A SYSTEM OF SYSTEMS – An Overview of Energy for Transportation and Micro-grid Generation

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OUTLINE

1. What is **System of systems?** – 7/numerous definitions
2. Introduction to SoS
3. SoS Engineering – Issues and Problems
4. Applications – Earth, Military & Space
5. Energy systems Fuels & Microgrids – **Cases for SoS**
6. Brief outline of ACE Center Case Studies of SoS at University of **Texas**
7. Conclusions

Definitions of SoSE

1. A System-of-Systems (SoS) is a "super-system" comprised of elements that are themselves complex, independent systems which interact to achieve a common goal. (Pearlman, 2006)
2. SoS large-scale concurrent and distributed systems

   Application: Private Enterprise. (Kotov, 1997; Jamshidi, 2005)

Definitions of SoSE, cont'd

3. SoS has characteristics: operational independence, geographic distribution, emergent behavior, and evolutionary development.

   Application: Military. (Sage & Cuppan, 2001)

4. SoS pursues development, integration, interoperability, and optimization of systems to enhance performance in future battlefield scenarios. Application: Military. (Pei, 2000)

Definitions of SoSE, cont'd

5. SoS is concerned with interoperability and synergism of Command, Control, Computers, Communications, and Information (C4I) for Intelligence, Surveillance, and Reconnaissance (ISR) Systems.

Application: Military. (Manthrope, 1996)

Definitions of SoSE, cont'd

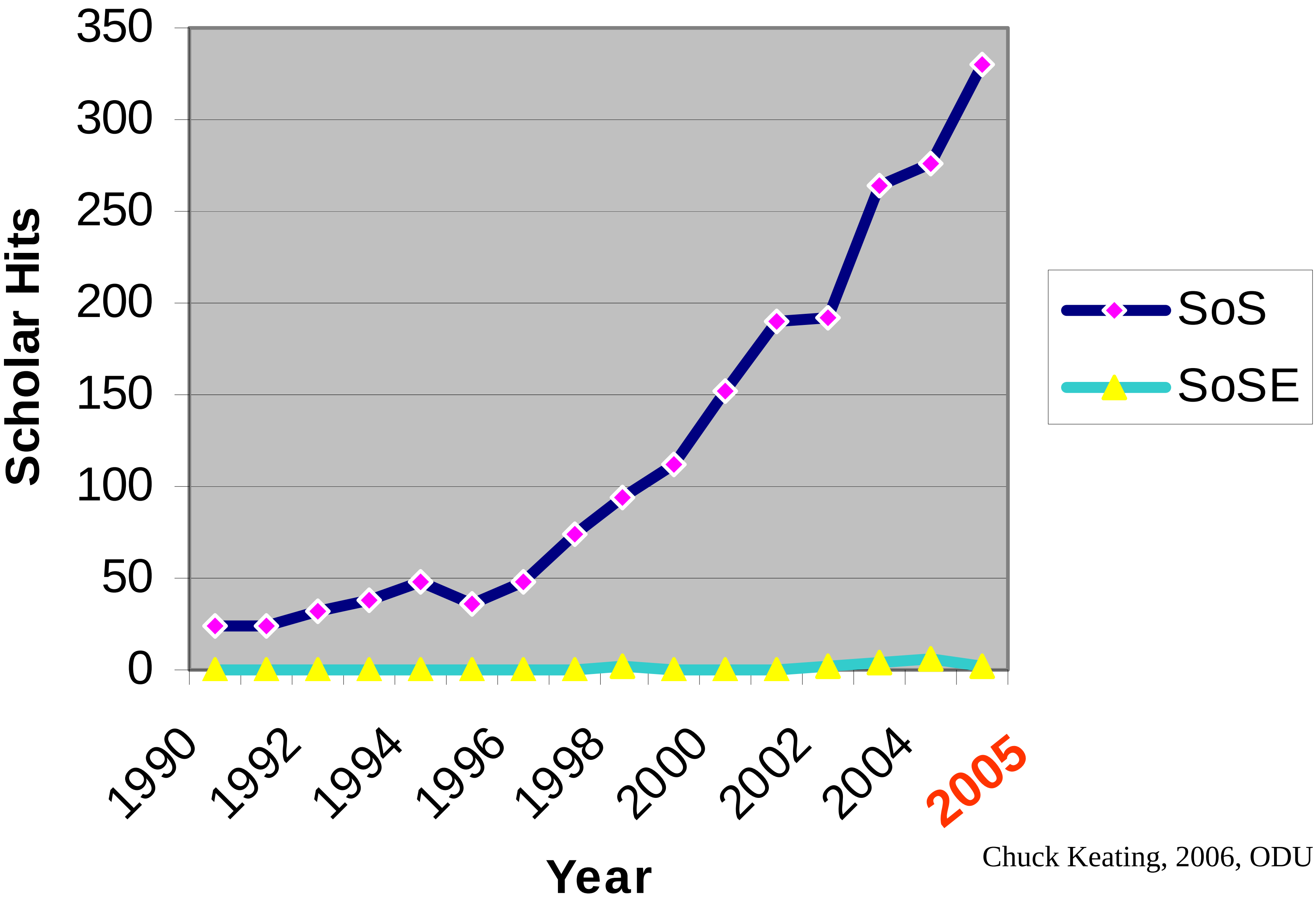
6. SoS is a complex system consisting of an integration of other complex systems with a unified goal --- improve performance measures. E.g.: Cost, robustness, reliability, etc.

Application: Environment, Energy, Defense, etc.. (Jamshidi, 2005)

System of Systems - Introduction

- Changing Aerospace and Defense Industry
- **Emphasis on “large-scale systems integration”**
  - Customers seeking solutions to problems, not asking for specific vehicles
  - **Mix of multiple systems capable of independent operation but interact with each other**
  - Emerging System of Systems Context

SoS: Increasing Popularity

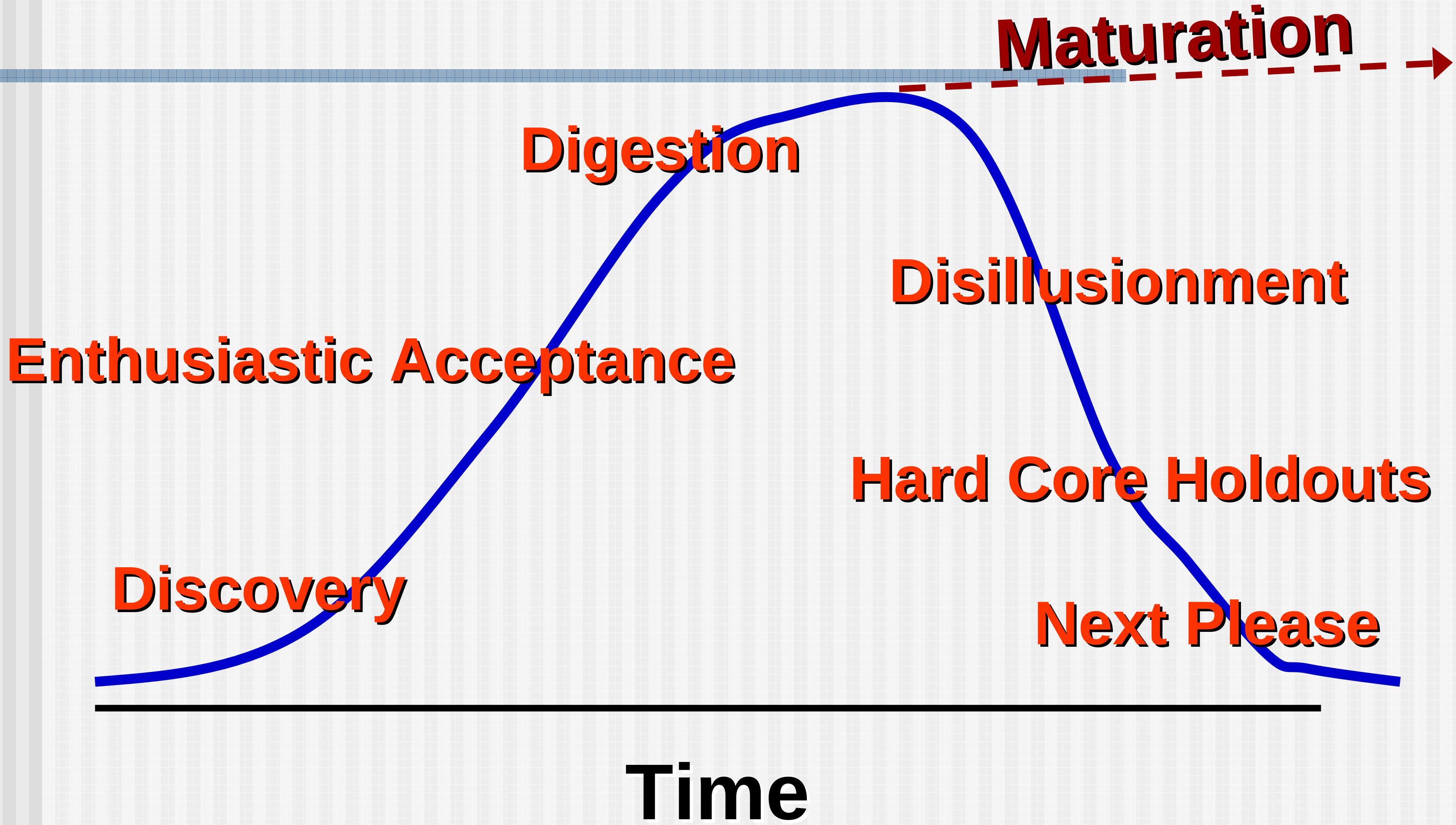


Chuck Keating, 2006, ODU

System of Systems - Introduction

- Is SoS a Fad or real?

