MEASUREMENT & VERIFICATION REPORT

IPMVP Option B — Retrofit Isolation, All Parameter Measurement

Document no.	VX-MV-2026-002 · Rev A
Project	Northline Foods — 6 t/h LPG-fired steam boiler, DXL two-stage — condensing heat recovery (CHR)
Client	Energy Service Company (ESCO) and plant owner
Prepared by	Vegax Energy — NCK Group LLC
M&V period	Baseline 12 months; reporting period 12 months
Status	Issued for acceptance

Verified saving	8.46 % ± 1.0 % of baseline fuel energy
Annual value	USD 338,049 per year (baseline fuel cost USD 3,995,788)
Recommended guarantee	7.46 % — USD 298,086 per year
Method	IPMVP Volume I, Option B — retrofit isolation, all parameters measured

This document is the English version of the report. A Vietnamese version is issued separately; the two versions are equally authentic and, in case of interpretation dispute, the measurement data and formulae (identical in both) prevail.

Document control

Rev	Date	Description	Prepared by	Approved by
A	2026-11-24	Issued for acceptance	Vegax Energy	—
		Next review: on completion of the reporting period		

1. Executive summary

This report documents the measurement and verification of savings from a boiler-house retrofit consisting of a condensing heat-recovery unit (CHR) installed downstream of the existing feedwater economizer. M&V follows IPMVP Option B (retrofit isolation with all parameter measurement) with continuous interval data.

Verified fuel saving is 8.46 % ± 1.0 % of baseline fuel energy. At a baseline fuel cost of USD 3,995,788/year, this equals USD 338,049/year. The conservative claim (verified saving minus one standard uncertainty) is 7.46 % = USD 298,086/year, which is the value recommended for contractual guarantee purposes.

Item	Value	Basis
Baseline thermal efficiency	81.93 % (HHV)	12-month baseline, corrected to standard conditions
Reporting-period efficiency	89.50 % (HHV)	Same tag set, continuous measurement
Verified saving	8.46 % of fuel energy	Option B, interval data, adjusted
Uncertainty (95 % confidence)	± 1.0 %	Combined measurement + modelling uncertainty
Baseline fuel cost	USD 3,995,788 / year	LPG at USD 26.70/MMBtu = USD 1.26/kg (HHV basis)
Fuel	LPG (commercial propane / butane), HHV 49.6 MJ/kg = 47.01 MMBtu/t	Measured by mass flow; the same fuel and the same price basis in all three sample reports
Verified annual saving	USD 338,049 / year	Saving × baseline cost
Recommended guaranteed value	7.46 % — USD 298,086 / year	Verified saving − 1σ

2. Project description and energy conservation measure (ECM)

The plant operates a 6 t/h LPG-fired steam boiler at an average load of 100 % and 8,000 operating hours per year. Baseline stack temperature was 186.9 °C, indicating recoverable sensible and latent heat. The ECM is a condensing heat-recovery unit that preheats make-up water and then feedwater, cooling flue gas to approximately 50 °C.

Parameter	Baseline	Design (post-retrofit)
Steam capacity	6 t/h	6 t/h (unchanged)
Average load	100 %	100 %
Operating hours	8,000 h/year	8,000 h/year
Flue gas temperature in / out	186.9 °C / 186.9 °C	186.9 °C / 50.3 °C
Feedwater temperature in / out	29,8 °C / 29,8 °C	29,8 °C / 85,0 °C
Thermal efficiency (HHV)	81.93 %	89.50 % (verified)
Fuel input	5,482 kW	5,019 kW (equivalent)

3. M&V scope, boundary and option selection

Measurement boundary: boiler, burner, feedwater and make-up water system, flue-gas path and the installed heat-recovery unit. The steam distribution network downstream of the boiler outlet header and the production process are outside the boundary; steam exported across the boundary is measured and used as an independent variable.

Option	Description	Suitability for this project
A	Retrofit isolation, key parameter measurement	Rejected: fuel and steam flow dominate the result; estimating them is not defensible for a guarantee.
B	Retrofit isolation, all parameter measurement	SELECTED: savings attributable to the ECM, all drivers measured continuously, uncertainty quantifiable.
C	Whole facility	Rejected as primary: production changes mask the ECM effect; retained only as a cross-check.
D	Calibrated simulation	Rejected: adequate instrumentation exists; simulation adds model risk.

