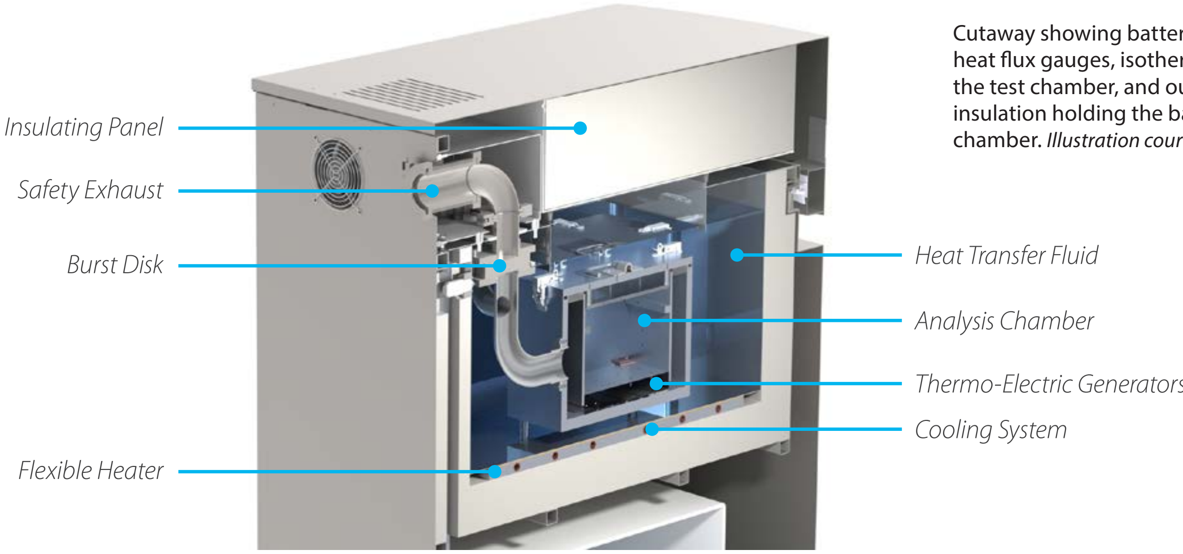
Isothermal Battery Calorimeters



Cutaway showing battery in the test chamber, heat flux gauges, isothermal fluid surrounding the test chamber, and outside container with insulation holding the bath fluid and the test chamber. *Illustration courtesy of NETZSCH*

Thermal Characterization for the Next Generation of Batteries

Rising fuel efficiency standards and consumer demand for environmentally friendly automobiles have manufacturers racing to put more hybrids (HEVs), plug-in hybrids (PHEVs), and fully electric vehicles (EVs) on the road. To make these options practical, automotive batteries need to operate at maximum efficiency, performing at optimal temperatures in a wide range of driving conditions and climates, and through numerous charging cycles.

High temperatures degrade batteries faster, while low temperatures decrease their power and capacity, affecting vehicle range, performance, and cost. NREL's Isothermal Battery Calorimeters (IBCs) are the only calorimeters in the world capable of providing the precise thermal measurements needed for safer, longer-lasting, and more cost-effective electric-drive vehicle batteries. As drivers continue to demand ever-more-green but affordable car models, NREL—in partnership with NETZSCH Instrument North America and with support from the U.S. Department of Energy (DOE)—is using IBCs to help industry design better thermal management systems for energy storage cells, modules, and packs for these electric-drive vehicles.

Three models, the Large-Volume IBC, the IBC 284, and the Module IBC, make it possible to test a full range of energy devices.

The breakthrough technology of the Isothermal Battery Calorimeters (IBCs) has been recognized with an R&D 100 Award, known in the research and development community as "the Oscars of Innovation."

Award Winner

IBCs are the only calorimeters in the world that:

- Determine heat levels and battery energy efficiency with 98 % accuracy
- Provide precise measurements through complete thermal isolation.

IBCs make it possible to:

- Accurately measure the heat generated by electric-drive vehicle batteries
- Analyze the effects of temperature on battery systems
- Pinpoint ways to manage temperatures for the best performance and maximum life.

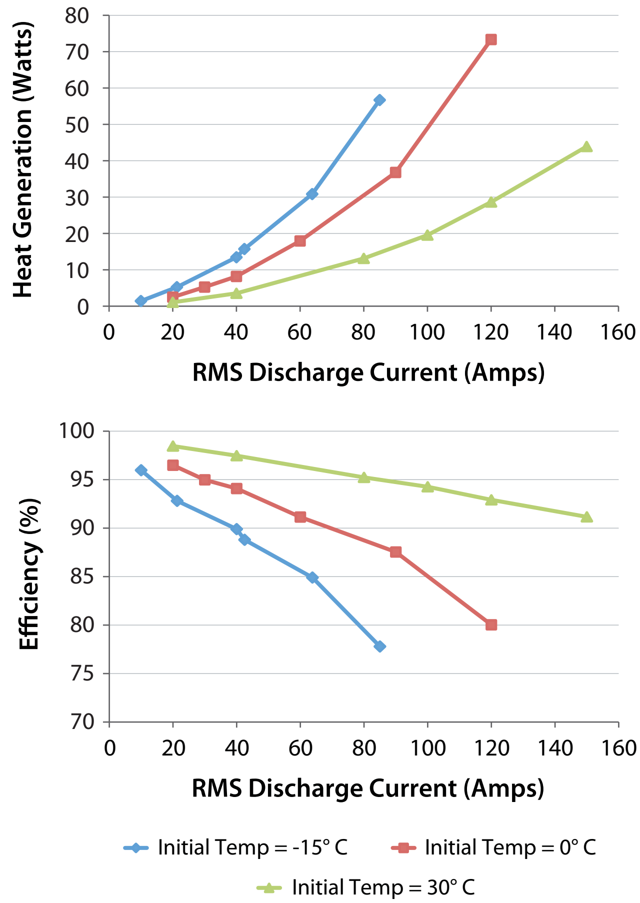
NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

