
# "Electroactive Polymer Artificial Muscle – A Polymer Based Generator?"

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# Outline

- AMI History
- What we do
- Development milestones
- How it works
- Key benefits
- Key advantages
- Potential electrical power generation
- Summary
- Acknowledgements

# Who We Are

- **AMI History**
  - Founded as an independent company in 2003
  - Spun-out of SRI to commercialize electro-active polymer artificial muscles (EPAM™)
  - $25M of funded development over ~ ten years
  - Located in Sunnyvale, CA
  - ~ 50 Employees

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# What We Do

- **New class of OEM *smaRTMOVE™* actuators, generators, and sensors for the consumer, medical, and industrial markets.**
- **This proprietary *smaRTMOVE™* (EPAM) technology meets the growing *market needs* for:**
  - Reduced power consumption
  - Higher mobility
  - Improved safety and reliability
  - Quieter operation
  - Fewer mechanics
  - Lower cost

***EPAM will do to actuators what semiconductors did to vacuum tubes***

# Development Milestones

- **1960's** – Japanese researchers identify first electro-active polymers (EAP), based on ionic gels, considered a scientific curiosity
- **1990's** – DARPA funds $10M's for advanced actuator research, leads to piezo, shaped memory alloy and EAP development
  - SRI researchers, led by Ron Pelrine, develop dielectric elastomer Electroactive Polymer Artificial Muscle (EPAM) using commonly available silicone and acrylic polymers, solving many of the technical and cost issues associated with wet, expensive materials used in ionic EAPs
- **2001** – 1st of more than 30 EPAM patents issued
- **2003** – Artificial Muscle Inc. founded by 3 SRI researchers to commercialize EPAM
- **2004** – AMI Product development initiated, EPAM development kits shipped to more than 20 companies
- **2005-07** – AMI product development achievements:
  - High-performance silicone material developed
  - Diaphragm Actuator product platform applicable to many product opportunities introduced
  - Low-cost drive electronics engineered
  - High-volume electrode printing process and inks developed
  - Announced 1st product for camera lens A/F actuator & trials begin with leading camera module suppliers, OEMs and handset mfg's.
  - Secondary products developed: micro pump for medical markets; dynamic valve for industrial markets;
  - AMI enters into manufacturing agreement to supply production needs
- **2008 – 1st Product launch, Mfg. scale-up, product revenues**

# Electroactive Polymer Artificial Muscle, EPAM

- **An EPAM device is composed of:**
  - A parallel plate capacitor comprised of:
    - a thin film elastomeric dielectric that has been pre-strained
    - Conductive conformable electrodes
- **The device is activated by:**
  - Applying an electrical charge to the electrode that creates an electrical field in the dielectric
  - The charged dielectric thins due to Maxwell Force causing an increase in the film's area
  - The resultant increase in Cartesian area is captured and converted to Z-Axis motion using AMI's patented design

# How it works… think of a flexible capacitor

- AMI's EPAM technology relies on the ability of our device to perform work in the form of "stroke". Stroke is governed by the following approximation for the film used:

$$\text{Stroke} \approx \frac{\varepsilon_o \times \varepsilon_s \times E^2}{Y},$$

Where:

