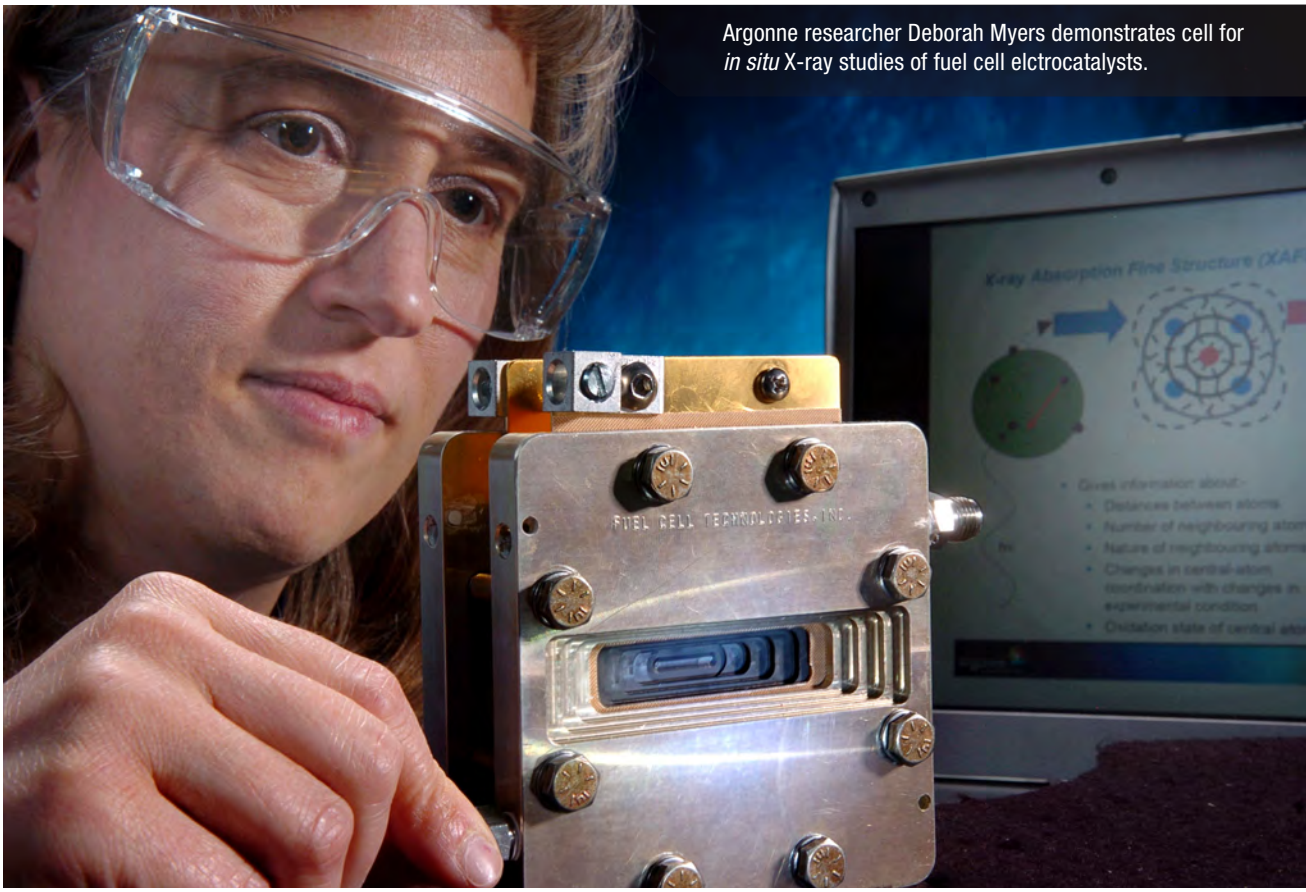
Argonne is developing technologies to reduce the cost and improve the durability of fuel cells used in transportation, stationary, and portable applications. By enabling clean, efficient, and reliable power generation, hydrogen and fuel cell technologies can play a vital role in decreasing our nation's dependence on petroleum and reducing greenhouse gas emissions.

