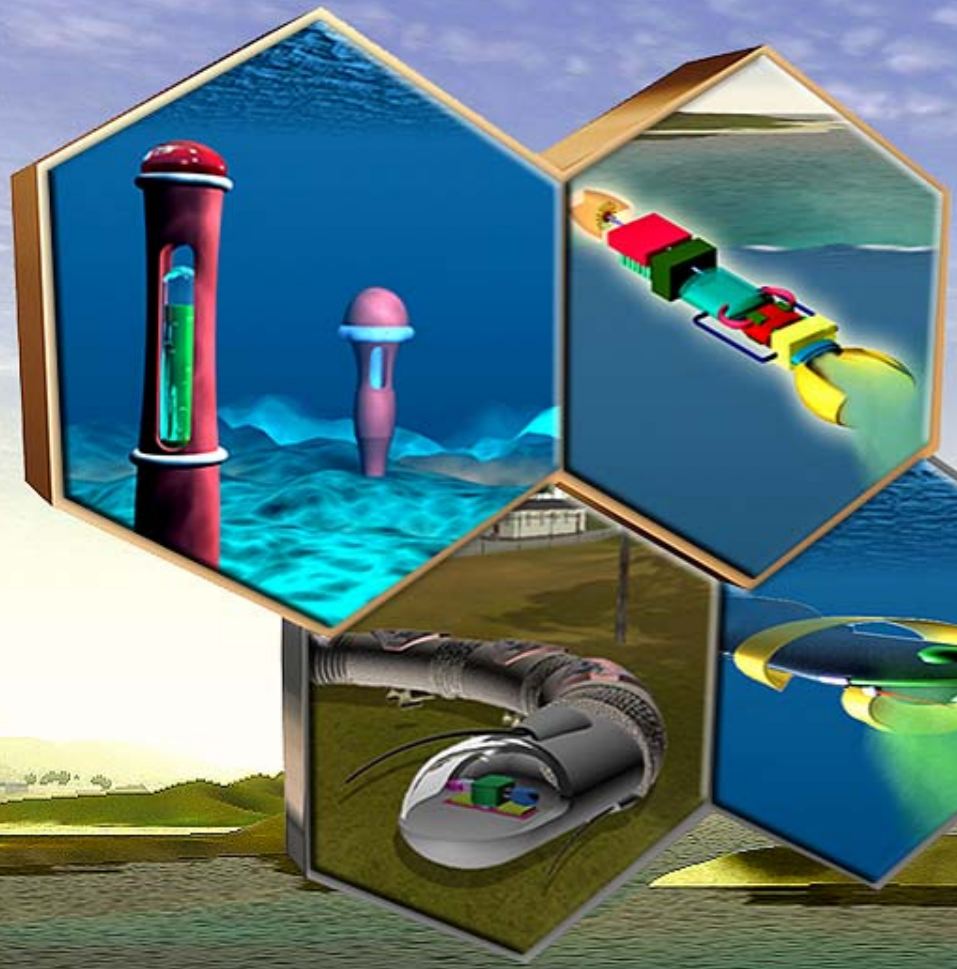


SUSTAINABLE LITTORAL SURVEILLANCE
(Energy Sources, Sensors, & Platforms)

Dr. Edward Carapezza
Program Manager

703/ 696-2317
ecarapezza@darpa.mil

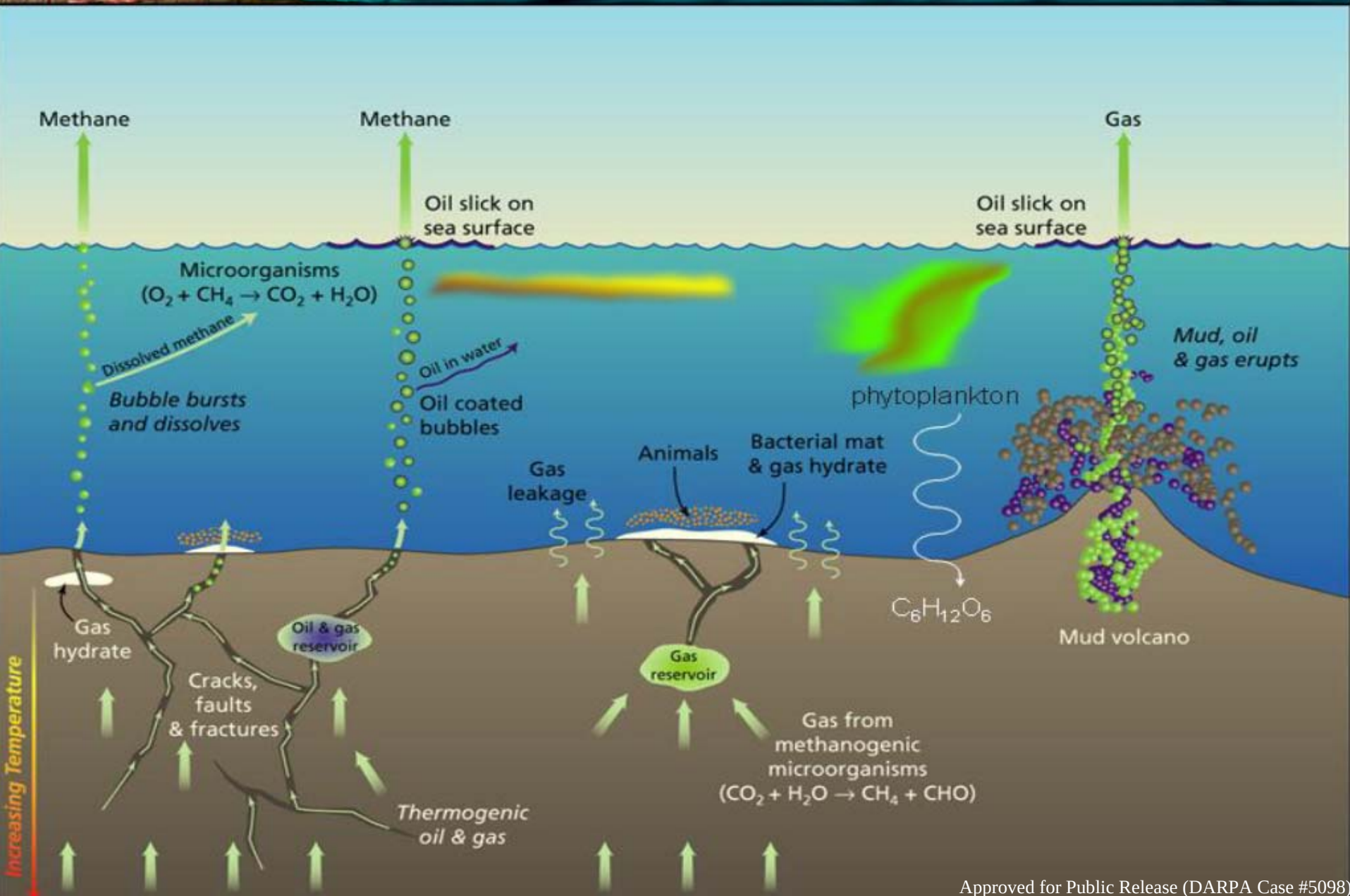
Program Goals
(What is Possible to Achieve)

Develop sustainable, microbial fuel cells (bottom mounted and in water column) to generate continuous, unattended power for greater than 10 years in both ocean and freshwater regions

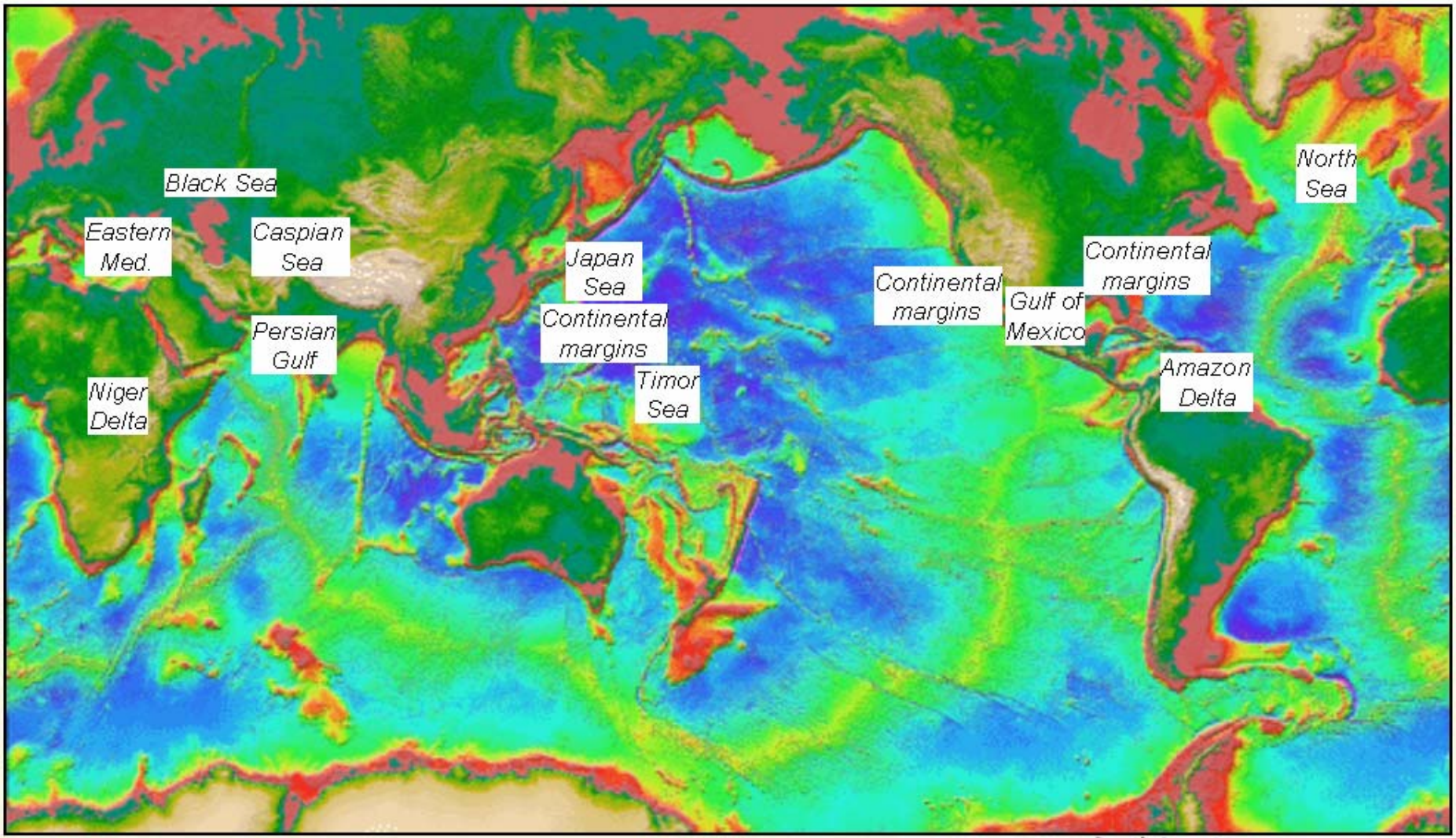
and

Develop unique mobile surveillance systems that utilize these microbial power plants and demonstrate systems with a high degree of autonomy, stealth, and weather tolerance with minimum cost and manpower risk

Organic Material in Sediments & Plankton/Methane in Water Column - Fuels to Power Surveillance Assets (Fixed & Mobile)

