# DEVELOPMENT OF COST-EFFECTIVE FLARING MITIGATION OPPORTUNITIES

## MITIGATION OF BLACK CARBON AND METHANE EMISSIONS

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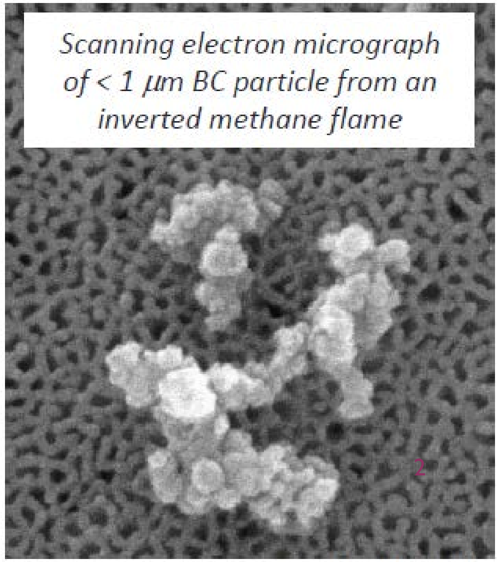
Presented at: CCAC Webinar

# BACKGROUND

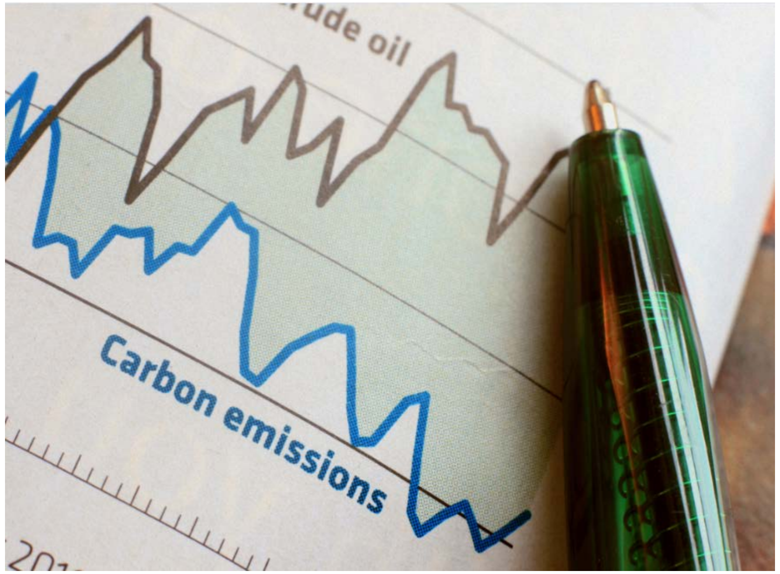
- Flare-generated pollutant emissions from the energy Industry are a significant global concern.
- Satellite data indicate 140 billion $m^3$ of gas flared annually (Elvidge et al., 2009).
- Pollutants of concern:
  - **Black carbon** (BC) [**GWP = 900**, IPCC AR5]
    - **2nd most important climate forcer after $CO_2$**.
    - **Very short atmospheric lifetime** (order of days to weeks), which offers **quick environmental payback on mitigation**.
    - **Mostly** caused by **incomplete combustion** of heavier HC components (e.g., **$C_3$, $C_4$ and $C_5$+).**
    - Component of fine particulate matter (**$PM_{2.5}$**)
    - Causal link with **lung cancer** and **cardiovascular mortality**.
  - Un-combusted methane (GWP = 34, IPCC AR5)
  - VOCs.
  - $CO_2$ [GWP = 1] [emissions equivalent to 77 million cars]



