

3D Printed Plug-In Hybrid Vehicle/ Additive Manufacturing in Integrated Energy Systems

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TENNESSEE
SUSTAINABLE TRANSPORTATION
AWARDS AND FORUM

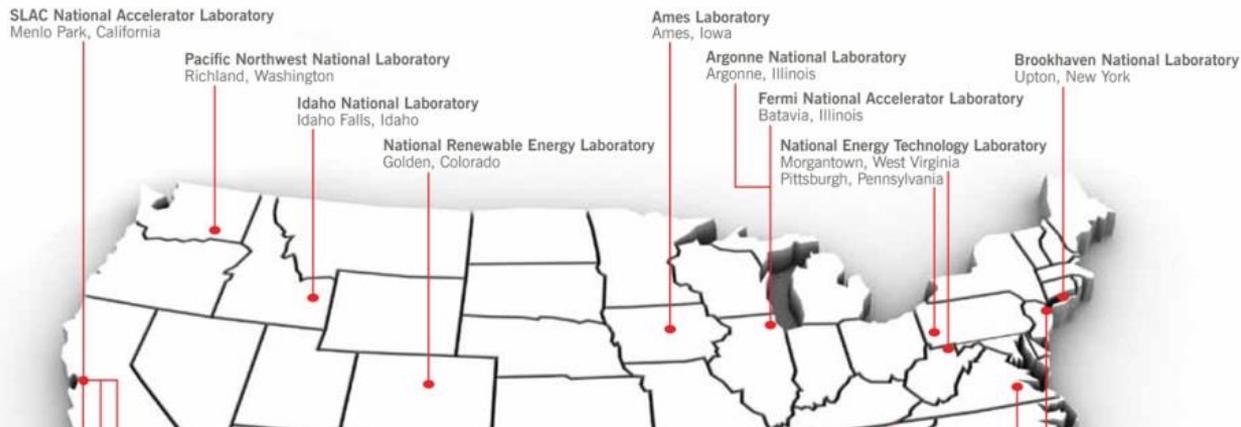
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Chattanooga, Tennessee



What is a Department of Energy (DOE) National Laboratory?

Together, the 17 DOE laboratories comprise a preeminent federal research system, providing the Nation with strategic scientific and technological capabilities. The laboratories:

- Execute long-term government scientific and technological missions, often with complex security, safety, project management, or other operational challenges;
- Develop unique, often multidisciplinary, scientific capabilities beyond the scope of academic and industrial institutions, to benefit the Nation's researchers and national strategic priorities; and
- Develop and sustain critical scientific and technical capabilities to which the government requires assured access.



Reference: Office of Science, <http://science.energy.gov/laboratories/>

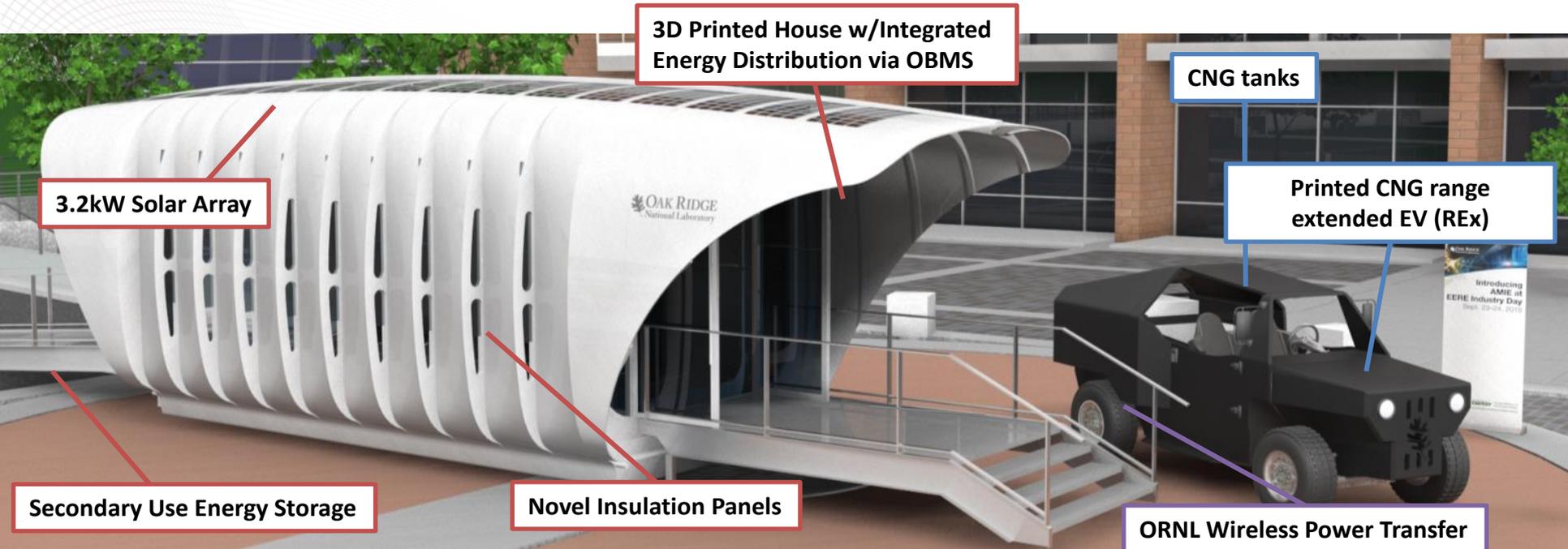
ORNL is the largest United States multi-program science and energy laboratory with core mission of transitioning science to solution

“ORNL's mission is to deliver scientific discoveries and technical breakthroughs that will **accelerate the development and deployment of solutions** in clean energy and global security, and in doing so create economic opportunity for the nation.”