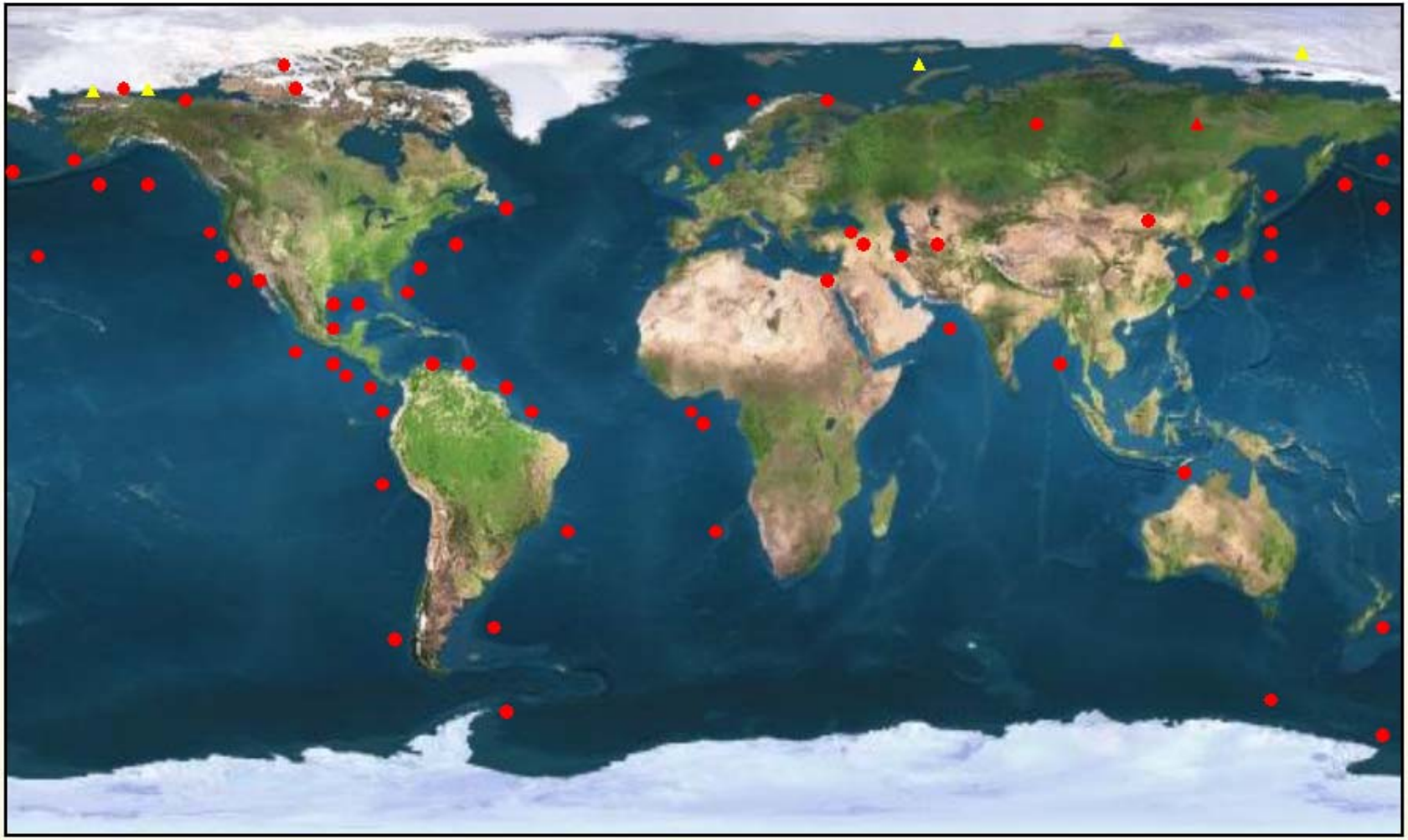


Organic Matter in Sediments on Continental Margins & Known Natural Methane Seep Regions



Smith, W., and Sandwell, D., 1997, Measured and Estimated Seafloor Topography, World Data Center for Marine Geology & Geophysics, Boulder Research Publication RP-1

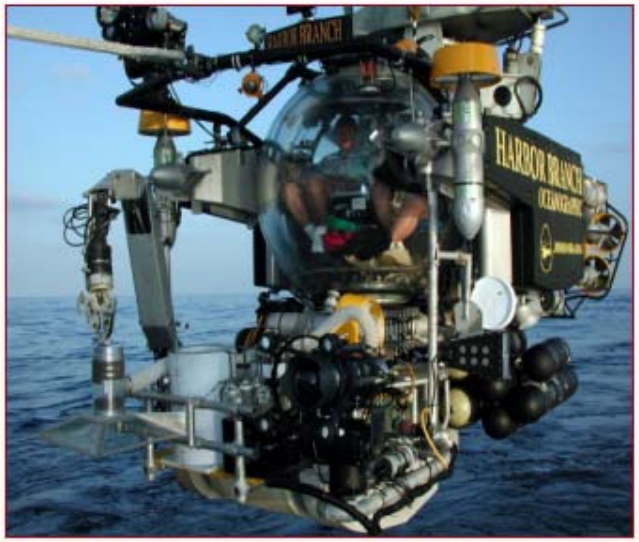
World Methane Hydrate Distribution

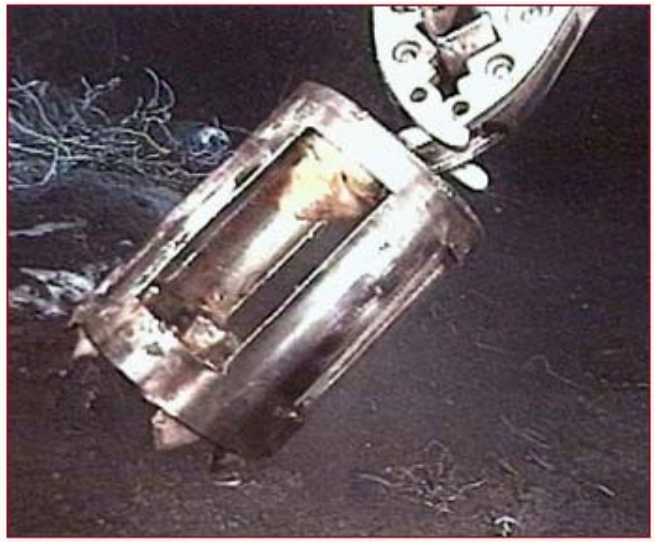


● Ocean Sediment △ Permafrost

Revised from Kvenvolden, 1988

Ocean Floor Methane Hydrates





How to Generate Electrical Power with Microbes and Naturally Occurring Organic Matter

- *Stationary Fuel Cells* *(Bottom Mounted in Sediment Layer):*

  1) Coastal Saltwater & Freshwater Sediments (solid decayed material in shallow areas)
     - moderate power densities possible (1 to 10 watt/m^2 electrodes)
     - sediments to support such cells are pervasive (most coastal, river & lake sites)

  2) Methane Seep Areas (gaseous methane fuel source in shallow areas)
     - high power densities possible (10's to 100's watt/m^2 electrodes)
     - large number of regions to support such cells (coastal and swampy freshwater sites)

  3) Methane Hydrate Areas (solid fuel source & disassociated methane at deep depths)
     - very high power densities possible (1 – 10 kilowatts/m^2 electrodes)
     - large number of regions to support such cells (only at > 500 meter depth in oceans)

- *Mobile Fuel Cells* *(in the Water Column):*

  1) Coastal Saltwater (solid biological & dissolved methane gas fuels in water column)
     - requires locating dense concentrations of zooplankton and phytoplankton (in concentrated up-down diurnal bio layers & at ocean current & mass boundaries)
     - moderate to high power densities possible with water column cells fueled by suspended detritus and harvested zooplankton, phytoplankton & methane

Four Part Development Approach
(to achieve true *Sustained* Littoral Surveillance)

Bottom Mounted Microbial Fuel Cells (stationary)

Water Column Microbial Fuel Cells (mobile)

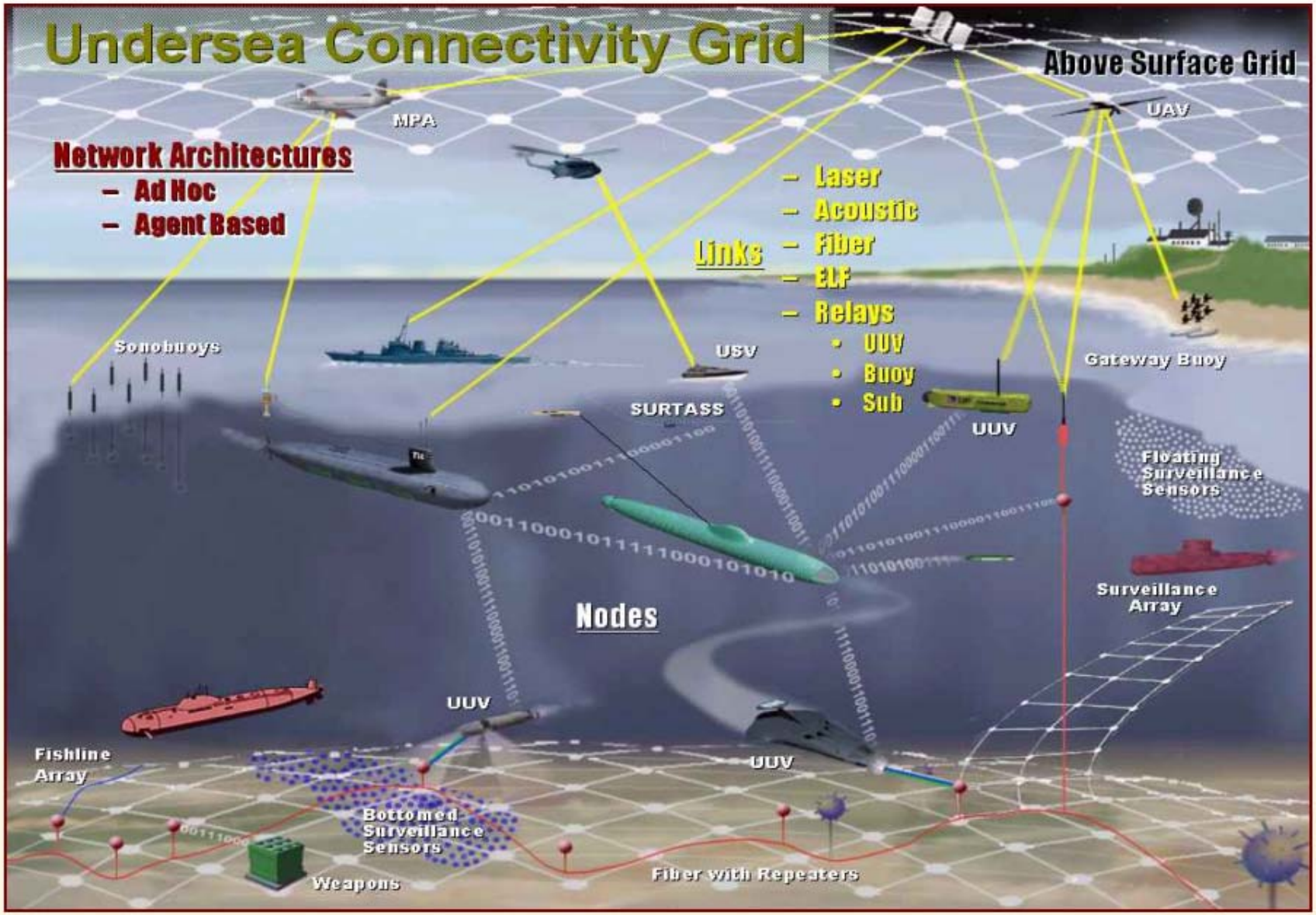
"Remora-Snake" Unmanned Amphibious Surveillance Platform