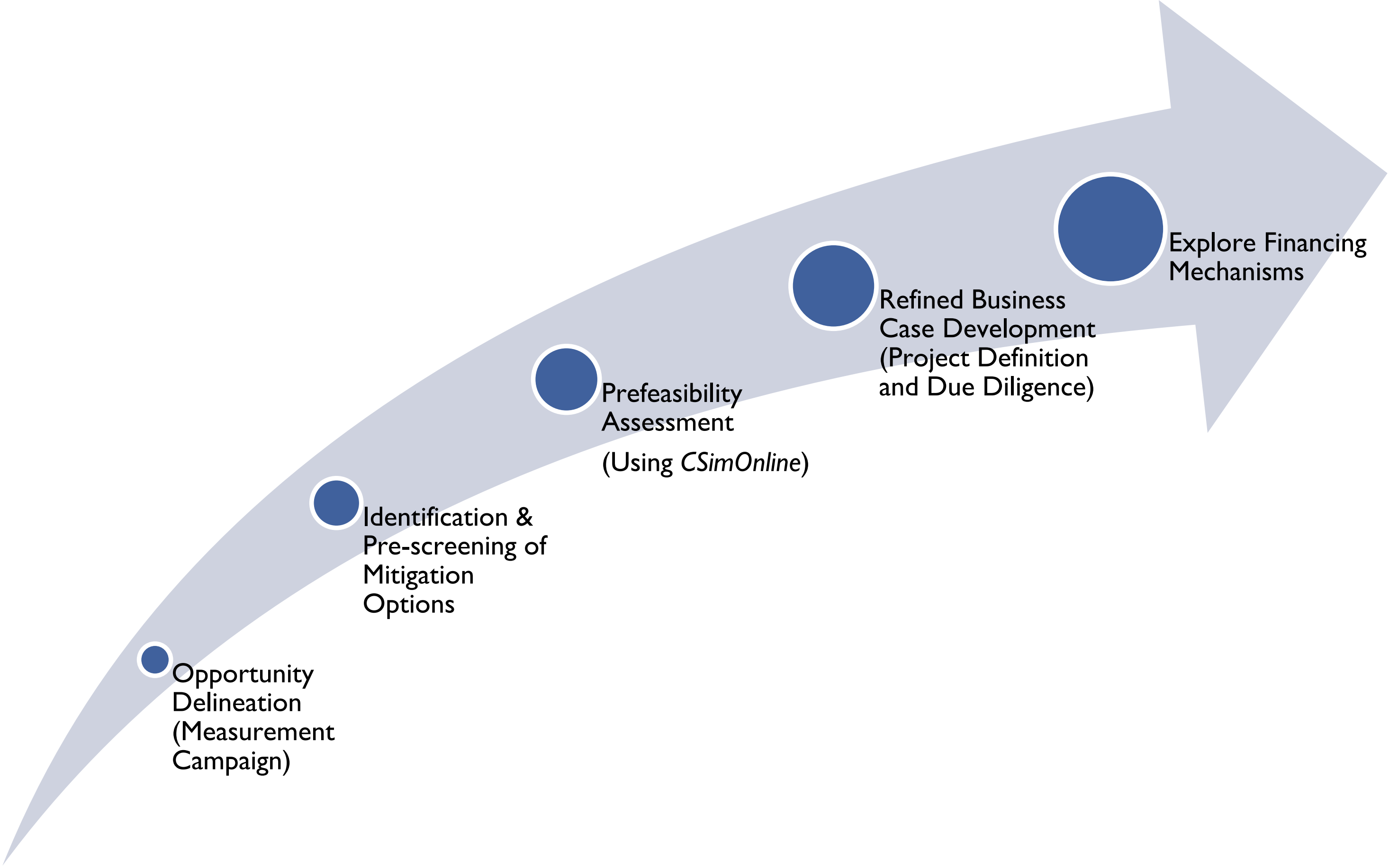
*Scanning electron micrograph of < 1 µm BC particle from an inverted methane flame*

# OBJECTIVES OF THE CCAC COLLABORATION

- Identify **high-impact** opportunities to **cost-effectively** achieve significant flaring **emission reductions**:
  - On an individual or highly replicable basis.
- Assess baseline emissions (SLCPs, GHGs and CACs), and reduction potential.
- Conduct a prefeasibility assessment of the applicable mitigation options to determine the best choice.
- Advance at least 2 of the projects to a refined business-case stage.
- If warranted, work with operators to identify financing mechanisms.

