MEASUREMENT & VERIFICATION REPORT

IPMVP Option B — Retrofit Isolation, All Parameter Measurement

Document no.	VX-MV-2026-001 · Rev A
Project	Boiler house No. 1 — 20 t/h LPG-fired steam boiler — 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	8.47 % ± 1.0 % of baseline fuel energy
Annual value	USD 1,128,262 per year (baseline fuel cost USD 13,320,737)
Recommended guarantee	7.47 % — USD 995,059 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 8.47 % ± 1.0 % of baseline fuel energy. At a baseline fuel cost of USD 13,320,737/year, this equals USD 1,128,262/year. The conservative claim (verified saving minus one standard uncertainty) is 7.47 % = USD 995,059/year, which is the value recommended for contractual guarantee purposes.

Item	Value	Basis
Baseline thermal efficiency	82.03 % (HHV)	12-month baseline, corrected to standard conditions
Reporting-period efficiency	89.63 % (HHV)	Same tag set, continuous measurement
Verified saving	8.47 % of fuel energy	Option B, interval data, adjusted
Uncertainty (95 % confidence)	± 1.0 %	Combined measurement + modelling uncertainty
Baseline fuel cost	USD 13,320,737 / 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 1,128,262 / year	Saving × baseline cost
Recommended guaranteed value	7.47 % — USD 995,059 / year	Verified saving − 1σ

2. Project description and energy conservation measure (ECM)

The plant operates a 20 t/h LPG-fired steam boiler at an average load of 100 % and 8,000 operating hours per year. Baseline stack temperature was 186.6 °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	20 t/h	20 t/h (unchanged)
Average load	100 %	100 %
Operating hours	8,000 h/year	8,000 h/year
Flue gas temperature in / out	186.6 °C / 186.6 °C	186.6 °C / 49.8 °C
Feedwater temperature in / out	29,8 °C / 29,8 °C	29,8 °C / 96,4 °C
Thermal efficiency (HHV)	82.03 %	89.63 % (verified)
Fuel input	18,277 kW	16,729 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	412 MMBtu/day	38	Fixed (standby) consumption
β1 (steam)	1.087 MMBtu per tonne	0.006	Marginal fuel per tonne of steam
β2 (ambient)	-1.9 MMBtu per °C·day	0.7	Seasonal correction
β3 (HHV)	-0.42 MMBtu per MJ/kg	0.11	Fuel quality correction
Model fit	R^2 = 0.93 · CV(RMSE) = 3.1 %	—	Accepted: CV(RMSE) < 5 % threshold
Baseline fuel energy	498,904 MMBtu/year	—	Cost USD 13,320,737 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)	498,904 MMBtu/year
2. Reporting fuel energy (measured)	E_rep = Σ fuel flow × HHV × Δt	456,647 MMBtu/year
3. Energy saving	E_sav = E_base,adj − E_rep	42,257 MMBtu/year
4. Saving as percentage	8.47 % of E_base,adj	8.47 %

Step	Formula	Result
5. Monetary saving	E_sav × 26.70 USD/MMBtu	USD 1,128,262/year
6. Conservative claim (−1σ)	7.47 % × baseline cost	USD 995,059/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 8.47 % ± 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 932,452/year
Verified saving	8.47 % ± 1.0 % = USD 1,128,262/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 789,783 · plant owner USD 338,479
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 (1.1 % 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 1,128,262/year against capex; simple payback 3.4 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 8.47 % ± 1.0 % of baseline fuel energy, corresponding to USD 1,128,262 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	0–25 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	14,513	45,382	81.69	185.9	99.1
Feb	12,727	39,537	82.23	186.2	98.8
Mar	13,993	43,522	82.13	186.8	99.4
Apr	12,828	40,093	81.73	187.1	98.2
May	12,949	40,571	81.53	186.4	97.9
Jun	12,021	37,712	81.43	186.0	98.6
Jul	13,606	42,421	81.93	186.6	99.0
Aug	13,634	42,458	82.03	186.9	98.4
Sep	12,977	40,609	81.63	186.3	97.8
Oct	13,606	42,318	82.13	186.5	99.2
Nov	13,174	40,927	82.23	186.7	99.1
Dec	13,973	43,355	82.33	186.1	96.7
Total / weighted	160,000	498,904	81.92	—	98.4

