WORK PLAN

noble energy

SPL
Southern Petroleum Laboratories, Inc.

Pressurized Hydrocarbon Liquids Sampling and Analysis Study
Work Plan

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June 13, 2017

Rev. 8

TABLE OF CONTENTS

Noble Energy / SPL Plan Revision History

New Document Number	Revised By	Revision Date	Approved By	Approval Date	Description of Primary Revisions
Rev 2	SPL	1/15/16			Added discussion of Multi-lab CRM Analysis sub-task
Rev 3	SPL	1/26/16			Revised Perturbation Study Tables 5A, 5B, and 7 to replicate final scope
Rev 4	SPL	6/8/16			Revised Table 7 for blown rupture discs on cylinders
Rev 5	SPL	3/7/17			Revised Table 9 (A&B) to replicate final scope and revised text to represent actual activities, where appropriate. Replaced CMSI with Movilab
Rev. 6	SPL	4/18/17			Revised with Tom edits and comments
Rev. 7	SPL	6/9/17			Revised Schedule and Deliverables
Rev. 8	SPL	6/13/17			Revised with Ricardo's Uncertainty Report

1.   Introduction

The purpose of the pressurized hydrocarbon (HC) liquid sampling and analysis (PHLSA) study is described in paragraph 37 of the Consent Decree:

"The purpose of the study is to isolate individual variables of the sampling and analytical methods typically used to obtain information regarding the flash potential and makeup of pressurized hydrocarbon liquids and to identify protocols for determining how these samples can be reliably obtained, handled, and analyzed to produce accurate analytical results for practical application in modeling flashing losses."

Based on this purpose, the primary objectives of the study were to:

- develop recommendations for the sampling and analysis of pressurized liquid hydrocarbons;

- evaluate the use of Process Simulation Model / Equation of State ("PSM/EOS") calculations to estimate the flash gas generated when pressurized hydrocarbon liquids are dumped to atmospheric storage tanks.

- estimate the uncertainties of the measured and PSM/EOS calculated flash gas-to-oil ratios (FGOR) and other parameters.

SPL's approach is to study the individual contributors to the overall uncertainty of the FGOR determination process. There are uncertainties produced from the tasks of pressurized hydrocarbon liquid sample collection, sample handling in the laboratory, sample analysis, process parameters measurement, and Process Simulation Model / Equation of State calculations. Industry standards do not provide adequate guidance to properly account for uncertainties of each of the tasks that comprise the process of collecting and analyzing pressurized condensate[1] samples, and the associated modeling of flashing losses from condensate depressurization. Primary uncertainties and deficiencies in these tasks include:

- The uncertainty of common industry sample collection methods for pressurized condensates is not known. GPA 2174, "Obtaining Liquid Hydrocarbons Samples for Analysis by Gas Chromatography", is the basis of most methods used for sampling pressurized condensates, and does not have a precision statement. The effects of variations to method sample collection parameters have not been documented.

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[1] The Consent Decree includes the following definition for condensate: ""Condensate" shall mean hydrocarbon liquids that remain liquid at standard conditions (68 degrees Fahrenheit and 29.92 inches mercury) and are formed by condensation from, or produced with, natural gas, and which have an American Petroleum Institute gravity ("API gravity") of 40 degrees or greater." The hydrocarbon liquids studied for this project are condensate according to this definition, and the terms "hydrocarbon liquids" and "condensate" are used interchangeably throughout this Work Plan.

- Not all analytical methods used for pressurized condensates are designed for the material that is being tested. A well-documented comparison of condensate analysis by commonly used methods is not publicly available. The effect of improper sample handling procedures in the laboratory is not known.

- The quality of measurement data (e.g., process temperatures and pressures) used to model flashing emissions is typically poor. Custody transfer measurement uncertainty is normally less than one percent, but allocation measurement data uncertainty is often greater than five percent. Samples obtained for this purpose are taken from allocation measurement points. The effect of this data uncertainty on flash gas generation rate estimation calculations is not known.

- The most commonly used computer software programs used to model flashing emissions often yield wide variations in calculated results. Many options (e.g., EOS, pseudo heavy (hypothetical) components, etc.) exist in most of these programs. A documented comparison of these programs is not publicly available.

- Seasonal effects, production cycles, and variations in operating conditions can produce quite different results in the modeling, and the overall effects of these parameters are not well known.

This Work Plan describes the SPL approach to filling these data gaps and the informational voids regarding sampling and analysis of pressurized condensates to calculate flashing emissions.

2.   Tasks

An overview of the project tasks is presented, and these tasks are further addressed in the following subsections.

Task	Description
1. Initial Sample Collection	Pressurized condensate samples were collected at the test facility and analyzed using four different methods: GPA 2186M, GPA 2103M (C10+), GPA 2103M (C100+), and flash liberation. A composite condensate composition was used for Task 2.
2. Development of Certified Reference Material	A NIST-traceable CRM (i.e., a gravimetrically blended condensate standard with low compositional uncertainty) was developed. The CRM was used to evaluate different Analytical Methods (Task 4) and different Operational Performance Checks (Task 7), to conduct the Sample Handling Perturbation Study (Task 6), and as the CRM for calibrations throughout the PHLSA Study.
3. Multi-lab Analytical Methods Study	CRM samples were analyzed by four different labs using three different analytical methods to compare the methods and evaluate reproducibility.

Task	Description
4. Analytical Methods Performance & Uncertainty	This task estimated the accuracy, precision, and overall uncertainty of four different analytical methods used for pressurized condensate analysis. CRM samples were analyzed by SPL using the four methods, and the results compared to the gravimetrically determined CRM composition.
5. Process Measurement Uncertainty Analysis	Instruments to measure process parameters were evaluated to estimate and minimize measurement uncertainty. Process measurements data were used in PSM/EOS calculations of atmospheric storage tank mass balances and flash gas generation, and measurement uncertainties propagate to these calculations.
6. Lab Sample Handling Perturbation Study	CRM samples were used to evaluate the impact of lab sample handling parameters – temperature, pressure, mixing, and GC sample injection rate – on pressurized condensate samples compositional analyses to develop recommendations for proper handling of lab samples.
7. Operational Performance Checks	Operational performance checks (e.g., IPT, bubble point pressure) to assess the reliability of pressurized condensates sampling and analysis results were evaluated to develop recommendations for conducting these checks.
8. Sample Collection Perturbation Study	The impact of sample collection parameters (e.g., cylinder type, location, rate, start time) on pressurized liquid HC sampling and analysis results were evaluated to develop recommendations for sample collection procedures. Perturbation samples were initially collected in January 2016 and also later in conjunction with Task 9.
9. Winter and Summer Three-Separator Pressure Range PHLSA Study	This task investigated the effect of separator pressure on pressurized liquid HC sampling and analysis results, and flash gas generation. In the Winter and in the summer, the separator was operated at three different pressures and replicate pressurized condensate samples were collected concurrent with process measurements for atmospheric storage tank mass balance & FGOR calculations.
10. Data Analysis	Using data from Tasks 1 - 9, the uncertainty associated with the sample collection, handling, and analysis processes were estimated along with the sensitivity of PSM/EOS calculations to key parameters and the uncertainty of PSM/EOS calculations of storage tank mass balances and flashing losses.

Task 1. Initial Sampling

This task collected of simultaneous (i.e., multiple sample locations/probes) and sequential (i.e., from a single sample location/probe) pressurized condensate samples at the Bernhardt production site to characterize the condensate composition. Table 1 shows the sample collection matrix which included collection of simultaneous CP cylinder samples from three sample probes spaced six inches. The samples were analyzed using four different methods (GPA 2186M, GPA 2103M (C10+), GPA 2103M (C100+), and flash liberation), and a composite of the measured condensate compositions was the target composition for the CRM developed in Task 2. A well cycle in the midst of the sample collection precluded drawing conclusions regarding the impact of sample collection start time.

Table 1. Initial Sampling and CRM Development Test Matrix

Operating Condition	Pressurized Condensate						PSM for Each Sample	Process Measure-ments[A]	Notes (operational performance checks)
	Sampling Parameters[A]	No. Samples: Analyze /Archive	Sequent-ial Samples	Simul-taneous Samples	Lab Analyses				
					Select Samples[A]	Each Sample[A]			
$P_{sep} \sim 220$ T_{sep} Separator Heater Off	GPA 2174; 500 ml CP sample cylinder; Sample rate: 60 ml/min.					Mol. Wt. Det. ASTM D-4052M Density by densitometer Bubble Point P&T by densitometer GPA 2103M (TCD portion only: C1-5)	Bubble point P @ T_{sep} liquids Density @ P_{sep} and T_{sep} liquids	P_{sep} T_{sep} ρ_{oil} $T_{sep\ liquids}$	Initial Pressure compared from sampling to laboratory conditions. (additional operational performance check) Bubble Point and Density comparisons: Physical measurements vs. EOS-analysis @ Sample collection P,T
	Sample location: <u>sample probe 1</u> [B]								
	S11. Sample start: < 30 min. after WC[C]	1/0	**X**	**I**	GPA 2186 C1-10+ GPA 2103M C1-10+ GPA 2103M C1-100+ Flash Liberation				
	S12. Sample start: after sample **S11**	1/0	**X**	**II**					
	S13. Sample start: after sample **S12.**	1/0	**X**	**III**					
	S14. Sample start: after sample **S13**	1/0	**X**	**IV**					
	S15. Sample start: after sample **S14**	0/1	**X**	**V**					
	S16. Sample start: after sample **S15**	0/1	**X**	**VI**					
	Sample location: <u>sample probe 2</u>[B]								
	S21. Sample start: < 30 min. after WC[C]	1/0	**Y**	**I**					
	S22. Sample start: after sample **S21**	1/0	**Y**	**II**					
	S23. Sample start: after sample **S22.**	1/0	**Y**	**III**					
	S24. Sample start: after sample **S23**	1/0	**Y**	**IV**					
	S25. Sample start: after sample **S24**	0/1	**Y**	**V**					
	S26. Sample start: after sample **S25**	0/1	**Y**	**VI**					
	Sample location: <u>sample probe 3</u>[B]								
	S31. Sample start: < 30 min. after WC[C]	1/0	**Z**	**I**					
	S32. Sample start: after sample **S31**	1/0	**Z**	**II**					
	S33. Sample start: after sample **S32.**	1/0	**Z**	**III**					
	S34. Sample start: after sample **S33**	1/0	**Z**	**IV**					
	S35. Sample start: after sample **S34**	0/1	**Z**	**V**					
	S36. Sample start: after sample **S35**	0/1	**Z**	**VI**					
NA	Storage Tank Liquids: 4 gals. in 5-gal. can (additional material for CRM)				ASTM D2887 (thru C100)				