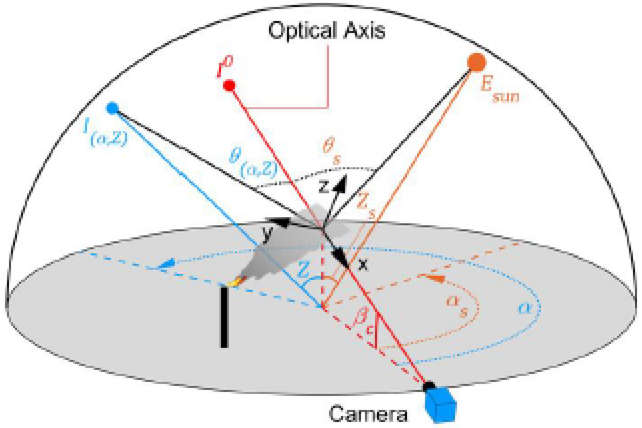


# COLLABORATION WORKFLOW



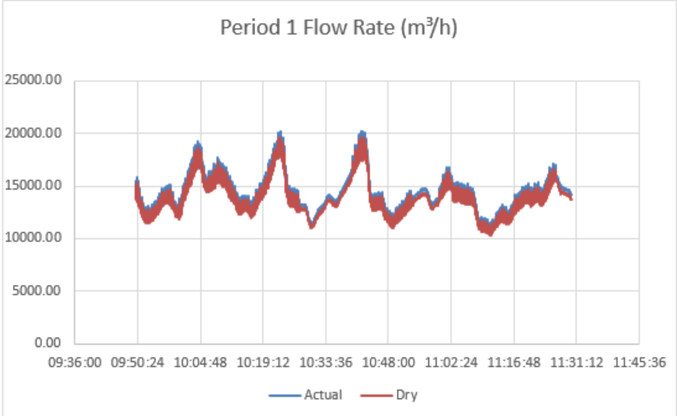
# MEASUREMENT PROGRAM

- **Eight sites surveyed** (2 from one operator and 6 from another) in 3 different regions.
- Inline **tracer tests** performed to accurately **assess flaring rates** and variability.
- **Sampling & laboratory analysis** of **flare gas, inlet oil, sales oil & solvent**.
- BC emission measurements were performed by **NRCan research team** using **Sky-LOSA**.




*Schematic of a sky-LOSA measurement*

**Tracer Test Results: Flare Gas Flow Rate Trend Data**




Period 1 Gas Composition Selection
- ○ Period 1 Composition
- ○ Full Accepted Range Composition
- ● Lab Measured Composition

| Property | Value | |
|---|---|---|
| | Actual | Dry |
| Average Flow Rate (m³/h) | 14267.33 | 13847.40 |
| Minimum Flow Rate (m³/h) | 10565.41 | 10254.43 |
| Maximum Flow Rate (m³/h) | 20220.46 | 19625.31 |
| Carbon Intensity (kg/m³) | 1.20 | 1.24 |
| Net Heating Value (MJ/m³) | 58.41 | 60.18 |
| Gross Heating Value (MJ/m³) | 63.48 | 65.35 |
| Molar Mass*(g/mol) | 45.41 | 46.24 |

