GTI ENERGY

FINAL TECHNICAL REPORT

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CPUC Gasification and Methanation System – Renewable NG Production from Biomass Feedstocks

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Preparation of Research Quantities of Syngas and Bio-Synthetic Natural Gas from Biomass Waste

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EXECUTIVE SUMMARY

This project used an integrated bench scale gasification and methanation process to demonstrate the technical feasibility of producing renewable natural gas (RNG) from biomass. The objective was to assess whether biomass could be effectively and reliably converted to a methane rich bio-derived synthetic natural gas (SNG) product in a configuration relevant to future commercial scale development. A simplified process flow diagram of the bench scale configuration is provided in Figure 1.

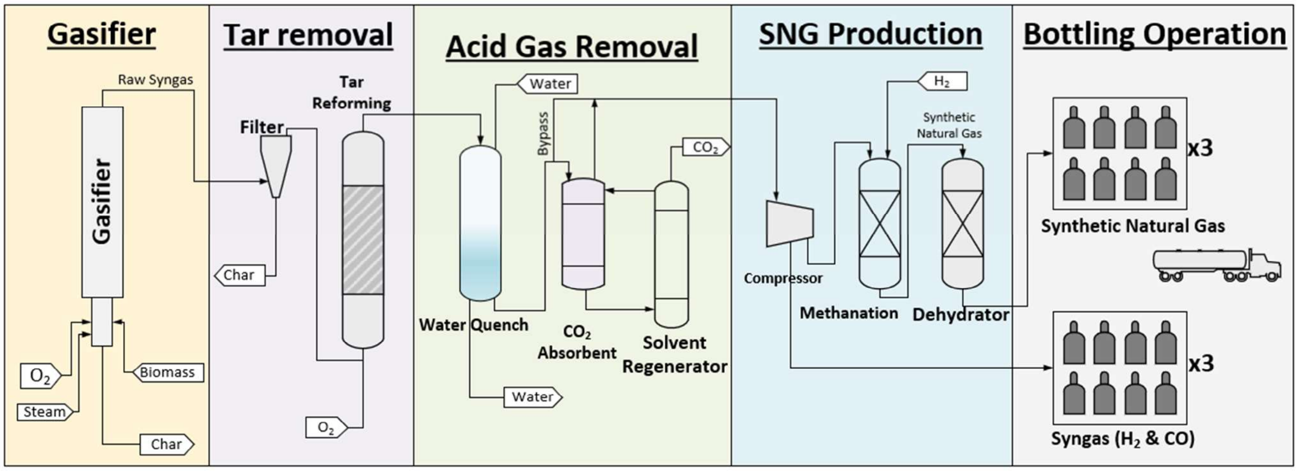


Figure 1 Simplified Process flow diagram of the gasification based methanation system

Biomass to RNG via gasification and methanation is being pursued as a conversion pathway for lignin rich organic wastes where conventional anaerobic digestion may be less effective. In this approach, biomass is converted to a syngas mixture of hydrogen and CO through thermochemical processing, followed by catalytic conversion to methane. The present bench scale study was conducted to generate performance and operability information needed to support future development and commercialization of biomass derived RNG.

Three biomass feedstocks were evaluated to compare handling behavior, operability impacts, and performance sensitivity across the integrated process, including impacts on methane yield and product gas quality.

1. Forest woody waste, forest residue feedstock, FS-1
2. Agricultural waste, walnut shells sourced from California, FS-2
3. Urban green waste, Menards pine bark mulch, FS-3

The evaluation included defined operating procedures for start-up, steady state operation, and shutdown, along with sampling and analytical methods to characterize major gas components and relevant contaminants. Results were reviewed and quality checked to support performance assessment and to identify data limitations associated with transient operation, sampling constraints, and analytical uncertainty.

Feedstock preprocessing results confirmed that moisture, particle size distribution, and fines content influence handling and feeding behavior and can affect stability in the gasifier and downstream process units. Pelletization provided a reliable approach to improve bulk handling and feeding consistency and established the basis for pellet quality metrics and acceptance criteria that can be applied in future campaigns.

GTI Energy's system configuration allows for operation of all process steps in sequence. However, as practiced for this program the acid gas removal system to remove CO_2 was not utilized as the addition of hydrogen allowed for methanation of nearly all carbon oxides in the syngas stream increasing the methane yield of the process. Typical syngas produced from biomass in this system contain approximately 14% CO and 56% CO_2. Methanation of CO_2 therefore significantly increases methane production relative to CO only methanation. Additionally, GTI Energy operated the system in a two-step mode (gasification to bottled syngas, then bottled syngas to methanation) to minimize the loss of product effect that can occur during process disruptions.   Key process improvements were implemented that materially improve process operability, product quality and relevance to commercial operation. The operability process improvements will allow for future tests to be done in a continuous single step operation.

During the project GTI Energy, CPUC, OEHHA and UC Davis communicated very closely through monthly meetings to go through the status of the project and progress. During these meetings GTI Energy presented the progress of design, construction and operation of the test skid and reported any challenges due to the technical complexity of the project. These meetings also included detailed explanation and walkthrough of the process and individual components of the test skid as well as how they interacted to produce the bio-SNG product. After ensuring the test skid was operating as expected, during the subsequent processing of the different feedstocks the frequency of the interagency meetings was increased to bi-weekly meetings. These meetings steered the project to successful completion of Final Gas Phase generation from three different kinds of feedstocks as described in GTI Energy's proposal.

The entire project, from design, construction and operation of the equipment to identifying, procuring and processing the feed material needed, was performed by GTI Energy. There were no subcontractors involved. Required materials, including feedstock, were procured and by GTI Energy. Produced gas from all feedstocks were analyzed by GTI Energy Analytical Lab Services and shipped to UC Davis research team.

The study demonstrated production of methane rich product gas and identified the primary technical and operational factors that must be addressed to improve process scale up for commercial deployment. Key drivers include feedstock consistency, solids handling reliability, stability of operating conditions, and control of contaminants that can affect methanation catalyst performance. These findings establish a technically defensible basis for targeted improvements in feedstock quality control, solids handling and gas cleanup process design, and methanation system operating strategy to support longer duration testing and future scale up.

Figure 2 Laboratory test rigs - Bench scale gasification and methanation units at GTI Energy

INTRODUCTION

Objective

The objective of this report is to document the integration and evaluation of the GTI Energy bench scale gasification and methanation system developed to support the California Public Utilities Commission (CPUC) project. The system is designed to convert biomass feedstocks into renewable natural gas, RNG, through a sequence of unit operations that include feedstock preparation, gasification, gas cleanup and conditioning, tar mitigation, compression, and methanation, followed by drying and product gas collection.

GTI Energy successfully processed three biomass feedstocks through the bench scale system to evaluate integrated operability and performance. This report summarizes the system configuration and operating approach, the feedstocks processed, and the results that support the system capability to produce a methane rich RNG product.

Feedstocks Evaluated

Three biomass feedstocks were evaluated to compare handling behavior, operability impacts, and performance sensitivity across the integrated bench scale gasification and methanation process, including effects on methane yield and product gas quality.

1. Forest woody waste, forest residue feedstock, FS-1
2. Agricultural waste, walnut shells sourced from California, FS-2
3. Urban green waste, store-bought pine bark mulch, FS-3

FEEDSTOCK SELECTION AND PROCUREMENT CONSIDERATIONS

GTI Energy conducted feedstock screening, procurement and processing to identify representative materials within each feedstock category and to support stable bench scale operation. During this effort, GTI Energy encountered multiple vendor and logistics issues, including changes in supplier availability and variability in delivered material characteristics. These factors affected the original selection plan and required refinement of the final feedstock set. The three feedstocks evaluated in this report were selected based on availability, ability to be prepared and fed consistently, and suitability for gasification and downstream operation.

FS-1 Forest woody waste, forest residue feedstock

FS-1 consisted of clean woody material procured as chips from California. Initial third-party processing was not completed as originally planned, so GTI Energy adjusted the feed preparation approach and completed the final material processing at its facility. The material was prepared through additional size reduction and densification to pellets, followed by crumbling and screening at GTI Energy to achieve the target size range for bench scale feeding. During processing, small amounts of non-feed material were observed and removed as part of normal material preparation and screening. GTI Energy successfully processed and gasified FS-1 through the bench scale system.

Figure 3. FS-1 Forest Woody Waste

Figure 4 FS-1 Pelletized

FS-2 Agricultural waste, walnut shells sourced from California

The agricultural waste category required multiple procurement, and preparation attempts due to vendor issues and challenges associated with varying as-received moisture content and contamination in candidate materials from batch to batch. Attempts at third party processing different batches of agricultural waste with multiple vendors were unsuccessful. After evaluating alternatives, GTI Energy selected walnut shells sourced from California that met handling and preparation requirements. This feedstock was the most straightforward to prepare and feed among the three and was successfully gasified through the bench scale system.

Figure 5 FS-2 Crushed Walnut Shells from California

FS-3 Urban green waste, store-bought pine bark mulch

Urban green waste presented procurement and preparation challenges due to variable moisture content and contamination levels. Observed contaminants were primarily physical debris such as rocks, cable/wire fragments, and plastics. Similarly, to FS-2, multiple attempts at third-part processing were unsuccessful. In-house processing was successful but significant dust generation from the crumbled pellets led to unfavorable feed behavior in the gasifier feed system. After evaluating alternatives, GTI Energy selected store-bought pine bark mulch as a representative urban green waste feedstock that could be consistently processed to meet bench scale feeding requirements. GTI Energy prepared FS-3 in-house by air drying the pine bark mulch nuggets, reducing the size of the material in a knife mill using the largest available screen (a single pass through the knife mill was performed on as-received material) and classifying the milled product with a linear screener to isolate the target size fraction. When additional target size material was required, the oversize fraction was collected and re-milled through a second pass, while fines removed during screening were collected separately. FS-3 was then gasified through the bench-scale system.

Figure 6 FS-3 as received

Figure 7 FS-3 After Chipper

Figure 8 FS-3 After in-house Pelletization

FEEDSTOCK DESCRIPTION AND CHARACTERIZATION

Table 1 summarizes proximate analysis, ultimate analysis, and heating value for FS-1 through FS-3, with additional details on feedstock composition provided in Appendix A. The characterization results show differences in ash content, elemental composition, and heating value across the three feedstocks.

Table 1 Feedstock characterization summary for FS-1 through FS-3

Feedstock Characterization Summary				
		FS-1	**FS-2**	**FS-3**
Parameters	Basis and Units	Forest Woody Waste	Walnut Shells	Pine Bark Mulch
Proximate Analysis				
Moisture	As received basis, %	10.67	6.80	8.81
Volatile Matter	As received basis, %	63.42	79.51	67.61
Ash (750 °C)	As received basis, %	18.97	0.62	0.98
Fixed Carbon	As received basis, %	6.94	13.07	22.06
Ultimate Analysis				
Ash (750 °C)	Dry basis, %	21.23	0.67	1.08
Carbon	Dry basis, %	41.32	51.29	55.80
Hydrogen	Dry basis, %	4.32	5.78	5.50
Nitrogen	Dry basis, %	0.17	0.16	0.21
Sulfur	Dry basis, %	0.09	0.08	0.08
Oxygen (by difference)	Dry basis, %	32.87	42.02	37.25
HHV (Higher Heating Value)	Dry basis, Btu/lb	6,900	8,750	9,230

FS-1 showed substantially higher ash content than the other feedstocks, with 18.97% ash on an as received basis and 21.23% ash on a dry basis. By comparison, FS-2 and FS-3 had low ash content, with dry basis ash values of 0.67% and 1.08%, respectively. The higher ash fraction in FS-1 corresponds to greater solids and ash handling demand relative to FS-2 and FS-3 because ash represents the non-combustible inorganic fraction of the feedstock and therefore remains as solid residue during thermochemical conversion and downstream processing.

Ultimate analysis results show that FS-2 and FS-3 had higher carbon content than FS-1, with carbon values of 51.29% for FS-2 and 55.80% for FS-3 compared to 41.32% for FS-1 on a dry basis. FS-1 also had lower oxygen content by difference, 32.87%, compared to 42.02% for FS-2 and 37.25% for FS-3. These differences are consistent with the heating value results, where FS-1 had the lowest HHV at 6,900 Btu/lb on a dry basis, while FS-2 and FS-3 had higher HHV values of 8,750 and 9,230 Btu/lb, respectively.

Moisture content across the three feedstocks ranged from 6.80% to 10.67% on an as received basis. FS-1 had the highest moisture at 10.67%, FS-2 had the lowest moisture at 6.80%, and FS-3 was 8.81%. Differences in moisture were relatively small compared with the differences in ash content and heating value across the three feedstocks.

PROCESS DESCRIPTION

The CPUC bench-scale system was designed, built and operated to demonstrate the conversion of biomass feedstocks into renewable natural gas (RNG) using an integrated gasification and methanation process. While the equipment was bench scale the process steps, sequencing, and operating approach were selected to be technically representative of a commercially relevant configuration. The system followed an integrated process flow that prepared and metered the biomass feedstock, converted solids into a raw syngas stream, conditioned the syngas through tar/particulate control and gas cleanup, and upgraded the cleaned gas via catalytic methanation to produce a methane-rich product. The upgraded gas was then dried and routed to the bottling operation for sample collection and distribution to the client. A simplified diagram of the overall system configuration is provided in *Figure 1*.

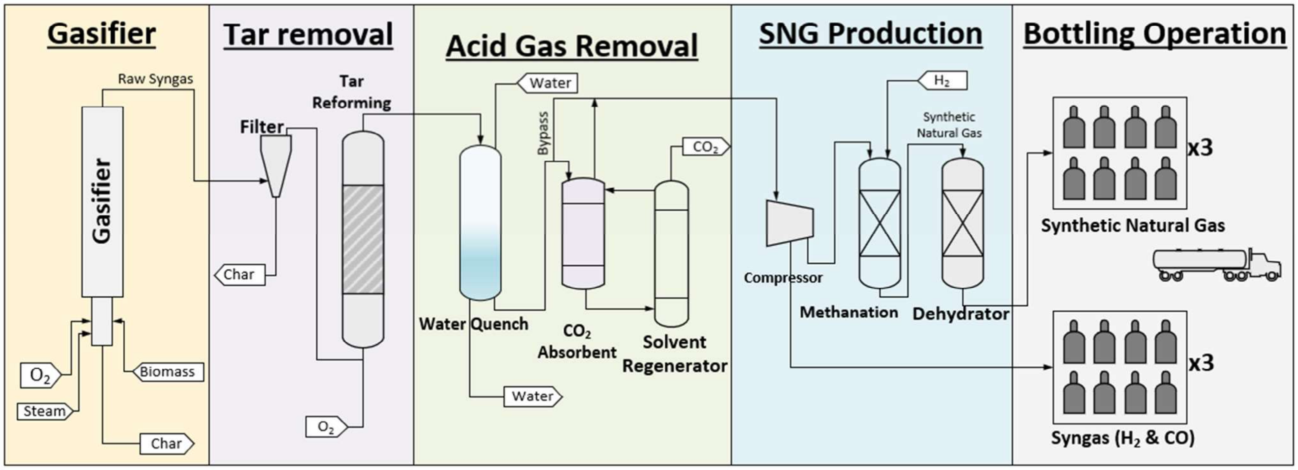


Figure 1. Simplified Process flow diagram of the gasification based methanation system

Feeding System

Prepared (dried and sized) biomass feedstock was metered into the gasifier at controlled feed rates using a lock hopper and screw feeder assembly. Preparation generally consisted of sizing the feedstock into a range compatible with the gasification process used, which in this case was a fluidized bed. The testing confirmed steady and reproducible introduction of solids into the reactor under pressurized conditions (~50 psig). FS-1 and FS-2 were typically operated at feed rates on the order of ~2.5 lb/hr, while FS-3 was operated at a reduced feed rate of approximately 1 lb/hr due to feed handling and metering (controlled solids feeding) limitations associated with this material at the bench scale. The limitations here referred to periodic issues such as jamming or inconsistent flow that caused disruptions to flow.

Table 2 Summary of Feedstock type, size and preparation method

Feed Stock Size				
#	**Feed Type**	**Feed Description**	**Feed Size** (U.S. sieve size fractions)	**Feed Prep Method**
FS-1	Forest Woody waste	California Forest Residue	72% -8+10 16% -10+12 12% -12+14	GTI Energy prepared FS-1 in-house by reducing the size of the forest residue using a feed crusher (single pass) and classifying the crushed product with a linear screener to isolate the target −8 +14 size fraction. When additional target-size material was required, the oversize fraction was collected and re-crushed through a second pass, while fines removed during screening were collected separately.
FS-2	Agricultural waste	Walnut Shells	-8+20 from bag	Prepared by California based Vendor
FS-3	Urban green waste	Pine Bark Mulch	-8 +14	GTI Energy prepared FS-3 in-house by air drying the pine bark mulch nuggets, reducing the size of the material in a knife mill using the largest available screen (a single pass through the knife mill was performed on as-received material) and classifying the milled product with a linear screener to isolate the target size fraction. When additional target size material was required, the oversize fraction was collected and re-milled through a second pass, while fines removed during screening were collected separately

Gasifier

The gasifier converted solid biomass into raw syngas using steam and oxygen mixtures, with the addition of carbon dioxide to transport the feed into the gasifier downstream of the metering screw. The vessel was instrumented for temperature and pressure monitoring and was designed for high temperature operation (1400–1600 °F).

Catalytic Tar Cracker

The raw syngas was routed through a cyclone and char vessel for particulate removal before entering the catalytic tar cracker. The reformer was heated in multiple zones and cracked heavy hydrocarbons and condensable tars into lighter species such as CH_4, improving downstream gas cleanup efficiency. A bed of commercial tar reforming catalyst arranged on a honeycomb support was used.

Water Quench

The reformed syngas stream was rapidly cooled in a water quench. This step reduced the gas temperature to conditions suitable for acid gas removal and simultaneously removed water soluble impurities such as HCl and NH3, along with any remaining condensable organics, such as trace tars.

Compression

A compressor was then employed to boost the syngas pressure to ~1250 psig. Since the next step was a physical solvent wash, the higher pressure was needed to absorb the acid gas components (primarily H2S and CO2) with a reasonable flow of solvent.

