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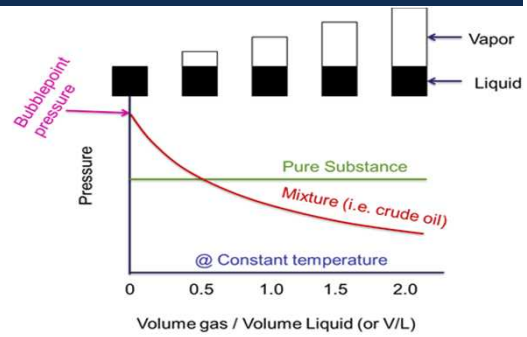

Crude Oil Characterization Research Study Update

Presentation to

American Fuel & Petrochemical Manufacturers

Rail Policy Working Group Meeting
Houston, TX
May 18, 2016

Presented by
David L. Lord, Ph.D.
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Albuquerque, NM 87185

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Outline

- Problem Statement and Objectives
- Project Governance and Workflow
- Overview of Task 2 – Task 3 Testing
- How AFPM can help
- Project Management Contacts
- Project Publications

Technical Objectives

PROBLEM STATEMENT

Problem Statement

- Crude transport by rail poses risks recognized by US and Canadian regulators
- Hazards have been realized in a number of high-profile train derailments leading to oil spills, environmental contamination, fire, property damage, and fatalities
- Open debate on whether the types of crude (tight oil vs. conventional production) have significant bearing on severity of transportation accidents

NTSB (2014). "Preliminary Report Railroad DCA14MR004." National Transportation Safety Board, Washington, DC 20594.

TSBC (2014). "Runaway and Main-Track Derailment Montreal, Maine & Atlantic Railway Freight Train Lac-Megantic, Quebec 06 July 2013." ***R13D0054***. Transportation Safety Board of Canada, Gatineau QC K1A 1K8. Railway Investigation Report.

DOE/DOT Project Objectives

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- Determine what combinations of sample capture and analysis methods are suitable for characterizing selected physical properties of volatile crudes
- Evaluate selected physical properties of crude oils (tight vs. conventional production) that are moved within rail transport environment that may have some bearing on flammability risks
- Measure combustion properties (flame dimensions, surface emissive power) of selected crude oils (tight vs. conventional) in controlled burn scenarios that have bearing on hazard determination
- Compare combustion properties to existing published data on other flammable liquids, including methanol, ethanol, jet fuel, hexane
- Evaluate if selected tight oils exhibit measurably different combustion properties from conventional crudes and the reference fluids tested previously

