Supply Chain-Based Solution to Minimize Fuel Tax Evasion:

Project Overview

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Acknowledgements

- Exploratory Advanced Research Program funds provided by Federal Highway Administration, U.S. Department of Transportation
- In-kind contribution provided by Pilot Travel Centers, Inc.
- DAS provided by FMCSA to support WRI learning
- Oak Ridge National Laboratory's research team consists of subject matter experts on:
  - **Sensors**
  - **Chemistry**
  - **Communications, telematics**
  - **Statistics and modeling**

Research Teams

Project Manager: Gary Capps

1. **Fuel Marker (tag) :** Maggie Connatser, Sam Lewis
2. **Fuel Marker Sensor:** Duncan Earl, Tim McIntyre, David West
3. **Communications:** Gary Capps, Mary Beth Lascurain, Oscar Franzese
4. **Evidential Reasoning Algorithm:** Ho-Ling Hwang, Shih-Miao Chin
5. **Field Testing and System Validation:** Gary Capps, Mary Beth Lascurain, Sheila Moore

Research Objectives

Develop an innovative solution to minimize:

1. "Blending" of non-taxable (non-highway use diesel fuel) low-taxable (jet fuel) petrochemical products with taxable fuel products
2. Cross-jurisdiction evasion of taxable fuel products
3. Doping of fuel with hazardous waste[1]
4. Fuel theft[1]

[1]Of secondary importance for this effort.

Research Approach

- This research centralizes the monitoring and tracking, and automatically identifies vehicles, routes, transfer points, and retail locations that are a part of the typical fuel supply chain.
- The "*legitimacy*" of individual on-loads, offloads, and movements will be determined by:

Approach (cont.)

- Integrating and validating information from:
  1. GPS and geo-fencing, and
  2. Different types of sensors
     - Fuel marker optical sensor
     - Valve sensor
     - Hatch sensor
     - Pressure sensor + Weight sensor = Fuel Level
- Analyzing the integrated data by using an evidential reasoning system to decipher the "*legitimacy*" of individual on-loads, offloads, and movements

Operational Scenario

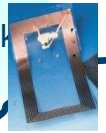
Interrogate real-time cargo integrity on-load locations, off-load locations, and route deviations

Transmit location, marker, & volume information to CCC

Respond to route deviation & cargo tampering by using vehicle immobilization technologies

Bulk facility

Install GPS, nano-chemical marker sensor, and valve sensor on tanker truck



Shipping Document wirelessly transmitted to CCC

Fuel Terminal Rack

Command and Control Center (CCC)

- **Evidential reasoning tools for profiling analysis:**
  - **Where are the on-load and off-load points?**
- **Interrogate tags to determine whether the fuel marker status changes, and/or whether the valves are open at a location (e.g., bulk facility) not specified in the shipping document.**
  - **If suspicious, notify appropriate parties and enforcement personnel.**

Five innovative aspects to this pilot research

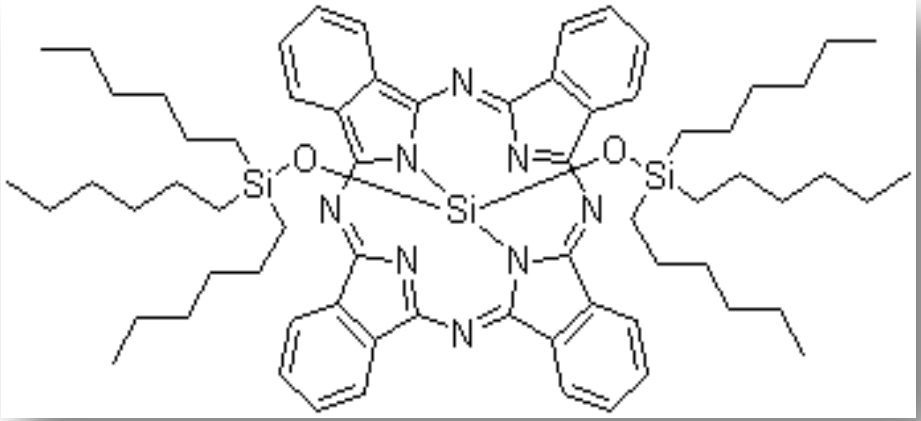
1. Instead of relying on a single solution, fuel tax evasion will be minimized through the integration of multiple measures.
2. This research recognizes that there is not a "silver bullet" for preventing fuel tax evasion. As such, solutions will be tailored to address specific scam(s).
4. Sensors have been developed and evaluated to determine their feasibility to authenticate the presence and concentration of fuel-markers in the fuel. This research will harness advances in sensor technology, authentication technology, wireless communications, vehicle-tracking, and information analysis.
5. Presumably, the control center will be able to communicate with law enforcement personnel in a timely manner to allow them to investigate potential fuel diversion activities.