Our fuel cell and hydrogen research includes:

- Reducing the cost of fuel cells by developing electrocatalysts that reduce or eliminate the need for precious metals, and support materials for electrocatalysts that increase their performance and durability
- Improving the durability of fuel cells by developing an understanding of how electrocatalysts degrade during fuel cell operation, how impurities in hydrogen and air affect performance, and developing protective coatings to reduce materials corrosion in fuel cells
- Developing technologies for producing hydrogen from fossil fuels, such as natural gas; from renewable fuels, such as biomass-derived ethanol; or from water using closed thermochemical process cycles



Argonne researcher James Bendert evaluates new electrocatalysts in a single-cell test fixture.



Argonne researcher Deborah Myers demonstrates cell for *in situ* X-ray studies of fuel cell elctrocatalysts.

- Advancing the performance of on-board hydrogen storage systems by developing nanostructured hydrogen storage materials
- Conducting systems modeling and analyses of fuel cell and hydrogen storage systems to identify the component performance characteristics and system configurations needed to meet DOE and industry targets for automotive and combined heat and power applications
- Assessing life cycle energy use and emissions for hydrogen fuel cell vehicles and combined heat, hydrogen, and power fuel cell systems, and determining hydrogen supply infrastructure requirements, performance, and cost
- Providing fuel cell developers with independent, unbiased analyses of their fuel cells systems through performance testing conducted at Argonne's Fuel Cell Test Facility

Industrial Technologies

Strengthening U.S. Industry

Argonne partners with industry to develop sustainable process technologies for improved energy efficiency, better environmental performance and reduced production costs for American manufacturers. By making improvements in energy use, the U.S. industrial sector is better positioned to compete in today's global market.

Our industrial technology research includes:

- Developing transformational technologies for traditional industries such as:
  - inert carbon-free anodes to virtually eliminate the greenhouse gas emissions associated with primary aluminum production
  - electrochemical alternatives to energy-intensive heat treatment processes
- Conducting R&D on novel technologies such as laser ignition and air enrichment to improve the efficiency and emissions performance of stationary engines for combined heat and power systems

These high-performance pump seals are coated with the Argonne-developed ultrananocrystalline diamond coating. The Lab worked with Advanced Diamond Technologies, Inc., to bring this product to market.

Researcher Elena Timofeeva conducts a quality control evaluation of thermal nanofluids, which can help enhance heat transfer.

- Developing advanced coatings for friction reduction and wear resistance such as ultrananocrystalline diamond coatings for high-performance pump seals
- Advancing the commercial deployment of nanomanufacturing technology with process engineering research and manufacturing R&D to enable scalable, cost-effective nanotechnologies such as:
    - high-performance catalysts for manufacturing chemicals
    - nanobased lubricants for increased wear resistance and friction reduction
    - thermal nanofluids for more effective heat transfer
    - atomic layer deposition for high throughput manufacture of photovoltaic cells

Building Technologies

Making Buildings More Energy Efficient

Argonne is researching ways to reduce the energy use of buildings. This research contributes to DOE's target of achieving marketable, net-zero energy residential buildings by 2020 and net-zero energy commercial buildings by 2025. Net-zero energy buildings create as much energy using on-site power generation systems as they consume.

Our building technology research includes:

- Using advanced power systems simulation tools to analyze building-level energy storage technologies and how they might contribute to a more flexible, dynamic and efficient interaction between buildings and the power grid
- Using an agent-based modeling and simulation approach to develop a new commercial building sector model to study infrastructure, policy, and behavioral issues relevant to meeting sector-wide energy efficiency targets
- Developing and applying human dimensions insights to maximize the effectiveness and accelerate the energy savings of DOE's building technologies efforts
- Partnering with private sector industry leaders and other members of the National Laboratory Collaborative for Building Technologies to conduct research and deploy best practices under DOE's Commercial Building Partnerships
- Assisting DOE in developing a roadmap to outline the activities and milestones needed to achieve affordable, net-zero energy commercial buildings

The U.S. Green Building Council's LEED (Leadership in Energy and Environmental Design) certification system is a voluntary, performance-oriented mechanism used to evaluate the design and performance of buildings. Argonne is currently pursuing LEED certification for its Center for Nanoscale Materials (below) and other facilities.