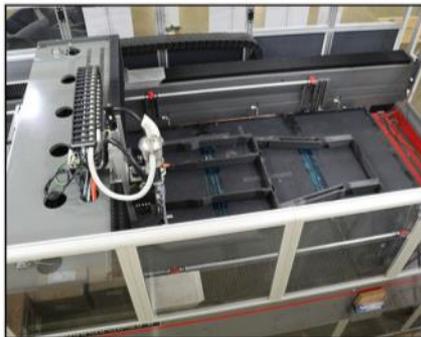
Source: <http://www.ornl.gov/ornlhome/about.shtml>



Connected printed building and vehicle via series plug-in hybrid NG concept with wireless power transfer from vehicle to building



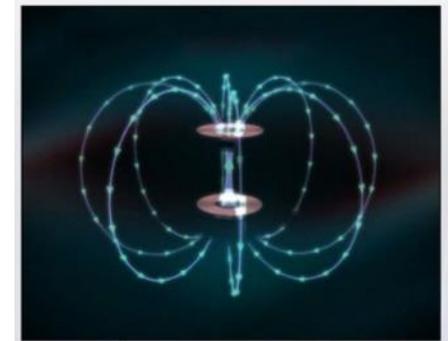
Big area additive manufacturing



Rapid controls development



Wireless power transfer



Meet AMIE

Additive Manufacturing Integrated Energy



Meet AMIE

Additive Manufacturing + Integrated Energy

Leveraging DOE Energy Efficiency and Renewable Energy (EERE) programs

Building Technologies

Building partnerships: ORNL, the University of Tennessee (UT), and industry

Advanced Manufacturing

Integrating clean energy technologies and additive manufacturing to produce a 3D printed house and vehicle

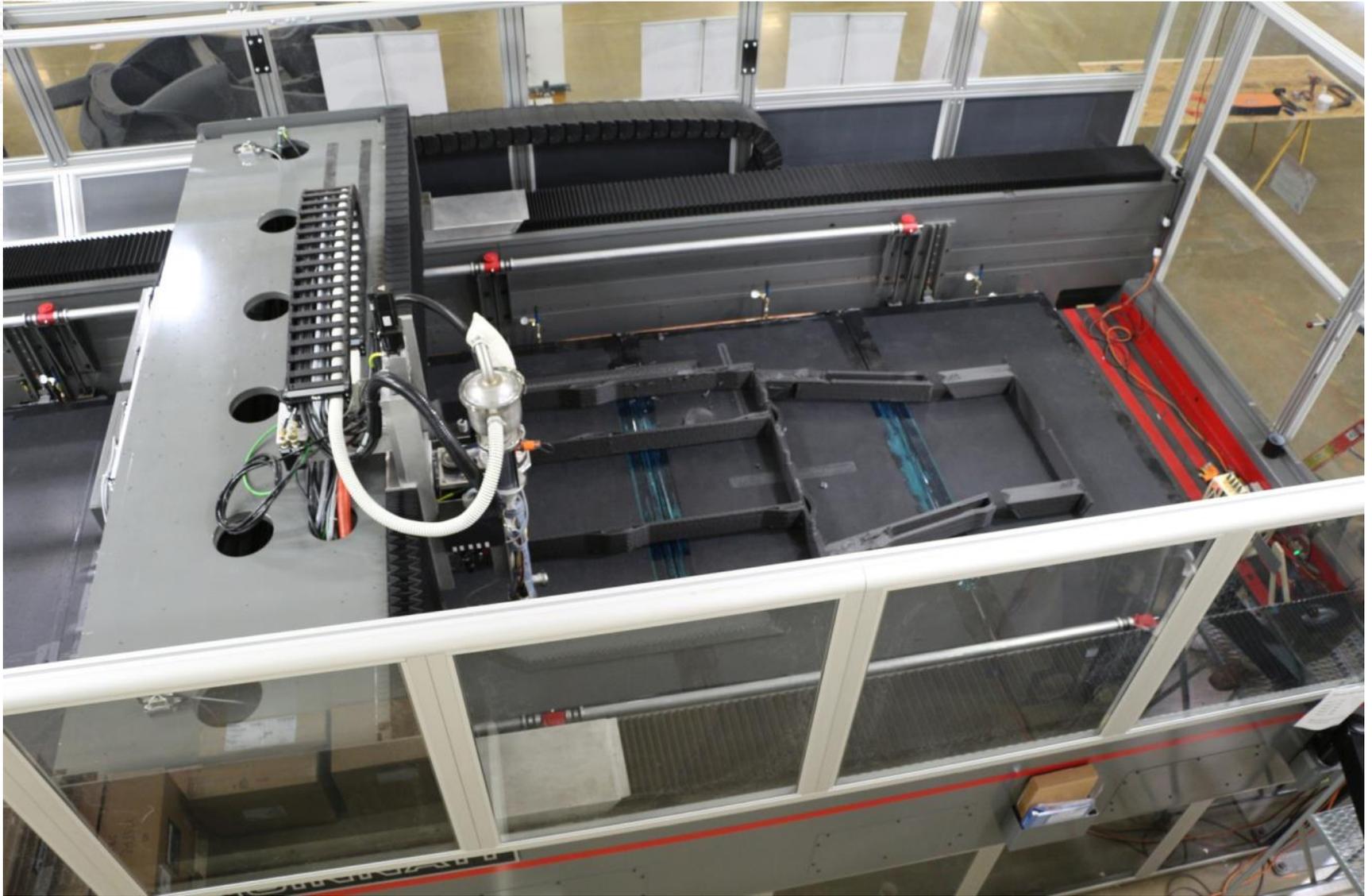
Vehicle Technologies

Demonstrating how the vehicle engine can generate enough energy to power the house and store energy for future use

Sustainable Electricity



Wait, what? – Get back to the 3D Printed part!



Big Area Additive Manufacturing (BAAM)

- We mean big!



Maker Bot

Desktop 3D Printer

[0.93 x 0.5x0.51 ft]