Utilization of Fuel Marker in Fuel Tax Evasion Project

Sequence of events in dilution monitoring using fuel marker

- Fuel marker introduced at a known level in taxed fuel at the fuel distribution center
- Sensor monitors this level constantly at a regular rate on the tanker
- Blending of untaxed or otherwise non-compliant fuel leads to a dilution of the taxed diesel and its intrinsic fuel marker
- Dilution results in a reduction in the optical emission signal from the fuel marker
- Sensor detects this change in signal
- Event is recorded and altered monitoring may be initiated

Fuel Marker

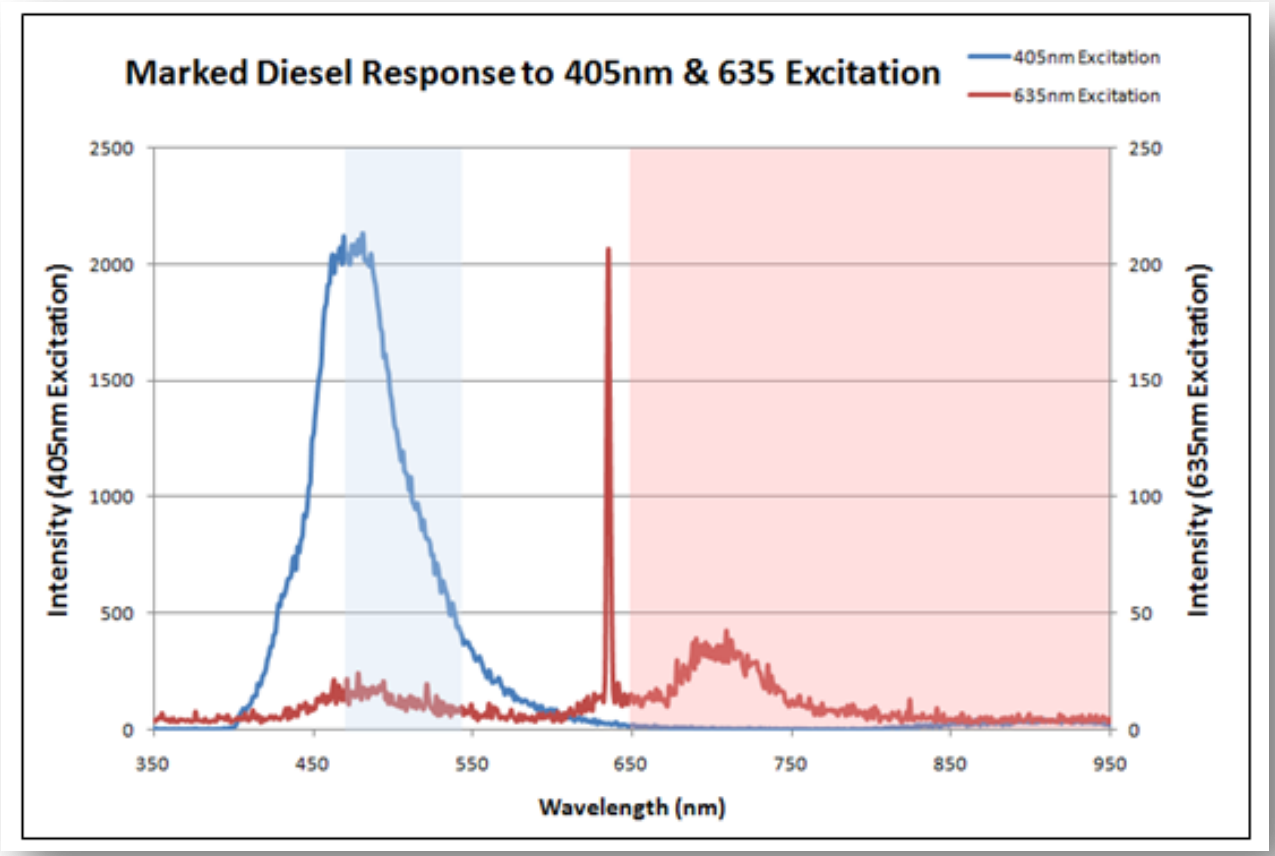


2,3-naphthalocyaninato-bis(trihexylsiloxy)silane,bis(trihexylsiloxy)silicon 2,3-naphthalocyanine (**SiNaph**) in its single macromolecule structure

Characteristics -

- Compatibility with fuels and engines,
- Production of no objectionable emissions or bi-products,
- No visibility to the naked eye,
- Chemical stability under thermal extremes over the period of months, and
- Provision of high enough optical yields to produce detectable fluorescence in the parts-per-billion range.