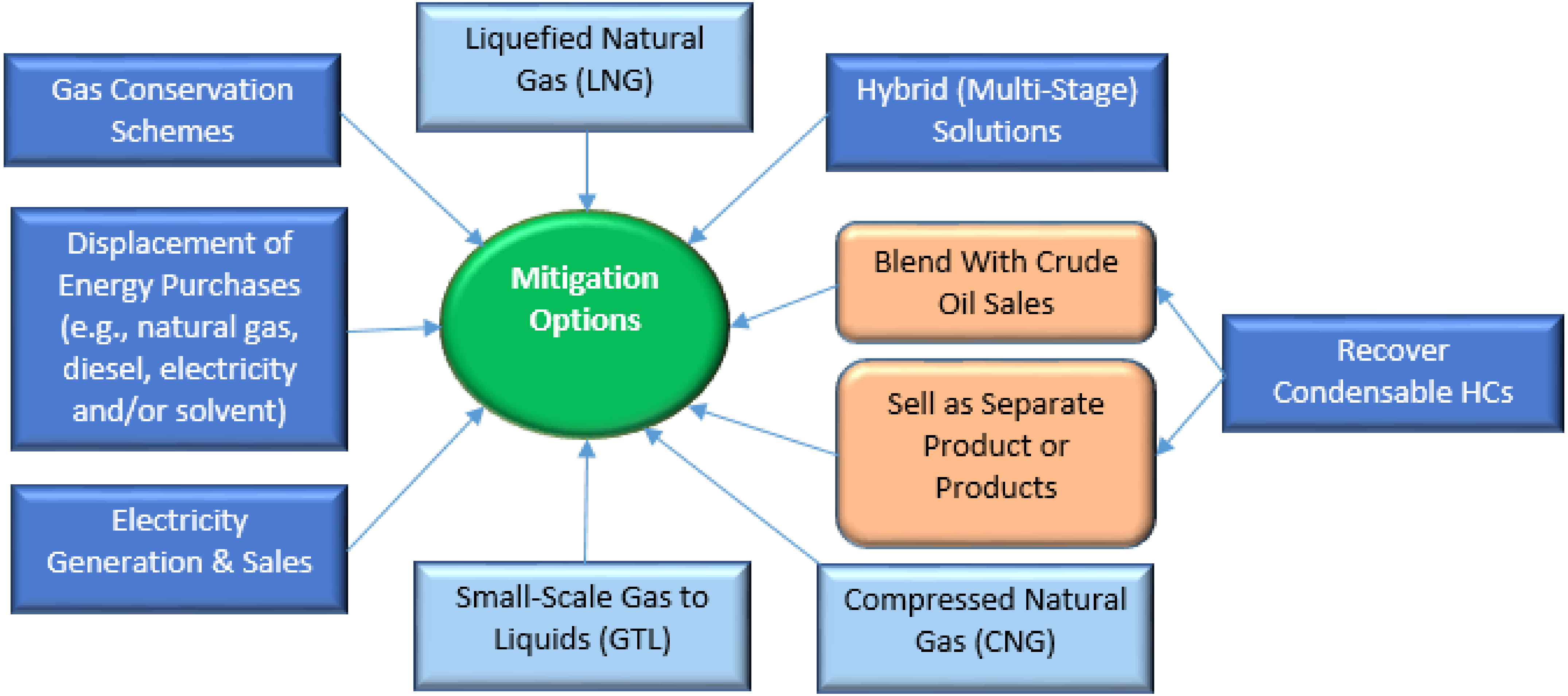
**Stream Composition**

| Compound | Concentration (mol%) | |
|---|---|---|
| | Normal | Dry |
| $C_1$ | 22.96 | 23.66 |
| $C_2$ | 2.38 | 2.45 |
| $C_3$ | 2.87 | 2.96 |
| $iC_4$ | 1.45 | 1.50 |
| $nC_4$ | 5.11 | 5.26 |
| $iC_5$ | 10.42 | 10.73 |
| $nC_5$ | 9.72 | 10.01 |
| $C_6$+ | 7.00 | 7.21 |
| $CO_2$ | 31.22 | 32.17 |
| $H_2S$ | 0.00 | 0.00 |
| $N_2$ | 3.93 | 4.05 |
| $H_2O$ | 2.94 | 0.00 |
| Other | 0.00 | 0.00 |
| Total | 100.00 | 100.00 |

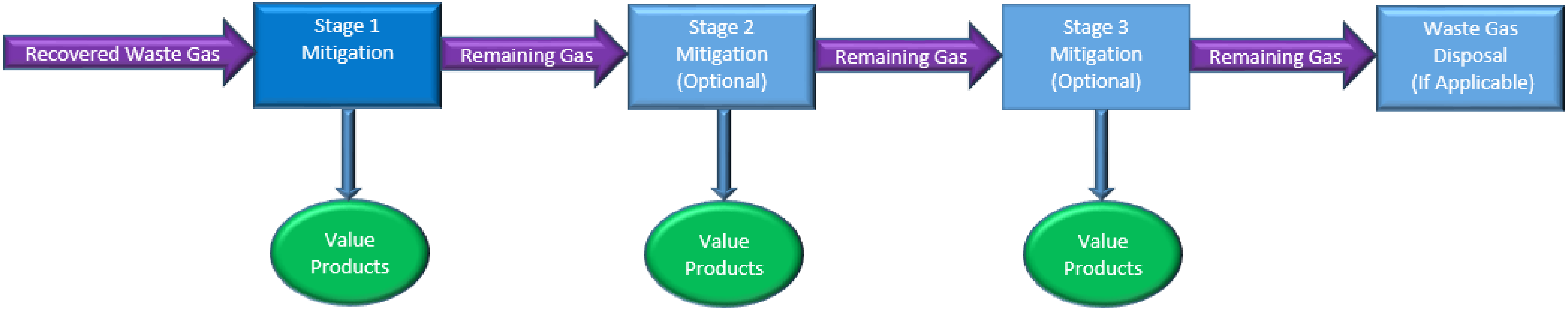
Notes:

*Molar Mass assumes average $H_2O$ selected on GasComp sheet and balance is $N_2$

