

A large, 3D, red, blocky 'THANK YOU' text graphic. The letters are thick and have a slight shadow on the surface below them. The background is a light gray and white checkerboard pattern.

Meeting Agenda:

1. Introductions
2. Background (why are we here)
3. Project Overview
4. Data Requirements and Availability
5. Modelling Activities and Results
6. Optimisation of Combustion Efficiency and CO₂e
7. Uncertainty in Combustion Efficiency, CO₂, CH₄ and CO₂e
8. Culzean Field Trial Review
 1. Process modelling
 2. IT Architecture and Connectivity
 3. Configuration and Adjustment
 4. Data Visualisation and Reporting
9. Open Discussion

Reductions in Global Warming

There is a NEED to improve our control of the quantities of Methane which are emitted to the atmosphere via flaring from oil and gas production facilities because:

Methane has an impact on atmospheric warming estimated to be more than ***80 times greater*** than CO₂ (over 20 years).

Therefore, if we can reduce the quantities of Methane emitted to atmosphere it creates the potential to slow down global warming in the near term and buy us time to transition towards renewable energies.

Flaring from oil and gas production facilities is the process of burning the various hydrocarbon components which make up the waste, or excess, gas produced (Methane, Ethane, Propane, Butane etc.) and thereby converting these to Carbon Dioxide (CO₂).

The term associated with the effectiveness of a flare is ***Combustion Efficiency*** and if there are inefficiencies in the flaring process this will result in some gas not being burnt.

As natural gas is primarily made up of Methane; poor Combustion Efficiency will lead to greater emissions of Methane to atmosphere.

Academic and Industry Background

A Flare Research Project^[1], conducted by the University of Alberta (UoA) in Canada over a twenty-year period, has delivered a semi-empirical methodology for measuring and calculating flare combustion efficiency.

The UoA methodology describes the required process measurement inputs and provides an equation which can be used to calculate the Combustion Efficiency of a flare.

$$\text{Combustion Efficiency} = 1 - 0.001066e^{\left(\frac{0.317 * Windspeed}{(ExitVel * g * Dia)^{0.33}}\right)} \left(\frac{LHV_{CH_4}}{LHV_{Flare}}\right)^3$$

This methodology is referenced by the Oil and Gas Methane Partnership (OGMP), within their Technical Guidance Document - Flare Efficiency^[2], as being suitable for use in determining the combustion efficiency of gas flared from oil and gas production facilities.

The OGMP guidance document requires the utilisation of direct measurements and/or simulation of process variables in order to determine Combustion Efficiency using the UoA methodology in order to achieve a Level 4 reporting standard – indicating that a high-quality quantification method is in place.

Accord Combustor Concept

The flare Combustion equation is given as:

$$\text{Combustion Efficiency} = 1 - 0.001066e^{\left(\frac{0.317 * Windspeed}{(ExitVel * g * Dia)^{0.33}}\right)} \left(\frac{LHV_{CH4}}{LHV_{Flare}}\right)^3$$

Where:

Windspeed : is the localised speed of the prevailing wind at the flare

ExitVel : is the velocity of the gas within the flare pipeline

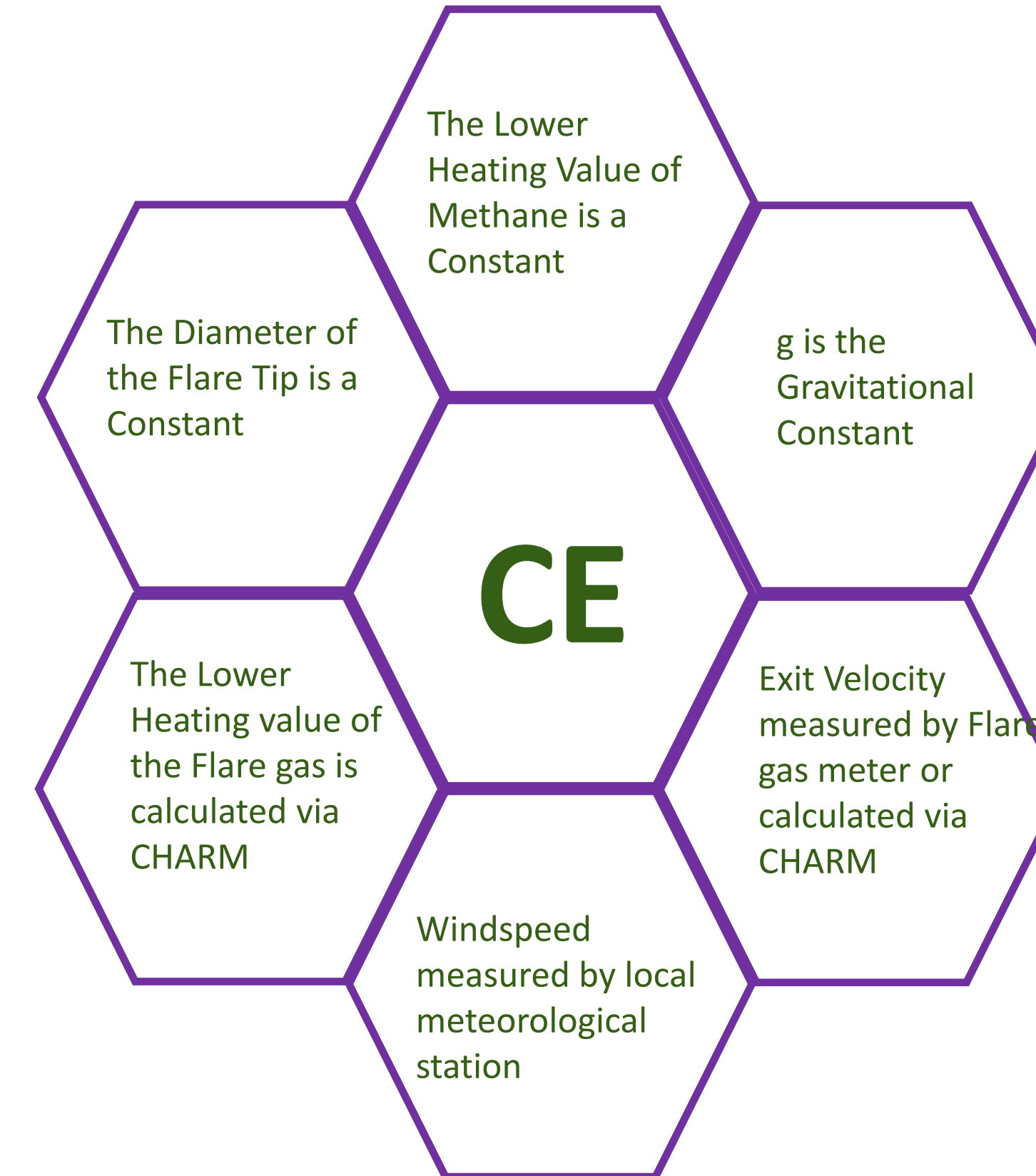
Dia : is the diameter of the flare pipe

G : is the gravitational constant

LHV_{CH4} : is the lower heating value of Methane

LHV_{Flare} : is the lower heating value of the flare gas composition

The variables of the equation must be obtained by direct measurement or process simulation



All variables for use in the Combustion Efficiency equation can be directly measured or calculated via process simulation using Accord's CHARM software.

The uncertainty associated with Combustion Efficiency is estimated by combining all inputs within an uncertainty calculation to deliver a traceable output.

The variables which we can modify and use to optimise Combustion Efficiency in operation are the Velocity of the flare gas and the Lower Heating Value of the flare gas

What is the Purpose of a Flare System

The flare provides a means of safe disposal of the vapor streams from operating facilities, by burning them under controlled conditions such that adjacent equipment or personnel are not exposed to hazards, whilst at the same time meeting pollution control and public relations requirements. Some of the design considerations are:

- Routine and emergency flaring conditions – high capacity for emergency blow down scenario
- Minimise radiated heat – quickly remove heat source from the operating plant and the flare tip
- Reduce noise and vibration from flaring – risk to personnel and damage to operating plant
- Minimise pollution to the environment – smokeless flaring, low luminosity, high Combustion Efficiency

**Can future flare designs improve
Combustion Efficiency and/or Optimise
Emission Rates?**

High Level Project Activities:

- Desktop Modelling of 4 operating assets – report results
- Field Trial on 1 operating asset – monitor results

Summary:

- Modelling process is repeatable across assets
- Operator support is required to develop and verify simulation
- Recognise the unique aspects of each plant design and operation
- Timeline to finalise model varied between 2 and 4 working weeks

The Modelling Process:-

- Simulate the operating plant and confirm CHARM matches with HYSYS LHV and/or sample compositions
 - Recognise that each operating asset is unique in some way and operators have the final sign off that LHVs are matched
 - Recognise that sampled compositions may not include for downstream purge flow (N2 or Fuel Gas)
 - Recognise that the extent of process modelling may vary dependent upon plant design and operating modes e.g., hub versus single field
- Determine Flare Exit Velocity from meter rates and flare dimensions
 - Recognise that engineering units need to be specified and that Volume flow may need to be determined from Mass/Density



BP Glen Lyon

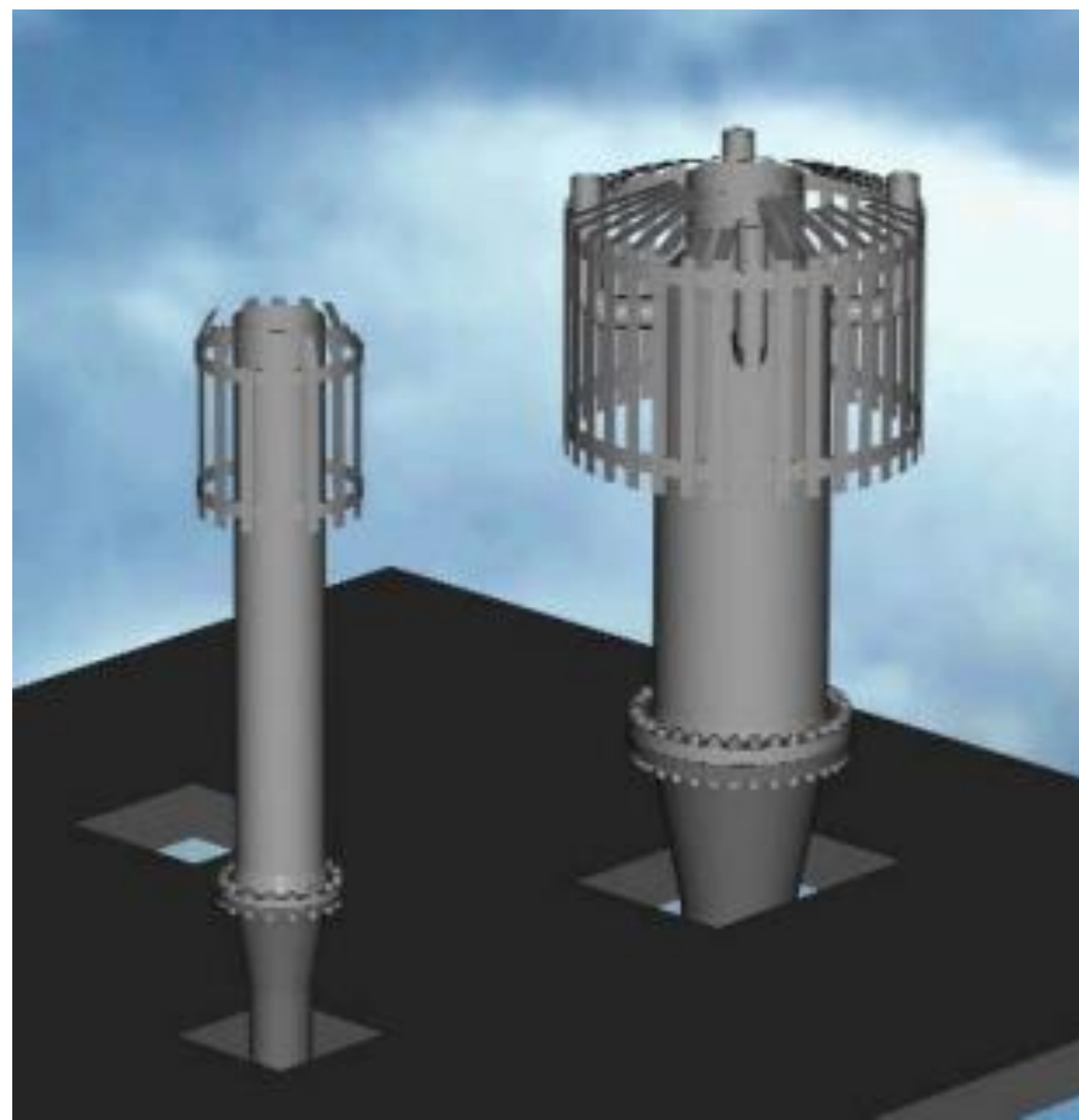
TotalEnergies Culzean

GBA Combined
HP&LP Flare



Harbour Energy
Britannia

Birwelco HP and LP Flare



Ithaca
Captain FPSO

Kaldair LP Flare

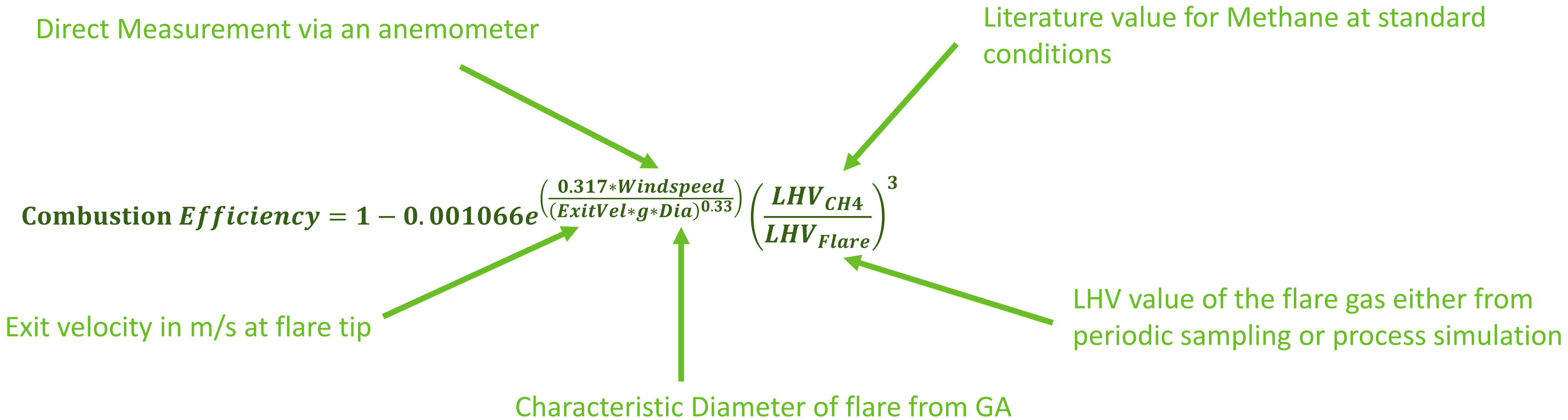


Serica,
Bruce

Birwelco HP (2 stage) Flare
and Kaldair LP Flare



Data Requirements - UoA Calculation



Characteristic Diameter

- UoA equation assumed no windshield and used the OD of the flare pipe
- The CD is related to the surface on which the wind acts
- Bigger CD results in larger CE

Exit Velocity

- Determined from CSA and metering
- For accuracy volumetric meter readings are preferred
 - Lower uncertainty
 - Minimal conversions have taken place

Data Requirements – Asset and Modelling information

- Diagrams – used to build CHARM model and specify combustor
 - PFD showing overall process and salient equipment
 - GA's of Flare tips and/or Data sheets
 - P&IDs of flare system showing meters, KO drums, purges
- Validated Process models – Used to build CHARM model and define input data
 - Models that the operator uses to model the asset and give representative results
- Field Feed information – Used as input to CHARM model
 - Composition
 - Rate
 - GOR
- Vessel operating conditions – Used as input to CHARM model
 - Average PI operating conditions
 - Conditions from validated process models
 - Periodic Spot values
 - Design values
- Metering information – Used to validate model and as input to combustor
 - Flare rates
 - Flare compositions
 - Purge information
- Weather information – Fed directly to combustor
 - Location of anemometer relative to flare tip
 - General understanding of any shielding on instrument

Harbour Britannia Flare System



HP Flare

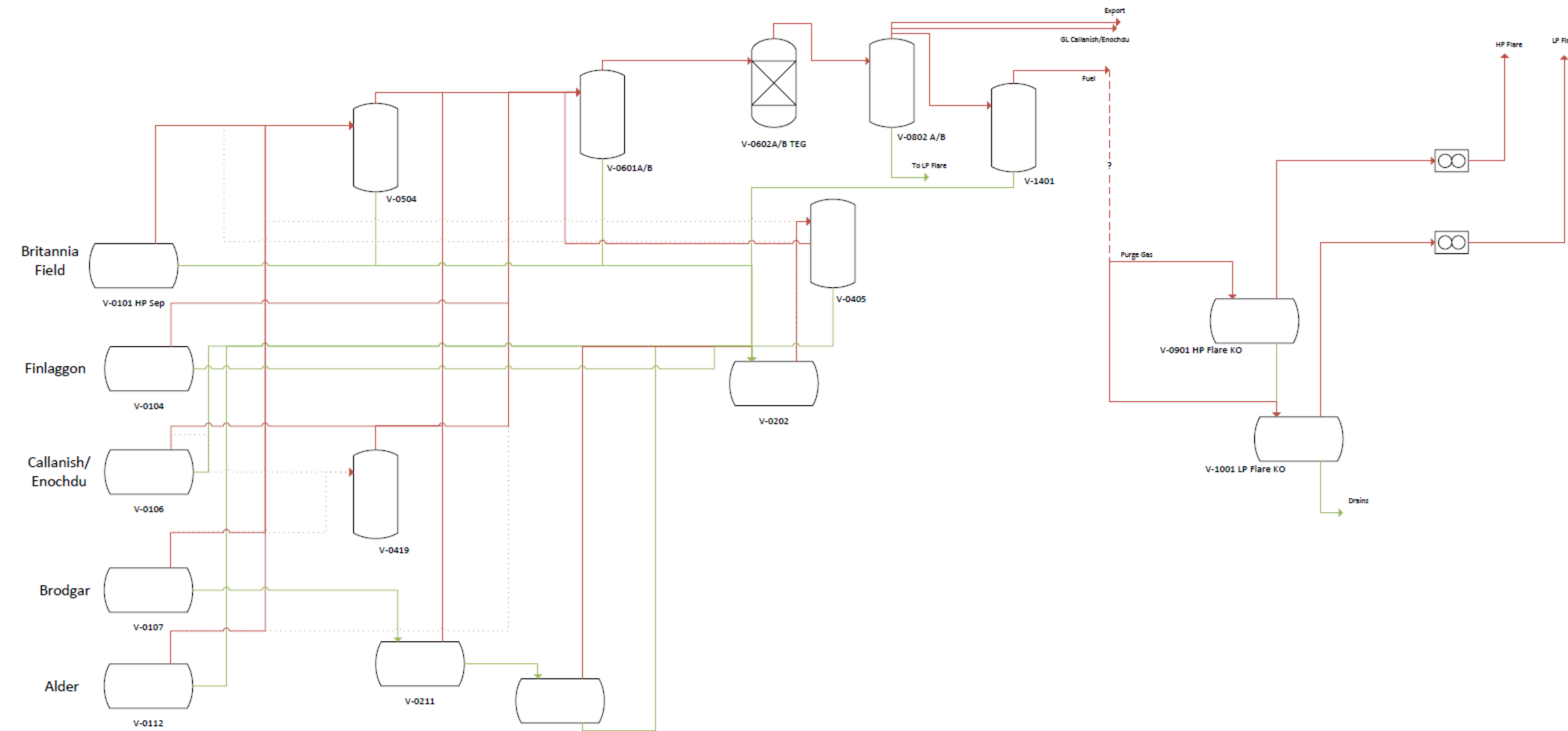
- Single meter measuring total stream to flare
- Geometrically different from UoA study
 - One large central Flare tip
 - Four smaller 'let down nozzles' at 0°, 90°, 180° & 270°
- CSA calculated as the sum of all areas
- Characteristic diameter set as diameter of the windshield