Acid Gas Removal (AGR) System (If Operated)

The process was equipped with an Acid Gas Removal (AGR) system consisting of an absorber and a regenerator using Morphysorb solvent. The function of this system was to remove sulfur compounds that could deactivate the methanation catalyst and to adjust the hydrogen to carbon ratio by removing CO_2 to provide the appropriate stoichiometric composition to the methantion reactor. For the test campaign described in this report, the AGR step was not operated and the conditioned syngas was routed directly to the methanation section, where CO and CO_2 were converted to methane. This was possible because during trial runs the sulfur content in the syngas was measured to be acceptably low and the syngas hydrogen to carbon ratio could be adjusted by adding hydrogen rather than removing CO_2.

Methanation Unit.

Prior to methanation, the raw syngas from compression was adjusted to the target H2 to carbon oxides ratio by addition of hydrogen from purchased cylinders. The conditioned syngas was then introduced to the methanation reactor, where the required H2 addition was governed by reaction stoichiometry: 3 moles of H2 per mole of CO and 4 moles of H2 per mole of CO2, with a slight excess to drive high conversion. In this step, carbon monoxide and carbon dioxide reacted with hydrogen to produce methane and water, yielding a methane-rich product gas consistent with renewable natural gas (RNG).

The methanation catalyst was obtained from Johnson Matthey Katalco and was representative of commercially used formulations. Because methanation was highly exothermic, the allowable inlet concentration of combined CO and CO_2 to the reactor was limited to approximately 3–4 vol%, corresponding to a peak bed temperature not to exceed ~840 °F. Syngas carbon oxides concentrations produced in the gasifier varied by feedstock and were typically higher than this limit; therefore, a portion of the methane-rich product gas was recycled to dilute the reactor feed to the allowable carbon oxides range and to support stable reactor temperature control.

The methanation effluent was cooled via indirect heat exchange, and the water produced during reaction was condensed and collected downstream of the coolers. After cooling and knock-out, the product gas stream was split; a portion was returned to the recycle compressor to dilute the flow of inlet gas to the methanator, and the remainder was sent to further downstream drying and bottling (or to vent during startup/shutdown or off-spec operation, as applicable or needed). Product gas composition was verified prior to cylinder filling to confirm it met applicable RNG specifications. Since the feedstock was biomass, the product was classified as renewable natural gas (RNG).

Bottling Operation

The dried and compressed methane-rich product gas was routed to a manifold system for cylinder filling. The bottling manifold included isolation valves and pressure indication to support controlled filling and inventory tracking. The cylinder filling system was equipped with vent safeguards and appropriate overpressure protection to ensure safe, reliable product collection and handling. The bottling target was two 50-L cylinders filled to ~1200 psig each; however, actual cylinder fill pressures and collected volumes varied by run.

Figure 9 Product handling -Cylinder filling and bottling operations for renewable natural gas (RNG).

Gas Analysis

Throughout operation, gas sampling is performed at multiple points using a dedicated analyzer system to monitor key process streams and confirm system performance. Online analyzers included Teledyne Model 7500 infrared (IR) analyzer and a gas chromatograph (GC). The IR analyzer measures gas concentration based on infrared absorption and was used for continuous monitoring of CH4, CO, and CO2. A Rosemount X-Stream analyzer was used for measuring O2, and a Siemens Ultramat 6 analyzer was used for reading low CO. The GC separates and quantifies individual gas species and was used to measure H_2, CH_4, CO, CO_2, and N_2 in the syngas and RNG streams. The GC is a Calidus CS fast gas chromatograph. These measurements enabled real time tracking of gas composition and verification of stable operation. Supporting instrumentation includes back pressure regulators, mass flow controllers, a dry test meter, and temperature and pressure indicators at critical points in the process. Process operation and data logging are managed through a computer based control system and data recorder. System safety is supported through area monitors, pressure relief devices, alarms, and automated shutdown logic implemented through the Human Machine Interface (HMI).

Figure 10 Control room interface - Process monitoring and instrumentation overview

OPERATING CONDITIONS

The integrated gasification, cleanup, and methanation system was operated under representative conditions to demonstrate stable production of renewable natural gas (RNG) using the three biomass feedstocks evaluated in this study (FS-1 through FS-3). Feedstocks were metered into the gasifier using a controlled screw feeder and lock hopper arrangement, with periodic feed additions of approximately 5–9 lb to maintain steady operation. FS-1 and FS-2 were typically operated at feed rates on the order of ~2.5 lb/hr, while FS-3 was operated at a reduced feed rate of approximately 1 lb/hr due to feed handling and metering limitations associated with this material at the bench scale.

Gasification and Cleanup

The gasifier was maintained at 50 psig. Temperatures were ramped to target setpoints and held constant throughout the run.

- Gasifier outlet flow: ~25 SLPM
- Mass balance closure: 84–97%

Optional AGR configuration (not operated in this campaign): If the AGR section were to be used, the regenerator CO_2 vent flow would be on the order of ~9.5 SLPM.

Two-Step Operation and Bottling

System operation was carried out in two steps. In the first step, syngas was produced during gasification and collected in cylinders for interim storage. In the second step, the bottled syngas was subsequently fed to the methanation system for conversion to RNG, followed by bottling of the methane-rich product gas. This operating approach enabled stable gasifier operation while maintaining traceability of gas composition.

Syngas and RNG bottling operations were performed using pressure rated cylinders

- Cylinder pressurization initiated at ~200 psig
- Cylinder filling rate: ~100 psig/hour
- Final pressures target achieved: 950–1,150 psig

Methanation Operation

The methanation reactor (V-410) was brought online using surplus syngas stored during gasification operations. During startup, the H_2 to carbon oxides ratio was adjusted using bottled hydrogen, followed by transition to syngas feed from previously bottled syngas produced during gasification. Stable operation was achieved at reactor pressures of approximately 900–1,030 psig and temperatures in the range of 420–780 °F.

- Total flow to reactor: ~15 SLPM (not including recycle)
- H_2 addition: ~10.3–10.8 SLPM (trimmed for stoichiometric CO/CO_2 conversion as needed)
- Syngas: ~4.2 SLPM (from bottled cylinders at 1000–1150 psig)
- Recycle flow: 62–64 SLPM (recycle ratio ~4.1–4.3 mol/mol)
- Cylinder pressurization: confirmed product collection and steady operation.

Although the production of the syngas was performed separately from the methanation process, the overall system is capable of operating both the gasification and methanation steps contiguously. During testing with new solid feedstocks, variations in particle size distribution, moisture content, bulk density, and fibrous structure affected feeding behavior and led to occasional gasifier interruptions. The small scale of the system, including relatively small-diameter solids handling components, increased susceptibility to bridging and transient flow disruptions compared to commercial-scale designs. To avoid propagating these disturbances to the methanation unit and to prevent loss of valuable syngas during short test campaigns, GTI Energy operated the system in batch mode as described.

This approach did not affect process integrity or product traceability. Both the intermediate syngas and the final RNG were bottled in new and evacuated cylinders.

Operating Summary

Routine maintenance included catalyst bed replacement, clinker removal, instrumentation calibration, and leak checks, ensuring reliable system performance across the test runs.

Across the test campaign, system reliability was primarily influenced by solids handling and feeding variability when processing new feedstocks. These events were managed through batch operation and routine maintenance to maintain safe operation and product traceability.

Table 3 Summary of Operating Conditions

Summary of Operating Conditions	
Unit / Parameter	Typical Range / Performance
Gasifier	1,400 °F and 50 psig
Mass Balance Closure	84–97%
Product Handling	Cylinder pressurization 200 → 1000 - 1,150 psig ~100 psig/hr
Methanation Reactor	900–1,030 psig, 410–800 °F, 12–15 SLPM methane flow
H_2 Addition	10.3–10.8 SLPM controlled
Expected Product Quality	80–99 vol% CH_4, <0.5 vol% CO, <3 vol% CO_2,< 2 vol% H_2

Figure 11 represents gasifier operating trends during FS-2 (walnut shells) feed operation on December 1. Gasifier temperature (blue, left axis) was maintained at approximately 1,350–1,400 °F for most of the run. Gasifier pressure (orange, right axis) operated primarily in the range of approximately 35–45 psig, with a brief transient excursion to approximately ~50 psig before returning to the typical operating band. FS-1 was operated under similar gasifier temperature and pressure conditions as FS-2, with both feedstocks generally maintained within the same target operating conditions. Overall, the figure shows stable temperature control within the target operating window during FS-2 feeding, while pressure exhibited expected step changes and gradual adjustments consistent with routine operational control and system response.

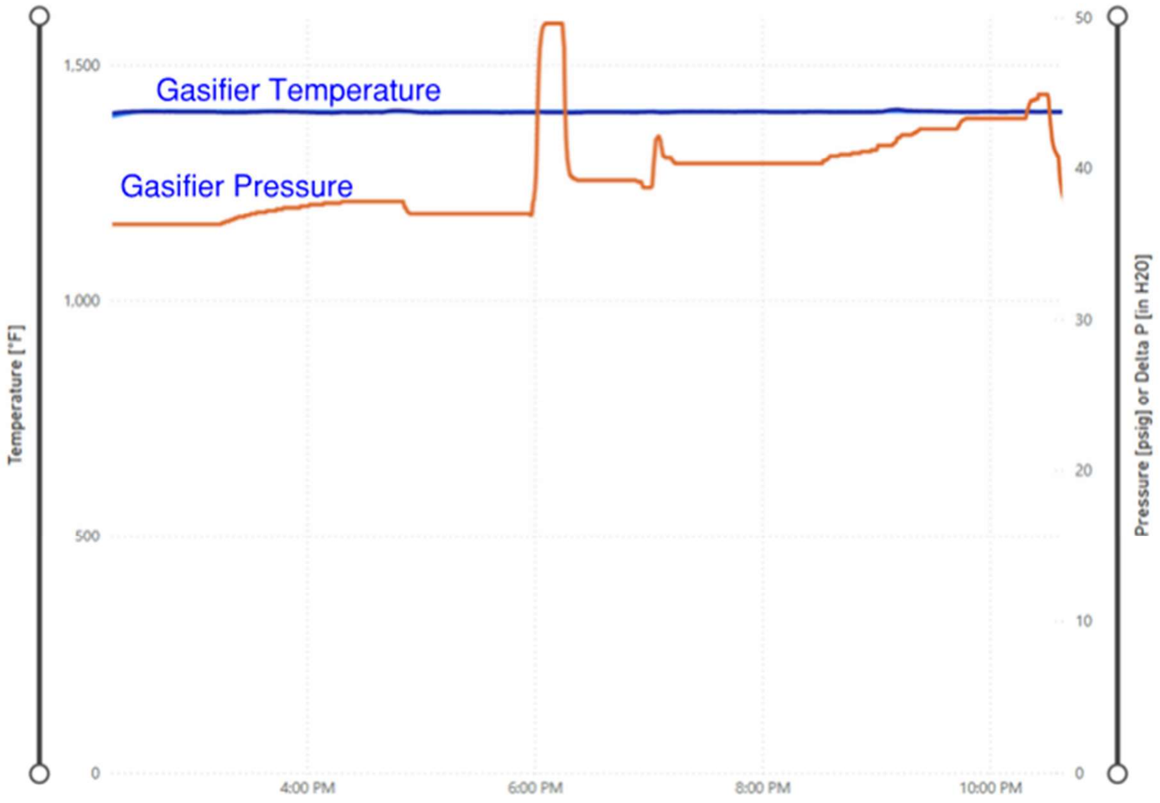


Figure 11 Gasifier Operating Pressure and Temperature during FS-2 testing on Dec 1st

Figure 12 represents methanator operating trends during FS-2 testing. Methanation reactor temperature (multiple blue lines, left axis) was maintained at approximately 740–800 °F over the operating period, with minor fluctuations around the target setpoint. The light blue and dark blue lines correspond to two different temperature probes located near the top of the methanator. These probes are used to confirm reaction initiation and to monitor the hottest temperatures in the reactor. Methanation reactor pressure (orange, right axis) remained relatively stable at approximately ~850–900 psig, with small step changes consistent with routine operating adjustments. Overall, the figure indicates stable methanator operation with temperature control within the target operating window and steady pressure during the run.

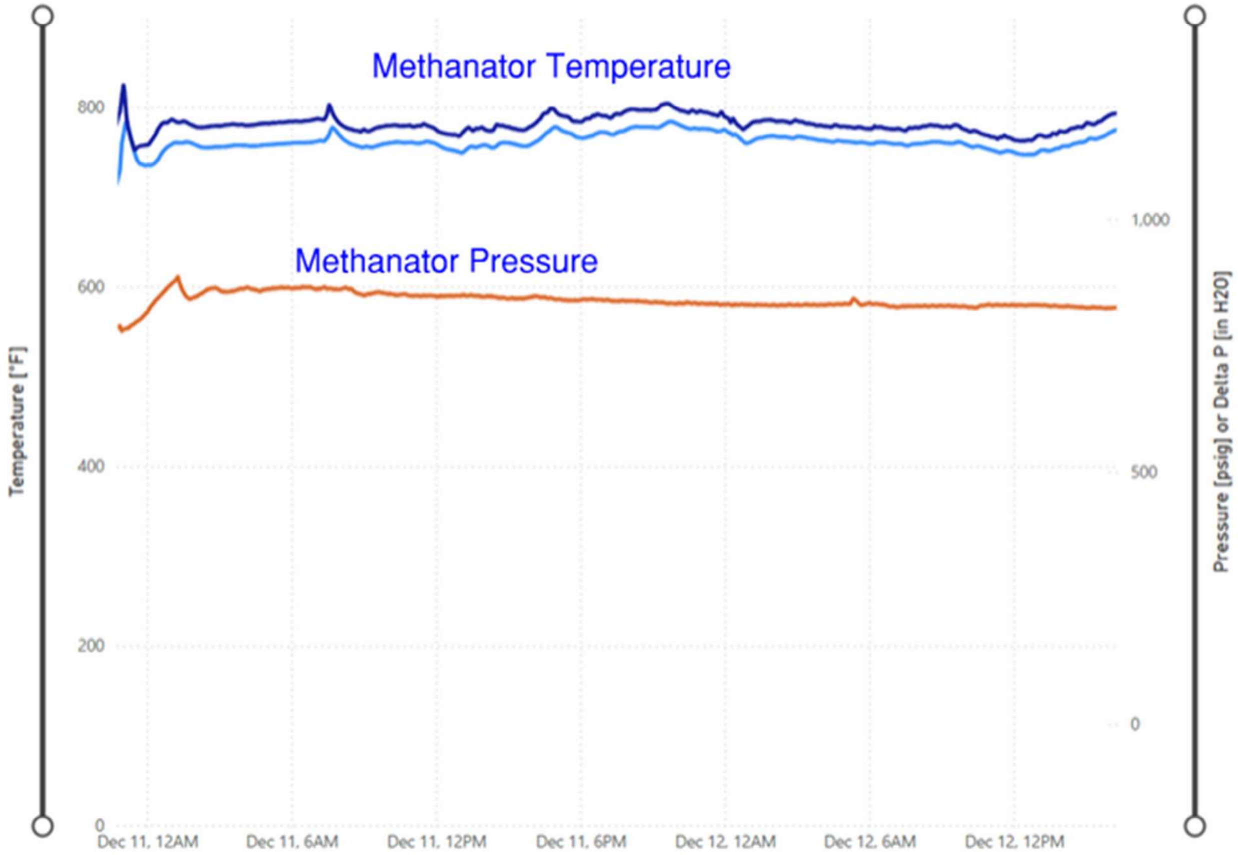


Figure 12 Methanator Operating Pressure and Temperature during FS-2 testing

RESULTS

The integrated biomass gasification and methanation campaign was successfully executed, demonstrating stable production of renewable natural gas (RNG) under representative operating conditions using the final feedstocks, FS-1 through FS-3, evaluated in this study.

Gasification

The gasifier and cleanup system were operated continuously with steady feed addition and controlled quench operation. Cylinder filling was carried out at ~100 psi/hour, with target pressure of 1200 psig but the actual cylinder fill pressures and collected volumes varied by run. The gasifier and associated cleanup systems were operated with steady feed addition and controlled quench operation. Syngas production was stable throughout the gasification runs, and the produced syngas were collected in high pressure cylinders for interim storage. Net productive gasification operation was maintained, during which syngas was successfully directed to high-pressure cylinders. Cylinder filling for syngas was performed at approximately ~100 psig/hour across multiple cylinders, achieving final pressures in the range of ~900–1,150 psig across runs.

Methanation

The methanation reactor was brought online using bottled syngas. Additional bottled hydrogen was used as needed to meet the reaction stoichiometry requirements discussed above, Reactor pressure was held near 1,000 psig, with operating temperatures stabilized in the range of ~480–800 °F. Hydrogen addition was controlled between 10.5–12 SLPM, with syngas feed maintained at approximately 3–4.5 SLPM from cylinders. The recycle ratio was sustained at ~4.1–4.3 mol/mol, supporting stable temperature control and consistent methane production. The methanation reactor operated stably across the target pressure (900–1,030 psig) and temperature 740 °F. Product gas composition was confirmed by laboratory analysis to be methane-rich, consistent with renewable natural gas (RNG).

SYNGAS ANALYSIS

Laboratory analysis was performed on syngas samples collected downstream of gasification. Gas composition was measured in accordance with ASTM D1946 for major components and GC/FID methods for trace hydrocarbons. The principal constituents of the bottled syngas produced from the three feedstocks (FS-1 through FS-3) are summarized in Table 4. Additional details on syngas composition are provided in Appendix B.

Table 4 Syngas Composition after Gasification, BDL: below detection limit

Bottled Syngas Analysis				
		FS-1	**FS-2**	**FS-3**
Components	**Units**	Forest Woody Waste	Walnut Shells	Pine Bark Mulch
CH4	mol%	5.33	4.53	5.37
CO	mol%	15.5	10.9	13.8
CO2	mol%	53.8	55.3	56.1
H2	mol%	24.6	28.6	24.1
Nitrogen	mol%	0.11	0.34	0.13
Ethane	mol%	0.140	0.083	0.164
Ethene	mol%	0.434	0.300	0.309
Ethyne	mol%	0.005	BDL	0.003
Benzene	mol%	0.0587	0.0001	0.0002
Toluene	mol%	0.0038	BDL	BDL
m,p-Xylene	mol%	0.0002	BDL	BDL
Styrene	mol%	0.0002	BDL	BDL
o-xylene	mol%	BDL	BDL	BDL
Naphthalene	mol%	BDL	0.0007	BDL
Hexanes	mol%	0.0012	BDL	BDL
Decanes	mol%	BDL	0.0002	BDL
Total*	mol%	100	100	100

*Additional components were also detected, but they were present at trace or minor levels and are not fully listed in this table. See Appendix B for additional syngas composition details.