A. Refer to Quality Assurance Project Plan (QAPP).   for measurement / test method details. B. Sample probes located in Coriolis meter pipeline spaced at a distance of 6 inches. C. Well Cycle

Task 2. Development of CRM

This task was to create a custom certified NIST Traceable Gravimetric Certified Reference Material (CRM) as a baseline reference for the study. Analytical accuracy is impacted by the CRM uncertainty, the similarity of the CRM to the samples under analysis, and the analytical method precision. Thus, for this study, the CRM was custom made to minimize the differences between the known and unknown.

The CRM was used to evaluate different analytical methods and operational performance checks, to conduct the Sample Handling Perturbation Study, and as the Certified Reference Material for calibrations throughout the PHLSA Study.

Table 2 describes the stages of the CRM development methodology.

Table 2. CRM Development Methodology

Stage	Description
1.1. Initial Sample Collection from the HP-Separator	16 pressurized liquid hydrocarbon samples were collected from the HP-Separator at the Bernhardt 31-32D well site using GPA 2174. For each sample, about 400 mL were collected in a 500 ml constant pressure (CP) cylinder.
1.2. Compositional Analyses	Compositional analyses of the pressurized liquid HC samples were conducted using the four analytical methods to be compared in the study: GPA 2186, GPA 2103M (C10+), GPA 2103 (C100+) and GPA 2103M (Mod-Pod). Each analysis was performed in triplicate, requiring 12 samples. The remaining 4 samples collected in Stage 1.1 were archived.
1.3. Determine Target CRM Composition	The average chemical composition from the 12 sample analyses in Stage 1.2 determined the Target CRM Composition.
2.1. CRM "Hexanes Plus" Fraction Production	The GPA 2103M (C10+) and GPA 2103M (C100+) protocols include a depentanization step that produces a "Hexanes Plus" (C6+) fraction. This depentanization step (via ASTM D2001) requires 50 mL from each 400 ml sample.
2.2. Target CRM C6+ Fraction Composition	There were six 50 ml portions as described in Step 2.1. After depentanization, approximately 240 ml of C6+ material were available for compositional analysis, as well as physical density and molecular weight determination.
3.1. Storage Tank Condensate Collection	8 gallons of condensate were collected in two 5-gallon containers from the atmospheric storage tank during the Stage 1.1 sampling event. This atmospheric condensate was used to produce C6+ material required to produce CRM.

Stage	Description
3.2. Depentanization of Atmospheric Condensate	Using ASTM 2892, the 8 gallons of atmospheric condensate will be depentanized using a 5 to 1 reflux ratio on the distillation column.
3.3. Depentanized Atmospheric Condensate Composition Determination	The composition of the depentanized atmospheric condensate was determined using ASTM D2887 for C6-C100 species and ASTM D6730 to confirm C6-C10 isomers. Three compositional analyses were conducted as well as physical density and molecular weight determination.
3.4. Addition of C6+ Compounds to the Depentanized Atmospheric Condensate	The depentanized atmospheric condensate composition determined in Stage 3.3 was compared to the depentanized pressurized HC liquid composition (i.e., the target CRM C6+ fraction) determined in Stage 2.2. The compositions differed (e.g. weathering of the atmospheric liquids could have included C6+ losses and/or a fraction of the C6+ compounds could be lost during the atmospheric condensate depentanization process (Stage 3.2)), and C6+ components (e.g., 2-methylpentane and lighter) were gravimetrically added to the depentanized atmospheric condensate.
3.5. Combine the Depentanized Liquids	After the depentanized atmospheric condensate and the depentanized pressurized HC liquid compositions were equilibrated, the two samples were combined for a total volume of approximately 24 liters (i.e., about 8 gallons from Stage 3.4 + about 240 mL from Stage 2.2) with the target CRM C6+ composition.
4.1. CRM Composition: Mass Percent and Density	The target CRM Composition determined during Stage 1.3 included the density and mass percent of each component (Methane, Carbon Dioxide, Ethane, Propane, Isobutane, n-Butane, Isopentane, n-Pentane and Hexanes Plus including Benzene, Toluene, Ethyl Benzene, meta-Xylene, para-Xylene and ortho-Xylene, etc.).
4.2. Gravimetric Addition of C5 through C1	The mass percent of CRM C1 through C5 species determined in Stage 1.3 was used to calculate the mass of C1 – C5 hydrocarbons that were added to the depentanized liquid to replicate the target CRM composition. The mass additions to the CRM development blend were in ascending order of vapor pressure. The required mass of C5 was first added to the mixture, then C4, C3, C2, and C1 species were blended (CO_2 was added if needed). A Certificate of Gravimetric Composition was prepared and listed the concentrations and uncertainty of each component added to the blend as well as the physical properties of the blend and the C6+ fraction. The result is a large pressurized blend cylinder containing the target CRM composition.

Stage	Description
4.3. CRM Blend Stabilization	The pressurized blend cylinder was mixed for two hours to ensure blend homogeneity. Back-pressure was applied to the piston cylinder to ensure phase fidelity.
4.4. CRM Blend Compositional Analysis	Compositional analyses were performed on CRM samples from the pressurized blend cylinder by SPL using all four analytical methods used to determine the CRM composition and two independent labs using their "best methods".
4.5. CRM Composition Verification	Refer to discussion below
5.1. CRM Sample Cylinders	The total pressurized CRM blend volume was allocated to a minimum of 41 CRM samples in 500 mL cylinders: 10 made by DCG and 9 by SPL for CRM Composition Verification, 8 CRM samples were required for the sample handling task (4 CRM samples for water displacement and 4 CRMs for pressurized piston), 10 CRM samples were required for analytical methods evaluations and up to 4 CRM samples were required for calibration of analytical equipment.

CRM Composition Certification and Uncertainty

The scales used to blend the CRM are NIST traceable and the scale provides a report of the percent accuracy on each weighing. The materials used to make the additions are certified to a percent purity (all materials SPL purchases are over 99% purity). These materials are analyzed to determine the quantity and quality of the material, and to identify contaminants. The mass of each contaminant is accounted for in each addition. The blend addition cylinder is tare weighted before and after each addition, as well as weighed full for each addition. Thus, the CRM blend components that are NIST traceable are the C1 – C5 components and the total mass of C6+ components that are added gravimetrically.   The CRM blend individual C6+ components are verified analytically and are not NIST traceable. Refer to Final Uncertainty Report – CRM Uncertainty.

Task 3. **Multi-Laboratory Study** (Independent Laboratory Analyses for CRM Composition Verification and Analytical Methods Evaluation)

The concentrations of the CRM C1 – C5 components are expected to have very low uncertainties because the gravimetric addition uses a NIST traceable scale to add high purity compounds. However, the concentrations of the CRM "natural" C6+ components must be determined using standard analytical methods for hydrocarbons. SPL used in-house analysis to determine the C6+ components concentrations. In addition, the CRM was analyzed by outside

independent labs using their best methods to provide a robust data set to verify the concentrations of the CRM C6+ components. These analyses also provided a comparison of industry standard analytical methods for pressurized condensate that include GPA 2186, GPA 2103, and flash liberation analysis.

To enhance the analytical methods evaluation, some CRM samples were spiked with known amounts of select hydrocarbons and all analytical labs analyzed both CRM and "CRM spike" samples. This is similar to a method of additions analytical technique, and the spike recoveries provide an indication of analytical method accuracy. Spike compounds included a C1 – C5 compound, a BTEX, and a C10+ compound. These parameters were chosen as representative parameters for each analytical subset of GPA-2103M. The first analytical subset is GC-TCD (thermal conductivity detector) determination of C1-C5 concentrations. The second detection subset is a naphtha distillation cut followed by GC-FID (flame ionization detector) analysis to determine C6 – C10+ compounds including key isomers such as BTEX. The third subset measures the physical properties of the "heavy" C10+ fraction. A distillation cut produces a C10+ fraction, and C10+ fraction density is measured by a density meter and molecular weight (MW) is determined by other means such as cryette.

Four labs analyzed the CRM and CRM spike samples. Table 3 summarizes the labs and associated analyses.

Table 3. Summary of Multi-lab Study CRM and CRM Spike Analyses.