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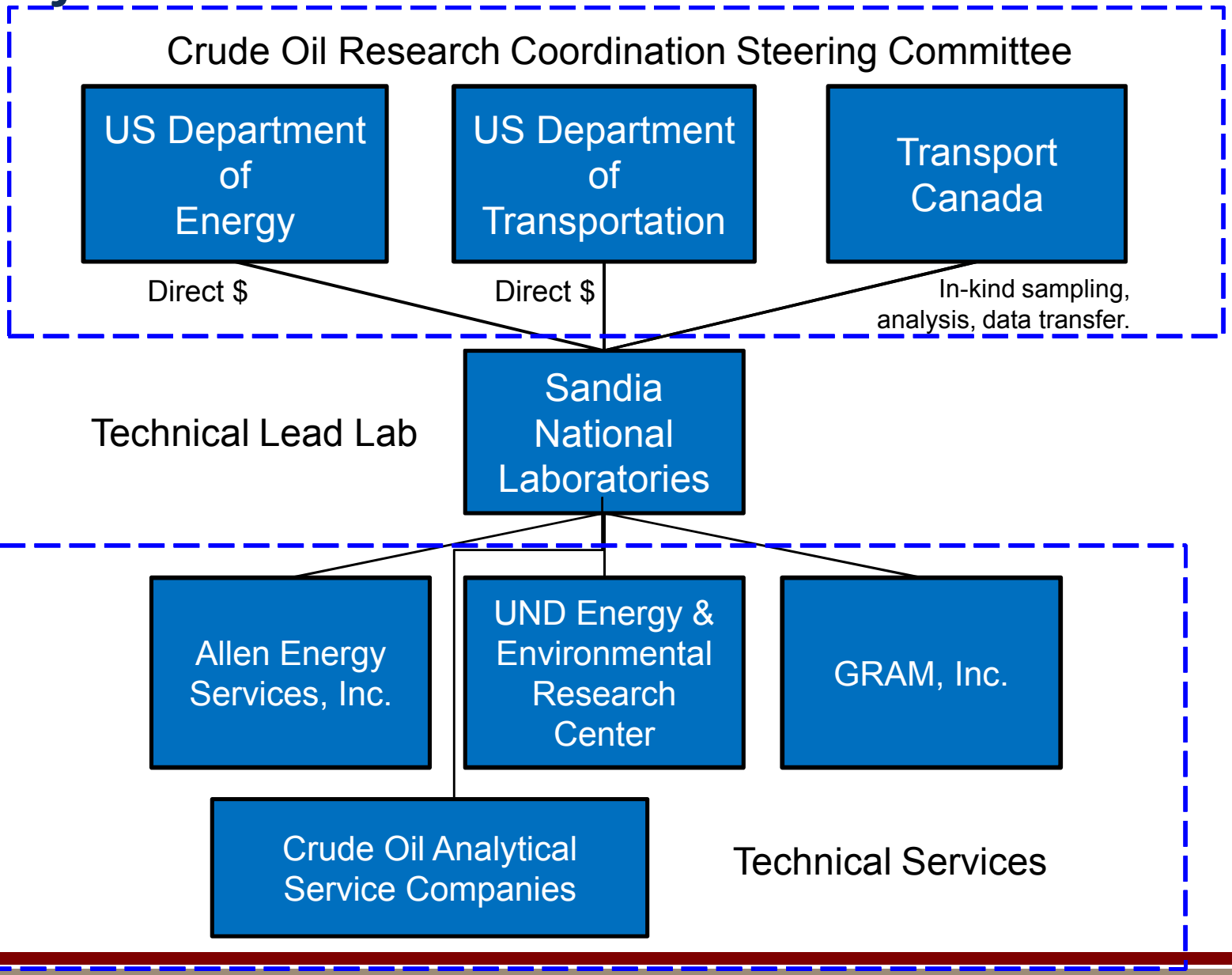
PROJECT GOVERNANCE

Project Governance



Overall Project Workflow

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Phase I | **Phase II** | **Phase III**

Problem Definition Phase
Completed

Literature Survey → Sampling and Analysis Plan

Experimental Phase
Current/future SNL future work scope

- Task 1: Analyze existing data
- Task 2: Sampling and analytical method evaluation
- Task 3: Combustion experiments and modeling
- Task 4: Crude characterization, tight vs. conventional
- Task 5: Railcar combustion testing and modeling
- Task 6: Comprehensive oil characterization

Peer review

Concept Phase Only

Implementation Phase
All stakeholders

- Utilize knowledge gained during prior phases to inform decisions on:
  - Industry best practices
  - Standards
  - Regulations

