



# Low Power Microrobotics

Utilizing Biologically Inspired Energy Generation

(6 month review)

Gregory P. Scott (PI)

Leonard Tender

Stephen Arnold

Naval Research Laboratory

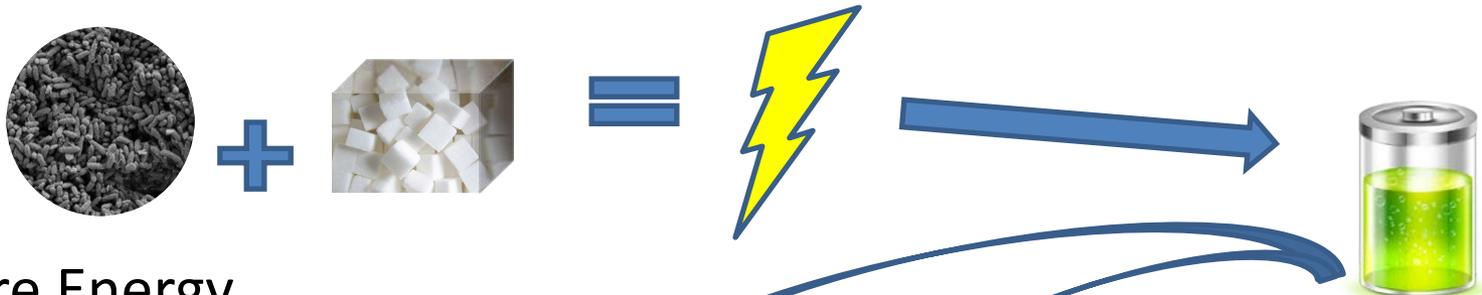
# The Storyline

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- You're doing what!?
- Who's doing this?
- What is this all about?
  - The Microbial Fuel Cell
  - Low Power Electronics
  - Bio-inspired Locomotion
- Where are you now?
- What's next?