Analytical Lab	Analytical Method (M = modified)	Number of CRM1 Analyses	Number of CRM2 Analyses
1	GPA 2103M	3	3
	Flash Liberation	3	3
2	GPA 2186M	3	3
	GPA 2103M	3	3
3	GPA 2186M	3	3
	Flash Liberation	3	3
4	GPA 2186M	3	3
	GPA 2103M	3	3
	Flash Liberation	3	3

Task 4. Analytical Method Performance and Uncertainty Evaluation

The goal of this phase of the study was define the accuracy, precision, and overall uncertainty of four different methods used for pressurized condensate analysis. Forty analyses, ten by each

of the four analytical methods, of CRM samples were used to evaluate the analytical methods. The analytical data, including density and bubble point, were provided to MOVILAB to estimate the precision and uncertainty of each method. The two methods with the best precision, lowest uncertainty, and best operational performance (verified by density and bubble point) were used for analytical testing for the remainder of the study.

Three analytical methods measure C1-C10+, and the fourth measures C1-C100+. The C1-C100+ analytical method was included to assess how increased analytical detail impacts PSM/EOS modeling. PSM/EOS was used to calculate bubble point pressure and density of the NIST traceable gravimetrically certified CRM composition. The analyzed compositions were modeled by PSM/EOS at laboratory temperature and cylinder pressure to determine bubble point pressure and density. Physical determinations of CRM bubble point pressure and density (at cylinder pressure and laboratory temperature) were compared to the PSM/EOS calculated values for gravimetric and analyzed compositions.

Table 4. Analytical Method Performance and Uncertainty Tasks

No. of Samples	Lab Analyses for Each Sample [A]	Process Simulations for Each Sample Analysis	Notes
10 CRM samples	GPA 2186 (C1 – C10+, including BTEX) GPA 2103M (C1 – C10+, including BTEX) GPA 2103M (C1 – C100+, including BTEX (ASTM D7169, C6 - C100)) Flash Liberation / Mod-POD (C1 – C10+, including BTEX)	Bubble point @ T_{lab} - EOS Density @ T_{lab} - EOS	For each sample analysis, conduct Bubble Point and Density comparisons @ T_{lab} EOS-sample analysis composition vs. EOS-Certified composition (as described above)

A. Refer to QAPP for method details

Task 5. Process Measurement Uncertainty Analysis

In order to determine uncertainty process meters, manufacturer's specifications and the calibration data available were considered. Liquid flow meters are under metrological control upon proving calibrations.

For FOX gas flow meters, in spite of calibration, manufacturer does not provide correction factors or directions to make corrections in the event of differences of measured gas and calibration gas, therefore increasing uncertainty.

Uncertainties of process measurements are representative of field instrumentation, and can be inferred to similar systems. These uncertainty estimates are required to assess the uncertainty of PSM/EOS models and Mass Balance estimates.

Task 6. Sample Handling Perturbation Study

The goal of this phase of the study was to evaluate the impact of laboratory sample handling parameters – temperature, pressure, mixing, and GC sample injection rate – on pressurized HC samples compositional analysis. The task results were used to develop recommendations for proper sample. CRM samples were used in the Sample Handling Perturbation Study. Theoretically, the CRM's will yield a constant condition when properly handled until emptied. However, the most severe of the perturbations could compromise the blend which required starting each series with the least potential impact and monitoring compositions as the perturbation became more severe. Sample distortions from improper sample handling primarily adversely affects lighter, more volatile components such as methane and ethane. Heavier hexanes plus compounds are impacted much less severely; therefore, the sample handling perturbation study focused on the GC portion of the GPA 2103 analysis , and the shrinkage determination and subsequent distillations steps of Method 2103 were not conducted.

The laboratory sample handling perturbations task was designed to identify proper protocols for handling pressurized condensate samples. The industry analytical standards provide some guidance, as do manufacturers of sample cylinders, but laboratory sample handling procedures are not available. This study tested a range of five perturbations for four key parameters of sample handling for both CP sampling and CV sampling: mixing, purge rate (flow rate of sample through the GC sample inlet system), and sample conditioning with regards to temperature and pressure. A total of sixteen perturbations were conducted, with a baseline of the most conservative handling conditions run at the beginning, middle and end of the study. The baseline line condition is indicated in Table 5, and each perturbation was conducted with the other three parameters at the baseline line condition. The intent was that the least rigorous combination that does not produce sample distortion would be used for the remainder of the study

Table 5. Laboratory Sample Handling Perturbation Study Tasks

No. of Samples	Lab Analyses for Each Sample	Process Simulations for Each Sample	Notes (operational performance checks)
68 samples (developed from 8 CRM samples) - 34 CP samples (Table 5a) - 34 CV samples (Table 5b) Refer to Table 5a and Table 5b for sample handling perturbations	Density @ P_{sep}, T_{sep}, plus Bubble point @ P_{sep}, T_{sep} (by densitometer) GPA 2103M (C1 – 6+) [A]	Density@ P_{sep}, T_{sep} - EOS, plus Bubble Point @ P_{sep}, T_{sep} – EOS, plus FGOR - EOS	Initial Pressure compared from sampling to laboratory conditions. Bubble Point and Density comparisons @ P_{sep}, T_{sep}: Physical measurements vs. EOS-analysis

A. Analysis procedures were based on results of the Analytical Method Performance study (best performing method was used). Refer to QAPP for method details.

Table 6A. Laboratory Sample Handling Perturbations for CP Cylinder Sampling

Parameter	Pert 1 [A]	Pert 2	Pert 3	Pert 4	Baseline	Pert 1	Pert 2	Pert 3	Pert 4 [A]
Mixing (rocks)	0	6	12	18	**24**				
Purging (ml/sec.)					**1**	**2**	**4**	**8**	**12**
Pressure (psia) [B]	365	415	465	**515**	**1115** [B]				
Temperature (°F)					**55°F**	65°F	70°F	*73*	75

A. If the data trend suggested further change in a parameter could improve method performance, then the matrix was expanded.

B. Liquid standard injection pressure for Pert 4.

Table 6B. Laboratory Sample Handling Perturbations for CV Cylinder Sampling

Parameter	Pert 1 [A]	Pert 2	Pert 3	Pert 4	Baseline	Pert 1	Pert 2	Pert 3	Pert 4 [A]
Mixing (rocks)	0	6	12	18	**24**				
Purging (ml/sec.)					**1**	**2**	**4**	**8**	**12**
Pressure (psia) [B]	365	415	465	**515**	**1115** [B]				
Temperature (°F)					**55°F**	65°F	70°F	*73*	75

A. If the data trend suggested further change in a parameter could improve method performance, then the matrix was expanded.

B. Liquid standard injection pressure for Pert 4.

Task 7. Operational Performance Checks

The purpose of this task was to evaluate operational performance checks that assess the reliability of pressurized condensates sampling and analysis results. These checks include:

- Bubble Point Check. The Bubble Point calculated from analytical composition by EOS was compared to the measured Bubble Point from the initial pressure test and Psep at Tsep.

Initial pressure tests compare the sample pressure at the time of sample collection (prior to removal of outage) to the "initial" sample pressure in the lab prior to sample analysis (after re-pressurization). This phase of the study assigns reasonable expectations for comparing initial pressure to the sample point pressure at sample point temperature. The laboratory Crystal gauge (refer to Figure 2) readings were corrected to psia for this procedure to account for differences in ambient pressure in the lab and at the sample collection location (i.e., elevation effect). Figure 1 presents the steps for the initial pressure test and subsequent GC analysis for both CP and CV cylinders.

Step	CV Cylinder	CP Cylinder
1	Attach Crystal gauge to cylinder via tee.	Attach Crystal gauge to cylinder via tee.
2	Pre-condition sample to sample point temperature.	Pre-condition sample to sample point temperature.
3	Pressurize sample to appropriate charge pressure with water via Sprague pump.	Pressurize sample to appropriate charge pressure with helium on pre-charge side.
4	Mix sample by rocking appropriate number of times.	Mix sample by rocking appropriate number of times.
5	Reduce pressure from pre-charge side of cylinder by slowly dripping water from the bottom of the cylinder until the pressure stabilizes.	Reduce pressure from pre-charge side of cylinder by venting helium until the pressure stabilizes.
6	Read pressure on Crystal gauge and record. Compare gauge reading to pressure of the sample point.	Read pressure on Crystal gauge and record. Read cylinder gauges and record. Compare gauge readings to pressure of the sample point.
7	Pressurize sample to appropriate charge pressure.	Pressurize sample to appropriate charge pressure.
8	Mix sample by rocking appropriate number of times.	Mix sample by rocking appropriate number of times.
9	Connect sample line to GC, purge and inject.	Connect sample line to GC, purge and inject.

Figure 1. Initial pressure test procedure for CP and CV cylinders.