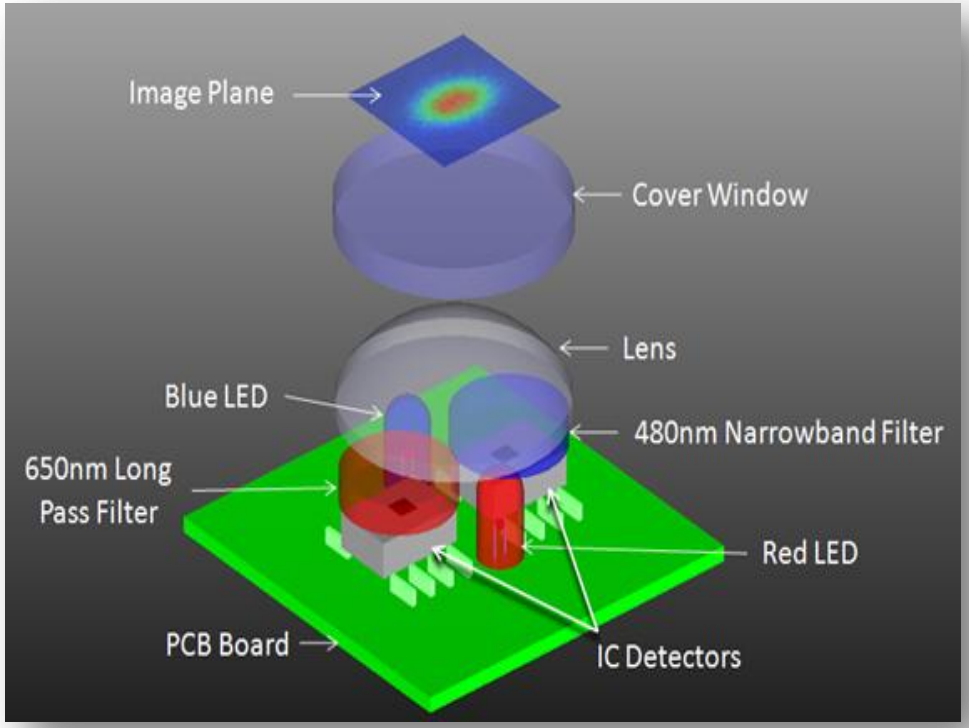
Fuel Marker Spectrum



Dual Emission lines of SiNaph(800ppb) in Diesel Fuel (Peaks at 460nm and 690nm)

Marker Sensor Optical Design

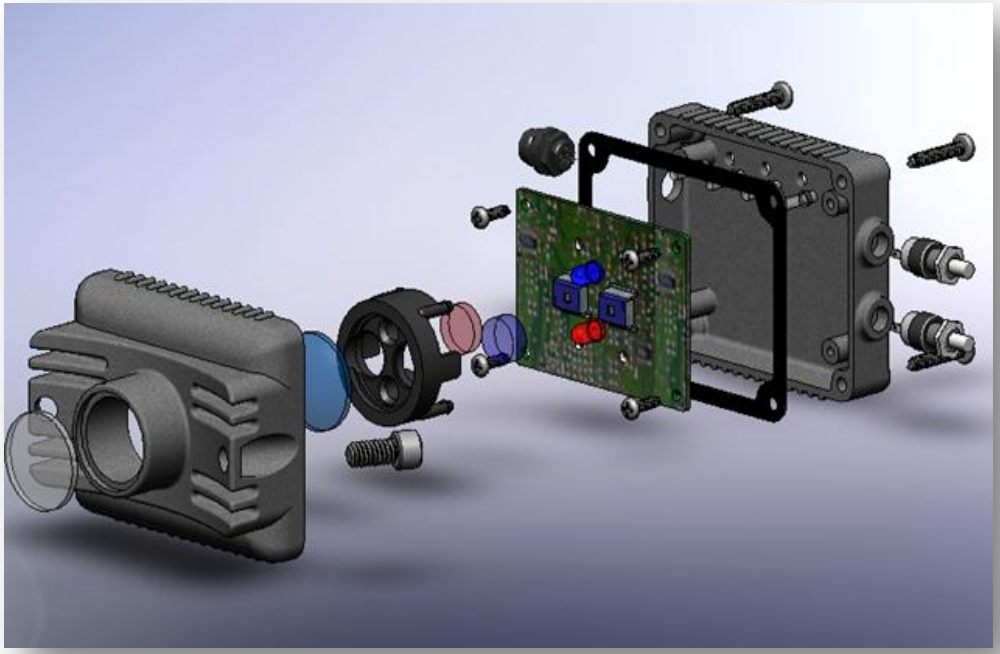
- Required illuminating same spot with two discrete LEDs
- Required integrated filtering and detection optics
- Required low cost detectors
- Modeled and optimized in ZEMAX
- Utilized low-cost optics (≈$60)