LP flare

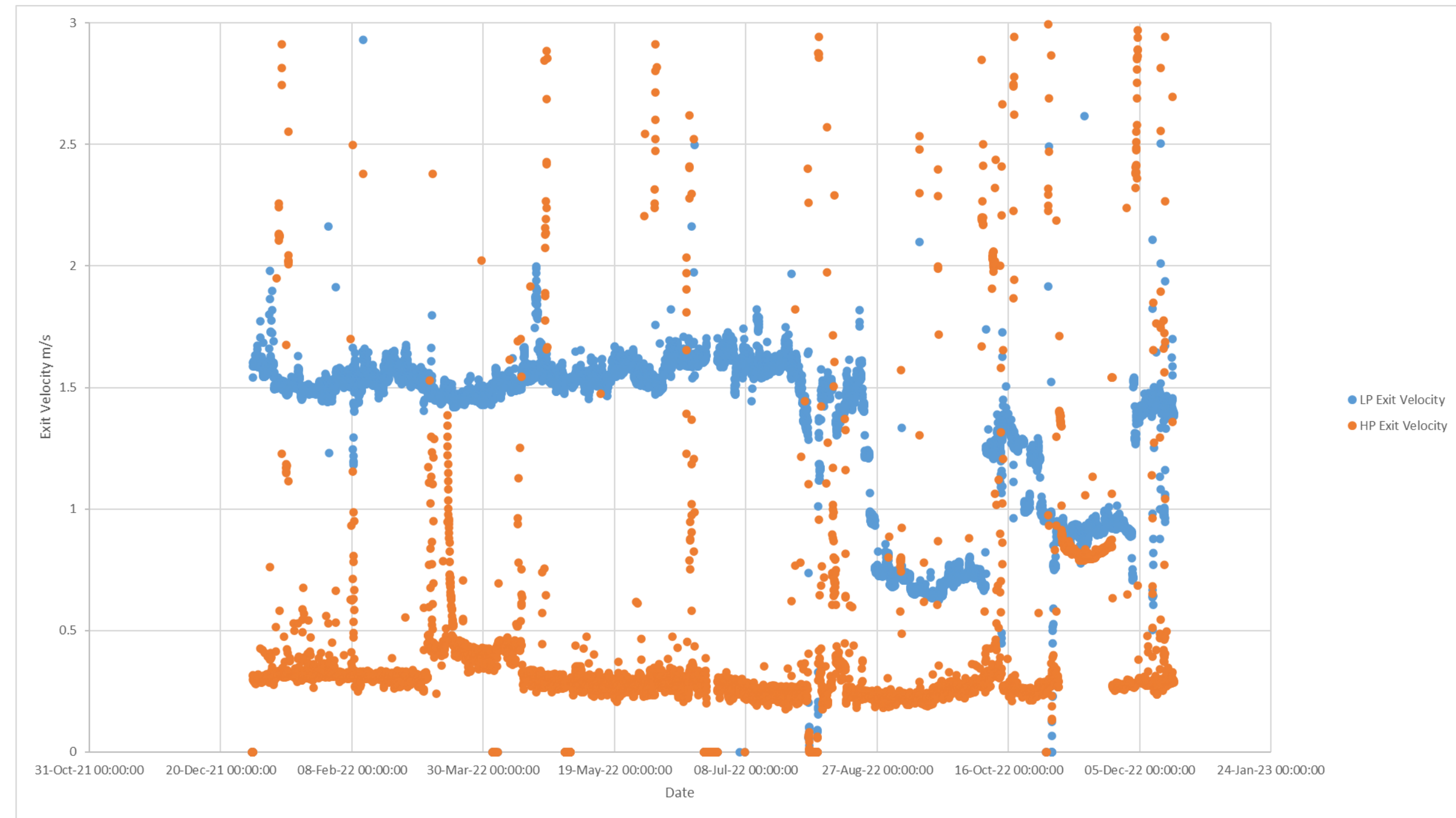
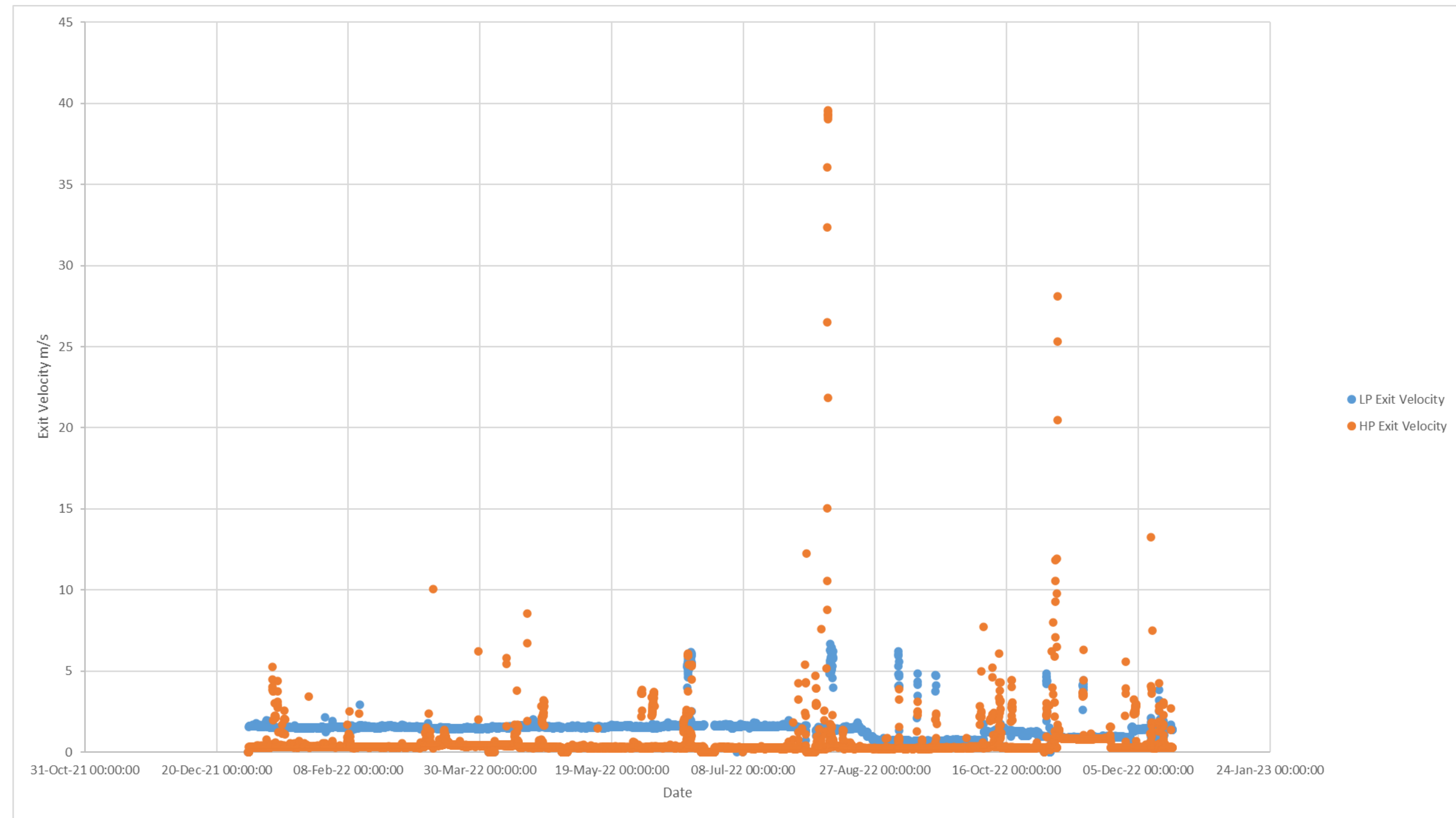
- Single meter measuring total stream to flare
- Geometrically consistent with UoA study
 - Windshield use as characteristic diameter
- Higher flowrates compared to HP Flare

Harbour Britannia Supplied Data & CHARM model

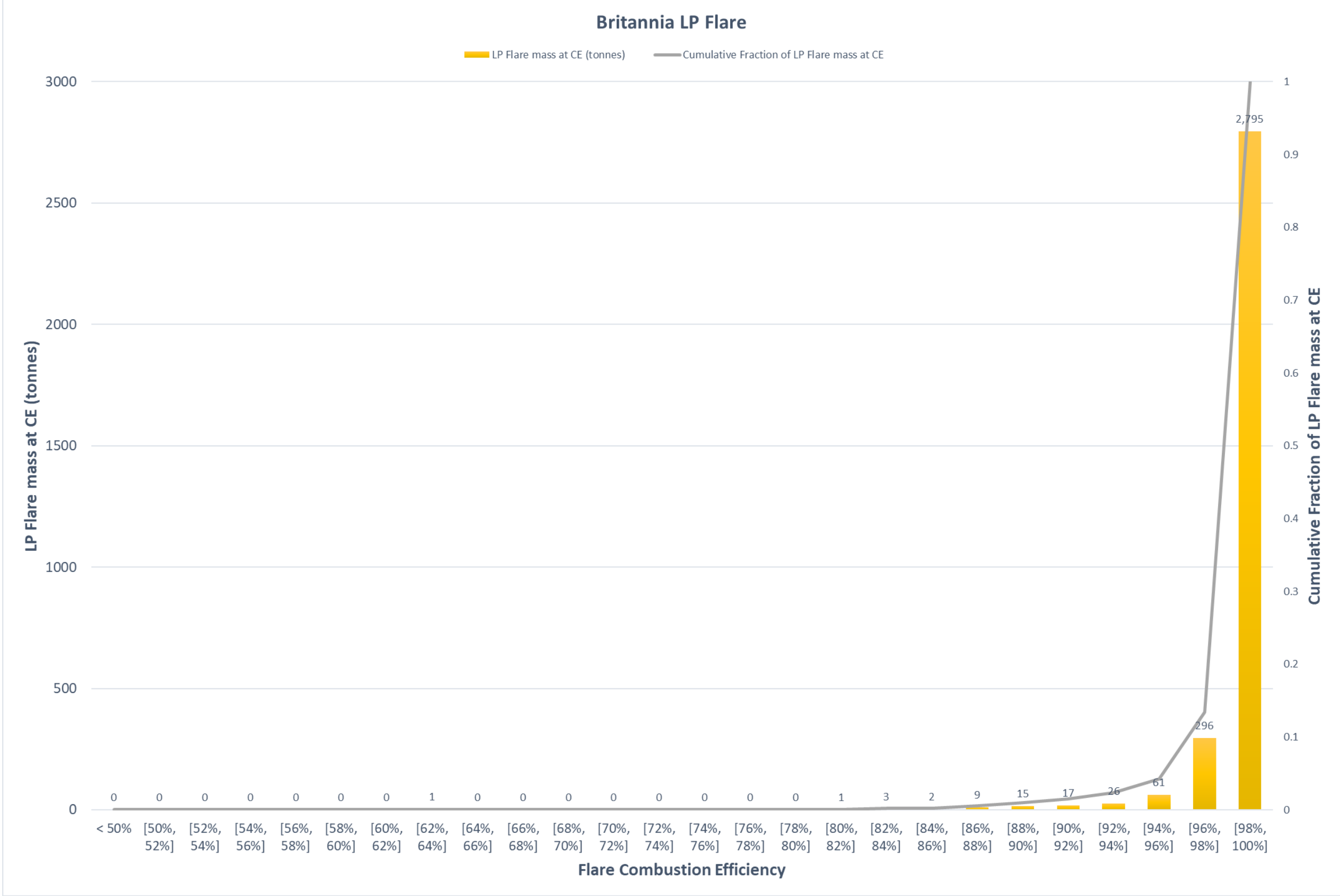
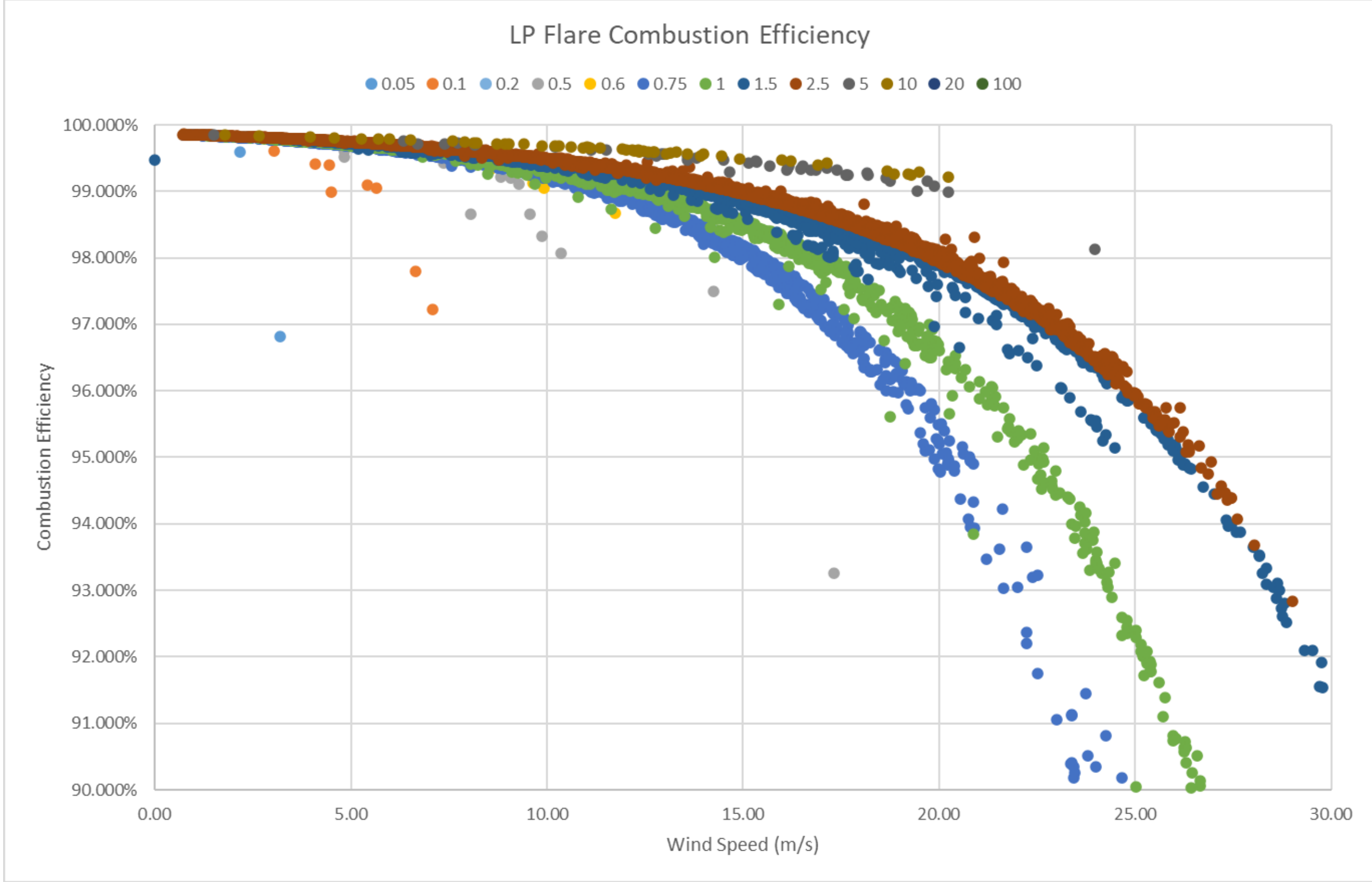
- Flare Compositional data
 - Export gas used as proxy for both LP and HP Flare
- HYSYS model & PFDs with standard Op conditions
- Britannia, Alder, Brodgar Callanish, Enochdhu & Finlaggon Field daily allocation rates
 - Oil, Gas and Water for GOR matching
- Field compositions as per HYSYS model
- Daily average plant operating conditions