Chemical engineer Patricia Gillenwater tests the acidity of samples produced in Argonne's pilot-scale Separative Bioreactor.

Environmental scientists Gayathri Gopalakrishnan (left) and Paul Benda study contaminated and unused land as potential sites for growing biofuel crops.

Biomass

Growing New Energy Sources

Argonne is working toward a viable, sustainable biomass industry through its research in biomass feedstocks, cost-effective conversion technologies and objective life cycle analyses. By producing renewable biofuels, bioproducts and biopower, the U.S. can diversify domestic energy supply, create jobs, lessen dependence on oil and reduce greenhouse gas emissions.

Our biomass research includes:

- Improving energy efficiency for product recovery through the Argonne-developed Separative Bioreactor, a platform technology that allows both the continuous production and recovery of biobased chemicals and fuels
- Evaluating the potential use of contaminated and unused land to grow crops for biofuel
- Employing chemical and biological approaches to the production of infrastructure-compatible advanced biofuels that will directly replace gasoline or diesel
- Conducting field experiments to evaluate and develop technologies that provide more sustainable biomass systems by addressing biomass feedstock water use and carbon sequestration
- Developing integrated systems that enable the conversion of biomass feedstock to synthesis gas, which in turn can be used as a fuel to generate electricity or be converted to other biofuels and chemicals