Life Cycle of a Fad



Keating 2006

System of Systems

- **SoS**: A metasystem consisting of multiple autonomous embedded complex systems that can be diverse in:
  - ✓ **Technology**
  - ✓ **Context**
  - ✓ **Operation**
  - ✓ **Geography**
  - ✓ **Conceptual frame**
- An airplane is not SoS, an airport is a SoS.
- **A robot is not a SoS, but a robotic colony (a swarm) is a SoS**
- Significant challenges:
  - **Determining the appropriate mix of independent systems**
  - **The operation of a SoS occurs in an uncertain environment**
  - **Interoperability**

System of Systems PROBLEM THEMES

1. Fragmented Perspectives
2. Lack of Rigorous Development
3. Lack of Theoretical Grounding
4. IT Dominance
5. Limitations of trad. SE single system focus
6. Whole Systems Analysis

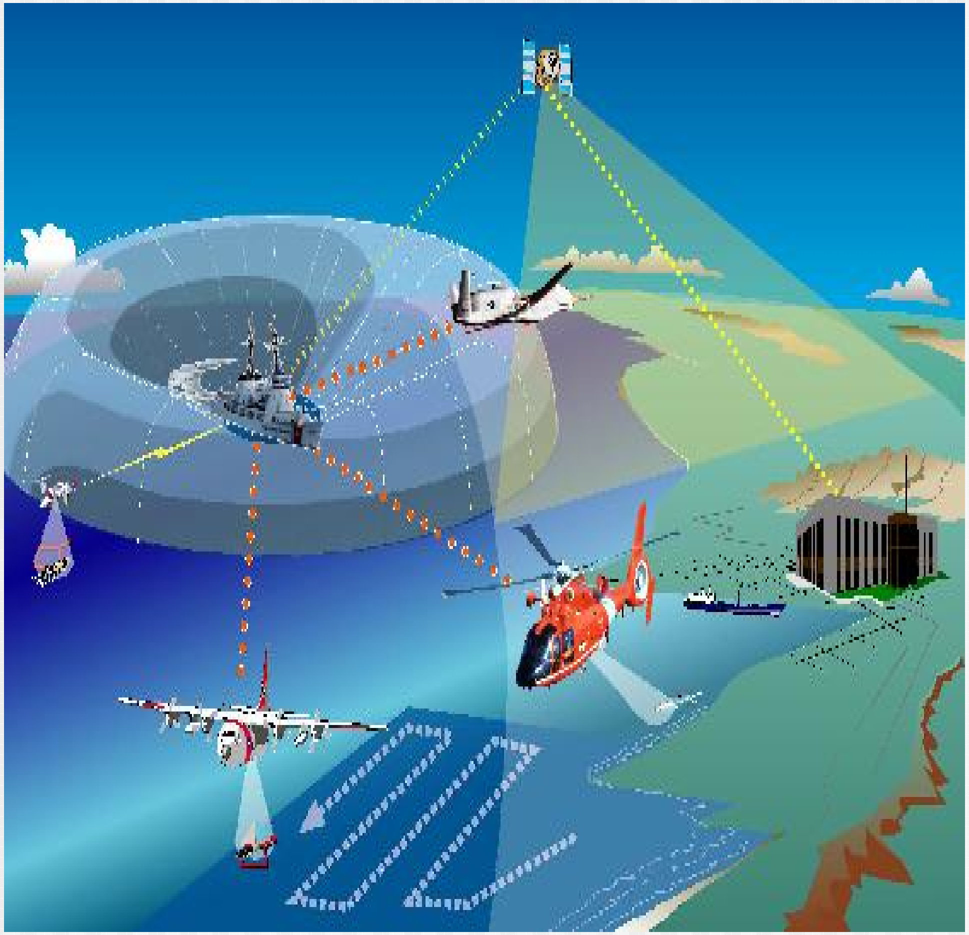
Keating, et al., 2003

Application Domains of System of Systems

1. Planet Earth - GEOSS
2. MILITARY – coast guard deep water, future combat missions, etc.
3. SPACE – robot colonies, formation flying objects
4. National Security
5. Homeland Security
6. Environment
7. Energy
8. Sensor Networks

EMERGING CONTEXT: SYSTEM OF SYSTEMS

- Meeting a need or set of needs with a mix of *independently operating* systems
  - New and existing aircraft, spacecraft, ground equipment, other independent systems
- System of Systems Examples
  - **Coast Guard Deepwater Program**
  - FAA Air Traffic Management
  - Army Future Combat Systems
  - Robotic Colonies



Global Earth Observation System of Systems

GEOSS

Courtesy – Jay Pearlman, Boeing

What is GEOSS?

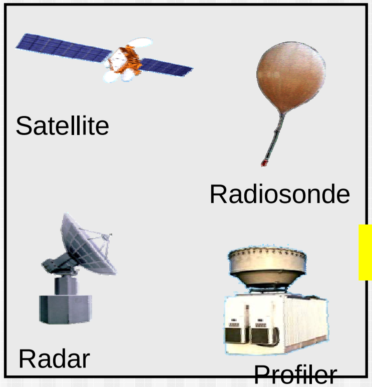
Address the need for timely, quality, long-term, global information as a basis for sound decision making.

- **Improved coordination of strategies and systems for Earth observations to achieve a comprehensive, coordinated, and sustained Earth observation system of systems;**
- **A coordinated effort to involve and assist developing countries in improving and sustaining their contributions to observing systems, their effective utilization of observations and the related technologies;**
- **The exchange of observations recorded from *in situ*, air full and open manner with minimum time delay and cost**

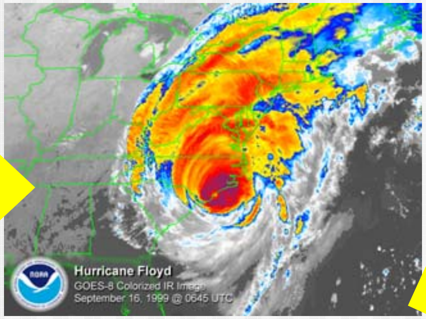
Courtesy – Jay Pearlman, Boeing Co.

SoS Example - Weather Ocean and First Responders Systems

Measurements & Analysis

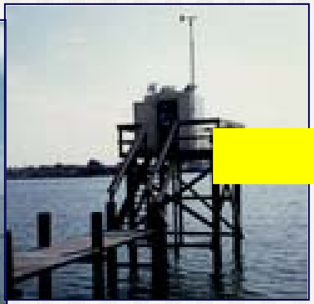


System Products



Responders' Information

Weather Systems



California Pictures

Integrated Storm Impact & Response

Courtesy – Jay Pearlman, Boeing Co.

Ocean State Systems

What is a system of systems

Retail businesses

Freeways

Transportation SoS: Roads +GPS+ ONSTAR

IPOD

Unanticipated benefits of SoS extension beyond MP3 player (Blogs, PODCAST) or Internet purchases