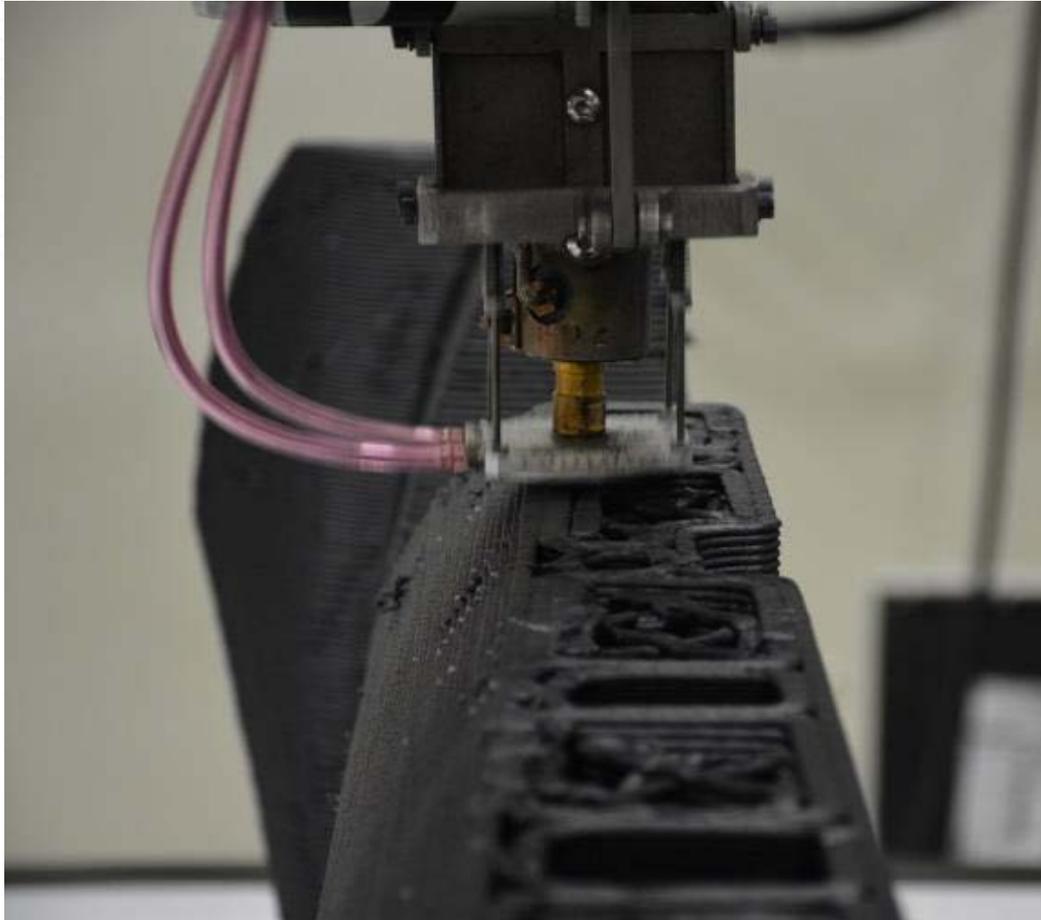
ORNL

BAAM "Bertha"

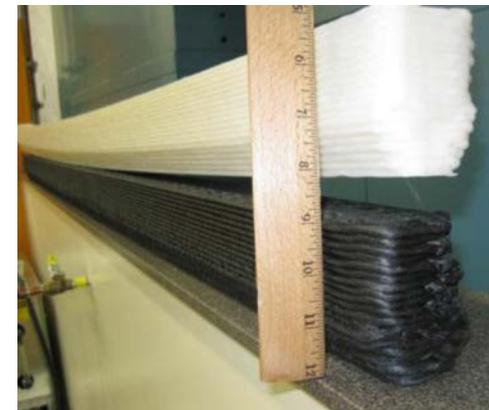
[20.0 x 8.0 ft x 6.0 ft]

Additive Manufacturing 101: Polymer BAAM

- **Carbon fiber filled ABS plastic** (acrylonitrile butadiene styrene)
 - Enables fast printing with virtual no workpiece distortion during cooling



Extruder Type	Single screw
Extrusion rate	80 lb/hr
Extruder temperature	230°C
Bed temperature	110°C



Printed ABS

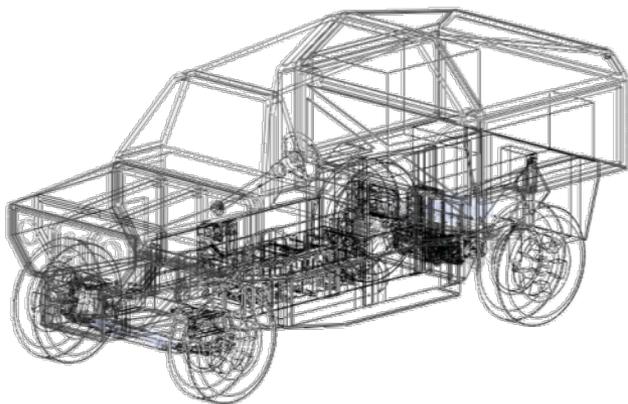
Printed ABS
+20% CF

Effect of carbon fiber addition to
ABS on workpiece curl

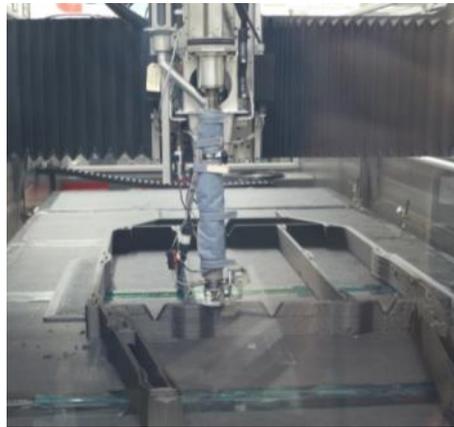
Additive manufacturing enables rapid innovation

- **Products move to market more quickly than with traditional manufacturing**
 - Designs can be changed on the fly
 - Products are available for testing quickly so designers can make adjustments
- **AMIE demonstration project:**
 - **Conceived, designed, tested, and built in less than 1 year**
 - **Completely assembled in 3 weeks**

Computer designed parts



Files sent to printer



Printed parts assembled



Bi-directional wireless charging enables printed car to power printed house

World's first bi-directional wireless power transfer for level two charging

Hybrid electric powertrain with onboard power generation from natural gas

Single engine generates power for home and extends vehicle range

Intelligent control system moves energy between solar, vehicle, and battery

Additive manufacturing enables fast prototyping, builds flexible platform for R&D



The AMIE 3D Printed Utility Vehicle (PUV)

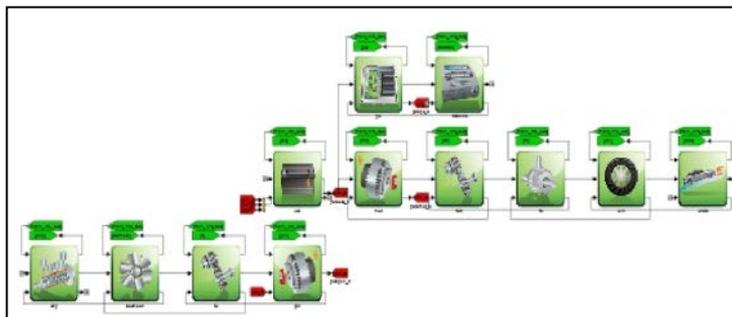
3D-printed CNG extend range PEV with bi-directional wireless power transfer