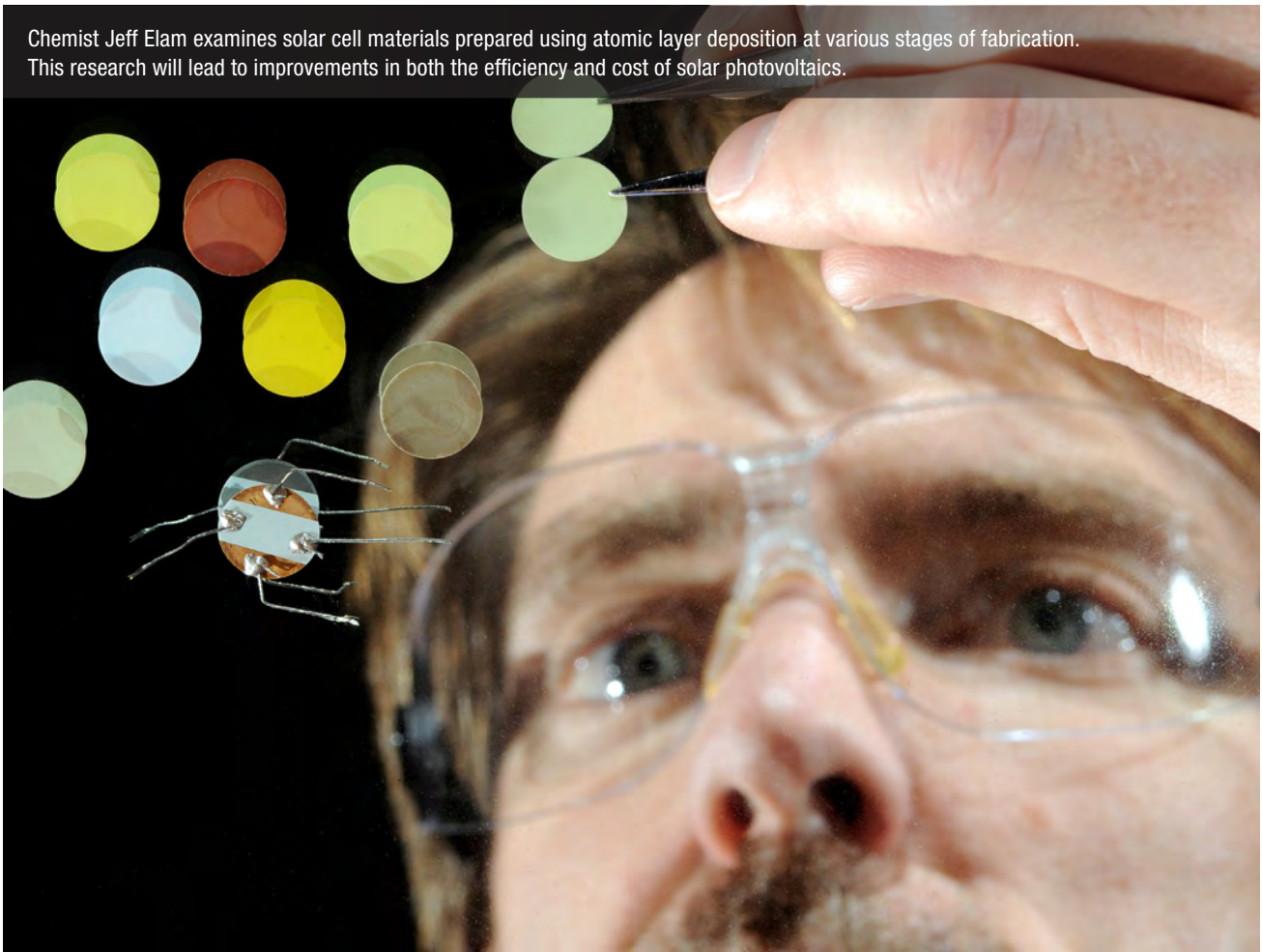
Solar

Creating a Brighter Future

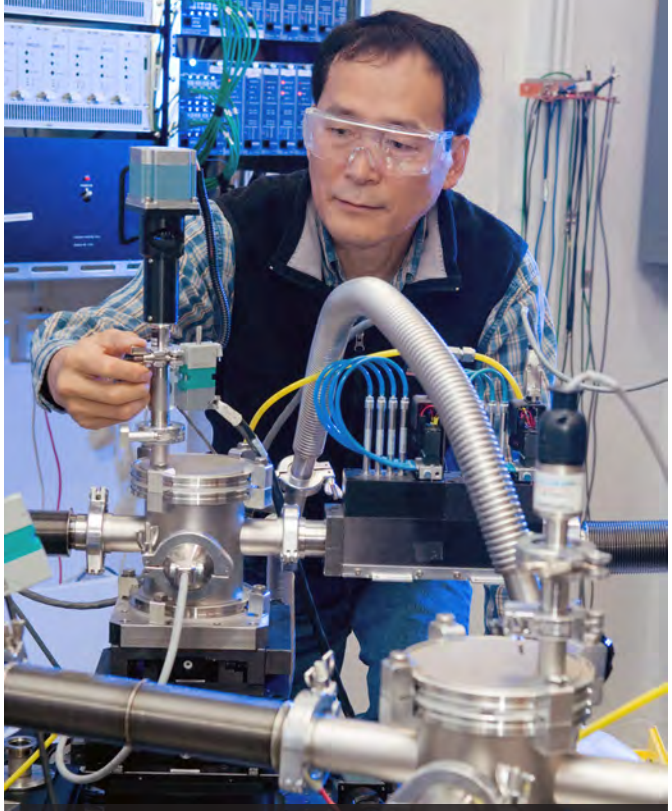
Argonne is developing advanced materials, technologies and integrated systems that will reduce costs and enhance the performance of photovoltaic and concentrating solar energy systems.

Our solar energy research includes:

- Using atomic layer deposition to improve the efficiency of low-cost photovoltaic materials by depositing both transparent conductors and photovoltaic active materials onto nanoporous scaffolds
- Improving the energy conversion performance of concentrating solar power with the development of novel heat exchange concepts, heat transfer fluids and thermal storage media
- Employing consumer-choice modeling to develop a utility-based understanding of market responses to metering and price signals for photovoltaic market penetration
- Assessing environmental impacts and identifying mitigation measures for developing commercial-scale solar energy projects on federal lands



Chemist Jeff Elam examines solar cell materials prepared using atomic layer deposition at various stages of fabrication. This research will lead to improvements in both the efficiency and cost of solar photovoltaics.



Physicist Hoydoo You studies supercritical carbon dioxide and feldspar interfaces at the Advanced Photon Source in an effort to improve energy recovery in enhanced geothermal systems.

Geothermal

Unearthing Abundant Energy

Argonne is developing technologies to improve how we find, access and use energy from Earth's abundant geothermal resources. Specifically, we are looking at ways to advance the use of enhanced geothermal systems (EGS), which are engineered underground reservoirs that have been created to pull geothermal heat from areas that are not naturally productive.