Aircraft

Nine GEOSS Societal Benefit Areas

Natural & Human Induced Disasters

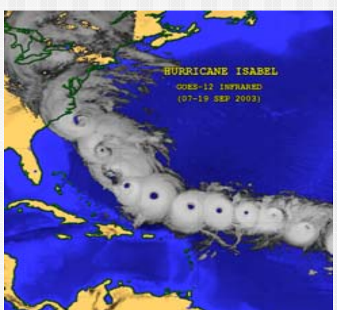
Water Resources

Ecosystems

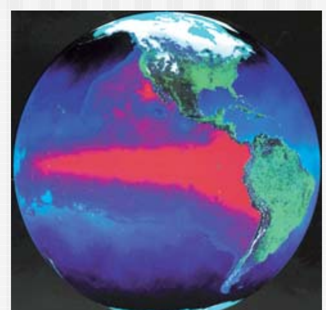
Human Health & Well-Being

Energy Resources

Sustainable Agriculture & Desertification



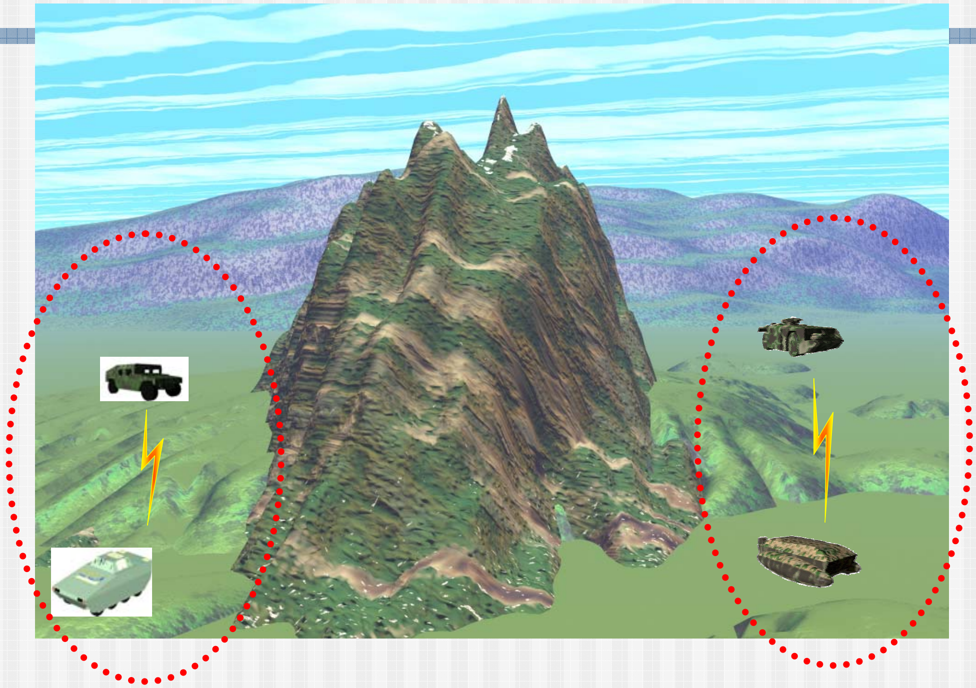
Weather Information and Forecasting



Climate Variability & Change

Oceans

Consider The Following



(1) A Deployed Force (and Network) Partitioned Due to Terrain Features

(2) Perform Analysis Which Yield the Initial Set of Links

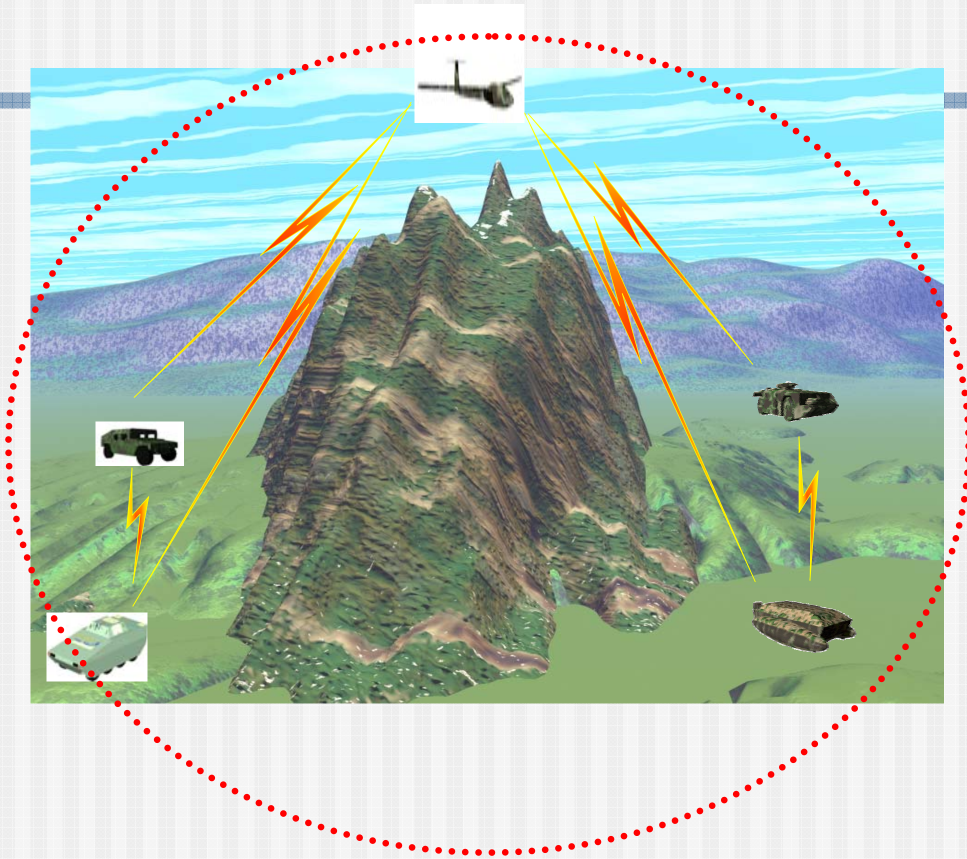
(3) Local Connectivity is Achieved, but the Forces (and Network) Are Still Partitioned

(4)
Technical Enablers: Algorithms, Power Profiles
Example Data Sources: DoDAF, Systems Book, etc
Scenario Cost Implications: "$Baseline 1"

(5) To Meet Operational Need, Consider Introducing an Airborne Comm Asset (UAV Flying Overhead or a Satellite Link, Depending on Coverage Constraints)

Courtesy Monica Stapleton, US Army

Consider A Change In Operations



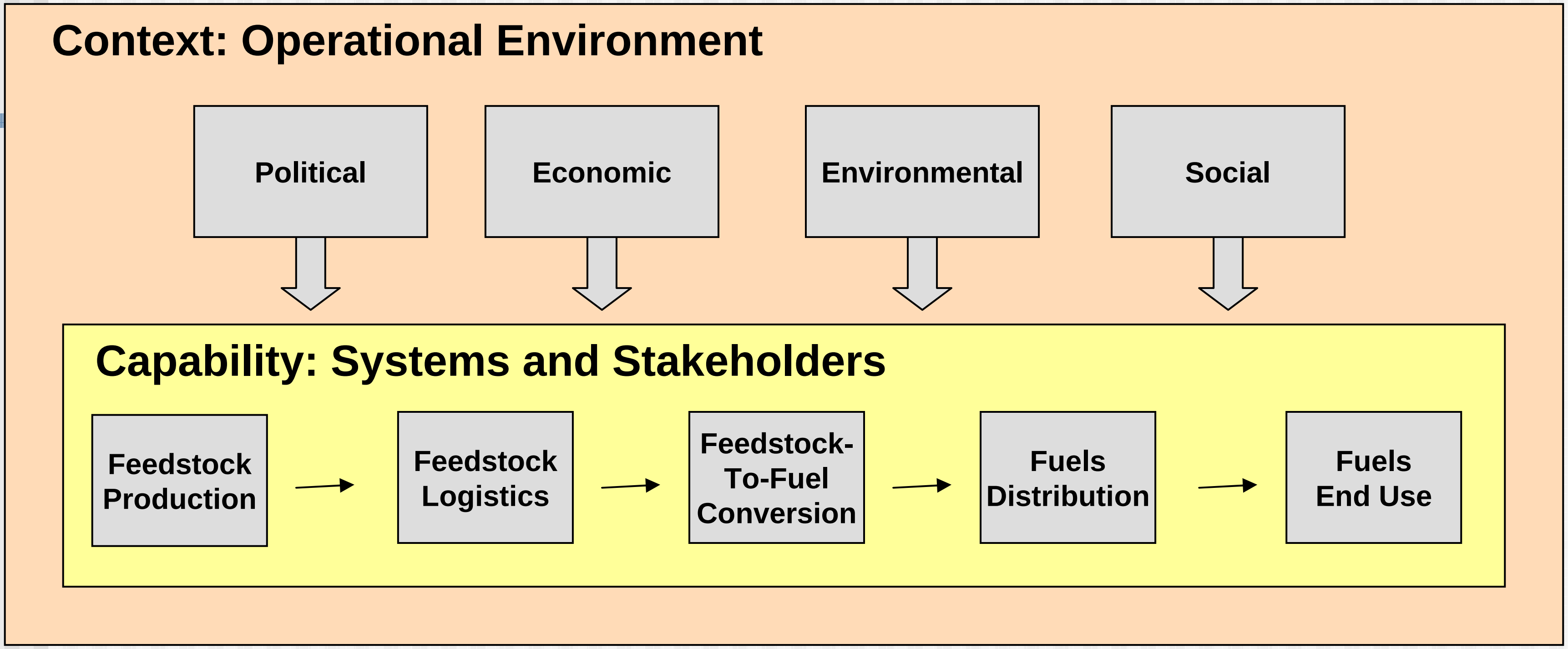
(1) Introduce a UAV Flying Overhead

(2) Perform Analysis to Determine Connectivity of Platforms Within Communications Range

(3) Networks Are Merged to Provide Full Network Connectivity

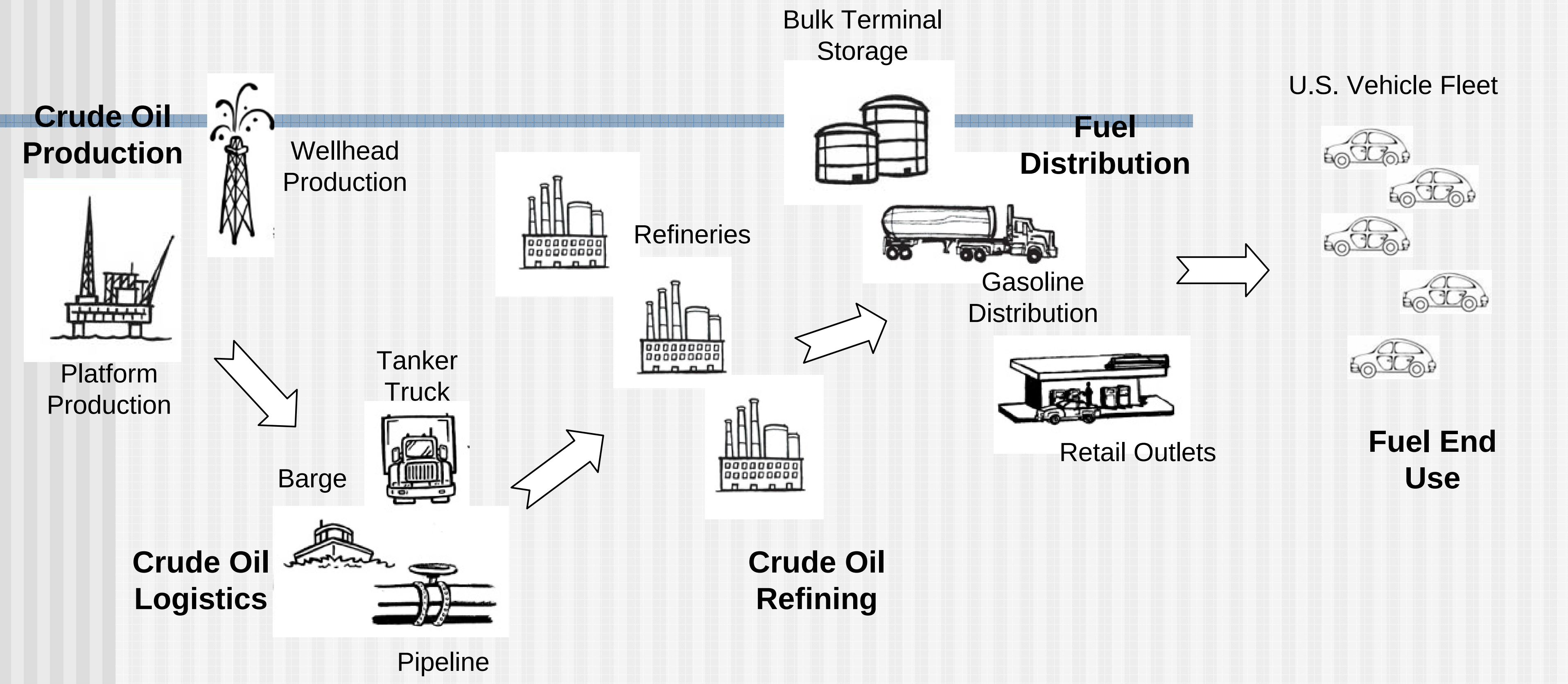
(4)
<u>Technical Enablers</u>: UAV With Comm Relay Package, Maintenance Infrastructure (Refueling, Launch/Retrieval Mechanisms)
<u>Data Sources:</u> DoDAF, Systems Book, etc
<u>Scenario Cost Implications</u>: "$Baseline 1 + UAV"