Option B is selected because the contract requires attributing savings to the ECM, because the measurement boundary is a discrete system that can be isolated with permanent instrumentation, and because a quantified uncertainty is required for the performance guarantee.

4. Baseline determination

4.1 Baseline period and data quality

The baseline covers 12 consecutive months preceding the retrofit, at 15-minute interval resolution. Data completeness is 98.4 %; missing intervals were gap-filled only where the gap is shorter than two hours and never for fuel-flow data. All data are stored with immutable timestamps and a hash chain for audit purposes.

4.2 Instrumentation

Tag	Measurement	Instrument / principle	Accuracy	Calibration interval
FT-101	Steam flow to process	Vortex / differential pressure	± 1.0 % of reading	12 months
FT-201	LPG flow	Thermal mass / rotary	± 1.0 % of reading	12 months
AI-301	Flue gas O_2	Zirconia in-situ analyser	± 0.2 % O_2 abs.	6 months
TE-401/402	Flue gas temperature in / out	Type K thermocouple, 4-wire	± 1.0 °C	12 months
TE-501/502	Water temperature in / out	PT100 4-wire RTD	± 0.3 °C	12 months
FT-601	Water flow (secondary side)	Electromagnetic	± 0.5 % of reading	12 months
GC-701	LPG composition / HHV	Laboratory analysis, monthly composite	± 0.3 % HHV	Monthly

4.3 Baseline model

Baseline fuel energy is modelled as a function of steam load, ambient temperature and fuel heating value, using ordinary least squares on 15-minute data aggregated to daily values:

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E_fuel_base = β0 + β1·S + β2·(T_amb − T_ref) + β3·HHV + ε
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Coefficient	Value	Std. error	Interpretation
β0	356 MMBtu/day	26	Fixed (standby) consumption
β1 (steam)	1.087 MMBtu per tonne	0.008	Marginal fuel per tonne of steam
β2 (ambient)	-1.5 MMBtu per °C·day	0.5	Seasonal correction
β3 (HHV)	-0.39 MMBtu per MJ/kg	0.12	Fuel quality correction
Model fit	R^2 = 0.93 · CV(RMSE) = 3.6 %	—	Accepted: CV(RMSE) < 5 % threshold
Baseline fuel energy	149,655 MMBtu/year	—	Cost USD 3,995,788 at USD 26.70/MMBtu

5. Reporting period measurement and adjustments

The reporting period uses the identical tag set and interval resolution. Two adjustment classes are applied:

- Routine adjustments — steam load, ambient temperature and fuel HHV, applied through the baseline model coefficients.
- Non-routine adjustments — documented changes in operation, fuel type, production schedule or equipment. Each event requires a written change log entry signed by both parties before the affected data are used.

No non-routine adjustment was required in this reporting period. Data availability was 99.1 % and all instruments were within calibration.

6. Savings calculation

Savings are computed at the measurement boundary, in energy units first and converted to currency using the contract fuel price. Heating values are stated on an HHV basis throughout; LHV values, where quoted by equipment suppliers, are converted before use.

Step	Formula	Result
1. Baseline fuel energy (adjusted)	E_base,adj = model(load, ambient, HHV)	149,655 MMBtu/year
2. Reporting fuel energy (measured)	E_rep = Σ fuel flow × HHV × Δt	136,994 MMBtu/year
3. Energy saving	E_sav = E_base,adj − E_rep	12,661 MMBtu/year
4. Saving as percentage	8.46 % of E_base,adj	8.46 %

Step	Formula	Result
5. Monetary saving	E_sav × 26.70 USD/MMBtu	USD 338,049/year
6. Conservative claim (−1σ)	7.46 % × baseline cost	USD 298,086/year

Rounding: percentages to two decimals, currency to the nearest USD 1. Intermediate values are carried unrounded; small differences of ±0.2 % may appear if recomputed from rounded inputs.

7. Uncertainty analysis

Uncertainty is estimated at 95 % confidence as the root-sum-square of independent contributions: instrument accuracy, calibration drift, data completeness, and baseline model error.