Our geothermal energy research includes:

- Designing chemical energy carrier systems for the enhanced conversion of EGS heat
- Developing advanced ultrasonic waveguide and far-field electromagnetic sensors to measure key EGS reservoir patterns including directional temperature, pressure and fluid flow
- Performing synchrotron X-ray studies of supercritical carbon dioxide and reservoir rock interfaces to improve energy recovery
- Developing easy-to-use, readily-accessible and standardized tools for DOE and industry to examine geothermal technology-related issues such as water consumption, carbon footprint, cost, environmental impacts and employment effects

Wind & Hydropower

Harnessing Clean Energy

Argonne is researching ways to improve wind and hydropower technologies and increase the use of these clean energy resources in the marketplace. Water and wind power have the potential to further diversify the domestic energy portfolio, but continued research is needed to improve reliability and to support deployment and long-term maintenance.

Our wind energy research includes:

- Advancing wind power forecasting techniques and improving their use in the operation of electrical power systems that have large shares of power generated by wind
- Improving mathematical algorithms and operational procedures for addressing the increased uncertainty and variability of wind power
- Improving the efficiency and reliability of drivetrain components in windmills by smart surface and lubrication engineering
- Providing environmental assessments of wind power developments including critically important ecological and visual impacts

To improve wind power technology and its use in electricity market operations, Argonne has assembled a team of experts in wind power forecasting, electricity market modeling, wind farm development and power system operations.

In addition to new hydropower technology development, researchers are looking at ways to improve the efficiency, flexibility and environmental performance of existing facilities, such as the hydroelectric power plant at Glen Canyon Dam in Arizona.

Our hydropower research includes:

- Developing new tools and methods to measure and predict the environmental impacts of advanced water power technologies, such as marine and hydrokinetic devices, in coastal environments and inland waterways
- Developing analytical tools to improve the efficiency, economic benefits and environmental performance of hydropower facilities, thereby allowing operators to optimize hydropower plants, processes and equipment
- Conducting environmental studies that address the barriers to implementing conventional hydropower in the U.S. (as related to power-efficient and environmentally effective in-stream flow releases)

Analysis

Providing Impartial and Credible Information

Argonne-developed methodologies and analytical tools provide a credible basis for analyzing energy, environmental and economic implications of technology options. Argonne's transportation simulation tools streamline the development of advanced vehicle technologies; the Lab's grid models are used worldwide to analyze alternative power generation strategies including deployment of renewable energy technologies.

Our analysis capabilities include:

- **GREET** – The Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model is an analytical tool that provides comparisons of the energy use and emissions impact of various vehicle and fuel combinations on a life cycle basis. It is a key tool used by DOE's Biomass, Fuel Cell Technologies, Vehicle Technologies and Geothermal programs to evaluate the greenhouse gas emissions of technology portfolios.
- **PSAT/PSAT-PRO** – The Powertrain System Analysis Toolkit is a flexible computer simulation package that allows engineers to quickly and efficiently evaluate different powertrains, component technologies and control strategy options for advanced vehicles.

Engineers Antoine Delorme (front) and Aymeric Rousseau work on AUTONOMIE, Argonne's new simulation software program for evaluating advanced vehicle technologies.

Researchers Andrew Burnham (clockwise from left), Jeongwoo Han, Amgad Elgowainy and Michael Wang continue to update and expand Argonne's GREET model. Industry and government agencies consider GREET to be the "gold standard" for well-to-wheel analyses of vehicle and fuel systems.

- **AUTONOMIE** – AUTONOMIE is the next-generation plug-and-play software program for evaluating the fuel consumption benefits of both vehicle components and powertrain throughout the different phases of model-based design, from modeling to hardware implementation.
- **ENPEP-BALANCE** – The Energy and Power Evaluation Program (ENPEP-BALANCE) allows users to evaluate entire energy systems for a country or region (supply and demand sides) and the environmental implications of different energy strategies.
- **GTMax** – The Generation and Transmission Maximization (GTMax) model helps optimize the operation of electric power systems and analyze regional interconnections. It is applicable for both regulated and deregulated power markets.
- **EMCAS** – The Electricity Market Complex Adaptive System (EMCAS) uses an agent-based modeling approach to simulate the operation of today's restructured electricity markets. It can be used as an "electronic-laboratory" to simulate market operation and bidding strategies of generation companies, as well as to project likely impacts of different market rules and regulatory decisions before they are implemented.

