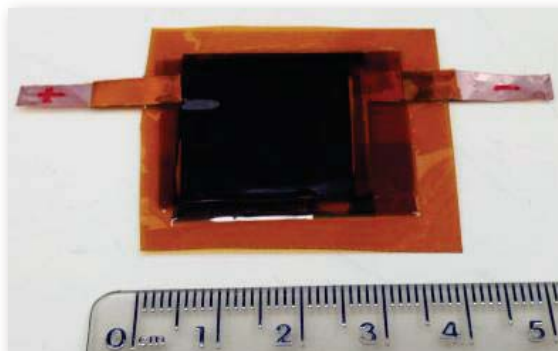


# Flexible Graphene-Based Energy Storage Devices For Space Application Project

Center Innovation Fund: KSC CIF Program

Space Technology Mission Directorate ( STMD )

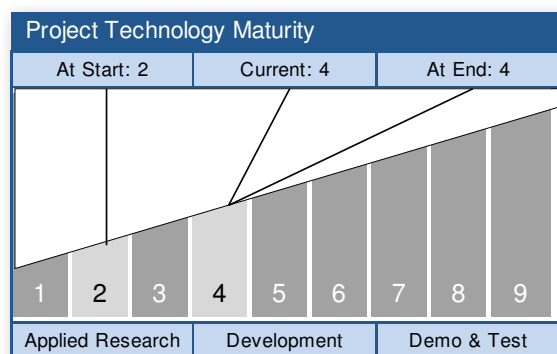
National Aeronautics and  
Space Administration



## ABSTRACT

Develop prototype graphene-based reversible energy storage devices that are flexible, thin, lightweight, durable, and that can be easily attached to spacesuits, rovers, landers, and equipment used in space.

*Thin film graphene ultracapacitor prototype made at KSC*



Technology Area: Space Power & Energy Storage TA03 (Primary)  
Nanotechnology TA10 (Secondary)

## ANTICIPATED BENEFITS

### To NASA funded missions:

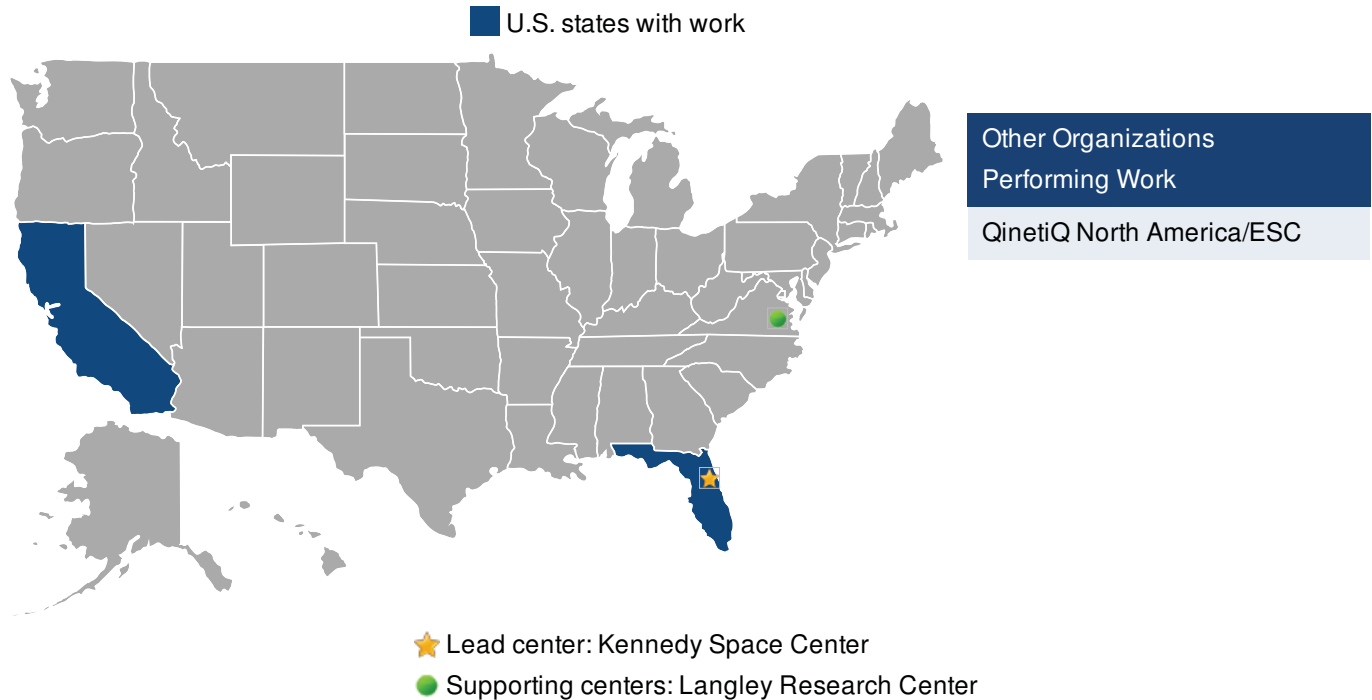
Crew exploration missions, habitats, planetary probes, rovers and landers, orbiters, life support systems will benefit from these revolutionary devices