Energy Fuels for US Transportation

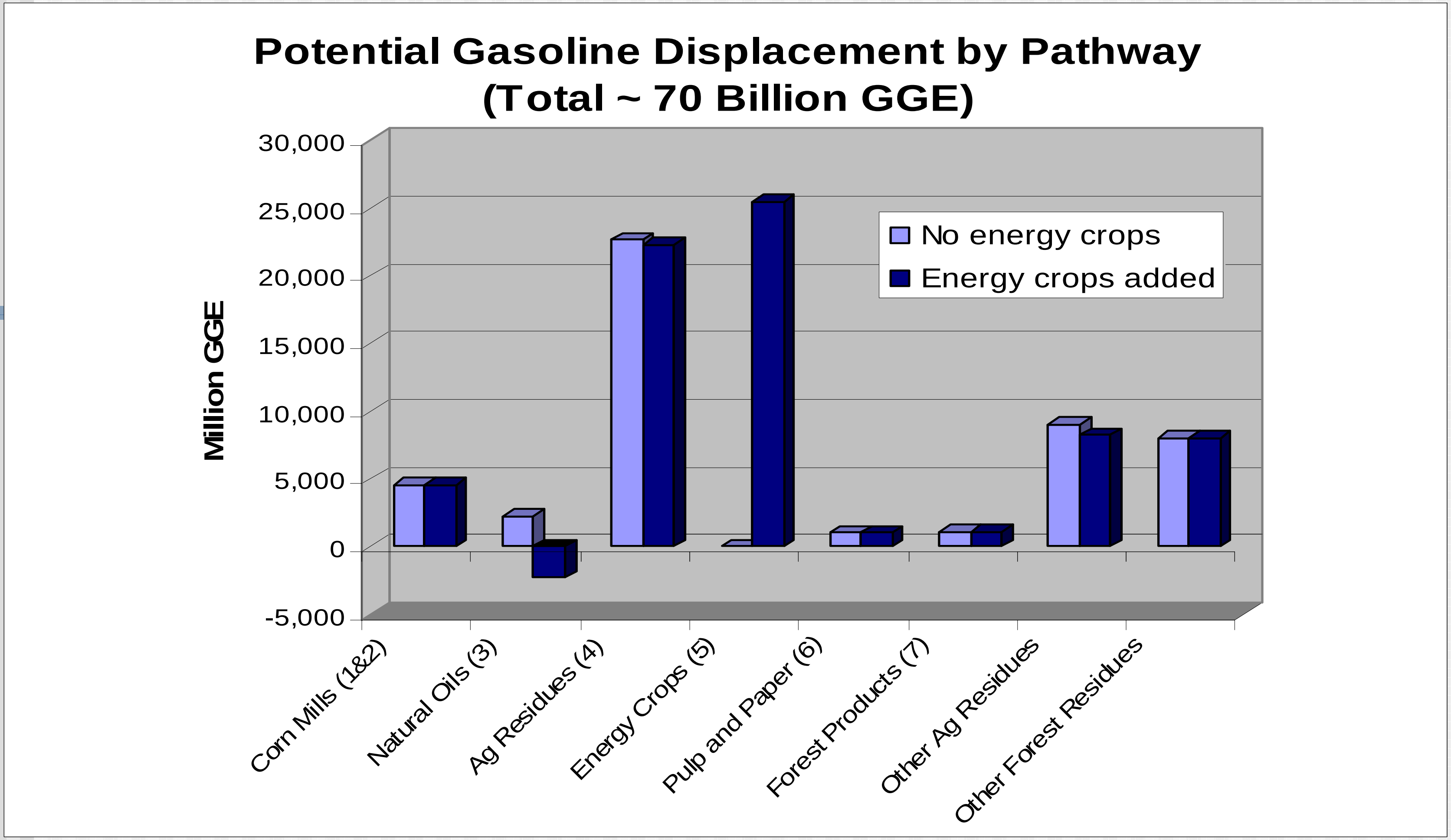


Transportation Fuel System of Systems - The transportation fuel SoS can be represented here and described in terms of capability and context.

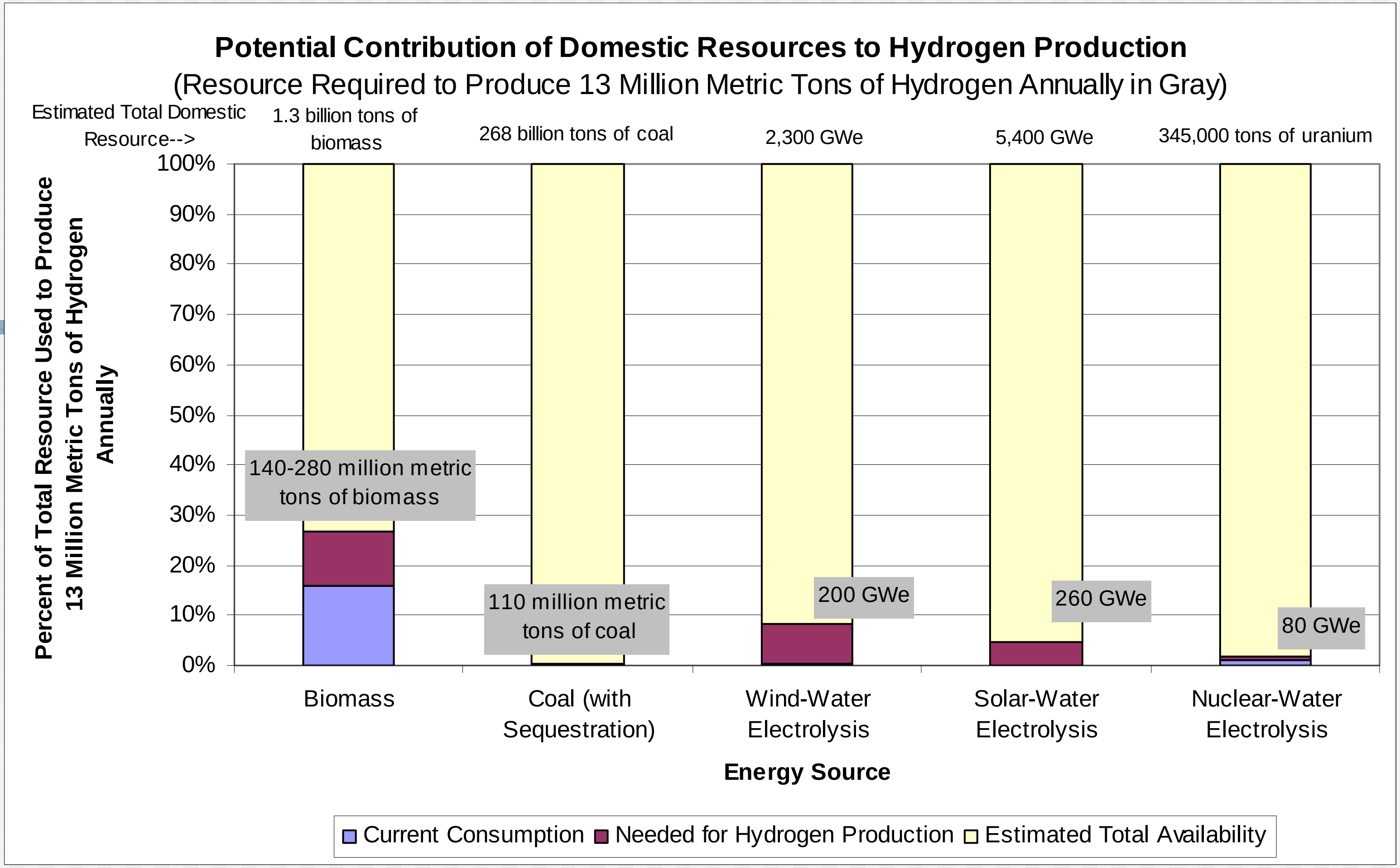
(Duffy et al. 2008)