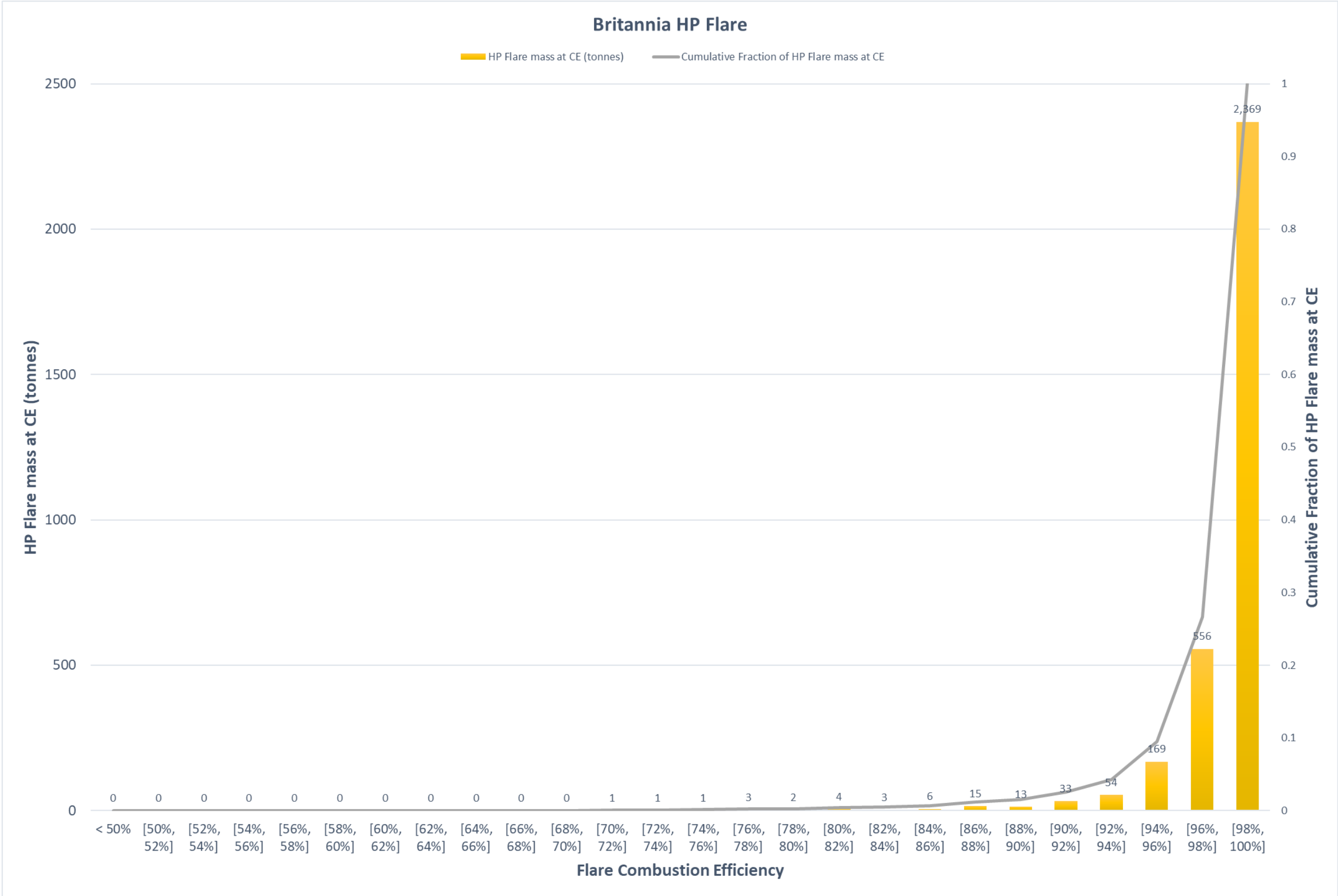
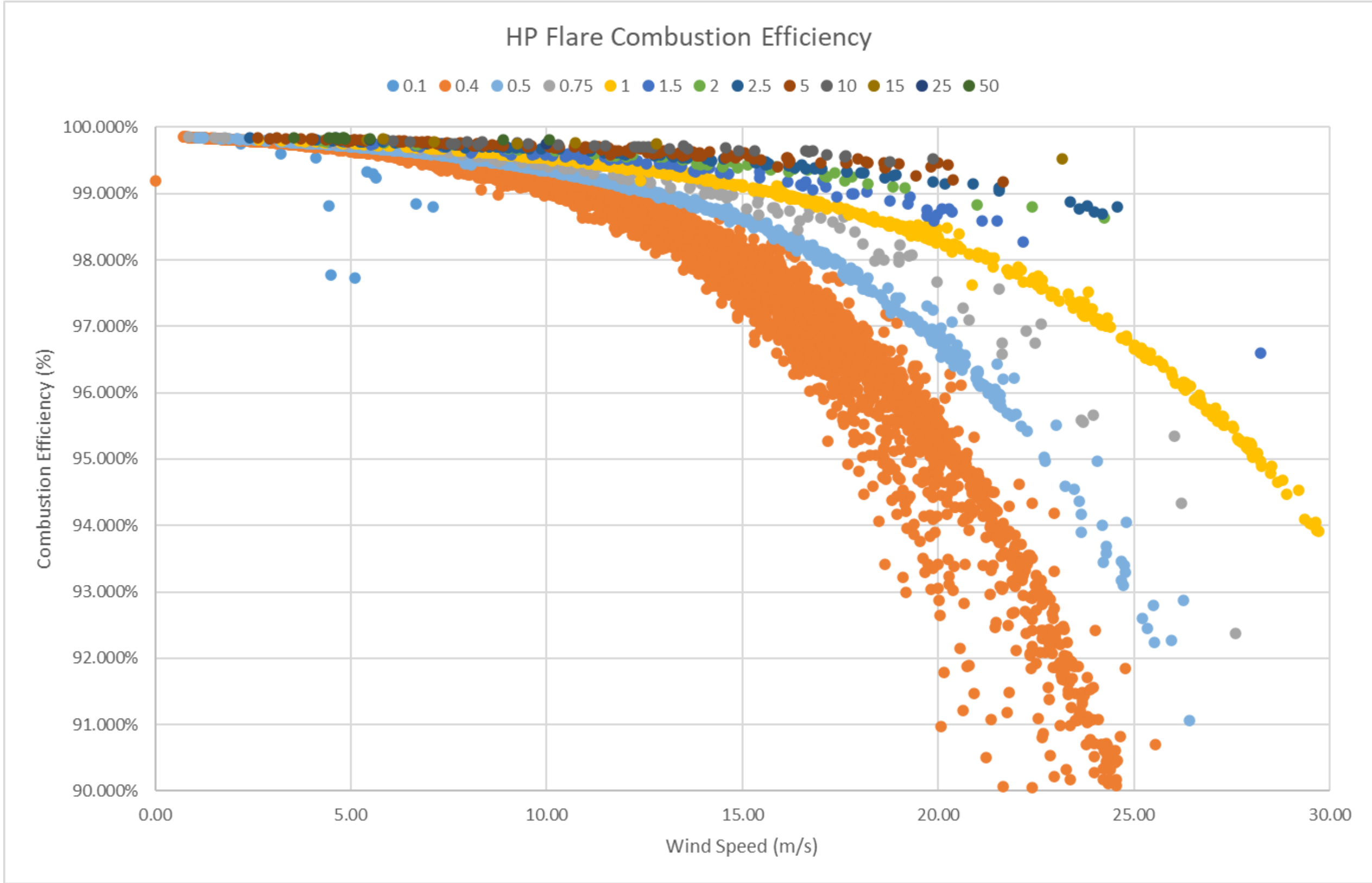
Harbour Britannia Flare Exit Velocities



Harbour Britannia LP Flare



Harbour Britannia HP Flare



Ithaca Captain Flare System

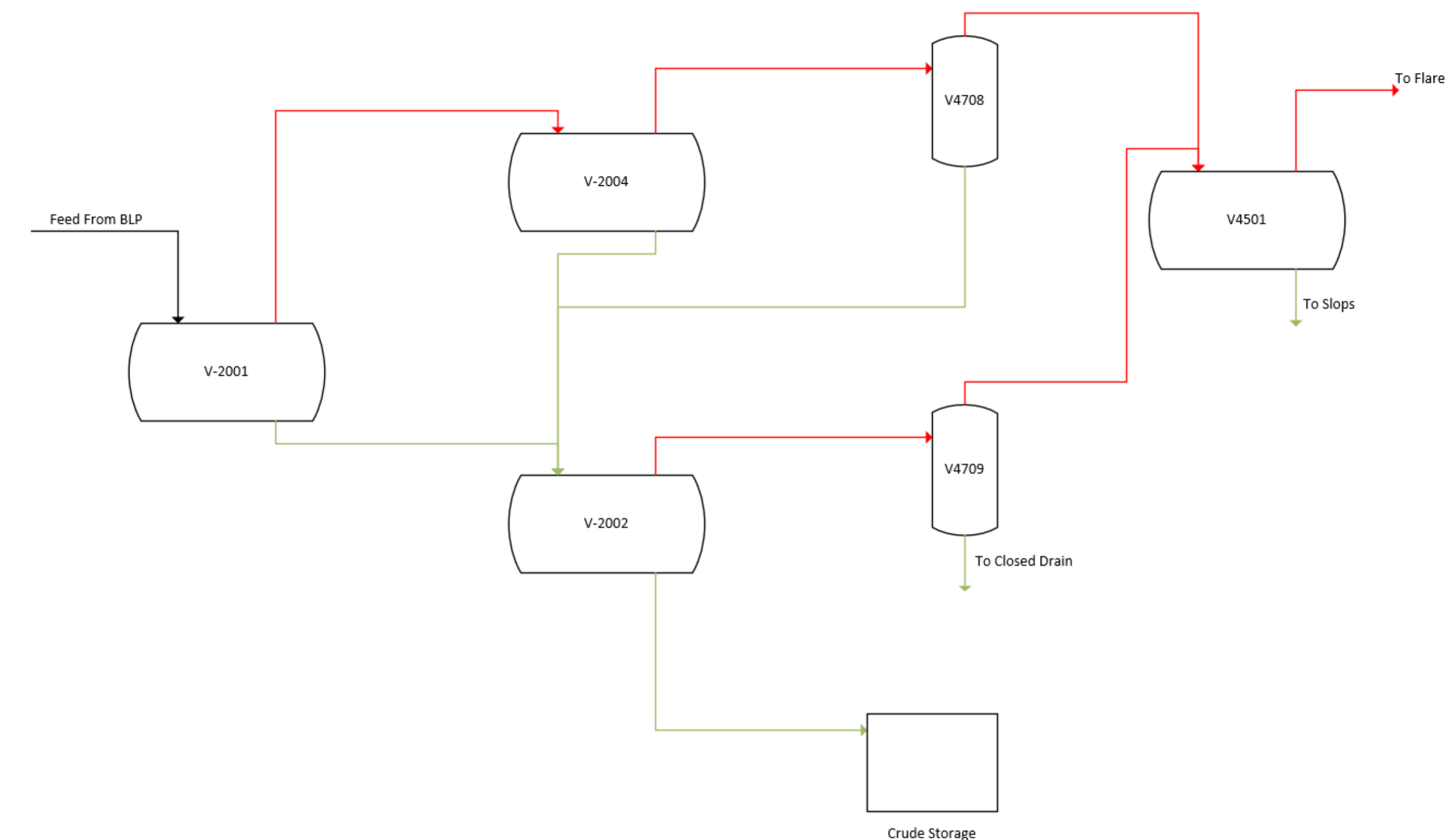


Captain FPSO Flare

- Single meter measuring total stream to flare
- Single Nozzle design
 - Two pilots at 0° and 180°
- Geometrically consistent with UoA study
 - Single flare tip design, most consistent with UoA work
 - No windshield at flare tip therefore OD of flare used as characteristic diameter
- Compared to others a simple system to model

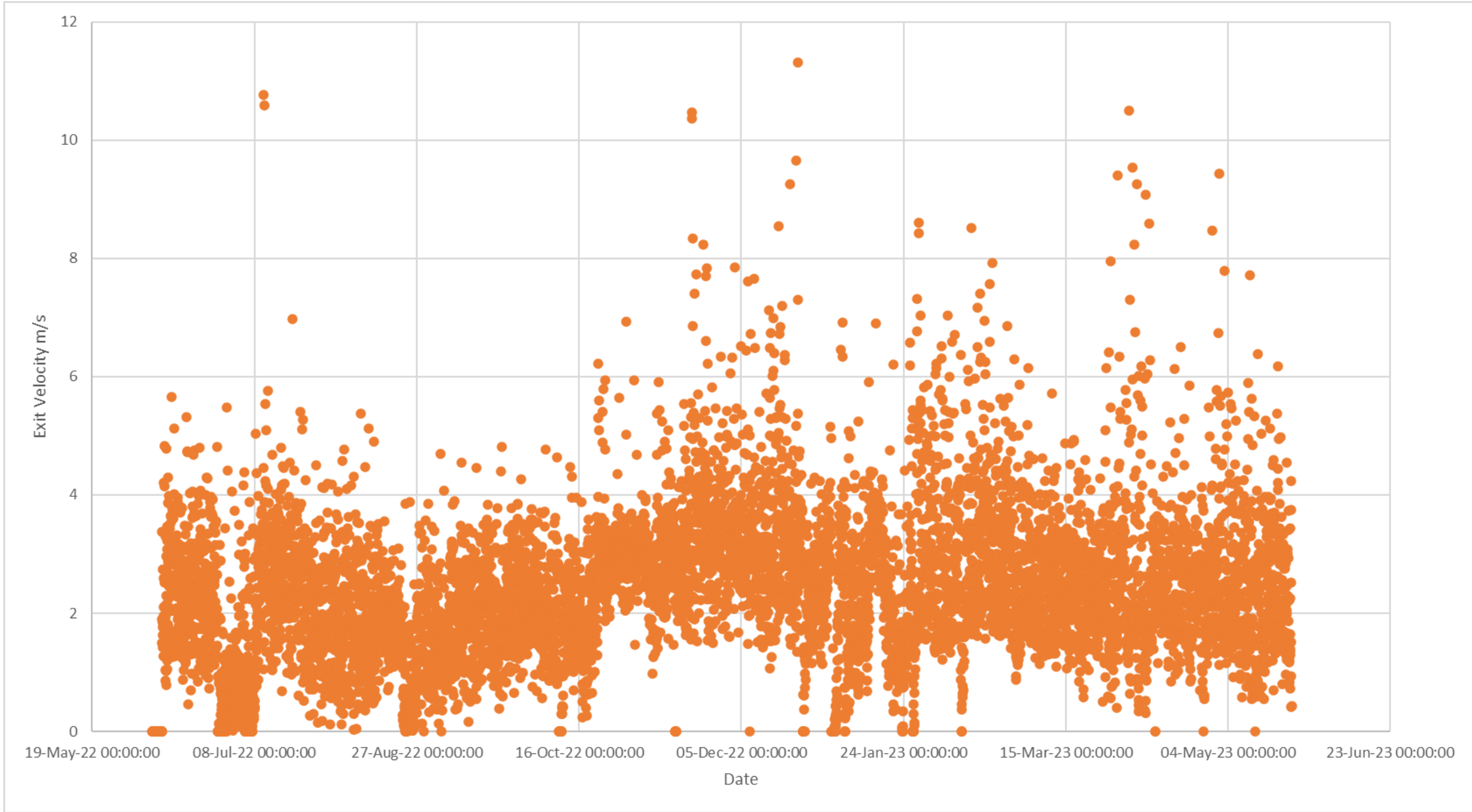
Ithaca Captain Supplied Data & CHARM model

- Flare Compositional data
 - Annual samples of BLP produced gas used as proxy for FPSO produced gas
 - Captain Crude oil is dead, and gas is microbial in nature approximately 95 wt% CH₄
- HYSYS model & PFDs with standard Op conditions
- Wet Volumetric flow ex BLP was provided as input to FPSO model
 - Converted to dry mass via a fixed BS&W and Density
- BLP feed compositions as per HYSYS model
- Daily average plant operating conditions



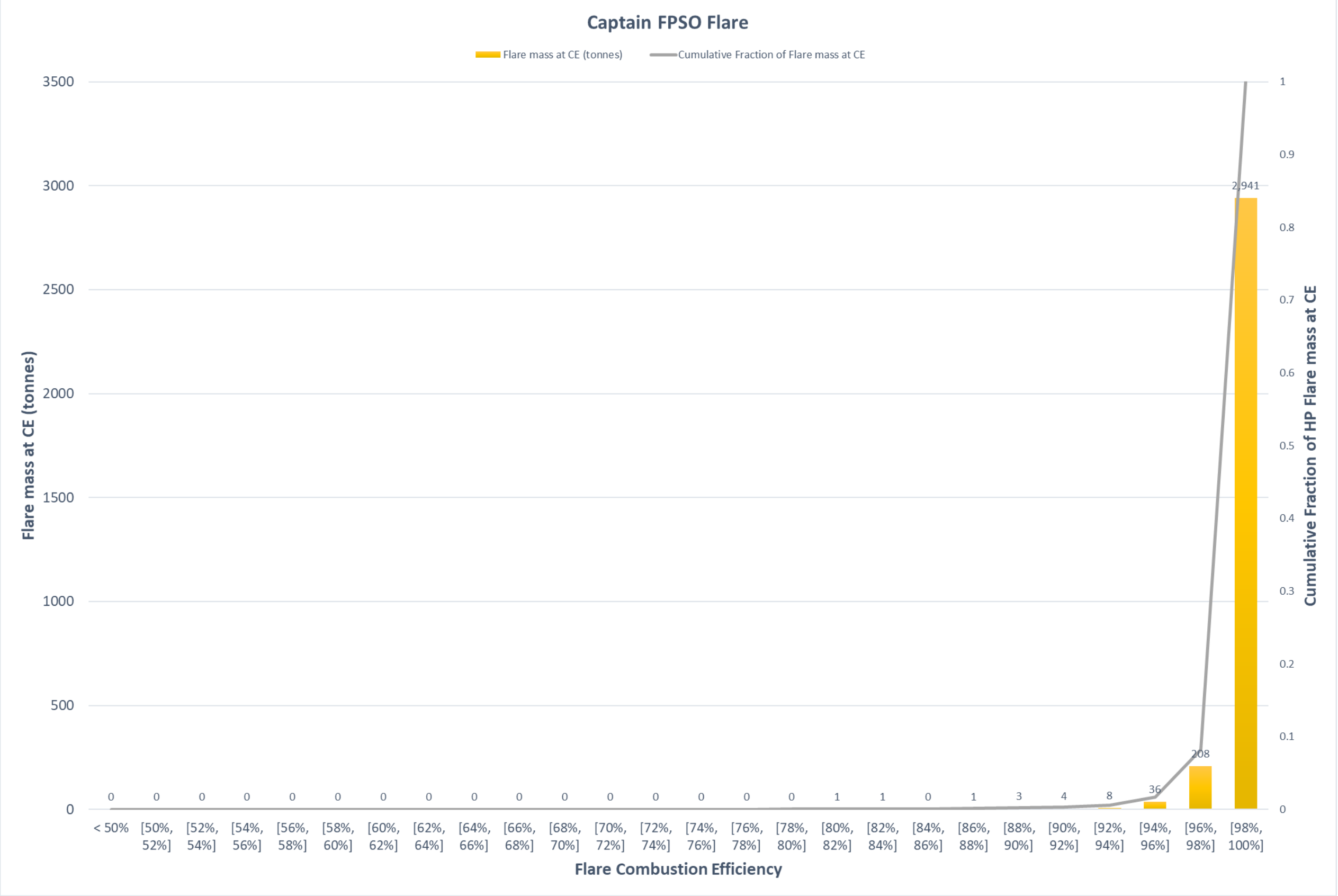
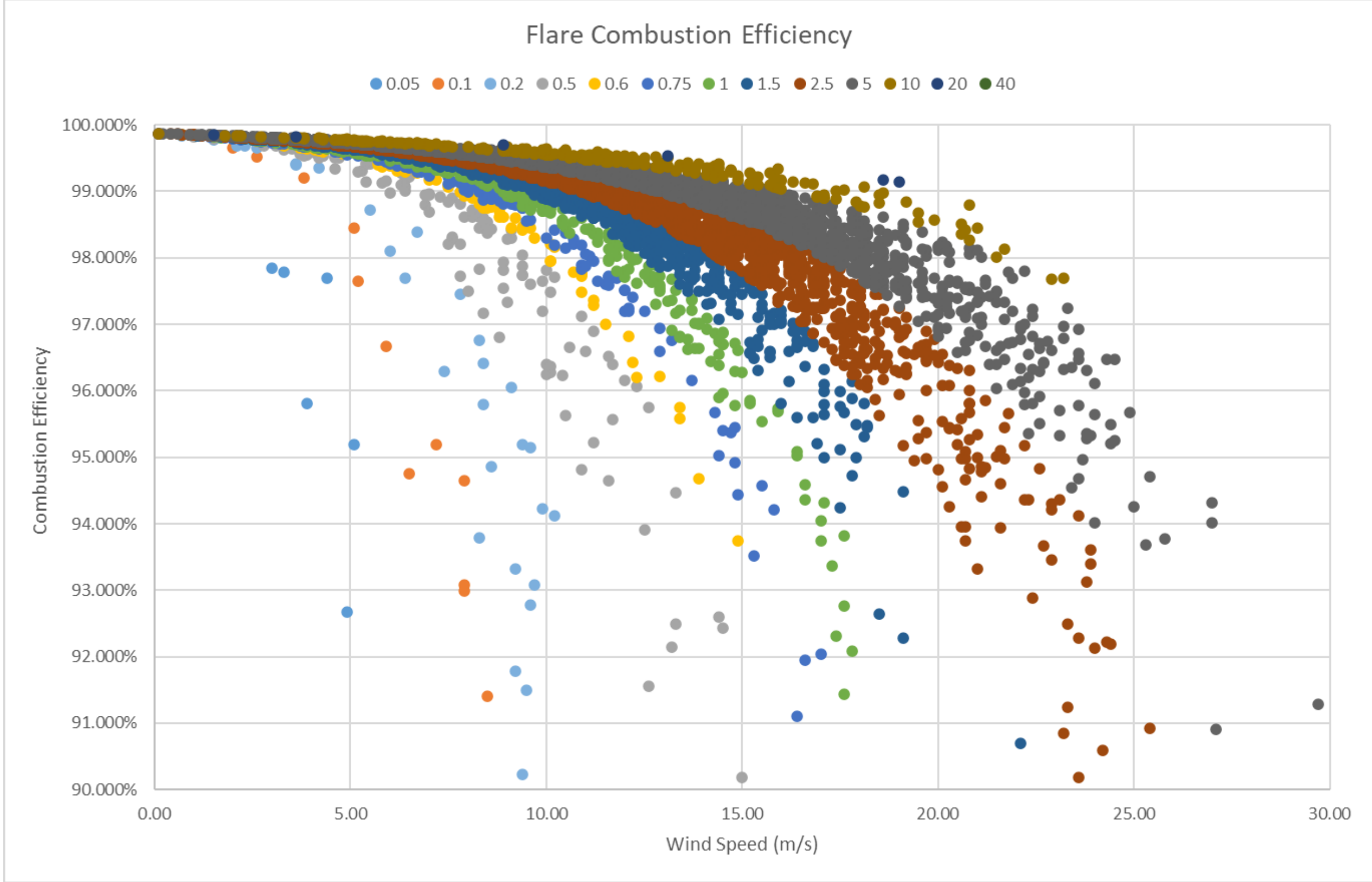