Source	Contribution (1σ)	Note
Steam flow measurement	0.60 %	± 1.0 % instrument, load-weighted
Fuel flow measurement	0.50 %	± 1.0 % instrument, corrected for pressure/temperature
Temperature measurements	0.30 %	Effect on enthalpy and gas-side heat balance
LPG analysis / HHV	0.30 %	Monthly composite samples
Baseline model (CV-RMSE)	0.50 %	Daily aggregation
Combined (RSS)	1.02 %	Reported as ± 1.0 %

Cross-check: the gas-side and water-side heat balances agree within 1.6 % for the heat-recovery unit (Appendix A4). Savings are therefore declared as 8.46 % ± 1.0 % (95 % confidence).

8. Roles and responsibilities

Activity	ESCO	Plant owner	M&V provider
Approve M&V plan	A	A	R
Provide fuel invoices and gas analysis	C	R	I
Maintain and calibrate instruments	I	R	C
Collect and validate interval data	I	C	R
Produce savings report	C	I	R
Accept report / raise dispute	R	R	I

R = responsible, A = accountable, C = consulted, I = informed.

9. Data quality rules and fail-closed conditions

- Data completeness below 90 % in a reporting month ⇒ the month is not used for savings declaration; the period is extended.
- Any instrument found outside calibration ⇒ affected data are invalidated retrospectively and the saving is recalculated.
- Heat-balance closure worse than 3 % on a whole-unit basis ⇒ no savings are declared until the cause is resolved.
- Savings are never rounded upwards, and no saving is declared when the measured saving is smaller than the combined uncertainty.
- Raw data, calibration certificates and the change log are retained for the full contract term plus five years, and are available to third parties on request through a read-only data feed.

10. Reporting schedule

Deliverable	Frequency	Due
M&V plan	Once, before retrofit	Signed prior to construction
Monthly data quality statement	Monthly	10th of the following month
Interim savings report	Quarterly	15 days after quarter end
Annual verification report	Annual	30 days after period end
Reconciliation with utility invoices	Annual	With annual report

11. Application A — ESCO performance contract

Under the ESCO contract this report is the settlement instrument. The plant owner invests nothing: the ESCO buys, owns and installs the condensing heat-recovery unit in the stack, and is paid only out of the saving that the meters prove. The guaranteed value is a floor that protects the plant owner, not the reference for sharing:

Element	Value / rule
Guaranteed saving (contract floor, 7 % design)	7.0 % of baseline fuel cost = USD 279,705/year
Verified saving	8.46 % ± 1.0 % = USD 338,049/year
Capital and ownership	ESCO — build, own, operate, transfer. The plant owner invests nothing and provides no security; the unit stays ESCO property until transfer
Shared saving	70 % ESCO / 30 % plant owner of the full verified saving measured against the baseline — not only of the surplus above the guaranteed value
Annual settlement at the verified saving	ESCO USD 236,634 · plant owner USD 101,415
Term and transfer	5 years from acceptance. At the end of year 5 title to the unit passes to the plant owner at nominal value, and the plant owner keeps 100 % of the saving from year 6 onward
Shortfall mechanism	If verified saving < guaranteed, ESCO pays the difference, capped at the annual M&V fee × 3
Financing	Green-loan financed by the ESCO; the savings receivable is assigned to the lender under a tripartite agreement between plant owner, lender and ESCO
M&V fee	USD 12,000/year (3.5 % of verified saving) — borne by the ESCO out of its 70 % share; no cost to the plant owner
Adjustment triggers	Load change > 15 %, fuel change, or > 30 days downtime — re-baselined by written agreement

This structure avoids the industry failure mode of over-claiming: typical ESCO guarantees of 25–40 % for steam systems are not physically reachable from a 82 % HHV baseline, where the theoretical ceiling is about 95 %.

12. Application B — plant owner (internal accounting, ISO 50001)

For the plant owner the report is the evidence base for the energy management system and for capital-expenditure justification. Savings are reported as an energy performance indicator (EnPI) per tonne of steam, so that production changes do not distort the trend.

Element	Value / rule
EnPI	GJ fuel per tonne of steam; baseline 3,29, reporting 3,01
Reporting basis	Calendar month, corrected to reference ambient temperature
Use in ISO 50001	Documented as a significant energy use with verified improvement
Budget justification	Verified USD 338,049/year against capex; simple payback 8.2 months
Internal audit trail	Same data set, read-only export, retained 5 years

13. Limitations and assumptions

- Savings are valid only for the measured load, ambient and fuel-quality envelope; extrapolation outside it requires re-baselining.
- The measurement boundary excludes steam distribution losses; improvements there are not credited to this ECM.
- Fuel price is fixed contractually at USD 26.70/MMBtu; price variation affects monetary, not energy, savings.
- No account is taken of interactive effects between this ECM and future measures; combined savings are not additive and must be computed sequentially.