# Project Overview

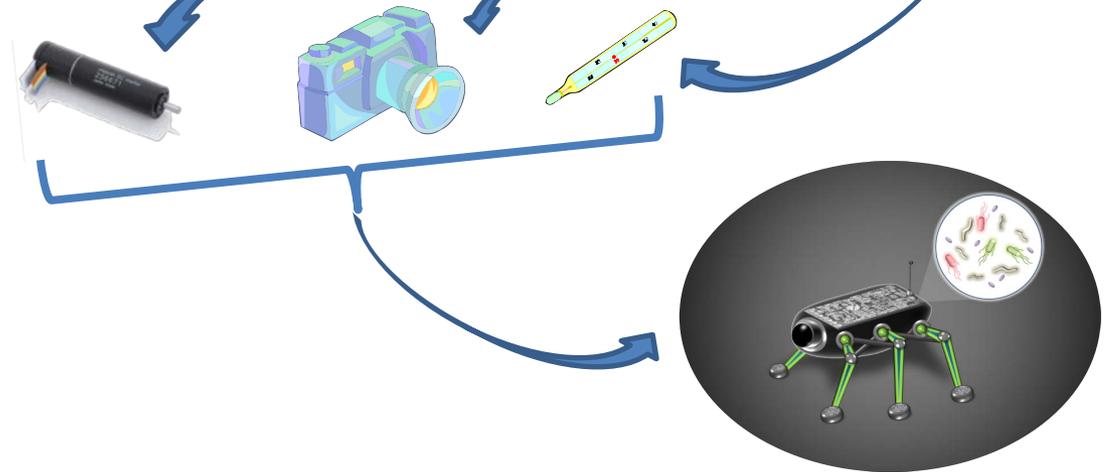
- Create Electricity



- Store Energy

- Power Systems

- Put it all together





# The Naval Research Lab (NRL)

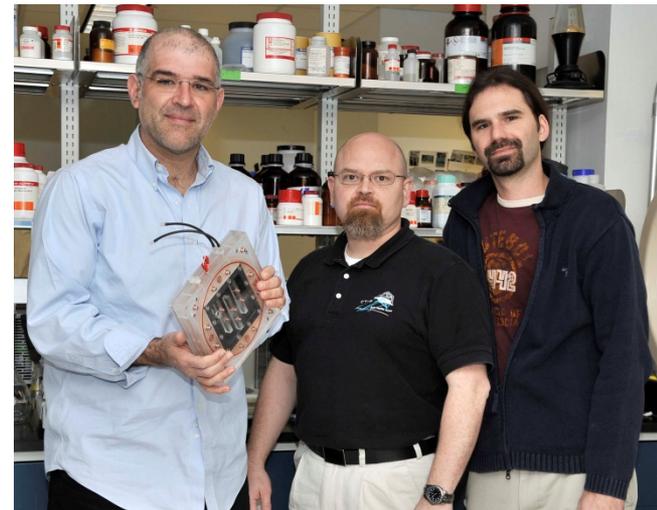
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- Spacecraft
  - Developing spacecraft for the DoD since 1960s, 100 launched to date.
  - Developed GPS, 1<sup>st</sup> full lunar mapping (Clementine), 1<sup>st</sup> Recon. satellite
- Robotics
  - >\$30M in research funding towards FRENDD-related tech.
  - Expanding into micro-vehicle, CubeSat manipulators, etc.
- MFCs
  - >\$4M in “waste-to-energy” research funding since 2000
  - 1<sup>st</sup> practical application of an MFC – meteorological buoy

# NRL Investigators

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- Dr. Gregory P. Scott (PI) – *Space Robotician*
  - Project Integration
  - Locomotion and Mechanical Sub-Systems
- Dr. Leonard Tender – *Microbial Electro-chemist*
  - Microbial Fuel Cell Development
  - Energy Generation Sub-System
- Dr. Stephen Arnold – *Computer Scientist*
  - Control System Development
  - Electrical Sub-System



# Project Breakdown

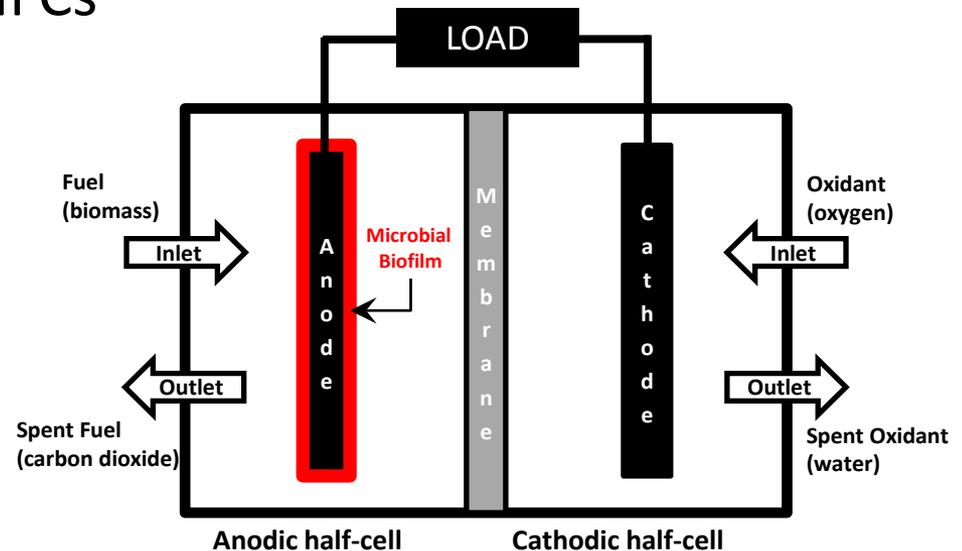
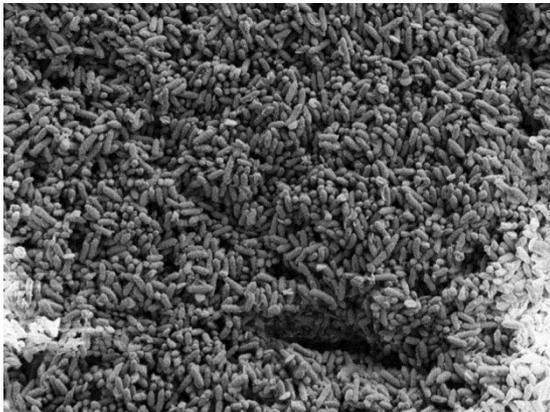
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- Three primary research areas:
  - The Microbial Fuel Cell
  - Low Power Electronics
  - Bio-inspired Locomotion
- Project objective:
  - **NOT** to have a full working robot!
  - **IS** to improve capabilities of each individual system, with reliance on every other system
  - **IS** to link 3 independent sub-systems into a single test system

