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HMCRP Project HM-04: Emerging Technologies Applicable to Hazardous Materials Transportation Safety and Security

National Transportation Stakeholders Forum

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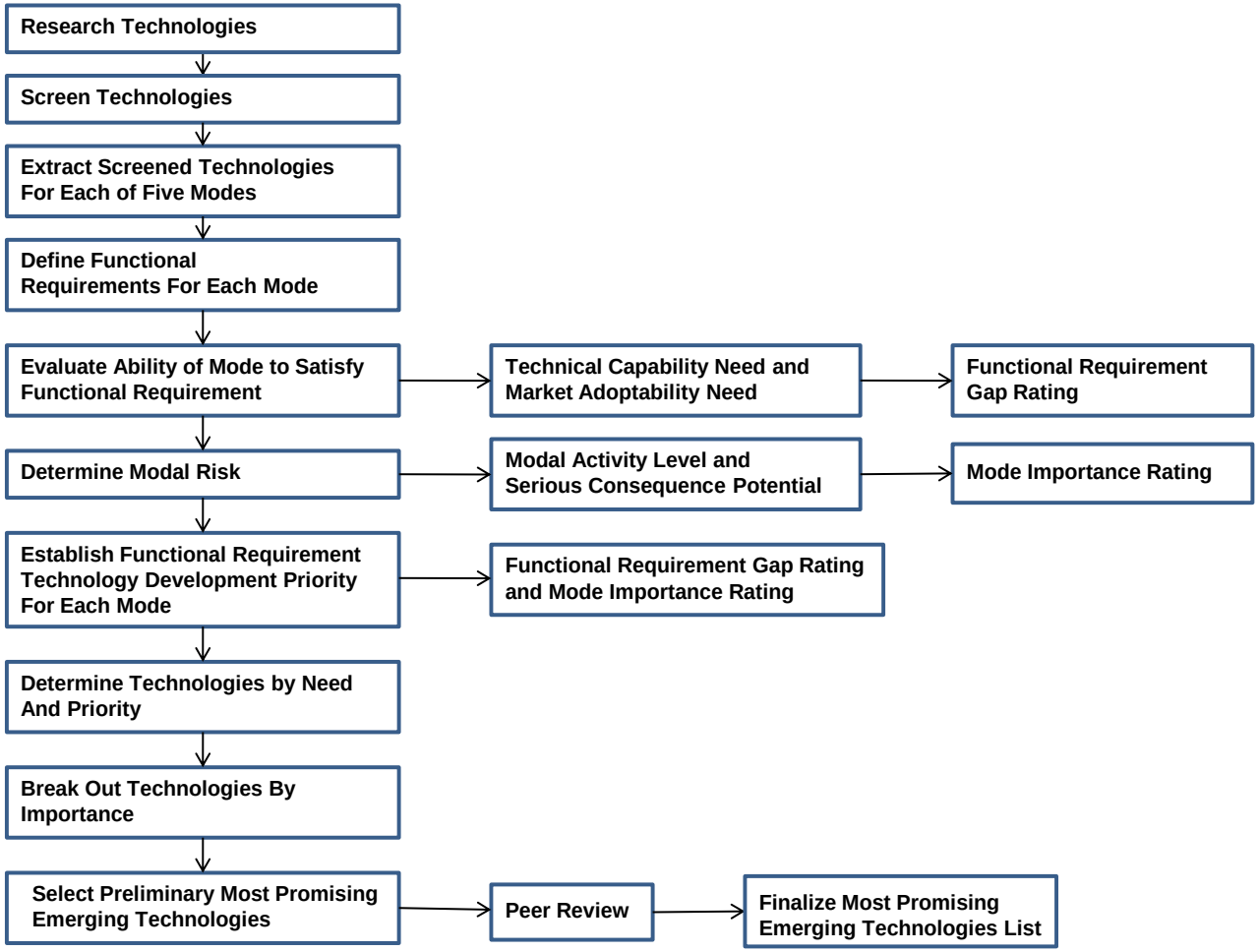
Project Objectives

- Develop a list of near-term (less than 5 years) and longer-term (5–15 years) technologies that are candidates for enhancing safety and security of Hazmat transportation;
- Identify emerging technologies that hold the greatest promise (in terms of effectiveness) of being introduced during these near- and longer-term spans; and
- Identify potential impediments to and opportunities for their development, deployment, and maintenance (e.g., technical, economic, legal, and institutional).