14. Statement of verification

The undersigned confirm that the measurement and verification described in this report was carried out in accordance with IPMVP Volume I, Option B, and that the verified saving for the reporting period is 8.46 % ± 1.0 % of baseline fuel energy, corresponding to USD 338,049 per year.

ESCO representative	Plant owner	M&V provider (Vegax Energy)
(signature)	(signature)	(signature)

APPENDIX — MEASUREMENT DATA AND CALCULATIONS

Evidence of baseline (before) and post-retrofit (after HR installation) performance

This appendix contains the raw measurement basis for the verification: the instrument register, the 12-month baseline and reporting-period data, the heat-balance test of the heat-recovery unit, the efficiency worksheet, the savings worksheet, and an interval data sample. Every figure in the main report can be recomputed from these tables.

Appendix A1 — Instrument and calibration register

Tag	Service	Range	Accuracy	Last calibration	Deviation found	Next due
FT-101	Steam flow	0–7 t/h	±1.0 % RD	2026-02-14	+0.35 %	2027-02-14
FT-201	LPG flow	0–2,500 kg/h	±1.0 % RD	2026-02-11	−0.22 %	2027-02-11
AI-301	Flue gas O_2	0–21 % O_2	±0.2 % abs.	2026-03-02	+0.06 % O_2	2026-09-02
TE-401	Flue gas in	0–600 °C	±1.0 °C	2026-02-20	+0.4 °C	2027-02-20
TE-402	Flue gas out	0–300 °C	±1.0 °C	2026-02-20	−0.3 °C	2027-02-20
TE-501/502	Water in / out	0–150 °C	±0.3 °C	2026-02-20	+0.1 / −0.1 °C	2027-02-20
FT-601	Water flow	0–15 m^3/h	±0.5 % RD	2026-02-18	+0.18 %	2027-02-18
GC-701	LPG HHV (lab)	48.5–50.5 MJ/kg	±0.3 %	Monthly composite	±0.12 %	Monthly

Appendix A2 — Baseline period data (before retrofit)

Month	Steam (t)	Fuel (MMBtu)	η HHV (%)	Flue gas out (°C)	Completeness (%)
Jan	4,347	13,412	82.80	186.7	99.1
Feb	3,811	11,852	82.13	186.9	98.8
Mar	4,190	13,049	82.03	187.4	99.4
Apr	3,891	12,177	81.63	187.7	98.2
May	3,874	12,153	81.43	187.2	97.9
Jun	3,595	11,293	81.33	186.8	98.6
Jul	4,072	12,712	81.83	187.3	99.0
Aug	4,081	12,726	81.93	187.5	98.4
Sep	3,883	12,167	81.53	187.0	97.8
Oct	4,072	12,682	82.03	187.1	99.2
Nov	3,996	12,430	82.13	187.3	99.1
Dec	4,185	13,001	82.23	186.8	96.7
Total / weighted	48,000	149,655	81.93	—	98.4

Baseline fuel energy 149,655 MMBtu at USD 26.70/MMBtu = USD 3,995,788 per year. Steam energy is computed from measured steam flow and an enthalpy rise of 2,695 kJ/kg. The flue-gas outlet column confirms that no heat recovery was in service during the baseline: the stack ran at design temperature all year.

Appendix A3 — Reporting period data (after HR installation)

Month	Steam (t)	Fuel (MMBtu)	η HHV (%)	Flue gas out (°C)	Completeness (%)
Jan	4,347	12,515	88.74	50.1	99.4
Feb	3,811	10,804	90.10	50.5	99.0
Mar	4,190	11,907	89.90	50.3	99.6
Apr	3,891	11,131	89.30	50.6	98.8
May	3,874	11,107	89.10	50.5	98.4
Jun	3,595	10,331	88.90	50.2	99.1
Jul	4,072	11,610	89.60	50.3	99.3
Aug	4,081	11,623	89.70	50.6	98.9
Sep	3,883	11,121	89.20	50.0	98.2
Oct	4,072	11,623	89.50	50.3	99.5
Nov	3,996	11,356	89.90	50.5	99.2
Dec	4,185	11,866	90.10	50.6	98.6
Total / weighted	48,000	136,994	89.50	—	99.1

Steam output is unchanged month by month (same production); the reduction in fuel is the measured effect of the heat-recovery unit. Flue gas outlet temperature is the control value confirming the unit operated within design all year.