Modeled Optical Design

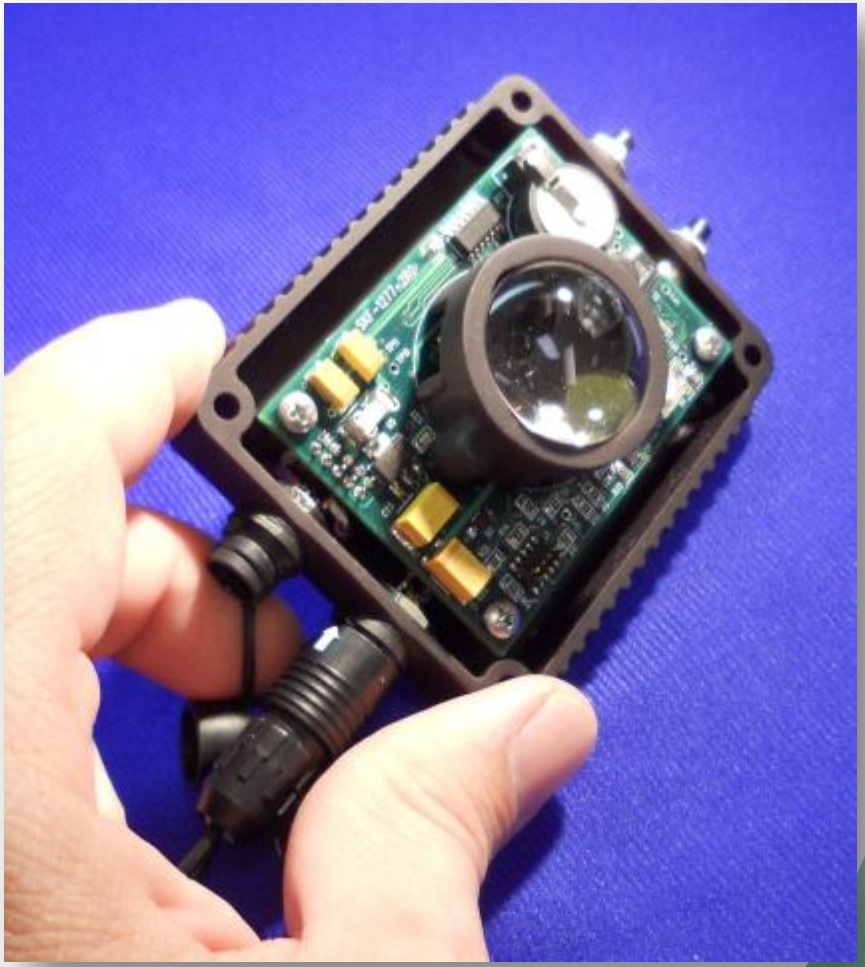
Marker Sensor Mechanical Design

- Required low-cost materials
- Had to accurately align optics and electronics
- Targeted stereo ligthography for rapid prototyping and testing
- Modeled in Solidworks
- Projected housing cost for low-volume injection molding (≈$5)



Mechanical Housing Design

Marker Sensor Prototype



Communications - Data Flow

Vehicle Data Bus

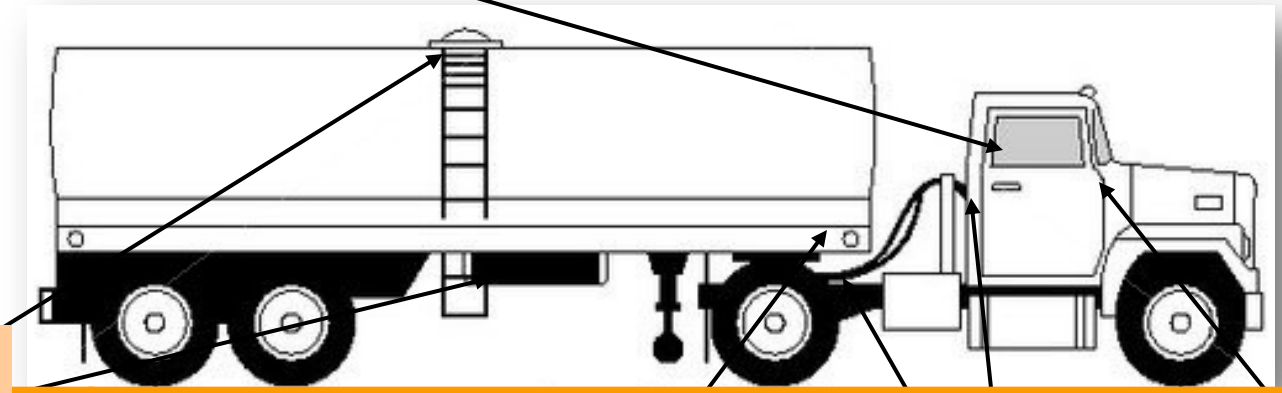
J1939 or J1708 Data Bus

ORNL DAS

Data Set
- Sensor Status
- Position/Speed

ORNL BOS

DAS and Off-Vehicle Communications



Sensors

Discrete Sensors
-Fuel Markers
-Fuel Level
-Valve Position
-Hatch Position
-Vehicle Weight

Sensor Back End
- Polls RS-485 Devices
- Monitors Switches

Trailer Side
- PLC4Trucks
- Virtual J-1939

J560 Connectors

Tractor Side
- PLC4Trucks
- J1939

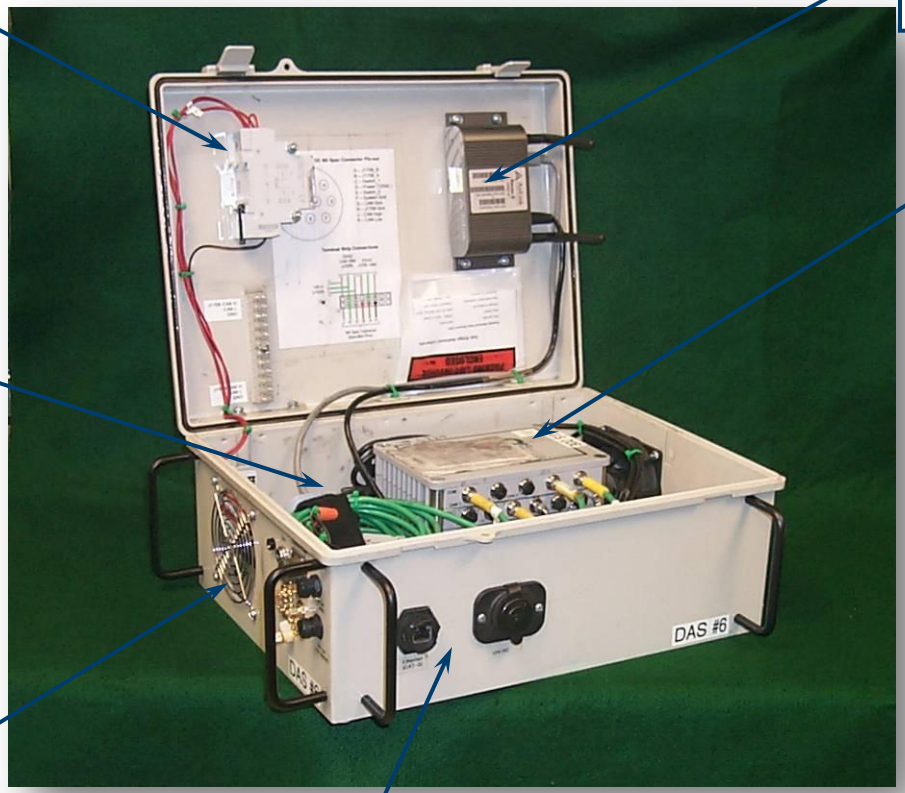
Tractor-Trailer Communications Unit (T2TCU)