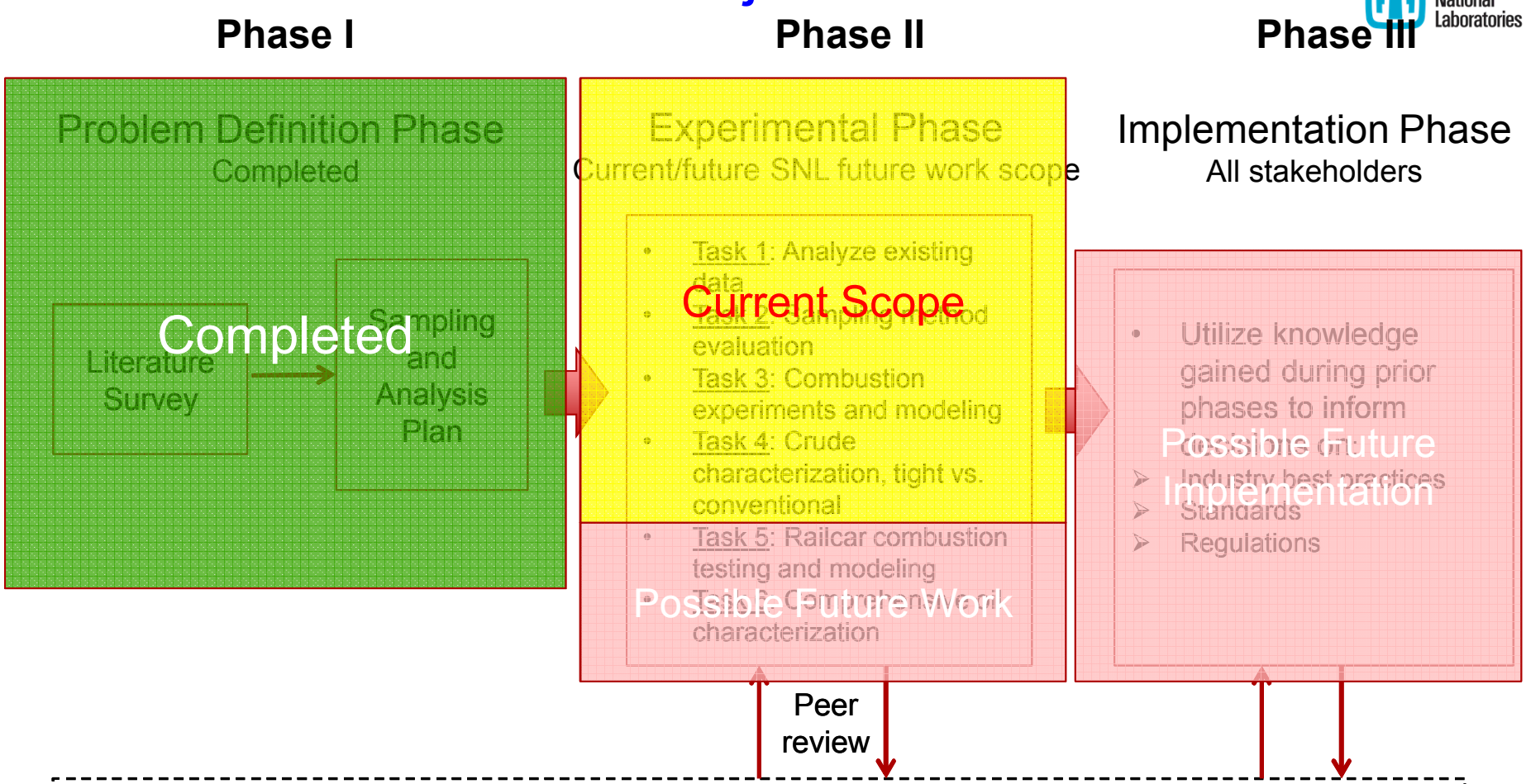
Public outreach

API: American Petroleum Institute
COQA: Crude Oil Quality Association
CCQTA: Canadian Crude Quality Technical Association

ASTM: ASTM International Standards
GPA: Gas Processors Association
SPR: Strategic Petroleum Reserve

} Phase III

Overall Project Workflow



High-Level Project Schedule, Phase II

		Year 1				Year 2			
Task	Description	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1	Review new & emerging data								
2	Evaluate sampling and analysis methods								
3	Large sample acquisition, combustion tests, modeling								
4	Tight vs. conventional crude characterization								

Crude Oil Property and Combustion Tests

TESTING OVERVIEW

Task 2 Overview

- Compare sample capture and analysis methods for two selected North American crude oils
  - Prefer upstream production or tank terminals handling tight oils
- Sandia National Laboratories and Transport Canada will administer parallel tests using a variety of sample capture and analysis methods
- Critical review of open vs. closed capture and applicability for use on minimally stabilized oils for measuring:
  - Crude vapor pressure VPCRx(T) at selected V/L and temperature
  - Pressurized GC light ends concentration
  - Unpressurized GC DHA and simulated distillation
  - Unpressurized physical property measurements MW, SG, viscosity
  - IBP based on 0.5 wt% determination