PHEV Powertrain Development Process

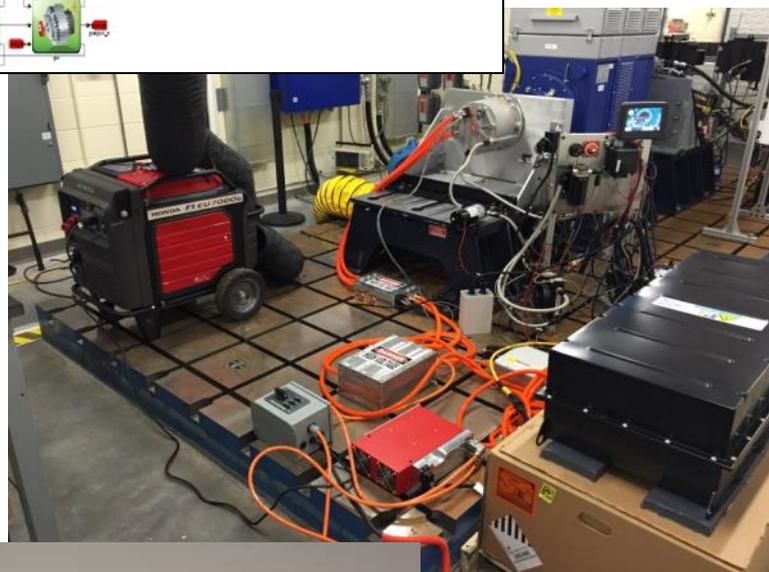
1. Vehicle Simulation

- Component sizing and selection
- Performance prediction
- Control strategies development



2. Powertrain-In-the-Loop

- Motor battery and other components of electric drivetrain installed in dynamometer cell
- Interface validation
- Performance testing
- Control strategies refinement

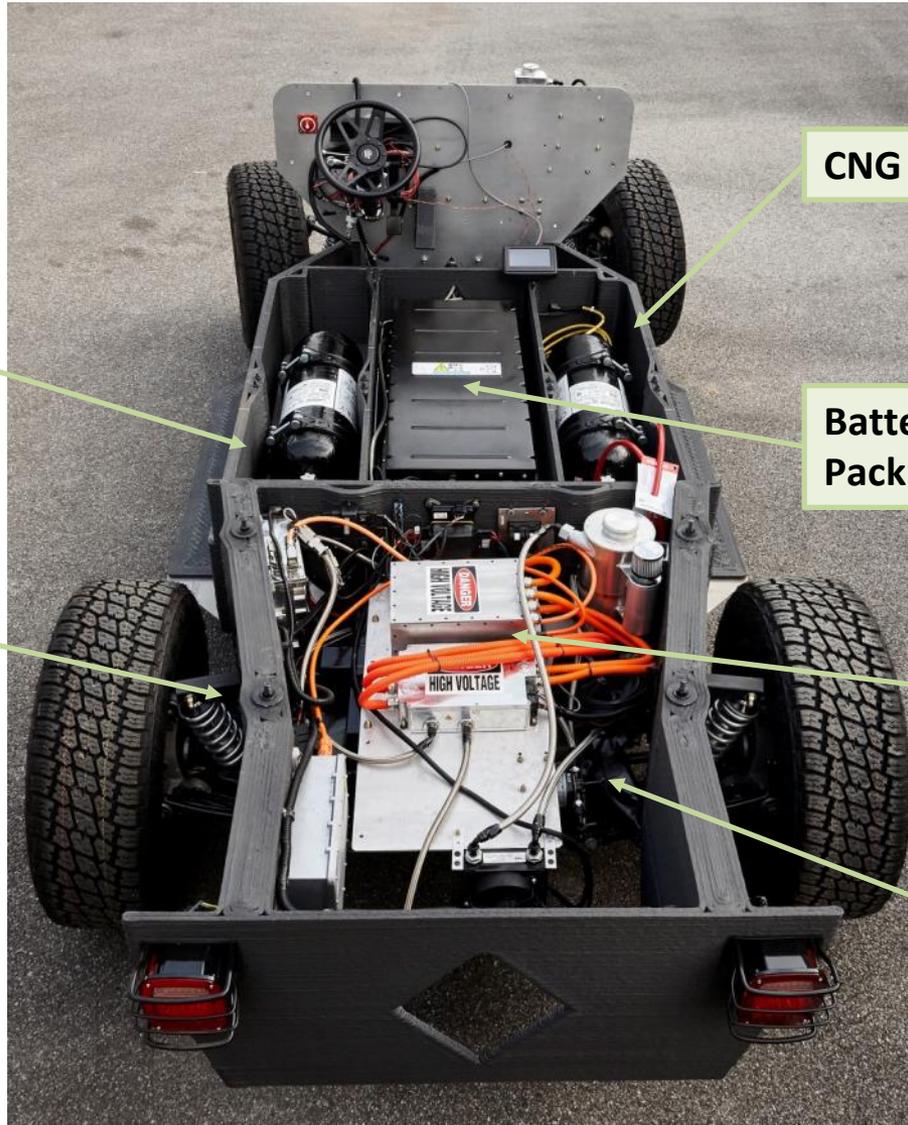


3. Vehicle Implementation

- Powertrain installation in vehicle



Flexible printed vehicle platform integrates technologies for integrated energy systems research and development