There is a clear and stated need for such flexible, lightweight and low volume batteries for commercial and military applications. Applications include rugged batteries for smart phones, energy storage for solar panels, and wearable batteries.

### To NASA unfunded & planned missions:

Crew exploration missions, habitats, planetary probes, rovers and landers, orbiters,...

Read more on the last page.



## DETAILED DESCRIPTION

Develop prototype graphene-based reversible energy storage devices that are flexible, thin, lightweight, durable, and that can be easily attached to spacesuits, rovers, landers, and equipment used in space. These graphene-based devices can store energy as well as deliver energy with much faster charging cycles than batteries. They can provide power to spacesuit life support subsystem modules and to portable electronics as well as to equipment on rovers and landers. These devices can also power “smart” garments and wearable electronics for civilian and military use on Earth.

Several methods for the production of graphene have been developed in recent years. The most promising techniques for the production of high-quality bulk graphene-based devices begin with graphite oxide (GO). Several methods to reduce GO have been developed, including chemical, thermal, and flash reduction. Not all of these methods produce high quality graphene and the ones that do, use relatively expensive equipment. A new and inexpensive solid state method developed by this proposal’s co-investigator at UCLA produces high...

### MANAGEMENT

**Program Director:**  
John Falker

**Program Executive:**  
Karen Thompson

**Program Manager:**  
Nancy Zeitlin

**Project Manager:**  
Nancy Zeitlin

**Principal Investigator:**  
Carlos Calle

**Co-Investigators:**  
Richard Kaner Paul Mackey

## DETAILED DESCRIPTION (CONT'D)

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quality graphene films with a surface area of 1500 m<sup>2</sup>/g, which is much larger than that reported for thermally or chemically converted graphene. Oxygen reduction with this method reaches much higher values than the more widely used chemical reduction method. These graphene sheets are mechanically strong, have high electrical conductivity, and can be used directly as electrodes in energy storage devices. This form of graphene is potentially useful for ultracapacitors with remarkable energy and power densities.

A new experimental setup for the reduction of GO based on the UCLA laser-scribed graphene (LSG) method was designed at the KSC laboratory. This new method uses a diode pumped laser system with tunable power and short wavelengths. After a few months of optimization, the method successfully produced high quality graphene electrodes. This process results in graphene with a reduction level that is superior to traditional methods for the reduction of GO. This low oxygen content is required for building durable supercapacitors.

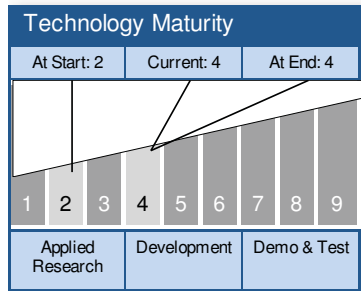
XPS analyses of the graphene sheets that we have produced show that the carbon content of the films ranges from 96% to 98.5% while the oxygen content is in the range of 1.4% to 3%. By comparison, more widely used chemical reduction methods reduce oxygen content to 10% or higher. The carbon and oxygen content of the unreduced graphene oxide ranges between 66% to 70% and 29% to 32% respectively.