Process for Selecting Most Promising Emerging Technologies



Functional Requirements

- Generic requirements applicable to all 5 transport modes:
  - A. Package Integrity
  - B. Equipment Reliability
  - C. Operator Performance
  - D. Hazmat Commodity Identification/Awareness
  - E. Communication
  - F. Tracking
  - G. Security
  - H. Emergency Response
- Requirements that apply only to the Highway and Rail modes:
  - I. Vehicle Identification
  - J. Hazmat Route Restrictions
- Requirement that applies only to the Highway mode:
  - K. Driver Identification Known

Functional Requirement Gap Rating – Rail

Market Adoptability Need Rating	Low	Medium	High
High	**Medium**	**High** F. Tracking	**High**
Medium	**Low** C. Operator Performance	**Medium** A. Package Integrity B. Equipment Reliability	**High** G. Security
Low	**Low** D. HM Commodity ID I. Vehicle ID J. HM Route Restrictions	**Low** E. Communication H. Emergency Response	**Medium**

Technical Capability Need Rating

Mode Importance Rating

Serious Consequence Potential (Volume Per Shipment)	Low	Medium	High
High	**Medium** Air	**High** Rail Barge	**High**
Medium	**Low**	**Medium**	**High** Truck Pipeline
Low	**Low**	**Low**	**Medium**

Modal Activity Level (Ton-Miles)

Technology Development Priority – Rail

Mode Importance Rating	Low	Medium	High
High	**Medium** C. Operator Performance D. HM Commodity ID E. Communication H. Emergency Response I. Vehicle ID J. HM Route Restrictions	**High** A. Package Integrity B. Equipment Reliability	**High** F. Tracking G. Security
Medium	**Low**	**Medium**	**High**
Low	**Low**	**Low**	**Medium**

Functional Requirement Gap Rating

Technology Need Areas Ranked by Order of Importance

Technology Need Area Ranking	Marine	Rail	Highway	Air	Pipeline	Cross-Cutting	Total High Priority	Total Medium-Low Priority
1. Cargo/Infrastructure Condition Sensors	✓	✓✓	✓✓		xxxxx	xx	5	7
2. Vehicle/Cargo Integrity	x	✓			xx	✓✓✓ x x	4	5
3. Operator Access Control		✓	✓✓✓	xx		x	4	3
4. Vehicle Location Status	✓	✓	✓✓				4	
5. Alert/Incident Notification Systems	✓	✓ x	✓	x	x	xxx	3	6
6. Innovative Power Sources for Vehicle Components	✓	✓	✓			xx	3	2
7. Overcoming Communication Gaps	✓ x	✓✓		x			3	2
8. Advanced Cargo Locks & Seals	✓	✓	✓	x			3	1
9. Cargo Content Identification	✓	✓		xxx		x	2	4
10. Screening & Inspection	✓	✓		x			2	1
11. Operator Condition Monitoring Systems	x			xx			0	3
12. On-Scene Response Capability				xx		x	0	3

Key: ✓ = high-priority functional requirement need
x = medium to low priority functional requirement need

Most Promising Emerging Technologies

- Monitoring & Surveillance Group
  - Networked RFID/GPS/GLS with ubiquitous sensors and cargo monitoring
  - Pressure gauges & chemical detection sensors
  - Fiber-optic/photonic sensors & optical scanners
  - Improved locking with fiber-optic seals, low power RFID, and remote monitoring of seal array
  - Intelligent video tracking & surveillance system
- Alternative Power Generation Group
  - Wireless power
  - Nanopiezoelectronics
  - Plastic thin-film organic solar cells
- Infrastructure Group
  - Container integrity (e.g., armor & self-sealing technologies, engineered metal structures, composites

Most Promising Technology Selections

- Networked RFID/GPS/GLS with ubiquitous sensors and cargo monitoring
  - Multiple sensors tied into a central monitoring site where system control functions also may exist. Ubiquitous sensors refers to the concept of a "system of systems," possibly a nationwide sensor network.
  - Alerts or problems with the cargo condition could be detected by fixed sensors at locations such as truck stops, or even by other vehicles.
- Pressure gauges & chemical detection sensors (category of two related technology needs with functionally similar purposes)
  - Improved sensors (e.g., nanowire technology, color metric barcodes, and gas chromatography) that can accurately detect pressure changes and chemical releases with very low false alarm rates.
  - Capability of embedded sensors to detect anomalous conditions at lower thresholds and higher reliability so that an alert can be automatically generated, which applies to pipelines as well as vehicle cargo.