What Makes Battery Temperature Important?

A well-designed thermal management system is critical to the life and performance of HEVs, PHEVs, and EVs. Regulation of battery pack temperature helps maximize performance (power and capacity) and charge acceptance (during regenerative braking), while minimizing battery degradation, and vehicle operating and maintenance expenses.

As electrochemical devices, batteries' performance and lifespan are affected by temperature. High temperatures increase side reactions, leading to shorter battery life and greater battery replacement costs. Surges in temperature can also jeopardize safety by triggering battery fires or explosions.

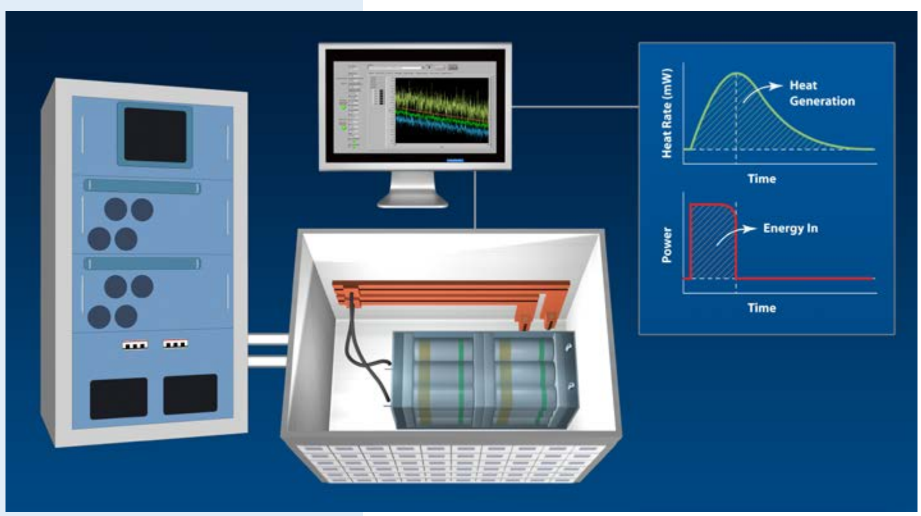
Development of precisely-calibrated battery systems relies on accurate measurements of heat generated by battery modules during the full range of charge/discharge cycles, as well as determination of whether the heat was generated electrochemically or resistively.



Right: Heat generation and efficiency curves for a PHEV battery at various discharge currents and temperatures. This critical information helps regulate battery temperature by identifying conditions that result in undesirable temperature spikes.

NREL's Isothermal Battery Calorimeters are designed to:

- Obtain accurate heat generation data for battery cells, components, and packs under different modes of system operation, battery power profiles, and operating temperatures
- Measure round-trip energy efficiency (i.e., distinguish energy stored from waste heat generated) for use in estimating vehicle energy consumption
- Compile data to validate and refine thermal models developed by researchers, battery developers and vehicle manufacturers
- Generate a performance history to evaluate the effects of aging and cycling
- Evaluate physical and electrochemical design changes that could lead to better battery modules and improved performance
- Understand the heat lost due to inefficient interconnects within a module or pack, as well as those from the energy storage cells
- Evaluate the efficacy of liquid-cooled energy storage systems.