For all feedstocks, the syngas was dominated by CO_2, H_2, and CO, with methane present at minor levels. Trace aromatics and paraffins were detected at low concentrations. Benzene was observed at trace levels across the feedstocks, while toluene, xylenes, and other aromatics were either present at very low concentrations or below detection limits. Naphthalene was detected only for FS-2 at trace concentration. Higher paraffinic hydrocarbons (C_6^+) were present at very low levels, with total concentrations on the order of 10^{-3} to 10^{-2} mol% of the product gas. Overall, the syngas composition was suitable for use as methanation feed, with CO and CO_2 as the dominant carbon containing species and only minor concentrations of aromatics, and higher hydrocarbon. See Appendix B for additional syngas composition details.

PRODUCT GAS ANALYSIS

Product gas collected in cylinders downstream of the methanation step was analyzed in accordance with ASTM D1946 for major gas components, with heating value and Wobbe index calculated per ASTM D3588 on a dry basis. The resulting RNG compositions for the three feedstocks (FS-1 through FS-3) are summarized in Table 5. Additional details on RNG composition and VOCs are provided in Appendices C and D.

Table 5 RNG Composition

RNG Analysis				
		FS-1	**FS-2**	**FS-3**
Components	**Units**	Forest Woody Waste	Walnut Shells	Pine Bark Mulch
CH4	mol%	91.2	99.3	97.8
CO	mol%	BDL	BDL	BDL
CO2	mol%	4.80	0.15	0.53
H2	mol%	3.7	0.46	1.4
Ethane	mol%	0.025	0.012	0.011
Nitrogen	mol%	0.27	0.11	0.24
Ethene	mol%	BDL	BDL	BDL
Ethyne	mol%	BDL	BDL	BDL
Benzene	mol%	0.0001	BDL	BDL
Toluene	mol%	BDL	BDL	BDL
m,p-xylene	mol%	BDL	BDL	BDL
Styrene	mol%	BDL	BDL	BDL
o-xylene	mol%	BDL	BDL	BDL
Naphthalene	mol%	0.0006	BDL	BDL
Hexanes	mol%	BDL	BDL	BDL
Decanes	mol%	BDL	BDL	BDL
Total	mol%	100	100	100
HHV[2]	Btu/scf (dry)	937.5	1008.5	997
Wobbe Number[2]	Btu/scf	1226	1355	1334
Note 1: Additional components were also detected, but they were present at trace or minor levels and are not fully listed in this table. See Appendix C and D for additional syngas composition details. Note 2: HHV and Wobbe Index reported on a dry basis per ASTM D3588				

Across all cases, the product gas was methane rich, with CH_4 concentrations ranging from approximately 91 to 99 mol%, reflecting effective conversion of CO and H_2 during methanation. Residual concentrations of CO, H_2, and CO_2 were low, indicating reliable methanation reactor performance and stable operation. Minor quantities of light hydrocarbons (e.g., ethane) were detected at trace levels, while higher hydrocarbons and aromatics were generally below detection limits.

Calculated higher heating values (HHV) for the RNG samples ranged from approximately 937.5 to 1,008.5 Btu/scf (dry), with corresponding Wobbe numbers between ~1,226 and 1,355 Btu/scf, depending on feedstock. While the HHV for FS-1 was slightly below the California pipeline target value of approximately 970 Btu/scf, the FS-2 and FS-3 product gases met or exceeded the criteria. This result does not represent an inherent limitation of the process for FS-1 but rather the FS-1 campaign early operation of a newly integrated system while the methanation unit was still being stabilized and operators were gaining familiarity with the system. Later runs with FS-2 and FS-3 were conducted after improved system reliability and operational familiarity were established, and these runs produced on-spec RNG. With appropriate tuning of methanation operating conditions, FS-1 is also expected to be capable of producing on-spec RNG.

Overall, the product gas compositions demonstrate that the process successfully produced a high methane RNG stream with favorable combustion properties and minimal inert dilution.

Trace Hydrocarbon and VOC Considerations

Extended hydrocarbon and VOC analyses were performed to characterize trace level constituents in the RNG product gas. Aromatic compounds, higher paraffins (C_6+), and other regulated VOCs were generally below detection limits across the samples, consistent with expectations for methanated biomass derived gas.

For FS-2 and FS-3, acetone was detected at low parts per billion by volume (ppbv) levels, with concentrations of 1,055 ppbv and 47 ppbv, respectively. Acetone is not considered a target product of gasification or methanation and, based on GTI Energy pilot scale operating experience, has not been treated as a characteristic component of syngas or RNG product gas.

In the present study, acetone detection is therefore interpreted as more likely related to laboratory operational practices rather than fuel chemistry, specifically the routine use of acetone for cleaning heat exchangers and associated bench scale equipment. This cleaning protocol introduces the possibility of trace solvent carryover into downstream sampling hardware. Supporting evidence includes historical pilot gasifier data in which acetone was not detected in syngas or product gas, as well as confirmation that acetone is not used in industrial gasification processes.

Accordingly, acetone detected in the FS-2 and FS-3 RNG samples should be considered a result of laboratory maintenance procedures, not a characteristic of the produced RNG. The presence of acetone does not reflect intrinsic fuel quality and is not expected to occur in scaled or commercial implementations of the process. See Appendix D for additional VOC details.

Overall Product Gas Quality Assessment

The RNG analyses confirm that the product gases generated from all three feedstocks exhibit high methane content, low inert concentrations, and favorable heating values, consistent with renewable natural gas suitable for transportation and energy applications. Minor deviations from pipeline injection specifications in FS-1 were primarily driven by residual CO_2 rather than incomplete methanation or hydrocarbon contamination.

The results demonstrate consistent methanation performance across diverse biomass feedstocks and support the technical viability of the process for producing high quality RNG. Future optimization efforts will focus on further reducing residual CO_2 to consistently meet pipeline specifications while maintaining stable reactor operation and product gas quality.

CONCLUSION

This study demonstrated the technical feasibility of producing renewable natural gas (RNG) from biomass using the GTI Energy integrated gasification and methanation bench scale process. Across the three feedstocks evaluated, stable operation was achieved for syngas generation, gas conditioning, methanation, and product gas collection in cylinders. The resulting product gases were methane rich and confirm effective conversion of CO, CO_2 and H_2 in the methanation reactor, with low residual CO_2 and H_2 and limited inert dilution.

The bench scale system was operated in a two-step configuration consisting of syngas generation followed by methanation using bottled intermediate syngas. This approach was selected to simplify laboratory operations, enhance traceability of gas composition, and maintain stable control during early-stage development on this relatively small scale system. While this batch style operation introduces additional uncertainty in trace level measurements relative to a fully continuous plant, it does not alter the underlying gasification or methanation chemistry. The major gas compositions, methane yields, and reactor performance trends observed are representative of biomass derived RNG production pathways.

For this campaign, the Acid Gas Removal (AGR) system was not operated because CO_2 conversion was achieved directly through catalytic methanation using controlled supplemental injected hydrogen addition. Sulfur species were observed only at low ppm levels and did not limit short bench-scale operation, however, commercial systems would include sulfur polishing to meet pipeline specifications and protect methanation catalysts. Optimization of methanator operating conditions, including H_2 to carbon oxides ratio management through implementation of an operator facing calculation tool on the HMI, enabled improved CO_2 conversion performance. Under optimized conditions, FS-2 and FS-3 product gases achieve methane concentrations meeting or exceeding 97% CH_4 and corresponding heating value targets. The lower methane concentration observed for FS-1 was attributable primarily to residual CO_2 and reflects early operating conditions rather than a fundamental process limitation with the particular feedstock.

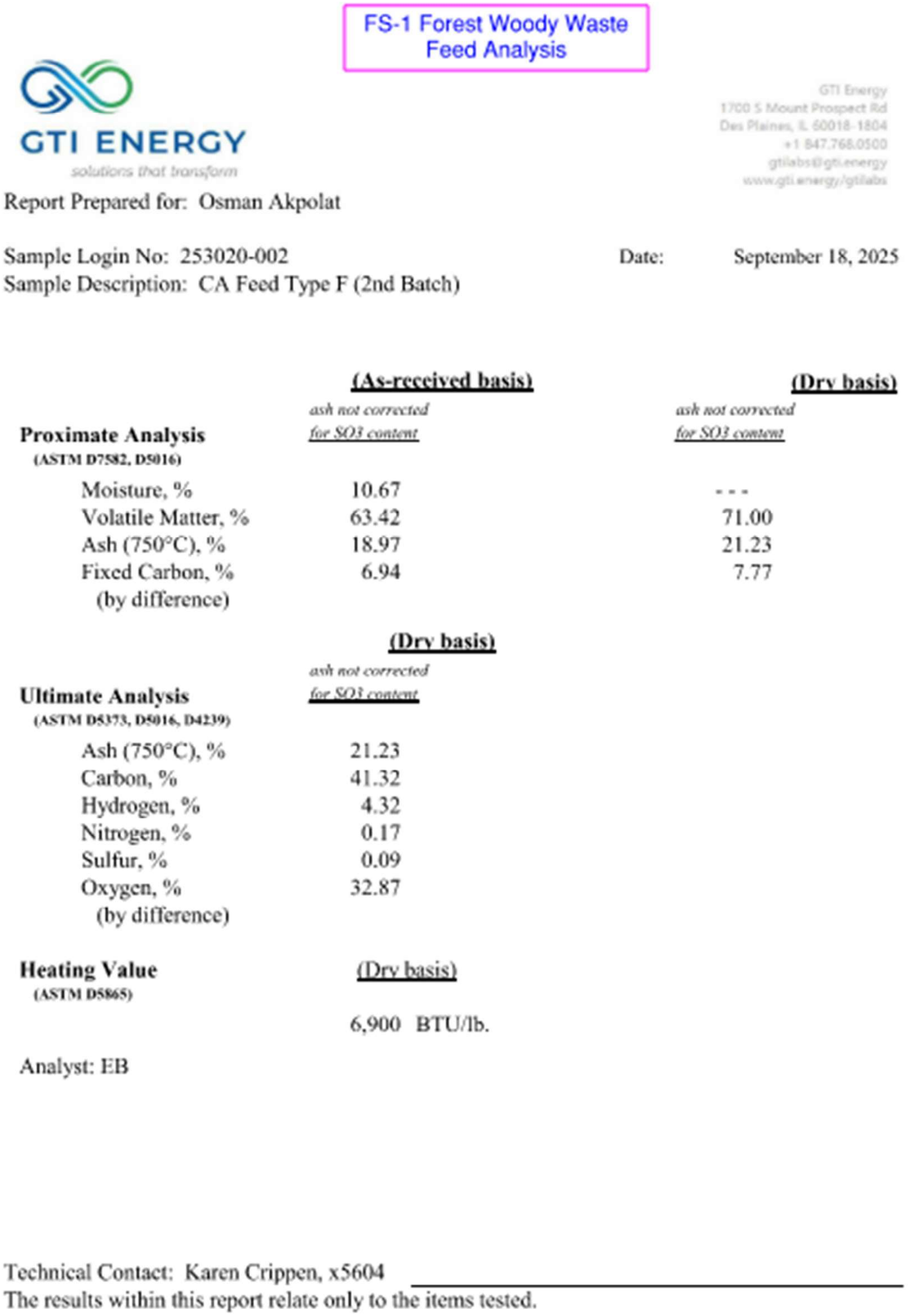
In a commercial configuration without externally available hydrogen, incorporation of a water gas shift reactor (WGS) and downstream AGR would be required to manage carbon oxides and achieve comparable pipeline specifications. With appropriate syngas conditioning and hydrogen management, either process pathway is capable of producing pipeline quality RNG.

Trace constituents were not a focus of this campaign and no trace metals speciation testing was performed as part of the GTI Energy analytical scope. If trace elements are observed in future expanded testing, the most likely contributors are the inherent mineral content of biomass feedstocks and potential carryover of entrained fine ash or particulates from gasification. In rare cases, interaction with high temperature mechanical equipment may also contribute to trace elemental signatures. These species are not products of methanation chemistry and can be further minimized in scaled systems through tighter feedstock quality control and enhanced particulate removal and gas cleaning.

Similarly, solvent related compounds detected at trace levels are attributed to routine laboratory maintenance practices characteristic of research scale equipment and are not intrinsic to the gasification or methanation process. Continuous commercial operation with integrated cleanup and longer catalyst lifetimes would not be expected to exhibit such carryover.

Overall, the data generated in this study provide a technically defensible basis for scale up. The results demonstrate reliable methanation performance, effective CO and CO_2 conversion under optimized conditions, and the demonstrated capability to achieve pipeline quality methane concentrations when operated with appropriate stoichiometric control and process integration. Future development efforts will focus on continuous integrated operation, further optimization of carbon oxide management, and incorporation of commercial scale gas conditioning steps to ensure consistent compliance with pipeline injection specifications while maintaining process efficiency and stability.

APPENDIX A – FEEDSTOCK COMPOSTION



FS-1 Forest Woody Waste
Feed Analysis

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www.gti.energy/gtilabs

Report Prepared for: Osman Akpolat

Sample Login No: 253020-002 Date: September 18, 2025
Sample Description: CA Feed Type F (2nd Batch)

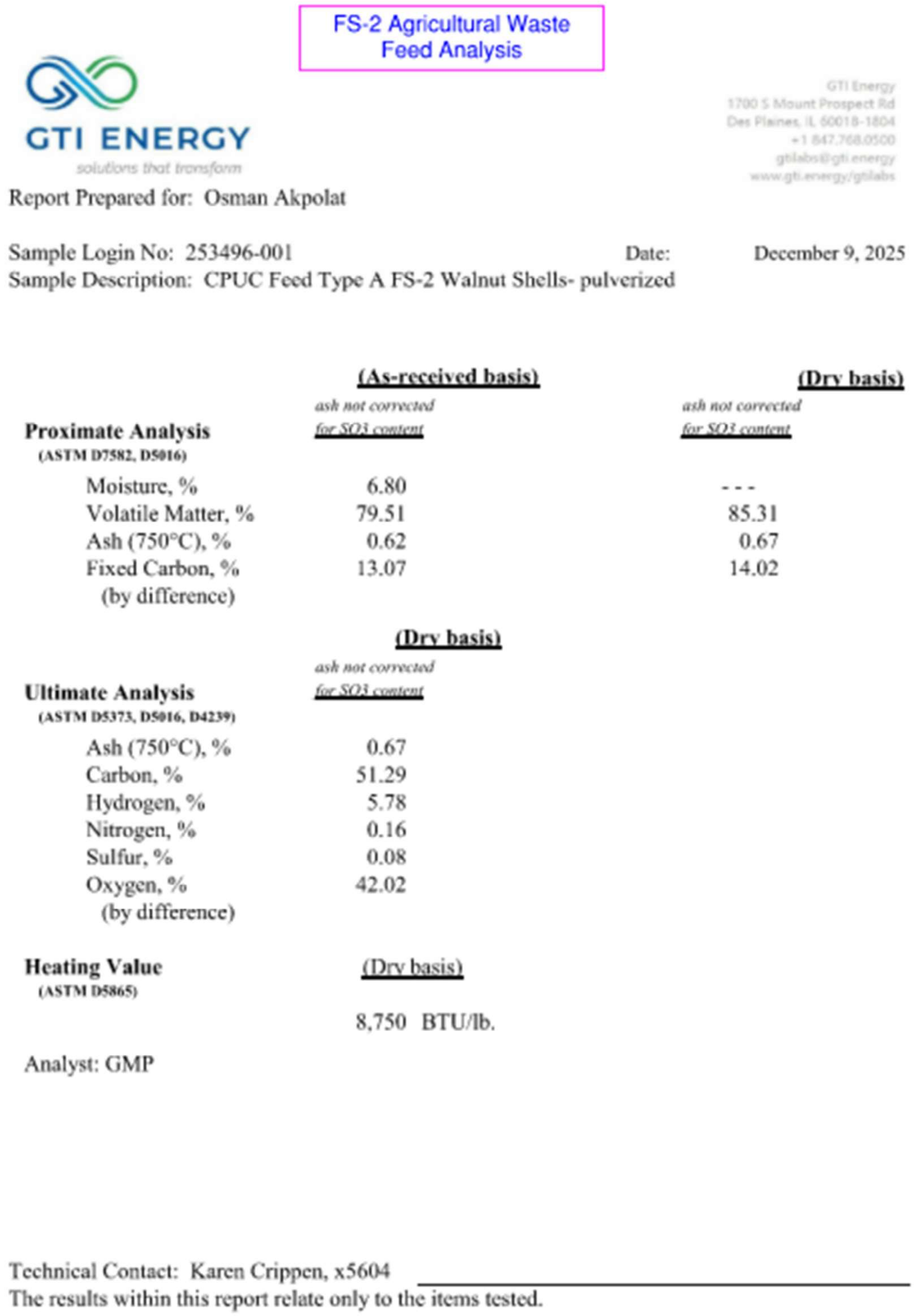
Proximate Analysis (ASTM D7582, D5016)	(As-received basis) *ash not corrected for SO3 content*	(Dry basis) *ash not corrected for SO3 content*
Moisture, %	10.67	- - -
Volatile Matter, %	63.42	71.00
Ash (750°C), %	18.97	21.23
Fixed Carbon, % (by difference)	6.94	7.77

Ultimate Analysis (ASTM D5373, D5016, D4239)	(Dry basis) *ash not corrected for SO3 content*
Ash (750°C), %	21.23
Carbon, %	41.32
Hydrogen, %	4.32
Nitrogen, %	0.17
Sulfur, %	0.09
Oxygen, % (by difference)	32.87

Heating Value (ASTM D5865)	(Dry basis)
	6,900 BTU/lb.