# MITIGATION TECHNOLOGY CLASSES (*CSIMONLINE*)



# HYBRID (MULTI-STAGE) MITIGATION STRATEGIES (*CSIMONLINE*)



# PRE-SCREENING OF MITIGATION OPTIONS

- Filtering of options based on site-specific factors and constraints.

| Option No. | Primary Technology | Subcategory | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6 | Site 7 | Site 8 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1.1 | Gas Conservation Scheme | Recover gas and compress into onsite gas gathering system. | | | | | | | | ✓ |
| 1.2 | | Recover gas and compress into nearby gas gathering system. | | | | | | | | |
| 1.3 | | Recover gas and compress into onsite flow line to downstream oil treating facility. | | | | ✓ | | | | |
| 1.4 | | Recover gas and compress into inlet of contiguous gas plant inlet. | | | | | ✓ | | | |
| 1.5 | | Recover gas and compress into gas reinjection system. | | | | | ✓ | | | |
| 1.6 | | Recover gas and compress into fuel gas system for general onsite use (to displace NG purchases). | | | | | | | ✓ | |
| | | Recover gas and compress into fuel gas system for electric power generator (to displace electricity purchases). | | ✓ | | | | | | |
| 1.7 | | Recover residue gas from Option 2 extraction process and input to fuel gas system (to displace NG purchases). | | | | | | | ✓ | |
| 1.8 | | Recover residue gas from Option 2 extraction process and input to gas gathering system. | | | | | | | | ✓ |
| 1.9 | | Recover gas and build gas gathering system to conduct to nearby gas plant or oil treating facility. | | | | ✓ | | | | |
| 2.1 | Liquids Recovery (Electric power purchased from utility grid and residue gas flared) | Extract condensable hydrocarbons from waste gas and blend into sales oil (JT) | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ |
| 2.2 | | Extract condensable hydrocarbons from waste gas and blend into sales oil (C3 Refrigeration) | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ |
| 2.3 | | Extract condensable hydrocarbons from waste gas and blend into sales oil (Chilled Water to 10 °C) | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ |
| 2.4 | | Extract condensable hydrocarbons and fractionate to produce stabilized condensate and LPG sales products (install extraction and fractionation process). | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ |
| 2.5 | | Extract condensable hydrocarbons and fractionate to produce stabilized condensate and LPG sales products (send flare gas to existing extraction and fractionation process). | | | | | Same as 1.4 | | | |
| 3.1 | Electric Power Generation | Recover gas and compress into fuel gas system for existing power generator (displace electricity purchases). | | ✓ | | | | | | |
| 3.2 | | Convert or retrofit existing diesel-fueled generators to natural gas-fueled generators (use flare gas for fuel with balance continuing to be flared). | ✓ | | | | | | | |
| 3.3 | | Completely replace existing diesel-fueled generators with natural-gas fueled generators (use flare gas for fuel with balance continuing to be flared). | ✓ | | | | | | | |
| 3.4 | | Install generator to produce electric power from total raw flare gas stream (for onsite and field use with the balance being sold to the electric utility grid). | ✓ | | ✓ | ✓ | | ✓ | | ✓ |
| 3.5 | | Install power plant to generate electric power from Option 2 residue gas for process needs and flare balance. | ✓ | | ✓ | ✓ | | ✓ | | ✓ |
| 3.6 | | Install power plant to generate electric power from all Option 2 residue gas for site and field electricity needs with the balance being sold to the electric utility grid. | ✓ | | ✓ | ✓ | | ✓ | | ✓ |
| 3.7 | | Direct residue gas from Option 2 extraction process to existing power generator to reduce electric power purchases from the utility grid. | | ✓ | | | | | | |
| 4.1 | GTL (Not considered for now) | N/A | | | | | | | | |
| 5.1 | LNG (Not considered for now) | N/A | | | | | | | | |

# PRE-FEASIBILITY ASSESSMENT OF EACH MITIGATION OPTION OVER PROJECT TIME SERIES (*CSIMONLINE*)

## Scenario Modelling

- Carbon price: $6 USD/tonne $CO_2E$ (Current Colombia Price) [GHG=$CO_2$, $CH_4$ & $N_2O$]
- Carbon price: $6 USD/tonne of $CO_2E$ [GHG & BC]
- Carbon price: $55 USD/tonne of $CO_2E$ (Climate pollutant social cost) [GHG & BC]

## Design Optimization

- Optimize design, operating conditions & sizing of the mitigation measure to achieve the best economics.
- End of Project Life = end of mitigation viability or equipment life (10 years).