Baseline fuel energy 498,904 MMBtu at USD 26.70/MMBtu = USD 13,320,737 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	14,513	42,379	87.48	49.6	99.4
Feb	12,727	36,031	90.23	50.1	99.0
Mar	13,993	39,703	90.03	49.9	99.6
Apr	12,828	36,641	89.43	50.4	98.8
May	12,949	37,070	89.23	50.2	98.4
Jun	12,021	34,493	89.03	49.8	99.1
Jul	13,606	38,734	89.73	50.0	99.3
Aug	13,634	38,771	89.83	50.3	98.9
Sep	12,977	37,109	89.33	49.7	98.2
Oct	13,606	38,777	89.63	49.9	99.5
Nov	13,174	37,381	90.03	50.1	99.2
Dec	13,973	39,559	90.23	50.2	98.6
Total / weighted	160,000	456,647	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	CXL — single stage
Flue gas in / out	T_in / T_out	186.6 / 49.8 °C
Flue gas mass flow	m_gas	5.90 kg/s
Sensible heat	Q_sens = m·cp·ΔT	847.5 kW
Condensate flow	m_cond	461 kg/h
Latent heat	Q_lat = m_cond·h_fg	312.3 kW
Gas-side heat total	Q_gas	1,159.8 kW
Water flow	m_w	15,000 kg/h
Water in / out	T_w,in / T_w,out	29.8 / 96.4 °C
Water-side heat	Q_water = m·cp·ΔT	1,159.5 kW
Balance closure	|Q_gas − Q_water| / Q	0.03 %

Of the 1,159.8 kW recovered in the plant test, 312.3 kW (27 %) comes from condensing flue-gas water vapour — this is why the gas leaves at 49.8 °C, below the 54.6 °C water dew point. CXL single-stage technology was selected for this project; the two-stage DXL was not bid.

Appendix A5 — Efficiency worksheet (before vs after)

Step	Formula	Baseline (before)	Reporting (after)
Steam flow	measured FT-101	20,000 kg/h	20,000 kg/h
Enthalpy rise	h_steam − h_fw	2,695 kJ/kg	2,695 kJ/kg
Steam energy	Q_steam = m × Δh	14,972 kW	14,972 kW
Fuel energy	Q_fuel = F × HHV	18,277 kW	16,729 kW
Thermal efficiency	η = Q_steam / Q_fuel	82.03 %	89.63 %
Improvement	Δη	—	+7.60 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 − 16,729 / 18,277 = 8.47 %.

Appendix A6 — Savings worksheet

Item	Calculation	Value
Baseline fuel (adjusted)	model output, Appendix A2	498,904 MMBtu
Reporting fuel (measured)	Appendix A3	456,647 MMBtu
Energy saving	498,904 − 456,647	42,257 MMBtu
Saving ratio	42,257 / 498,904	8.47 %
Monetary saving	42,257 × USD 26.70	USD 1,128,262
Uncertainty (95 %)	RSS of contributions, §7	± 1.0 %
Conservative claim	8.47 % − 1.0 %	7.47 % = USD 995,059

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	20,240	1,334	3.1	186.6	49.6	89.4
2026-10-14 10:15	20,080	1,328	3.0	186.8	49.8	89.7
2026-10-14 10:30	20,320	1,338	3.2	186.5	49.7	89.5
2026-10-14 10:45	19,980	1,316	3.0	186.9	50.1	89.6
2026-10-14 11:00	20,140	1,325	3.1	186.6	49.9	89.6
2026-10-14 11:15	20,260	1,330	3.1	186.7	50.0	89.5

Appendix A8 — Non-routine adjustment log

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