Analyst: EB

Technical Contact: Karen Crippen, x5604
The results within this report relate only to the items tested.



FS-2 Agricultural Waste
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Report Prepared for: Osman Akpolat

Sample Login No: 253496-001 Date: December 9, 2025
Sample Description: CPUC Feed Type A FS-2 Walnut Shells- pulverized

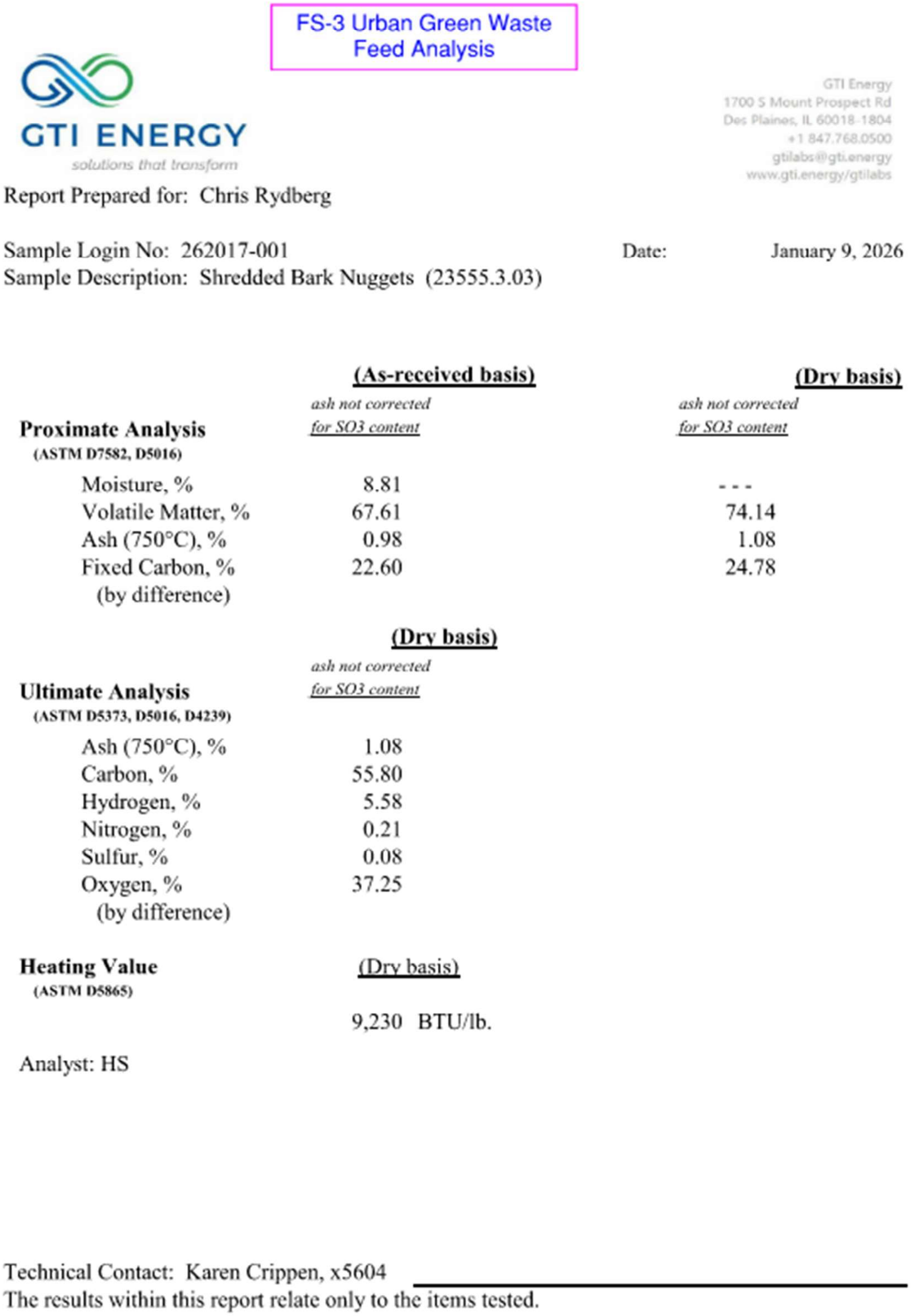
Proximate Analysis (ASTM D7582, D5016)	**(As-received basis)** *ash not corrected for SO3 content*	**(Dry basis)** *ash not corrected for SO3 content*
Moisture, %	6.80	- - -
Volatile Matter, %	79.51	85.31
Ash (750°C), %	0.62	0.67
Fixed Carbon, % (by difference)	13.07	14.02

Ultimate Analysis (ASTM D5373, D5016, D4239)	**(Dry basis)** *ash not corrected for SO3 content*
Ash (750°C), %	0.67
Carbon, %	51.29
Hydrogen, %	5.78
Nitrogen, %	0.16
Sulfur, %	0.08
Oxygen, % (by difference)	42.02

Heating Value (ASTM D5865)	(Dry basis)
	8,750 BTU/lb.

Analyst: GMP

Technical Contact: Karen Crippen, x5604
The results within this report relate only to the items tested.



FS-3 Urban Green Waste Feed Analysis

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www.gti.energy/gtilabs

Report Prepared for: Chris Rydberg

Sample Login No: 262017-001 Date: January 9, 2026
Sample Description: Shredded Bark Nuggets (23555.3.03)

Proximate Analysis
(ASTM D7582, D5016)

	(As-received basis) *ash not corrected for SO3 content*	**(Dry basis)** *ash not corrected for SO3 content*
Moisture, %	8.81	- - -
Volatile Matter, %	67.61	74.14
Ash (750°C), %	0.98	1.08
Fixed Carbon, % (by difference)	22.60	24.78

Ultimate Analysis
(ASTM D5373, D5016, D4239)

	(Dry basis) *ash not corrected for SO3 content*
Ash (750°C), %	1.08
Carbon, %	55.80
Hydrogen, %	5.58
Nitrogen, %	0.21
Sulfur, %	0.08
Oxygen, % (by difference)	37.25

Heating Value
(ASTM D5865)

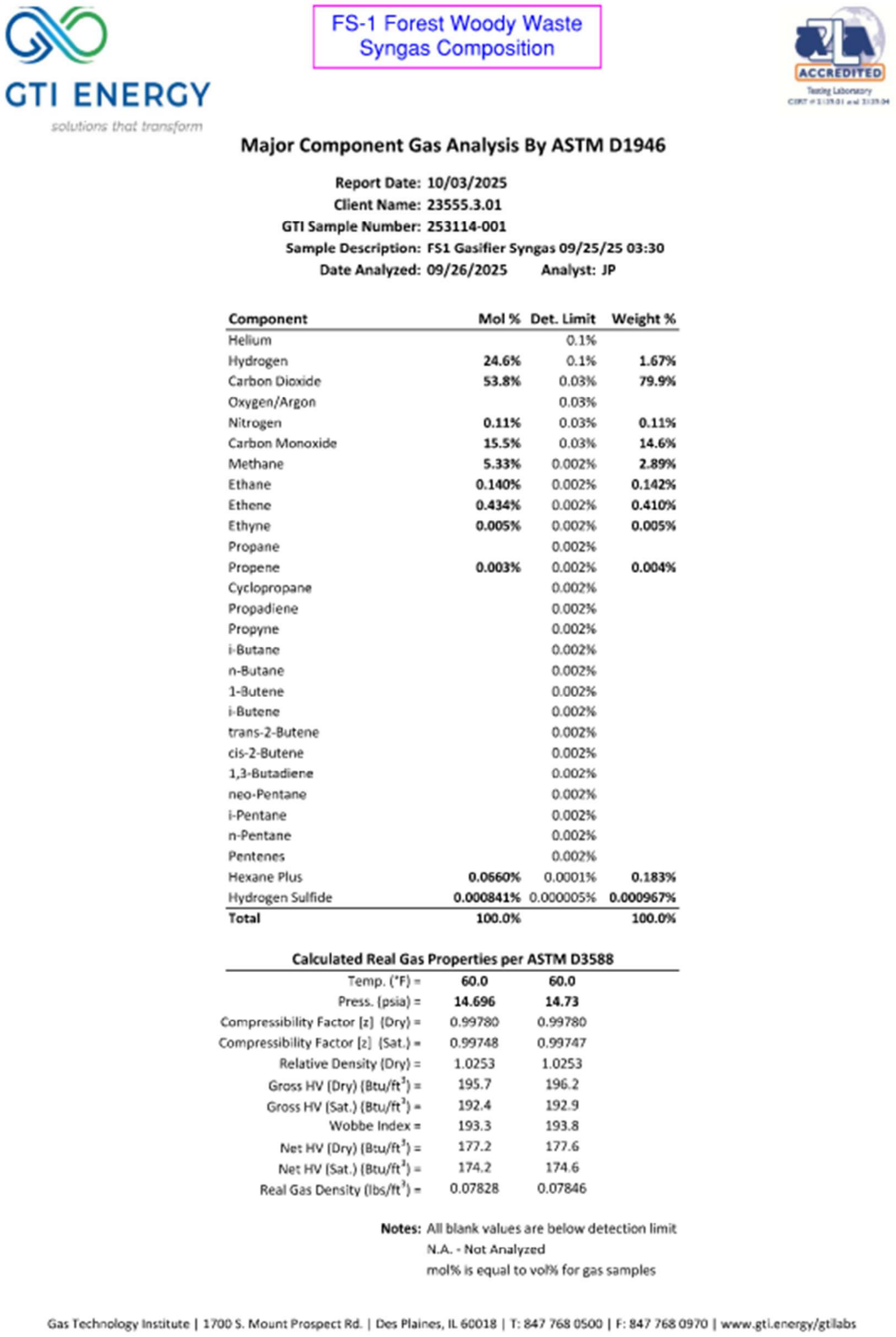
(Dry basis)

9,230 BTU/lb.

Analyst: HS

Technical Contact: Karen Crippen, x5604
The results within this report relate only to the items tested.

APPENDIX B – SYNGAS COMPOSITION



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FS-1 Forest Woody Waste
Syngas Composition

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Major Component Gas Analysis By ASTM D1946

Report Date: 10/03/2025
Client Name: 23555.3.01
GTI Sample Number: 253114-001
Sample Description: FS1 Gasifier Syngas 09/25/25 03:30
Date Analyzed: 09/26/2025 **Analyst:** JP

Component	Mol %	Det. Limit	Weight %
Helium		0.1%	
Hydrogen	**24.6%**	0.1%	**1.67%**
Carbon Dioxide	**53.8%**	0.03%	**79.9%**
Oxygen/Argon		0.03%	
Nitrogen	**0.11%**	0.03%	**0.11%**
Carbon Monoxide	**15.5%**	0.03%	**14.6%**
Methane	**5.33%**	0.002%	**2.89%**
Ethane	**0.140%**	0.002%	**0.142%**
Ethene	**0.434%**	0.002%	**0.410%**
Ethyne	**0.005%**	0.002%	**0.005%**
Propane		0.002%	
Propene	**0.003%**	0.002%	**0.004%**
Cyclopropane		0.002%	
Propadiene		0.002%	
Propyne		0.002%	
i-Butane		0.002%	
n-Butane		0.002%	
1-Butene		0.002%	
i-Butene		0.002%	
trans-2-Butene		0.002%	
cis-2-Butene		0.002%	
1,3-Butadiene		0.002%	
neo-Pentane		0.002%	
i-Pentane		0.002%	
n-Pentane		0.002%	
Pentenes		0.002%	
Hexane Plus	**0.0660%**	0.0001%	**0.183%**
Hydrogen Sulfide	**0.000841%**	0.000005%	**0.000967%**
Total	**100.0%**		**100.0%**

Calculated Real Gas Properties per ASTM D3588

Temp. (°F) =	**60.0**	**60.0**
Press. (psia) =	**14.696**	**14.73**
Compressibility Factor [z] (Dry) =	0.99780	0.99780
Compressibility Factor [z] (Sat.) =	0.99748	0.99747
Relative Density (Dry) =	1.0253	1.0253
Gross HV (Dry) (Btu/ft^3) =	195.7	196.2
Gross HV (Sat.) (Btu/ft^3) =	192.4	192.9
Wobbe Index =	193.3	193.8
Net HV (Dry) (Btu/ft^3) =	177.2	177.6
Net HV (Sat.) (Btu/ft^3) =	174.2	174.6
Real Gas Density (lbs/ft^3) =	0.07828	0.07846

Notes: All blank values are below detection limit
N.A. - Not Analyzed
mol% is equal to vol% for gas samples

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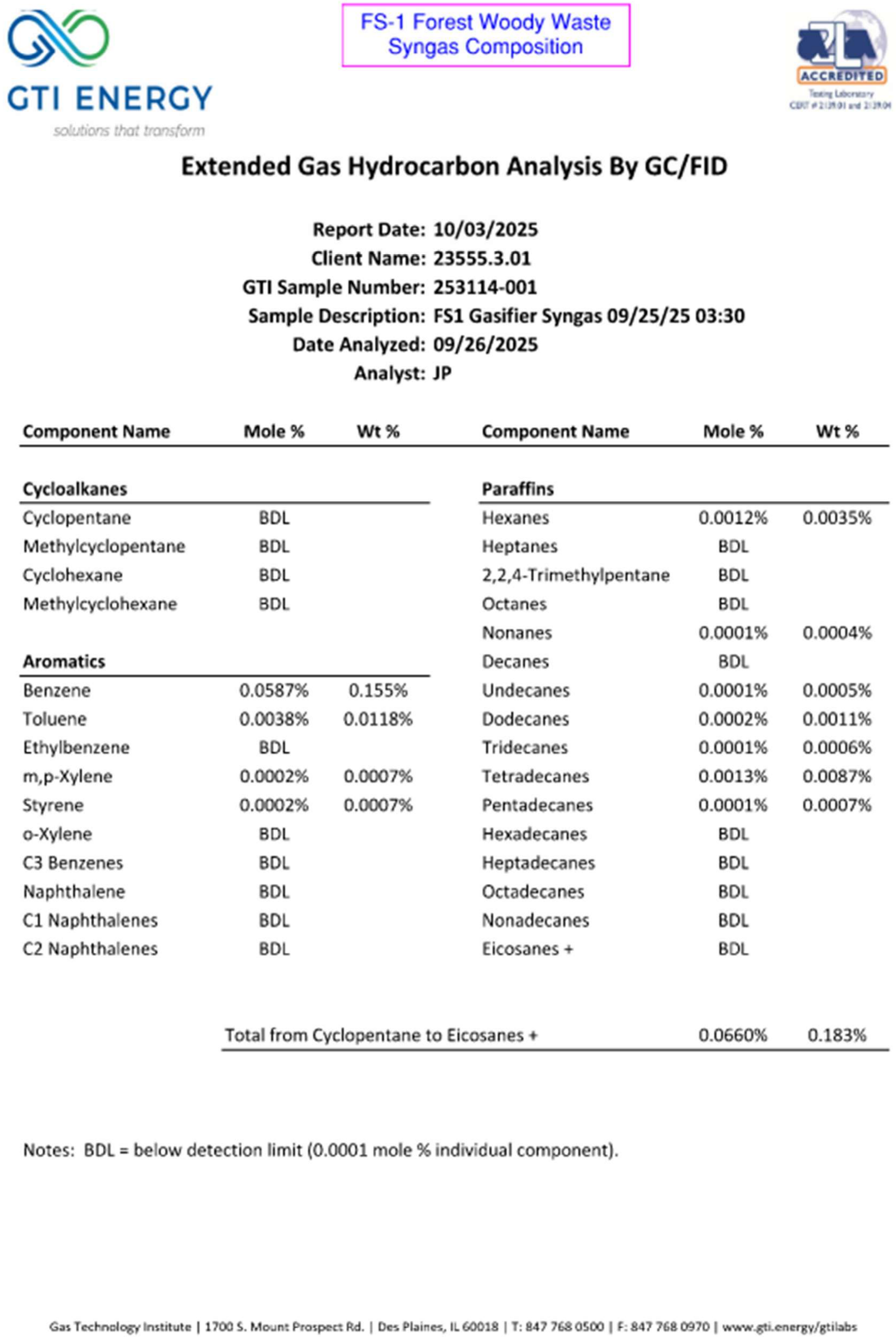

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FS-1 Forest Woody Waste
Syngas Composition

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Testing Laboratory
CERT # 2139.01 and 2139.04

Extended Gas Hydrocarbon Analysis By GC/FID

Report Date: 10/03/2025
Client Name: 23555.3.01
GTI Sample Number: 253114-001
Sample Description: FS1 Gasifier Syngas 09/25/25 03:30
Date Analyzed: 09/26/2025
Analyst: JP

Component Name	Mole %	Wt %	Component Name	Mole %	Wt %
Cycloalkanes			**Paraffins**		
Cyclopentane	BDL		Hexanes	0.0012%	0.0035%
Methylcyclopentane	BDL		Heptanes	BDL	
Cyclohexane	BDL		2,2,4-Trimethylpentane	BDL	
Methylcyclohexane	BDL		Octanes	BDL	
			Nonanes	0.0001%	0.0004%
Aromatics			Decanes	BDL	
Benzene	0.0587%	0.155%	Undecanes	0.0001%	0.0005%
Toluene	0.0038%	0.0118%	Dodecanes	0.0002%	0.0011%
Ethylbenzene	BDL		Tridecanes	0.0001%	0.0006%
m,p-Xylene	0.0002%	0.0007%	Tetradecanes	0.0013%	0.0087%
Styrene	0.0002%	0.0007%	Pentadecanes	0.0001%	0.0007%
o-Xylene	BDL		Hexadecanes	BDL	
C3 Benzenes	BDL		Heptadecanes	BDL	
Naphthalene	BDL		Octadecanes	BDL	
C1 Naphthalenes	BDL		Nonadecanes	BDL	
C2 Naphthalenes	BDL		Eicosanes +	BDL	
	Total from Cyclopentane to Eicosanes +			0.0660%	0.183%

Notes: BDL = below detection limit (0.0001 mole % individual component).