Engine research scientist Christopher Powell fits a specially designed X-ray pressure window to a high-pressure chamber used for diesel spray research at the Advanced Photon Source.

Facilities

Where Innovation Happens

Argonne designs, builds and operates world-class scientific and engineering research facilities that are essential to the development of advanced energy-efficient technologies. Our facilities include:

- **Advanced Powertrain Research Facility** – A state-of-the-art vehicle test facility with both two-wheel and four-wheel drive chassis dynamometers, capable of benchmarking conventional, hybrid and advanced electrical propulsion systems that run on a wide variety of fuels
- **Distributed Energy Research Facility** – A component test facility for evaluating advanced combustion technology and alternative fuels on the performance of both reciprocating and turbine stationary engines for combined heat and power systems
- **Electrochemical Analysis and Diagnostics Laboratory** – An extensive battery and fuel cell testing facility that provides independent battery performance and life testing services for DOE, other government agencies and industry

- **Illinois Center for Tribology Research** – A center that conducts research to resolve critical friction, wear and lubrication issues in alternative energy technologies and extreme environments
- **End-of-Life Vehicle Recycling Pilot Plant** – A facility that allows engineers to benchmark and develop materials recovery and recycling technologies, test actual materials, determine the feasibility of processing them and generate scale-up and design data for commercial-scale facilities
- **Center for Nanoscale Materials** – A premier user facility, providing expertise, instruments and infrastructure for interdisciplinary nanoscience and nanotechnology research
- **Advanced Photon Source** – A national synchrotron X-ray research facility providing the brightest X-ray beams in the Western Hemisphere to more than 5,000 scientists worldwide

The Advanced Powertrain Research Facility's new two-wheel drive dynamometer is dedicated to the testing and development of electric vehicles and applications for renewable fuels.

Battery researchers Khalil Amine (left), Chris Johnson, Sun-Ho Kang and Mike Thackeray helped develop composite cathode materials that have been licensed to BASF.

Chemist Chris Marshall displays a container of Argonne's Diesel $DeNO_x$ Catalyst, which significantly reduces nitrogen oxide emissions.

Technology Transfer

Bringing New Technologies to the Marketplace

Argonne collaborates with industries from all economic sectors to ensure the effective development, deployment and transfer of technology into commercial use. In the past five years, our success has been recognized with 19 awards from *R&D Magazine* (R&D 100) and three Federal Laboratory Consortium (FLC) awards for excellence in technology transfer. During that time, Argonne has also emphasized the creation of intellectual property, with 259 patents filed, 198 patents awarded and 198 new licenses signed.

Some recent examples of our successful technology transfers include:

- **Composite Cathode Materials** – Signing licensing agreements with BASF and Toda Kogyo to mass produce and market Argonne's patented composite cathode materials to manufacturers of advanced lithium-ion batteries
- **Lithium-ion Battery Technology** – Partnering with EnerDel, Inc., to introduce a nanophased lithium titanium oxide spinel anode system made for use in high-power lithium-ion batteries for hybrid electric vehicles
- **Separative Bioreactor** – Working with an industrial equipment provider and a bioprocessor to license and commercialize this platform technology
- **Diesel $DeNO_x$ Catalyst** – Licensing a catalyst designed to reduce nitrogen oxide emissions from diesel engines by 95 to 100 percent to Integrated Fuel Technologies, Inc.
- **Advanced Batteries** – Licensing two new start-up companies, Envia and NanoeXa, to produce advanced batteries for the emerging hybrid vehicle market and other high-power applications

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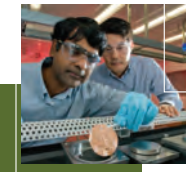
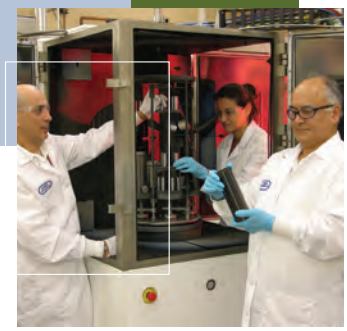

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