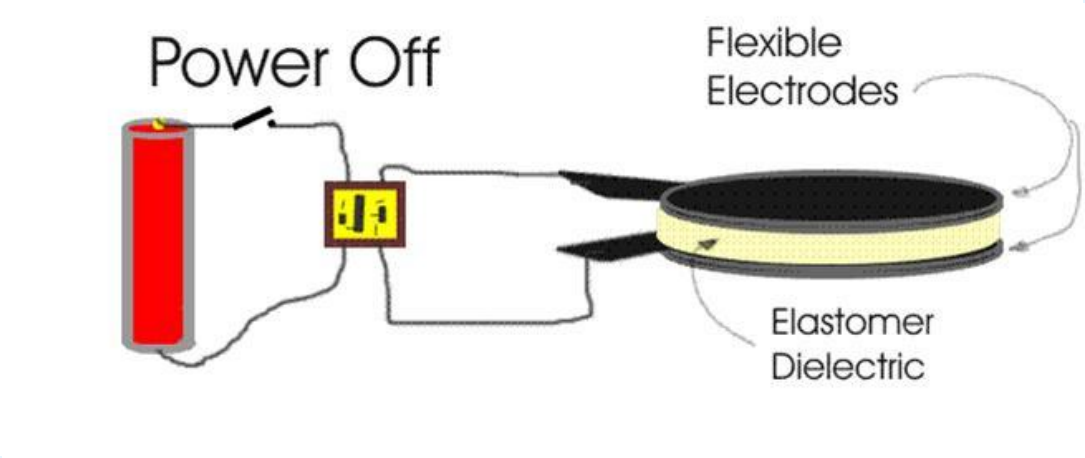
$\varepsilon_o$ = Permittivity of air

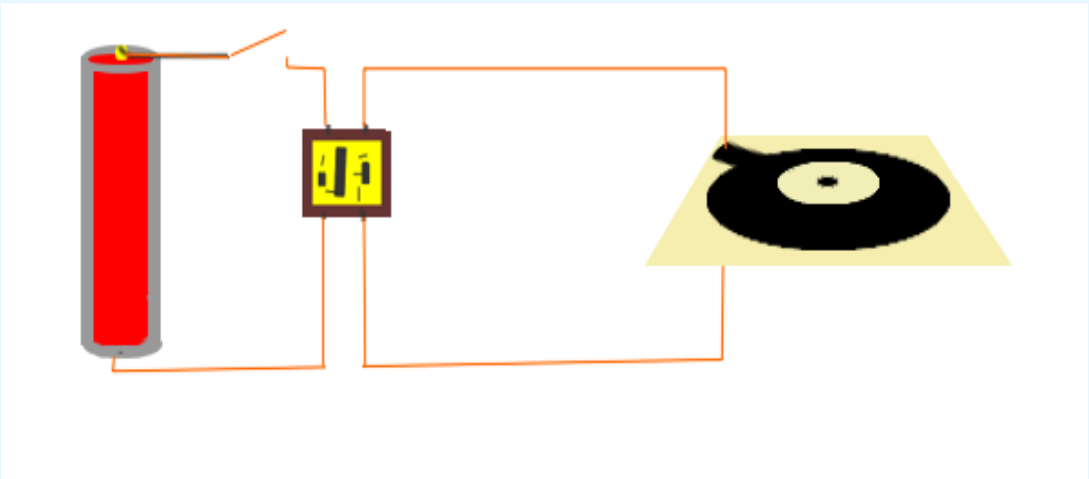
$\varepsilon_s$ = Dielectric Constant

E = Electric field or operating voltage/thickness

Y = Young's Modulus

# How it works… think of a flexible capacitor



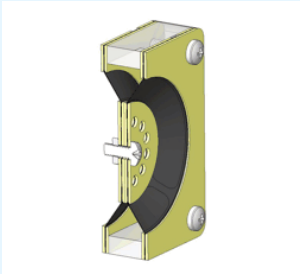
CLICK UMA TO ANIMATE

# Key Benefits of *smaRTMOVE*™

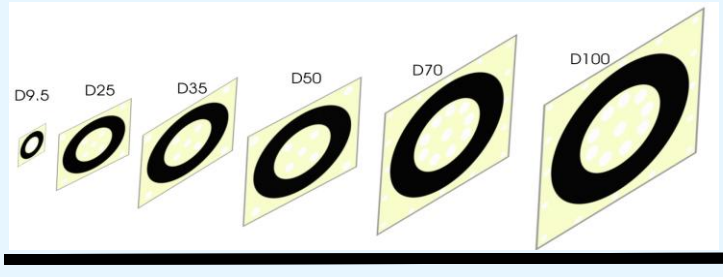
- **The new *smaRTMOVE* technology platform enables a new class of products which are:**
  - Energy efficient
  - Inexpensive
  - Lightweight
  - Small and quiet
- **These new products:**
  - Generate little heat
  - Produce no magnetic fields
  - Have a broad frequency response
  - Provide direct drive