"Basking Shark" Unmanned Gliding Surveillance Platform

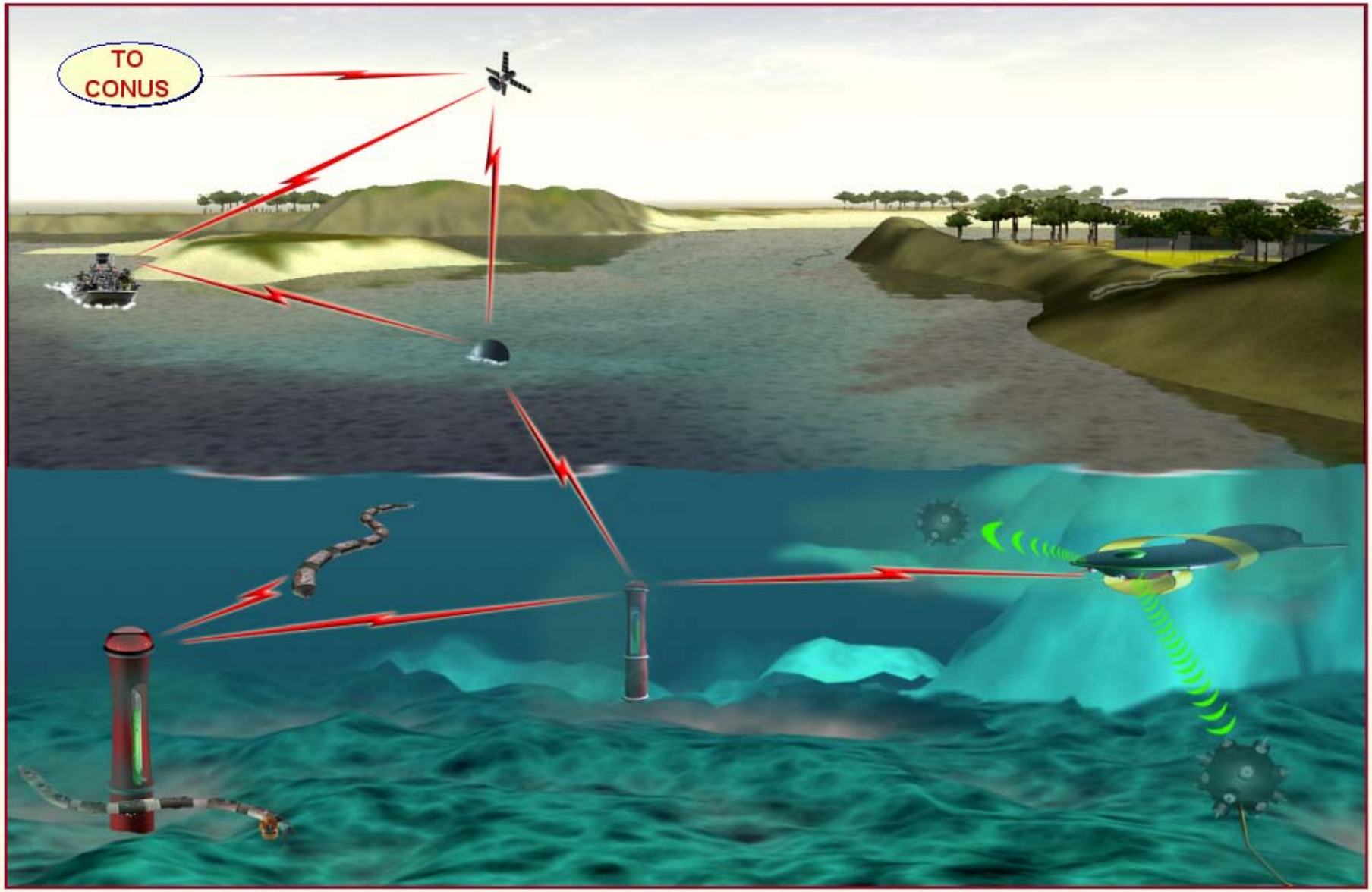
Tactical Missions:
Potential Operational Capability and Utility

TODAY: Littoral World with Highly Capable, High Priced Assets

but without "Sustained Presence"

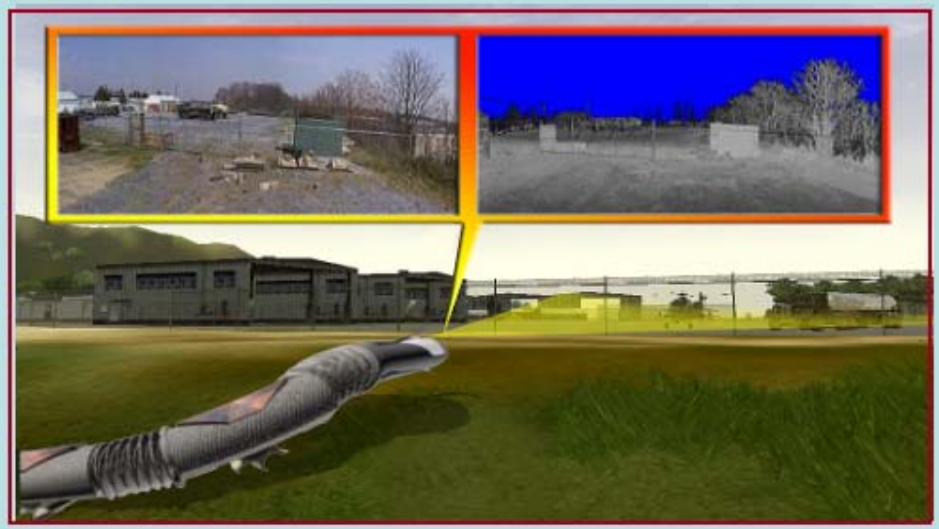


FUTURE: Littoral World with *"Sustained Presence"* and Mission Configurable, Highly Capable, Low Cost Assets

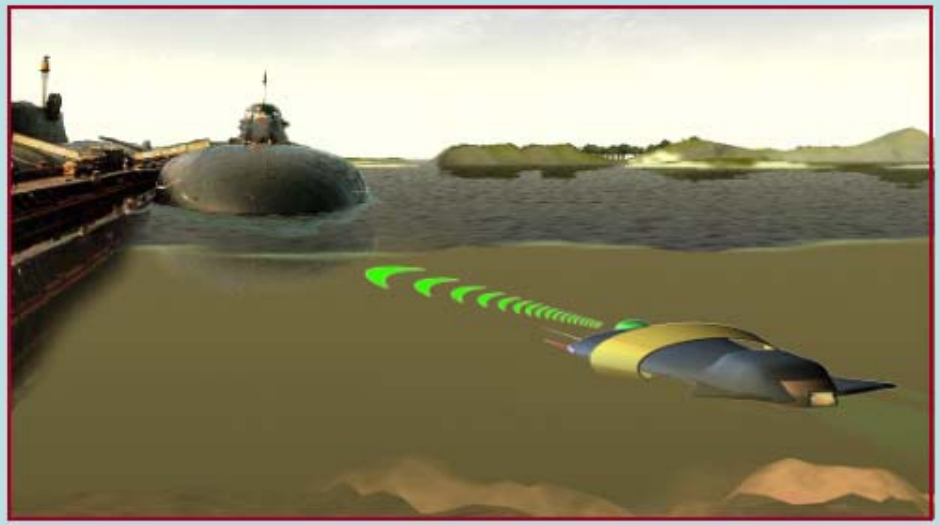


"Sustained Presence" with Novel & Stealthy Electric Surveillance Vehicles

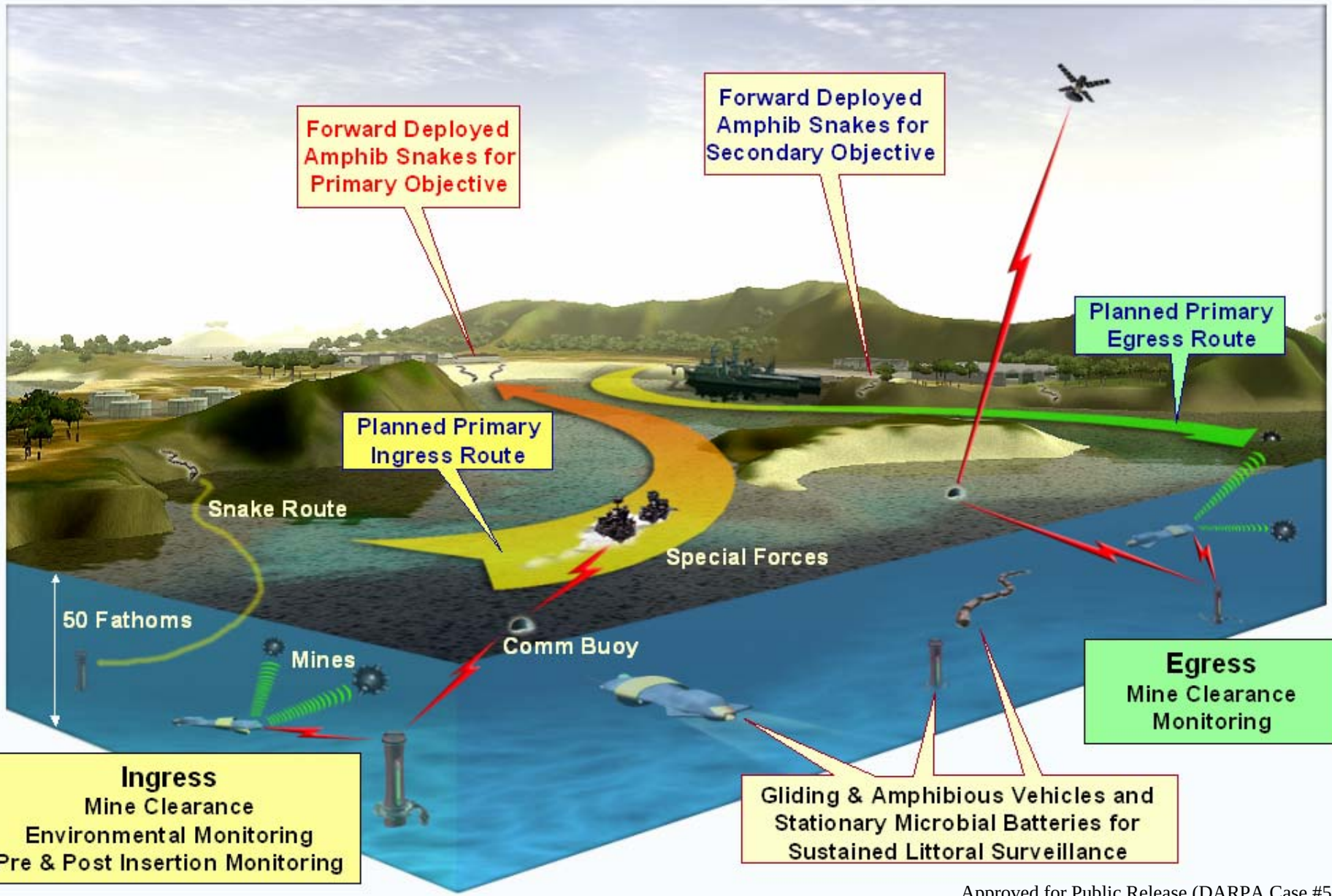
- "Remora-Snake" Amphibian Surveillance System – with reconfigurable sensor suites:
  - 2D & 3D Imaging (VIS & IR)
  - Acoustic
  - Chemical
  - Biological