Ithaca Captain Flare Exit Velocities



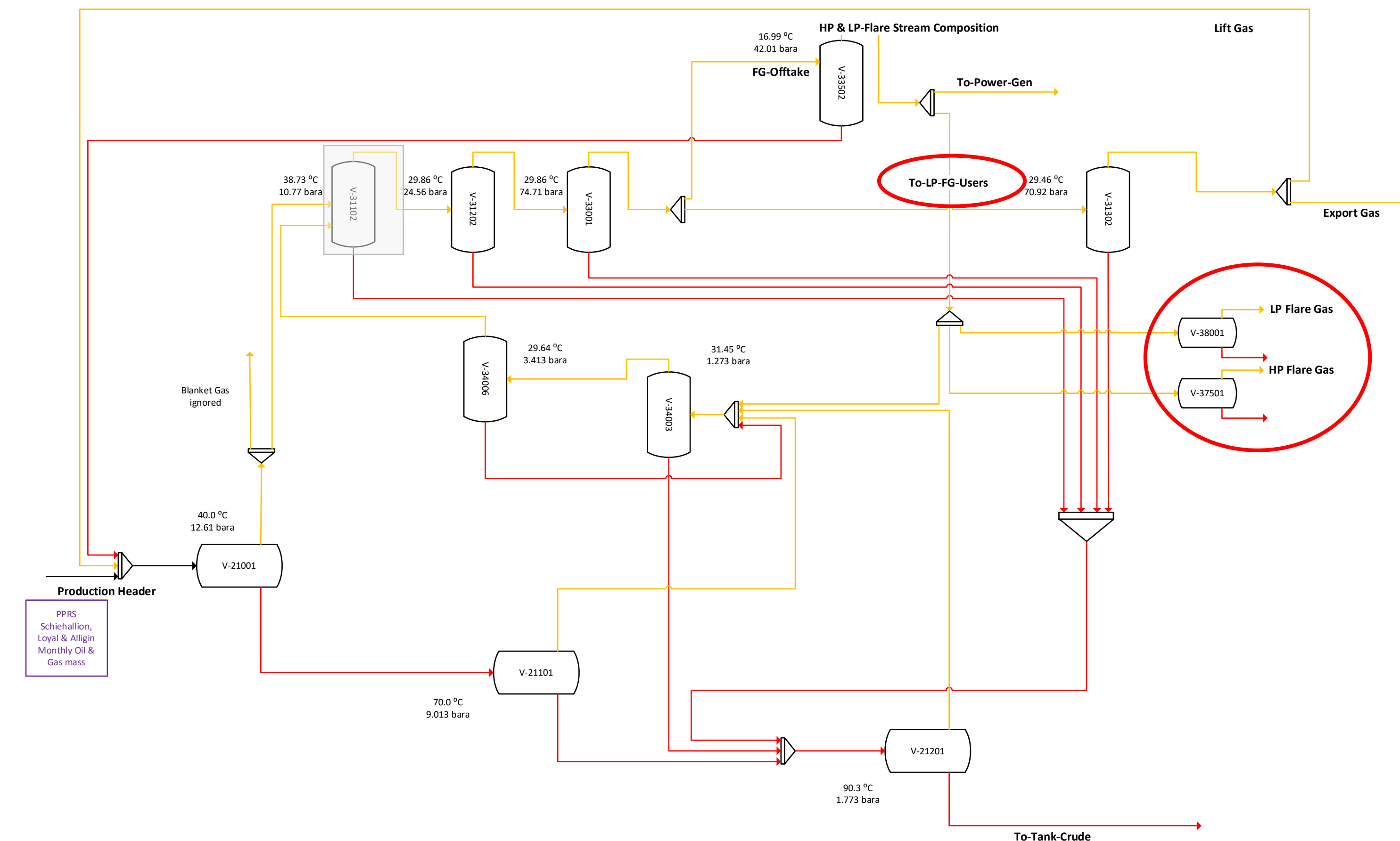
| | Lab | HYSYS Fuel gas stream (V-4708) | CHARM Fuel Gas Stream (V-4708) | CHARM Combined Flare Stream |
|----------------|----------|--------------------------------|--------------------------------|-----------------------------|
| | Weight % | weight% | Weight % | weight% |
| Nitrogen | 1.036% | 0.9940% | 0.9994% | 0.9994% |
| Carbon Dioxide | 3.366% | 3.8271% | 3.8186% | 3.8186% |
| Methane | 95.259% | 94.7038% | 94.7086% | 94.7086% |
| Ethane | 0.111% | 0.2120% | 0.2101% | 0.2101% |
| Propane | 0.062% | 0.0629% | 0.0622% | 0.0622% |
| I Butane | 0.036% | 0.0486% | 0.0480% | 0.0480% |
| N Butane | 0.065% | 0.0105% | 0.0104% | 0.0104% |
| I Pentane | 0.022% | 0.0135% | 0.0134% | 0.0134% |
| n Pentane | 0.018% | 0.0045% | 0.0045% | 0.0045% |
| Hexane | 0.021% | 0.0520% | 0.0521% | 0.0521% |
| Heptane | 0.003% | 0.0180% | 0.0181% | 0.0181% |
| Octane | 0.001% | 0.0106% | 0.0107% | 0.0107% |
| Nonane | 0.000% | 0.0084% | 0.0085% | 0.0085% |
| Decane+ | 0.00% | 0.0203% | 0.0216% | 0.0216% |
| LHV | 47.82 | 47.61 | 47.60 | 47.60 |

Ithaca Captain Flare

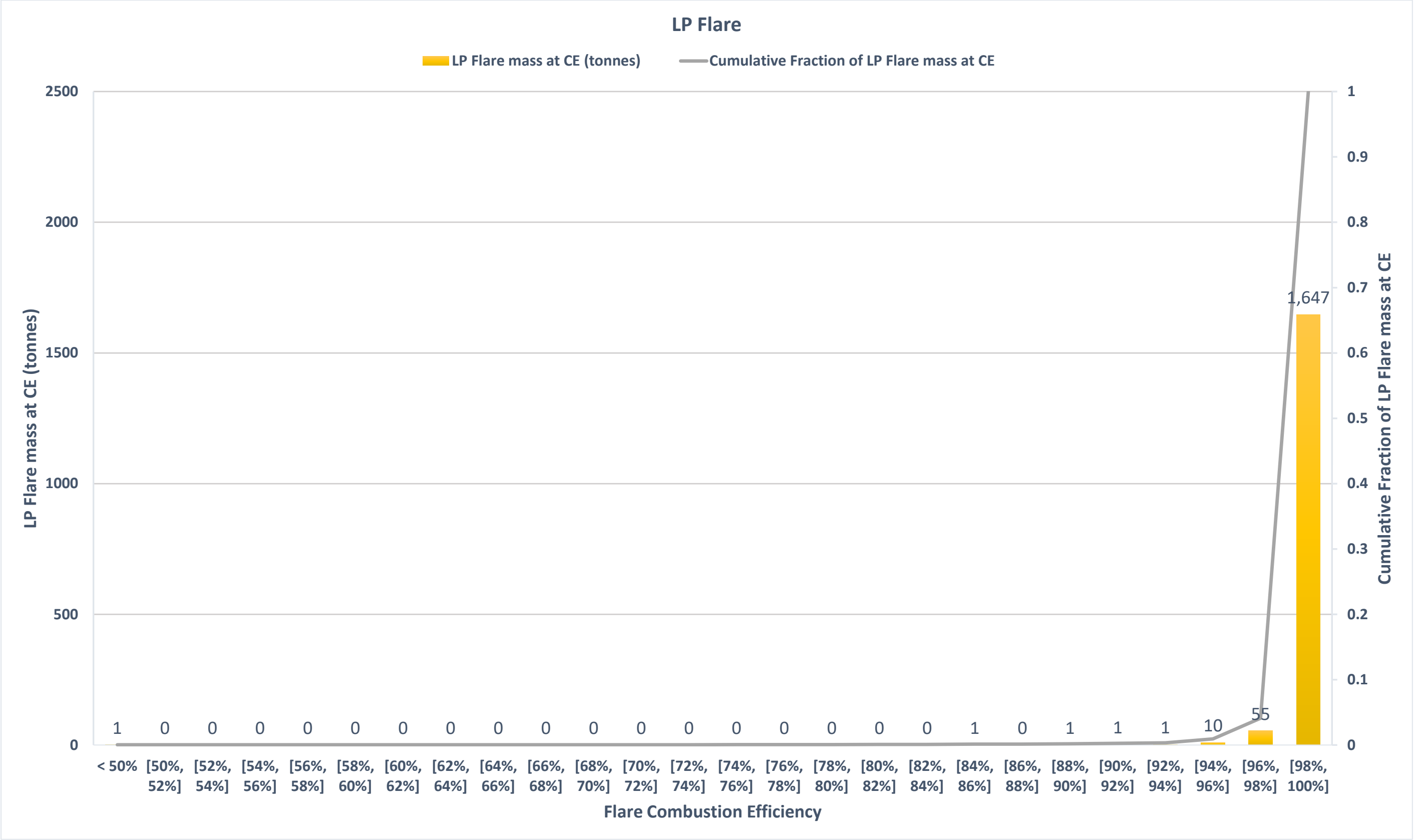
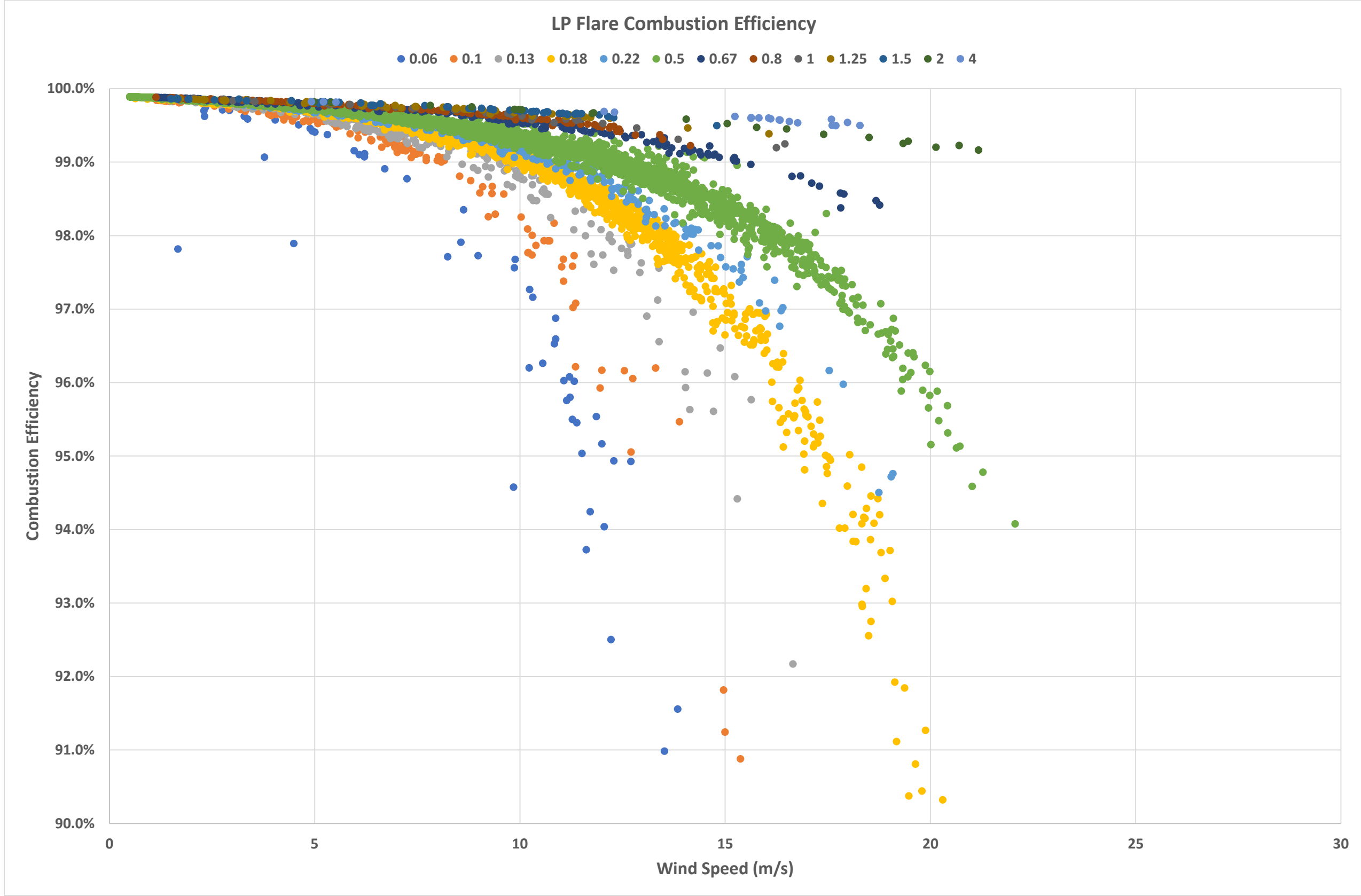


bp Glen Lyon Supplied Data & CHARM model

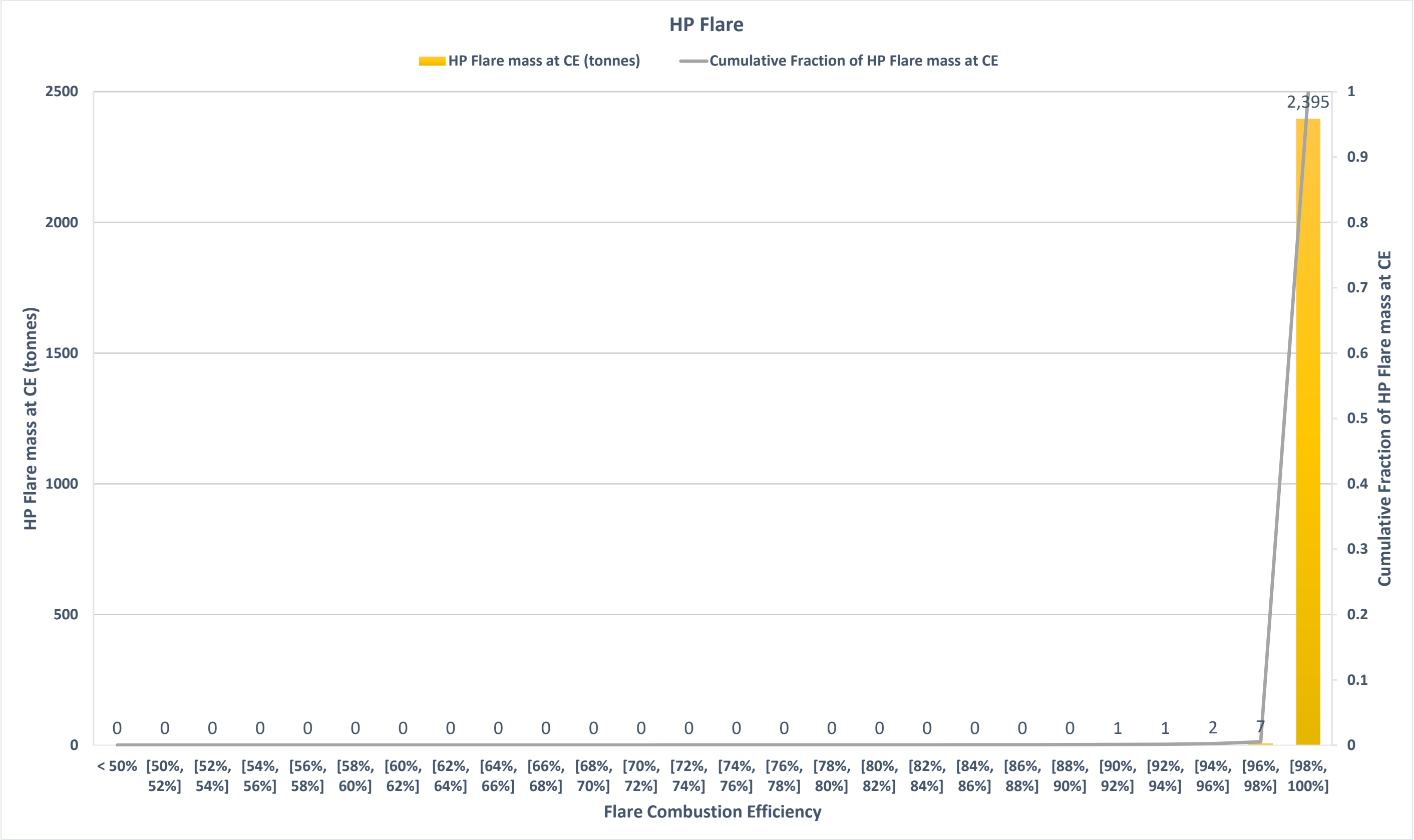
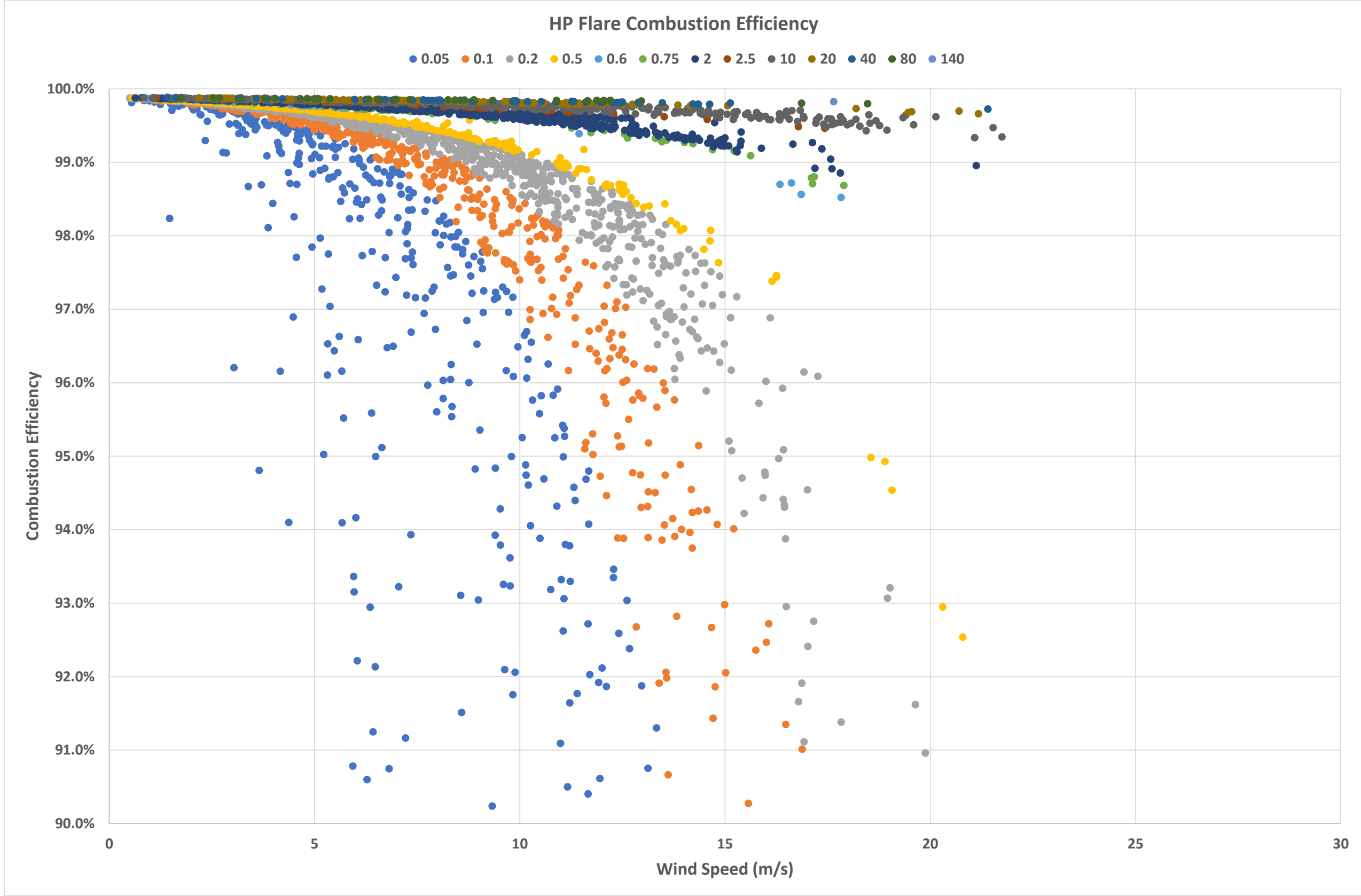
- Flare Sample data
- HYSYS model & PFDs with standard Op conditions
- Schiehallion, Loyal, Alligin production data: downloaded from NSTA and averaged
- Field compositions as per HYSYS model
- Daily fuel gas usage
- Daily average plant operating conditions