# Project Breakdown

## *Microbial Fuel Cell Theory*

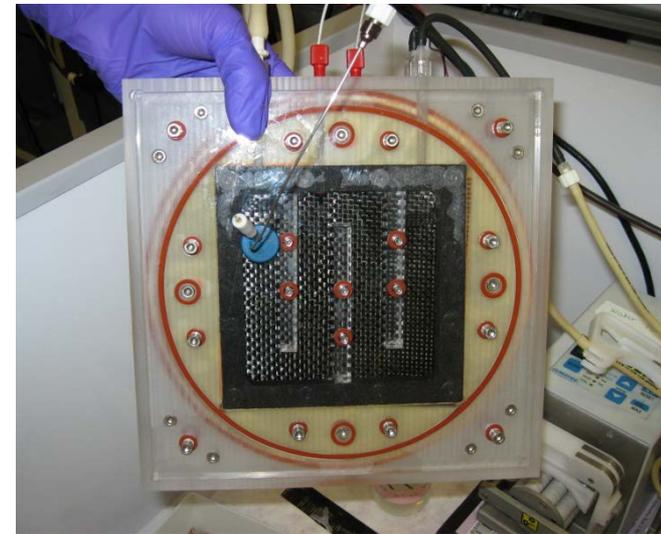
- MFC – fuel cell that uses microbes to generate energy
- High energy density: 14,600 kJ per 1 kg of acetate (sugar)
  - ~11x lithium battery (1,300 kJ/kg)
  - ~10x hydrogen-oxygen fuel cell (1,290 kJ/L H<sup>2</sup> at 2000 psi) {converted}
- Sediment vs. pure culture MFCs



# Project Breakdown

## *Microbial Fuel Cell Development*

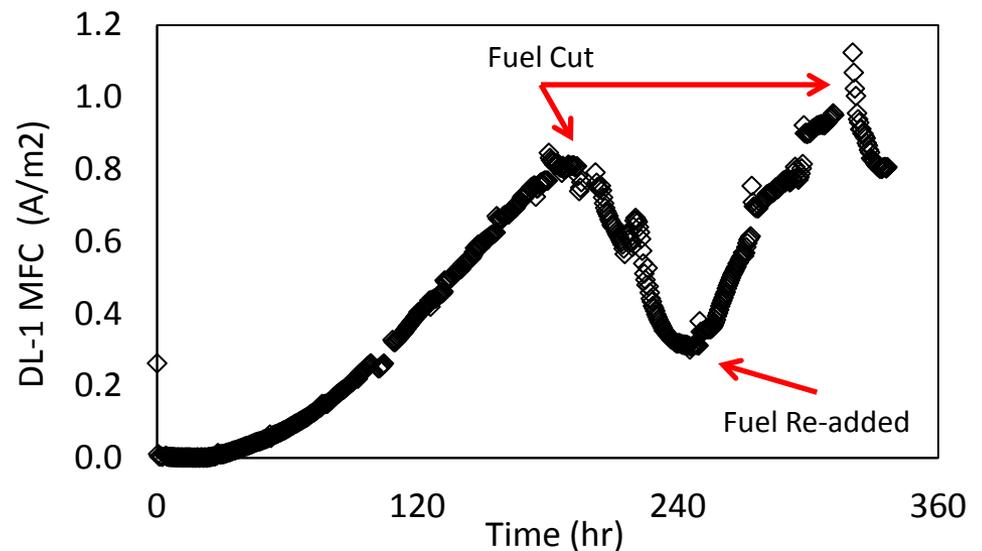
- Same concept as the NASA-developed hydrogen fuel cell
- Research-grade pure-culture prototype MFC
  - 0.2 L total volume (0.1 L in each chamber)
- Core energy generation:
  - Carbon fiber anode, permeable membrane, carbon fiber cathode
  - All compressed together to minimize separation and improve efficiency
  - Membrane causes high internal resistance which lowers output V
  - *Geobacter sulfurreducens* (DL-1 strain)
    - breaks down biomass (sugar) at anode
    - results in CO<sub>2</sub>, H<sup>+</sup> and e<sup>-</sup>