Printed frame and body

CNG Tank

Battery Pack

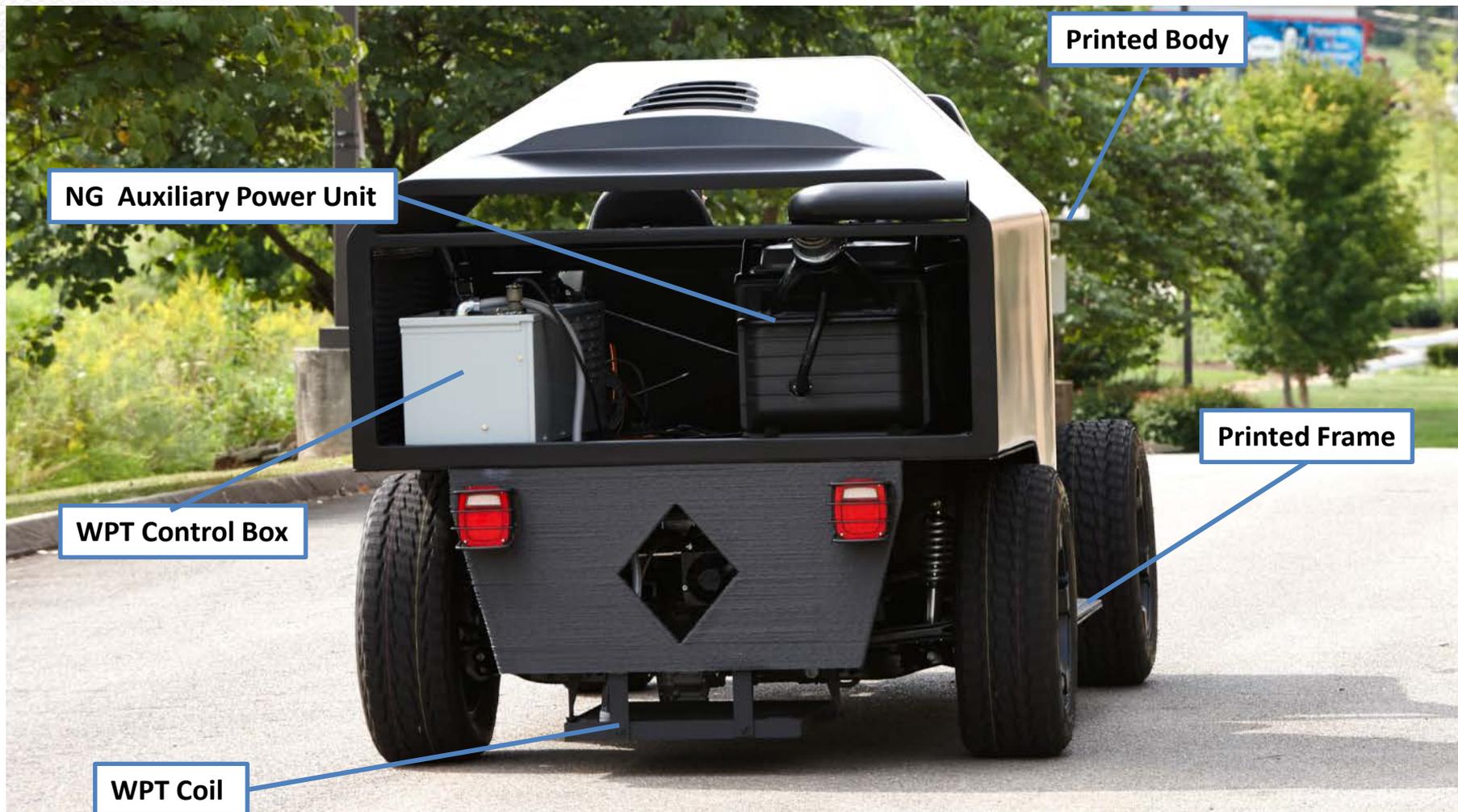
Conventional parts integrated on (Tires, suspension steering wheel)

DC/DC Converter

Ability to integrate different range extender engines/ prime movers

Electric Drive

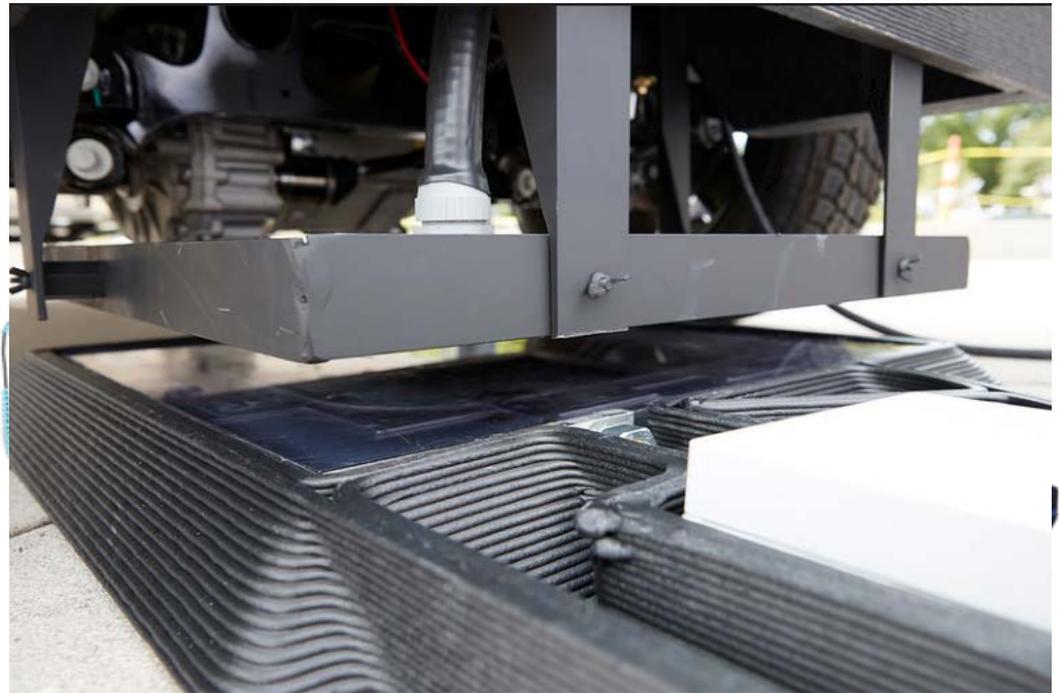
Printed natural gas extended range electric vehicle with wireless power transfer (WPT)



AMIE wireless power transfer

- **First-ever Level 2 bidirectional wireless charging system**
- **Wireless charging plates are aligned when vehicle parks over charging pad**
- **Intelligent control system transfers energy from solar system or battery to house or vehicle while vehicle is parked**
 - Today's technology replaces the control room needed for this coordination 20 years ago with a chip
- **Transfer of power is as fast and becoming nearly as efficient as wired energy from the grid**

March 31, 2016: ORNL achieved this world's first 20-kilowatt wireless charging system for passenger cars with 90 percent efficiency



Why? There are some big questions we want to answer

Advanced
Manufacturing

Building
Technologies

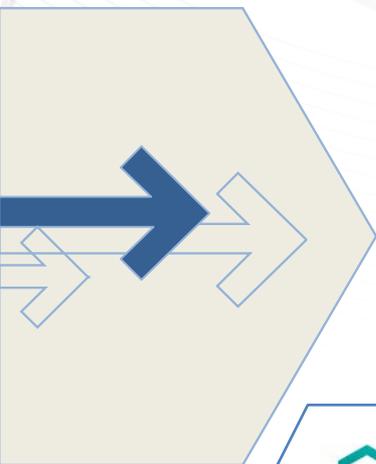
Vehicle
Technologies

Sustainable
Electricity

- Can vehicles and buildings be integrated in terms of sharing energy in a way that offers greater energy savings?
 - Integrated energy
- Are there novel ways of transferring power between vehicles, buildings and the grid/ renewable sources?
 - Wireless power transfer
- Can additive manufacturing (3D printing) open new solutions for energy research and development?
 - Rapid innovation