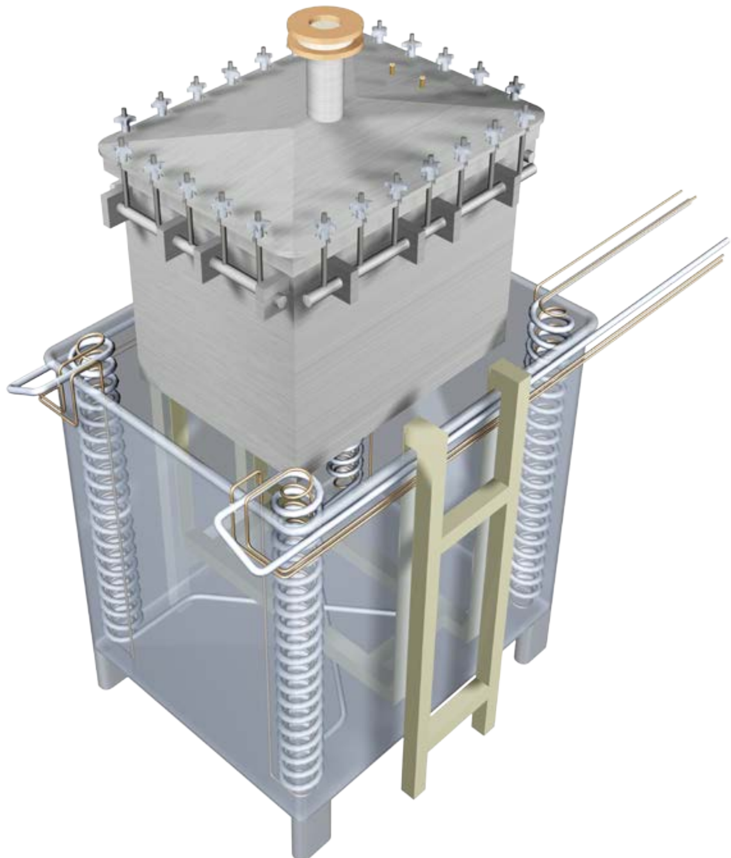


Above: Battery in the test chamber of the IBC (bottom). In the graph (right), the red curve shows electrical power input to the battery, and the green curve shows the heat signature measured.
Illustration by Dean Armstrong, NREL

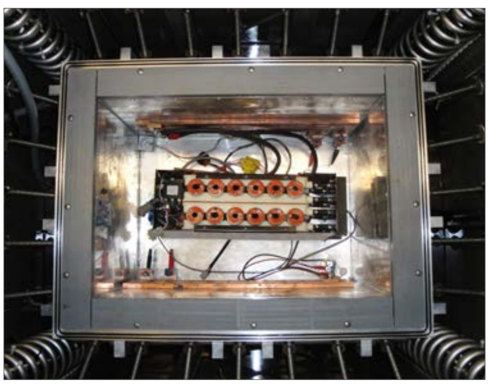
Calorimeter Readings Lead to Fine-Tuned Energy Storage Designs

The United States Advanced Battery Consortium (USABC) and its partners—including Johnson Controls Inc., Saft, A123 Systems, Compact Power Incorporated, EnerDel, and other companies—rely on NREL for precise measurement of energy storage devices' heat generation and efficiency under different states of charge, power profiles, and temperatures. The IBCs are the first calorimeters designed to analyze heat loads generated by complete battery systems. The instruments can measure heat generation rates as low as 15 mW and up to 4,000 W, with overall heat-load-measuring accuracy from a battery to within ±1%.

These IBC capabilities make it possible for battery developers to predict thermal performance before installing batteries in vehicles. Manufacturers use these metrics to compare battery performance to industry averages, troubleshoot thermal issues and fine-tune designs.



Above: A chamber-within-a-chamber, an isothermal bath, an external housing with insulating material, and a sophisticated series of thermal controls to keep temperatures constant and readings accurate.
Illustration by Dean Armstrong, NREL



Left: A large battery module in the Large-Volume IBC test chamber, with cooling/heating coils in each corner.
Photo by Dirk Long, NREL 6310097

Isothermal Battery Calorimeter Specifications

Specifications	IBC 284 (Cell)	Module IBC	Large-Volume IBC (Pack)
Maximum Voltage (volts)	50	500	600
Sustained Maximum Current (amps)	250	250	450
Excursion Currents (amps)	300	300	1,000
Volume (liters)	9.4	14.7	96
Maximum Dimensions (cm)	20.3 x 20.3 x 15.2	35 x 21 x 20	60 x 40 x 40
Operating Temperature (°C)	-30 to 60	-30 to 60	-40 to 100
Maximum Constant Heat Generation (W)	50	150	4,000

Highlights

- Accuracy of 98%
- Ability to test cells from 0.5 Ah to 100 Ah
- Ability to measure battery packs with energy content of 2 Wh to 10 kWh
- Assessment of heat systems, including interconnects
- Innovative thermal isolation and isothermal bath providing errors of less than ±1%
- Simulation of full conditions and charging cycles
- Ability to test liquid-cooled batteries.

NREL's Sustainable Transportation RD&D

As the only national laboratory solely dedicated to renewable energy and energy efficiency, NREL spearheads the RD&D needed to put sustainable transportation solutions on the road. The laboratory's innovative and integrated approach helps government, industry, and other partners develop and deploy the components and systems needed for market-ready, high-performance, low-emission, fuel-efficient passenger and freight vehicles, as well as energy storage components for next-generation vehicles.

For more information on NREL's transportation RD&D capabilities and successes, go to *www.nrel.gov/transportation*.

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Top Left: An external heating and cooling system (right) keeps the isothermal bath of the calorimeter (left) at a uniform and constant temperature. *Photo by Ahmad Pesaran, NREL 19190*

Bottom Left: The lid of the test chamber is sealed with 24 clamps before the chamber is immersed in the isothermal bath. *Photo by Dennis Schroeder, NREL 18907*

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