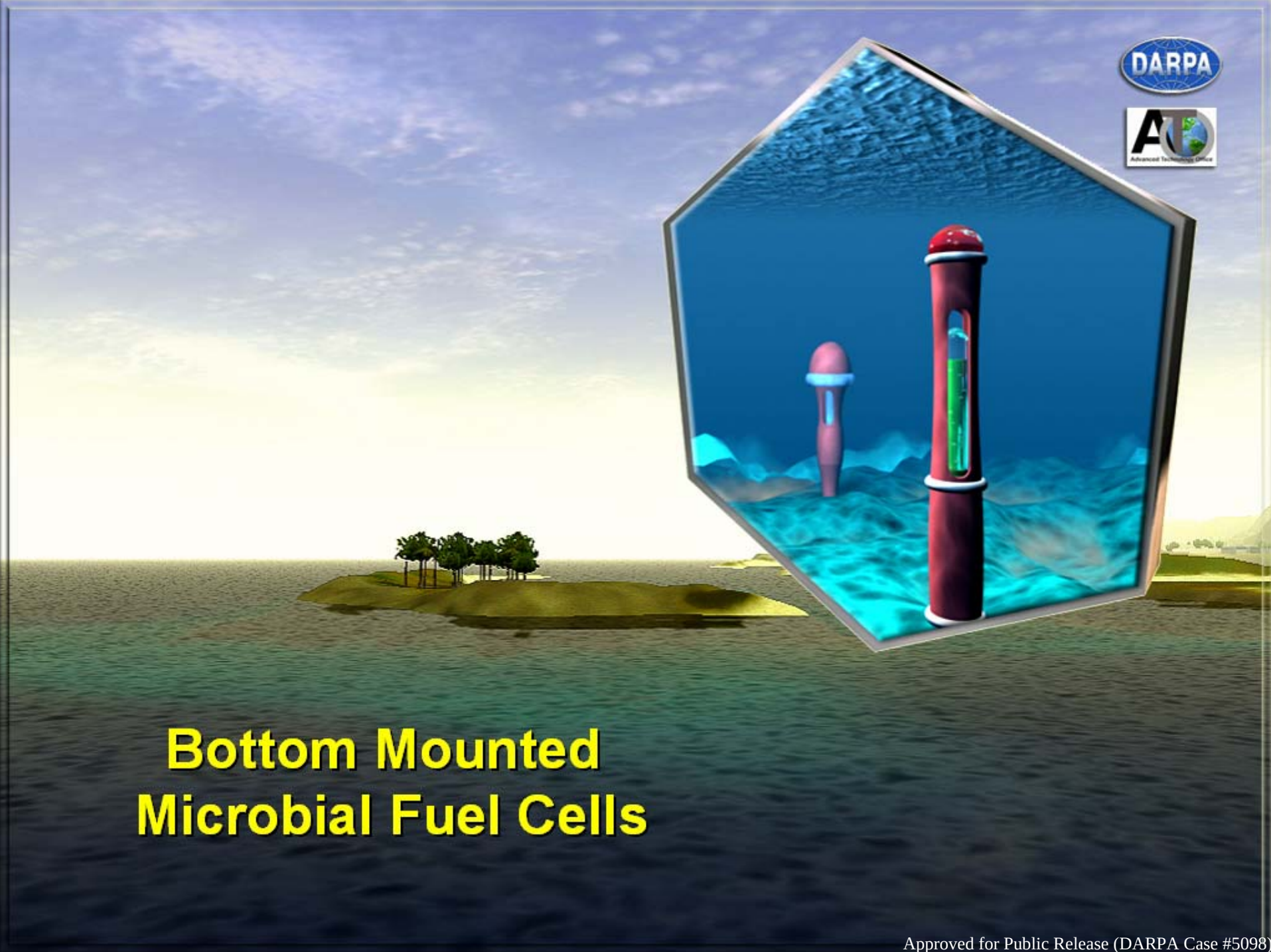


- "Basking Shark" Gliding Surveillance System – with reconfigurable sensor suites:
  - 2D & 3D Imaging (VIS & IR)
  - Acoustic
  - Chemical
  - Biological



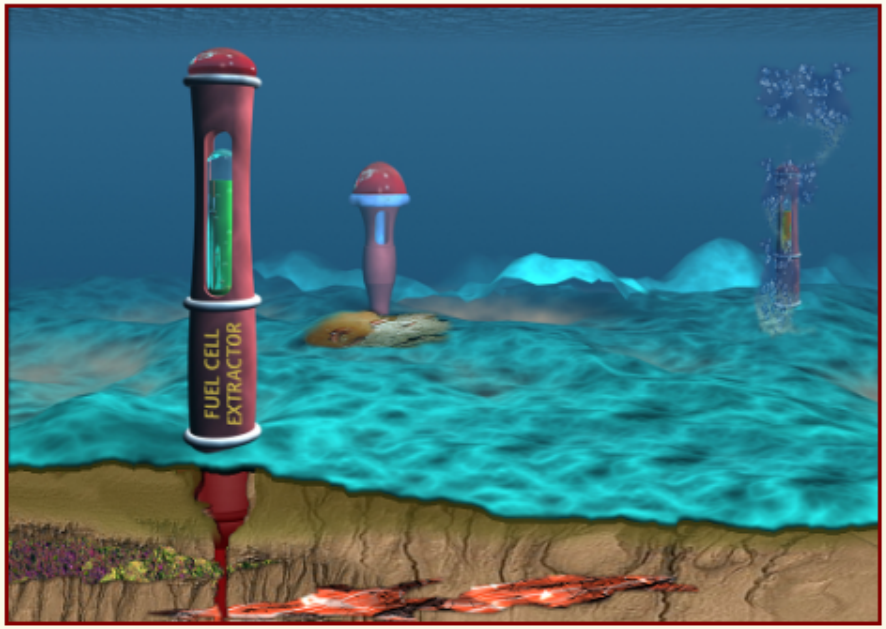
Future Littoral Missions: *Sustained Presence* (Real-Time Surveillance & Intel Collection)

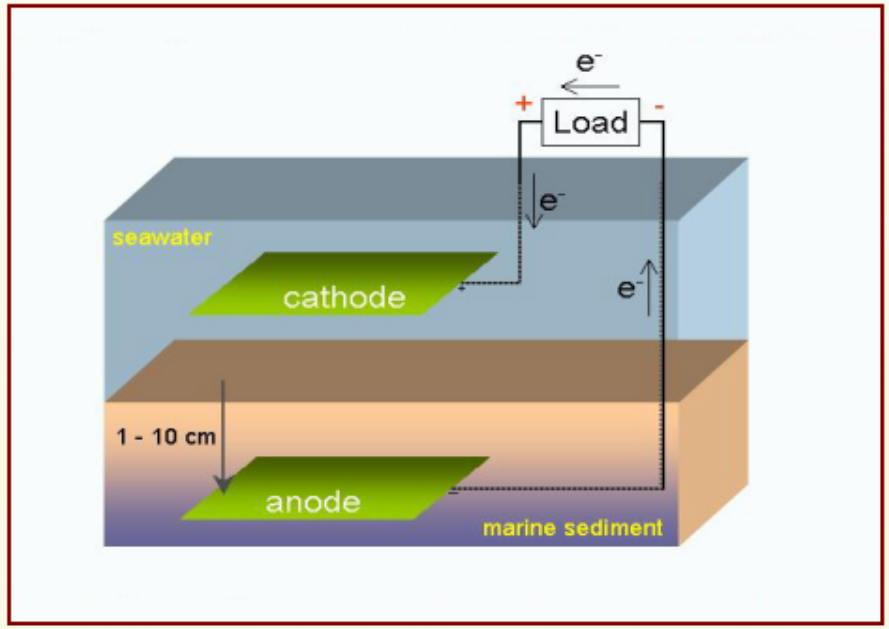




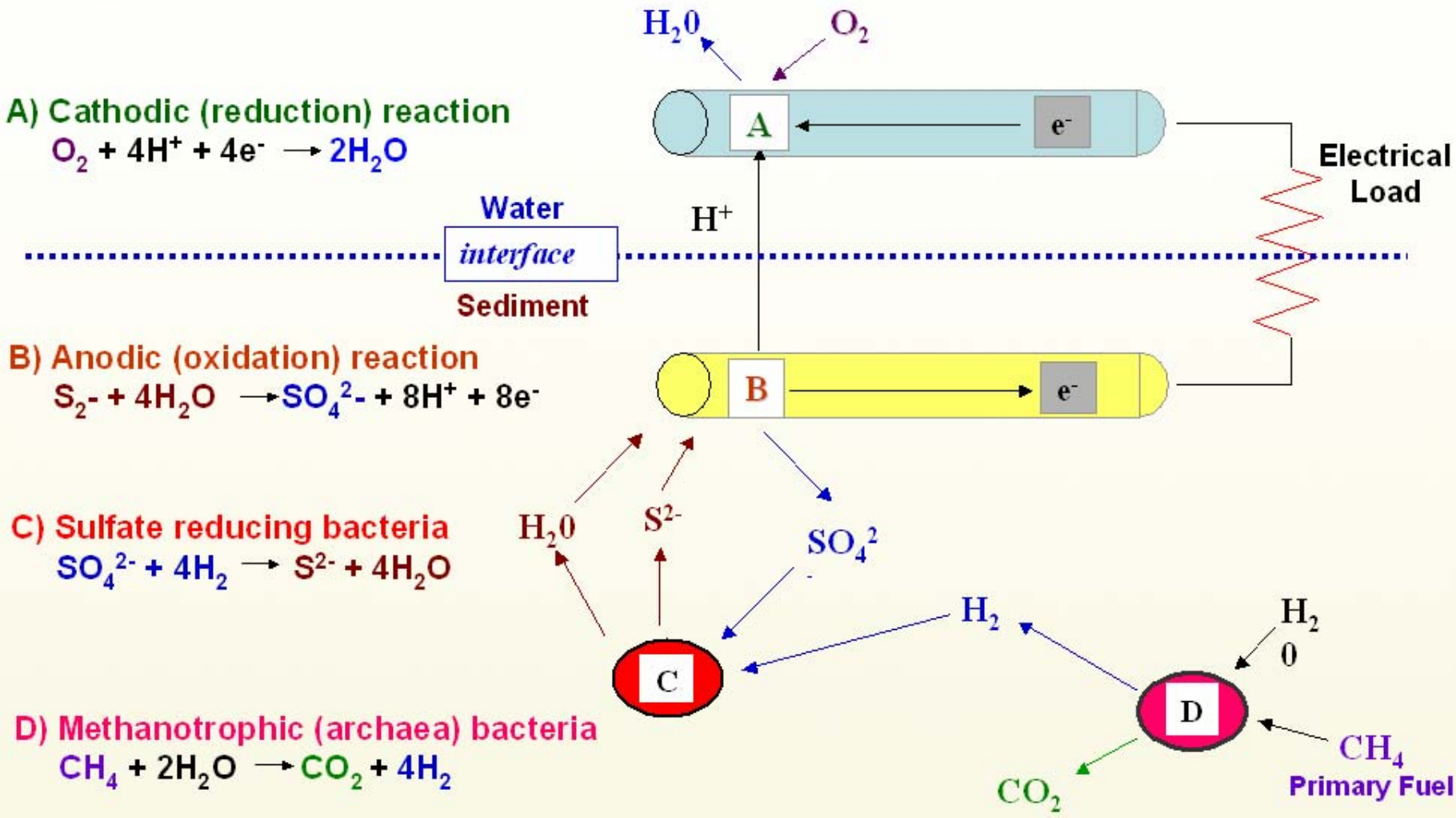
Bottom Mounted Microbial Fuel Cell Objectives
(*How Goal will be achieved*)