## Economic Analysis

- Year-1 CAPEX (Class 4 and 5) and time series OPEX.
- Value of incremental commodity sales and avoided energy purchases.
- Carbon tax, royalties (20%), inflation (3%), discount rate (10%), income tax (33%).

## Emissions Assessment

- BC, GHG and CAC emissions for mitigated and un-mitigated cases over entire time series.

## Energy & Material Balance

- Rigorous Flowsheet Simulation of each year in the time series.
- Disposition of inlet streams (sales, fuel, venting & flaring).
- Equipment operating range and flow variability considered.

## Production Decline

- Base-year production activity levels.
- Time series decline based on historical production data or assumed decline rate (e.g., 8%).

# REFINED BUSINESS CASE DEVELOPMENT FOR BEST MITIGATION OPTION

## Improved Project Definition

- Document **design specifications**.
- Prepare **drawings** depicting basic implementation details (e.g., PFD, P&ID and Plot Plan).
- **Review** with operator's engineering & operations staff.

## Improved Cost Estimate (Class 3)

- Obtain **vendor pricing** for key components.
- Develop itemized estimate of **installation costs** (by senior cost estimator and construction manager).

## Refined Business Case

- **Update** techno-economic and environmental **analysis**.
- Prepare **final report** and present **to** senior **operator executives**.

# APPLIED COMMODITY PRICING

**Table i: Applied commodity prices.**

| Commodity | Value | Units of Measure |
|---|---|---|
| Natural Gas | 3.10 | USD/GJ |
| Ethane | 60.26 | USD/$m^3$ (Liquid) |
| LPG | 0.14 | USD/L (Liquid) |
| Pentanes Plus ($C_5$+) | 389.84 | USD/$m^3$ (Liquid) |
| Hydrogen | 2.00 | USD/kg |
| | 0.17 | USD/$m^3$ (gas) |
| Electricity | 0.15 | USD/kW·h (Purchases) |
| | 0.15 | USD/kW·h (Sales) |

# RELATIVE COMMODITY PRICING

| Table iii: Relative commodity price index expressed on a gross energy basis (HHV). | |
|---|---|
| **Commodity** | **Value Relative to Processed Natural Gas** |
| Natural Gas | 1.0 |
| Ethane | 1.0 |
| LPG | 1.8 |
| Pentanes Plus ($C_5$+) | 4.1 |
| Hydrogen | 4.5 |
| Electricity | 13.4 |

# APPLIED ECONOMIC PARAMETERS

**Table iii: Applied economic parameters.**

| **Parameter** | **Value** |
|---|---|
| Project Life | Lesser of asset life and project viability |
| Life of New Equipment | 10 years |
| Discount Rate | 10% |
| Annual Asset Depreciation Rate (Capital Cost Allowance) | 10% of book value |
| Life of New Equipment | 10 years |
| Asset Salvage Value Determination | Straight-line depreciation of the aggregate equipment purchase price over 10 years. |
| Inflation Rate | 3.0% |
| Royalty Rate | 20% |
| Tax Rate | 33% |
| Import Duty | 20% |
| Carbon Pricing | \$6 USD/tonne $CO_2E$ GHG (Scenario 1)<br>\$6 USD/tonne $CO_2E$ GHG+BC (Scenario 2)<br>\$55 USD/tonne $CO_2E$ GHG+BC (Scenario 3) |
| Production Decline Rate | As per site-specific production decline curve determined based on historical production data; otherwise, 8% of the previous year's production (default if no data available). |

| | | | |
|---|---|---|---|
|  |  |  |  |
| **Site 1: (113,847 $m^3/h$)** | **Site 2: (88 $m^3/h$)** | **Site 3: (1,284 $m^3/h$)** | **Site 4: (629 $m^3/h$)** |
|  |  |  |  |
| **Site 5: (1,307 $m^3/h$)** | **Site 6: (92 $m^3/h$)** | **Site 7: (463 $m^3/h$)** | **Site 8: (140 $m^3/h$)** |