***smaRTMOVE technology will replace traditional electromechanical motion***

# Single Platform UMA



Universal Muscle Actuator™



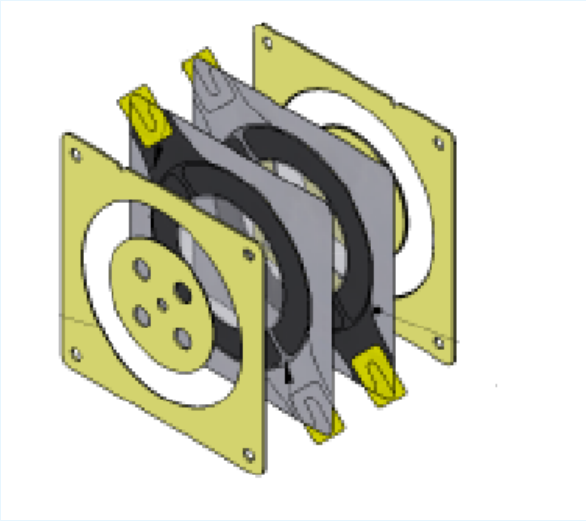

**Lens Positioners Valve Actuators Pump Actuators Power Generation**
**Sensors Smart Seals Acoustic Speakers**

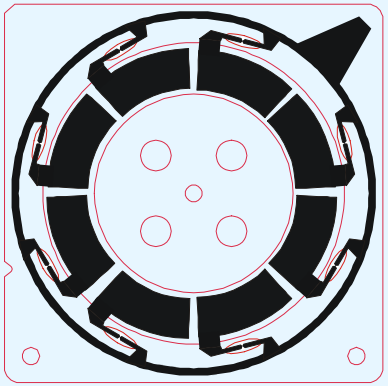
- **Universal Muscle Actuator (UMA)**
  - Addresses 75% of current applications
  - Patented Double Diaphragm Platform
- **Scalable performance parameters**