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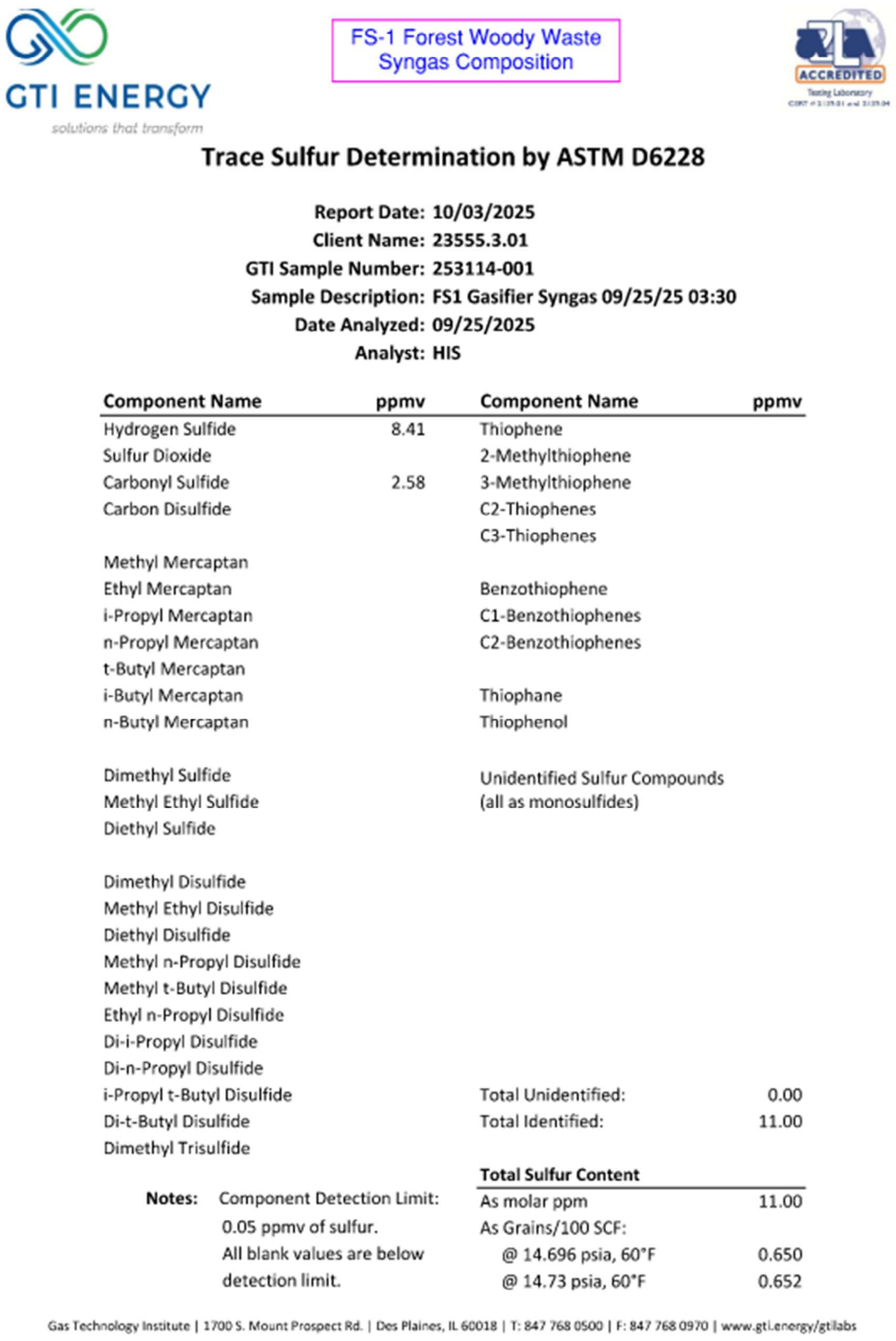

FS-1 Forest Woody Waste
Syngas Composition

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Testing Laboratory

Trace Sulfur Determination by ASTM D6228

Report Date: 10/03/2025
Client Name: 23555.3.01
GTI Sample Number: 253114-001
Sample Description: FS1 Gasifier Syngas 09/25/25 03:30
Date Analyzed: 09/25/2025
Analyst: HIS

Component Name	ppmv	Component Name	ppmv
Hydrogen Sulfide	8.41	Thiophene	
Sulfur Dioxide		2-Methylthiophene	
Carbonyl Sulfide	2.58	3-Methylthiophene	
Carbon Disulfide		C2-Thiophenes	
		C3-Thiophenes	
Methyl Mercaptan			
Ethyl Mercaptan		Benzothiophene	
i-Propyl Mercaptan		C1-Benzothiophenes	
n-Propyl Mercaptan		C2-Benzothiophenes	
t-Butyl Mercaptan			
i-Butyl Mercaptan		Thiophane	
n-Butyl Mercaptan		Thiophenol	
Dimethyl Sulfide		Unidentified Sulfur Compounds	
Methyl Ethyl Sulfide		(all as monosulfides)	
Diethyl Sulfide			
Dimethyl Disulfide			
Methyl Ethyl Disulfide			
Diethyl Disulfide			
Methyl n-Propyl Disulfide			
Methyl t-Butyl Disulfide			
Ethyl n-Propyl Disulfide			
Di-i-Propyl Disulfide			
Di-n-Propyl Disulfide			
i-Propyl t-Butyl Disulfide		Total Unidentified:	0.00
Di-t-Butyl Disulfide		Total Identified:	11.00
Dimethyl Trisulfide			

Total Sulfur Content	
As molar ppm	11.00
As Grains/100 SCF:	
@ 14.696 psia, 60°F	0.650
@ 14.73 psia, 60°F	0.652

Notes: Component Detection Limit:
0.05 ppmv of sulfur.
All blank values are below
detection limit.

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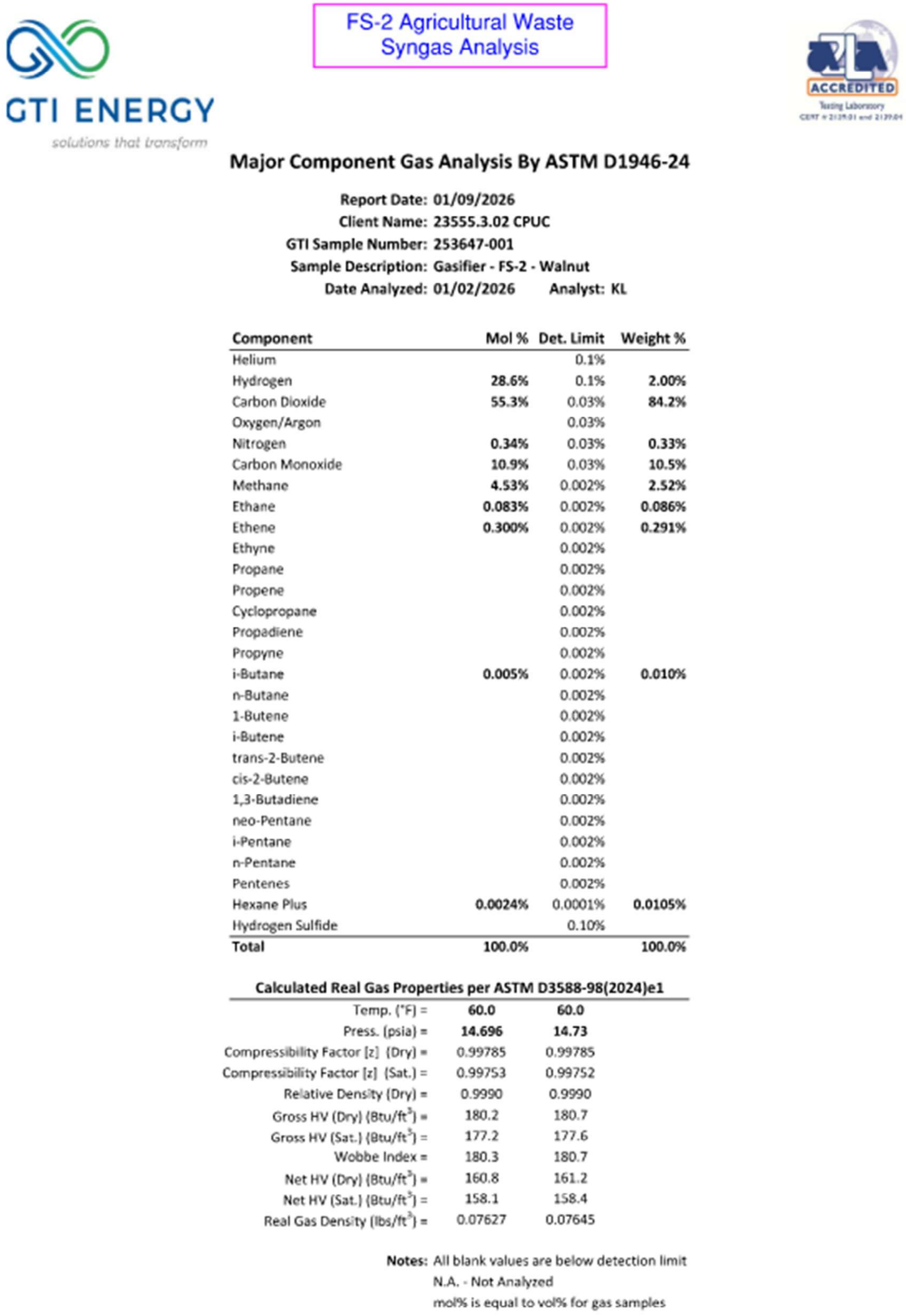

FS-2 Agricultural Waste
Syngas Analysis

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CERT # 2139.01 and 2139.04

Major Component Gas Analysis By ASTM D1946-24

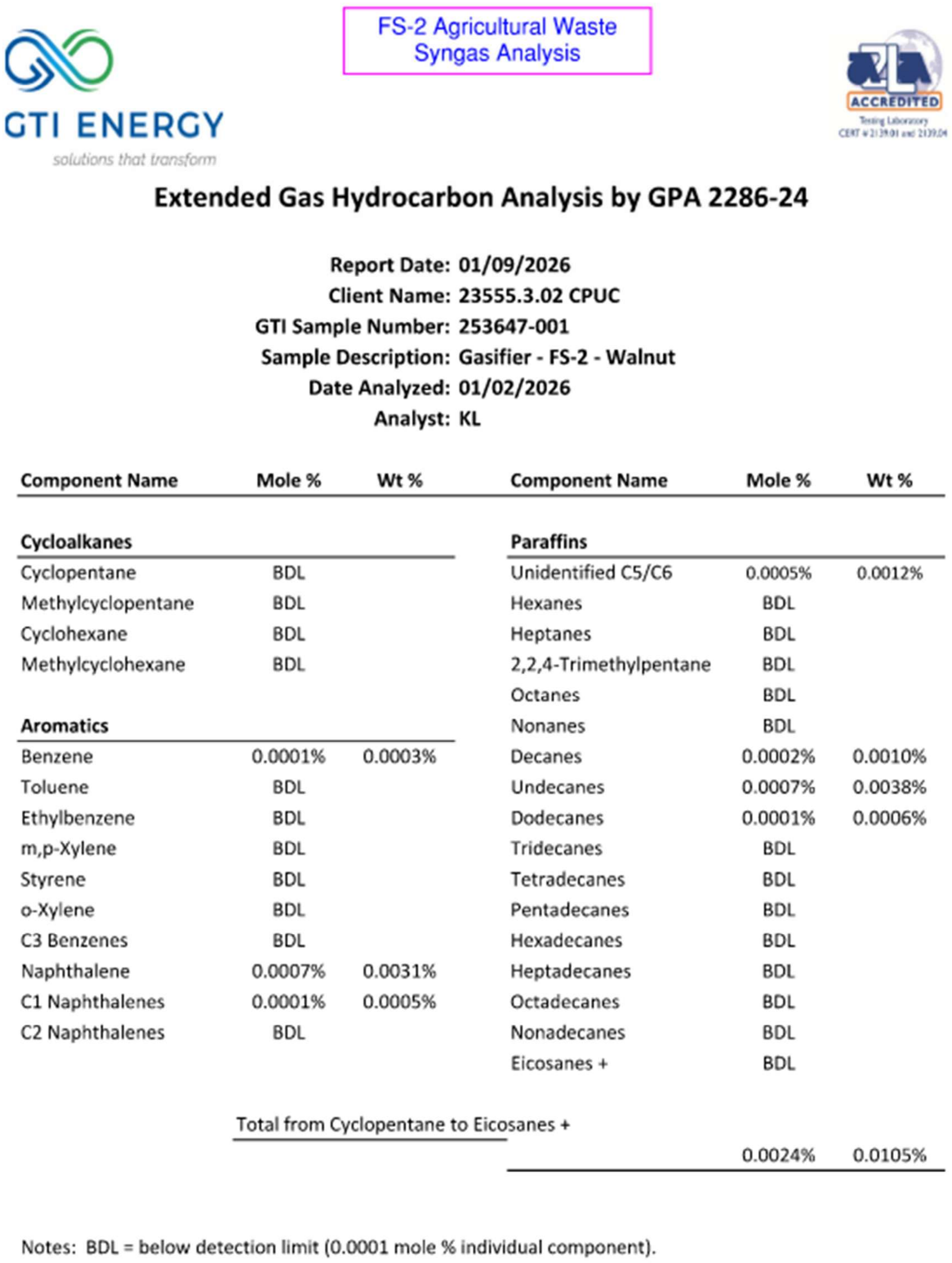
Report Date: 01/09/2026
Client Name: 23555.3.02 CPUC
GTI Sample Number: 253647-001
Sample Description: Gasifier - FS-2 - Walnut
Date Analyzed: 01/02/2026 **Analyst:** KL

Component	Mol %	Det. Limit	Weight %
Helium		0.1%	
Hydrogen	**28.6%**	0.1%	**2.00%**
Carbon Dioxide	**55.3%**	0.03%	**84.2%**
Oxygen/Argon		0.03%	
Nitrogen	**0.34%**	0.03%	**0.33%**
Carbon Monoxide	**10.9%**	0.03%	**10.5%**
Methane	**4.53%**	0.002%	**2.52%**
Ethane	**0.083%**	0.002%	**0.086%**
Ethene	**0.300%**	0.002%	**0.291%**
Ethyne		0.002%	
Propane		0.002%	
Propene		0.002%	
Cyclopropane		0.002%	
Propadiene		0.002%	
Propyne		0.002%	
i-Butane	**0.005%**	0.002%	**0.010%**
n-Butane		0.002%	
1-Butene		0.002%	
i-Butene		0.002%	
trans-2-Butene		0.002%	
cis-2-Butene		0.002%	
1,3-Butadiene		0.002%	
neo-Pentane		0.002%	
i-Pentane		0.002%	
n-Pentane		0.002%	
Pentenes		0.002%	
Hexane Plus	**0.0024%**	0.0001%	**0.0105%**
Hydrogen Sulfide		0.10%	
Total	**100.0%**		**100.0%**

Calculated Real Gas Properties per ASTM D3588-98(2024)e1

Temp. (°F) =	**60.0**	**60.0**
Press. (psia) =	**14.696**	**14.73**
Compressibility Factor [z] (Dry) =	0.99785	0.99785
Compressibility Factor [z] (Sat.) =	0.99753	0.99752
Relative Density (Dry) =	0.9990	0.9990
Gross HV (Dry) (Btu/ft^3) =	180.2	180.7
Gross HV (Sat.) (Btu/ft^3) =	177.2	177.6
Wobbe Index =	180.3	180.7
Net HV (Dry) (Btu/ft^3) =	160.8	161.2
Net HV (Sat.) (Btu/ft^3) =	158.1	158.4
Real Gas Density (lbs/ft^3) =	0.07627	0.07645

Notes: All blank values are below detection limit
N.A. - Not Analyzed
mol% is equal to vol% for gas samples



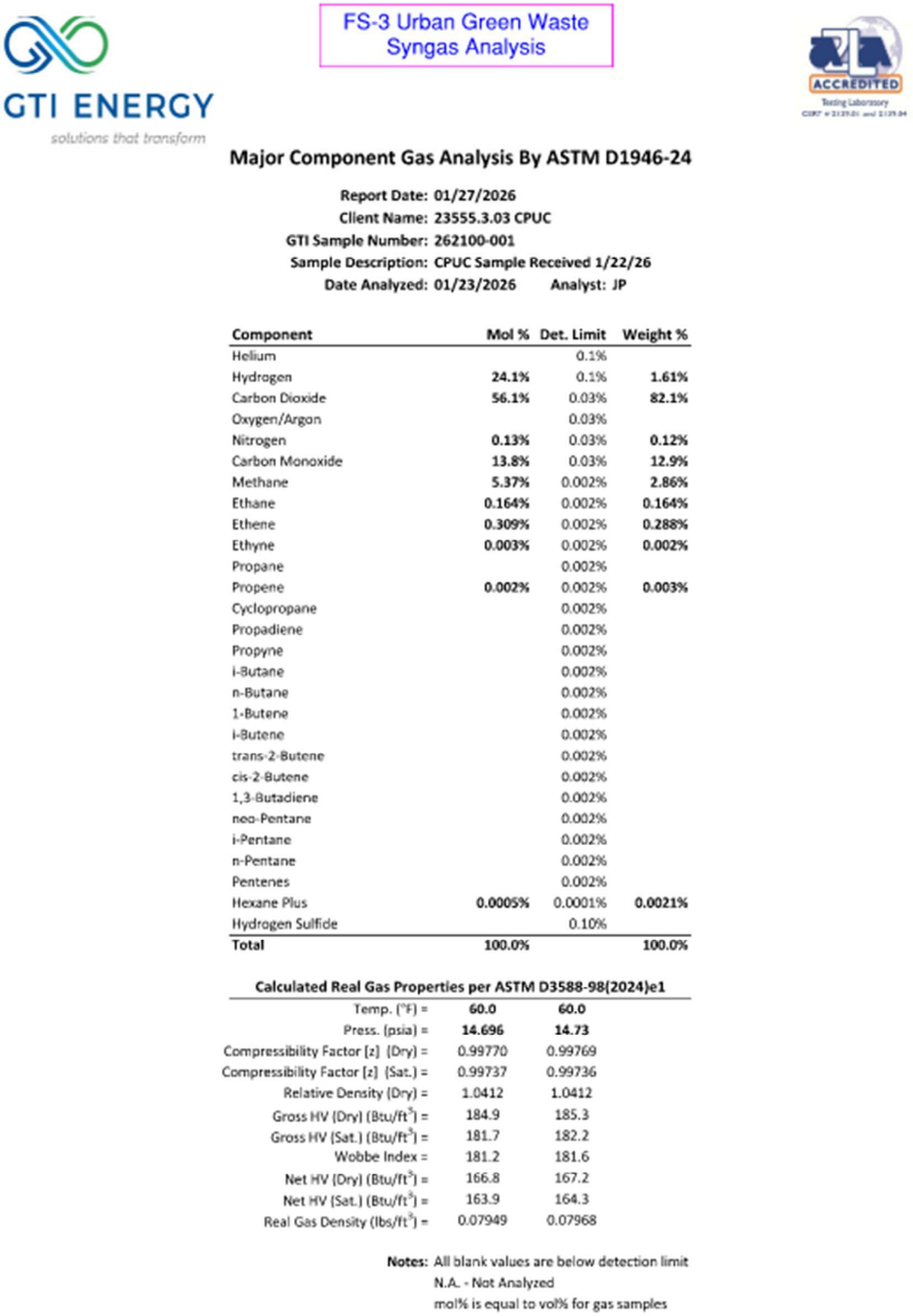
FS-2 Agricultural Waste
Syngas Analysis

Extended Gas Hydrocarbon Analysis by GPA 2286-24

Report Date: 01/09/2026
Client Name: 23555.3.02 CPUC
GTI Sample Number: 253647-001
Sample Description: Gasifier - FS-2 - Walnut
Date Analyzed: 01/02/2026
Analyst: KL