# RESULTS

| Site | Currrent Flaring Value | | CAPEX | NPV[1] | Payback Period | IRR[1] | Project Life | Lifetime Emissions Reduction | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Energy Basis ($10^6$ USD/y) | Commodity Basis ($10^6$ USD/y) | ($10^6$ USD) | ($10^6$ USD) | (Years) | (%) | (Years) | BC (kt) | CH4 (kt) | GHG[2] (kt $CO_2E$) | VOC (kt) |
| 1 | 25.5 | 76.1 | 75.5 | 273.1 | 1.4 | 75.4 | 10 | 3.3 | 3.8 | 2,673.0 | 28.4 |
| 2 | 0.342 | 0.849 | 0.2 | 4.5 | 0.3 | 347.9 | 10 | <0.1 | 0.1 | 21.9 | 0.4 |
| 3 | 3.882 | 12.033 | 2.5 | 42.2 | 0.4 | 284.8 | 10 | 0.6 | -0.2 | 494.8 | 1.0 |
| 4 | 1.005 | 1.666 | 1.7 | 1.2 | 5.2 | 22.6 | 10 | 0.1 | 0.5 | 195.3 | 0.6 |
| 5 | 1.931 | 2.673 | 1.4 | 6.2 | 1.5 | 79.3 | 10 | <0.1 | 1.6 | 370.8 | 0.5 |
| 6 | 0.123 | 0.206 | 0.7 | 0.4 | 7.3 | 18.4 | 10 | <0.1 | 0.1 | 1.6 | -0.3 |
| 7 | 0.437 | 0.446 | 0.1 | 1.1 | 0.5 | 208.0 | 10 | <0.1 | 0.5 | 85.6 | <0.1 |
| 8 | 0.125 | 0.126 | 0.1 | 0.3 | 1.4 | 54.5 | 10 | <0.1 | 0.2 | 27.3 | <0.1 |

1 - After Tax

2 - Based on a GWP of 900 for BC, 25 for $CH_4$ and 1 for $CO_2$.

# RESULTS

| Site | Mitigation Measure Code | Stage 1 Code | Stage 2 Code | Stage 3 Code | Project Life (Years) | Capital Expense ($10^6$ USD) | Lifetime BC Reductions (t) | Lifetime GHG Reductions (kt $CO_2E$) | After-Tax NPV ($10^6$ USD) | Payback Period (Years) | IRR (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | OP-001-ACG | NGL Recovery (Air Cooled) | Electric Power Generation | None | 10 | 75.5 | 3,258.9 | 2,673.0 | 273.1 | 1.44 | 75.4 |
| 2 | OP-002-ACG | Flare Gas Recovery Compressor | NGL Recovery (Air Cooler) | None | 10 | 0.2 | 45.2 | 21.9 | 4.5 | 0.31 | 347.9 |
| 3 | OP-003-ACG | NGL Recovery (Air Cooled) | Electric Power Generation | None | 10 | 2.5 | 629.4 | 494.8 | 42.2 | 0.38 | 284.8 |
| 4 | OP-004-PB | Connect to GGS (17 km away) | None | None | 10 | 1.7 | 93.6 | 195.3 | 1.2 | 5.19 | 22.6 |
| 5 | OP-005-P | Flare Gas Recovery (Inject at Gas Plant Inlet) | None | None | 10 | 1.4 | 37.5 | 370.8 | 6.2 | 1.47 | 79.3 |
| 6 | OP-006-ACG | NGL Recovery (Air Cooler) | Electric Power Generation | None | 10 | 0.7 | -14.8 | 1.6 | 0.4 | 7.3 | 18.4 |
| 7 | OP-007-VC | Install a VFD on the Existing | None | None | 10 | 0.1 | <0.1 | 85.6 | 1.1 | 0.51 | 208.0 |
| 8 | OP-008-B | Install blower and piping to | None | None | 10 | 0.1 | <0.1 | 27.3 | 0.3 | 1.42 | 54.5 |
| | | | **Total (Excluding Site 6):** | | | **81.5** | **4,064.6** | **3,868.7** | **328.6** | | |

Legend:
- Near-term Implementation
- Medium-term Implementation
- Additional Due Dilligence Required
- No Operator Feedback Yet
- No Action Planned