Figure 2 presents the initial pressure test setup and Figure 3 shows a Crystal pressure gauge.
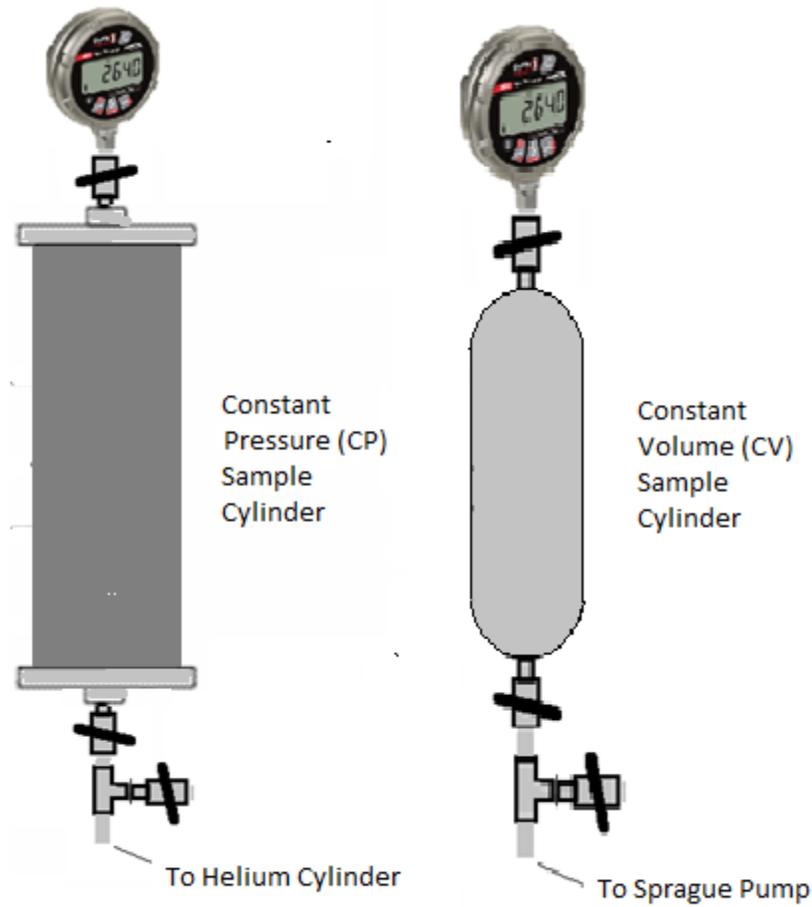
Figure 2.   IPT setup for CP and CV cylinders.

Figure 3. Crystal XP2i gauge (accuracy = 0.1% of reading).

The Crystal XP2i gauge pressure measurement accuracy is +/- 0.1% of reading.   The pressurized densitometer provides two means of operational performance checks, density at flowing pressure and temperature and Bubble Point. Both density and bubble point determined by densitometer, are compared to the density measured by the Coriolis meter and sample point pressure at sample point temperature. These operational performance checks provide an indication of the validity of field samples, and were used to evaluate the sampling procedures used in the study.
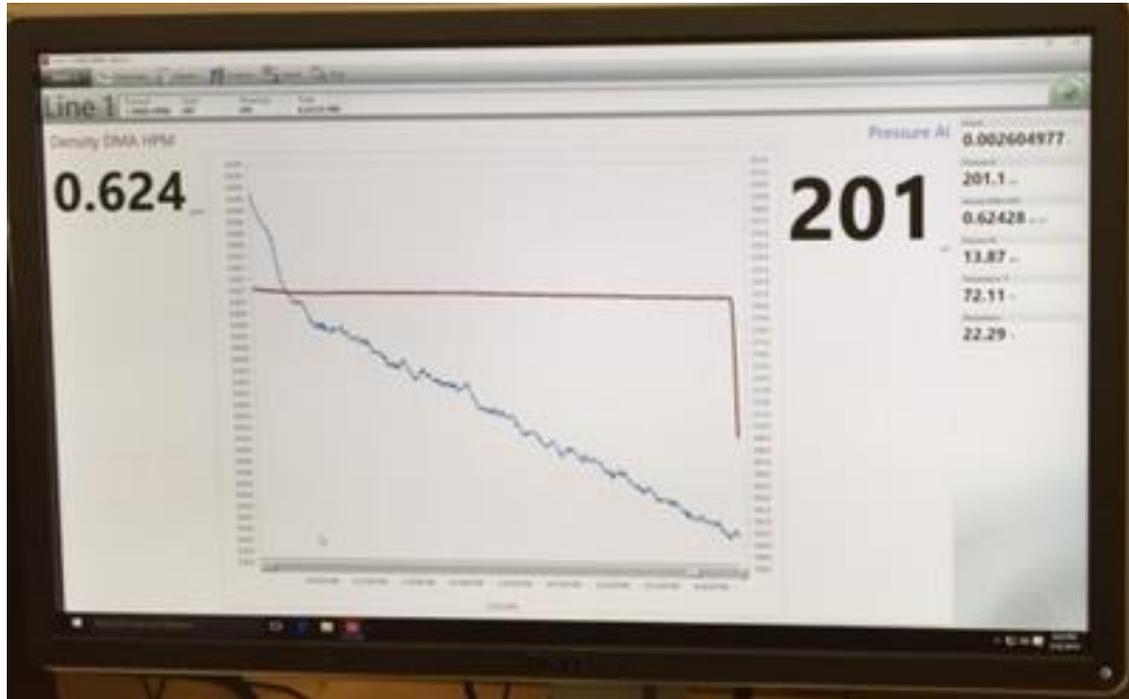
Figure 4. – Density vs. pressure (illustration of bubble point determination).

Task 8. Sample Collection Perturbation Study

The sample collection perturbation study was conducted in two phases, in January 2016 and during the summer phase pressure range testing. Table 7 lists the sampling parameters that were evaluated, and the schedule for collecting these samples. The Displacement Constant Volume (CV) Method vs. the Constant Pressure (CP) Cylinder Method for sampling were compared during this study. The CP / CV comparison included the collection of side-by-side, simultaneous CP cylinder and CV cylinder samples during every test. Table 8A presents the January 2016 sample collection perturbation test matrix, and includes the collection of comparable CP and CV samples. Table 8B presents the sample collection perturbation test schedule. Tables 10 and 11 (in Task 9) present the July 2016 test matrix including the remaining sampling perturbation tests.

Table 7. Sample Collection Perturbations [A, B]

Parameter	Pert 2	Pert 1	Baseline	Pert 1	Pert 2	Pert 3	Schedule
Sample Start Time[C]			Within 30 minutes after well cycle / separator dumps end	During well cycle/ separator dumps	90 minutes after well cycle / separator dumps completed	150 minutes after well cycle / separator dumps completed	January 2016
Purge (Sample Collection) Rate[C]		20 ml/ minute	60 ml/minute	100 ml/minute			January 2016
Purge (Sample Collection) Rate	20 ml/ minute	40 ml/ minute	60 ml/minute	100 ml/minute	180 ml/minute		July 2016
Sample Location[D]		Sight Glass	Sample Probe				July 2016

A.   Constant Pressure Cylinder vs. Constant Volume Cylinder, as well as simultaneous vs. sequential sampling will be considered as perturbations.

B.   Sample cylinder size perturbation tests removed from test matrix to accommodate expanded sample collection rate perturbation test matrix.

C.   Sampling perturbation tests conducted at a target separator pressure of 225 psig.

D.   Sample location perturbation tests conducted at a purge rate of 20 ml/min (refer to Table 10).

Table 8A. Sample Collection Perturbation Study Test Matrix (January 2016)

Operating Condition	Pressurized Condensate						Process Measure-ments[A]	Notes (operational performance checks)
	Sampling Parameters[A]	No. of Samples: Collect/Analyze /Archive	Sequent-ial Samples	Simul-taneous Samples	Lab Analyses[A] Each Sample	PSM for Each Sample		
P_{sep}: ~ 225 psig T_{sep}: ~ 80°F Separator Heater On	GPA 2174; 500 ml **CV** Sample Cylinder Sample location: sample probe				Density, P&T + Bubble Point P&T GPA 2103 (C1 – C10+, including BTEX)[B] GPA 2103 Mod-POD (C1 – C10+, including BTEX) [B]	EOS Density at sample collection P&T, plus Bubble Point P at sample collection T	P_{sep} T_{sep} ρ_{oil}	Initial Pressure compared from sampling to laboratory conditions. Bubble Point and Density comparisons @ Sample collection P,T: Physical measurements vs. EOS-analysis
	Sample start time: <u>after well cycle (WC) starts</u> Sample rate (SR): 60 ml/min.	2/2/0	**X**	**I**				
	BASELINE Sample start time: < 30 min. after WC end SR: 60 ml/min.	4/3/1	**X**	**II**				
	Sample start time: <u>90 min. after WC end</u> SR: 60 ml/min.	2/2/0	**X**	**III**				
	Sample start time: <u>150 min. after WC end</u> SR: 60 ml/min.	2/2/0	**X**	**IV**				
	Sample start time: < 30 min. after WC end SR: <u>20 ml/min.</u>	2/2/0		**V**				
	Sample start time: < 30 min. after WC end SR: <u>100 ml/min.</u>	2/2/0		**VI**				
	GPA 2174; 500 ml **CP** Sample Cylinder Sample location: sample probe						P_{sep}	Initial Pressure compared from

Operating Condition	Pressurized Condensate						Process Measurements[A]	Notes (operational performance checks)
	Sampling Parameters[A]	No. of Samples: Collect/Analyze /Archive	Sequential Samples	Simultaneous Samples	Lab Analyses[A] Each Sample	PSM for Each Sample		
P_{sep}: ~ 225 psig T_{sep}: ~ 80°F Separator Heater On	Sample start time: <u>after WC starts</u> SR: 60 ml/min.	2/1/1	Y	I	Density, P&T + Bubble Point P&T GPA 2103 (C1 – C10+, including BTEX) [B] GPA 2103 Mod-POD (C1 – C10+, including BTEX) [B]	EOS Density P&T, plus Bubble Point P&T	T_{sep} ρ_{oil}	sampling to laboratory conditions. Bubble Point and Density comparisons @ Sample collection P,T: Physical measurements vs. EOS-analysis
	BASELINE Sample start time: < 30 min. after WC end SR: 60 ml/min.	4/3/1	Y	II				
	Sample start time: <u>90 min. after WC end</u> SR: 60 ml/min.	2/1/1	Y	III				
	Sample start time: <u>150 min. after WC end</u> SR: 60 ml/min.	2/1/1	Y	IV				
	Sample start time: < 30 min. after WC end SR: <u>20 ml/min.</u>	2/1/1		V				
	Sample start time: < 30 min. after WC end SR: <u>100 ml/min.</u>	2/1/1		VI				

A. Refer to QAPP for measurement / test method details

B. Analysis procedures were based on results of the Analytical Method Performance study (best performing method was used).