Task 2 Test Matrix

		Property Measurement								
Sample Technique	**Standard**	TVP	Compositional Analysis 1	Compositional Analysis 2	Compositional Analysis 3	Avg MW	Relative Density	Viscosity	Flashpoint	IBP (0.5 wt%)
SPR Tight Line to Mobile Laboratory		ASTM D6377 & Separator shut-in	BPP flash gas GC analysis	GOR flash gas GC analysis	Separator liquid C30+	frz pt dep	ASTM D5002	N/A	N/A	EOS with flash gas
Floating Piston Cylinder	ASTM D3700-14	ASTM D6377-M	GPA2103 M	GPA2177 + ASTM D7900 + ASTM D7169	ASTM D8003 + ASTM D7169 + GOR flash gas	frz pt dep	ASTM D5002	ASTM D7042	ASTM D93 or D56	GPA 2103/2177
Water Displacement	GPA 2174-14	ASTM D6377-M	GPA2103 M	GPA2177 + ASTM D7900 + ASTM D7169	ASTM D8003 + ASTM D7169 + GOR flash gas	frz pt dep	ASTM D5002	ASTM D7042	ASTM D93 or D56	GPA 2103/2177
Manual Syringe	ASTM D8009-15	ASTM D6377-M	GPA2103 M	GPA2177 + ASTM D7900 + ASTM D7169	ASTM D8003 + ASTM D7169 + GOR flash gas	frz pt dep	ASTM D5002	ASTM D7042	ASTM D93 or D56	GPA 2103/2177
Boston Round	ASTM D4057-12	ASTM D6377-M	GPA2103 M	GPA2177 + ASTM D7900 + ASTM D7169	ASTM D8003 + ASTM D7169 + GOR flash gas	frz pt dep	ASTM D5002	ASTM D7042	ASTM D93 or D56	GPA 2103/2177
Manual Syringe	ASTM D7975-14	ASTM D7975-14	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Color coding	Test Administrator
White	SNL
Red	TC
Blue	Both

- Test matrix will be run on two minimally stabilized North American crudes
- Objective is to compare multiple methods on a homogeneous sample
- Note: Oil variability across production regions or supply chain is addressed in Task 4 and potential Task 6, not Task 2

Task 2: Closer Look

Conceptual Example of PVT Data Consistency Check

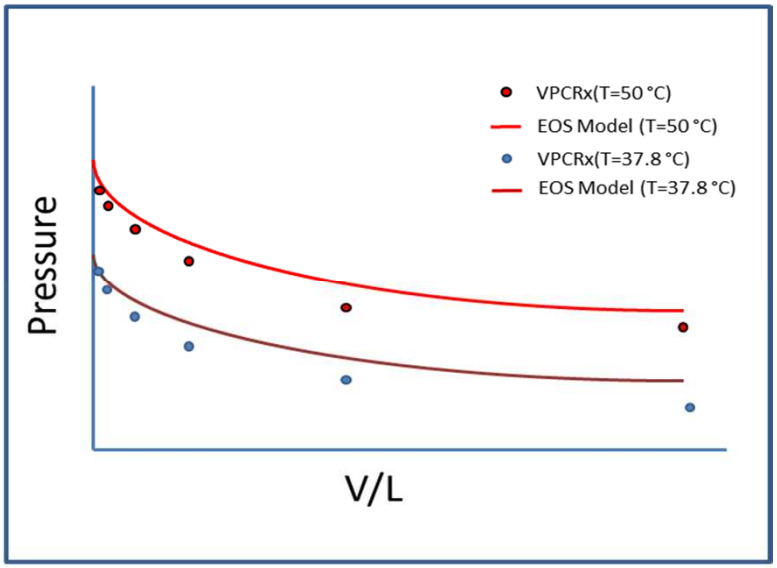
Measured Compositional Data

	SPR Bkn mole frac	WH108 mole frac
Nitrogen	0.0004	0.0006
Carbon Monoxid	0.0000	0.0000
Carbon Dioxide	0.0002	0.0007
Argon	0.0000	0.0000
Oxygen	0.0000	0.0000
Hydrogen Sulfid	0.0000	0.0000
Methane	0.0009	0.0004
Ethane	0.0073	0.0036
Propane	0.0345	0.0285
Iso-Butane	0.0145	0.0126
N-Butane	0.0541	0.0468
Iso-Pentane	0.0300	0.0301
N-Pentane	0.0468	0.0443
N-Hexane	0.1172	0.1173
Heptanes	0.1110	0.0927
Benzene	0.0044	0.0096
Toluene	0.0105	0.0162
Ethyl Benzene	0.0034	0.0042
Xylenes	0.0211	0.0183
Residual	0.5438	0.5745