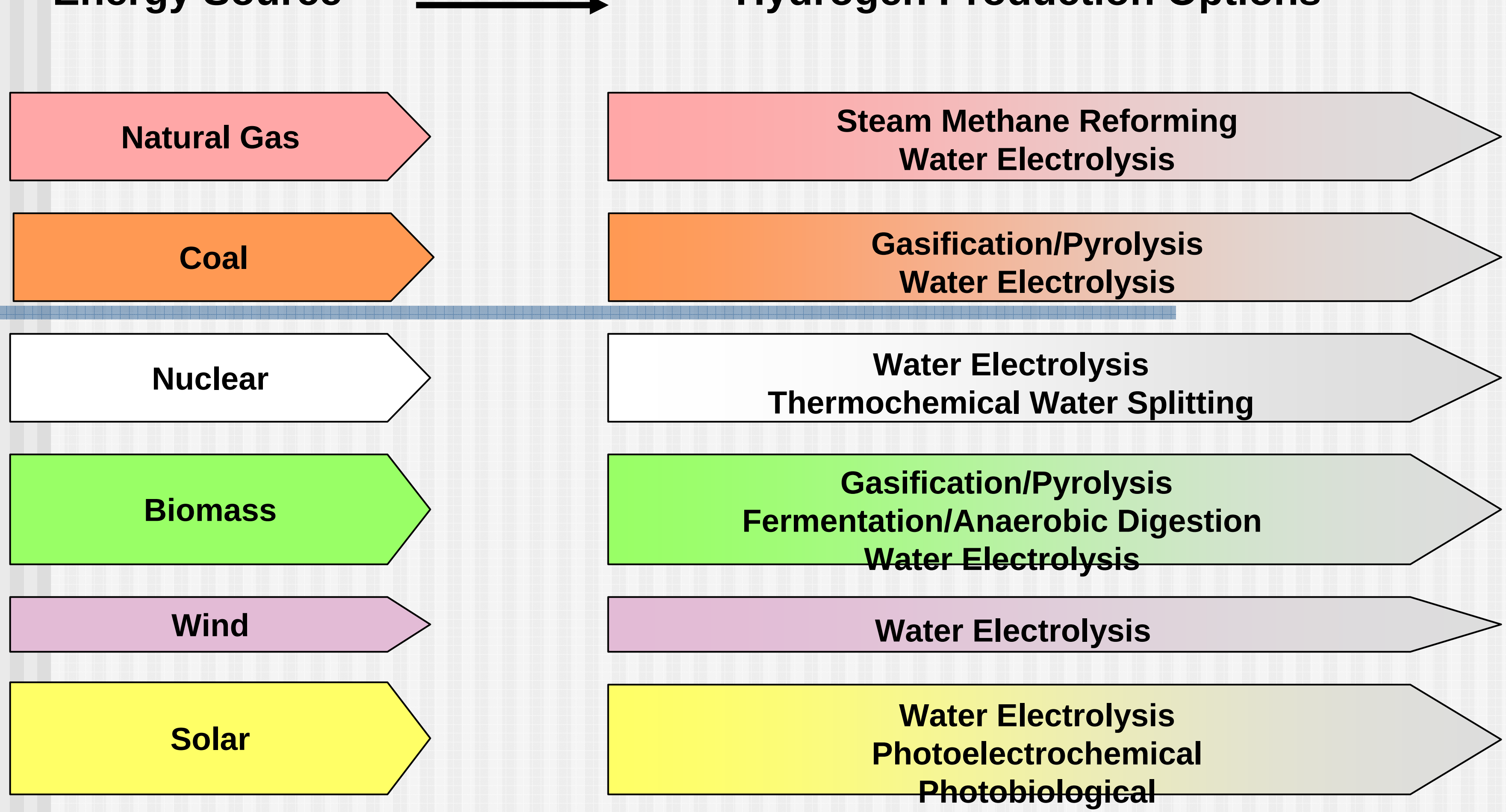
The primary objective of each system is described in the context of the existing transportation SoS, which moves crude oil from its source to the final processed fuel used by consumers, (Duffy, et al., 2008)



In 2030, a variety of sustainable, cost-effective, regionally-available, lignocellulosic feedstocks will be integrated into the current agricultural and forestry industries and available for biofuels production. Agricultural resources (corn stover, straw, switchgrass) and forest resources (forest thinnings, logging residues, urban wood residues) dedicated to biofuels production will total 600 million dry tons. The feedstocks with the greatest ultimate ethanol production potential include agricultural residues, perennial energy crops and forest residues. **Duffy, et al. 2008**

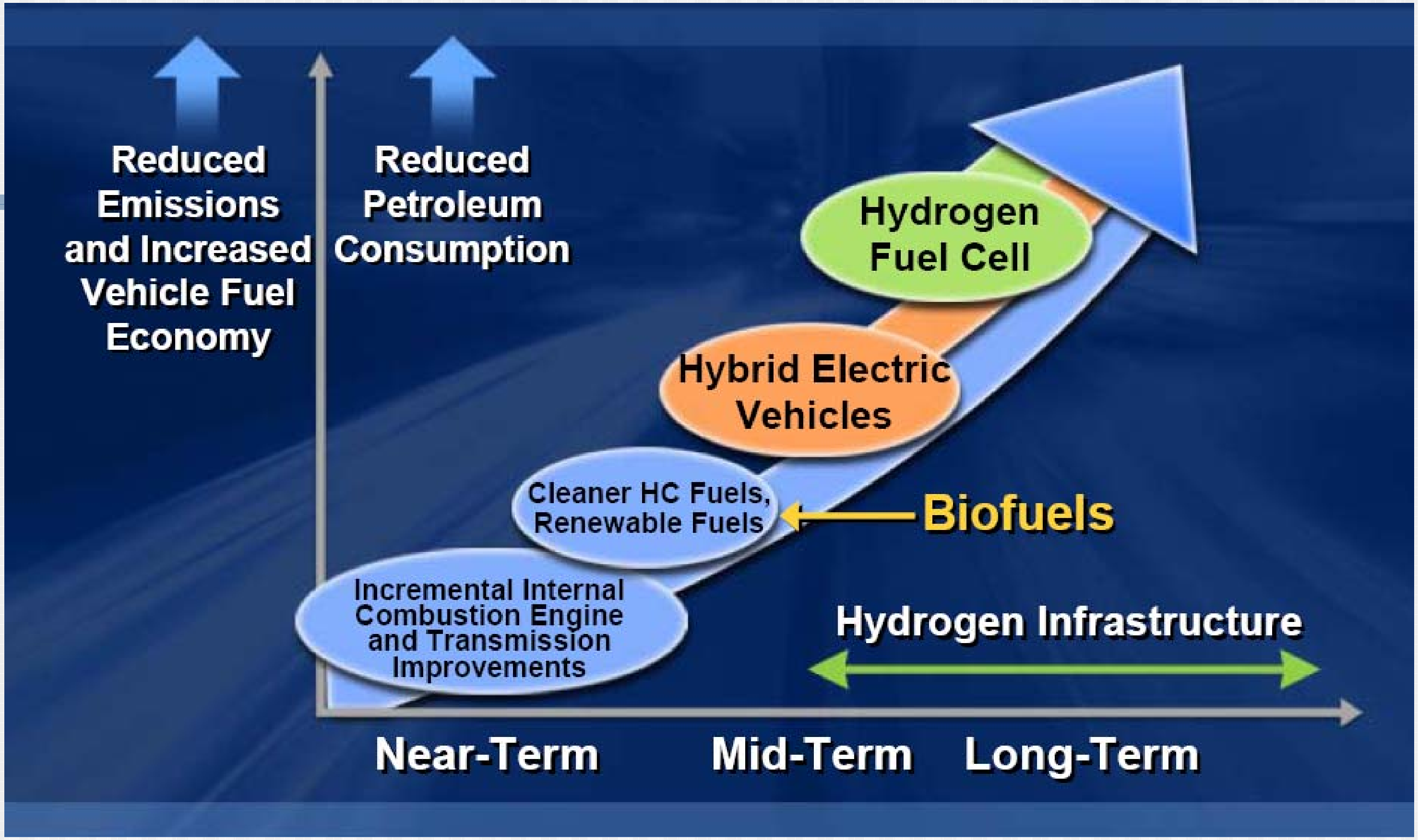


In 2040, a variety of domestic feedstocks will be available for hydrogen production including biomass; coal (with carbon sequestration); water in combination with electricity-generating renewables such as wind and solar power, as well as nuclear power. By then, the amount of each resource required to produce 13 million metric tons of hydrogen (20% of the total projected hydrogen demand of 64 million metric tons) (Duffy, et al. 2008)



Hydrogen Production System - In 2040, 64 million metric tons of hydrogen will be produced in centralized facilities in remote locations, in power parks and fueling stations in our communities, in distributed facilities in rural areas, and at customers' homes and businesses. Thermal and electrochemical processes will use fossil fuels, biomass, or water as feedstocks and release little or no carbon dioxide into the atmosphere. (Duffy, et al. 2008)

A Future Vision for Transportation



No single solution is envisioned for the future and the “best” solution (optimum mix of technologies and systems) will likely change over time.

A phased approach will allow new energy systems to be integrated into the existing transportation fuel infrastructure as technologies and systems advance to the point of commercial readiness.

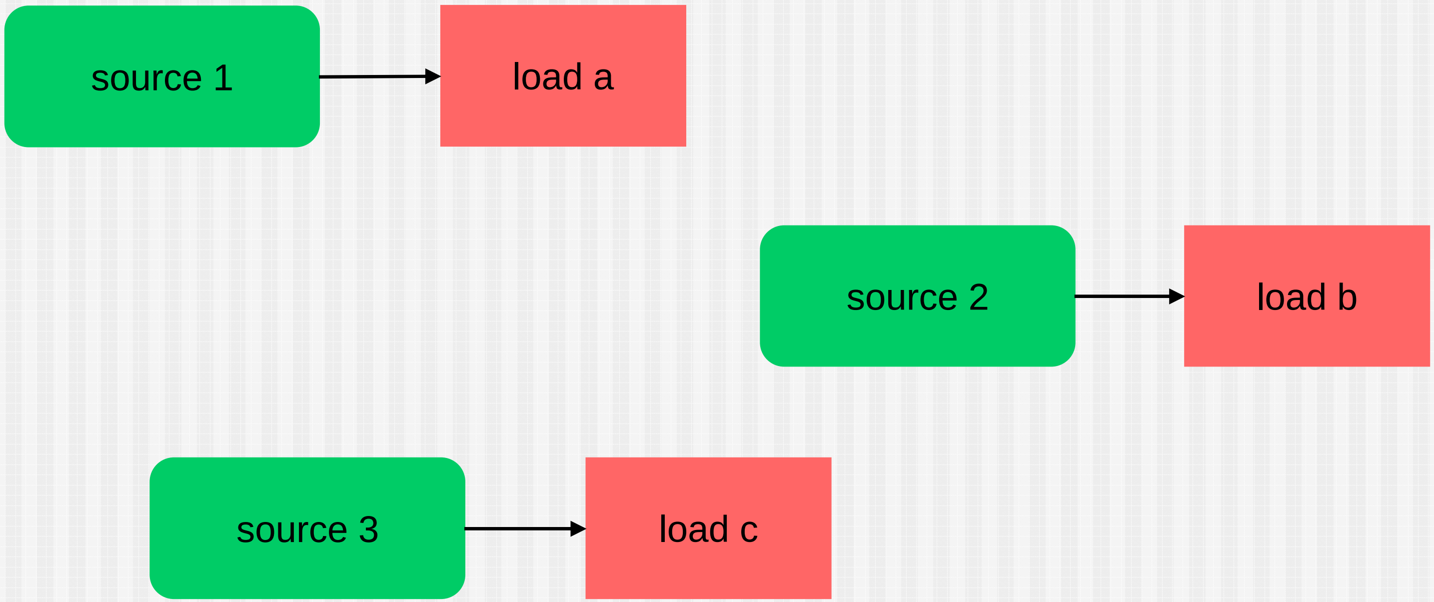
Microgrids

A microgrid is a collection of small, non-collocated electric power sources, storage devices, and power conditioners interconnected to meet the power consumption needs of a designated community.