- **Scalable physical size (mini to macro)**
- **Simple manufacturing process**
  - 2-D flat film manufacturing process
  - Multiple configurations can be easily “printed”

***Addresses 75% of current applications***

# Technology is Scalable and Configurable

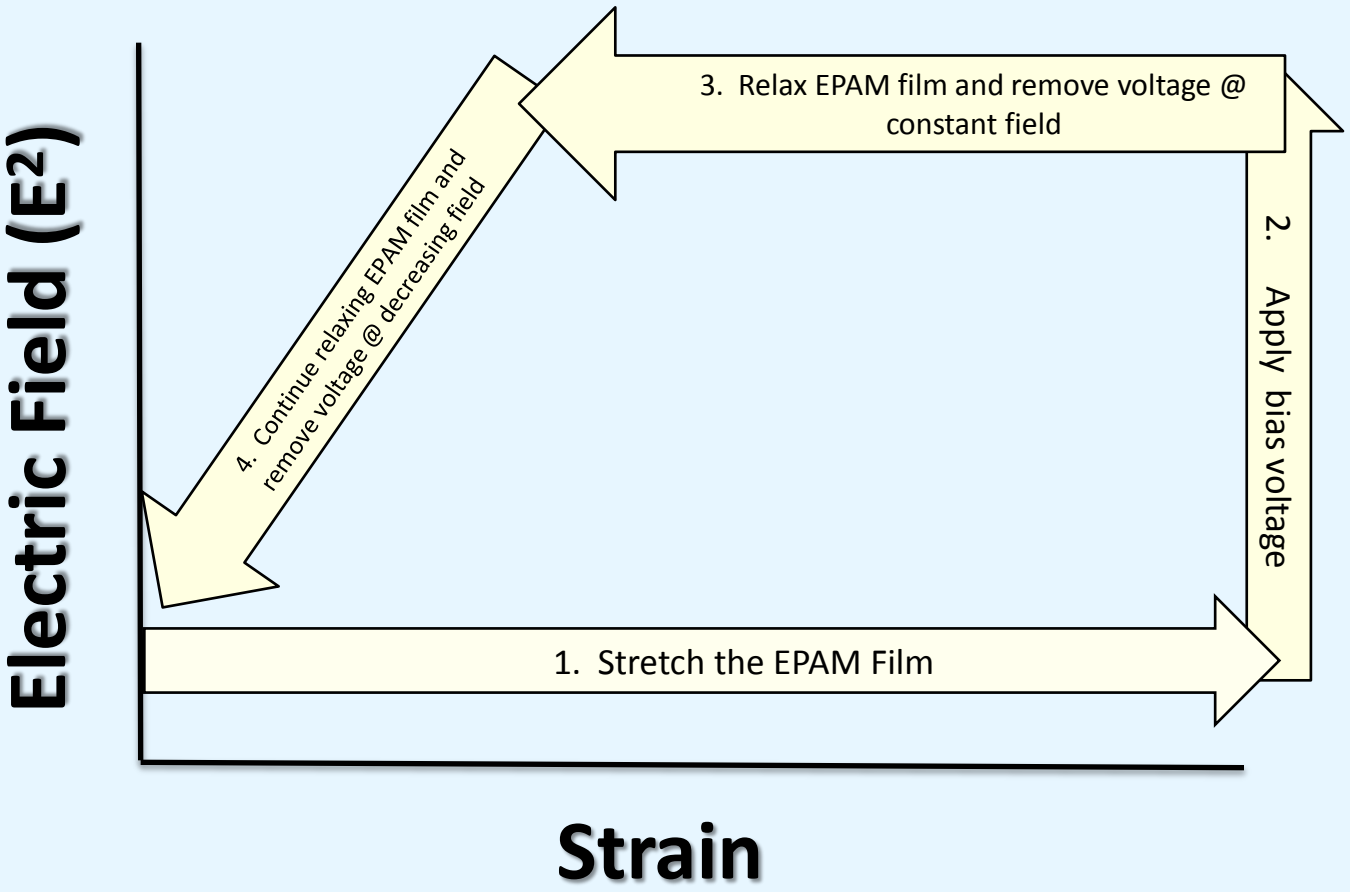
- Extremely Flexible Design
- Displacement and stroke scale with size
- Force scales linearly with number of layers
- Patterned electrodes enables complex movement