# Project Breakdown

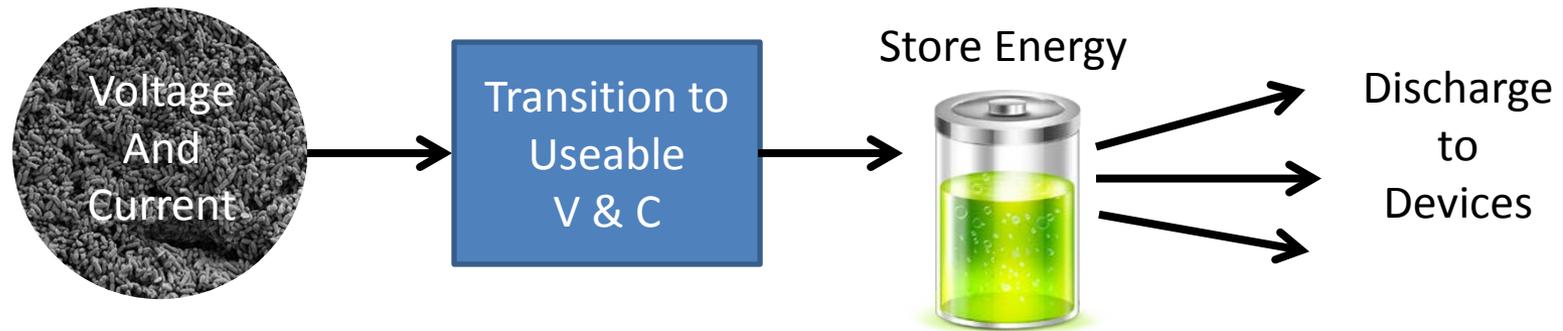
## *Microbial Fuel Cell Status*

- Prototype MFC built and inoculated
- Output power (single cell):
  - Inoculation period of 2-4 weeks
  - Then  $\sim 0.35$  V max,  $\sim 2$  mW continuous output
- Ongoing tests: pure culture *Geobacter* vs. waste water
- Power conditioner to upscale voltage to usable quantity
  - ... onward to the electrical system...



# Project Breakdown

## *Electrical System Theory*



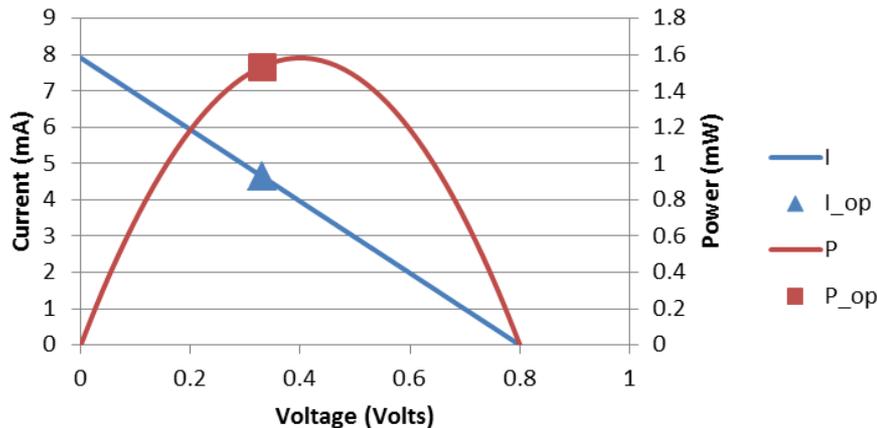
- MFC voltage is very small ( $\sim 0.35\text{V}$ )
- Must be increased to a usable value and stored
- Energy storage methods investigated
- Energy discharged as needed, once available

# Project Breakdown

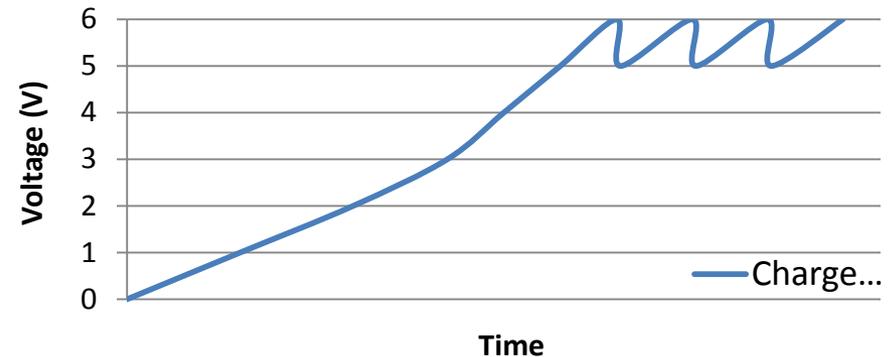
## *Electrical System Development*

- MFC direct output simulated as input to the electrical system
- Key focus area – time to charge and discharge super-capacitor
- Goal – time for charge/discharge to determine movement capability