Table 8B. Sample Collection Perturbation Study Schedule (January 2016)

Perturbation	Day	Well Cycle	Test Separator Pressure	Test Separator Temperature	Test Separator Heater Fuel Gas Source	Anticipated Test Separator Pressure Trend	Simultaneous	Sequential	Cylinder	Time to Start Sampling after well cycle/ final dump (min)	Purge/Sample Rate (ml/min)	Probe
	1	1	Start at 225 psig		Test Sep	Declining	I	Y	CP	0 - Start Sampling after 1st dump	60	1
	1	1			Test Sep	Declining	I	X	CV	0 - Start Sampling after 1st dump	60	3
	1	1			Test Sep	Declining	II	Y	CP	<30	60	3
	1	1			Test Sep	Declining	II	X	CV	<30	60	1
	1	1		75°F	Test Sep	Declining	III	Y	CP	90	60	1
	1	1			Test Sep	Declining	III	X	CV	90	60	3
	1	1			Test Sep	Declining	IV	Y	CP	150	60	3
	1	1			Test Sep, switch to Instrument Gas after sampling is completed	Declining	IV	X	CV	150	60	1
	1	2+ [A]	225 psig		Instrument Gas	Steady				None		
	2	1	Start at 225 psig		Test Sep	Declining	I	Y	CP	0 - Start Sampling after 1st dump	60	1
	2	1			Test Sep	Declining	I	X	CV	0 - Start Sampling after 1st dump	60	3
	2	1			Test Sep	Declining	II	Y	CP	<30	60	3
	2	1			Test Sep	Declining	II	X	CV	<30	60	1
	2	1		75°F	Test Sep	Declining	III	Y	CP	90	60	1
	2	1			Test Sep	Declining	III	X	CV	90	60	3
	2	1			Test Sep	Declining	IV	Y	CP	150	60	3
	2	1			Test Sep, switch to Instrument Gas after sampling is completed	Declining	IV	X	CV	150	60	1
	2	2+ [A]	225 psig		Instrument Gas	Steady				None		

Perturbation	Day	Well Cycle	Test Separator Pressure	Test Separator Temperature	Test Separator Heater Fuel Gas Source	Anticipated Test Separator Pressure Trend	Simultaneous	Sequential	Cylinder	Time to Start Sampling after well cycle/ final dump (min)	Purge/Sample Rate (ml/min)	Probe
Purge/Sample Rate (ml/min)	3	1	225 pisg		Instrument Gas	Steady	V		CP	<30	20	1
	3	1	225 psig		Instrument Gas	Steady	V		CV	<30	20	3
	3	2	225 psig	75°F	Instrument Gas	Steady	V		CP	<30	20	3
	3	2	225 psig		Instrument Gas	Steady	V		CV	<30	20	1
	3	3 + [A]	225 psig		Instrument Gas	Steady				None		
	4	1	225 psig		Instrument Gas	Steady	VI		CP	<30	100	1
	4	1	225 psig		Instrument Gas	Steady	VI		CV	<30	100	3
	4	2	225 psig	75°F	Instrument Gas	Steady	VI		CP	<30	100	3
	4	2	225 psig		Instrument Gas	Steady	VI		CV	<30	100	1
	4	3 + [A]	225 psig		Instrument Gas	Steady				None		
	5	1	225 psig		Instrument Gas	Steady	II		CP	<30	60	1
	5	1	225 psig		Instrument Gas	Steady	II		CV	<30	60	3
	5	2	225 psig	75°F	Instrument Gas	Steady	II		CP	<30	60	3
	5	2	225 psig		Instrument Gas	Steady	II		CV	<30	60	1

Assumptions and Guidelines for this 5-Day Test Matrix

- collect one CV and one CP sample during each sampling event to allow better control over sample rates, and provide paired CV/CP data.

- during the test series that evaluates the impact of the time from the well cycle end to the initiation of sampling (i.e., 0, 30, 90, and 150 minutes), fire the separator heater using test separator gas. The separator pressure is expected to drop during the sampling (i.e., Declining Separator Pressure Test Series). Then switch the separator fuel to instrument gas (from another separator) after completing the sampling and not sample after the next well cycle to allow the separator residual oil to re-equilibrate at the target separator operating pressure (225 pisg).

- For the test series that evaluates the sample rate (i.e., 20, 60, and 100 ml/min), fire the separator heater using instrument gas from another separator to provide a constant test separator pressure (i.e., Steady Separator Pressure Tests) and isolate the sample rate as the test parameter. Collect samples during the next well cycle - the separator residual oil should be remain in equilibrium at the target operating pressure (225 pisg).

- the time between well cycles is short enough to allow two Steady Separator Pressure tests (i.e., separator heater firing instrument gas) per day

- . The well was shut in after the well cycle and sample collection such that the well was fully pressurized for the next morning's testing.

Task 9. Three Separator Pressure Range and Seasonal PHLSA Studies

Winter and Summer Phase PHLSA Study Overview

The primary goals for this task were to assess: 1.) seasonal effects on pressurized condensate sampling and analysis and PSM/EOS modeling of flashing losses, and 2.) the effect of changes in separator operating pressure on pressurized condensate sampling and analysis and PSM/EOS modeling of flashing losses. In the Winter and in the Summer, the separator was operated at three different pressures (target separator operating pressures were 175, 225, and 260 psig) and pressurized HC samples were collected while process measurements were conducted for storage tank mass balance and FGOR calculations. SPL used 4 PSM/EOS models to estimate the storage tank mass balance and flashing losses based on these pressurized condensate samples and the process measurements. The following tables summarize these tests:

- Table 9 summarizes the Winter phase three-pressure range test matrix and lists the target separator operating conditions, pressurized condensate sample collection parameters, and associated lab analyses and PSM/EOS calculations for each sample.

- Table 10 summarizes the process samples (e.g., tank headspace gas) that were collected and analyzed in conjunction with pressurized condensate samples during each well cycle during the Winter phase testing.

- Table 11 summarizes the Summer phase three-pressure range test matrix and lists the target separator operating conditions, pressurized condensate sample collection parameters, and associated lab analyses and PSM/EOS calculations for each sample.

- Table 11A provides additional detail regarding the pressurized condensate sample collection during the Summer phase three-pressure testing.

- Table 12 summarizes the process samples (e.g., tank headspace gas) that were collected and analyzed in conjunction with pressurized condensate samples during each well cycle during the Winter phase testing.

MOVILAB will perform an overall uncertainty analysis that will use all of the individual uncertainties to give best case and worst case scenarios for estimating flashing emissions using pressurized condensate analyses and PSM/EOS calculations. A comprehensive detailed analysis will be performed to compare the theoretical and experimental results.

Prior to the sampling events, all metering and other process monitoring instrumentation were proved and/or calibrated to ensure process measurement data quality. The pressurized hydrocarbon liquid sampling technicians recorded readings of pressure, temperature and

volumes during each sampling event on the sample tag (i.e., for both pressurized HC liquids and other process samples). The samples were collected according to the sampling methods listed below and described in the QAPP. After sample collection, the sampling technicians recorded final readings for pressure, temperature and volumes and on the tag, and completed the Chain of Custody. Separator to tank oil dump volumes, and storage tank-to-burner pipeline gas flows and composition were measured and recorded for the duration of the well cycle to directly measure the flash gas-to-oil ratio (FGOR) and a storage tank mass balance (refer to Table 10 and Table 12). A field modification to the test matrix was the collection of an extra pressurized condensate "tank simulation" sample for the storage tank mass balance determinations. Oil samples collected directly from the storage tank had been weathering for months and experienced numerous heating and cooling cycles; thus, this oil is expected to have a different composition than recently flashed oil, and mass balance calculations using weathered oil would be biased. The "tank simulation" sample was flashed in the lab at the temperature and pressure measured in the vicinity of the storage tank downcomer, and the post-flash composition of this oil sample was used for the mass balance calculations. The tests were witnessed by a Noble Energy representative who documented the process conditions and sample collection during the well cycle.

Sample Collection and Analysis Methods

Methods for the collection of pressurized condensate samples are:

- GPA 2174 – Displacement Method Constant Volume Cylinder

- GPA 2174 – Constant Pressure Cylinder

These two methods were selected because they represent the most common current practices for collecting pressurized hydrocarbon liquid samples for analysis. These methods have been in place for over forty years and are widely used for sampling Natural Gas Liquids (NGL's) and pressurized condensate samples.

Methods for the analysis of pressurized condensate samples are:

- Bubble Point Pressure ASTM D-5002(M) (physical determination)

- Density ASTM D-4052 (M) (physical determination)

- Physical FGOR (physical measurement)

- GPA 2186 (C1-C10+, includes BTEX)

- GPA 2103 M (C1 - C10+, includes BTEX)

- GPA 2103 M (C1 - C100+, includes BTEX)

- GPA 2103M Flash liberation (C1 – C10+, includes BTEX)

Methods for storage tank condensate sampling are:

- ASTM D4057 (API MPMS Chapter 8.1) – Standard Practice for Manual Sampling of Petroleum and Petroleum Products

Methods for separator gas sampling are:

- GPA 2166 – Purge-Fill and Empty

Methods for flash gas sampling are:

- GPA 2166 – Evacuated Container (for storage tank headspace/flash gas)

- Tedlar Bag – required in Consent Decree

- GPA 2166 – Portable GC(sample will be used to adjust tank vent gas flow rate measurements for actual gas composition, since thermal dispersion meter used to measure the flash gas was calibrated on a fluid of different composition than the test site fluid)

Methods for separator gas and flash gas analysis are:

- GPA 2286

Additional detail regarding these measurement methods and the process monitoring information are presented in the QAPP.