bp Glen Lyon LP Flare



bp Glen Lyon HP Flare



Serica Bruce Flare System



HP Flare

- Single meter measuring total stream to 1st & 2nd stage flare

1st Stage HP Flare

- Routine operations

2nd Stage HP Flare

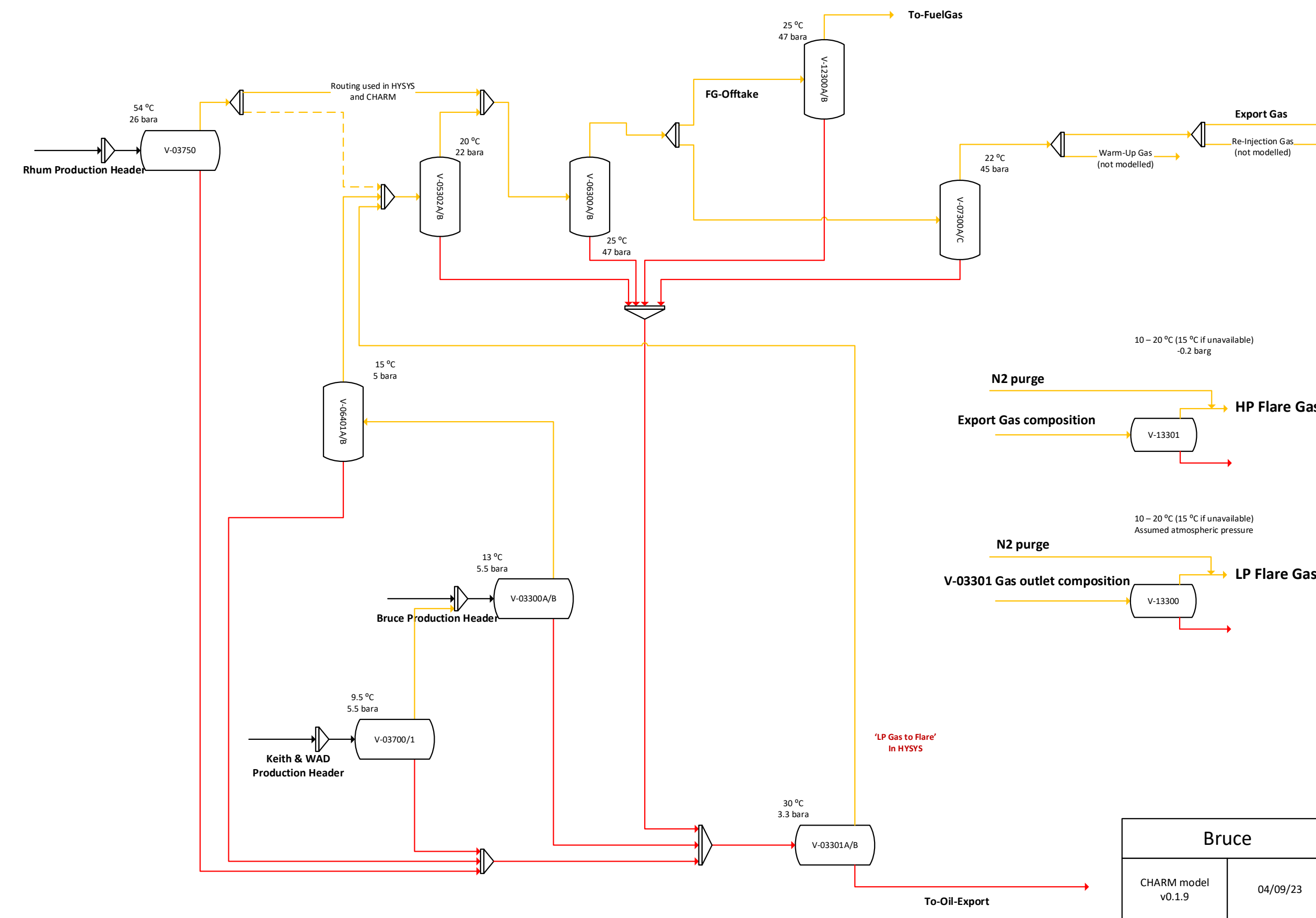
- Start-up / Shutdown / Safety usage
- Coanda array 9 x 'Tulip' Flare tips
- HP Flare > 1000 m³/h excluded from analysis

LP flare

- Routine operations

Serica Bruce Supplied Data & CHARM model

- Flare Sample data
 - HP flare: 5 export gas samples deemed representative
 - LP flare samples
- HYSYS model & PFDs with standard Op conditions
- Rhum – daily metered oil and gas production,
- Bruce – daily production data: downloaded from NSTA and averaged
- Keith & WAD – no production
- Field compositions as per HYSYS model
- Daily fuel gas usage
- Daily average plant operating conditions
- Input from Process Engineer



Serica Bruce LP Flare LHV

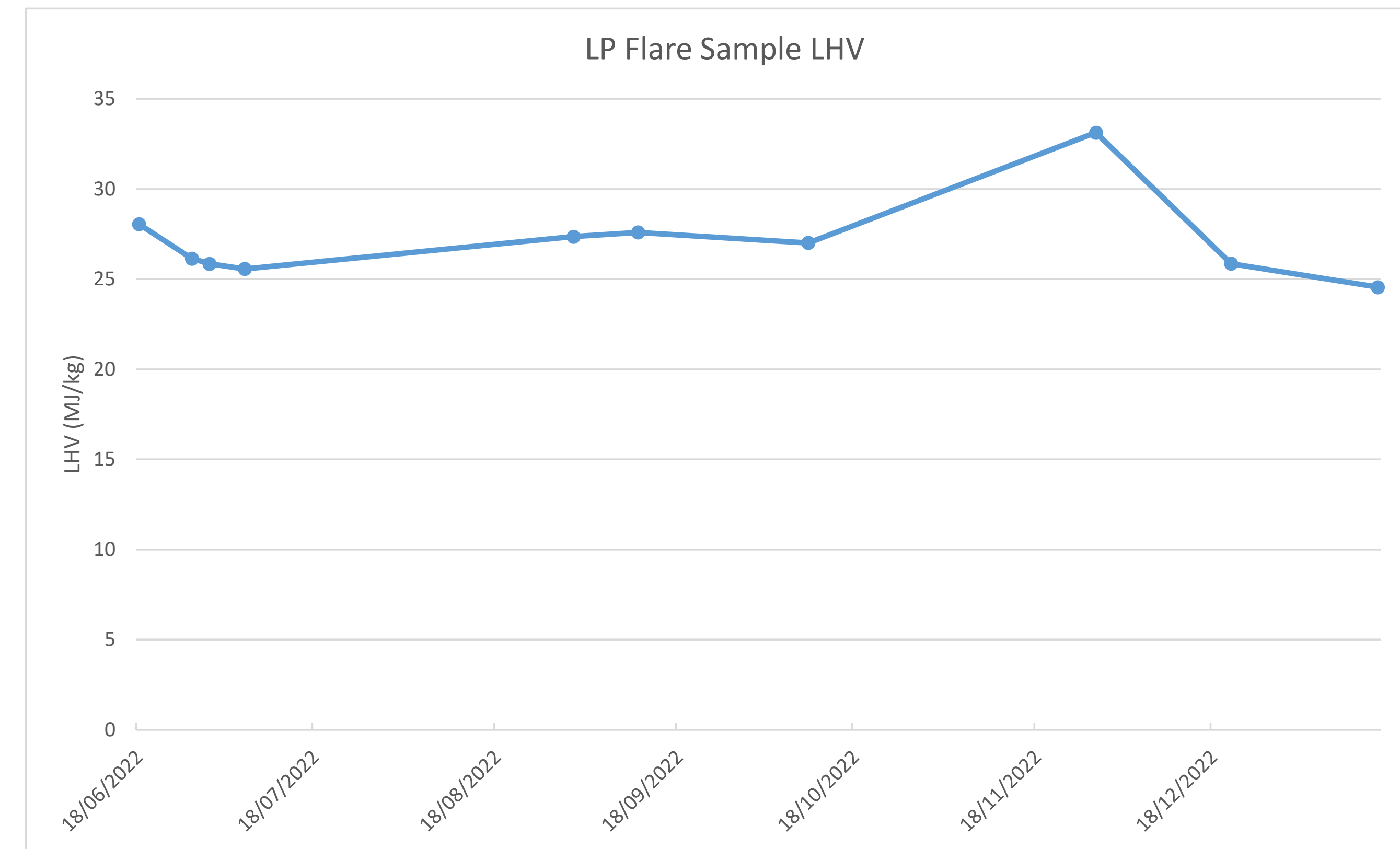
Primarily sourced from closed drains

Not modelled in process simulation

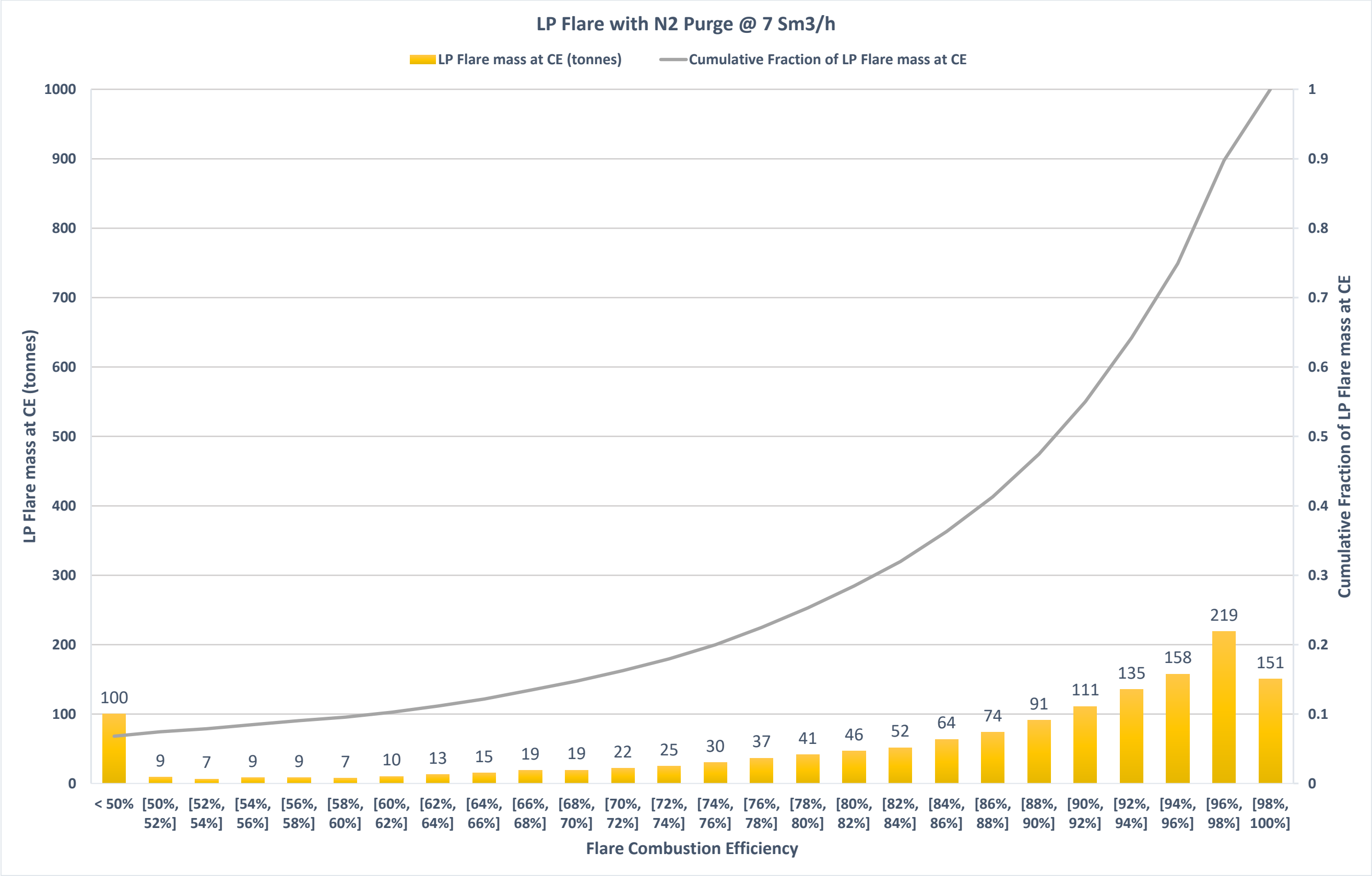
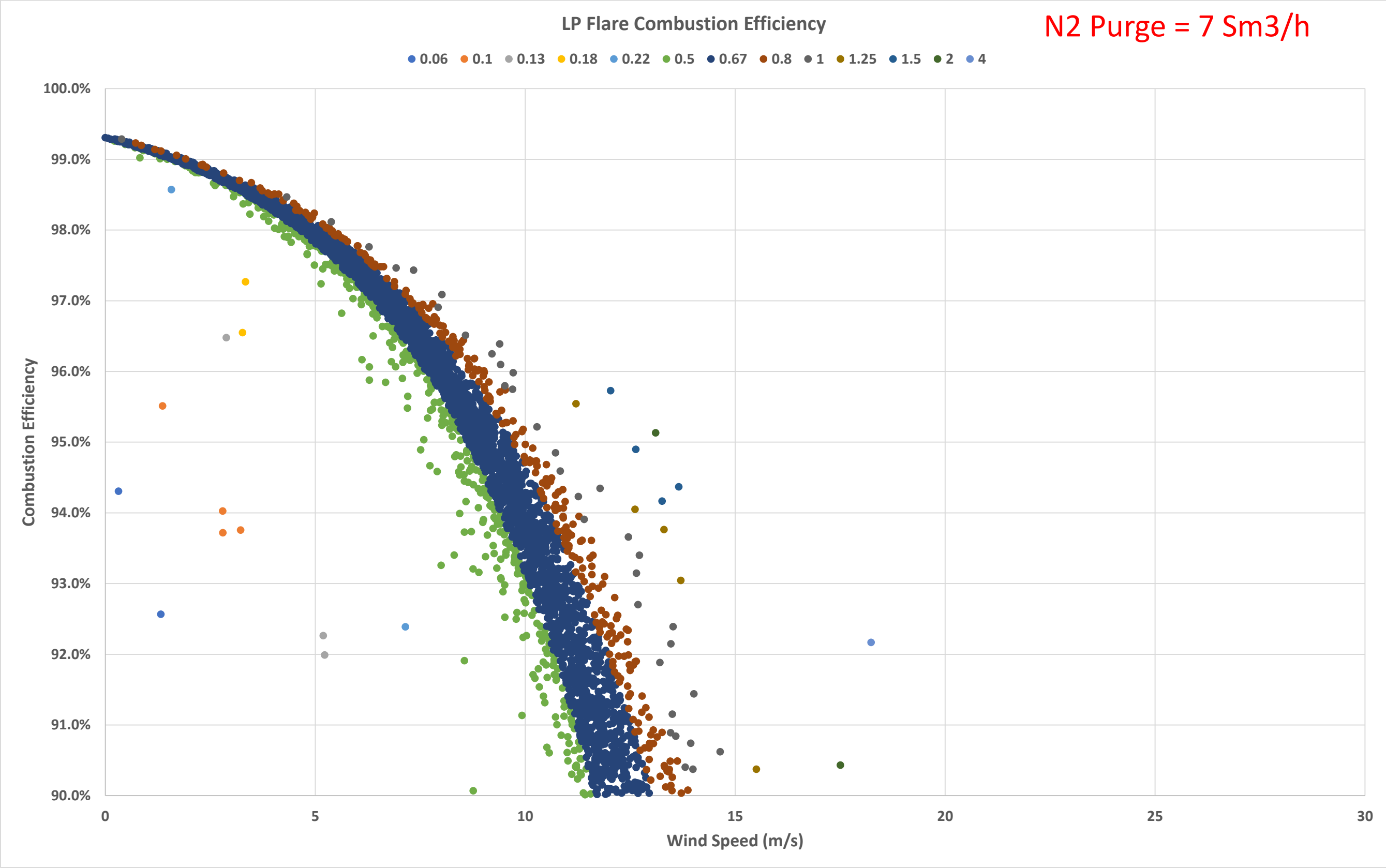
High N₂ and CO₂ content (~ 30 mol % total)

