

# Oil Framework V1.0

WHITEPAPER



# Executive Summary

Sylvera's Crude Oil Carbon Intensity Framework provides comparable, crude-stream-specific upstream carbon intensity values for 416 globally traded crude oil streams.

The framework enables like-for-like comparison of upstream emissions across geographies, operators, and production methods – moving beyond aggregate country-level labels to a more granular, comparable basis.

- Carbon intensity is expressed in gCO<sub>2</sub>e/MJ of crude oil, covering the cradle-to-gate system boundary (well-to-facility gate), aligned to IPCC AR6 GWP100
- The framework operates across four modelling tiers based on data availability: continent-level and country-level Ecolnvent emission factors, US State-level EPA facility data with API proximity weighting, and technology-specific adjustments for Norway (grid electrification) and Canada (oil sands)
- Each CI is paired with a confidence score (Very High to Very Low), reflecting the completeness of available emission drivers, the granularity of the emission factor used, and the reliability of the underlying data extraction
- The framework is designed to support mechanism eligibility assessment, connecting upstream CI values to downstream policy pathways including CORSIA, LCFS, and emerging low-carbon fuel standards

Carbon intensity values are calculated using Sylvera's proprietary methodology, integrating open-source databases (Ecolnvent 3.12, EPA Subpart W, GEM, CORSIA, LCFS, PRELIM) with targeted manual data extraction. The model combines LCA principles with commodity-specific expertise to deliver representative modelling pathways based on the best available data.

# Introduction to Oil

## Crude Oil Carbon Intensity Analysis

Crude oil supplies approximately 30% of global primary energy and underpins over 90% of transport energy consumption, including road freight, aviation, and maritime shipping. At roughly 100 million barrels per day, crude oil is a structural driver of inflation, energy security, and trade balances worldwide.

The emissions profile of oil is asymmetric across its value chain. Approximately 70% of lifecycle emissions occur at combustion, but upstream production emissions are both material and highly variable across geographies, operators, and production methods. The average upstream barrel emits 16–20 kg CO<sub>2</sub>e, yet best-in-class assets operate below 5–10 kg CO<sub>2</sub>e. If all producers converged toward best-in-class intensity, the IEA estimates operational emissions could fall by ~60% by 2030, eliminating roughly 3 Gt CO<sub>2</sub>e/year from a current base of 5.1 Gt (IEA, 2023).

Sylvera's framework assigns CI values to individual crude streams worldwide, shifting from aggregate country-level benchmarks to a continuous, stream-specific scale.

Beyond scoring, the framework supports mechanism eligibility assessment — enabling producers, refiners, and buyers to identify which streams qualify under CORSIA, LCFS, and emerging low-carbon fuel standards. By connecting upstream CI to downstream policy pathways, the framework makes carbon data directly actionable across the value chain.

## Our Approach

We calculate CI values by combining open-source databases with manual data extraction. Our model integrates commodity-specific expertise with LCA principles and leading emission factor databases to provide representative modelling pathways based on best available data.

## Understanding the Score

Each assessment produces a CI value (gCO<sub>2</sub>e/MJ of crude oil), accompanied by a confidence score (Very High to Very Low) reflecting the completeness of available field and facility data and the representativeness of emission factors used.

# LCA Methodology

## Framework Goal

The goal of the framework is to calculate crude-stream-specific carbon intensity values for global upstream crude oil production. The framework is informed by the principles of ISO 14040, 14044, and 14067 and provide a **standardised approach to enable like-for-like comparisons across the global market**. It also provides an actionable alternative to the fragmentation of different reporting scheme requirements, presenting a carbon intensity continuum beyond the limiting industry categorisation.

Beyond carbon intensity scoring, the framework is designed to support **mechanism eligibility assessment** – enabling oil producers, refiners, and buyers to understand which crude streams and supply chain actors may qualify under key decarbonisation mechanisms such as CORSIA, LCFS, and emerging low-carbon fuel standards. By connecting upstream CI values to downstream policy pathways, the framework makes carbon data **directly actionable** across the crude oil value chain.

## System Boundaries, Functional Unit, LCIA

**Functional Unit:** 1 MJ of crude oil (gCO<sub>2e</sub>/MJ)

**System Boundary:** Cradle-to-gate (well-to-facility gate)

### Included Processes:

- Crude oil production via conventional extraction, considering infrastructure inputs, energy requirements, and gas processing
- Vented, flared, and fugitive emissions, including methane slip
- Energy-intensive production methods (primary, secondary, and tertiary recovery)
- Pumping and separation of depleted oil fields (high water-oil ratio)
- Specific technology application (when relevant):
  - a. Electrification of oil fields (Norway)
  - b. Extraction and processing of unconventional oil (Canada)

### Excluded Processes:

- Land Use Change emissions
- Exploration phase and well testing

**Allocation Approach:** Upstream emissions are allocated in full to the crude output stream. Co-products are treated as burden-free.