ORNL DAS Capabilities

Optional timer mode for long-term data collection

Modules enabling data collection from J1939 and/or J1708

External connections to streamline installation



Components installed in protective case

Cellular modem for remote access

eDAQ-lite data acquisition unit

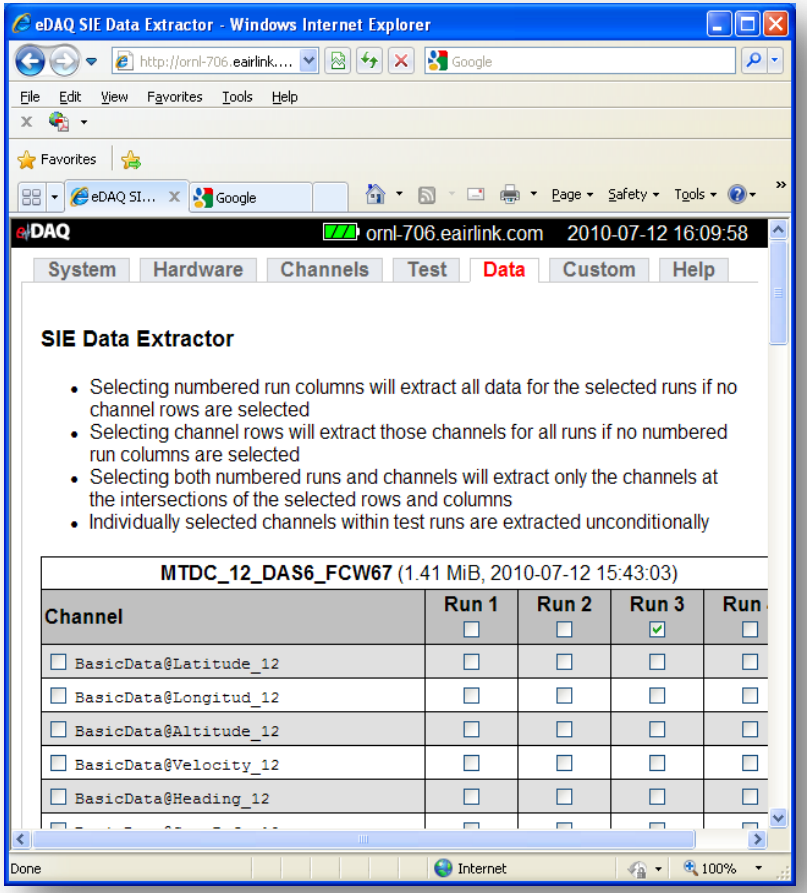
-Built-in, fully synchronized GPS

-Multiple CAN connections enabling sensor isolation

- Analog and digital inputs for sensor simulation

Data Retrieval Algorithm

- Use application program interface designed for data acquisition system (DAS)
- New data format allows data to be retrieved without interrupting data collection
- Data processed into standard CSV format
- System “reset” periodically to avoid exceeding on-board memory capacity



Web-Based Data Upload Interface

Why Evidential Reasoning?

- When one needs to combine evidence or data obtained from multiple sources.
- When one needs to make decisions based on information that is un-specific and ambiguous, and when there is considerable uncertainty .
- When one needs to model the abnormalities (or legitimacy) among different pieces of evidence.
- When one needs to include expert's subjective beliefs and prior knowledge.