Equation of State model PVT predictions

E1 (-)	0	0	0	0
E2	0.087	0.07	0.09	0.09
E3	0.24	0.23	0.25	0.24
E4	0.42	0.50	0.53	0.40
E5	1.10	1.06	1.40	1.35
E6	2.26	2.18	3.02	3.21
E7	4.62	4.31	6.16	7.63
P1 (psia)	19.34	15.94	19.82	19.89
P2	17.62	14.70	18.02	17.87
P3	15.89	13.23	16.22	15.86
P4	14.70	11.87	14.70	14.70
P5	12.45	10.51	12.61	11.83
P6	10.72	9.16	10.80	9.81
P7	9.00	7.8	9	7.8

Overlay PVT behavior for two-phase crude oil systems

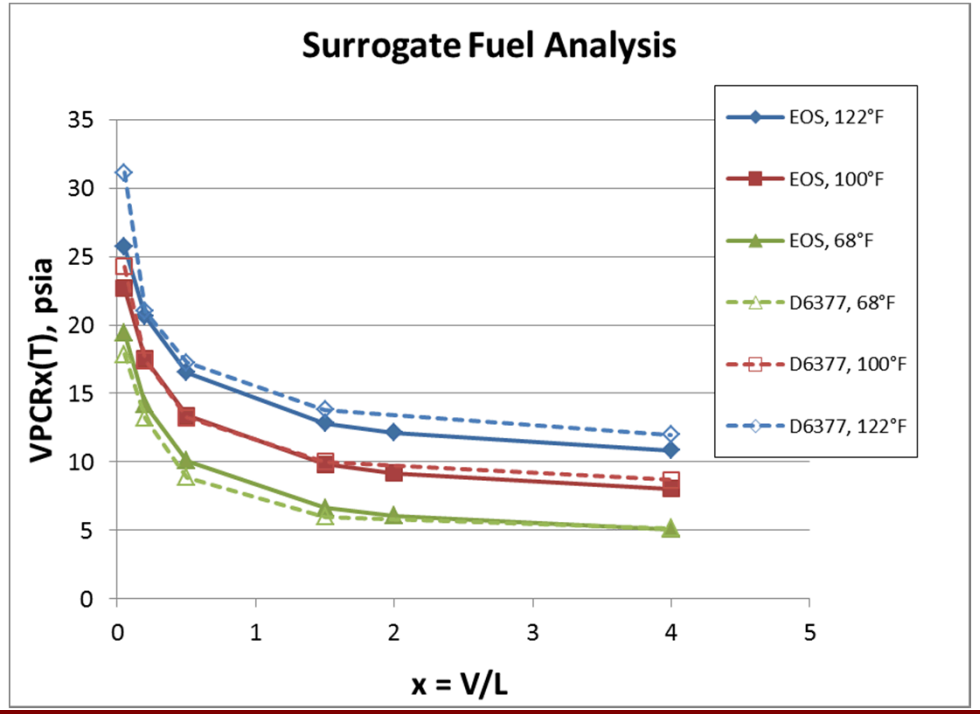


Measured VPCRx(T) Data

Temperature (°F)	(°C)	V/L	V/L	V/L	V/L	V/L	V/L
68	20	0.02	0.05	0.2	0.5	1.5	4.0
100	37.8	0.02	0.05	0.2	0.5	1.5	4.0
122F	50	0.02	0.05	0.2	0.5	1.5	4.0

Task 2 Closer Look

- Actual example of PVT Data consistency check
- Comparing EOS modeling with measured VPCRx(T) for a test fuel (jet A + gasoline) that will later be burned
- Data show reasonable agreement between simulated and measured PVT curves



Task 3 Overview

- Subject four selected North American crudes to basic property and controlled burn testing
- Span a range from tight oils (Bakken, Eagle Ford) with high visibility, to baseline light sweet (WTI, LLS), to specially-stabilized crude from the Strategic Petroleum Reserve
- Compare results against existing hydrocarbon liquid combustion test data