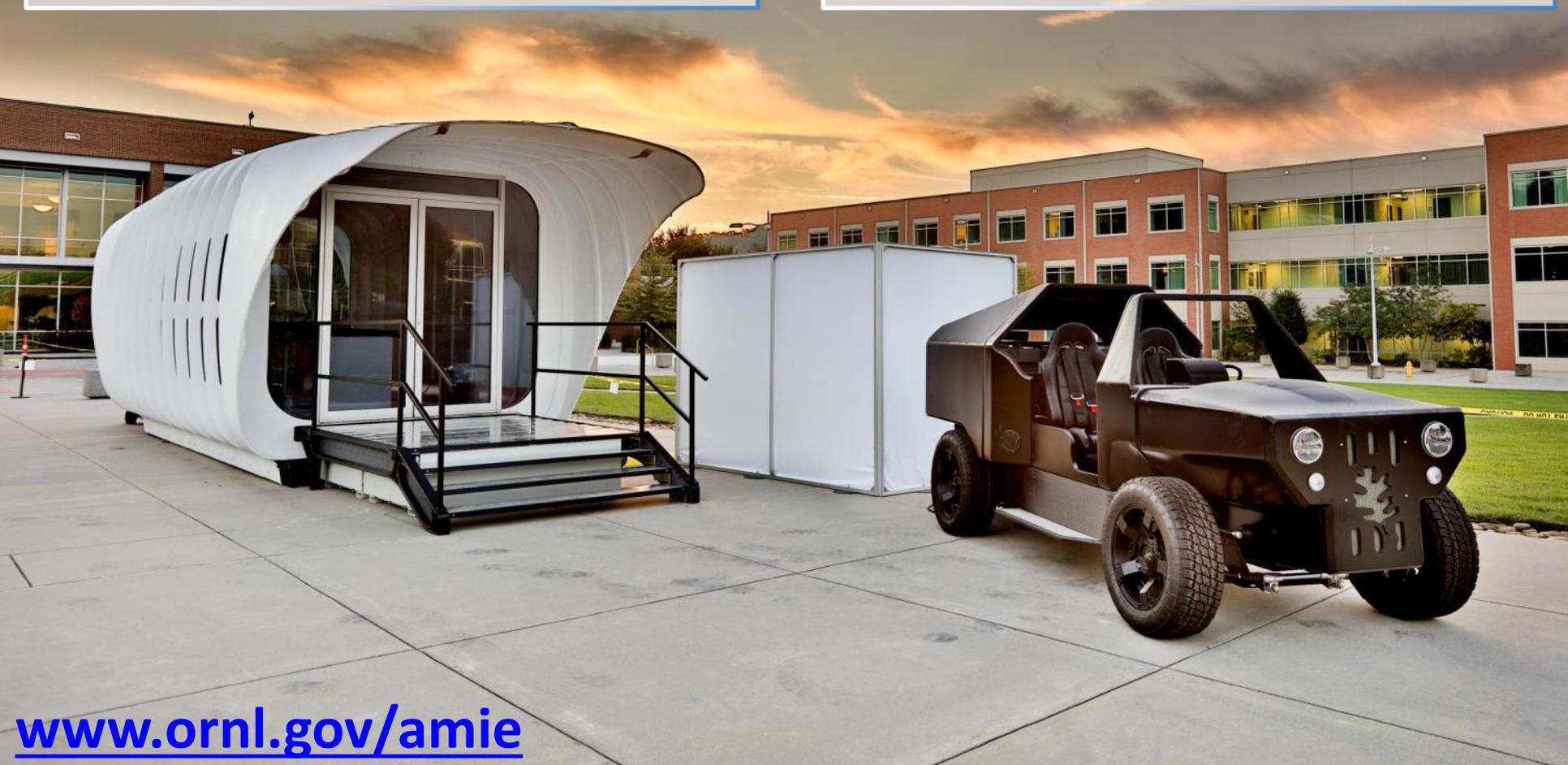
AMIE was showcased at US DOE EERE's Industry Day at ORNL in September 2015



Take Away's

- ORNL is exploring exciting and promising new energy efficiency technologies
- 3D printing is opening up options for research and design

- ORNL is not trying to sell this or any concept
- Not saying cars or houses will be printed in the future
- Exploring new areas and wanting to share results with the community



www.ornl.gov/amie

Thank you for your attention

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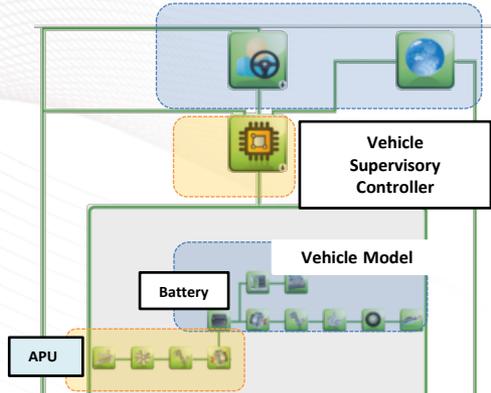