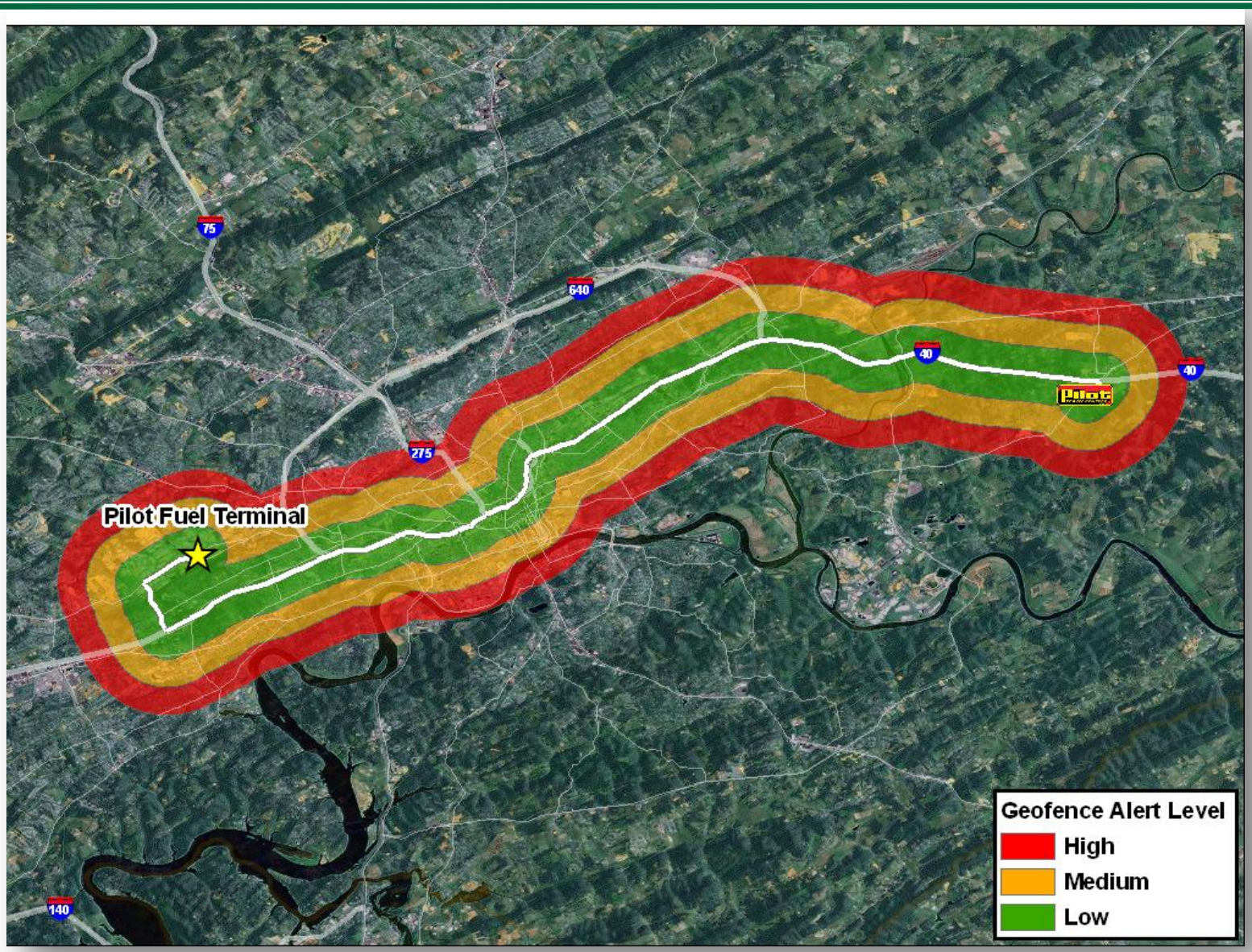
How Does It Work?

- "To see the future, one must look at the past."
- Assign probabilities to a chain of events, given current knowledge.
- Use combination rules (e.g., Dempster-Shafer theory) to fuse evidence from different sources - one of the major techniques for dealing with uncertainty.
- If the probability of incoming evidence deviates significantly from the baseline patterns, then the shipment is flagged as suspicious.
- Data are then used to "train" the system.