### Power and Current vs. Voltage



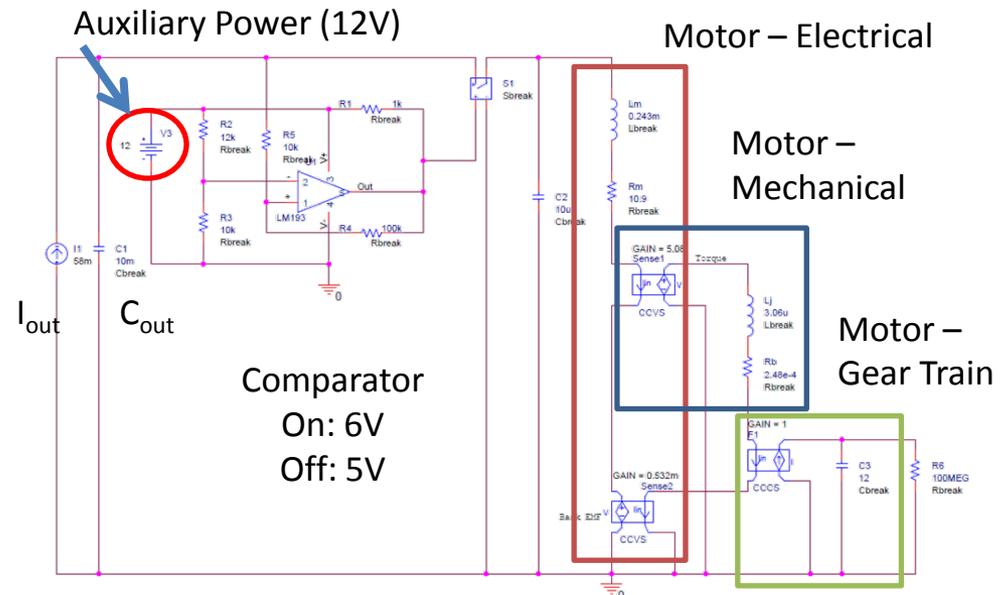
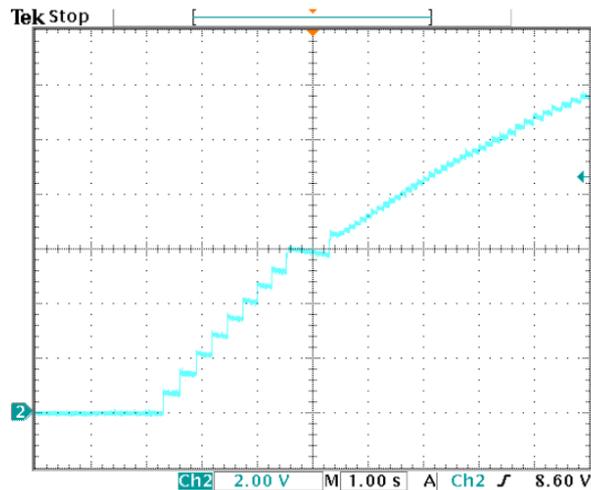
### Charge-Discharge Theory



# Project Breakdown

## Electrical System Status

- Expected MFC voltage and upcharge circuit to 12V simulated
- Charge/discharge capability of various supercaps simulated
- Locomotion mechanism energy requirements simulated
  - ... onward to the locomotion system...



# Project Breakdown

## *Locomotion System Theory*

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- Mechanism design requirements:
  - Vehicle must traverse asteroid terrain (rocky, low gravity)
  - ~1mW electrical input, 12V max step input from super capacitor
  - Minimize moving parts and actuators
  - Low activation cost (mechanical or electrical)
- Focus on biological systems for inspiration
- Considerations:
  - Bi-stable mechanism
  - Single geared motor actuation
  - Offset motor vibration
  - Flagellum-like movement