- ***Develop Bottom Mounted Microbial Fuel Cell System***
  - *characterize bacteria species & develop bacteria/fuel/oxidant process models*
  - *electrodes with increased surface area & tuned coatings to maximize electron flux*
  - *external cell environmental monitor (cell water/sediment biological & chemical state)*
  - *internal cell environmental monitor (electron flux, temp & power generation state)*
  - *sensor system (methane, oxidants, reactants,…) to survey for best fuel cell locations*
  - *utilize fresh and salt water sediments, methane seeps and methane hydrate deposits to generate electricity at levels from 1 watt/m^2 to 10 kilowatt/m^2*
  - *Demo potential for continuous electric power for surveillance operations for > 10 years*



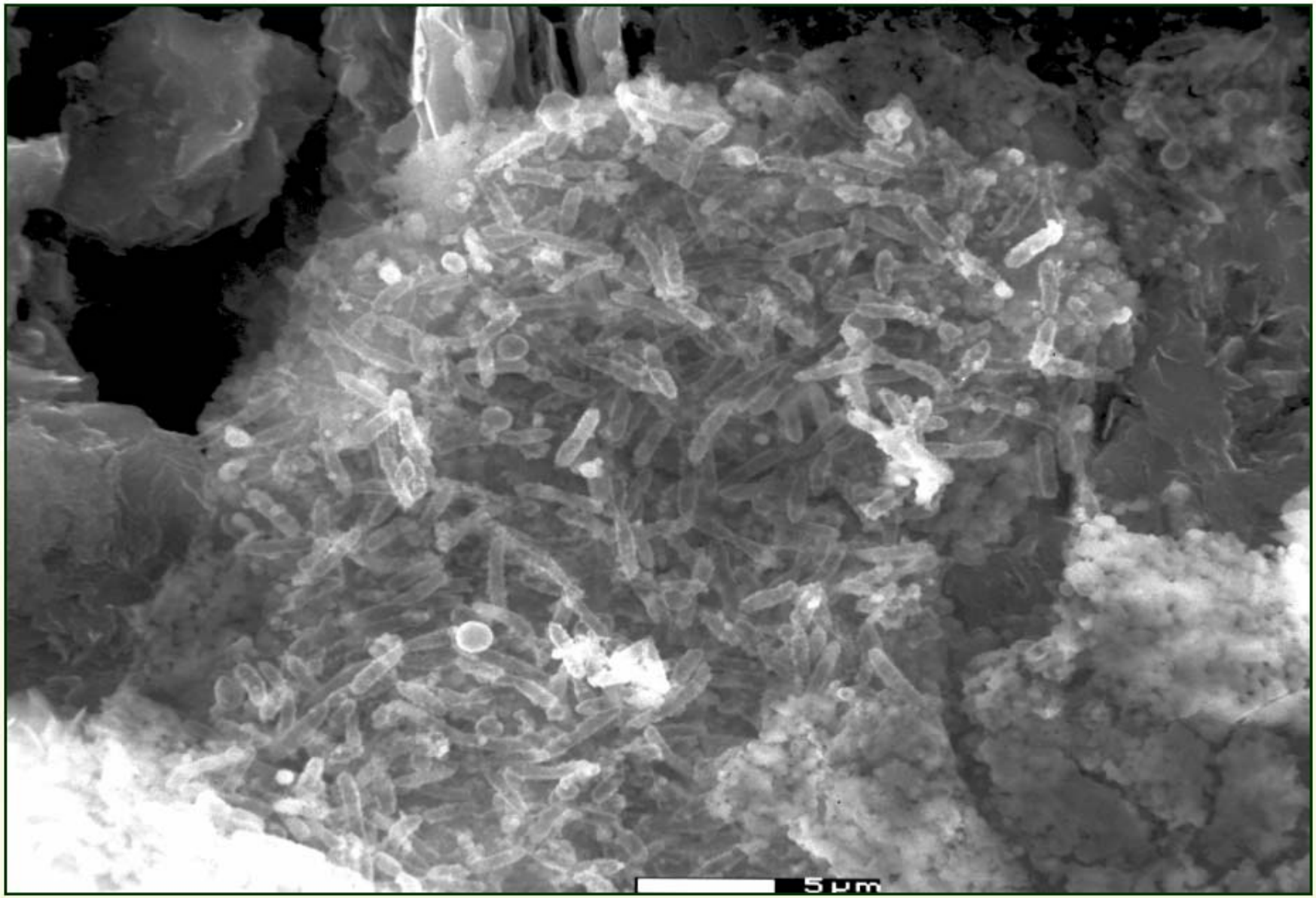


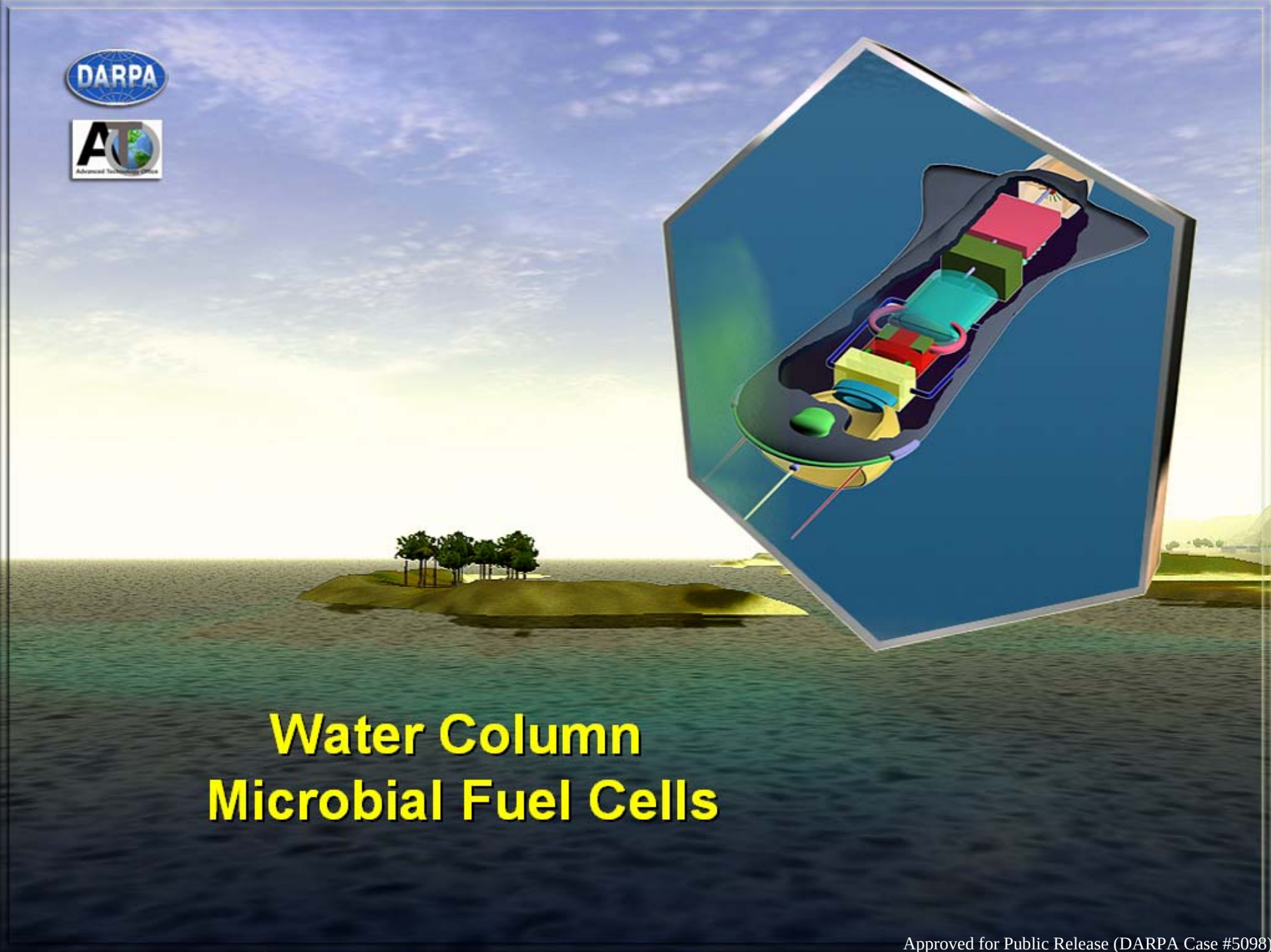
Microbial Fuel Cell Processes (at bottom sediment-water interface)



Methane is the carbon source for anaerobic consortia of archaea bacteria and sulfate reducing bacteria that produce sulfide, which is oxidized at the anode of the fuel cell

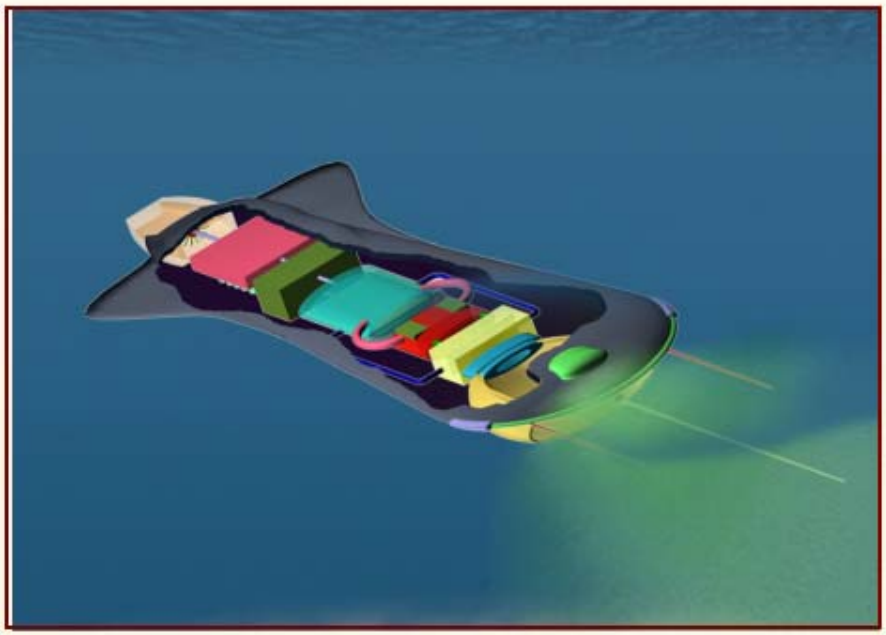
Microbial Species Perform Specialized Fuel Cell Functions (Example: Chromate Reducing Shewanella Bacteria)