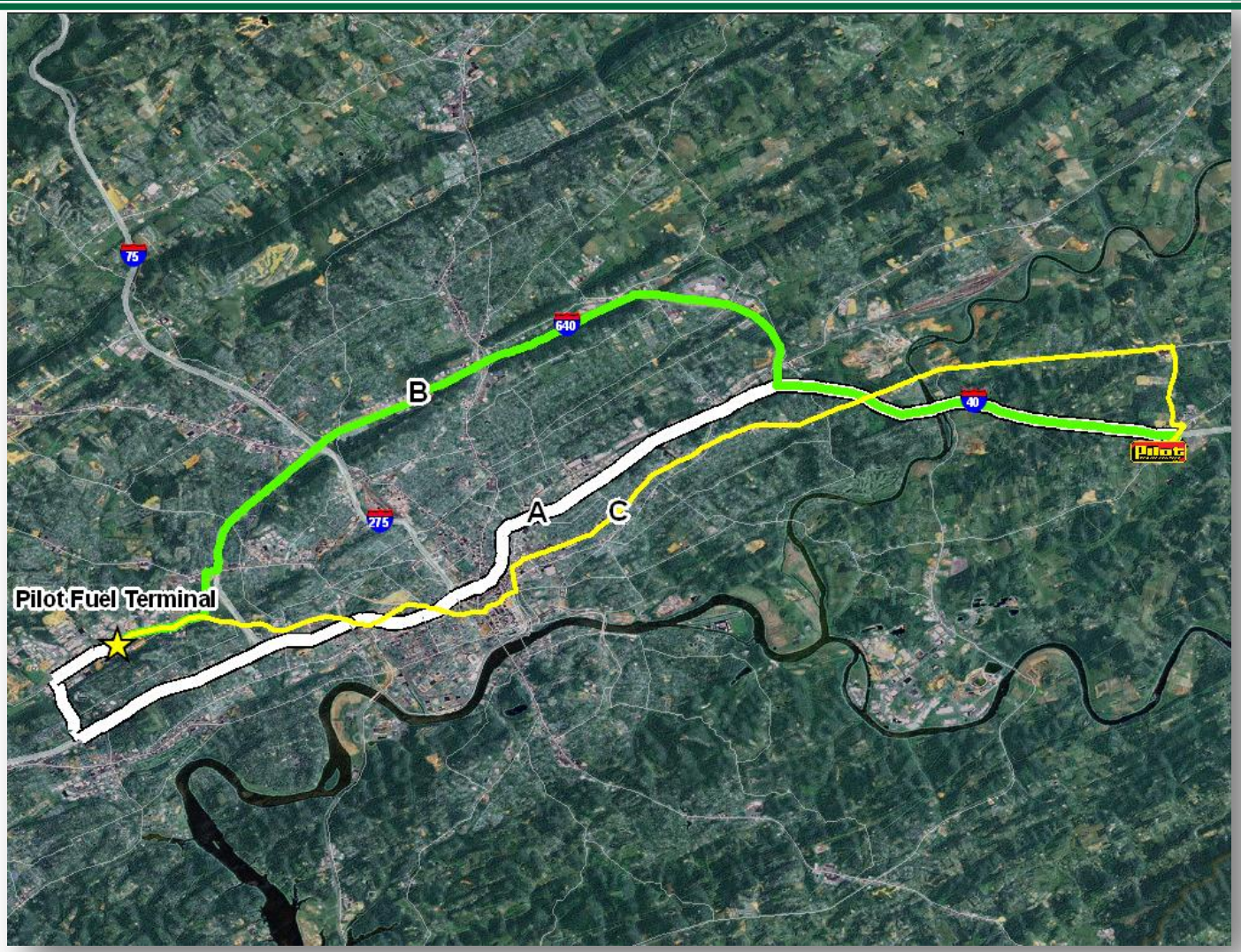
Two Approaches Will Be Used

- Rules-based
  - Ideal for detecting “blending”
  - For example, if fuel marker sensor shows that the characteristics of the fuel have been altered, then a warning will be issued.
- Evidential Reasoning
  - More appropriate for detecting “cross-jurisdiction” and theft

Intelligent GIS/GPS - Geofencing Alerts Levels



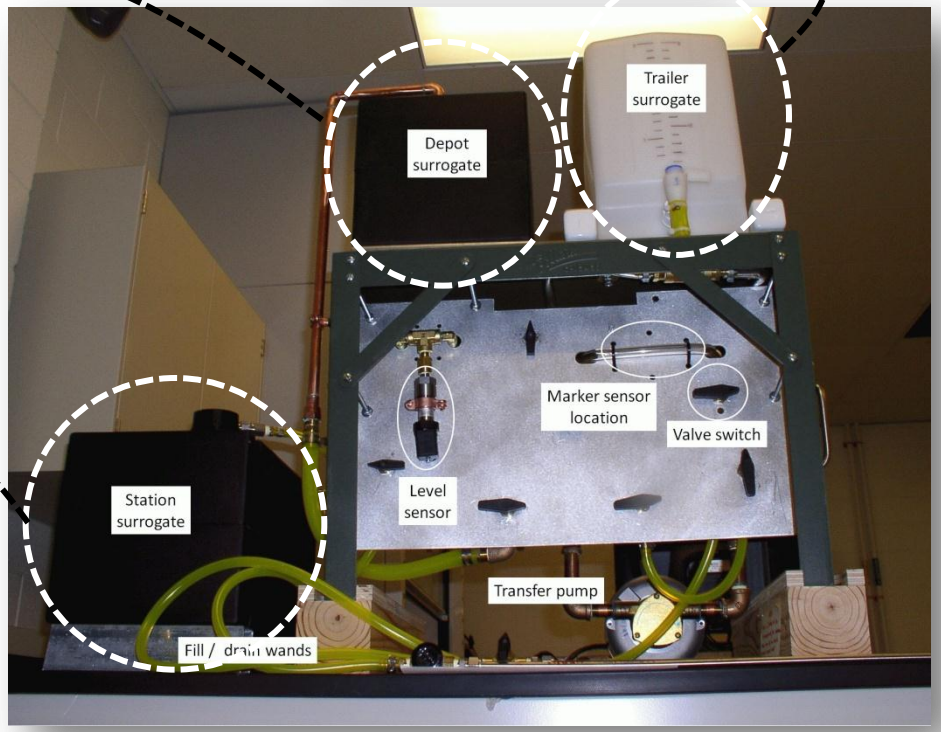
Multiple Delivery Routes Possible from Terminal to a Given Gas Station



Bench-Top Testing

Depot

Trailer



Station

Field Testing

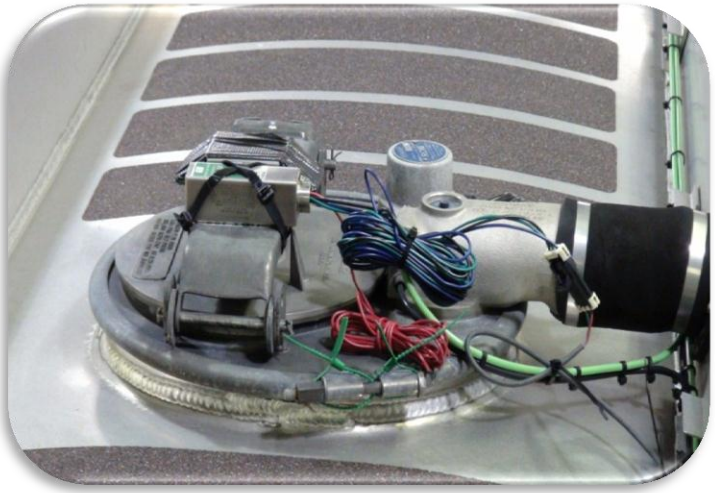
- Transportation Research Center, East Liberty, OH
  - 4,500 acre facility
  - Professional drivers
  - Fuel handling
  - Dye mixing
  - Miles of private roads
  - Staged uploading and delivery