The essential difference between microgrids and other configurations is the cooperative operation of the sources despite their physically separation.

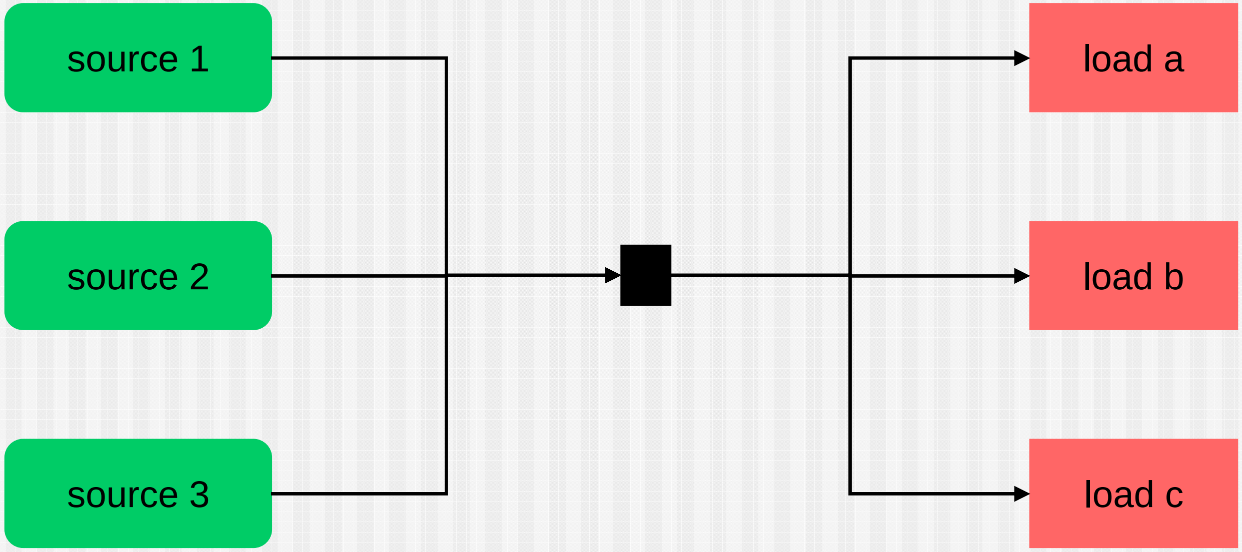
Energy Information Administration reports 28,744 dispersed and distributed generators with a total capacity of 14,532 MW *Dispersed* generators are not connected to the grid; *distributed* generators are.
http://www.eia.doe.gov/cneaf/electricity/epa/epat2p7c.html
(Phillips, 2008)

Microgrids



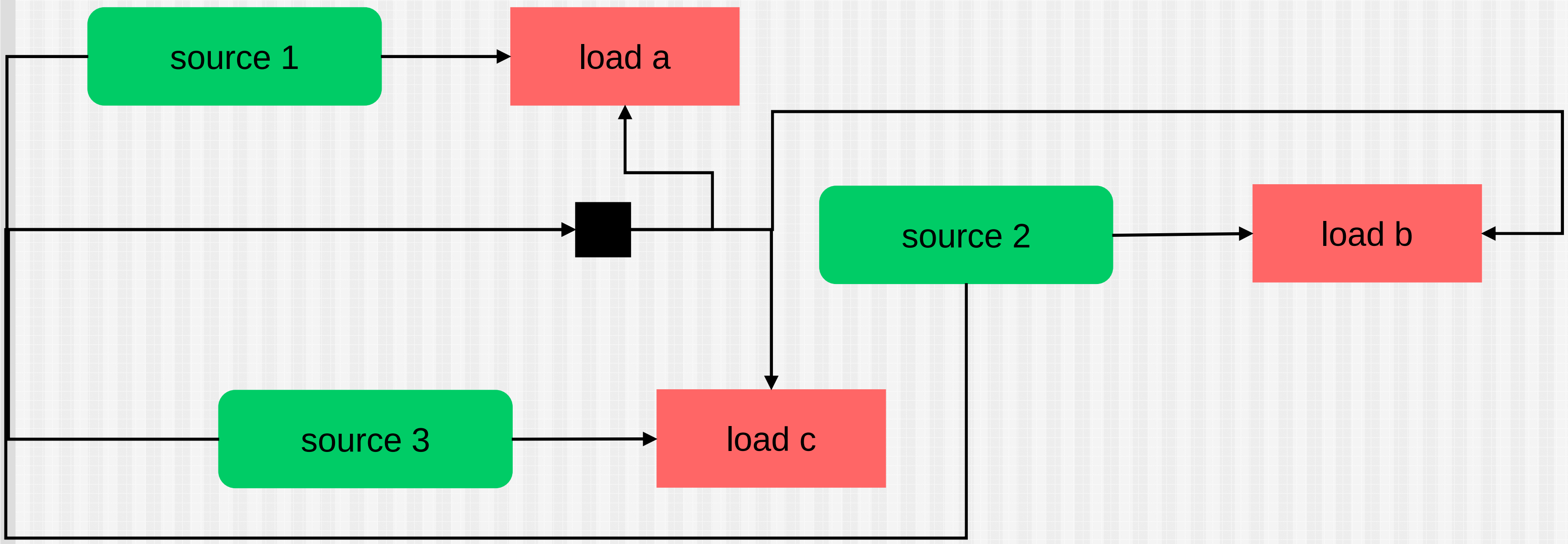
In an *independent* or *backup* setting, power is delivered to each load from a local source along a dedicated path. Loads are normally unsatisfied when sources fail.

Microgrids, 2



In a *Powerplant* setting, power is delivered to distributed loads from a set of collocated sources via a power distribution system. Power is normally transmitted over long distances.

Microgrids, 3



In a microgrid, primary power is delivered to distributed loads from local sources as in 1st configuration, but an ancillary distribution and energy management system delivers power efficiently in low load situations and supplies important loads when their local source fail.

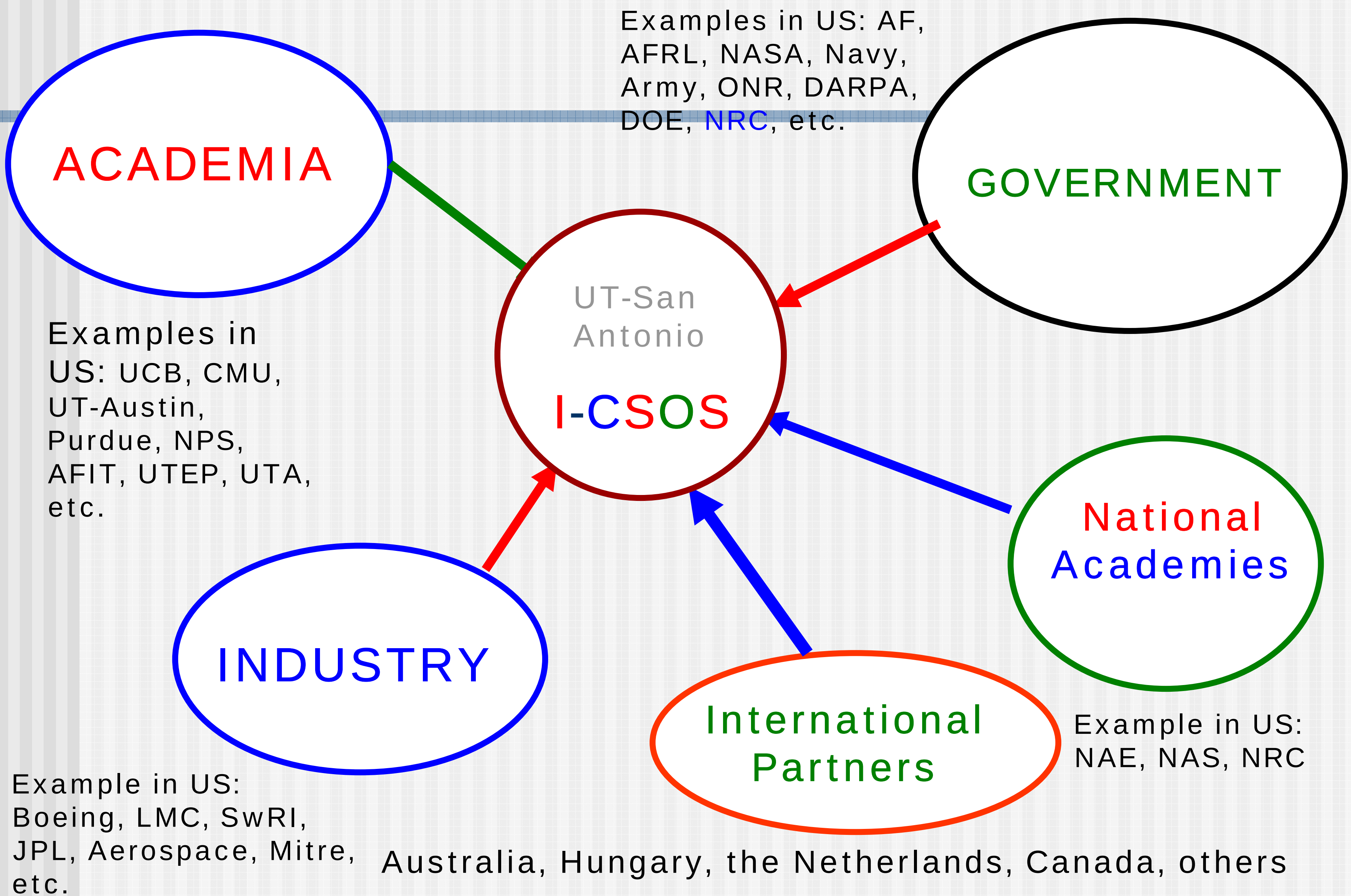
Microgrids, 4

Penetration of microgrids requires automation of their day-to-day operation.