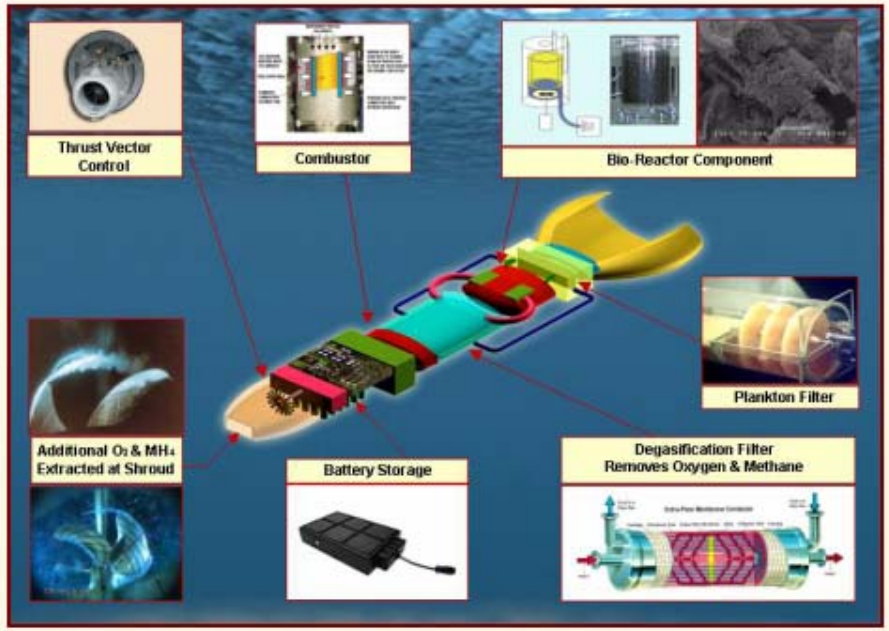




Water Column Microbial Fuel Cells (mobile)
(How Goal will be achieved)

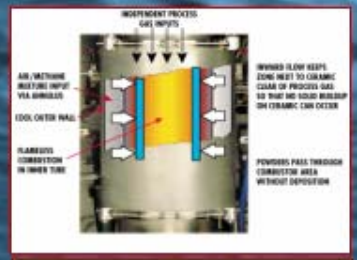
- **Develop Water Column Microbic Fuel Cell System**
  - *utilize fuels in the shallow water column (0 – 500 m)*
  - *extract dissolved oxygen & methane gases from the water column through combination of degassification membranes & incipient cavitation gas extractors*
  - *generate electricity from solid biomass fuels (organic detritis, zooplankton and phytoplankton) and from dissolved gases extracted from the water column*
  - *recharge onboard batteries (> 280 w-hr) from output of onboard solid biomass microbial reactor and through direct burning of methane gas*
  - *demo potential for continuous electric power for surveillance operations > 10 years*



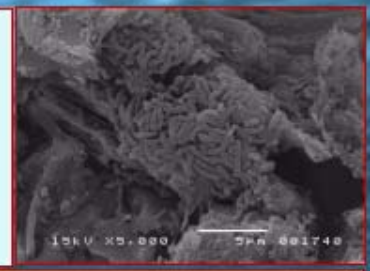


Related Features & Processes

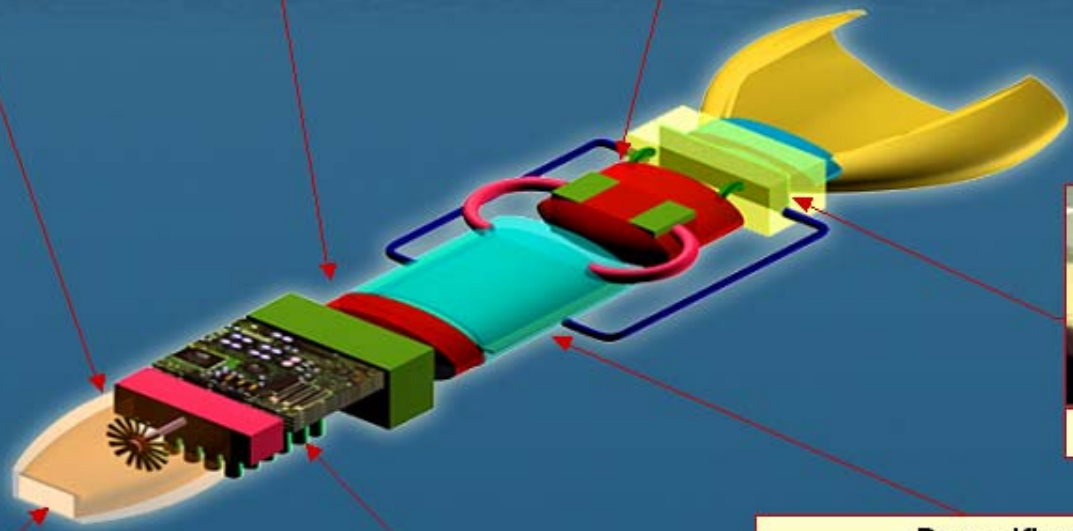
Thrust Vector Control



Combustor



Bio-Reactor Component



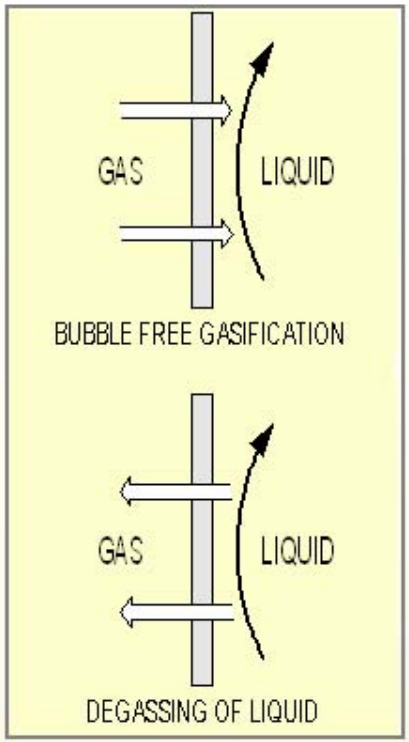
Plankton Filter

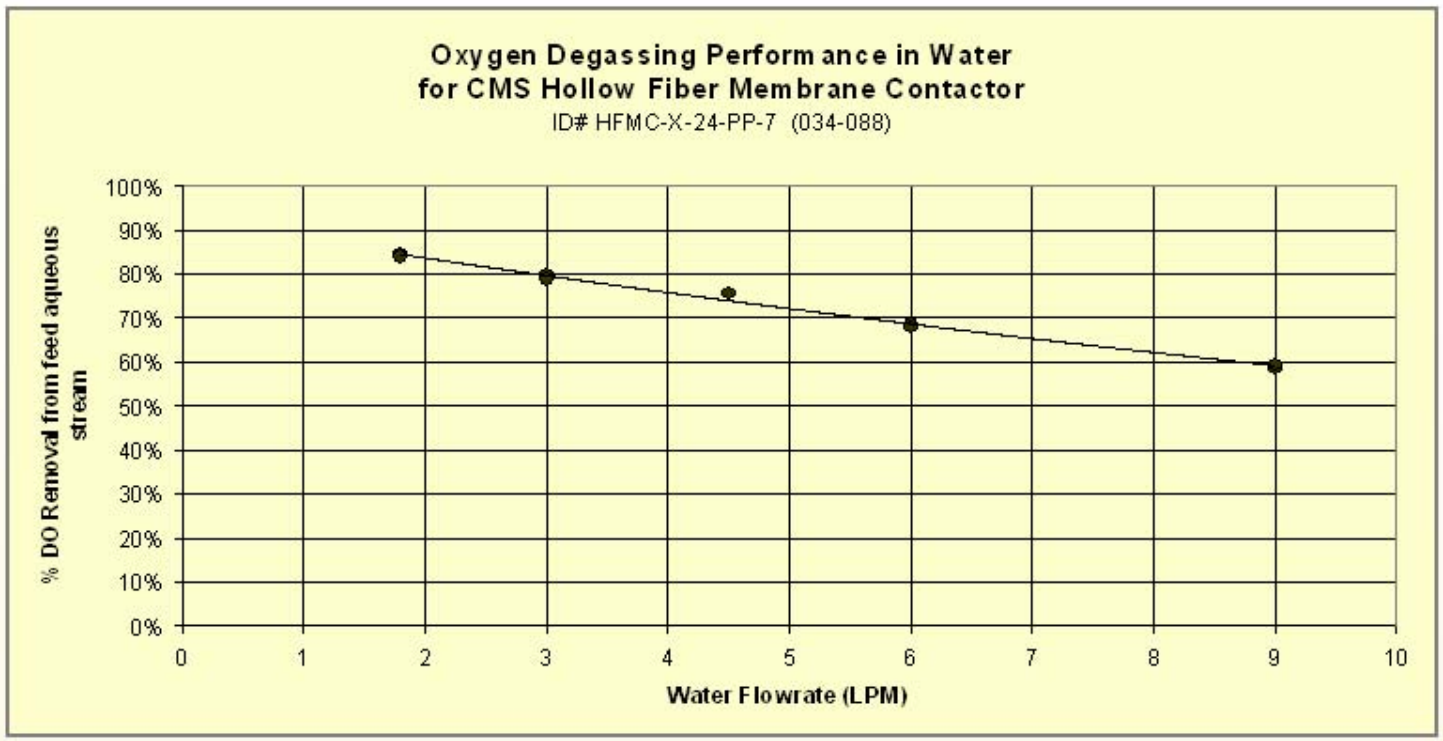
Additional O_2 & MH_4 Extracted at Shroud

Battery Storage

Degasification Filter Removes Oxygen & Methane

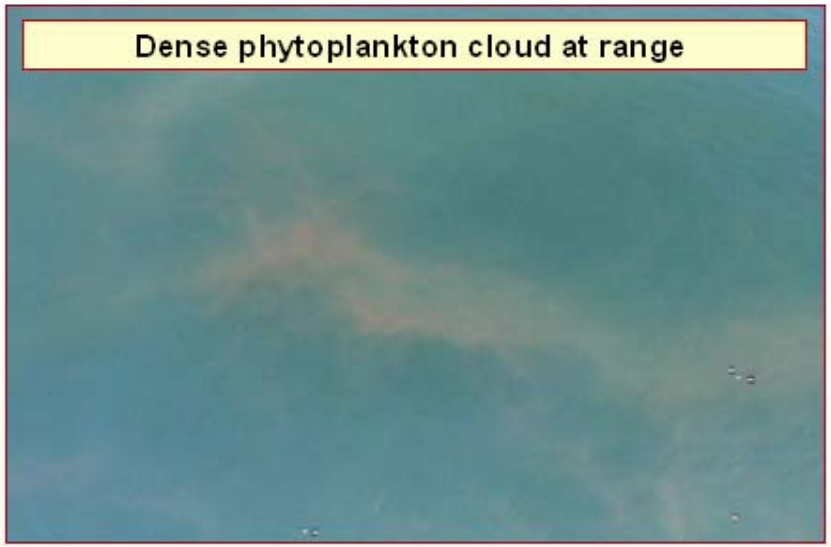
Dissolved Gases can be Extracted from Water Column (Filters & Cavitation Techniques)