Approach and Methodologies of Quantifying Flash Losses

Four commercially available process simulation modeling (PSM) / equation of state (EOS) software packages were used to calculate bubble point pressure, FOGR, and flash gas and post-flash oil composition using the pressurized liquid hydrocarbons compositional analyses. These four PSM/EOS software packages are identified as Sim 1, Sim 2, Sim 3, and Sim 4. SPL built a PSM/EOS model in Sim 1 representing the study site and all fluids from the pressurized condensate sampling location (separator) to the storage tank post-flash oil and flash gas. This model was then replicated for Sim 2, Sim 3, and Sim 4. SPL prepared a detailed set of instructions for data entry for the PSM/EOS models and each data set was entered into each of the four models to calculate the mass balance and flash gas emissions estimates. Each PSM will

use standard/default parameters. MOVILAB will use this data to estimate the uncertainty of flashing emissions calculated using pressurized condensate analysis and PSM/EOS.

SPL also modeled all of the analyses with corresponding input data in Sim 1 and Sim 4, and Noble in Sim 2 and Sim 3 to calculate flashing losses. Comparisons between these simulations were used to determine differences between various PSM/EOS software programs. Refer to Appendix V for details of PSM/EOS modeling and results.

Much of the uncertainty in a mass balance of this nature lies in the sampling, transport, and analysis of flash gas. The addition of the portable GC and on-site analysis for direct measurement of the flash gas composition improved the measurement data quality.

The following tables list the operating conditions and measurements for each set of seasonal tests to be used in the study. Figure 5 is an example field data sheet.

Figure 5. Field data sheet

PHLSA Study Checklist and Data Reporting Sheet for Summer Phase Sampling					
1. General					
Date & Time of Day					
Ambient Condition (sunny, cloudy etc.)					
Pressure Category (HP/MP/LP)					
Cycle Number (1/2/3/4)					
2. Pre-well Cycle Operational Checklist					
Turn-on the heat-tracing unit					
Shut in non-test wells					
Close 3" line from test-tank to burners					
Open 2" line from non-test tanks to burners					
Turn on compressor (if $P_{line} > P_{test}$)					
Drain the (tank) knockout pot					
Close drain valve of (tank) knockout pot					
Close PIT5 (0 - 1.5 psig Pressure Transducer) valve					
Operate Oil Dump Valve (empty oil box)					
Reset Fox Thermal meter 1 Totalizer to Zero					
Reset Fox Thermal meter 2 Totalizer to Zero					
Reset Fox Thermal meter 3 Totalizer to Zero					
Verify heat tracing unit is 120-150F (depends on ambient temp					
3. Flowmeters Totalizer Readings					
	Time	Fox1 (2-pt cal.) [MSCF]	Fox2 (3-pt cal.) [MSCF]	Fox3 (PRV vent) [MSCF]	Vane Anemometer [act. m^3]	Coriolis Meter [std. bbl]
Pre Cycle						
Post Cycle						
4. Well, Separator and Tank					
	Time	Tsep (bulk) [F] RTD1	Psep (bulk) [psig] PIT1	Oil Tank Temperature (at 12") [F] RTD8	Tank Headspace Temperature [F] RTD3	Well Pressures (tubing/casing) (psig)
Pre Cycle						
Post Cycle						
5. Miscellaneous					
	Time	Pyranometer Reading [W/m^2]	Ambient Pressure [psia]	Glycol Heat Tracing Unit Temperature [F]		
Pre Cycle						
Post Cycle						

CYCLE BEGINS

5A. Compressor Engine Operating Parameters

	Time	Engine Make and Model	Engine Speed	Suction Pressure (psig)	Discharge Pressure (psig)	
Reading 1						
Reading 2						

6. Oil Dumps

	Type (FF/N/M)	Vol. (std. bbl) / Duration (sec)		Type (FF/N/M)	Vol. (std. bbl) / Duration (sec)
Dump 1		/	Dump 6		/
Dump 2		/	Dump 7		/
Dump 3		/	Dump 8		/
Dump 4		/	Dump 9		/
Dump 5		/	Dump 10		/

CYCLE ENDS

7. Post-Well Cycle Operational Checklist

FIRST **Operate** Oil Dump Valve - Maunal Dump (empty oil box)	
Record "Post-Cycle" values in steps (3), (4) & (5) **AFTER Manual DUMP**	
Open PIT5 Pressure Transducer to 0 - 1.5 psig	
Turn on non-test wells	
Open 3" line from test-tank to burner	
Close 2" line from non-test tanks to burners	

8. Pressurized Condensate Samples Collection (CV and CP Samples)

	Time	Sample rate (mL/min)	Psep (psig)	Tsep (F)	
Start					
End					

9. Pressurized Condensate Samples Collection (Simulated Tank Samples)

	Time	Sample rate (mL/min)	Psep (psig)	Tsep (F)	
Start					
End					

Table 9. Winter Phase PHLSA Study High-, Mid-, and Low-Pressure Range Test Matrix

Well Cycle Operating Conditions	Pressurized Condensate						Process Measurements	Notes
	Sampling Parameters	No. of Samples: Collect/Analyze/Archive	Sequential Samples	Simultaneous Samples	Lab Analyses for Each Sample[A]	PSM for Each Sample		
	GPA 2174 Sample rate: 20 ml/min. Sample cylinder volume: 500 cc / 400 ml Sample location: sample probe Sample start time: < 30 min. after well cycle end				Bubble Point P at Tsep Density Physical FGOR	Bubble Point P at Sample T Density FGOR	Refer to Table 9	Each sample along with corresponding Process Samples and Process Measurement was used in a unique Mass Balance and Flashing Emissions Model in 4 PSM/EOS models
High-P $250 < P_{sep}$ $T_{sep} \sim$ 85°F	CV sampling	4/3/1[B]	X	I	GPA 2103 M (C1 - C10+, includes BTEX)	Mass Balance		
	CP sampling	4/3/1[B]		I				
	CP sampling	3/2/1[C]	X[A]		GPA 2103 M (C1 - C100+, includes BTEX			
Mid-P $200 < P_{sep}$ < 250 psig $T_{sep} \sim$ 85°F	CV sampling	3/2/0[D]	Y	II				
	CP sampling	3/3/0		II				
	CP sampling	3/3/0[C]	Y[A]		GPA 2186M (C1 – C10+, Includes BTEX			
Low-P $150 < P_{sep}$ < 200 psig $T_{sep} \sim$ 85°F	CV sampling	3/2/0[D]	Z	III				
	CP sampling	3/3/0		III				
	CP sampling	3/3/0[C]	Z[A]					

A. Refer to QAPP for measurement / test method details

B. High-pressure well cycle 2 samples archived because separator pressure was very unstable

C. These samples were collected immediately after the primary samples, flashed in the lab at the tank liquid temperature during the sample collection, and the post-flash liquid was analyzed for hydrocarbon components by GPA 2103 M (C1 - C10+, and BTEX)

D. Rupture disc blew on second CV cylinder

Table 10. Winter Phase PHLSA Study: Process Measurements Conducted During Each Well Cycle

Well Cycle (WC)	Parameter[A]	Samples per WC[A]	Lab Analyses for Each Sample[A]	Monitoring Instrument[A]	Notes
All	Storage Tank Vent Gas	9[B]	Portable GC	Not Applicable	See Field Data Sheet (Figure 5)
		1	Tedlar bag sample, Portable GC	Not Applicable	
		1	Evacuated sample bomb, GPA 2286	Not Applicable	
	Separator/ Sales Gas	1	GPA 2286	Not Applicable	
	Storage Tank Weathered Condensate	6[C]	GPA 2103 M (C1 - C10+, and BTEX)	Not Applicable	
	Pressurized Separator Water	1[D]	Water Flash Test and GPA 2286M	Not Applicable	
	$P_{atmosheric.}$	Not Applicable, continuous measurement by instrumentation		Pressure gauge (psig)	
	$T_{ambient.}$			Thermocouple/RTD	
	$P_{separator}$			Pressure gauge (psig)	
	$T_{separator}$			Thermocouple	
	$P_{storage\ tank\ headspace}$			Pressure gauge (oz/in^2)	
	$T_{storage\ tank\ vapor}$			Thermocouple/RTD	
	$T_{storage\ tank\ liquid}$			Thermocouple/RTD	
	$H_{storage\ tank\ (liquid\ level)}$			Float gauge	
	$Q_{storage\ tank\ vent\ gas}$			Gas flow meters	
	$Q_{separator\ oil}$			Coriolis meter	
	$\rho_{separator\ oil}$			Coriolis meter	
	$T_{sep-to-tank\ fluids}$			Thermocouple/RTD	
	$Q_{separator\ sales\ gas}$			Flow meter	
	$\text{⏁}_{separator\ dump}$			Dump valve position indicator	
	$I_{separator\ dump}$				

A. Refer to QAPP for measurement / test method details
B. Plan was to perform at least 3-pre well cycle, 3-during well cycle (well cycle duration permitting) and 3-post well cycle portable GC analyses for each well cycle.
C. Three storage tank oil samples were collected before and after the pressurized oil sample collection
D. One pressurized separator water sample was collected for each of the three operating pressure ranges.