Component Name	Mole %	Wt %	Component Name	Mole %	Wt %
Cycloalkanes			**Paraffins**		
Cyclopentane	BDL		Unidentified C5/C6	0.0005%	0.0012%
Methylcyclopentane	BDL		Hexanes	BDL	
Cyclohexane	BDL		Heptanes	BDL	
Methylcyclohexane	BDL		2,2,4-Trimethylpentane	BDL	
			Octanes	BDL	
Aromatics			Nonanes	BDL	
Benzene	0.0001%	0.0003%	Decanes	0.0002%	0.0010%
Toluene	BDL		Undecanes	0.0007%	0.0038%
Ethylbenzene	BDL		Dodecanes	0.0001%	0.0006%
m,p-Xylene	BDL		Tridecanes	BDL	
Styrene	BDL		Tetradecanes	BDL	
o-Xylene	BDL		Pentadecanes	BDL	
C3 Benzenes	BDL		Hexadecanes	BDL	
Naphthalene	0.0007%	0.0031%	Heptadecanes	BDL	
C1 Naphthalenes	0.0001%	0.0005%	Octadecanes	BDL	
C2 Naphthalenes	BDL		Nonadecanes	BDL	
			Eicosanes +	BDL	
Total from Cyclopentane to Eicosanes +				0.0024%	0.0105%

Notes: BDL = below detection limit (0.0001 mole % individual component).



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FS-3 Urban Green Waste Syngas Analysis

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Testing Laboratory

Major Component Gas Analysis By ASTM D1946-24

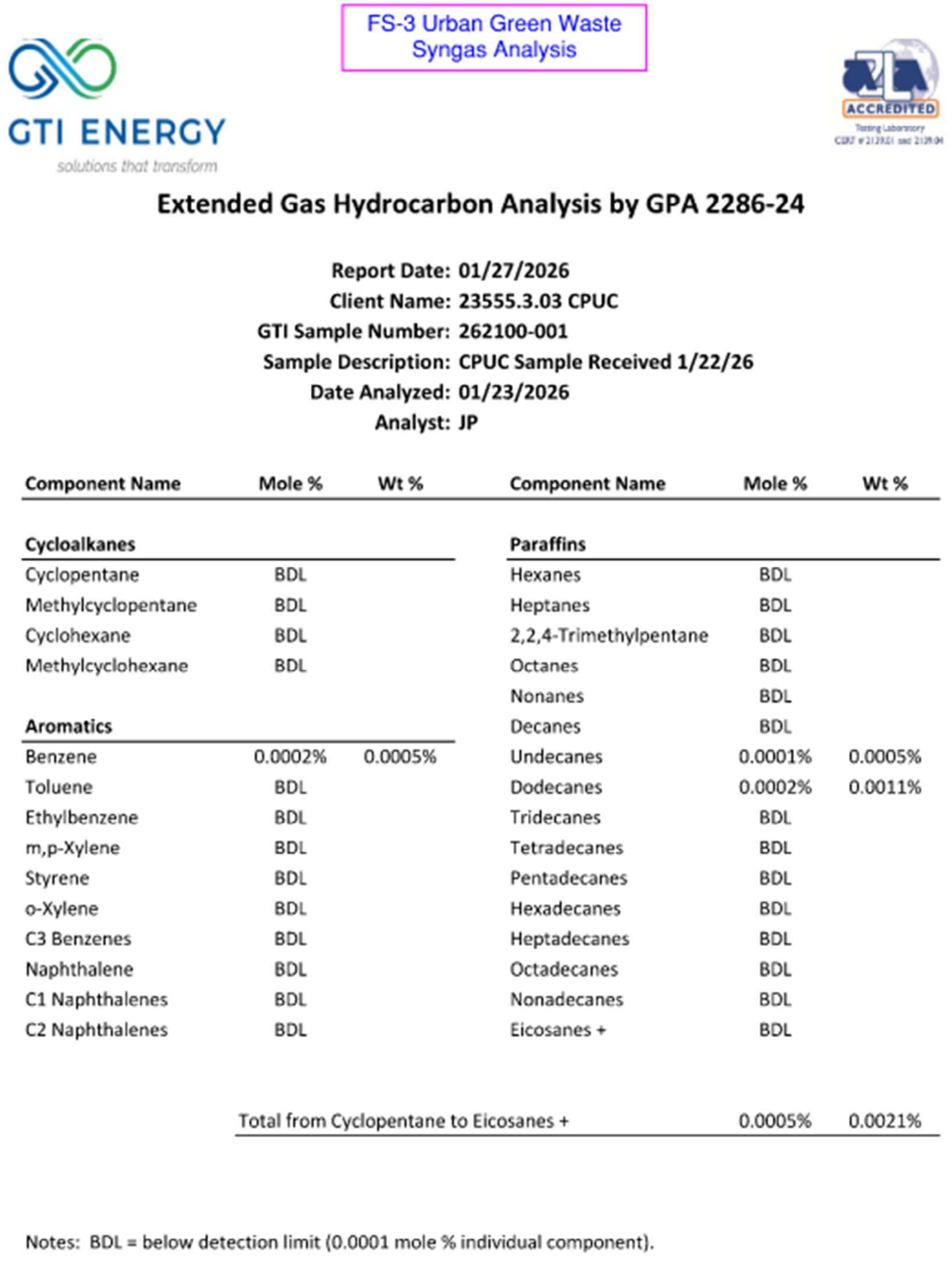
Report Date: 01/27/2026
Client Name: 23555.3.03 CPUC
GTI Sample Number: 262100-001
Sample Description: CPUC Sample Received 1/22/26
Date Analyzed: 01/23/2026 **Analyst:** JP

Component	Mol %	Det. Limit	Weight %
Helium		0.1%	
Hydrogen	**24.1%**	0.1%	**1.61%**
Carbon Dioxide	**56.1%**	0.03%	**82.1%**
Oxygen/Argon		0.03%	
Nitrogen	**0.13%**	0.03%	**0.12%**
Carbon Monoxide	**13.8%**	0.03%	**12.9%**
Methane	**5.37%**	0.002%	**2.86%**
Ethane	**0.164%**	0.002%	**0.164%**
Ethene	**0.309%**	0.002%	**0.288%**
Ethyne	**0.003%**	0.002%	**0.002%**
Propane		0.002%	
Propene	**0.002%**	0.002%	**0.003%**
Cyclopropane		0.002%	
Propadiene		0.002%	
Propyne		0.002%	
i-Butane		0.002%	
n-Butane		0.002%	
1-Butene		0.002%	
i-Butene		0.002%	
trans-2-Butene		0.002%	
cis-2-Butene		0.002%	
1,3-Butadiene		0.002%	
neo-Pentane		0.002%	
i-Pentane		0.002%	
n-Pentane		0.002%	
Pentenes		0.002%	
Hexane Plus	**0.0005%**	0.0001%	**0.0021%**
Hydrogen Sulfide		0.10%	
Total	**100.0%**		**100.0%**

Calculated Real Gas Properties per ASTM D3588-98(2024)e1

Temp. (°F) =	**60.0**	**60.0**
Press. (psia) =	**14.696**	**14.73**
Compressibility Factor [z] (Dry) =	0.99770	0.99769
Compressibility Factor [z] (Sat.) =	0.99737	0.99736
Relative Density (Dry) =	1.0412	1.0412
Gross HV (Dry) (Btu/ft^3) =	184.9	185.3
Gross HV (Sat.) (Btu/ft^3) =	181.7	182.2
Wobbe Index =	181.2	181.6
Net HV (Dry) (Btu/ft^3) =	166.8	167.2
Net HV (Sat.) (Btu/ft^3) =	163.9	164.3
Real Gas Density (lbs/ft^3) =	0.07949	0.07968

Notes: All blank values are below detection limit
N.A. - Not Analyzed
mol% is equal to vol% for gas samples



FS-3 Urban Green Waste Syngas Analysis

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CERT # 2139.01 and 2139.04

Extended Gas Hydrocarbon Analysis by GPA 2286-24

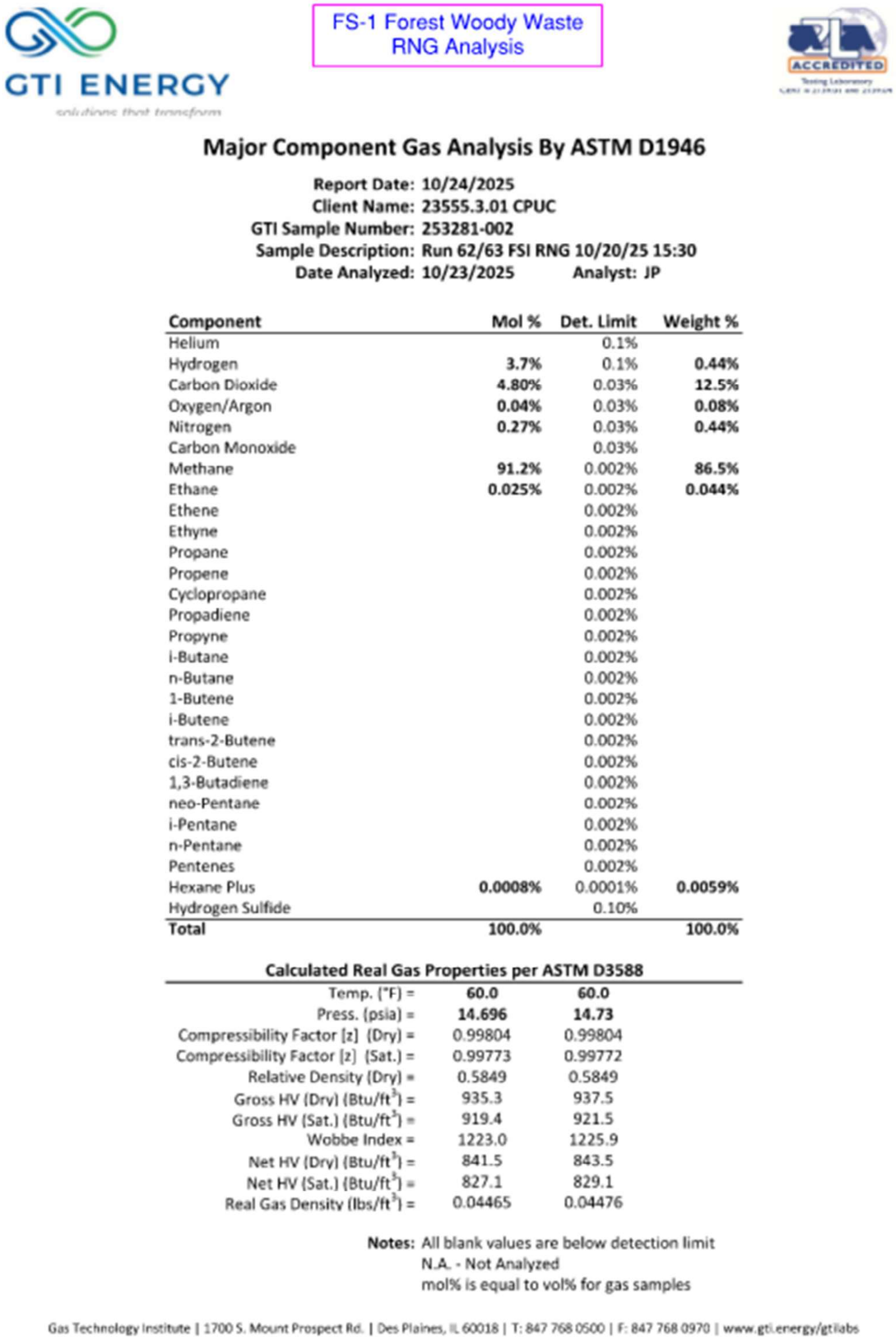
Report Date: 01/27/2026
Client Name: 23555.3.03 CPUC
GTI Sample Number: 262100-001
Sample Description: CPUC Sample Received 1/22/26
Date Analyzed: 01/23/2026
Analyst: JP

Component Name	Mole %	Wt %	Component Name	Mole %	Wt %
Cycloalkanes			**Paraffins**		
Cyclopentane	BDL		Hexanes	BDL	
Methylcyclopentane	BDL		Heptanes	BDL	
Cyclohexane	BDL		2,2,4-Trimethylpentane	BDL	
Methylcyclohexane	BDL		Octanes	BDL	
			Nonanes	BDL	
Aromatics			Decanes	BDL	
Benzene	0.0002%	0.0005%	Undecanes	0.0001%	0.0005%
Toluene	BDL		Dodecanes	0.0002%	0.0011%
Ethylbenzene	BDL		Tridecanes	BDL	
m,p-Xylene	BDL		Tetradecanes	BDL	
Styrene	BDL		Pentadecanes	BDL	
o-Xylene	BDL		Hexadecanes	BDL	
C3 Benzenes	BDL		Heptadecanes	BDL	
Naphthalene	BDL		Octadecanes	BDL	
C1 Naphthalenes	BDL		Nonadecanes	BDL	
C2 Naphthalenes	BDL		Eicosanes +	BDL	

	Mole %	Wt %
Total from Cyclopentane to Eicosanes +	0.0005%	0.0021%

Notes: BDL = below detection limit (0.0001 mole % individual component).

APPENDIX C – RNG COMPOSITION



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FS-1 Forest Woody Waste
RNG Analysis

ACCREDITED Testing Laboratory

Major Component Gas Analysis By ASTM D1946

Report Date: 10/24/2025
Client Name: 23555.3.01 CPUC
GTI Sample Number: 253281-002
Sample Description: Run 62/63 FSI RNG 10/20/25 15:30
Date Analyzed: 10/23/2025 **Analyst:** JP

Component	Mol %	Det. Limit	Weight %
Helium		0.1%	
Hydrogen	**3.7%**	0.1%	**0.44%**
Carbon Dioxide	**4.80%**	0.03%	**12.5%**
Oxygen/Argon	**0.04%**	0.03%	**0.08%**
Nitrogen	**0.27%**	0.03%	**0.44%**
Carbon Monoxide		0.03%	
Methane	**91.2%**	0.002%	**86.5%**
Ethane	**0.025%**	0.002%	**0.044%**
Ethene		0.002%	
Ethyne		0.002%	
Propane		0.002%	
Propene		0.002%	
Cyclopropane		0.002%	
Propadiene		0.002%	
Propyne		0.002%	
i-Butane		0.002%	
n-Butane		0.002%	
1-Butene		0.002%	
i-Butene		0.002%	
trans-2-Butene		0.002%	
cis-2-Butene		0.002%	
1,3-Butadiene		0.002%	
neo-Pentane		0.002%	
i-Pentane		0.002%	
n-Pentane		0.002%	
Pentenes		0.002%	
Hexane Plus	**0.0008%**	0.0001%	**0.0059%**
Hydrogen Sulfide		0.10%	
Total	**100.0%**		**100.0%**

Calculated Real Gas Properties per ASTM D3588

Temp. (°F) =	**60.0**	**60.0**
Press. (psia) =	**14.696**	**14.73**
Compressibility Factor [z] (Dry) =	0.99804	0.99804
Compressibility Factor [z] (Sat.) =	0.99773	0.99772
Relative Density (Dry) =	0.5849	0.5849
Gross HV (Dry) (Btu/ft^3) =	935.3	937.5
Gross HV (Sat.) (Btu/ft^3) =	919.4	921.5
Wobbe Index =	1223.0	1225.9
Net HV (Dry) (Btu/ft^3) =	841.5	843.5
Net HV (Sat.) (Btu/ft^3) =	827.1	829.1
Real Gas Density (lbs/ft^3) =	0.04465	0.04476

Notes: All blank values are below detection limit
N.A. - Not Analyzed
mol% is equal to vol% for gas samples