Backup Slides



Rapid vehicle prototyping for research and development

Vehicle Simulation Environment



Component sizing and development of vehicle's controls using simulations

ORNL HIL Development Lab

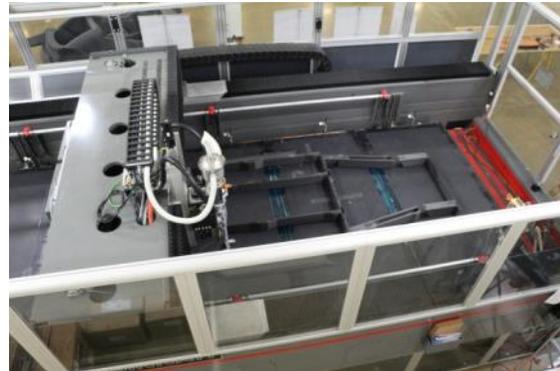


Powertrain testing in real world conditions via HIL environment

Powertrain Installed in Vehicle



Faster integration phase thanks to use of HIL debug controls and wiring



Additive Manufacturing
New Tool for Rapid
Prototyping

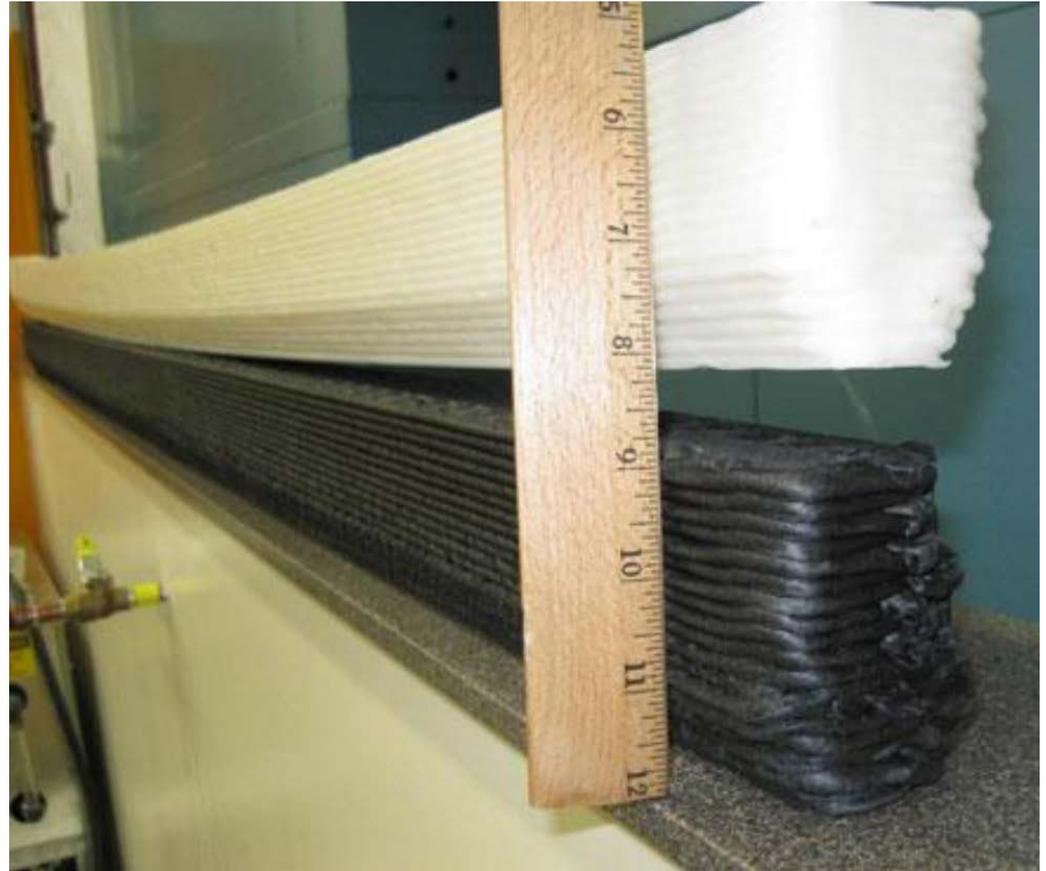
Working Prototype Vehicle



Prototype vehicle was able to driven the moment integration was completed

Use of Carbon Fiber Filled ABS

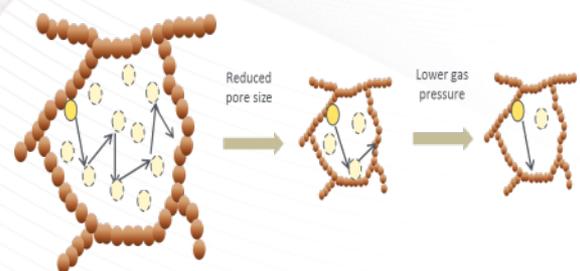
- This is a relatively new concept in which chopped carbon fiber is blended with a thermoplastic
- Previous experiments had determined that a blend of carbon fiber higher than 15%-20% led to significant reduction in warping out of the oven, detailed in a recent study on the effects of adding carbon fiber to ABS
- The effect on curl is apparent, as shown in the figure.
- This behavior makes the addition of carbon fiber an enabling technology for large printed workpieces and can eliminate the need for additional ovens to prevent curling.
- Carbon fiber reinforced ABS shows increased strength and significant reduction in distortion.



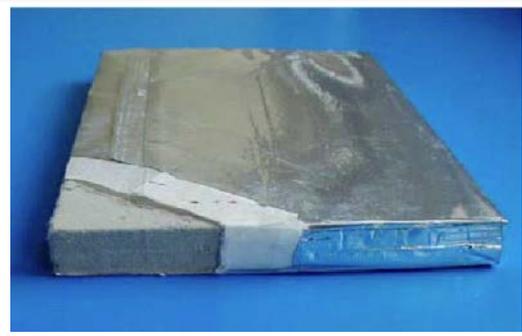
Effect of carbon fiber addition to ABS on workpiece curl