Appendix A4 — Heat balance test of the heat recovery unit

Test conditions: steady load, heat-recovery unit in service, bypass closed. Gas-side heat has two components — sensible heat from cooling the flue gas, and latent heat from condensing part of the water vapour. Water-side heat is computed from measured water flow and temperature rise. The two must agree within the stated uncertainty for the test to be valid.

Quantity	Symbol	DXL — two stage
Flue gas in / out	T_in / T_out	186.9 / 50.3 °C
Flue gas mass flow	m_gas	2.05 kg/s
Sensible heat	Q_sens = m·cp·ΔT	293.6 kW
Condensate flow	m_cond	251 kg/h
Latent heat	Q_lat = m_cond·h_fg	170.3 kW
Gas-side heat total	Q_gas	463.8 kW
Water flow	m_w	7,240 kg/h
Water in / out	T_w,in / T_w,out	29.8 / 85.0 °C
Water-side heat	Q_water = m·cp·ΔT	463.6 kW
Balance closure	|Q_gas − Q_water| / Q	0.05 %

Of the 463.8 kW recovered in the plant test, 170.3 kW (37 %) comes from condensing flue-gas water vapour — this is why the gas leaves at 50.3 °C, below the 54.6 °C water dew point. Reference boiler UB-04 (6 t/h), metered on Pulse at its rating: 6,000 kg/h steam, flue 186.9 °C in / 50.3 °C out, water 29.83 → 85.0 °C, 463.8 kW recovered, 8.46 % of fuel. The two-stage unit splits the duty between stage 2 (cold water) and stage 1 (hot water, to 85.0 °C).

Appendix A5 — Efficiency worksheet (before vs after)

Step	Formula	Baseline (before)	Reporting (after)
Steam flow	measured FT-101	6,000 kg/h	6,000 kg/h
Enthalpy rise	h_steam − h_fw	2,695 kJ/kg	2,695 kJ/kg
Steam energy	Q_steam = m × Δh	4,492 kW	4,492 kW
Fuel energy	Q_fuel = F × HHV	5,482 kW	5,019 kW
Thermal efficiency	η = Q_steam / Q_fuel	81.93 %	89.50 %
Improvement	Δη	—	+7.57 percentage points

Efficiency is stated on an HHV basis for both periods, using the same LPG analysis method. Expressed as fuel saving rather than efficiency points, the result is 1 − 5,019 / 5,482 = 8.46 %.

Appendix A6 — Savings worksheet

Item	Calculation	Value
Baseline fuel (adjusted)	model output, Appendix A2	149,655 MMBtu
Reporting fuel (measured)	Appendix A3	136,994 MMBtu
Energy saving	149,655 − 136,994	12,661 MMBtu
Saving ratio	12,661 / 149,655	8.46 %
Monetary saving	12,661 × USD 26.70	USD 338,049
Uncertainty (95 %)	RSS of contributions, §7	± 1.0 %
Conservative claim	8.46 % − 1.0 %	7.46 % = USD 298,086

Appendix A7 — Interval data sample (15-minute)

Time	Steam (kg/h)	LPG (kg/h)	O_2 (%)	Flue in (°C)	Flue out (°C)	η (%)
2026-10-14 10:00	6,072	400	3.1	186.9	50.1	89.3
2026-10-14 10:15	6,024	398	3.0	187.1	50.3	89.6
2026-10-14 10:30	6,096	401	3.2	186.8	50.2	89.4
2026-10-14 10:45	5,994	395	3.0	187.2	50.6	89.5
2026-10-14 11:00	6,042	398	3.1	186.9	50.4	89.5
2026-10-14 11:15	6,078	399	3.1	187.0	50.5	89.4

Appendix A8 — Non-routine adjustment log

Date	Event	Effect on baseline	Agreed by
—	No non-routine adjustment in this reporting period	None	ESCO / owner