Most Promising Technology Selections (cont'd)

- Fiber-optic/photonic sensors & optical scanners
  - Use of light to carry information for monitoring of cargo, or for fixed point monitoring of infrastructure health and environment problems.
  - Application on vehicles, as well as pipelines and other fixed structures such as tunnels and bridges, to help monitor and detect anomalous conditions at reduced cost.
- Improved locking with fiber-optic seals, low power RFID, and remote monitoring of seal array
  - Seals and locks with advanced encryption and other features that make them very difficult to defeat, which can be remotely monitored for intrusion and system functioning.
  - Ability to protect sealed Hazmat cargo is improved by defeating sophisticated intrusion attempts and reporting their occurrence.

Most Promising Technology Selections (cont'd)

- Intelligent video tracking & surveillance system
  - Software capable of capturing the image of a specific vehicle and passing this image from one linked camera to another so that its passage is tracked.
  - Hazmat vehicle carrying explosive or highly toxic material could be tracked by a series of video cameras that automatically hand off the vehicle's image as it passes through a HTUA.
- Wireless power
  - Wireless energy transfer or wireless power transmission in which electrical energy is transmitted from a power source to an electrical load without interconnecting wires.
  - "Energy harvesting" enabling technology that helps provide electrical power for sensors and other technologies that would otherwise be more expensive due to battery maintenance and replacement costs.

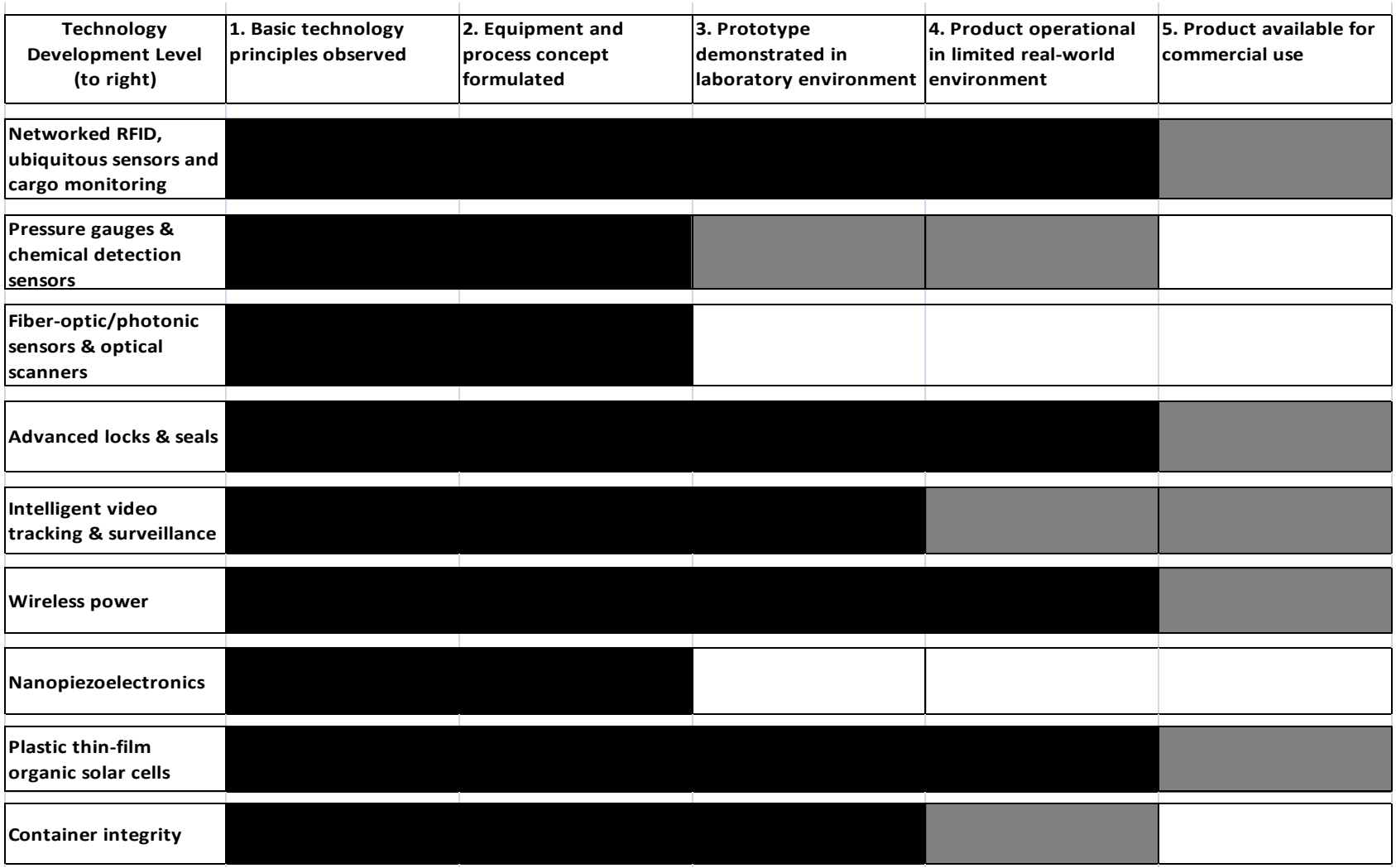
Most Promising Technology Selections (cont'd)