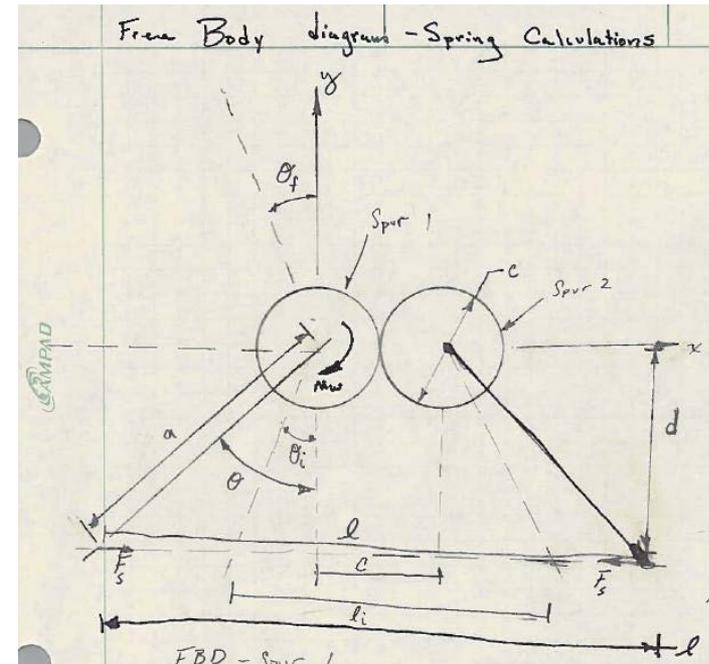
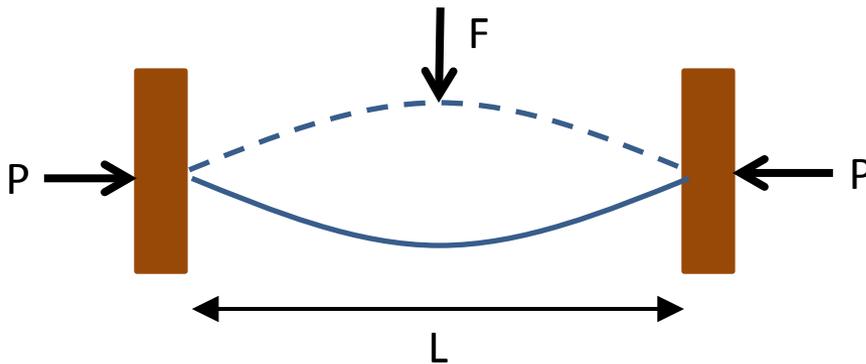


Asteroid EROS 433 Surface (from NEAR Mission)

# Project Breakdown

## *Locomotion System Development*

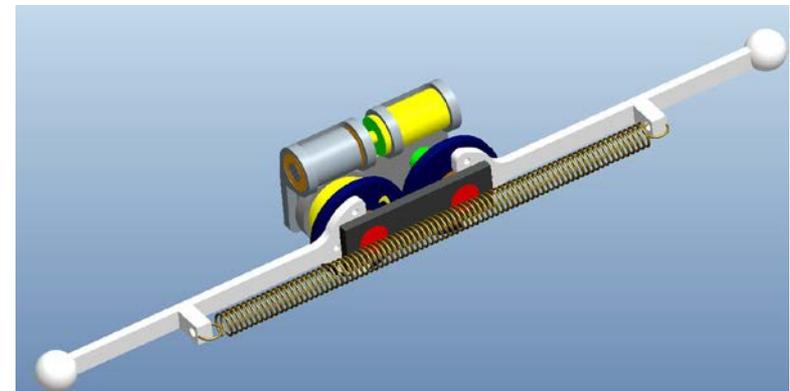
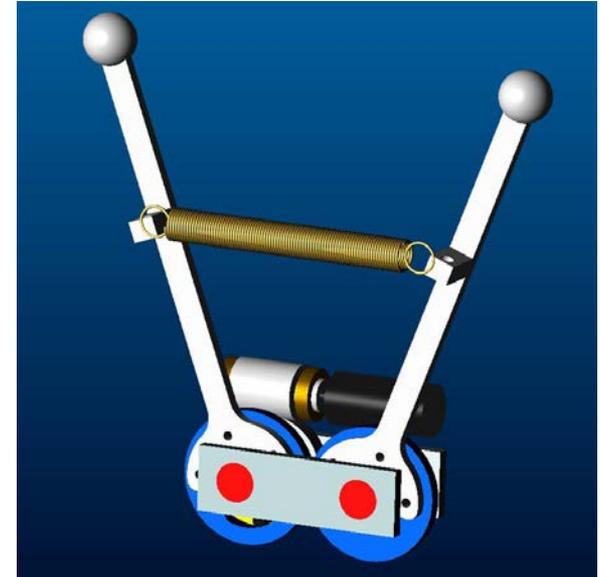
- Benchmarked hopping mechanism
  - Bi-stable, spring-loaded actuation
  - Actuator slowly builds up mechanical potential energy
  - Mechanism snaps into place at maximum potential
  - Snapping induces hopping motion
  - Single actuator for system simplicity



# Project Breakdown

## *Locomotion System Status*

- Mechanism designed in CAD
- Motor and gears modeled for system accuracy
- Simulation developed to model mechanism energy requirements



<b>Motor Rotation</b>		
Time of Discharging	0.06	s
Speed of motor	5000	rpm
Motor Rotations	300	rev
Gear box Reduction	67	:1
Worm Wheel Reduction	50	:1
Number of Teeth of worm wheel rotated	0.090	
Total number of discharges to actuate	217	
Time to charge	180	s
<b>Total Time to Actuate</b>	<b>651</b>	<b>minutes</b>
	<b>10.86</b>	<b>hours</b>



# Overall Project Status

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- All sub-system developments are progressing well
- Simulation of full system (MFC to electronics to actuator) complete
- Results show significant actuator inefficiencies – some re-development required
- Individual sub-system testing and refinement underway
- Press coverage – Wired, Popular Science, Space.com, ABC local news broadcast, international science radio shows, and more...