Low LHV ~ 28 MJ kg⁻¹ assumed for CE calculations

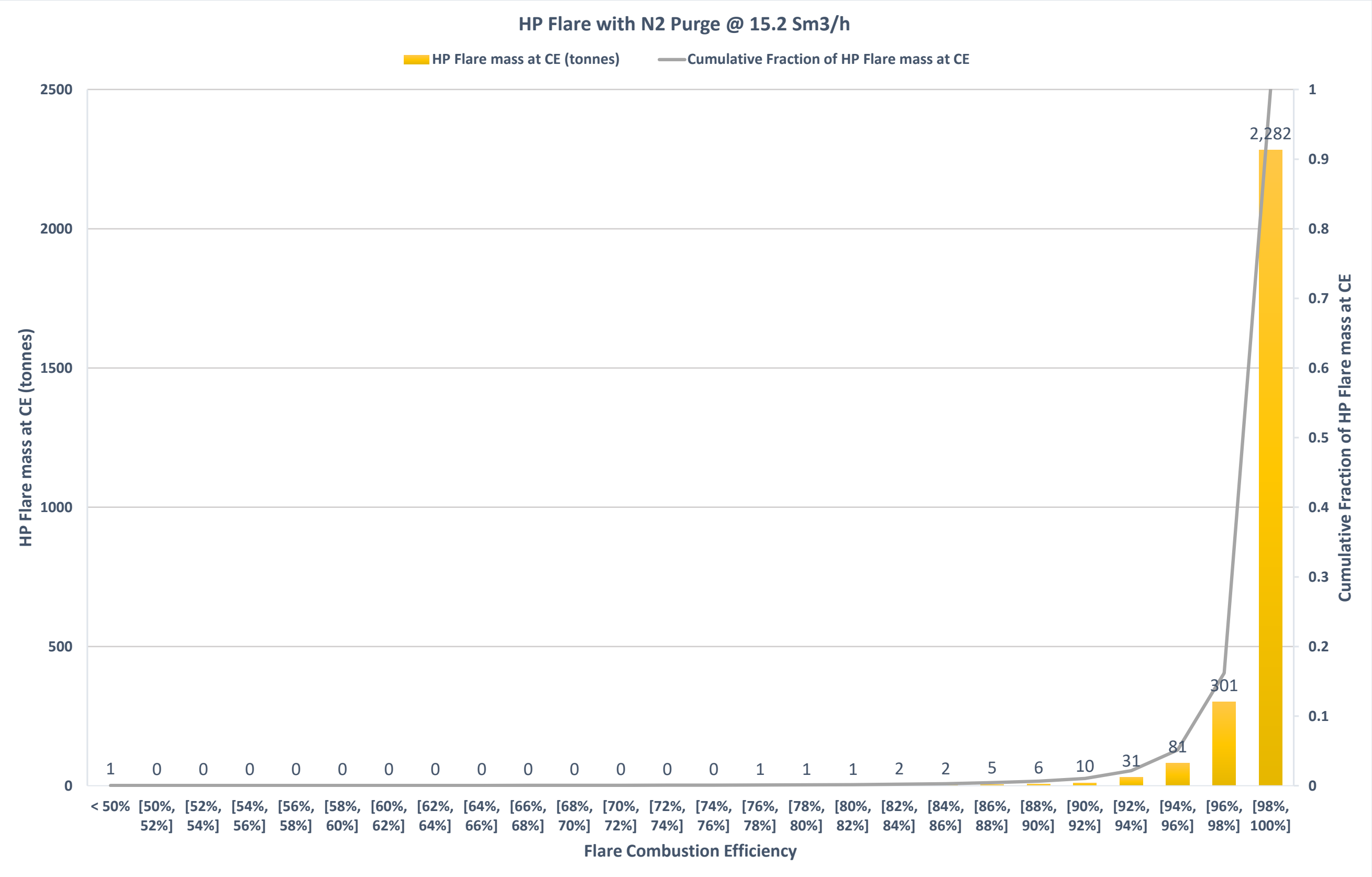
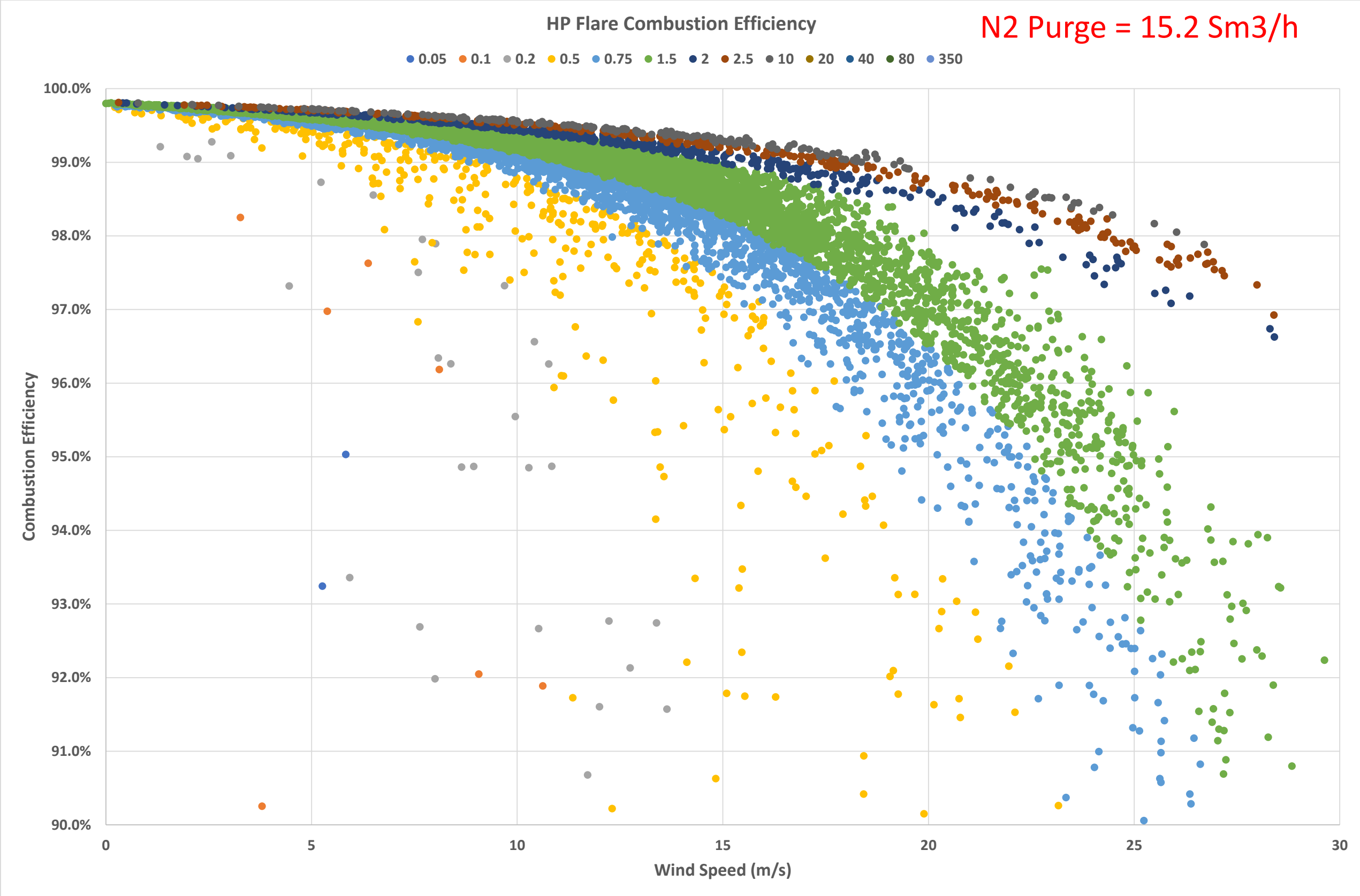
c.f. Glen Lyon 48 - 49 MJ kg⁻¹ & C₁ 50 MJ kg⁻¹



Serica Bruce LP Flare



Serica Bruce HP 1 Flare



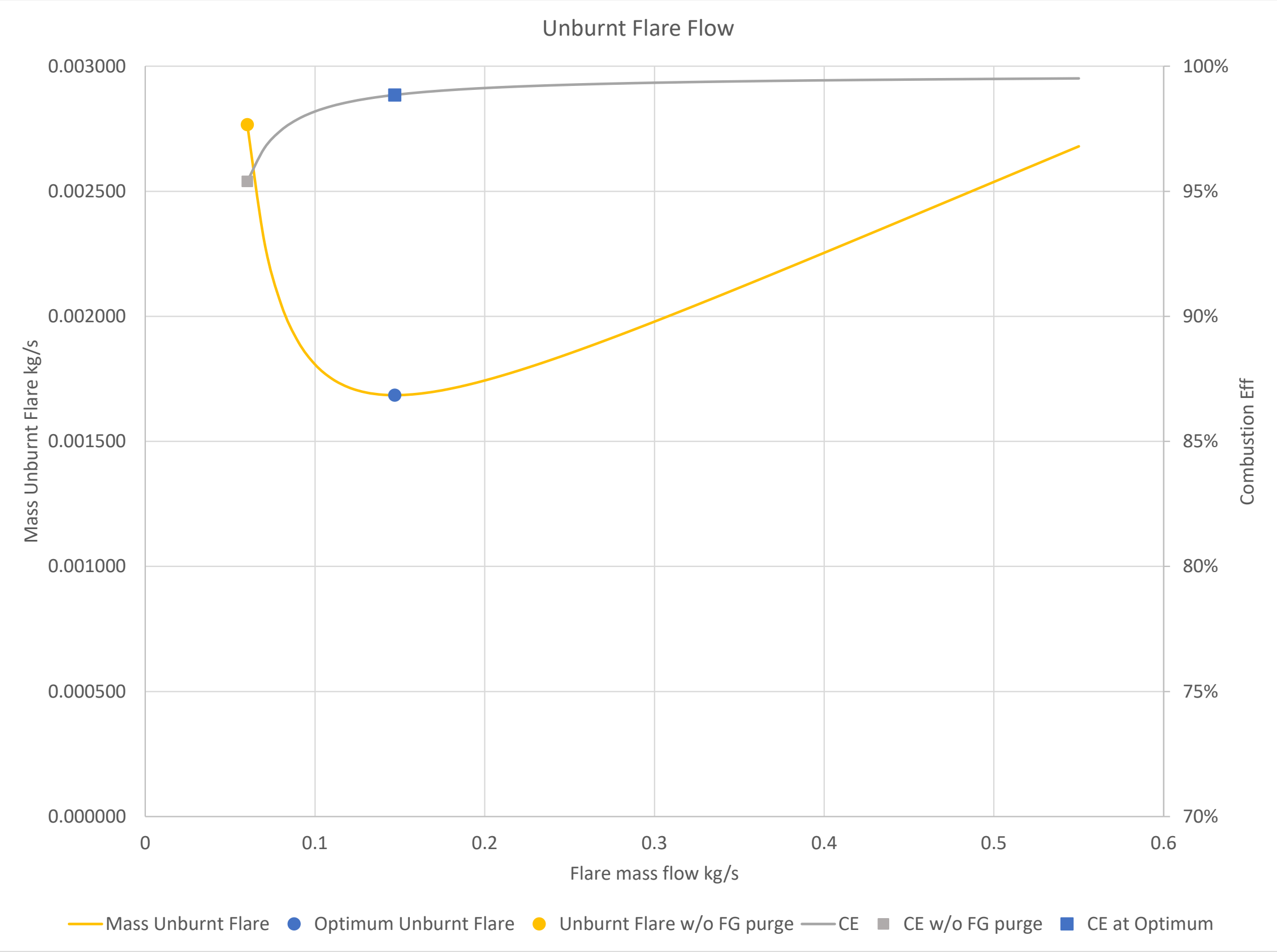
Optimisation

What should be optimised?

- Combustion Efficiency?
- Unburned Hydrocarbons?
- CO₂e mass?
- CO₂e \$?

Some examples of Serica Bruce LP Flare optimisation

Serica Bruce Fuel Gas Purge Example - Unburnt Flare Optimisation



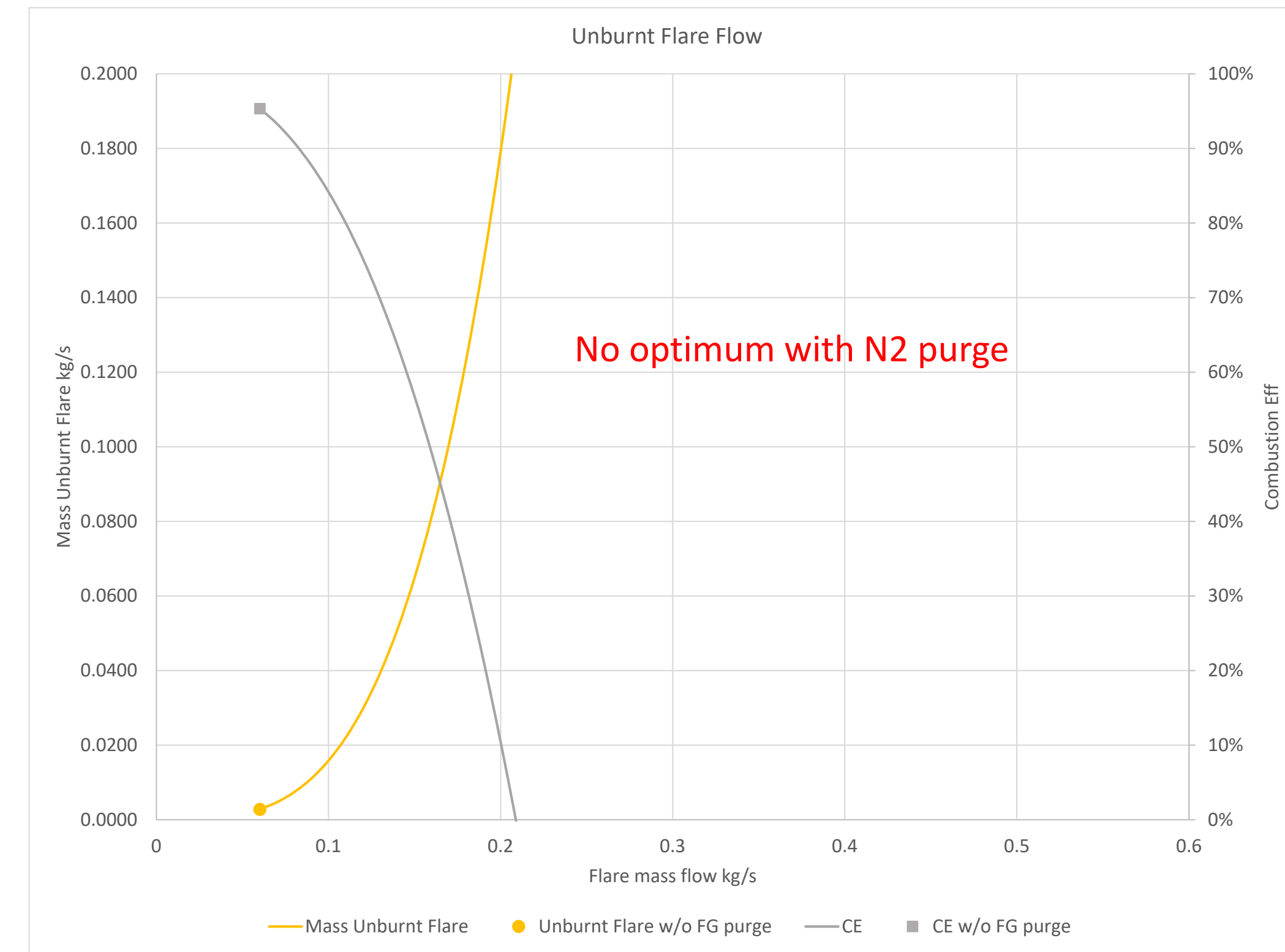
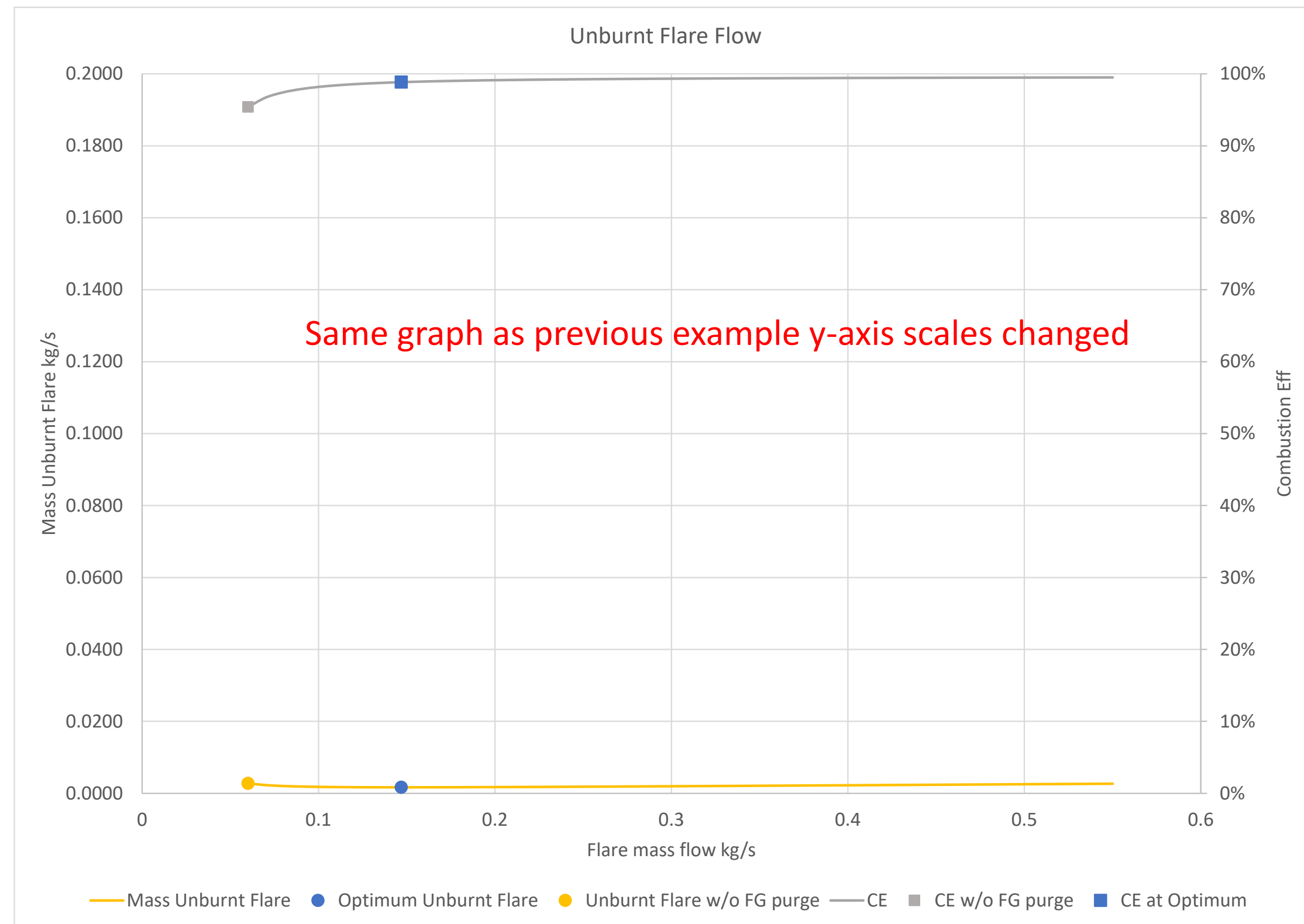
Switch off Nitrogen Purge

| Example conditions | |
|--------------------|----------------------------|
| Flare rate | 170 Sm3/h (190 kg/h) |
| N2 purge | No |
| Fuel Gas LHV | 42 MJ/kg |
| Wind Speed | 10 m/s (22.4 mph) |
| CE | 95.4% |
| Unburnt flare rate | 10.0 kg/h (0.24 tonne/day) |

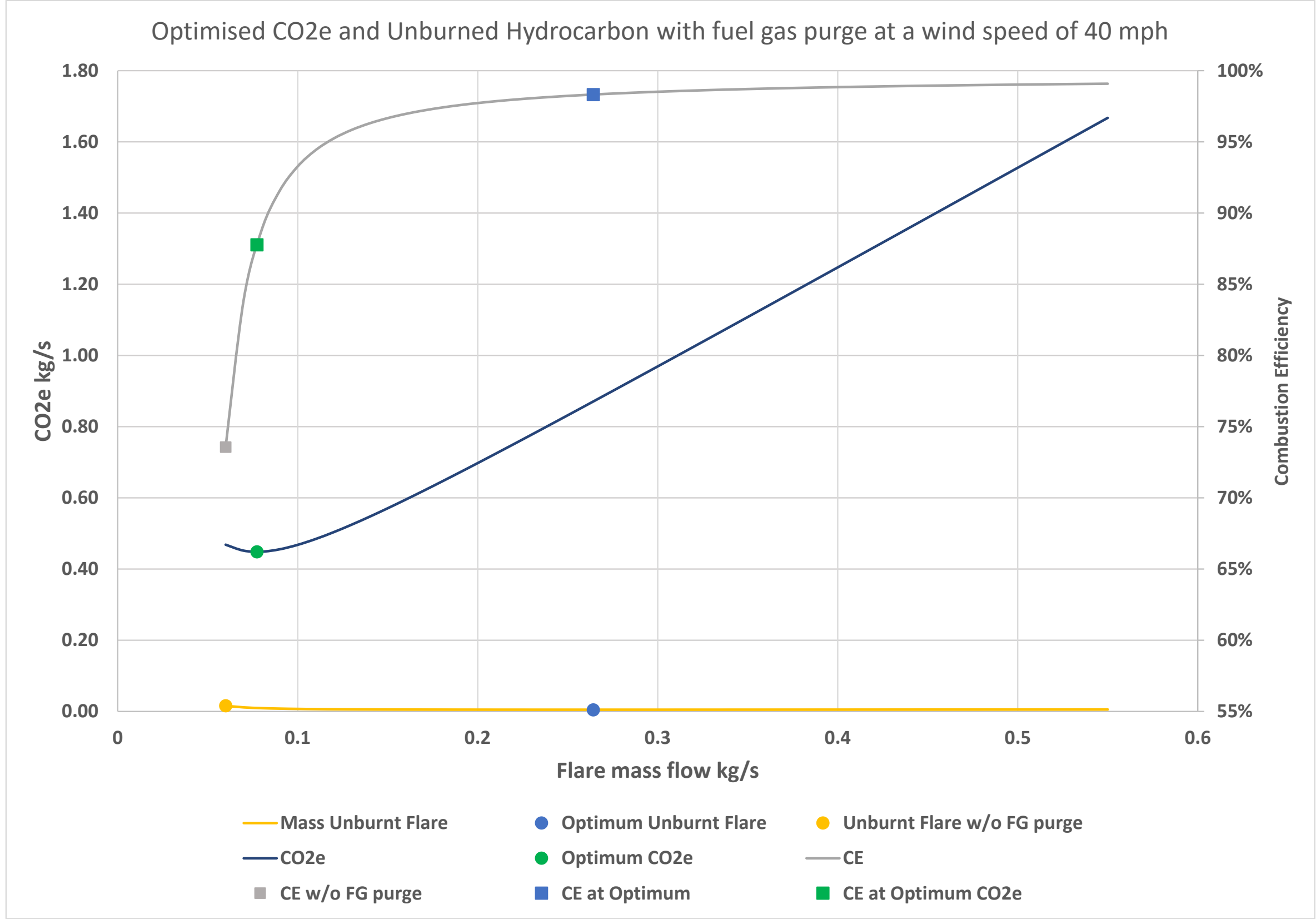
Turn on Fuel Gas Purge

| Optimum unburnt flare conditions | |
|----------------------------------|---------------------------|
| Fuel gas purge | 385 Sm3/h (313 kg/h) |
| CE | 98.8% |
| Unburnt flare rate | 6.1 kg/h (0.15 tonne/day) |
| Absolute reduction | 3.9 kg/h (0.09 tonne/day) |
| % reduction | 39 % |