- Nanopiezoelectronics
  - Generation of electrical energy via mechanical stress that deforms certain materials (e.g., zinc oxide) with very thin dimensions.
  - "Energy harvesting" enabling technology.
- Plastic thin-film organic solar cells
  - Non-rigid solar cells that can be molded into a variety of shapes to occupy space that would not be possible for current, conventional solar cells, operating with self-recharging flexible polymer batteries.
  - "Energy harvesting" enabling technology.

Most Promising Technology Selections (cont'd)

- Container integrity
  - Improvements to strength of containers such as rail and truck tank cars, casks, and pipelines without increasing weight (a top priority for the chemical shipping industry).
  - Category represented by a number of different structural improvements such as:
    - Specialty and treated steels
    - Engineered metal structures (e.g., egg crate, honeycomb, lattice block, corrugated)
    - Structural foams and adhesives
    - Composites/fiber-reinforced plastics
    - Insulation and thermal protection
    - Armor and self-sealing technologies
    - Impact resistant coatings
    - Valves and fittings
    - Railcar couplers (cushioning)

Technology Development Dashboard



Key Conclusions and Take-Aways

- Surveillance & Monitoring Group
  - Potential benefits are new capabilities to detect and report out-of-normal conditions and improved measures to deter unauthorized access.
  - Challenges that need to be overcome include making the systems more user-friendly and affordable with low life cycle costs, compliant with power and bandwidth standards, and capable of reading with high reliability at lower detection thresholds, in a rugged environment, with very low false positive alarm rates.
  - If development continues along the anticipated path, this capability should be substantially available in the market-place in the near-term (within five years) for the majority of most promising technologies examined, with a number of chemical detection sensors maturing in the longer term (6-10 years).

Key Conclusions and Take-Aways (cont'd)

- Alternative Power Generation Group
  - Potential benefits are electrical power available to sensors and communications devices that would not otherwise be put into use without that supply, and the potential to reduce the size of batteries or even eliminate them.
  - Challenges that need to be overcome include manufacturing at larger scale, certain physical application requirements, and integration with other technologies.
  - If development continues along the anticipated path, this capability should be substantially available in the market-place in the near term.

Key Conclusions and Take-Aways (cont'd)

- Infrastructure Group
  - Potential benefits are Hazmat containers (especially large tanks) that are stronger and more resistant to punctures or able to seal some leaks caused by punctures.
  - Challenges that need to be overcome include providing the extra strength for an affordable price within acceptable weight and size limitations.
  - If development continues along the anticipated path, this capability should be substantially available in the market-place in the near term.

For more information…

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Type of Technology Developers Interviewed

Technology Area	Respondents	Interviews
Networked RFID/ubiquitous sensors and cargo monitoring	▪ Company ▪ National Laboratory ▪ National Laboratory ▪ Company ▪ National Laboratory	5
Pressure gauges & chemical detection sensors	▪ Company ▪ Company (4 related but separate technologies)	5
Fiber-optic/photonic sensors & optical scanners	▪ Company	1
Advanced locks and seals	▪ National Laboratory ▪ Company	2
Intelligent video tracking & surveillance	▪ Company ▪ Company	2
Wireless power	▪ Company ▪ Company	2
Nanopiezoelectronics	▪ University	1
Plastic thin-film organic solar cells	▪ Company ▪ Company ▪ Company	3
Container Integrity	▪ USDOT Research Organization ▪ Company	2
	Total	23

Technology Maturity Comparison

Technology	Short Term	2-5 Years	6-10 Years	Category Totals
Networked RFID/ ubiquitous sensors and cargo monitoring	3	2		5
Pressure gauges & chemical detection sensors	2		3	5
Fiber-optic/photonic sensors & optical scanners			1	1
Advanced locks and seals	1	1		2
Intelligent video tracking & surveillance	1	1		2
Wireless power	2			2
Nanopiezoelectronics		1		1
Plastic thin-film organic solar cells	1	2		3
Container integrity	1		1	2
# of technology interviews	11	7	5	23