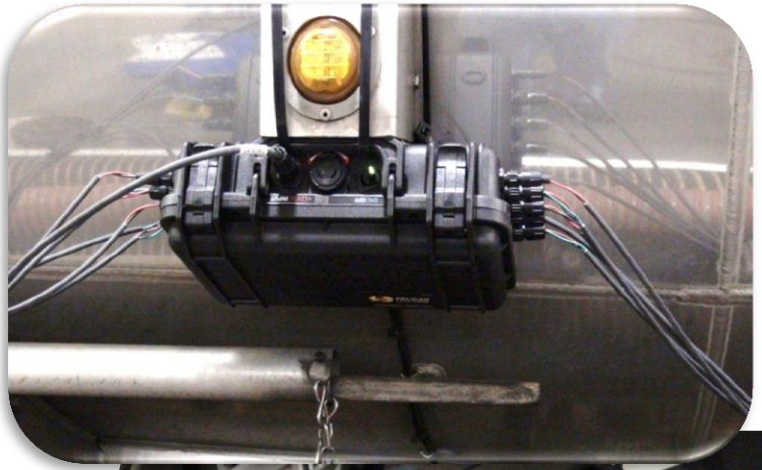
Field Testing

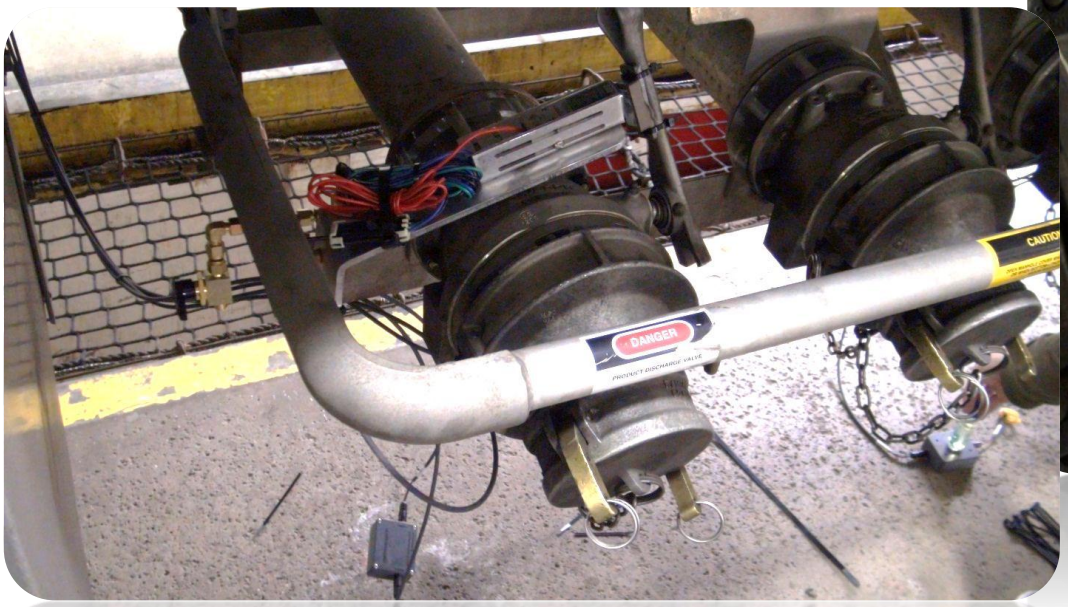
Testing Scenarios

- **Nominal** – legal movement of taxed and untaxed fuel (baseline)
- **Alternate Nominal** – legal movement of untaxed fuel (additional scenario for sensor verification)
- **Jurisdiction Crossing** – illegal diversion of taxed fuel
- **Theft** – portion of load of taxed fuel diverted/stolen en route
- **Blending I** – Dilution of marked fuel with an equal amount of unmarked fuel en route
- **Blending II** – mixing of a small amount of simulated hazardous waste with marked fuel en route
- **Blending III** – marked fuel mixed with unmarked fuel en route.

Field Testing – Vehicle Upfit







FTE Partnerships

- Pilot/Flying J Travel Centers – Test Vehicle
- Air-Weigh – Vehicle Weighing System
- FMCSA – Data Acquisition System (In support of WRI Learning from the CMVRTC)

Project Status

- Stable fuel marker identified
- Fuel marker sensor developed and tested
- Tractor-to-Trailer Communications Unit (T2TCU) developed and tested
- 1st Order evidential reasoning algorithm developed
- System bench top testing complete
- Fuel Loop testing complete (sensor qualification)
- Field testing complete
- Draft final report complete
- Currently completing Cost Effectiveness Evaluation

Trailer Integration Issues

- Hatch monitoring solution (type switch, location, mounting, wiring)
- Valve monitoring solution (type switch, location, mounting, wiring)
- Liquid level monitoring (type sensor, location, mounting, wiring)
- Marker sensor (location, mounting, wiring)

Trailer Integration Issues (cont.)

- Trailer-borne electronics (location, mounting, wiring)
- Cost per trailer
  - **switches, sensors, wiring**
  - **installation**
- Safety/approvals
- Others?