Rapid innovation is needed to meet energy savings goals

Leverage Science



Develop Technology



Demonstrate Energy Savings



January 2014



First printed go-cart structure

September 2014



First printed car, created in collaboration with industry

January 2015

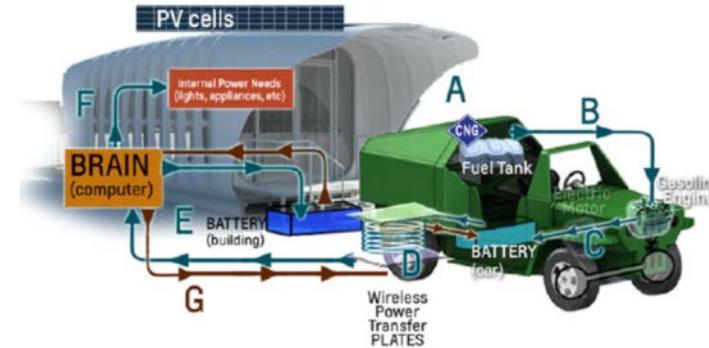


3D-printed Shelby Cobra

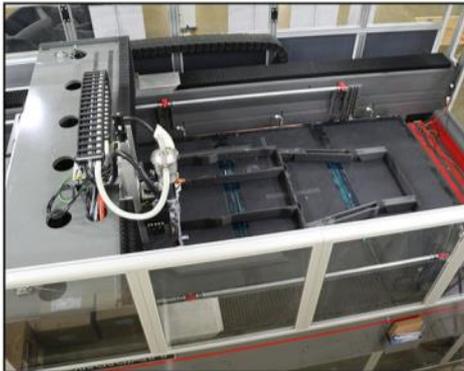
Modified atmospheric insulation



Integrated energy control



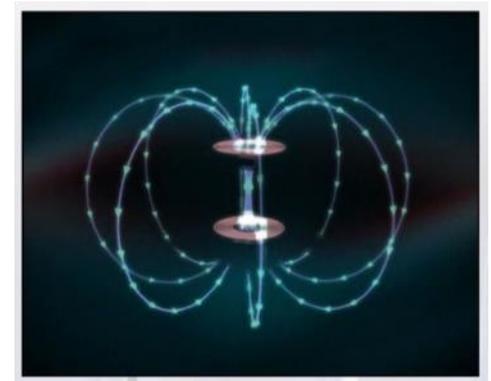
Big area additive manufacturing



Secondary use battery storage



Bi-directional wireless power transfer

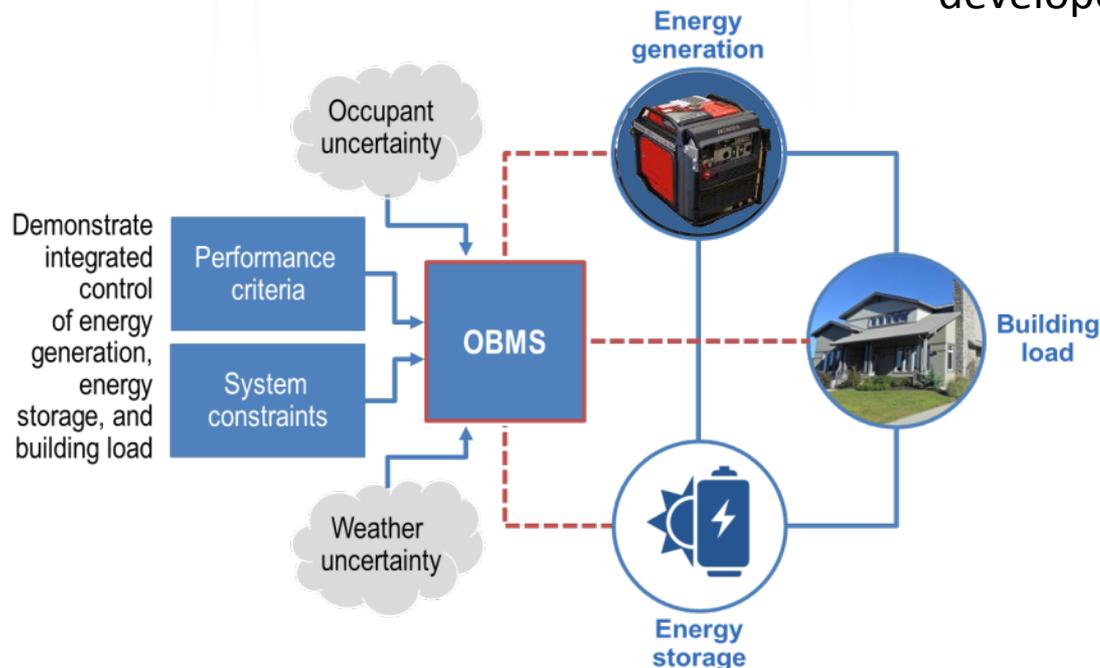


Transforming energy generation, storage, and distribution

Houses and vehicles have always been powered by separate energy sources—until now

AMIE provides an integrated solution for powering both a vehicle and a house

Energy flows both ways— from vehicle to house, from house to vehicle—through wireless technology developed at ORNL



Delivering innovation in clean, renewable energy

Integration of energy systems (PV, EV batteries, building, power grid) using advanced building control and power management strategies enables maximum use of renewable energy

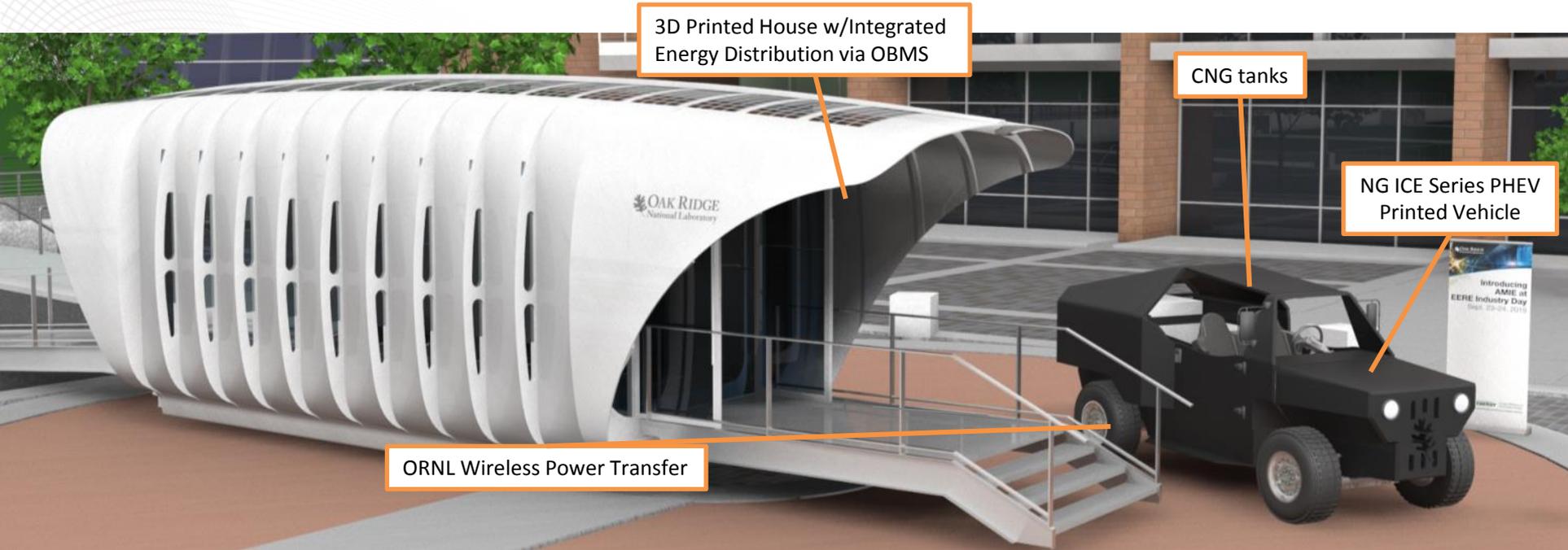
- On sunny days: PV system may meet most power needs
- At night or on cloudy days: House occupants can use electricity generated by the vehicle, stored in batteries, or provided by grid
- When electricity is plentiful: Vehicle battery can be recharged

Fitted with an advanced power control system and scaled up, this concept can support electricity needs worldwide

- Offset power supply disruptions
- Provide a self-contained off-grid system



Initial IES Demo – Connected printed building and vehicle via series plug-in hybrid NG concept with wireless power transfer from vehicle to building



Establishes flexible framework for evaluating/ developing new ways to integrate building/vehicle energy systems with industry partners

- Research into the optimal ways to integrate buildings/vehicles on both energy use and lifecycle
- Roadmap for research projects using various energy conversion system under development



Stirling HEG with QNERGY



MAHLE REX



High Efficiency ICE with Honda



AI-AIR Battery with Alcoa