**LCIA:** IPCC AR6 – GWP100 (CH<sub>4</sub> = 27.2)

# Data Source

## LCA Methodology

### Data Source

Facility Activity Data	Background Data
<p>Database: <a href="#">GEM Global Cement and Concrete Tracker</a></p> <p>Manual Extraction: facility websites, GEM-referenced articles, EPDs, Baidu profiles for Chinese facilities, PRELIM v1.6 (API, Sulfur %, Hydrogen % per crude grade)</p>	<p>Database: EcolInvent 3.11</p> <p>Other: open-source literature emission factors, peer-reviewed literature on energy and electricity intensities</p>

# Carbon Intensity Modeling

## Description

The **Carbon Intensity value**, measured in grams of CO<sub>2</sub>e per megajoule of crude oil (gCO<sub>2</sub>e/MJ), allows the comparison of crude streams' upstream emissions on a single axis. This value is calculated through a combination of public datasets and field-specific data, LCA mapping, and common practice assumptions when necessary and appropriate. To reflect differences in data quality and data availability, carbon intensity values are paired with **confidence scores**.

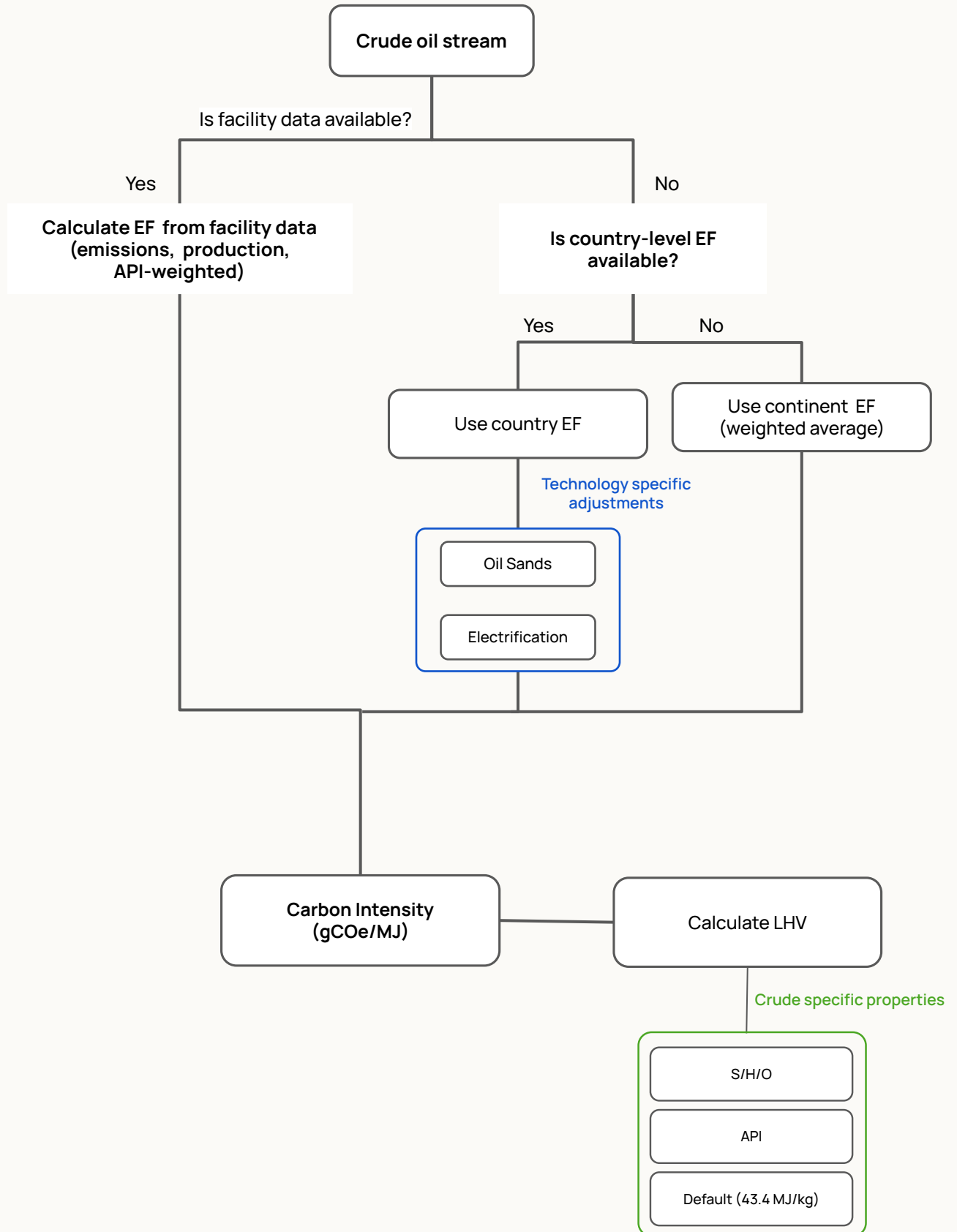
## Scoring Logic

**Four CI modelling tiers** exist depending on data availability at the crude stream and field level.

- **Tier 1: Country-Level Model with Continent Fallback:** Country-level emission factors (EFs) are used as the primary basis where available (e.g. Saudi Arabia, Brazil, UAE), converted from kgCO<sub>2</sub>e/kg oil to gCO<sub>2</sub>e/MJ using crude-specific Lower Heating Value (LHV). Where country-level EFs are unavailable, a continent-level EF is applied as a fallback, constructed as a production-weighted average of available country EFs within the region (e.g. Africa excluding Nigeria and Egypt).