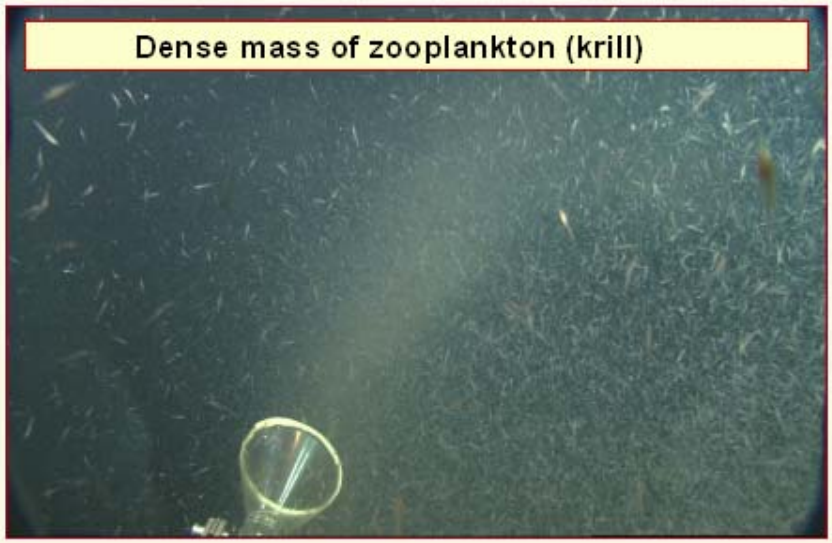




- Oxygen Degassing Example (filter results):
  - Teflon Co-Polymer coating on hollow fibers as filter element
  - Water temperature at 38 degrees C
  - Differential pressure at 1 psi across membrane
  - Higher flow rates expected at higher differential pressure to TBD limit

Dense Plankton Clouds at Density Boundaries
(Can be located & exploited as a *FUEL*)

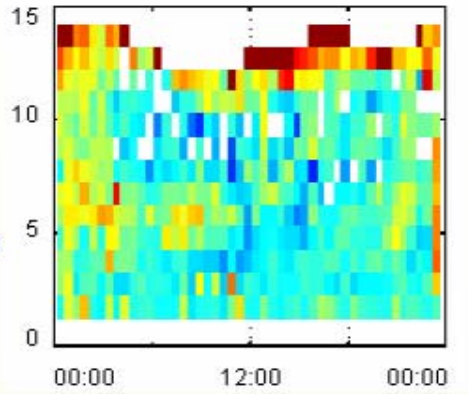




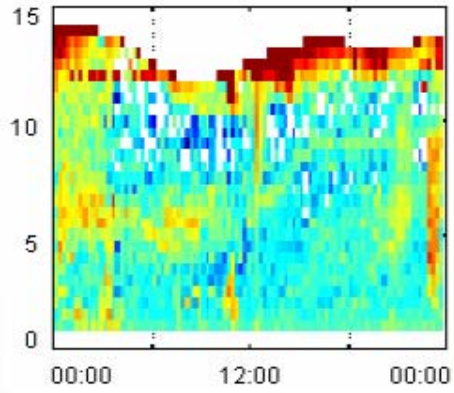
Thin Plankton Layers have Persistent Structure (detectable & exploitable)

These thin layer structures & associated plankton concentrations were seriously underestimated until recently due to poor resolution of available ocean instruments

1995 Instrument
Maximum Resolution:
spatial scale = 1 meter
temporal scale = 0.5 hours

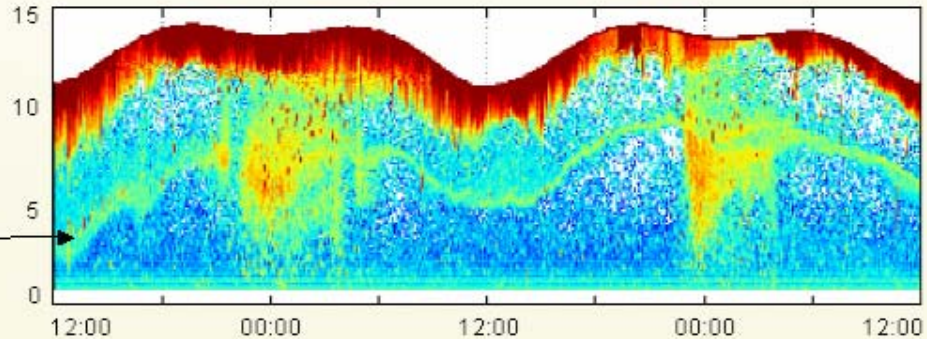


1996 Instrument
Maximum Resolution:
spatial scale = 0.5 meters
temporal scale = 0.25 hours



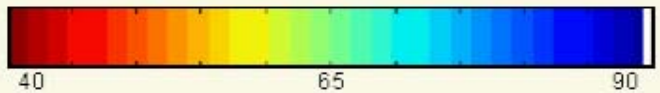
2001 Instrument
spatial scale = 12.5 cm
temporal scale = 1 minute

Thin Layer of zooplankton
(orange-yellow-green line)



X axis = time,

Y axis = depth, in meters
(bottom referenced)



Volume Scattering Strength (dB) at 265 KHz

Four Part Development Approach
(to achieve true *Sustained* Littoral Surveillance)

Bottom Mounted Microbic Fuel Cells (stationary)

Water Column Microbic Fuel Cells (mobile)

"Remora-Snake" Unmanned Amphibious Surveillance Platform

"Basking Shark" Unmanned Gliding Surveillance Platform

Why do we need "*Intelligent*" Littoral Surveillance Vehicles (Snake & Glider) Now?

Sustained Presence means surveillance vehicles and fuel cells may be in unattended use for years without direct human interaction.

Implication of this new capability - we need *Intelligent Systems* that can plan, act, and re-act in diverse situations & that can control many actuators to perform complex tasks such as:

EXAMPLE: Each Amphibian REMORA-SNAKE vehicle must be capable of performing some *SUBSET* of the following example complex behaviors/tasks:

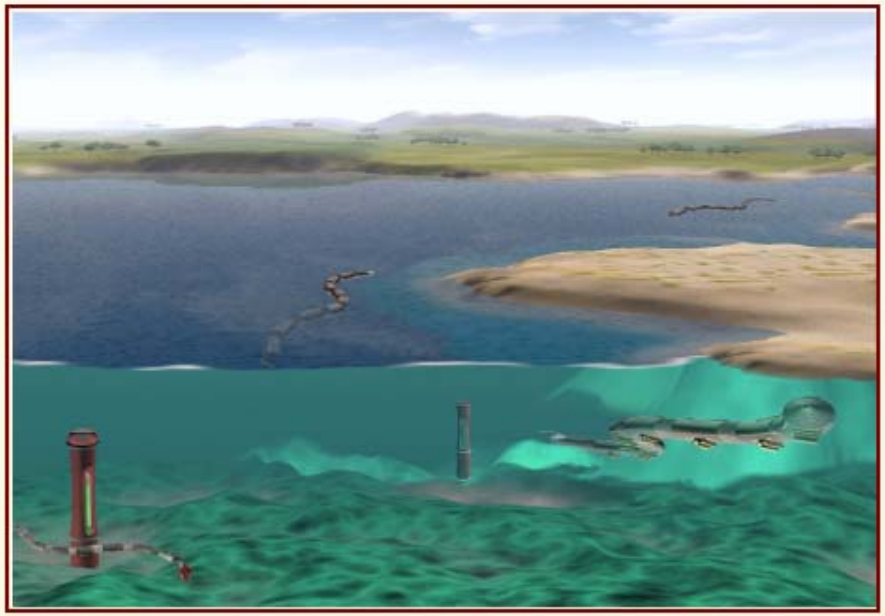
- transport and deploy bottom mounted microbic fuel cells
- maneuver to & attach/detach to bottom mounted fuel cells for charging operations
- maneuver to directed locations and to good (better) observation points
- erect and house sensors, masts and antennas
- transport and deploy payloads
- climb through fences, pipes, bushes
- swim up rivers, cross marshes and mud flats
- climb over or around obstacles, such as boulders
- gain access or cross highways and railroad beds
- climb trees and other structures
- manuever around and explore structures or confined spaces (buildings, caves,…)
- establish communications & transmit task, environmental, & health status info
- configure and control non imaging and imaging (camera) sensors

Why can we develop Intelligent Littoral Surveillance Vehicles (Snakes & Gliders) Now?

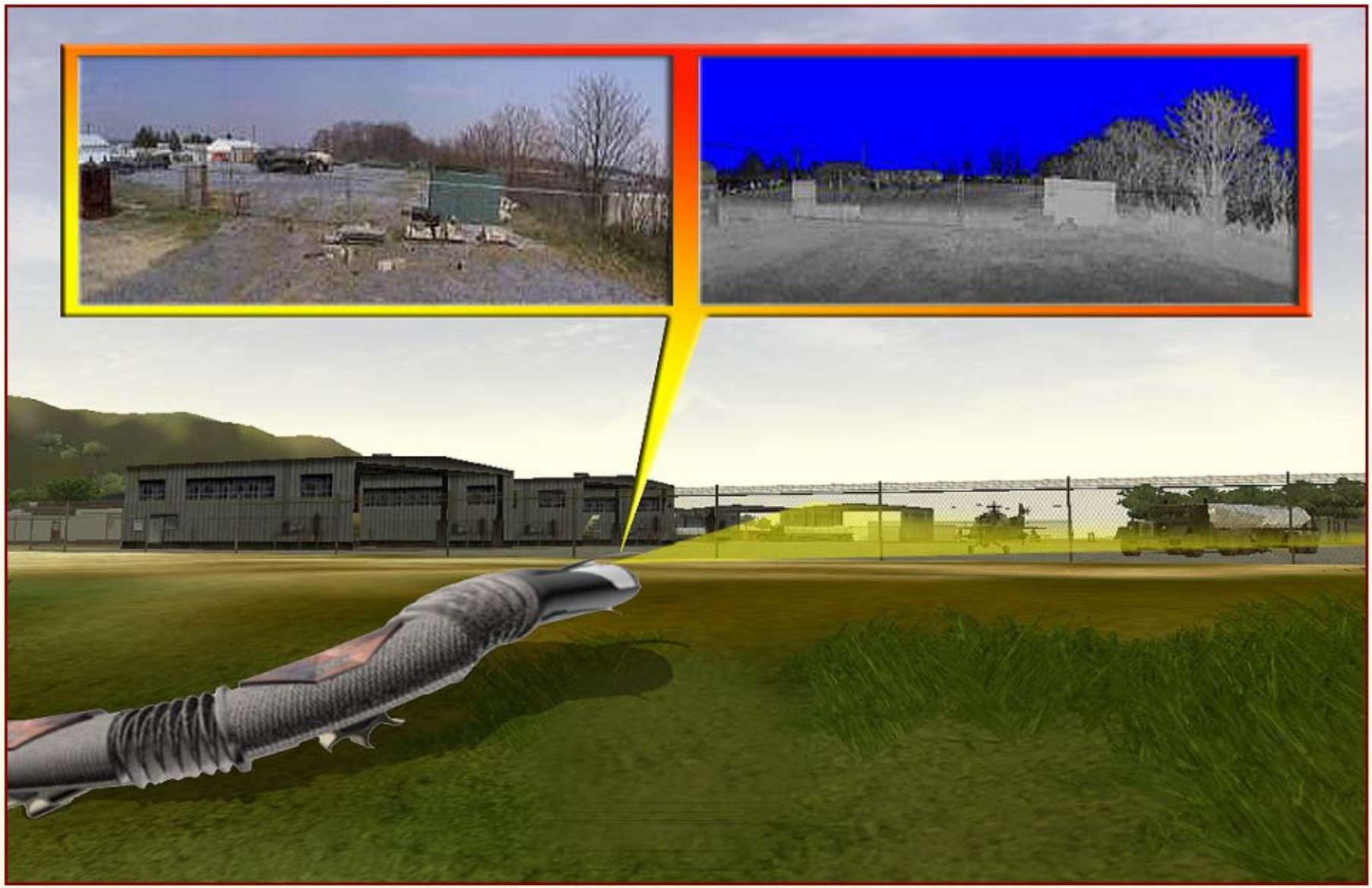
- More computing power
- Better understanding of the problem space
- Improved sensor technologies
- Improved algorithms
- Improved architectures