Burn Test Configurations

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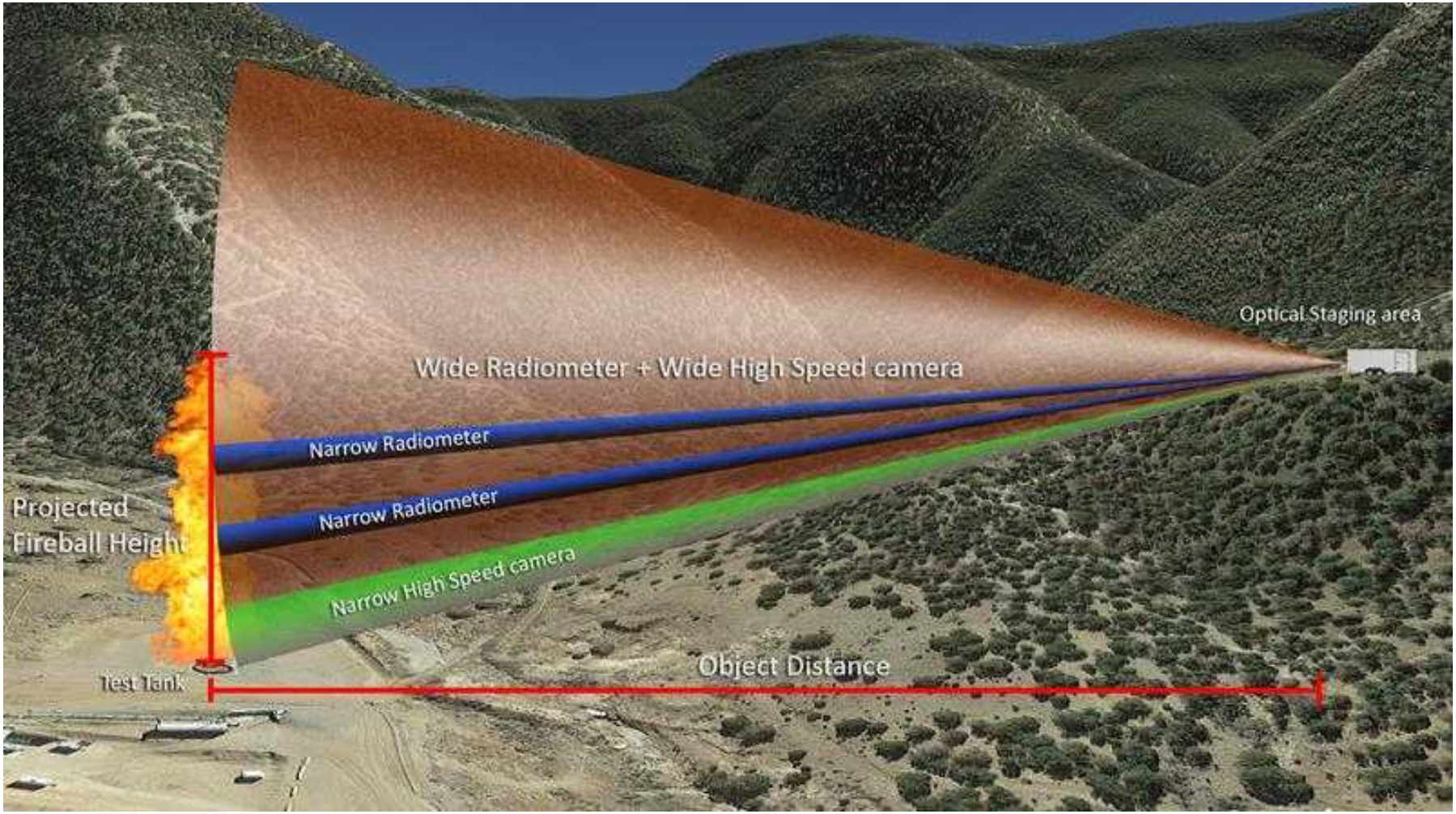
Pool fire

- Surface emissive power (SEP)
- Heat flux to engulfed objects
- Flame height
- Fuel consumption rate

Fireball

- Surface emissive power (SEP)
- Heat flux to nearby objects
- Fireball diameter
- Fireball duration