Advances in power control technology have enabled the essential connect-supply-shutdown-disconnect operations without significant higher-level concern.

What is needed is a unified logic process to apply the appropriate algorithms for deciding which sources should be providing power, how the power system should be reconfigured to isolate faults, what steps to take to recover from upsets, how to restore the system to operation after primary failures, what to do to halt or slow cascading failure, and when to separate from the primary grid when blackout threatens.

Partners of the Consortium

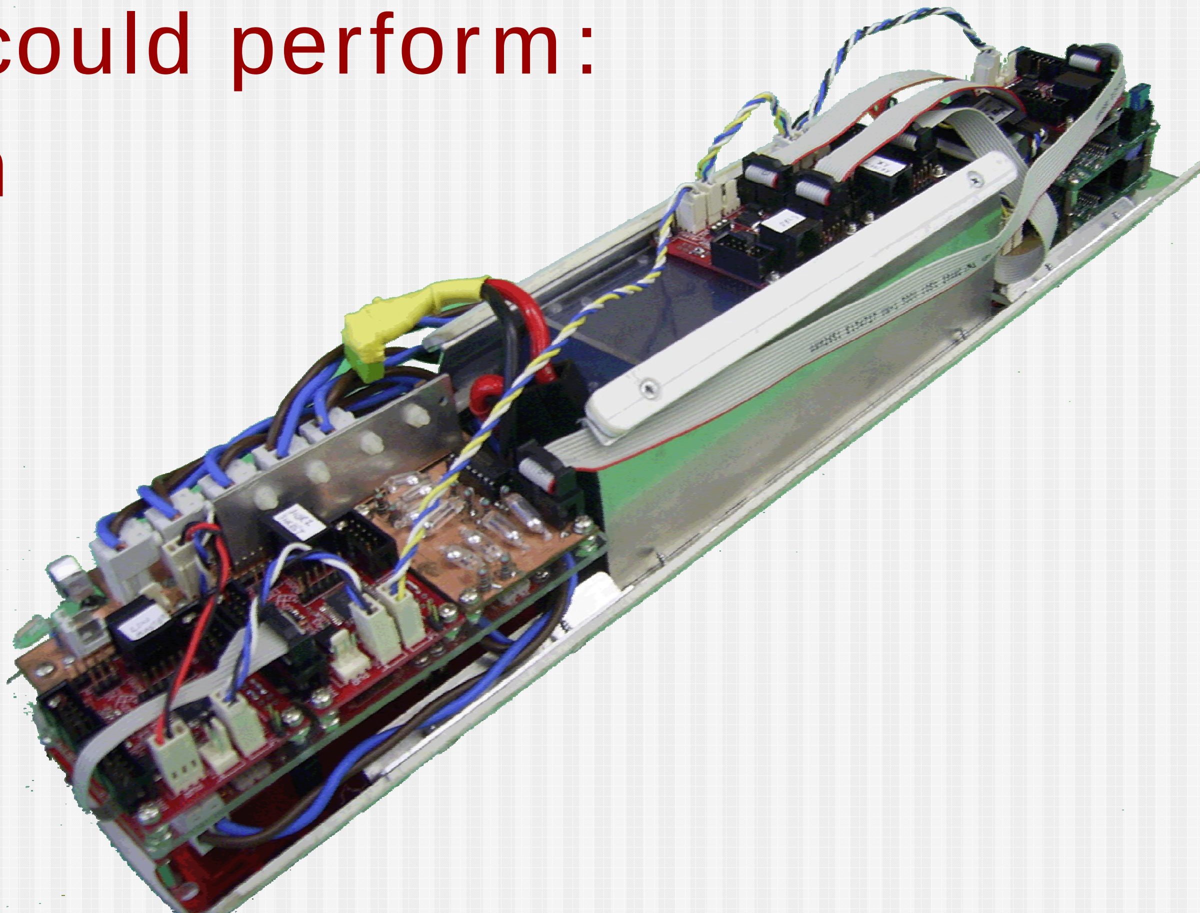


PBS TEXAS STATIONS DEMO

Through remote sensing capability the master rover picks up the alarm

Underwater Swarm Robotics Applications

- A swarm could perform:
- Inspection
- Search
- Rescue
- Mining
- Salvage



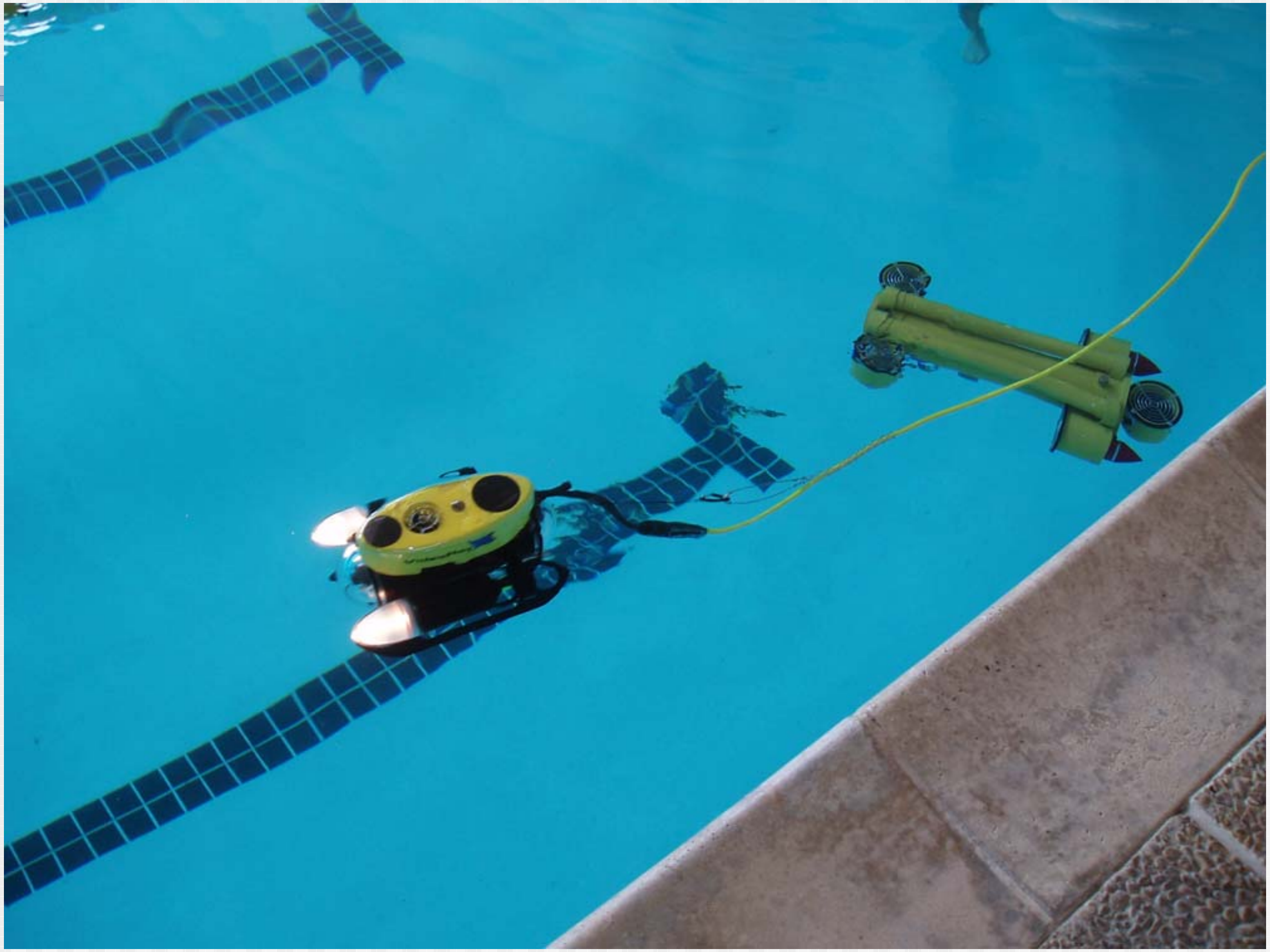
Underwater Swarm Robotics Requirements

- Low cost/modular underwater robots
- Obstacle detection/avoidance sensors
- External/inertial navigation
- Inter-robot communications

Underwater Swarm Robotics Problems

- WATER!!
- Radio does not work well underwater
- Sonar communications is very slow
- GPS does not work under...
  inertial navigation ...
- Visibility can be very ...
- 3D environment
- Electricity/Water don't mix

Currently …



A system of UWV – underwater vehicles for sensing and security

Currently …

A system of UWV – underwater vehicles for sensing and security

UAV Project
ACE LAB

Presented by: Aldo Jaimes

Fixed air wing

- Main Objective – Swarm of UAV
- **First objective – Autonomous flight**
- **Support – Scott Beatty (Edwards AFB) / Chris Mentzer (SwRI)**