Serica Bruce N₂ Purge Example – No Unburnt Flare Optimum



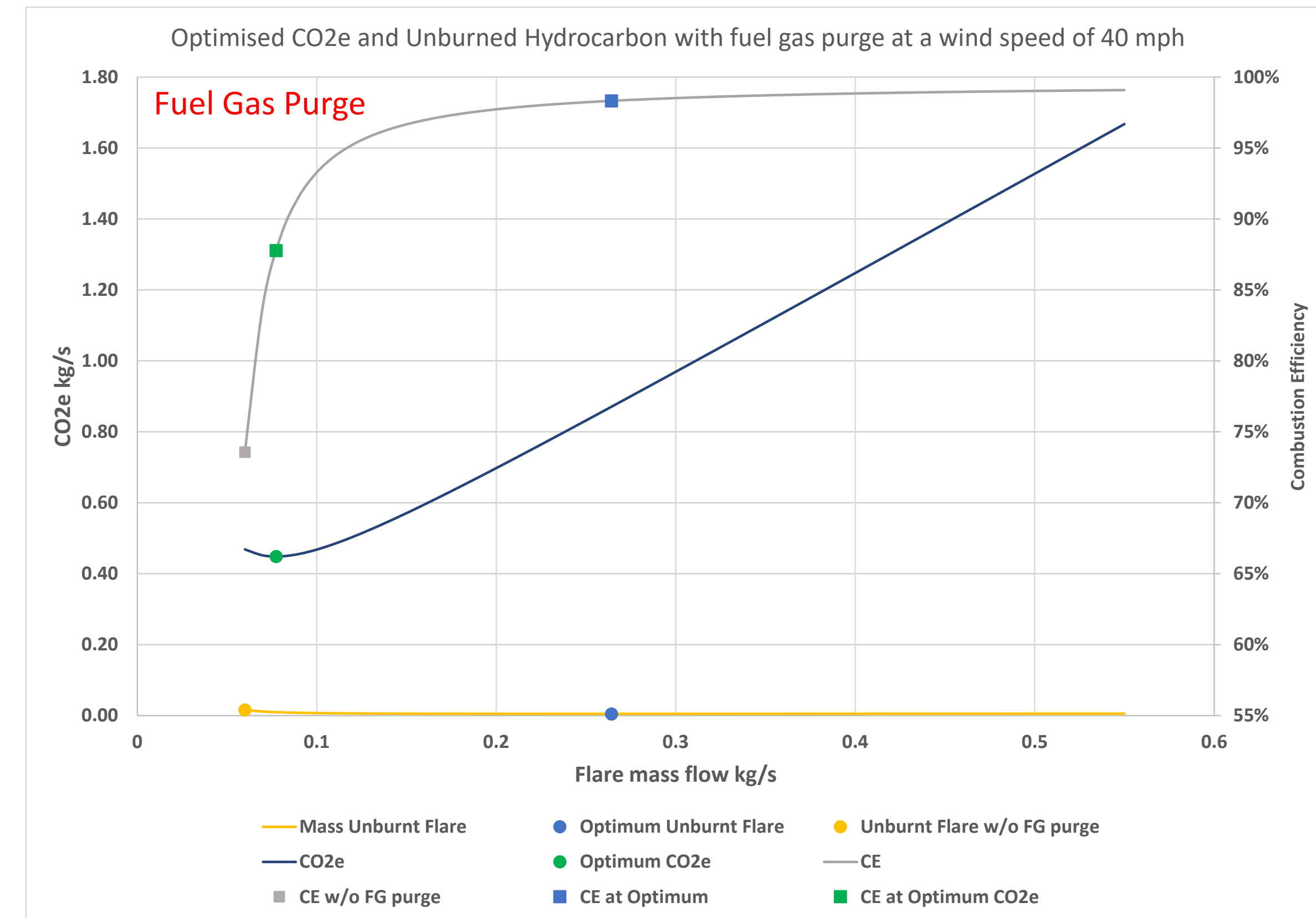
Serica Bruce Fuel Gas Purge Example – CO2e Optimisation



| Example conditions | |
|--------------------------|-----------------------------|
| Flare rate | 170 Sm3/h (190 kg/h) |
| Flare Emission Factor | 1.89 (tonnes CO2e/tonne) |
| Flare C1 | 28.9 wt % |
| N2 purge | No |
| Fuel Gas LHV | 42.9 MJ/kg |
| Fuel Gas Emission Factor | 2.60 (tonnes CO2e/tonne) |
| Fuel Gas C1 | 73.8 wt % |
| C1 GWP | 84 (tonnes CO2e/tonne) |
| Wind Speed | 17.88 m/s (40 mph) |
| CE | 73.6% |
| CO2e rate | 1685.6 kg/h (40.45 tonne/d) |

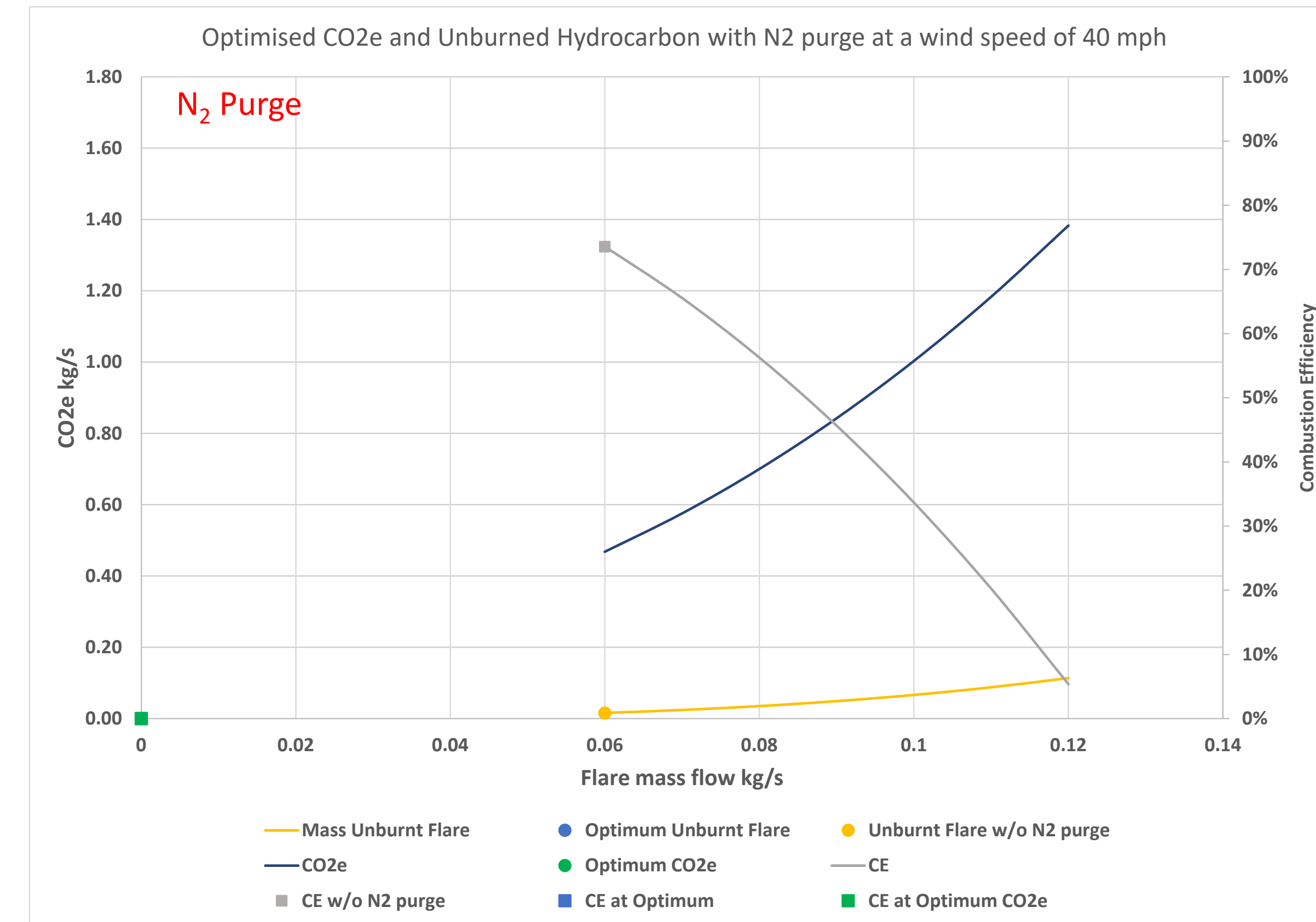
| Optimum CO2e conditions | |
|-------------------------|-------------------------------|
| Fuel gas purge | 77 Sm3/h (62.4 kg/h) |
| CE | 87.8% |
| CO2e rate | 1613.8 kg/h (38.73 tonne/day) |
| Absolute reduction | 71.7 kg/h (1.72 tonne/day) |
| % reduction | 4.4 % |

Serica Bruce N₂ Purge Example



N₂ purge example

- Combustion Efficiency plummets
- No CO₂e optimum
- Note Flare flow rate scale change
- UoA predicts
 - CE = 0
 - When N₂ purge ~ 0.063 kg s⁻¹



Optimisation

- Depending on the flare design, composition and ambient conditions it may not be possible to optimise CO₂e other than to reduce flaring
- Increasing flare Combustion Efficiency may not optimise greenhouse gas emissions
- Optimisation using Combustor is undertaken on a static basis at present as part of the implementation exercise
- Dynamic Optimisation would require Combustor to be integrated with the plant control system

Combustion Efficiency Uncertainty

Calculated in two recognised ways:

- Analytically using the GUM, propagation of uncertainties using Taylor Series Method
- Monte Carlo, cross check

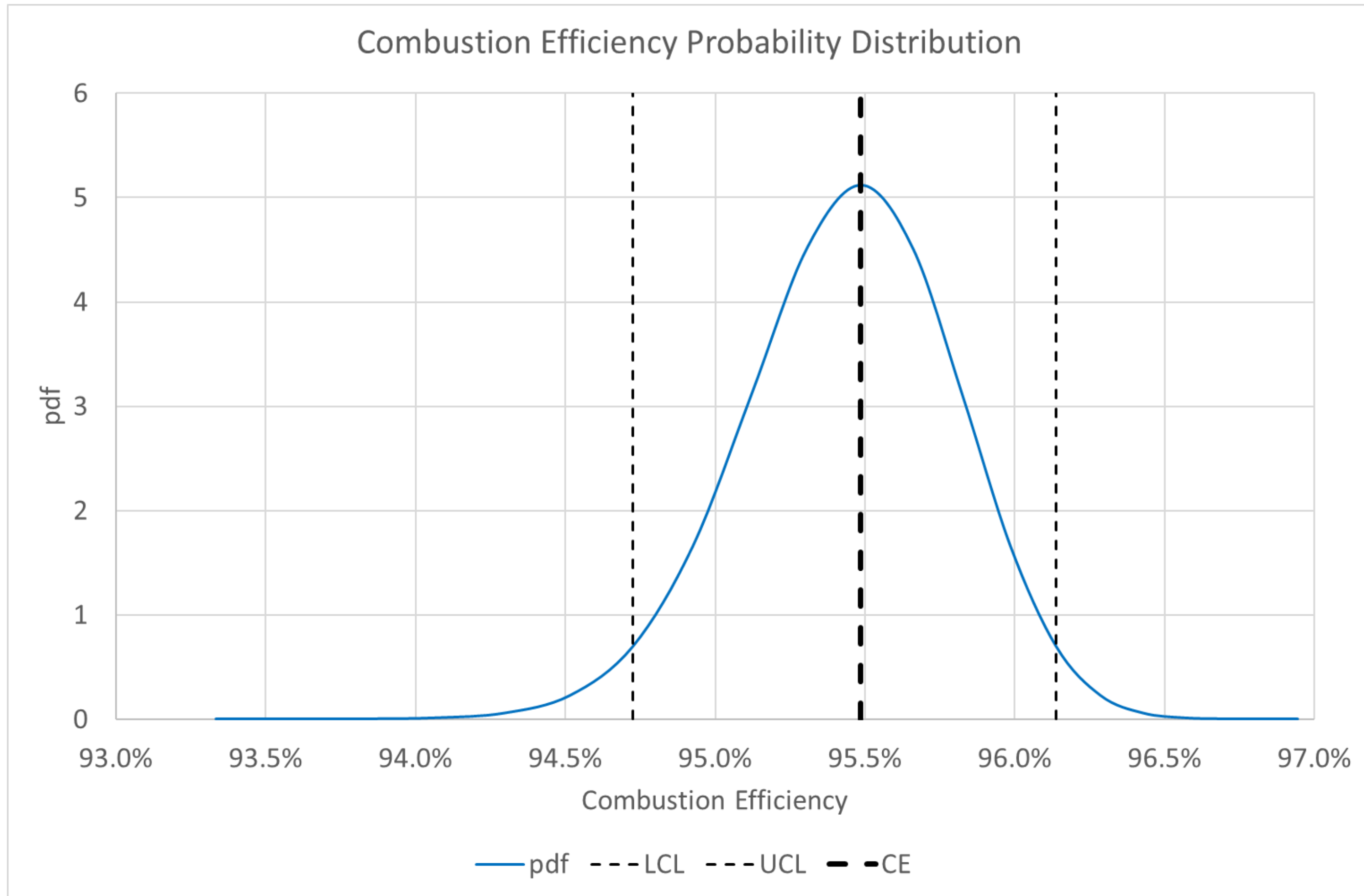
| | | |
|---------|-------------|----------------------------------|
| LHV_f | $\pm 0.6\%$ | Flare gas LHV from CHARM (MJ/kg) |
| U_w | $\pm 1\%$ | Wind speed (m/s) |
| U_f | $\pm 7.5\%$ | Flare exit velocity (m/s) |
| d | $\pm 1\%$ | Flare outer diameter (m) |
| A | | UoA equation constant |
| B | | UoA equation constant |
| AB | | Covariance term |

$$CE = 1 - A \left(\frac{LHV_{CH_4}}{LHV_f} \right)^3 e^{\left(\frac{B U_w}{(U_f g d)^{1/3}} \right)}$$

$$C_i = \frac{\partial CE}{\partial X_i}$$

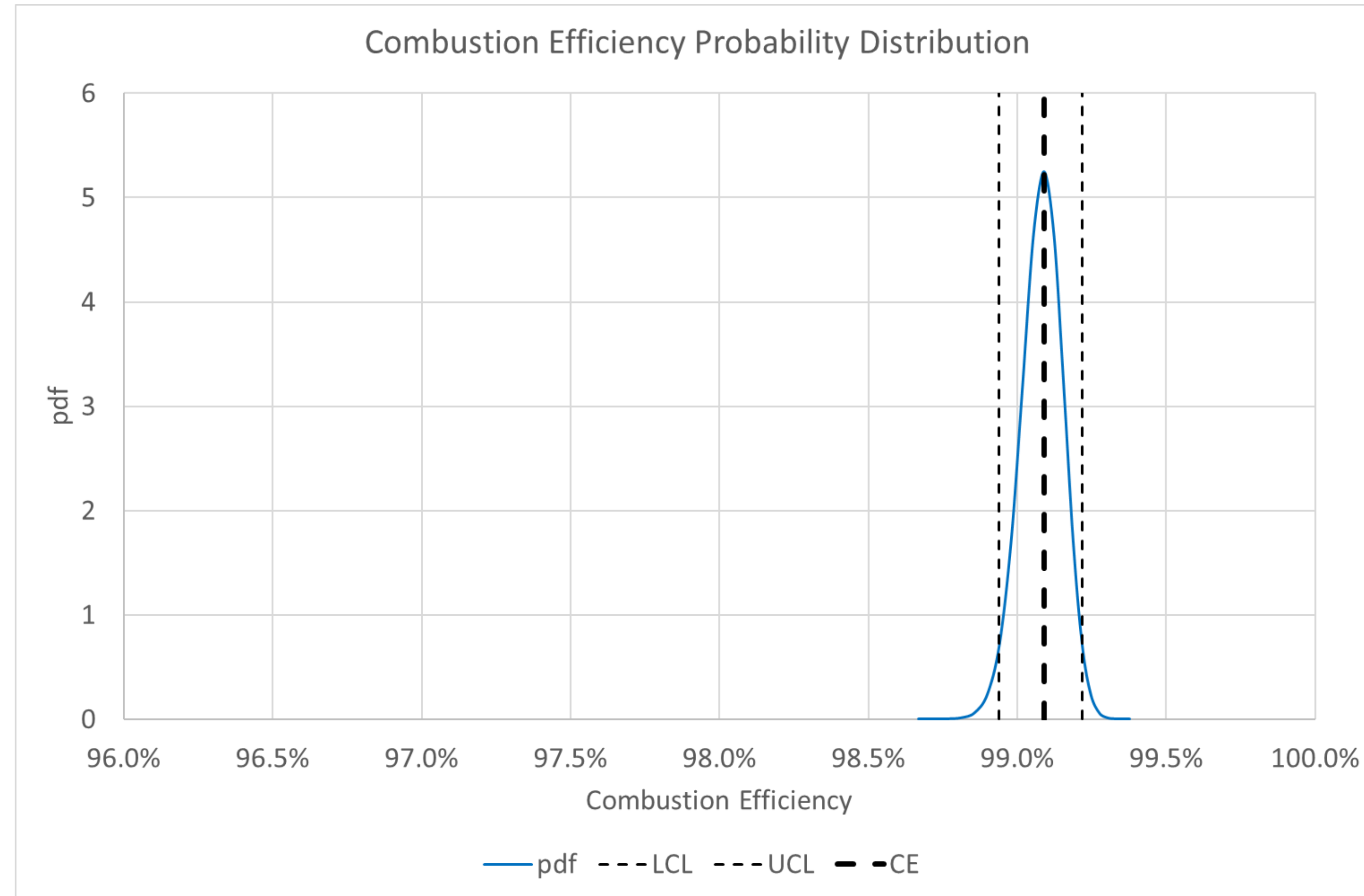
$$Unc_{CE} = \sqrt{\sum_i (C_i * Unc_{X_i})^2}$$