***Flexible, Scalable and Configurable***

# The Energy Production Cycle



# How it works…

$$C_i = \varepsilon_o \times \varepsilon_r \times \frac{A_i}{d_i} = 400nF$$

$$C_s = \varepsilon_o \times \varepsilon_r \times \frac{A_s}{d_s} = 1600nF$$

$$C_s \times V_s = Q_s = Q_i = C_i \times V_i$$

$$A_V = \frac{V_i}{V_s} = \frac{C_s}{C_i}$$

$$A_E = \frac{0.5 \times C_i \times V_i^2}{0.5 \times C_s \times V_s^2} = \frac{C_i \times V_i \times V_i}{C_s \times V_s \times V_s} = \frac{V_i}{V_s}$$

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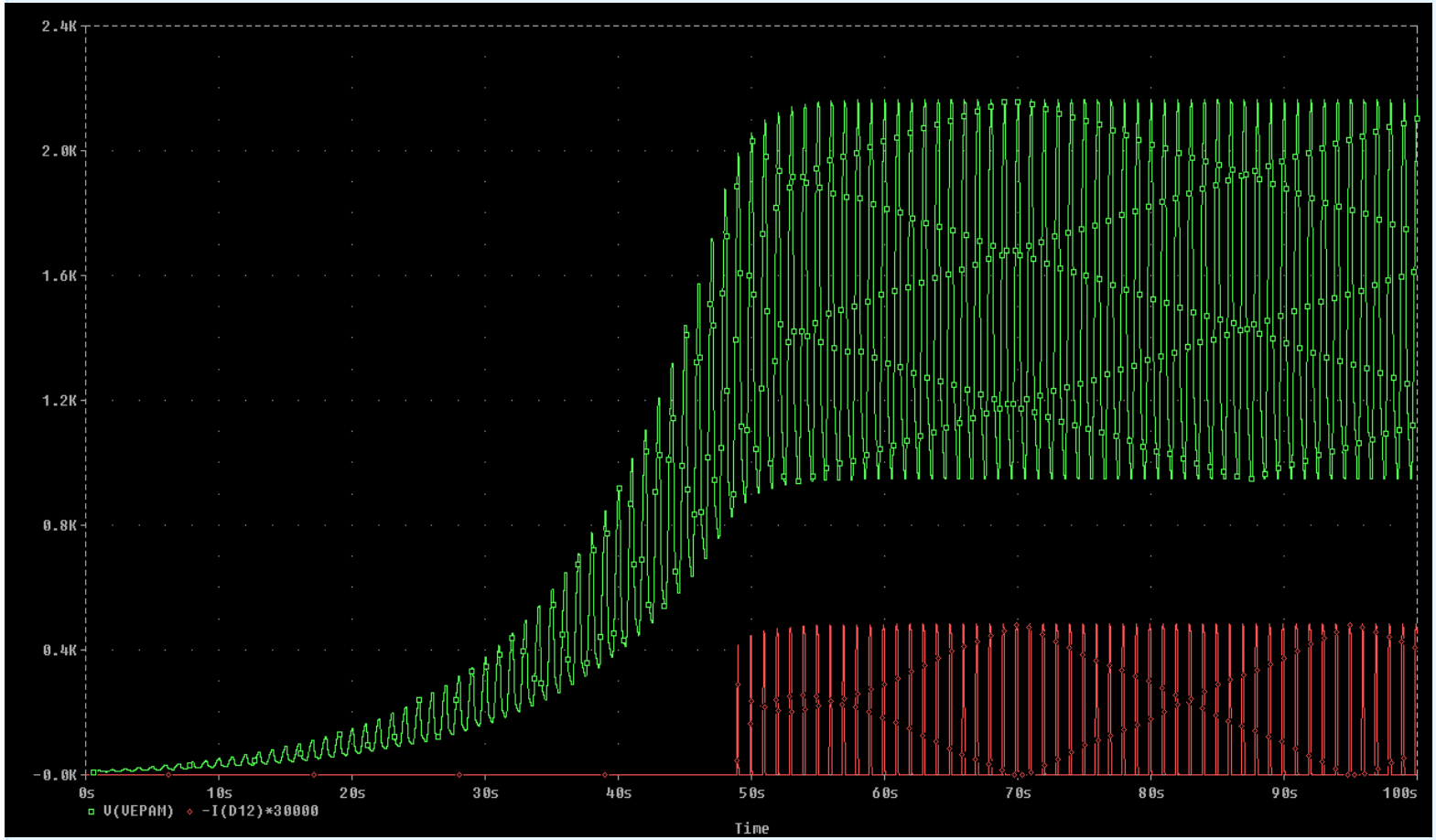
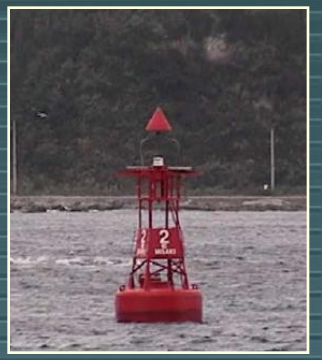
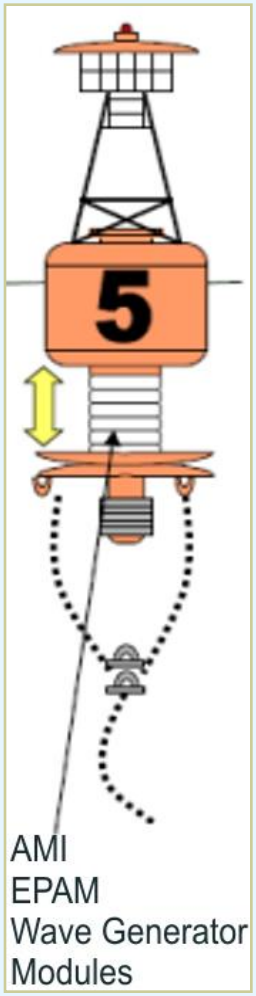
# Simulation Results of EPAM Generator