# OUTCOMES AND FOLLOW-ON WORK

- Six of the eight sites surveyed were identified as having financially attractive flaring mitigation opportunities.
- Intentions were expressed by Operator 1 to implement mitigation solutions for at least three, and possibly more, of the six sites surveyed for them.
- CEL will work with Operator 1 to evaluate the EPCM bids it is now in the process of obtaining for Sites 1 and 3.
  - Provide a comparative analysis by modelling each bidders proposed solution using CSimOnline.
  - Update several of the feasibility assessments based on more current and detailed user-supplied data.
- Upgrading and optimization of an existing flare for Operator 1 (a demonstration project to minimize BC emissions and consumption of pilot and purge gas, while improving flare reliability and maintainability):
  - Upgrades (retrofits): air assist, retractable ignitors, purge gas reduction seal and control system.
  - Measurements to show impact of air assist on the BC emissions, and establish optimum settings.
- Implementation of a company-wide measurement program focused on fugitive equipment leaks, casinghead venting and tank venting.
  - Identify material cost-effective mitigation opportunities.
  - Develop country-specific emission factors.
  - Knowledge transfer on the design of vapour control systems.

# HOW DO THESE OUTCOMES COMPARE TO PREVIOUS INITIATIVES AND WHAT IS THE DIFFERENCE IN APPROACH?

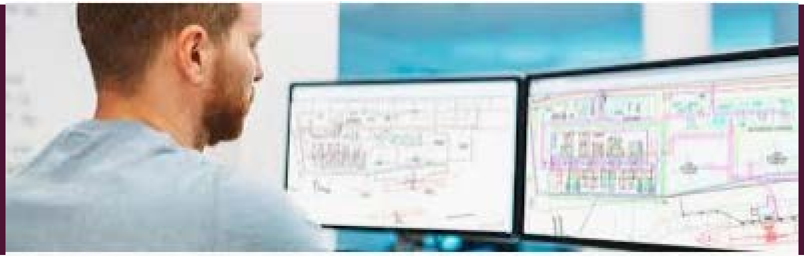
## Historical Approach

- Typical methodology:
  - Spot measurements performed to determine the magnitude of the potential opportunity.
  - No root-cause analysis or consideration of site-specific constraints.
  - Simplistic prefeasibility assessments to screen mitigation options and determine potential project economics (e.g., assumes typical control efficiencies, average costs and little or no consideration of project life potential).
- Typical operator response:
  - Skeptical of results given the lack of rigor and engineering analysis.
  - Reluctant to invest in further evaluation given resource constraints and challenges in getting reliable measurement data.

## Current Approach

- Methodology:
  - Representative time-series measurements, supplemental sampling & analyses, and collection of process operating conditions, and design drawings.
  - Reasonable due diligence coupled with intelligent front-end engineering design (FEED) performed using advanced modelling to provide optimized solutions (CSimOnline).
  - Advance the most promising opportunity to a refined-business-case level (including preliminary engineering drawings & vendor pricing for key items).
- Operator response:
  - Impressed by the thoroughness and rigor of the applied analysis approach, which exceeded their own capabilities & facilitated fast-tracking of the decision process.
  - Committing to advance the most promising opportunities, as well as plans to perform additional due diligence on others.
  - Dramatic improvement in willingness to cooperate and share data.

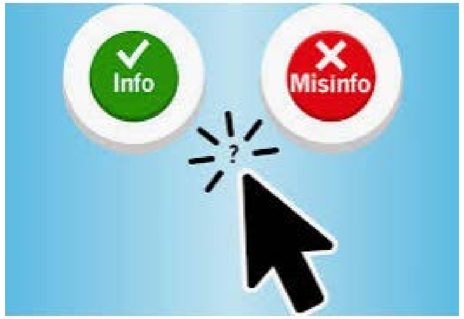
# CONCLUSIONS



- The markets act on good investment opportunities and pay a premium for green products:
  - Credible, technically sound and offers a reward that justifies the risks.
- Why do good mitigation opportunities get overlooked or rejected?
  - Outside a company's normal business model.
  - Unconvincing business case (unreliable measurements, oversimplified techno-economic analysis, inadequate due diligence).

*"… we employ large numbers of engineers and know our facilities, if these opportunities were real, we would have acted on them already… the results must simply reflect a maintenance or upset event and not normal operations… "*

- Addressing these issues and facilitating accelerated decision making, yields positive near-term & ongoing results.






# THANK YOU!

# POTENTIAL PROJECT FINANCING MECHANISMS

- Self-Financing
- External Financing
  - Debt Finance
  - Equity Finance
- Partnerships
  - General
  - Limited
  - Joint Venture
- Third-party Agreements
  - Concession Agreements
  - Sales Agreements
  - Service Agreements