Fireball Test SEP Instrumentation



Task 3 Test Matrix - Highlights

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Oil	Properties	Pool Fire 2m, 5m	Fireball 40 gal, 400 gal
Tight Oil #1	VPCRx(T), Light Ends, SimDis, IBP, MW, SG, flashpoint	SEP, flame height, burn rate	SEP, fireball diameter & duration
Tight Oil #2	VPCRx(T), Light Ends, SimDis, IBP, MW, SG, flashpoint	SEP, flame height, burn rate	SEP, fireball diameter & duration
Conventional light sweet oil	VPCRx(T), Light Ends, SimDis, IBP, MW, SG, flashpoint	SEP, flame height, burn rate	SEP, fireball diameter & duration
Stabilized SPR oil	VPCRx(T), Light Ends, SimDis, IBP, MW, SG, flashpoint	SEP, flame height, burn rate	SEP, fireball diameter & duration

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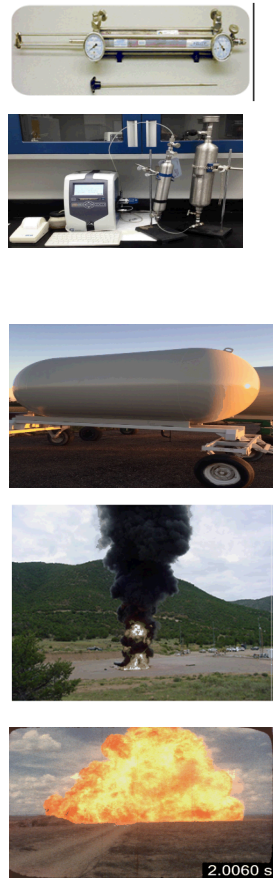
HOW AFPM CAN HELP

How AFPM can help

- Technical peer review of test plans, test reports
  - Need a point-of-contact for communications
- Access to sampling points for Tasks 2, 3, and 4
  - Sandia has 7-page sampling proposal (re: Tasks 2 and 3) for distribution to crude oil producers and/or terminal operators who may be interested in helping provide samples
  - Use and publication of data
    - Oil data acquired from the sampling event will be analyzed and published in unclassified, unlimited release technical research reports and presentations. Sandia will avoid any specific references to producer name, terminal operator name, or geographic location (lat/long) of the sampling location.
  - Contact David Lord for more information (slide 25)

Access to Crude Oil Samples

Sample Description	Target Timeframe (Calendar Year-Quarter)		Preferred Sample	Approx Quantity
Task 2 Parallel Test #1	CY2016	Q2	LACT or rail/pipeline terminal in central or southern U.S. that handles tight oil	15 gal (60 L)
Task 2 Parallel Test #2		Q2	LACT or rail/pipeline terminal that handles Bakken	15 gal (60 L)
Task 3 Burn Sample #1		Q3	Bakken	3,000 gal (72 bbl)
Task 3 Burn Sample #2		Q4	Eagle Ford	3,000 gal (72 bbl)
Task 3 Burn Sample #3	CY2017	Q1	SPR stabilized oil	3,000 gal (72 bbl)
Task 3 Burn Sample #4		Q2	WTI or LLS	3,000 gal (72 bbl)



Images courtesy of Intertek, Bosselman Tank & Trailer, Sandia National Laboratories

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- U.S. Department of Transportation
  - Joseph Nicklous
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Project Publications

- Lord, D., A. Luketa, C. Wocken, S. Schlasner, R. Allen and D. Rudeen (2015). "Literature Survey of Crude Properties Relevant to Handling and Fire Safety in Transport." *Unlimited Release* ***SAND2015-1823***. Sandia National Laboratories, Albuquerque, NM 87185.
- SNL (2015). "Crude Oil Characteristics Sampling, Analysis and Experiment (SAE) Plan." Office of Fossil Energy. U.S. Department of Energy, http://energy.gov/fe/articles/crude-oil-characteristics-research. 9-Jul-2015.
- Lord, D., R. Allen, C. Wocken and T. Aulich (2016). "DOE/DOT Crude Oil Characterization Research Study, Task 2 Sampling & Analysis Plan: Evaluate Crude Oil Sampling & Analysis Methods." *Unlimited Release* ***SAND2016-3079***. Albuquerque, NM 87185. *Anticipated release date June 6, 2016*.

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END OF PREPARED SLIDES