Table 11. Summer Phase PHLSA Study Low-, Mid-, and High-Pressure Range Test Matrix

Well Cycle Operating Conditions	Pressurized Condensate						Process Measure-ments	Notes
	Sampling Parameters	No. of Samples: Collect/Analyze /Archive	Sequential Samples	Simul-taneous Samples	Lab Analyses for Each Sample[A]	PSM for Each Sample		
	GPA 2174 Sample rate: 20 ml/min. Sample cylinder volume: 500 cc / 400 ml Sample location: sample probe Sample start time: < 30 min. after well cycle end				Bubble Point P at Tsep Density Physical FGOR GPA 2103 M (C1 - C10+, includes BTEX) GPA 2186M (C1 – C10+, Includes BTEX	BubblePoint P at sample T Density (ρ) FGOR Mass Balance	Refer to Table 11	Each sample along with corresponding Process Samples and Process Measurements will be used in a unique Mass Balance and Flashing Emissions Model in 4 PSM/EOS models
High-P 250 < P$_{sep}$ T$_{sep}$ ~ ambient[G]	CV sampling	3/3/0		I				
	CP sampling	3/3/0	X	I				
	CP sampling from sight glass[B], or CV sampling from sight glass[B]	2/2/0 1/1/0		I				
	CP sampling[C]	3/3/0[C]	X	I-1				
	Automated CP sampling[D]	3/3/0[D]		I-1				
Mid-P 200 < P$_{sep}$ < 250 psig T$_{sep}$ ~ ambient[G]	CV sampling[F]	5/5/0		II				
	CP sampling[F]	5/5/0	Y	II				
	CV sampling from sight glass[B], or CP sampling from sight glass[B]	2/2/0 1/1/0		II				
	CP sampling[C]	3/3/0[C]	Y	II-1				
	Automated CP sampling[D]	3/3/0[D]		II-1				
Mid-P 200 < P$_{sep}$ < 250 psig T$_{sep}$ ~ ambient[G]	CV sampling, Rate = 40 ml/min	2/2/0		IV[H]				
	CP sampling, Rate = 40 ml/min	2/2/0		IV[H]				
	CV sampling, Rate = 60 ml/min	2/2/0		V[H]				
	CP sampling, Rate = 60 ml/min	2/2/0		V[H]				

Well Cycle Operating Conditions	Pressurized Condensate						Process Measure-ments	Notes
	Sampling Parameters	No. of Samples: Collect/Analyze /Archive	Sequential Samples	Simul-taneous Samples	Lab Analyses for Each Sample[A]	PSM for Each Sample		
	CV sampling, Rate = 100 ml/min	2/2/0		VI[H]				
	CP sampling, Rate = 100 ml/min	2/2/0		VI[H]				
	CV sampling, Rate = 180 ml/min	2/2/0		VII[H]				
	CP sampling, Rate = 180 ml/min	2/2/0		VII[H]				
Low-P $150 < P_{sep} < 200$ psig $T_{sep} \sim$ ambient[G]	CV sampling	3/3/0	Z	III				
	CP sampling	3/3/0		III				
	CP sampling from sight glass[B], or CV sampling from sight glass[B]	2/2/0 1/1/0		III				
	CP sampling[C]	3/3/0[C]	Z	III-1				
	Automated CP sampling[D]	3/3/0[D]		III-1				

A. Refer to QAPP for measurement / test method details

B. Sampling perturbation study samples. Sight glass samples collected using best practices including flushing the site glass prior to well cycle.

C. "Tank Sim" samples were collected immediately after the primary samples, flashed in the lab at the tank liquid temperature and absolute pressure at tank down-comer exit (about 1 foot from tank bottom) during sample collection, and the post-flash liquid was analyzed for hydrocarbon components by GPA 2103 M (C1 - C10+, and BTEX)

D. "Densitometer" samples collected after the primary samples for densitometer measurements (e.g., bubble point pressure, density).

E. .

F. Three sets of samples collected at 20 ml/min, two sets of samples collected at sample collection rates indicated for well cycles 1 and 2 in Table 10B

G. The separator heater was not operating during the testing.

H. Refer to Table 10A

Table 11A. Daily Sample Collection* and Separator Operation Schedule for the Week of July 25

Test Series	Day	Well Cycle	Test / Well Cycle ID	Test Separator Pressure	Test Separator Temperature	Test Separator Heater Fuel Gas Source	Test Separator Pressure Trend	Sequential	Simultaneous	Cylinder	Target Time to Start Sampling after Well Cycle / Final Dump	Sample Rate (ml/min)	Sample Collection Location (Probe No. or Sight Glass (SG))
High Pressure Summer Tests	1	1	S-HP1	P > 250 psig	Ambient	None	Steady		I	CP	< 30 min [A]	20	1
	1	1		P > 250 psig	Ambient	None	Steady		I	CV	< 30 min [A]	20	3
	1	1		P > 250 psig	Ambient	None	Steady		I	CP	< 30 min [A]	20	SG
	1	2	S-HP2	P > 250 psig	Ambient	None	Steady		II	CV	< 30 min [A]	20	1
	1	2		P > 250 psig	Ambient	None	Steady		II	CP	< 30 min [A]	20	3
	1	2		P > 250 psig	Ambient	None	Steady		II	CV	< 30 min [A]	20	SG
	1	3	S-HP3	P > 250 psig	Ambient	None	Steady		III	CP	< 30 min [A]	20	1
	1	3		P > 250 psig	Ambient	None	Steady		III	CV	< 30 min [A]	20	3
	1	3		P > 250 psig	Ambient	None	Steady		III	CP	< 30 min [A]	20	SG
	1	4		**P ~ 225 psig**	Ambient	None					None		
	2	1		P ~ 225 psig	Ambient	None					None		
Mid Pressure Summer	2	2	S-MP1	P ~ 225 psig	Ambient	None	Steady		IV	CV	< 30 min [A]	20	1
	2	2		P ~ 225 psig	Ambient	None	Steady		IV	CP	< 30 min [A]	20	3
	2	2		P ~ 225 psig	Ambient	None	Steady		IV	CV	< 30 min [A]	20	SG
	2	3	S-MP2	P ~ 225 psig	Ambient	None	Steady		V	CP	< 30 min [A]	20	1
	2	3		P ~ 225 psig	Ambient	None	Steady		V	CV	< 30 min [A]	20	3
	2	3		P ~ 225 psig	Ambient	None	Steady		V	CP	< 30 min [A]	20	SG
	2	4	S-MP3	P ~ 225 psig	Ambient	None	Steady		VI	CV	< 30 min [A]	20	1
	2	4		P ~ 225 psig	Ambient	None	Steady		VI	CP	< 30 min [A]	20	3

Test Series	Day	Well Cycle	Test / Well Cycle ID	Test Separator Pressure	Test Separator Temperature	Test Separator Heater Fuel Gas Source	Test Separator Pressure Trend	Sequential	Simultaneous	Cylinder	Target Time to Start Sampling after Well Cycle / Final Dump	Sample Rate (ml/min)	Sample Collection Location (Probe No. or Sight Glass (SG))
	2	4		P ~ 225 psig	Ambient	None	Steady		VI	CV	< 30 min [A]	20	SG
Sample Collection Rate Perturbations Tests[B]	3	1	S-MP4[B]	P ~ 225 psig	Ambient	None	Steady	U	VII-1	CP	< 30 min [A]	100	3
	3	1		P ~ 225 psig	Ambient	None	Steady		VII-1	CV	< 30 min [A]	100	1
	3	1		P ~ 225 psig	Ambient	None	Steady	U	VII-2	CV	After 1st samples, < 30 min	40	3
	3	1		P ~ 225 psig	Ambient	None	Steady		VII-2	CP	After 1st samples, < 30 min	40	1
	3	2	S-MP5[B]	P ~ 225 psig	Ambient	None	Steady	V	VIII-1	CP	< 30 min [A]	60	3
	3	2		P ~ 225 psig	Ambient	None	Steady		VIII-1	CV	< 30 min [A]	60	1
	3	2		P ~ 225 psig	Ambient	None	Steady	V	VIII-2	CV	After 1st samples, < 30 min	180	3
	3	2		P ~ 225 psig	Ambient	None	Steady		VIII-2	CP	After 1st samples, < 30 min	180	1
	3	3	S-MP6	P ~ 225 psig	Ambient	None	Steady	W	IX-1	CV	< 30 min [A]	40	1
	3	3		P ~ 225 psig	Ambient	None	Steady		IX-1	CP	< 30 min [A]	40	3
	3	3		P ~ 225 psig	Ambient	None	Steady	W	IX-2	CV	After 1st samples, < 30 min	60	3
	3	3		P ~ 225 psig	Ambient	None	Steady		IX-2	CP	After 1st samples, < 30 min	60	1
Sample Collection	4	1	S-MP7	P ~ 225 psig	Ambient	None	Steady	X	X-1	CV	< 30 min [A]	180	1
	4	1		P ~ 225 psig	Ambient	None	Steady		X-1	CP	< 30 min [A]	180	3
	4	1		P ~ 225 psig	Ambient	None	Steady		X-2	CV	After 1st samples, < 30 min	100	3
	4	1		P ~ 225 psig	Ambient	None	Steady	X	X-2	CP	After 1st samples, < 30 min	100	1
	4	2	S-MP8	P ~ 225 psig	Ambient	None	Steady	Y	XI-1	CV	< 30 min [A]	60	1
	4	2		P ~ 225 psig	Ambient	None	Steady		XI-1	CP	< 30 min [A]	60	3