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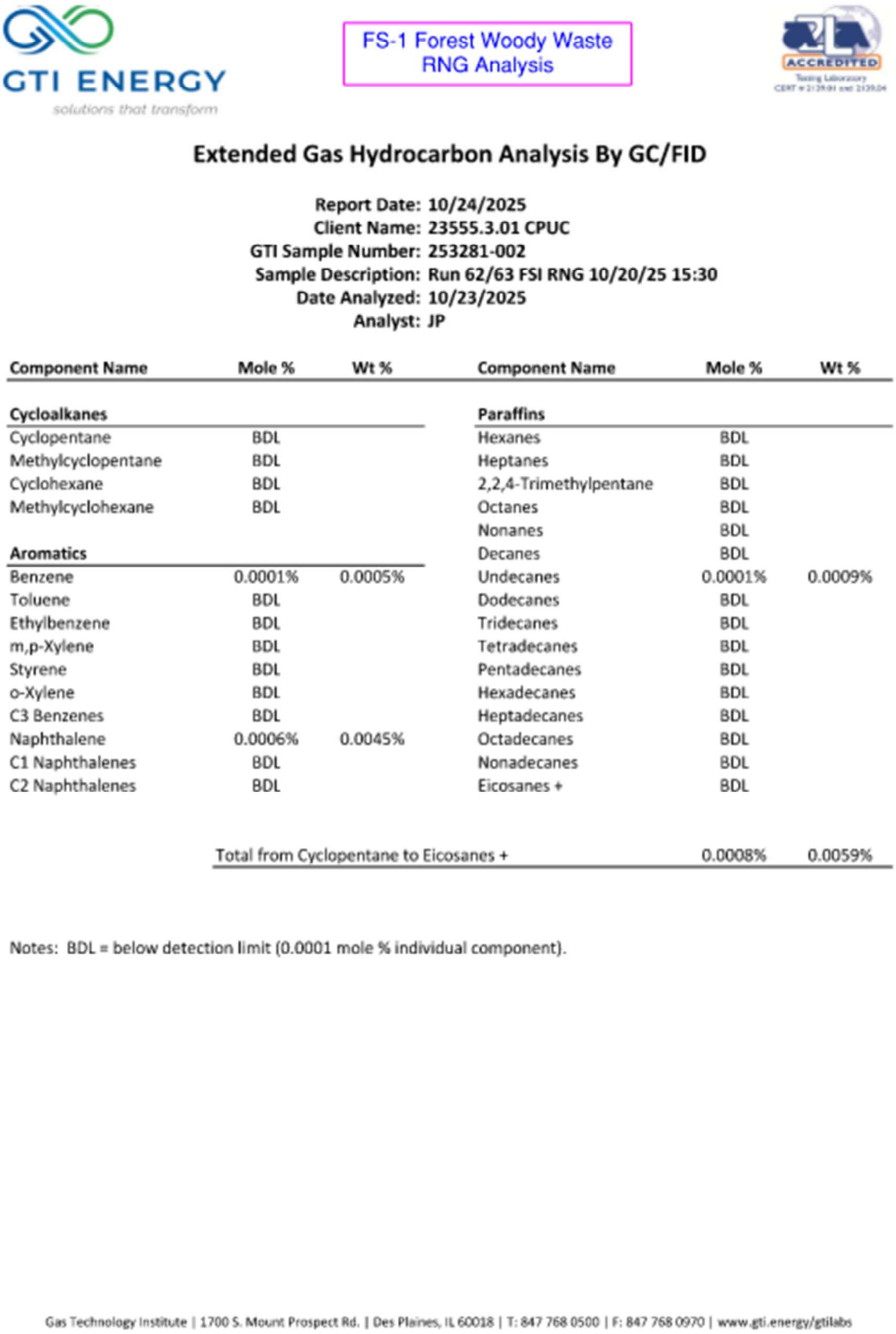

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FS-1 Forest Woody Waste
RNG Analysis

Extended Gas Hydrocarbon Analysis By GC/FID

Report Date: 10/24/2025
Client Name: 23555.3.01 CPUC
GTI Sample Number: 253281-002
Sample Description: Run 62/63 FSI RNG 10/20/25 15:30
Date Analyzed: 10/23/2025
Analyst: JP

Component Name	Mole %	Wt %	Component Name	Mole %	Wt %
Cycloalkanes			**Paraffins**		
Cyclopentane	BDL		Hexanes	BDL	
Methylcyclopentane	BDL		Heptanes	BDL	
Cyclohexane	BDL		2,2,4-Trimethylpentane	BDL	
Methylcyclohexane	BDL		Octanes	BDL	
			Nonanes	BDL	
Aromatics			Decanes	BDL	
Benzene	0.0001%	0.0005%	Undecanes	0.0001%	0.0009%
Toluene	BDL		Dodecanes	BDL	
Ethylbenzene	BDL		Tridecanes	BDL	
m,p-Xylene	BDL		Tetradecanes	BDL	
Styrene	BDL		Pentadecanes	BDL	
o-Xylene	BDL		Hexadecanes	BDL	
C3 Benzenes	BDL		Heptadecanes	BDL	
Naphthalene	0.0006%	0.0045%	Octadecanes	BDL	
C1 Naphthalenes	BDL		Nonadecanes	BDL	
C2 Naphthalenes	BDL		Eicosanes +	BDL	
			Total from Cyclopentane to Eicosanes +	0.0008%	0.0059%

Notes: BDL = below detection limit (0.0001 mole % individual component).

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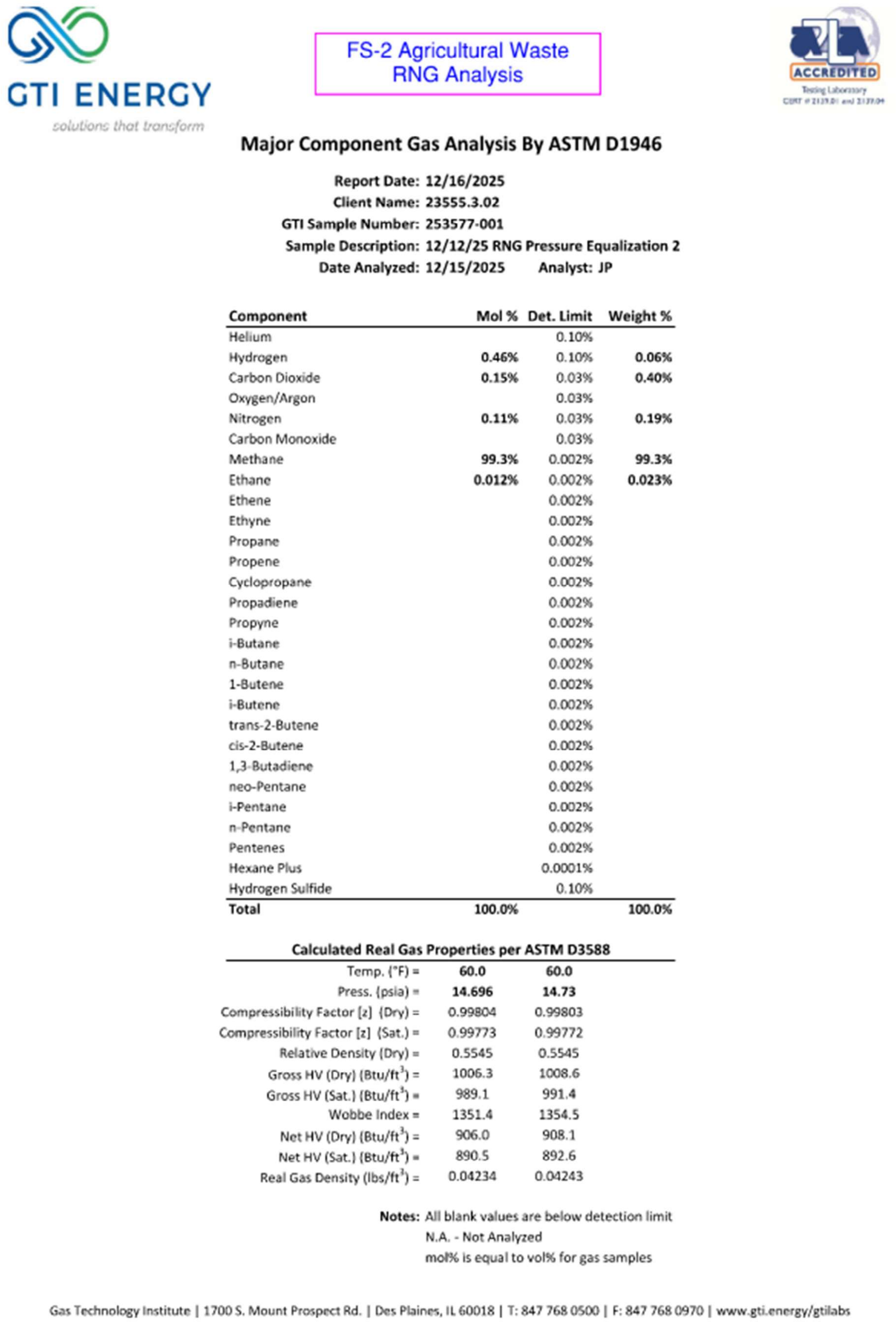

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FS-2 Agricultural Waste
RNG Analysis

Major Component Gas Analysis By ASTM D1946

Report Date: 12/16/2025
Client Name: 23555.3.02
GTI Sample Number: 253577-001
Sample Description: 12/12/25 RNG Pressure Equalization 2
Date Analyzed: 12/15/2025 **Analyst:** JP

Component	Mol %	Det. Limit	Weight %
Helium		0.10%	
Hydrogen	**0.46%**	0.10%	**0.06%**
Carbon Dioxide	**0.15%**	0.03%	**0.40%**
Oxygen/Argon		0.03%	
Nitrogen	**0.11%**	0.03%	**0.19%**
Carbon Monoxide		0.03%	
Methane	**99.3%**	0.002%	**99.3%**
Ethane	**0.012%**	0.002%	**0.023%**
Ethene		0.002%	
Ethyne		0.002%	
Propane		0.002%	
Propene		0.002%	
Cyclopropane		0.002%	
Propadiene		0.002%	
Propyne		0.002%	
i-Butane		0.002%	
n-Butane		0.002%	
1-Butene		0.002%	
i-Butene		0.002%	
trans-2-Butene		0.002%	
cis-2-Butene		0.002%	
1,3-Butadiene		0.002%	
neo-Pentane		0.002%	
i-Pentane		0.002%	
n-Pentane		0.002%	
Pentenes		0.002%	
Hexane Plus		0.0001%	
Hydrogen Sulfide		0.10%	
Total	**100.0%**		**100.0%**

Calculated Real Gas Properties per ASTM D3588

Temp. (°F) =	**60.0**	**60.0**
Press. (psia) =	**14.696**	**14.73**
Compressibility Factor [z] (Dry) =	0.99804	0.99803
Compressibility Factor [z] (Sat.) =	0.99773	0.99772
Relative Density (Dry) =	0.5545	0.5545
Gross HV (Dry) (Btu/ft^3) =	1006.3	1008.6
Gross HV (Sat.) (Btu/ft^3) =	989.1	991.4
Wobbe Index =	1351.4	1354.5
Net HV (Dry) (Btu/ft^3) =	906.0	908.1
Net HV (Sat.) (Btu/ft^3) =	890.5	892.6
Real Gas Density (lbs/ft^3) =	0.04234	0.04243

Notes: All blank values are below detection limit
N.A. - Not Analyzed
mol% is equal to vol% for gas samples

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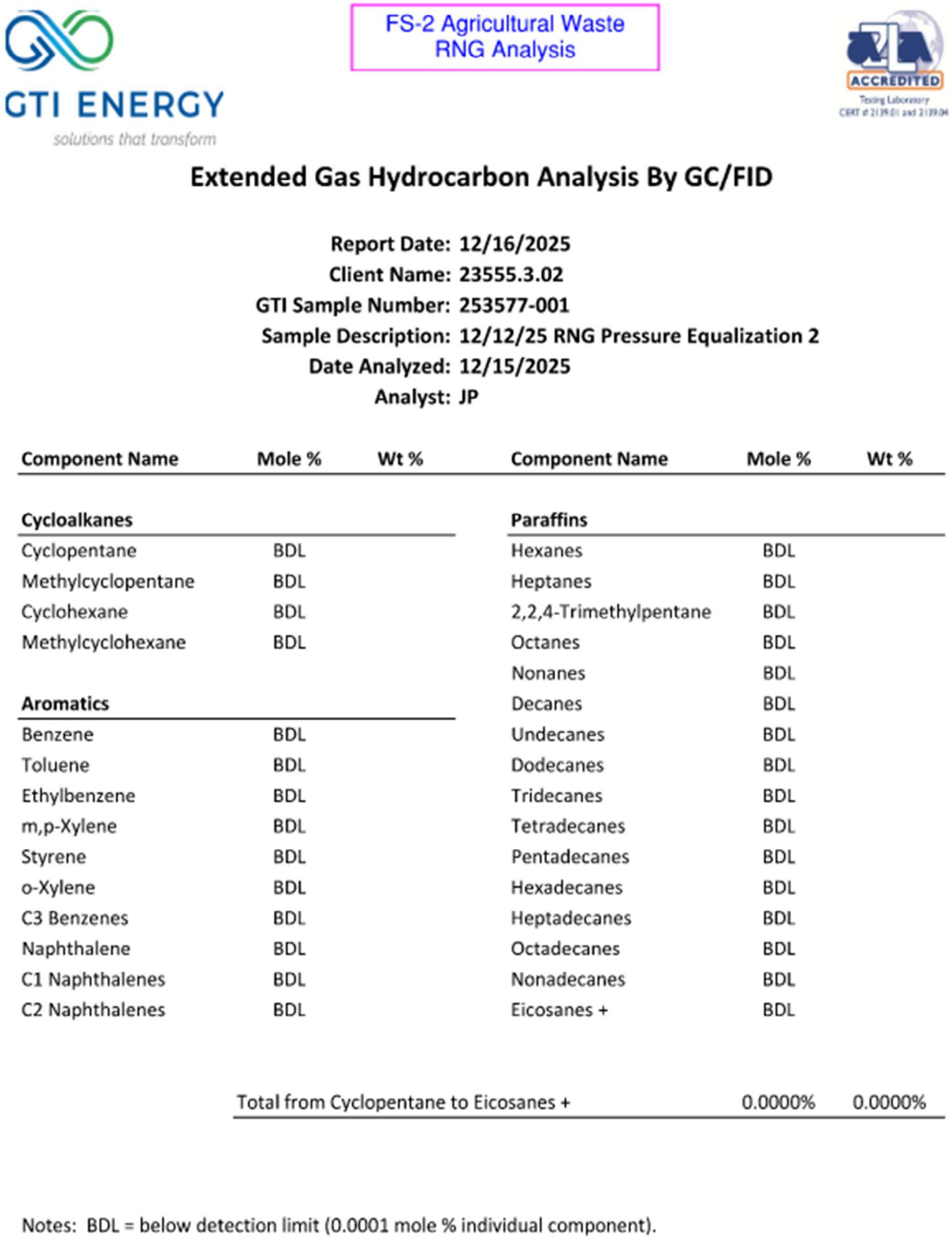

FS-2 Agricultural Waste
RNG Analysis

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CERT # 2139.01 and 2139.04

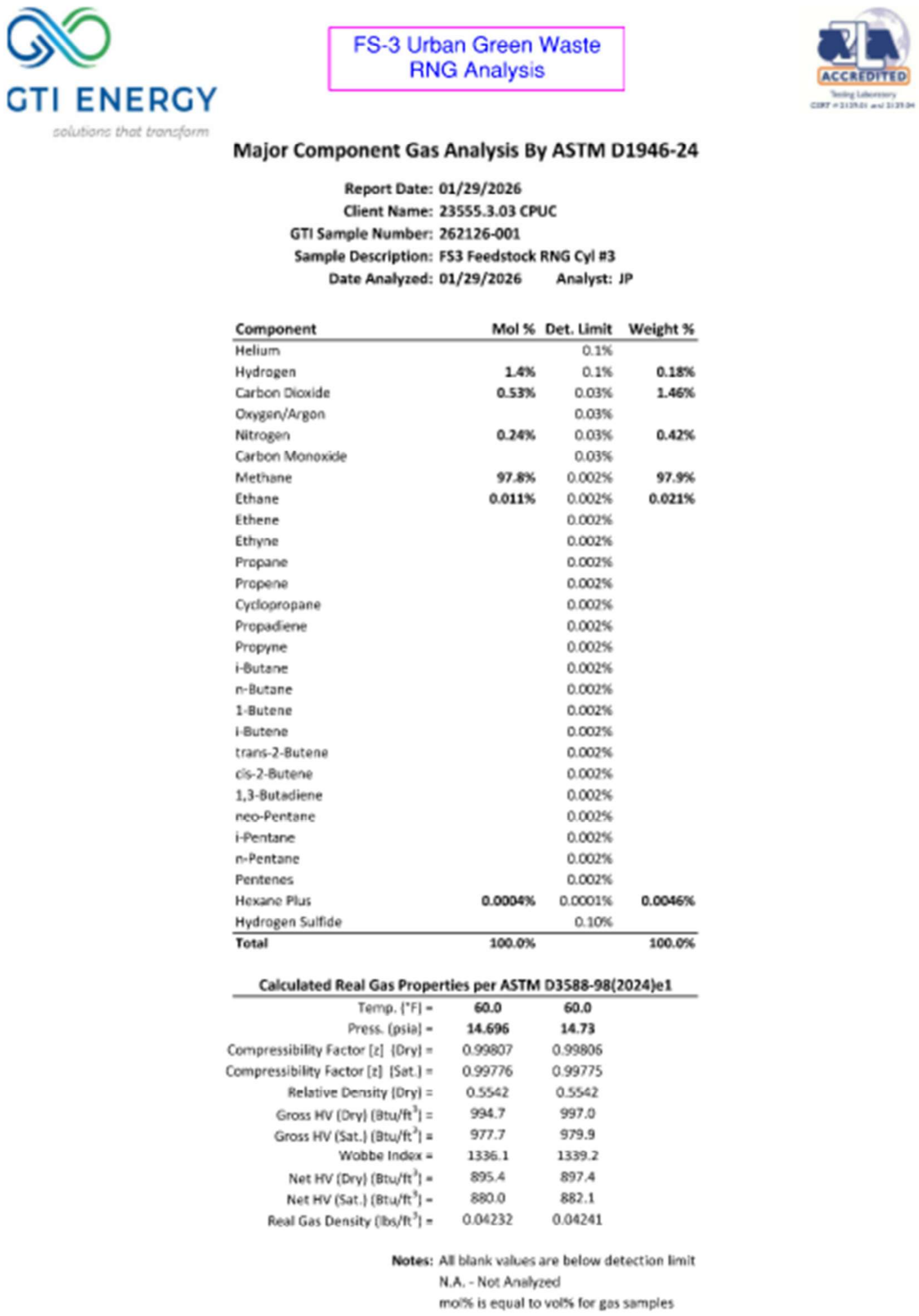
Extended Gas Hydrocarbon Analysis By GC/FID

Report Date: 12/16/2025
Client Name: 23555.3.02
GTI Sample Number: 253577-001
Sample Description: 12/12/25 RNG Pressure Equalization 2
Date Analyzed: 12/15/2025
Analyst: JP

Component Name	Mole %	Wt %	Component Name	Mole %	Wt %
Cycloalkanes			**Paraffins**		
Cyclopentane	BDL		Hexanes	BDL	
Methylcyclopentane	BDL		Heptanes	BDL	
Cyclohexane	BDL		2,2,4-Trimethylpentane	BDL	
Methylcyclohexane	BDL		Octanes	BDL	
			Nonanes	BDL	
Aromatics			Decanes	BDL	
Benzene	BDL		Undecanes	BDL	
Toluene	BDL		Dodecanes	BDL	
Ethylbenzene	BDL		Tridecanes	BDL	
m,p-Xylene	BDL		Tetradecanes	BDL	
Styrene	BDL		Pentadecanes	BDL	
o-Xylene	BDL		Hexadecanes	BDL	
C3 Benzenes	BDL		Heptadecanes	BDL	
Naphthalene	BDL		Octadecanes	BDL	
C1 Naphthalenes	BDL		Nonadecanes	BDL	
C2 Naphthalenes	BDL		Eicosanes +	BDL	

	Mole %	Wt %
Total from Cyclopentane to Eicosanes +	0.0000%	0.0000%

Notes: BDL = below detection limit (0.0001 mole % individual component).