Staff ACE LAB

- **Research Team (spring 2008) – 9 students**

Fixed air wing

- Work developed

  Flight simulator

  Practice airplane

  Research UAV information

Fixed air wing

UAV Micropilot

Characteristics:
Wingspan 69", wing area 793 sq inches, weight 6.5 pounds
1 HP, 2 cycle glow engine
MP2028g autopilot installed and pre-programmed
Cargo space approximately 70 cubic inches, ~3.5" x 7.5" x 3", max payload 2 pounds
8 ounce fuel capacity for 10 to 20 minute duration

Fixed air wing

RC airplane

Characteristics:
Wingspan 80 in
Wing Area 1180 in²
Fuselage Length 64- 3/4 in
Flying Weight 6 - 6.5 lbs

Characteristics:
Wingspan 70 in
Wing Area 900 in²
Fuselage Length 56 in
Flying Weight 5.5 lbs

Control board and sensors

Control board – Gumstix / Ciclone III
IMU – 3DM-GX2

GPS
Modem

Fixed air wing

- **Identification of topics**

  Control Communication Navigation

- **Future work**

  Load analysis

  Payload analysis

  Work in teams

Fixed air wing

- Identification of project topics

  Control Communication Navigation

- Future work

  Load analysis

  Payload analysis

  Work in teams

PBS TEXAS STATIONS DEMO

An alarming condition is observed in sensor network

PBS TEXAS STATIONS DEMO

Through remote sensing capability the master rover picks up the alarm

PBS TEXAS STATIONS DEMO

Haptic Controlled Rover requests an scout rover to check the authenticity of danger

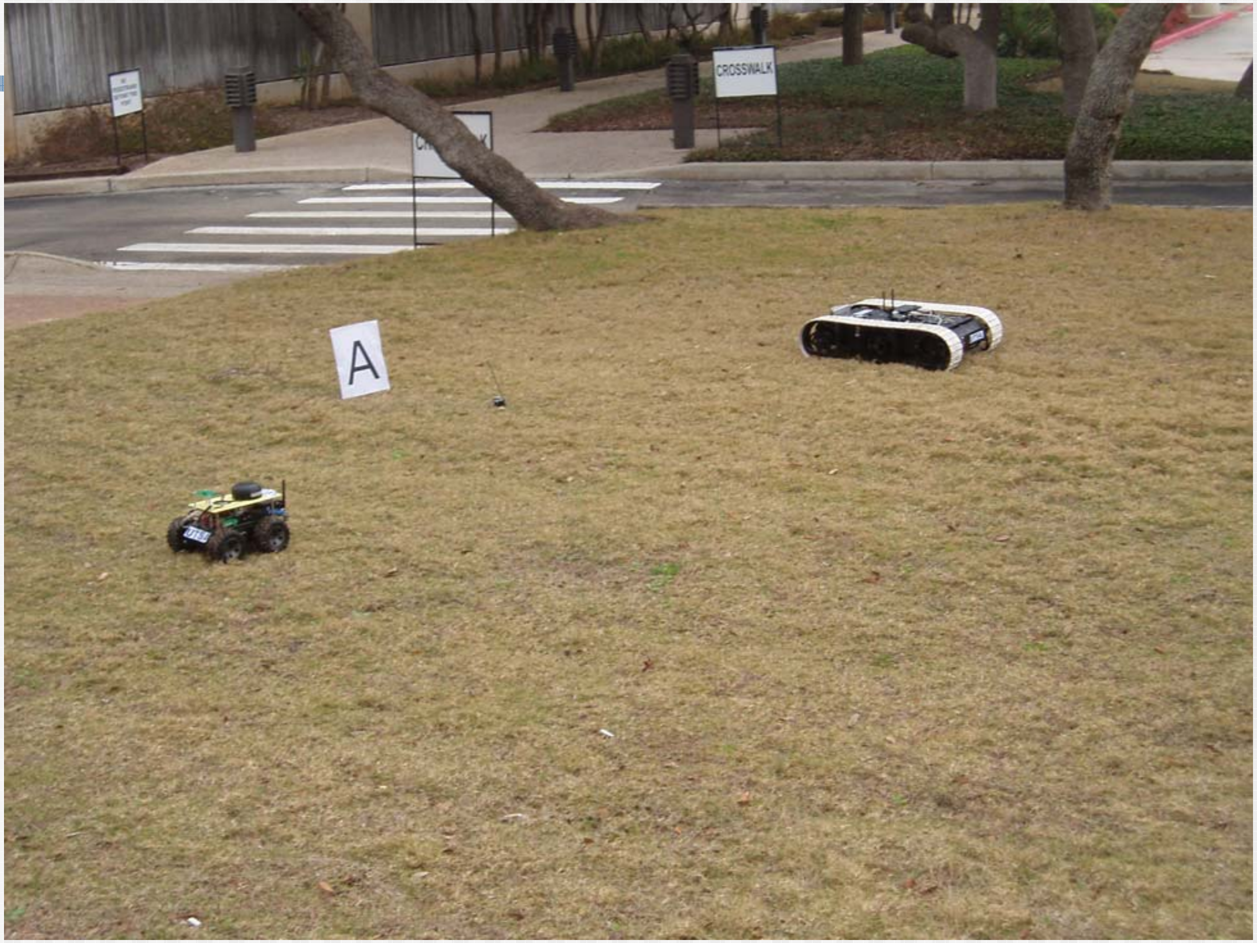
PBS TEXAS STATIONS DEMO

Scout Rover is on its way under GPS navigation to check on the danger

PBS TEXAS STATIONS DEMO

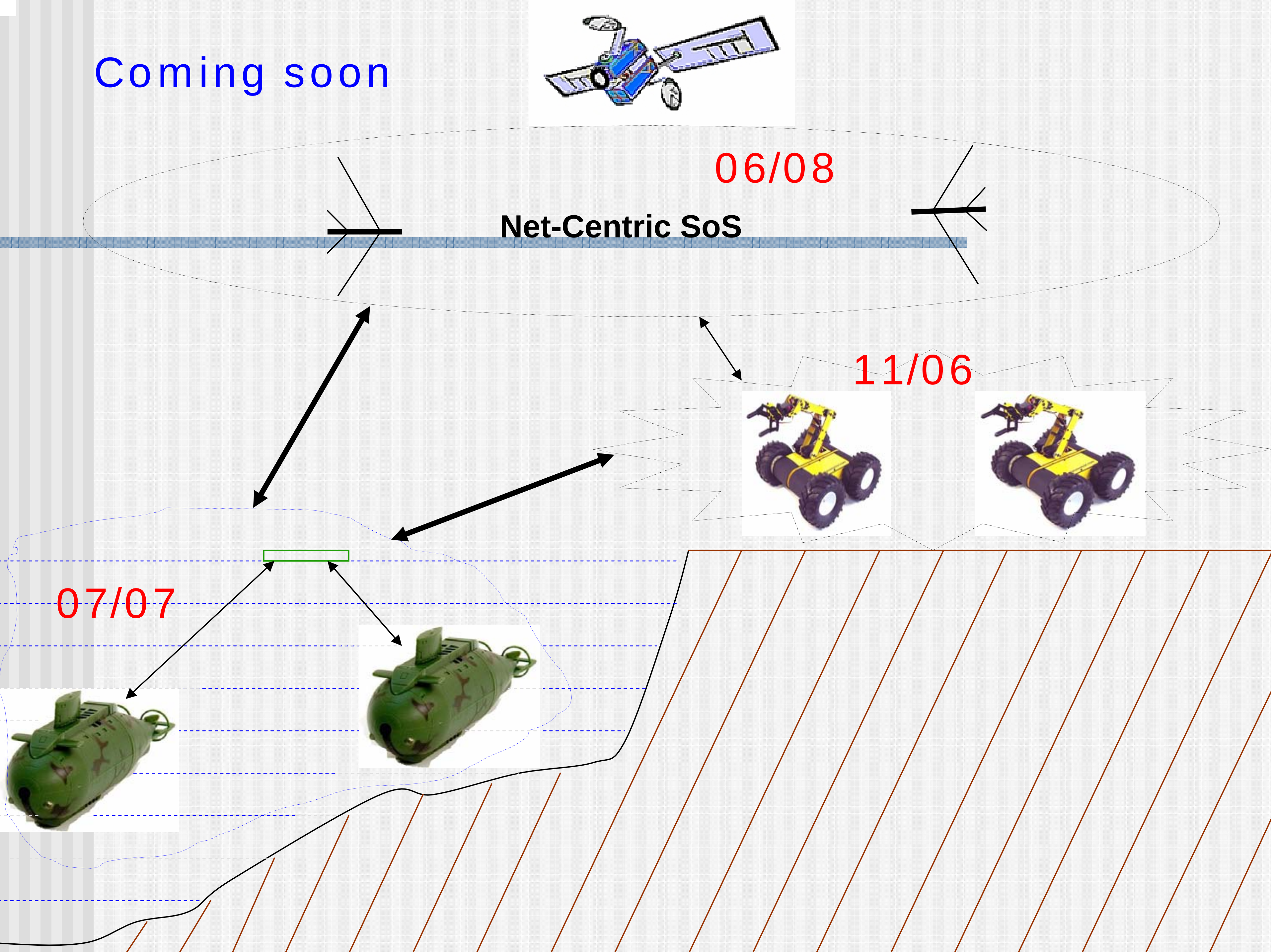
Scout Rover has found the danger spot

PBS TEXAS STATIONS DEMO



Scout & Base Rovers meet finally at the danger spot

Coming soon



Two upcoming Books on SoS …

Two edited volumes: i) *System of Systems Engineering – Innovations for the 21st Century*, Wiley & Sons, NY, 2008. (M. Jamshidi, ed.)

ii) *System of Systems - Principles and Application, Taylor* & Francis (CRC), Boca Raton, FL, USA, 2008

(M. Jamshidi, ed.)

Questions/Discussion

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