Graphene electrode sheets were made into solid squares for parallel-plate laser-scribed electrochemical capacitors (LSG-EC). LSG-ECs were driven through multiple charge/discharge cycles at the UCLA laboratory. The devices lose only about 3% of its capacitance after 10,000 cycles. The shelf life of these devices was also measured. The capacitance of these devices is retained after 120 days.



## TECHNOLOGY DETAILS

### Flexible Graphene-Based Energy Storage Devices for Space Application



### TECHNOLOGY DESCRIPTION

- Develop prototype graphene-based reversible energy storage devices that are flexible, thin, lightweight, durable, and that can be easily attached to spacesuits, rovers, landers, and equipment used in space. These graphene-based devices can store energy as well as deliver energy with much faster charging cycles than batteries. They can provide power to spacesuit life support subsystem modules and to portable electronics as well as to equipment on rovers and landers. These devices can also power “smart” garments and wearable electronics for civilian and military use on Earth.
- This technology is categorized as a hardware assembly for other applications
- Technology Area
  - TA03 Space Power & Energy Storage (Primary)
  - TA10 Nanotechnology (Secondary)

### CAPABILITIES PROVIDED

Graphene-based reversible energy storage systems have shown performances that surpass those of conventional batteries. Current performance of UCLA prototypes show superior performance to thin film high-power Li-ion batteries. However, unlike conventional batteries, these graphene-based devices are flexible, extremely thin and lightweight, and can be incorporated on astronaut garments and equipment without adding appreciable weight or bulk to the spacesuit. Graphene-based batteries will substantially reduce NASA payloads mass and volume, resulting in simpler designs and cost reductions.

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Performance Metrics		
Metric	Unit	Quantity
Power density	Wh/kg	50
Energy density	Wh/kg	50

## TECHNOLOGY DETAILS

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### **POTENTIAL APPLICATIONS (CONT'D)**

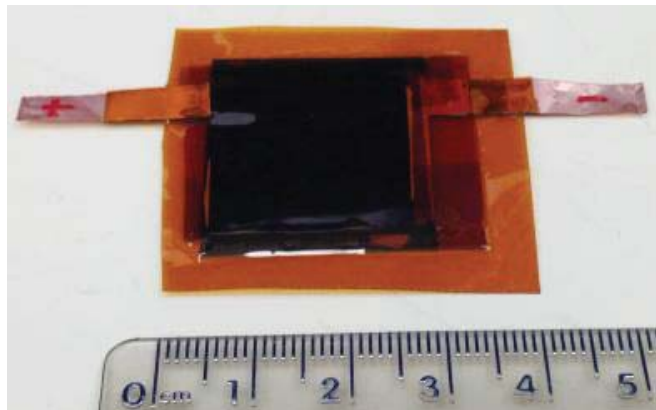
Crew exploration missions, habitats, planetary probes, rovers and landers, orbiters, life support systems will benefit from these revolutionary devices

There is a clear and stated need for flexible, lightweight and low volume ultracapacitors for commercial and military applications. Applications include rugged energy storage devices for smart phones, energy storage for solar panels, and wearable devices.



## IMAGE GALLERY

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Thin film graphene ultracapacitor prototype made at KSC

## ANTICIPATED BENEFITS

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### **To NASA unfunded & planned missions: (CONT'D)**

life support systems will benefit from these revolutionary devices

There is a clear and stated need for such flexible, lightweight and low volume energy storage devices for commercial and military applications. Applications include rugged energy storage devices for smart phones, energy storage for solar panels, and wearable devices.

### **To other government agencies:**

There is a clear and stated need for such flexible, lightweight and low volume energy storage devices for commercial and military applications. Applications include rugged energy storage devices for smart phones, energy storage for solar panels, and wearable devices

### **To the commercial space industry:**

Flexible, light weight, durable, low volume, high energy density and high power density energy storage devices will also benefit the commercial space industry.

### **To the nation:**

The nation commercial and government agencies will benefit from advanced energy storage devices such as the ones being developed under this project. More efficient and capable energy storage benefits the automotive, electronic, communications, and many other industries.