# Future Work

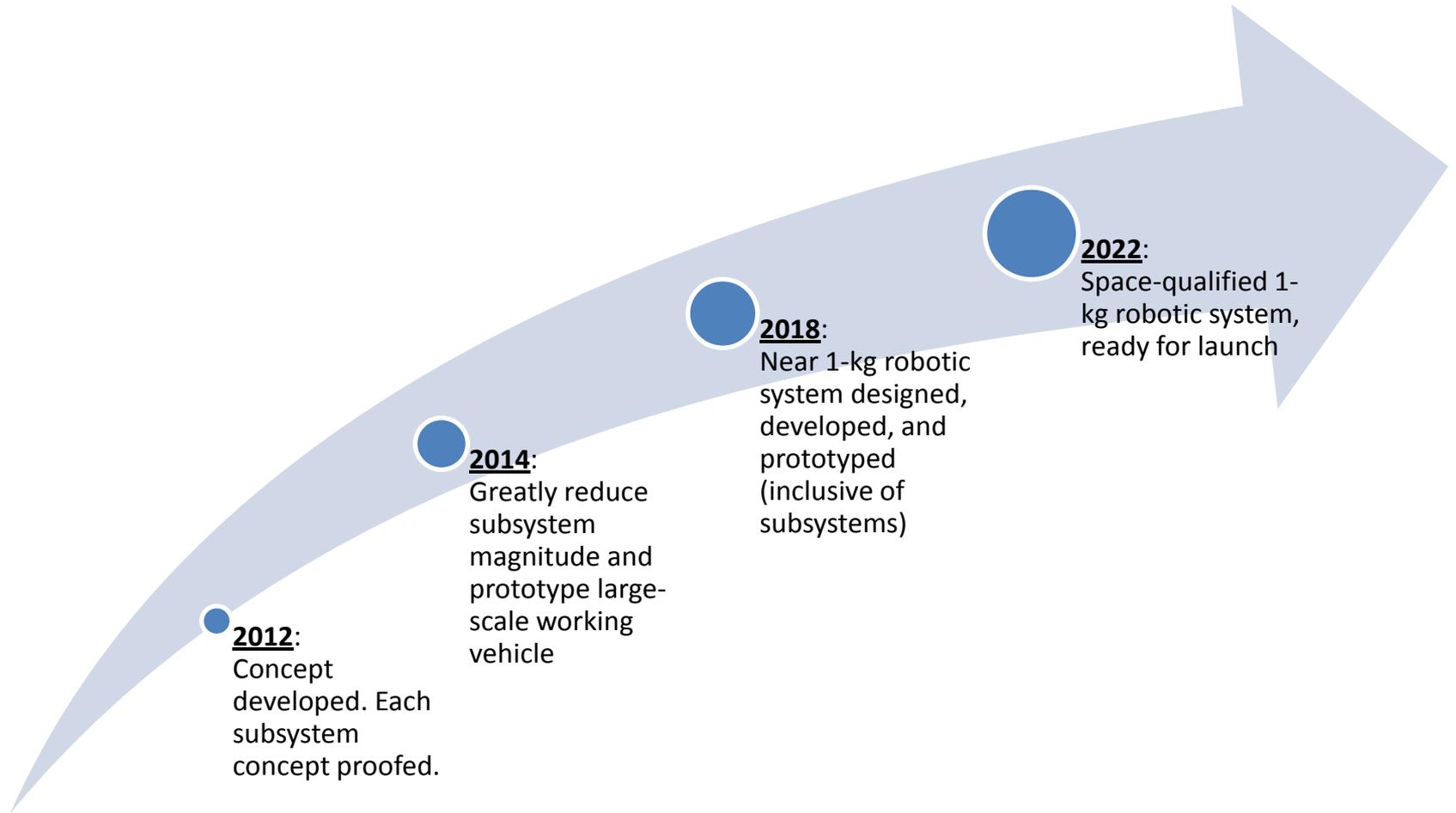
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- Benchmark MFC capabilities
- Complete breadboard electronics (based on MFC)
- Prototype locomotion mechanism
- Test individual sub-systems
- Perform benchtop test of systems working together
- Define approaches to:
  - Improve efficiency, reduce size/volume, and better integrate systems.
- Complete Phase II proposal and final report



# Future Work

## 10-year timeline





# Conclusions

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- The team has been successfully progressing with the project.
- The project is on schedule for a bench-top demonstration of the individual subsystems working in unison for July 2012.
- We are all excited about our success to-date and are looking forward to more in the near future.