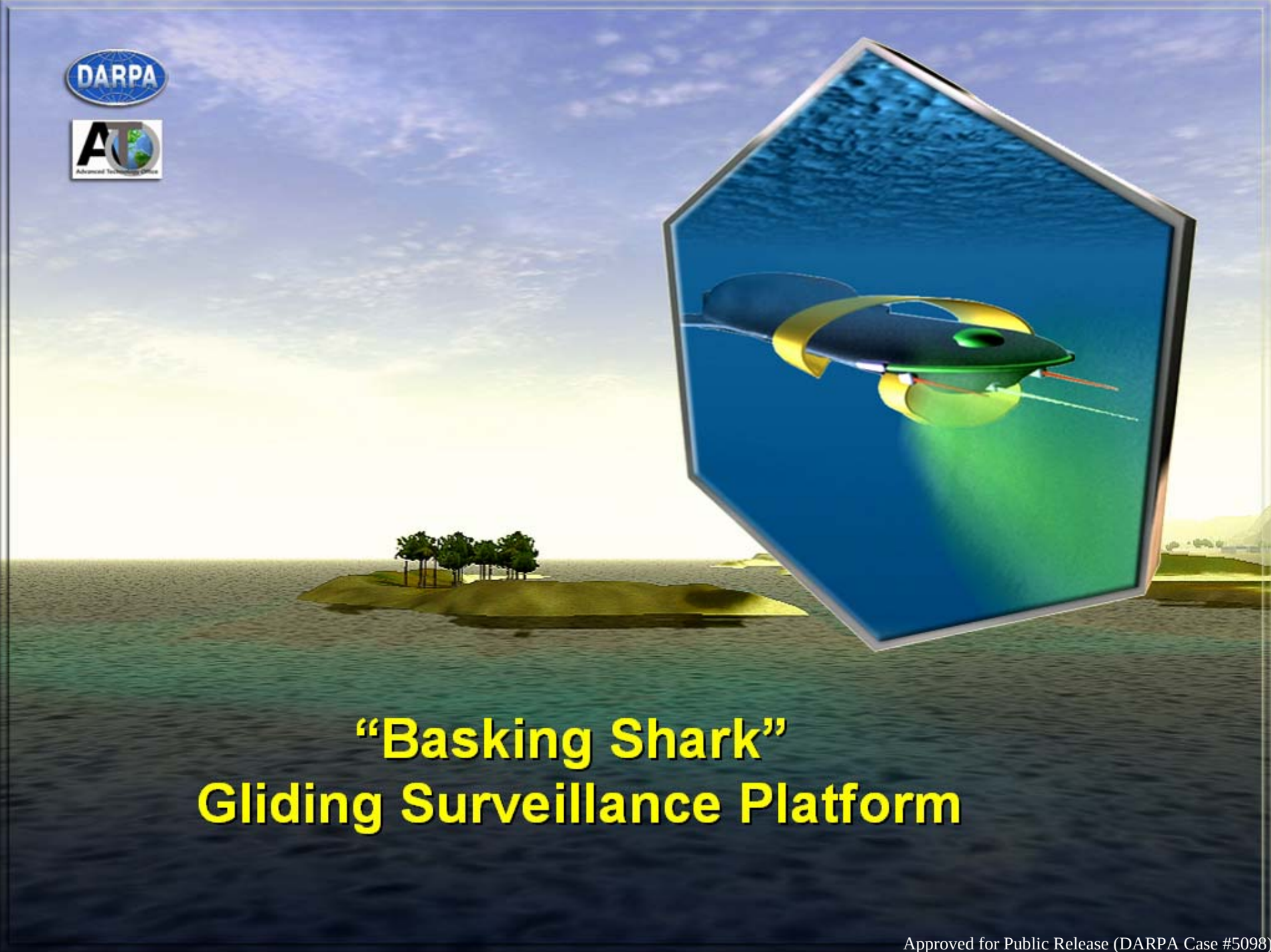
Remora-Snake Objectives
(How Goal will be achieved)

- **Develop an autonomous amphibious surveillance system**
  - position and anchor bottom mounted fuel cells
  - charge onboard batteries (> 280 w-hr) with bottom mounted fuel cells (primary method)
  - charge onboard batteries by land grazing (biomass reactor) or solar cells (secondary)
  - water travel > 6 km (round trip charge location to landfall) at speeds > 3 kts (1.5 m/sec)
  - land travel > 6 km (roundtrip to mission area) at speeds > 1.8 km/hr (0.5 m/sec)
  - 2-4 hr surveillance at primary mission area without "trap line" extra fuel cells on route



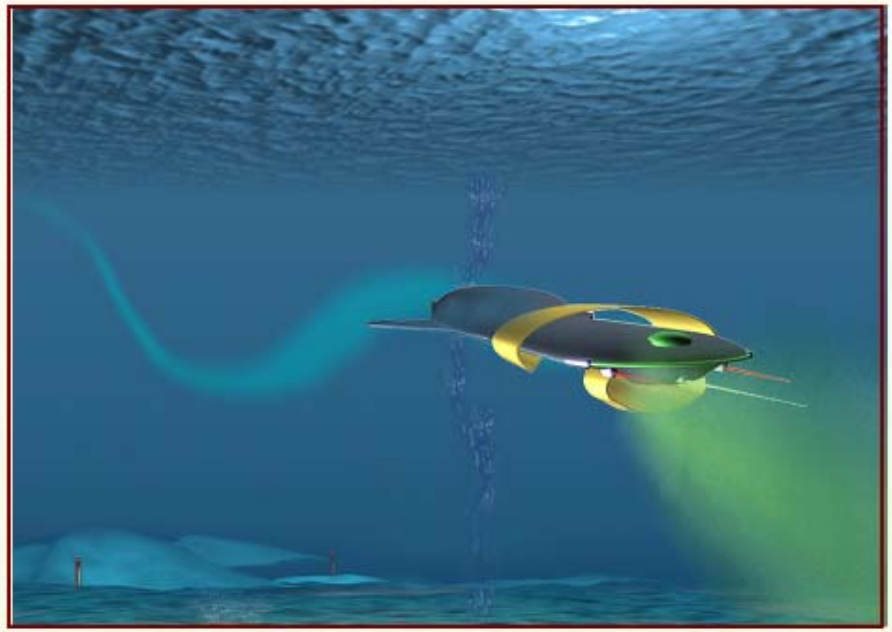
"Remora-Snakes" amphibians collect multi-sensor info (Visible, IR & LADAR images, acoustic, chem, bio,…)



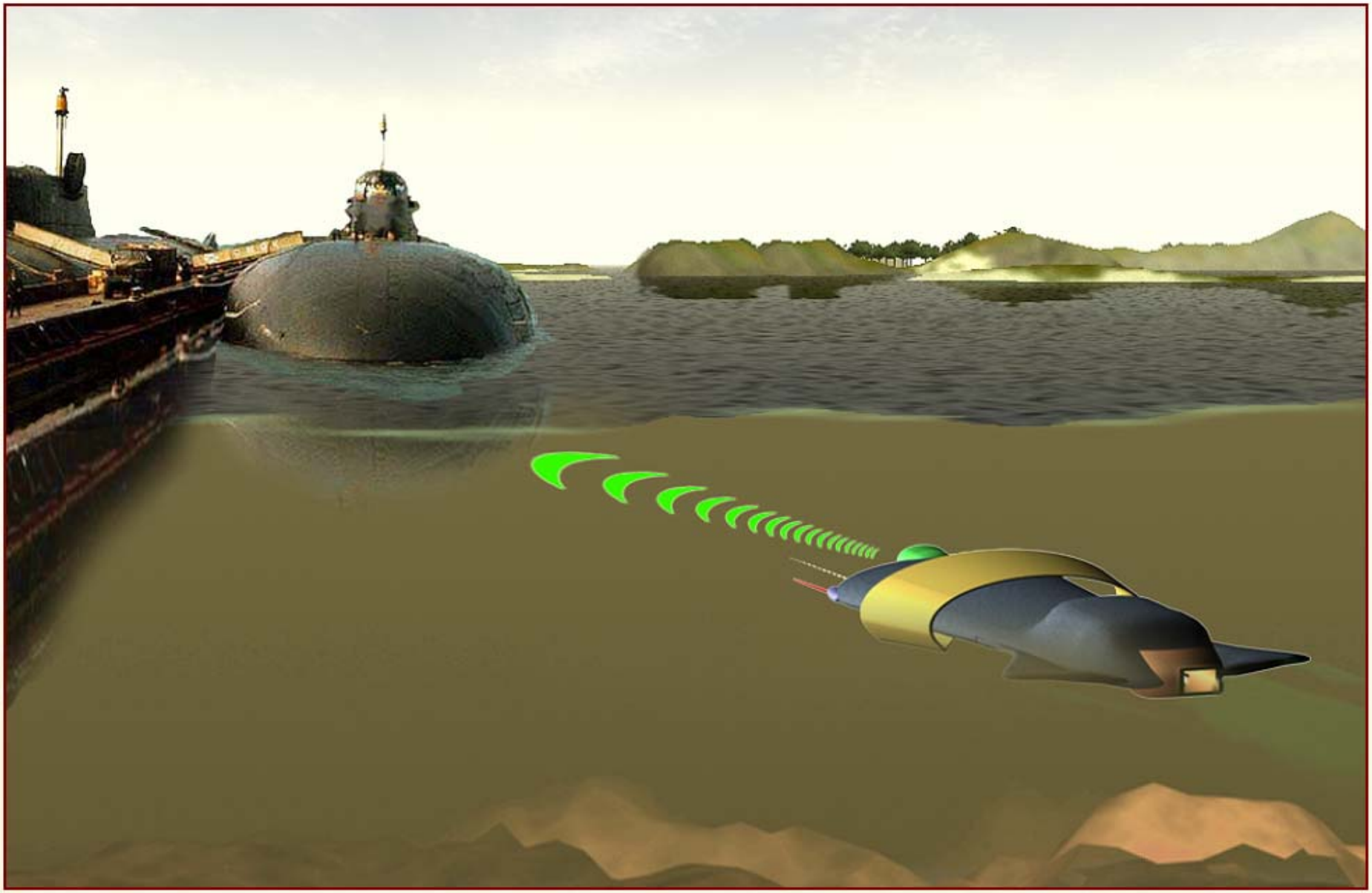


"Basking Shark" UUV Objectives
(*How Goal will be achieved*)

- ***Develop an autonomous gliding surveillance system***
  - *capable of gliding and loitering in the shallow water column (0 – 500 m)*
  - *capable of locating and extracting fuel (O_2 , CH_4 , & plankton) in water column*
  - *onboard batteries (> 280 w-hr) charged by onboard or bottom mounted fuel cells*
  - *capable of gliding & swimming > 48 km (round trip fuel cell recharge to mission surveillance area) in coastal waters at speeds > 6 kts (3 m/sec)*
  - *capable of continuous surveillance operations at target area with periodic bottom mounted fuel cell recharges if water column fuel supply diminishes significantly*



"Basking Shark" UUV's collect multi-sensor info (Visible, IR images, acoustic, chem, bio,…)



Phased Capability Demonstrations
Schedules & Milestones
Quantified Metrics