FS-3 Urban Green Waste
RNG Analysis

Major Component Gas Analysis By ASTM D1946-24

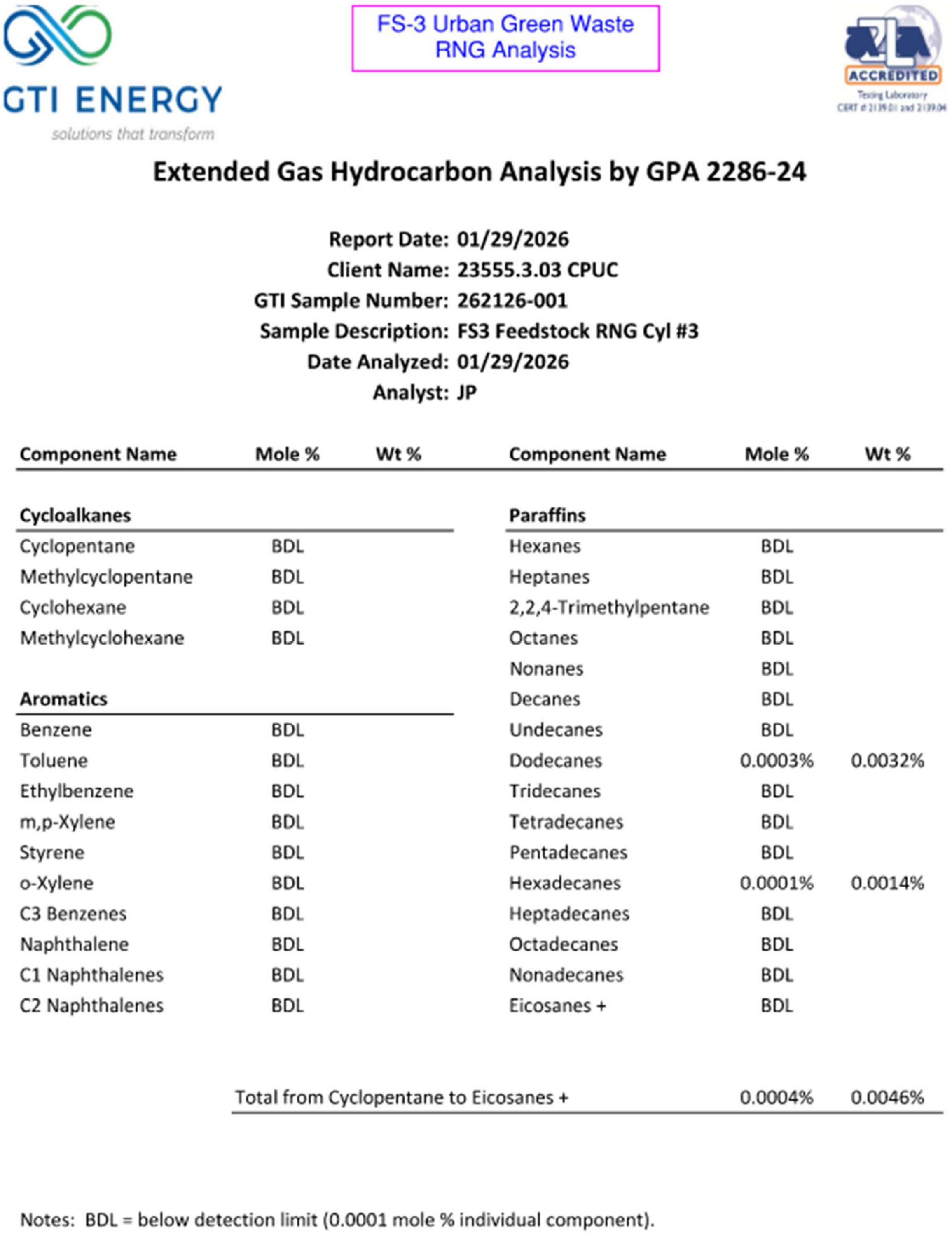
Report Date: 01/29/2026
Client Name: 23555.3.03 CPUC
GTI Sample Number: 262126-001
Sample Description: FS3 Feedstock RNG Cyl #3
Date Analyzed: 01/29/2026 **Analyst:** JP

Component	Mol %	Det. Limit	Weight %
Helium		0.1%	
Hydrogen	**1.4%**	0.1%	**0.18%**
Carbon Dioxide	**0.53%**	0.03%	**1.46%**
Oxygen/Argon		0.03%	
Nitrogen	**0.24%**	0.03%	**0.42%**
Carbon Monoxide		0.03%	
Methane	**97.8%**	0.002%	**97.9%**
Ethane	**0.011%**	0.002%	**0.021%**
Ethene		0.002%	
Ethyne		0.002%	
Propane		0.002%	
Propene		0.002%	
Cyclopropane		0.002%	
Propadiene		0.002%	
Propyne		0.002%	
i-Butane		0.002%	
n-Butane		0.002%	
1-Butene		0.002%	
i-Butene		0.002%	
trans-2-Butene		0.002%	
cis-2-Butene		0.002%	
1,3-Butadiene		0.002%	
neo-Pentane		0.002%	
i-Pentane		0.002%	
n-Pentane		0.002%	
Pentenes		0.002%	
Hexane Plus	**0.0004%**	0.0001%	**0.0046%**
Hydrogen Sulfide		0.10%	
Total	**100.0%**		**100.0%**

Calculated Real Gas Properties per ASTM D3588-98(2024)e1

Temp. (°F) =	**60.0**	**60.0**
Press. (psia) =	**14.696**	**14.73**
Compressibility Factor [z] (Dry) =	0.99807	0.99806
Compressibility Factor [z] (Sat.) =	0.99776	0.99775
Relative Density (Dry) =	0.5542	0.5542
Gross HV (Dry) (Btu/ft^3) =	994.7	997.0
Gross HV (Sat.) (Btu/ft^3) =	977.7	979.9
Wobbe Index =	1336.1	1339.2
Net HV (Dry) (Btu/ft^3) =	895.4	897.4
Net HV (Sat.) (Btu/ft^3) =	880.0	882.1
Real Gas Density (lbs/ft^3) =	0.04232	0.04241

Notes: All blank values are below detection limit
N.A. - Not Analyzed
mol% is equal to vol% for gas samples



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FS-3 Urban Green Waste
RNG Analysis

Extended Gas Hydrocarbon Analysis by GPA 2286-24

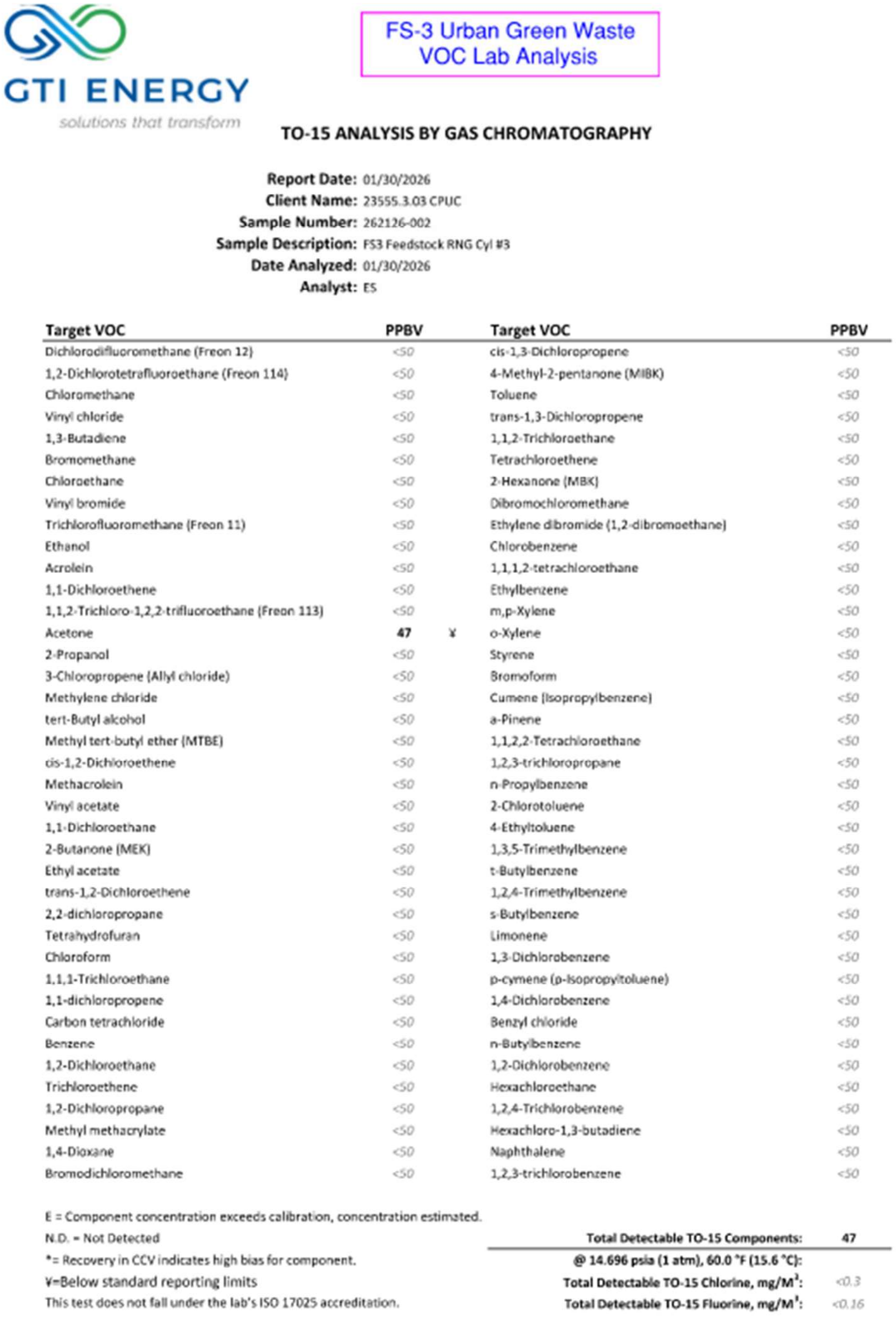
Report Date: **01/29/2026**
Client Name: **23555.3.03 CPUC**
GTI Sample Number: **262126-001**
Sample Description: **FS3 Feedstock RNG Cyl #3**
Date Analyzed: **01/29/2026**
Analyst: **JP**

Component Name	Mole %	Wt %	Component Name	Mole %	Wt %
Cycloalkanes			**Paraffins**		
Cyclopentane	BDL		Hexanes	BDL	
Methylcyclopentane	BDL		Heptanes	BDL	
Cyclohexane	BDL		2,2,4-Trimethylpentane	BDL	
Methylcyclohexane	BDL		Octanes	BDL	
			Nonanes	BDL	
Aromatics			Decanes	BDL	
Benzene	BDL		Undecanes	BDL	
Toluene	BDL		Dodecanes	0.0003%	0.0032%
Ethylbenzene	BDL		Tridecanes	BDL	
m,p-Xylene	BDL		Tetradecanes	BDL	
Styrene	BDL		Pentadecanes	BDL	
o-Xylene	BDL		Hexadecanes	0.0001%	0.0014%
C3 Benzenes	BDL		Heptadecanes	BDL	
Naphthalene	BDL		Octadecanes	BDL	
C1 Naphthalenes	BDL		Nonadecanes	BDL	
C2 Naphthalenes	BDL		Eicosanes +	BDL	

	Mole %	Wt %
Total from Cyclopentane to Eicosanes +	0.0004%	0.0046%

Notes: BDL = below detection limit (0.0001 mole % individual component).

APPENDIX D – VOC LAB ANALYSIS



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FS-3 Urban Green Waste
VOC Lab Analysis

TO-15 ANALYSIS BY GAS CHROMATOGRAPHY

Report Date: 01/30/2026
Client Name: 23555.3.03 CPUC
Sample Number: 262126-002
Sample Description: FS3 Feedstock RNG Cyl #3
Date Analyzed: 01/30/2026
Analyst: ES

Target VOC	PPBV		Target VOC	PPBV
Dichlorodifluoromethane (Freon 12)	<50		cis-1,3-Dichloropropene	<50
1,2-Dichlorotetrafluoroethane (Freon 114)	<50		4-Methyl-2-pentanone (MIBK)	<50
Chloromethane	<50		Toluene	<50
Vinyl chloride	<50		trans-1,3-Dichloropropene	<50
1,3-Butadiene	<50		1,1,2-Trichloroethane	<50
Bromomethane	<50		Tetrachloroethene	<50
Chloroethane	<50		2-Hexanone (MBK)	<50
Vinyl bromide	<50		Dibromochloromethane	<50
Trichlorofluoromethane (Freon 11)	<50		Ethylene dibromide (1,2-dibromoethane)	<50
Ethanol	<50		Chlorobenzene	<50
Acrolein	<50		1,1,1,2-tetrachloroethane	<50
1,1-Dichloroethene	<50		Ethylbenzene	<50
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113)	<50		m,p-Xylene	<50
Acetone	**47**	¥	o-Xylene	<50
2-Propanol	<50		Styrene	<50
3-Chloropropene (Allyl chloride)	<50		Bromoform	<50
Methylene chloride	<50		Cumene (Isopropylbenzene)	<50
tert-Butyl alcohol	<50		a-Pinene	<50
Methyl tert-butyl ether (MTBE)	<50		1,1,2,2-Tetrachloroethane	<50
cis-1,2-Dichloroethene	<50		1,2,3-trichloropropane	<50
Methacrolein	<50		n-Propylbenzene	<50
Vinyl acetate	<50		2-Chlorotoluene	<50
1,1-Dichloroethane	<50		4-Ethyltoluene	<50
2-Butanone (MEK)	<50		1,3,5-Trimethylbenzene	<50
Ethyl acetate	<50		t-Butylbenzene	<50
trans-1,2-Dichloroethene	<50		1,2,4-Trimethylbenzene	<50
2,2-dichloropropane	<50		s-Butylbenzene	<50
Tetrahydrofuran	<50		Limonene	<50
Chloroform	<50		1,3-Dichlorobenzene	<50
1,1,1-Trichloroethane	<50		p-cymene (p-Isopropyltoluene)	<50
1,1-dichloropropene	<50		1,4-Dichlorobenzene	<50
Carbon tetrachloride	<50		Benzyl chloride	<50
Benzene	<50		n-Butylbenzene	<50
1,2-Dichloroethane	<50		1,2-Dichlorobenzene	<50
Trichloroethene	<50		Hexachloroethane	<50
1,2-Dichloropropane	<50		1,2,4-Trichlorobenzene	<50
Methyl methacrylate	<50		Hexachloro-1,3-butadiene	<50
1,4-Dioxane	<50		Naphthalene	<50
Bromodichloromethane	<50		1,2,3-trichlorobenzene	<50

Total Detectable TO-15 Components:	**47**
@ 14.696 psia (1 atm), 60.0 °F (15.6 °C):	
Total Detectable TO-15 Chlorine, mg/M^3:	<0.3
Total Detectable TO-15 Fluorine, mg/M^3:	<0.16

E = Component concentration exceeds calibration, concentration estimated.
N.D. = Not Detected
*= Recovery in CCV indicates high bias for component.
¥=Below standard reporting limits
This test does not fall under the lab's ISO 17025 accreditation.

GLOSSARY

The following list of acronyms, abbreviations, and terms are applicable for this report:

Acronym or Term	Definition
AGR	Acid Gas Removal, a gas cleanup process used to remove CO_2 and sulfur containing species (e.g., H_2S) from syngas. *(Note: AGR was available but not operated during this operation.)*
BDL	Below Detection Limit, indicates that the component concentration was below the analytical detection limit of the measurement method.
CPUC	California Public Utilities Commission
FS-1	Feedstock 1, forest woody waste (forest residue feedstock).
FS-2	Feedstock 2, agricultural waste consisting of walnut shells sourced from California.
FS-3	Feedstock 3, urban green waste consisting of pine bark mulch.
GTI Energy	Institute of Gas Technology GTI Energy
GC/FID	Gas Chromatography with Flame Ionization Detection; analytical method used to quantify trace hydrocarbons and VOCs in gas samples.
GPA	Gas Processors Association standard/method.
HMI	Human Machine Interface; operator interface used to monitor and control system operation.
Methanation	Catalytic conversion of carbon oxides (CO and CO_2) with hydrogen (H_2) to form methane (CH_4) and water.
RNG	Renewable Natural Gas (biomass derived methane rich gas)
SLPM	Standard Liters per Minute, volumetric gas flow rate referenced to standard temperature and pressure conditions.
SNG	Synthetic natural gas
Syngas	Synthesis gas, gas mixture primarily composed of H_2, CO, CO_2, and CH_4 produced via biomass gasification.
VOC	Volatile Organic Compound; carbon-containing compounds that readily vaporize and may be regulated due to environmental or health impacts.
Wobbe Number	Fuel gas quality index defined as the heating value divided by the square root of specific gravity, used to assess interchangeability of fuel gases; reported on a dry basis per ASTM D3588.

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End of Report