Test Series	Day	Well Cycle	Test / Well Cycle ID	Test Separator Pressure	Test Separator Temperature	Test Separator Heater Fuel Gas Source	Test Separator Pressure Trend	Sequential	Simultaneous	Cylinder	Target Time to Start Sampling after Well Cycle / Final Dump	Sample Rate (ml/min)	Sample Collection Location (Probe No. or Sight Glass (SG))
	4	2		P ~ 225 psig	Ambient	None	Steady	Y	XI-2	CV	After 1st samples, < 30 min	180	3
	4	2		P ~ 225 psig	Ambient	None	Steady		XI-2	CP	After 1st samples, < 30 min	180	1
	4	3	S-MP9	P ~ 225 psig	Ambient	None	Steady	Z	XII-1	CV	< 30 min [A]	180	1
	4	3		P ~ 225 psig	Ambient	None	Steady		XII-1	CP	< 30 min [A]	180	3
	4	3		P ~ 225 psig	Ambient	None	Steady	Z	XII-2	CV	After 1st samples, < 30 min	40	3
	4	3		P ~ 225 psig	Ambient	None	Steady		XII-2	CP	After 1st samples, < 30 min	40	1
	4	5		**P ~ 175 psig**	Ambient	None					None		
	5	1		P ~ 175 psig	Ambient	None					None		
Low Pressure Summer Tests	5	1	S-LP1	P ~ 175 psig	Ambient	None	Steady	X	XIII	CP	< 30 min [A]	20	1
	5	1		P ~ 175 psig	Ambient	None	Steady		XIII	CV	< 30 min [A]	20	3
	5	1		P ~ 175 psig	Ambient	None	Steady		XIII	CP	< 30 min [A]	20	SG
	5	2	S-LP2	P ~ 175 psig	Ambient	None	Steady	Y	XIV	CV	< 30 min [A]	20	1
	5	2		P ~ 175 psig	Ambient	None	Steady		XIV	CP	< 30 min [A]	20	3
	5	2		P ~ 175 psig	Ambient	None	Steady		XIV	CV	< 30 min [A]	20	SG
	5	3	S-LP3	P ~ 175 psig	Ambient	None	Steady	Z	XV	CP	< 30 min [A]	20	1
	5	3		P ~ 175 psig	Ambient	None	Steady		XV	CV	< 30 min [A]	20	3
	5	3		P ~ 175 psig	Ambient	None	Steady		XV	CP	< 30 min [A]	20	SG

* Excludes "Tank Sim" and "Densitometer" samples listed in Table 10.

A. Sample collection typically initiated within 5 - 10 minutes of the last dump of the well cycle.

B. These were additional mid-pressure range mass balance tests. All process samples were collected and all process measurements were conducted.

Table 12. Summer Phase PHLSA Testing, Process Measurements Conducted During Each Well Cycle

Well Cycle (WC)	Parameter[A]	Samples per WC[A]	Lab Analyses for Each Sample[A]	Monitoring Instrument[A]	Notes
All	Storage Tank Vent Gas	9[B]	Portable GC	Not Applicable	See Field Data Sheet (Figure 5)
		1	Tedlar bag sample, Portable GC	Not Applicable	
		1	Evacuated sample bomb, GPA 2286	Not Applicable	
	Separator/ Sales Gas	1	GPA 2286	Not Applicable	
	Storage Tank Condensate	2[C]	GPA 2103 M (C1 - C10+, and BTEX)	Not Applicable	
	Pressurized Separator Water[C]	1[D]	Water Flash Test and GPA 2286M	Not Applicable	
	$P_{atmosheric.}$	Not Applicable, continuous measurement by instrumentation		Pressure gauge (psig)	
	$T_{ambient.}$			Thermocouple/RTD	
	$P_{separator}$			Pressure gauge (psig)	
	$T_{separator}$			Thermocouple	
	$P_{storage\ tank\ headspace}$			Pressure gauge (oz/in^2)	
	$T_{storage\ tank\ vapor}$			Thermocouple/RTD	
	$T_{storage\ tank\ liquid}$			Thermocouple/RTD	
	$H_{storage\ tank\ (liquid\ level)}$			Float gauge	
	$Q_{storage\ tank\ vent\ gas}$			Gas flow meters	
	$Q_{separator\ oil}$			Coriolis meter	
	$\rho_{separator\ oil}$			Coriolis meter	
	$T_{sep-to-tank\ fluids}$			Thermocouple/RTD	
	$Q_{separator\ sales\ gas}$			Flow meter	
	$?_{separator\ dump}$			Dump valve position indicator	
	$I_{separator\ dump}$				

A. Refer to QAPP for measurement / test method details

B. At least 3-pre dump cycle, 3-during dump cycle and 3-post dump cycle portable GC analyses were performed for each sampling sequence.

C. One storage tank oil sample was collected before and after pressurized condensate sampling events.

D. Separator water samples only collected during one of the three operating conditions.

Task 10. Data Analyses

Task	Description of Data Analyses
1. Initial Sampling and Development of Certified Reference Material (CRM)	MOVILAB used the analytical and gravimetric data used to develop the CRM to evaluate the CRM uncertainty. This analysis included evaluation of the gravimetric and analytical process, as well as calculations involved in development of the CRM.
2. Analytical Method Performance and Uncertainty	MOVILAB used calibration and analysis data from the Analytical Method Evaluation and Multilab Study portions of the PHLSA study to evaluate the precision and estimate the uncertainty of each of the four analytical protocols used in this phase of the study. (including potential modifications to evaluate the effectiveness of such modifications to reduce analytical uncertainty)
3. Process Measurement Uncertainty Analysis	MOVILAB used the instrument specifications and available calibration data for process measurements used in the PHLSA study to estimate the uncertainty of each process measurement.
4. Sample Handling Perturbation Study	MOVILAB used the calibration and analysis data from the Sample Handling Perturbation portion of the PHLSA study to estimate the uncertainty produced from improper sample handling.
5. Operational Performance Checks	MOVILAB used density and pressure measurements used in the Operational Performance Check portion of the PHLSA study to develop criteria for Operational Performance Checks.
6. Sample Collection Perturbation Study	MOVILAB used the calibration and analysis data from the Sample Collection Perturbation portion of the PHLSA study to estimate the effects from improper sampling protocols.
7. Three Separator Pressure Range and Seasonal PHLSA Studies	MOVILAB used the calibration, analysis and modeling data from the Three Separator Pressure Range and Seasonal PHLSA Studies, and data from other tasks listed above, to estimate the uncertainty of PSM/EOS models in estimation of flashing losses.

3. Deliverables

- Work Plan
- QAPP
- Process Measurement Uncertainty Analysis
- CRM Uncertainty Analysis
- Analytical Method Precision and Uncertainty Analysis
- Sample Handling Uncertainty Analysis
- Sampling Uncertainty Analysis
- Winter Phase Mass Balance and Flashing Emissions Model, Uncertainty Analysis and Sensitivity Study
- Summer Phase Mass Balance and Flashing Emissions Model, Uncertainty Analysis and Sensitivity Study
- Overall Uncertainty Analysis for PHSLA Process
- Final Project Report

4. Schedule

Work Plan	November 1, 2015 - June 12, 2017
QAPP	November 1, 2015 - April 26, 2017
Process Measurement Uncertainty	October 1, 2015 - June 11, 2017
Initial Sampling and Analyses	December 1, 2015 – December 18, 2015
Development of CRM	December 14, 2015 - December 23, 2015
Semi Annual Project Status Report	January 11, 2016
Analytical Method and Operational Performance Checks Study	December 28, 2015 - January 15, 2016
Multilab Study	February 20-28, 2016
Sample Handling Study	January 18, 2016 - February 5, 2016
Sampling Study	February 8, 2016 - February 26, 2016
Winter Phase Mass Balance and Flashing Emissions	March 10, 2016 - June 12, 2017

Model, Uncertainty Analysis and Sensitivity Study

Semi Annual Project Status Report	June 22, 2016
Summer Phase Mass Balance and Flashing Emissions Model,	July 22, 2016 - March 10, 2017
Uncertainty Analysis and Sensitivity Study	October 1, 2016 - June 11, 2017
Semi Annual Project Status Report	December 7, 2017
Final Report for the PHLSA Study	December 31, 2017

5. Personnel

Responsibilities	Leader	Key Personnel	Associated Study Tasks
Project Management	**Tom McGrath Alon Mandel**	**J. Landes R. Miller**	**1 - 10** (ALL)
Process measurement skid design, process measurement uncertainty	**T. McGrath Alon Mandel**	**J. Landes R. Aguiar**	**5** (Measurement) **9** (Measurement)
Field sampling	**R. Miller**	**B. Burns A. Hartman**	**1** (Sampling) **8** (Sampling) **9** (Sampling)
Analytical Testing	**C. Staley**	**T. Benz J. Ochterbeck**	**4** (Analysis) **6** (Analysis) **7** (Analysis) **8** (Analysis)
CRM Blending	**R. Rayon**		**2** (CRM)
QAPP, QA/QC	**D. Bowling**		**7** (QC)
PSM/EOS Modeling, Mass Balance	**J. Landes A. Mandel**	**M. Spurlock**	**9** (Mass Balance)

Responsibilities	Leader	Key Personnel	Associated Study Tasks
Uncertainty Analysis, Sensitivity Studies	**R. Aguiar**		**1** (Uncertainty) **2** (Uncertainty) **3** (Uncertainty) **4** (Uncertainty) **5** (Uncertainty) **6** (Uncertainty **7** (Validation) **8** (Uncertainty) **9** (Uncertainty & Sensitivity) **10** (Data Analyses)