# License – Wave Power Generation

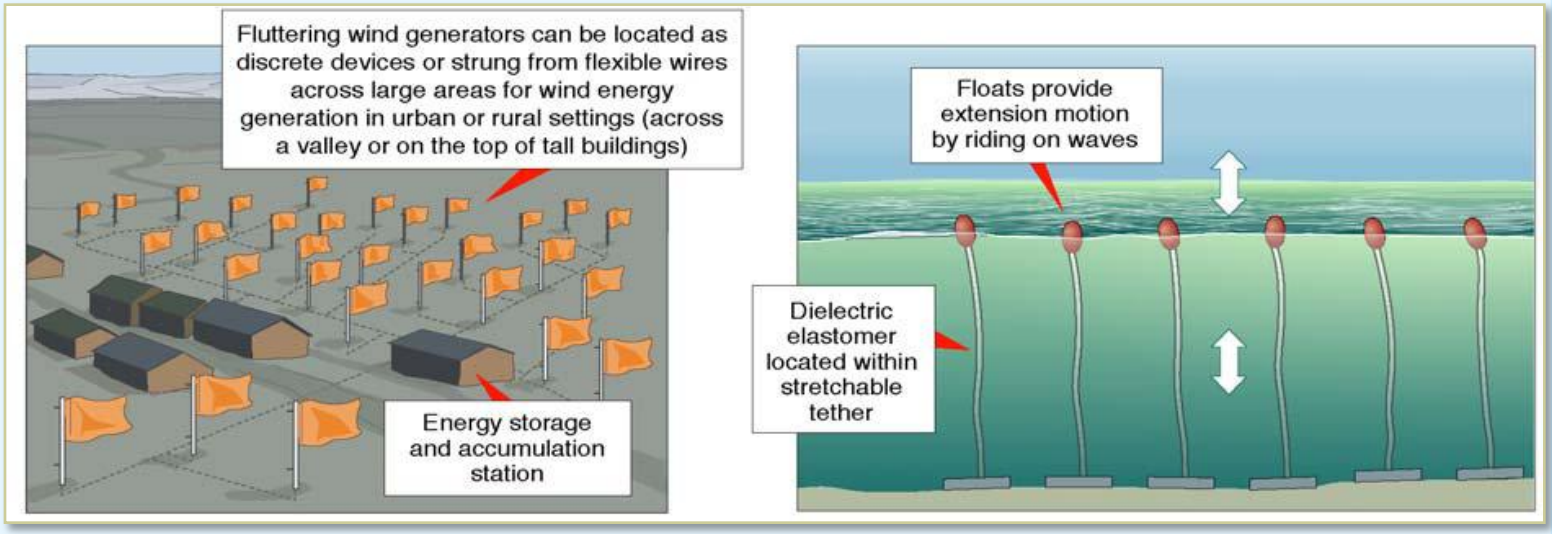


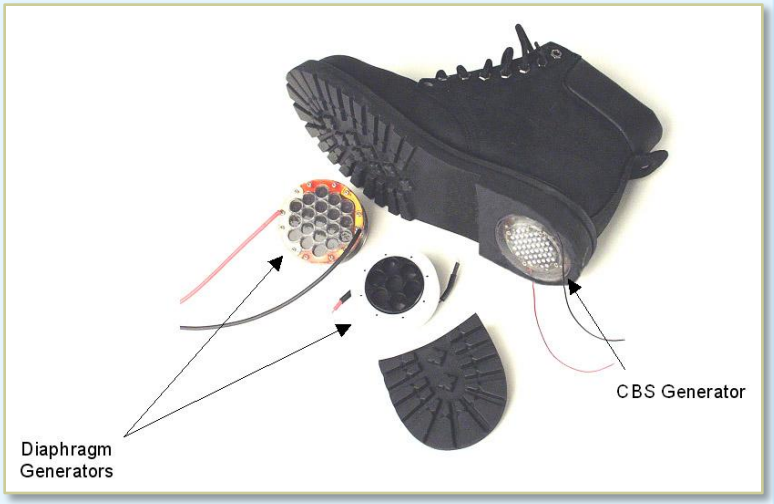



AMI
EPAM
Wave Generator
Modules

- **Market Opportunity**
  - Wave power is a viable alternative energy source in many regions
  - 1st application is self-powered wave power buoy for harbor, port, coastal safety – lights and beacons
  - Will also be used for Seawall generation
- **AMI Advantages**
  - Scalable, distributable energy
  - EPAM is ideal impedance match for wave power and other naturally occurring frequencies
  - EPAM generators are best suited for applications that have very high forces and very low velocities
  - EPAM generators ideally suited for applications using high DC voltages (2-10 kVdc) for distribution

# Many Other Power Generation Ideas…




Images courtesy of SRI International

# Summary

- Currently, AMI is starting to commercialize EPAM based actuators
- AMI's goal is to concentrate on market needs for improved actuators
- AMI has the strongest EPAM IP portfolio
- EPAM devices utilize Maxwell Force Cartesian Plane area growth and AMI's patented design to create Z-axis actuation
- The technology enables a new class of products with high energy density
- EPAM is viable for energy generation

# Acknowledgement


- SRI International
- Maria Peterson