# Questions

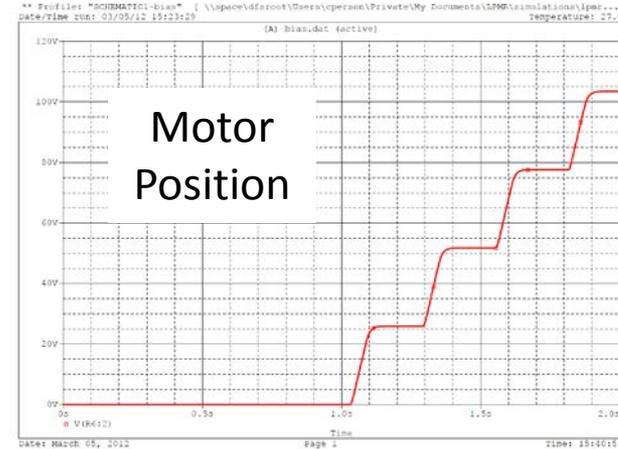
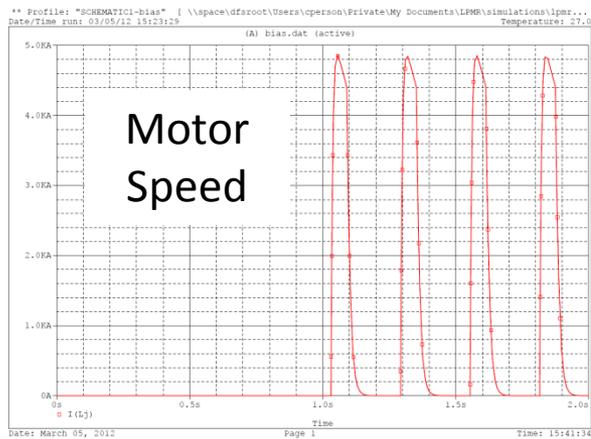
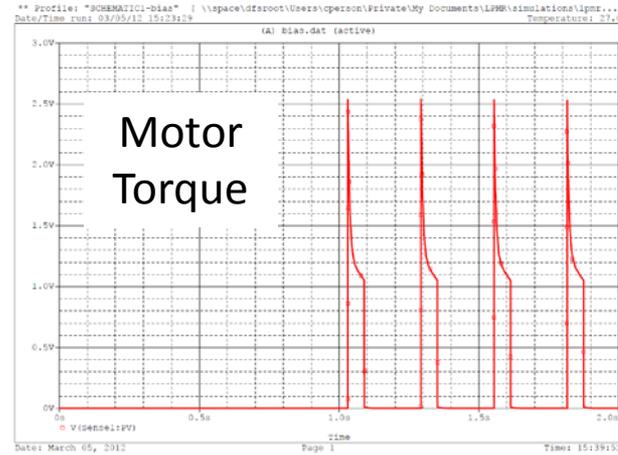
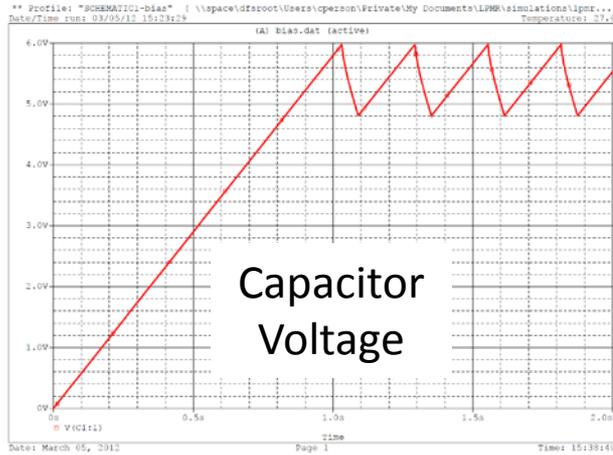
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Thank you for your attention!

Are there any questions?

# Backup – Motor Sim Results



# Backup – Energy Storage Tech