Actually, uses logarithmic formulation



High Wind Speed
19 m/s

Average Wind
Speed 10 m/s



Total Culzean Data & CHARM model

Update existing CHARM model for live use

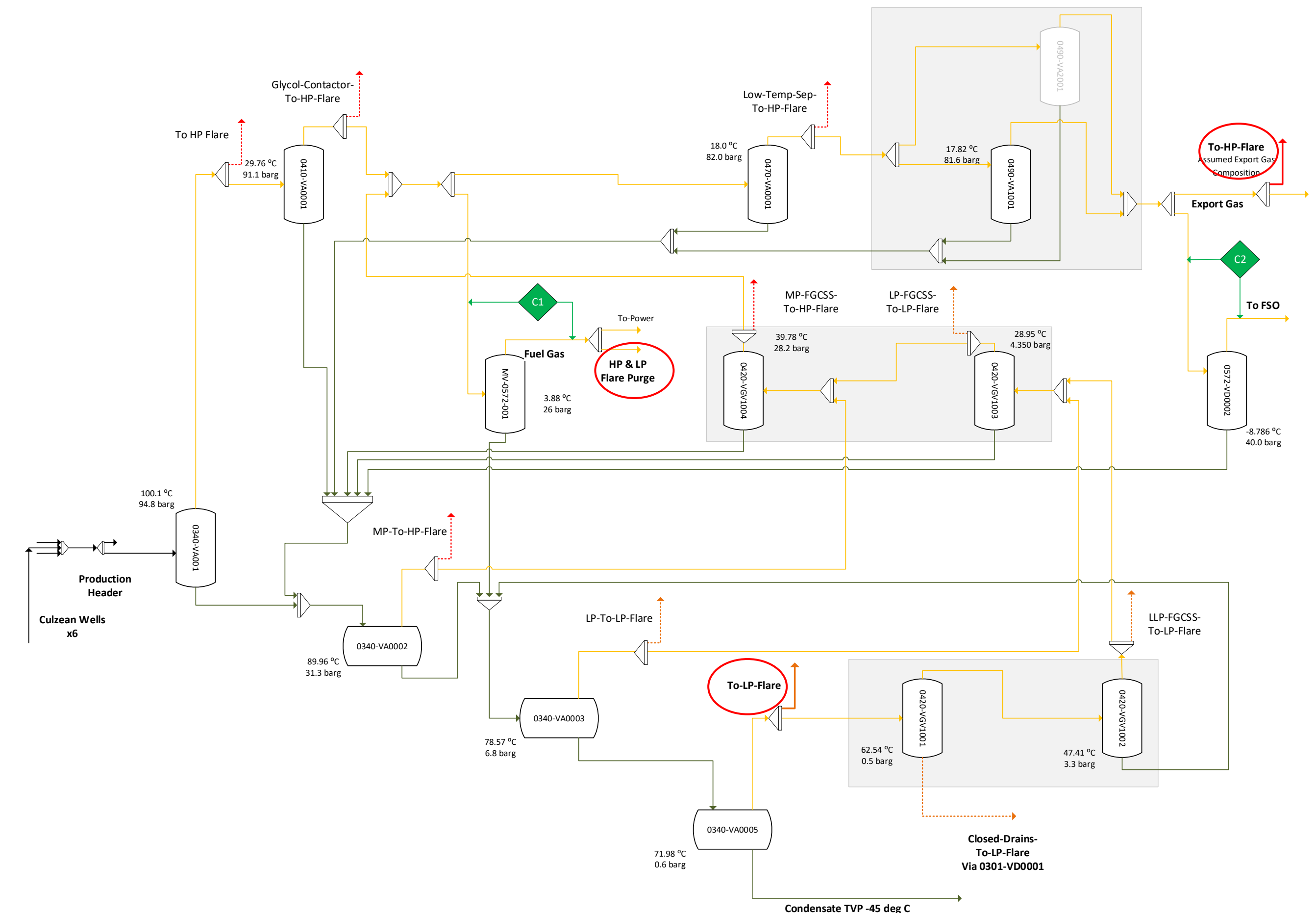
- Revalidate process model
- Identify live PI tags (Operating conditions, flare, fuel, purge gas rates)
- Identify dominant HP & LP flare sources

Well Production

- Live oil & gas production rates provided
- GOR-matched feed steams

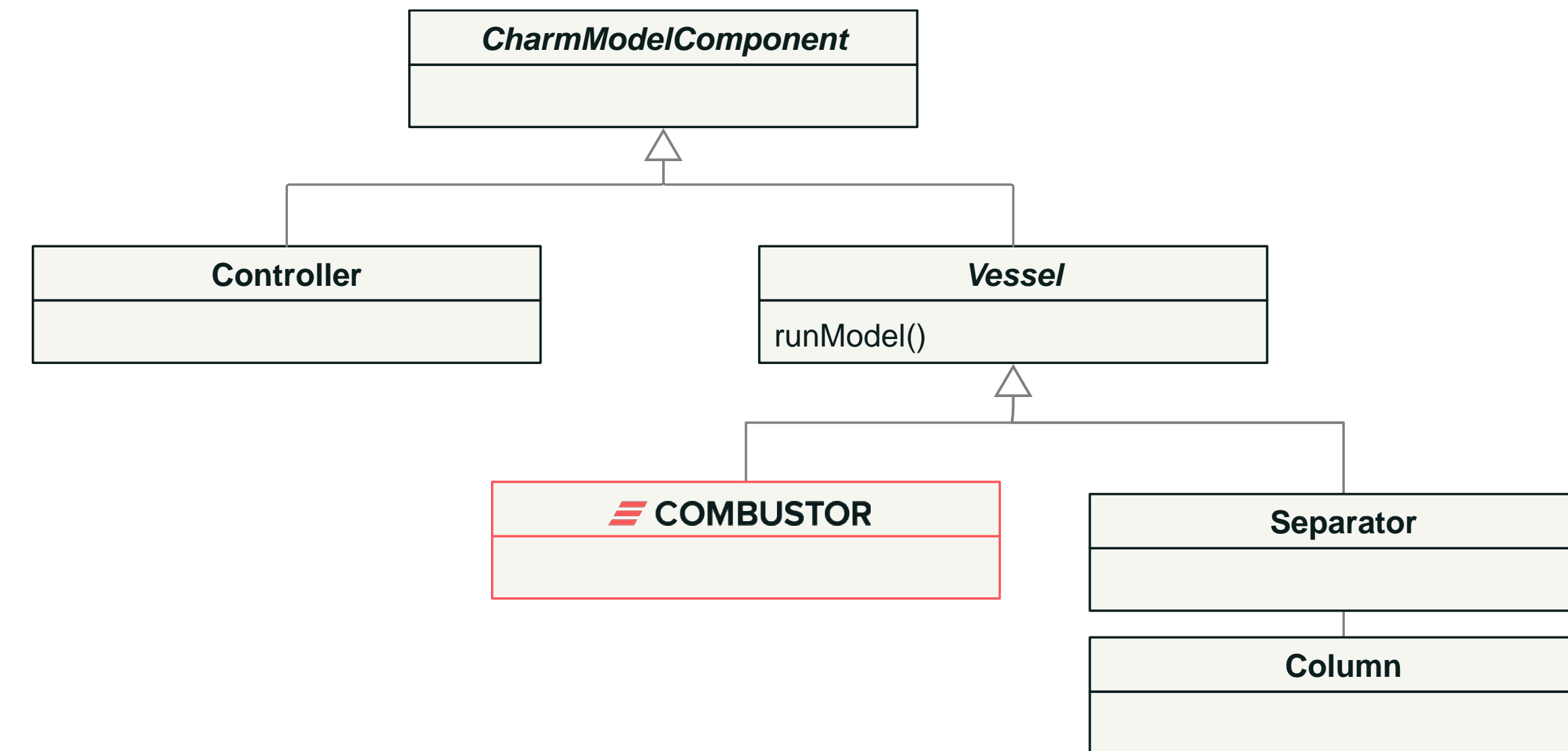
Purge gas

- Fuel / N2 purge gas upstream of KO drums
- Controller required to match each HP / LP flare meter measured flowrate



Implementation

- Integrated with the CHARM process modelling software
 - Java implementation – portable and efficient
 - Deployed on the cloud
 - Secure and controlled software environment
 - Additional calculations and extensions can be added
-
- Fast – typically 0.1 – 1s execution time depending on complexity of the process model
 - Simple runs can involve ~300 iterations of FlashCalculation; several million for more complex models
 - Reproducible – you always get the same answer
 - Reliable
-
- Full integration with CHARM allows complete modelling of the process
 - Allows use of CHARM “Controllers” to seek optimal solutions



$$CE = 1 - 0.001066 \cdot \exp \left(\frac{0.317 \cdot Windspd}{\sqrt[3]{ExitVel \cdot g \cdot Dia}} \right) \cdot \left(\frac{LHV_{CH4}}{LHV_{flare}} \right)^3$$

```

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    <windspeed>19.3</windspeed>
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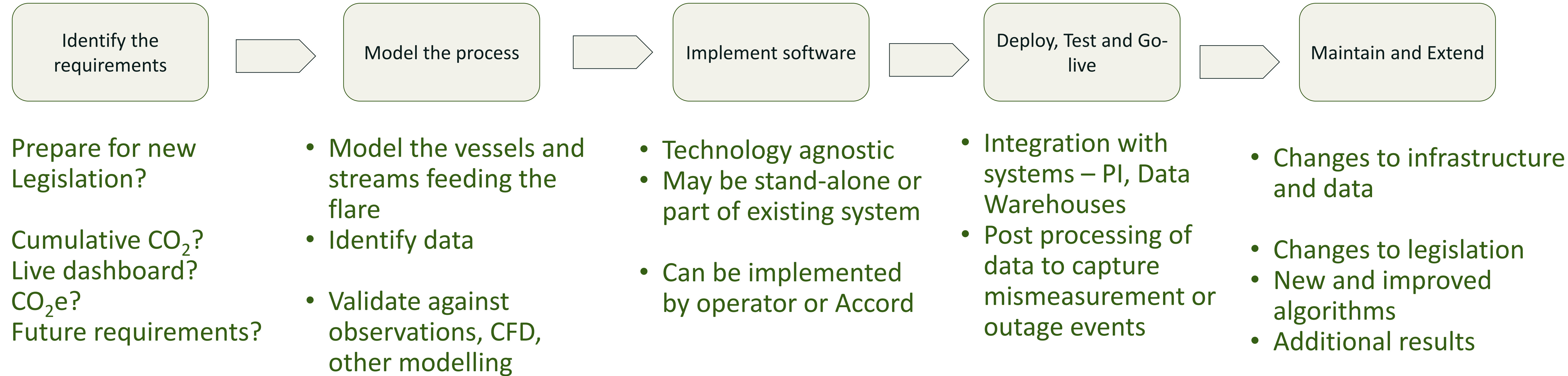
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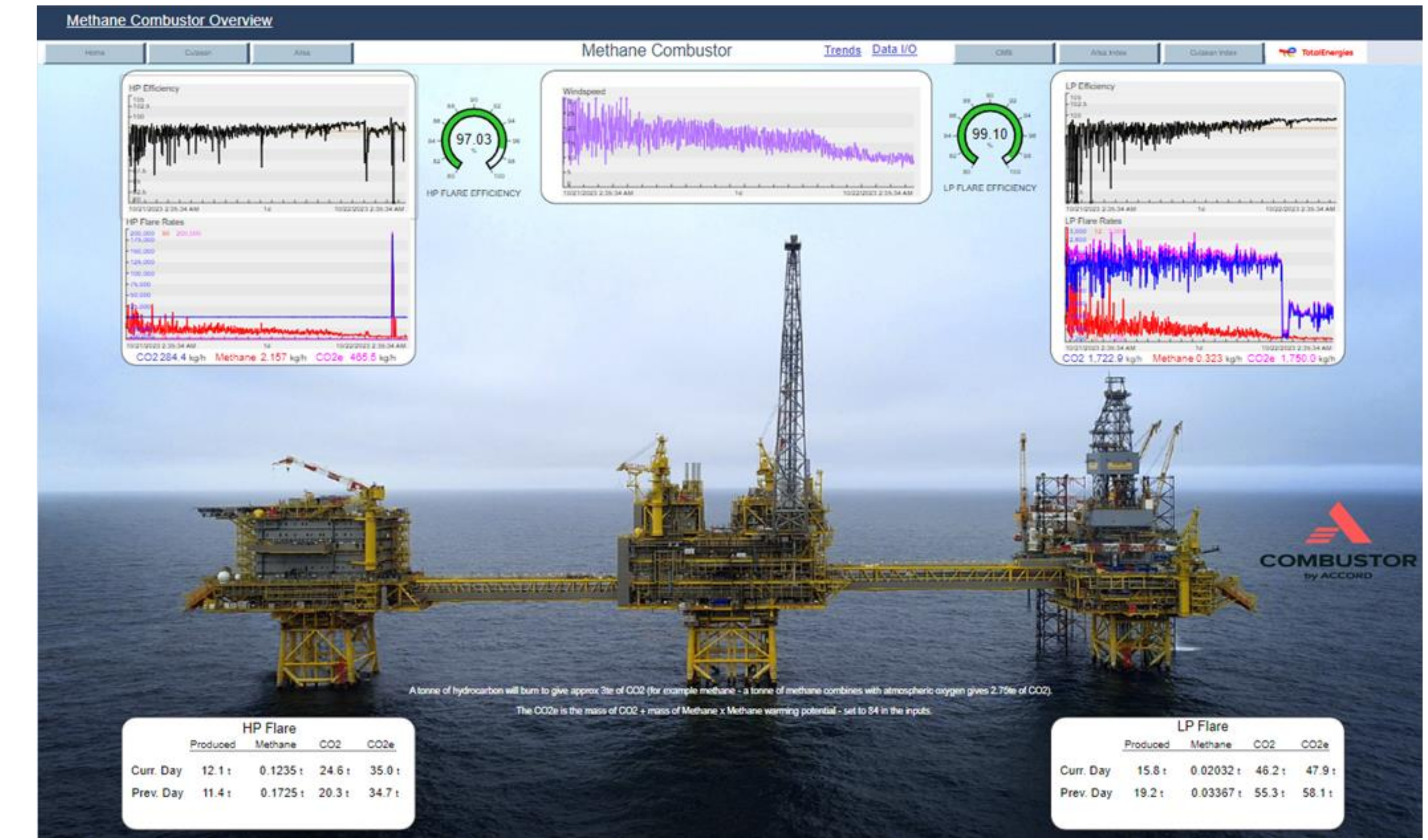
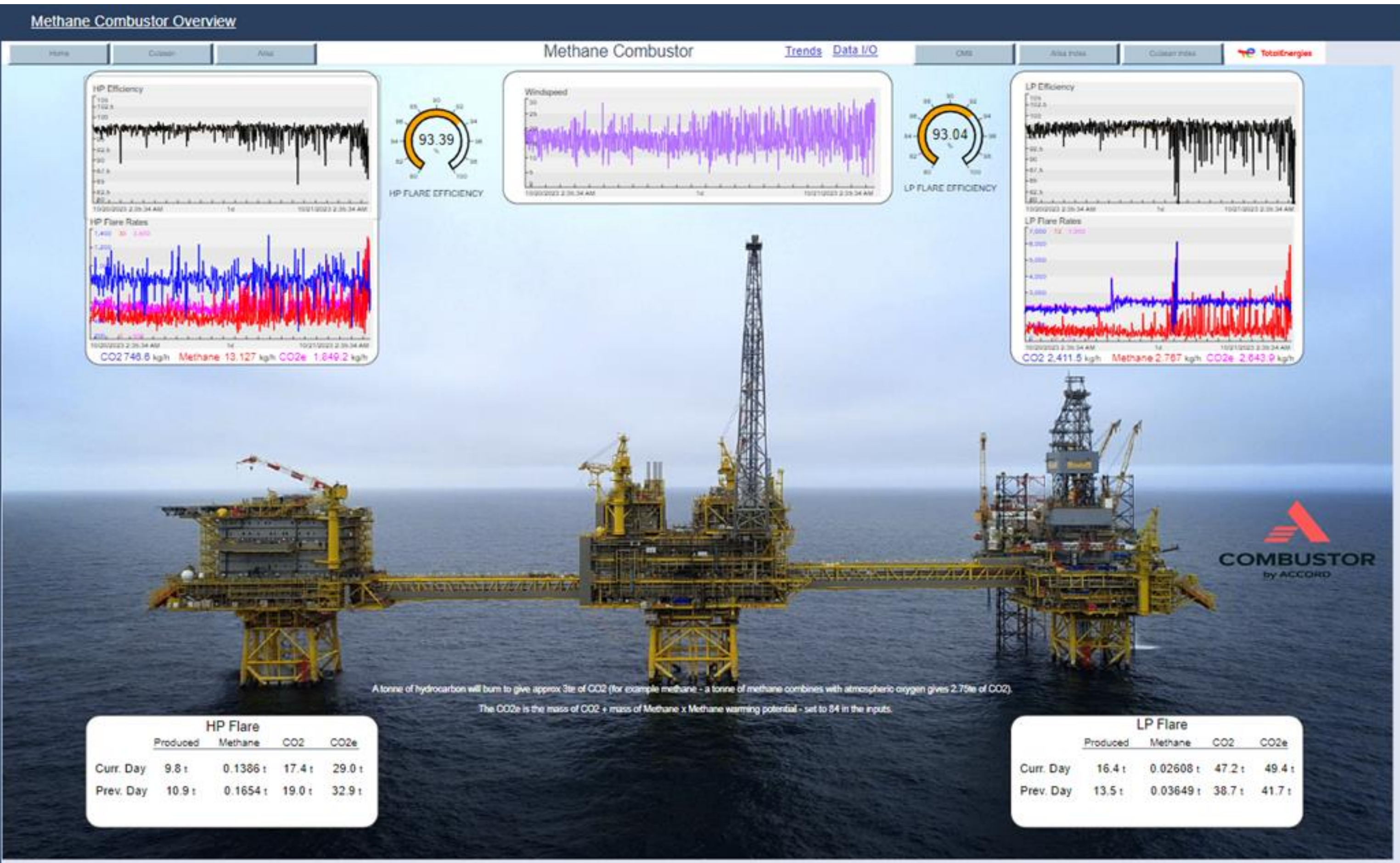
Combustor Deployment

- XML and industry-standard protocols used throughout
- Client generates input and sends the model configuration
- CHARM performs calculation
- Results sent back

Client's implementation transparent to Combustor

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 ion system
 sheet
 ng supervisory computer
 , Azure, Java, VB...





Some of the things we learned:-

- Modelling process is repeatable across assets
- Operator support is required to develop and verify simulation
- Timeline to finalise simulation model varied between 2 and 4 working weeks
- Software installation is relatively simple and quick
- LHV of flare gas needs to account for N2 and/or flare gas purge
- Optimisation of CO2e may not be possible on all assets – design dependent
- Uncertainty calculations need to account for the exponential nature of the UoA algorithm

Are there any next steps?

- Validate the Combustor methodology for GHG reporting (AA1000 Accreditation)
- Investigate potential for Magnaflare proposal

Some of the things we get from Combustor:

- Aligns with OGMP 2.0 and OEUK Methane Action Plan
- Minute by minute calculation of CO2, CH4, CO2e flow rates
- Cumulative totals and reporting for CO2, CH4 and CO2e
- Live uncertainty reporting for Combustion Efficiency
- Identify and optimise CO2e performance (where possible)
- Ability to post process data for mismeasurement events
- Can be updated to incorporate future plant changes
- Can be used to study and inform future plant changes
- Pre and post combustion compositional information
 - ISO6976 CVs, AGA8 Densities, etc.