- **Tier 2 – State-Level Model (US):** EPA facility-level data is used to model CIs at the US State level, with API proximity weighting to assign emissions to specific crude grades. *Example: Texas, drawing on 100+ EPA-reported facilities.*
- **Tier 3– Specific Technology Adjustment:** Country EFs are adjusted to reflect material technology-driven deviations. *Example: Norway (grid electrification, downward adjustment); Canada oil sands (×3 multiplier vs. conventional baseline).*

All tiers apply a **crude-stream-specific LHV conversion** to convert the baseline CI from kgCO<sub>2</sub>e/kg to gCO<sub>2</sub>e/MJ, using a ranked preference: S/H/O method > API method > default 43.4 MJ/kg.

# Carbon Intensity Logic

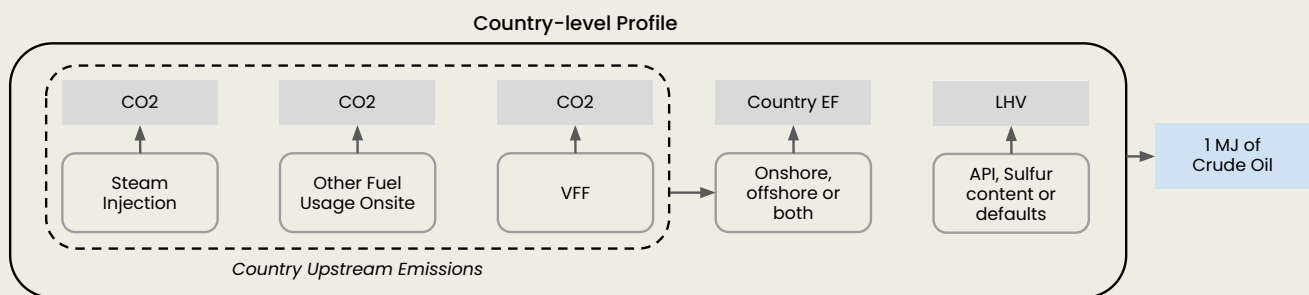


# Country-Level

## CARBON INTENSITY MODELING

Due to the lack of field-level data across countries – including major producers like Saudi Arabia, UAE, Kuwait, and Brazil – a **country-level model** is applied. Emission factors (EF) are obtained for onshore/offshore/both oil production per country from Ecolnvent. GEM is used to extract:

- Field annual oil production (to refer crude stream production in million bbl/year)
- Field owner (majority owner inferred as the major shareholder of the marketed crude stream)
- Field coordinates (to map crude stream location)
- Onshore/offshore/both classification (to select the appropriate EF)



## Scoring Logic

Country-level carbon intensities are modelled by attributing Ecolnvent emission factors – available at the country, onshore/offshore, or combined level – directly to crude streams originating from that geography.

When country-level emission factors are not available, continent-level factors are constructed as production-weighted averages of available country EFs within the region.

Crude-stream-specific carbon intensities are then derived by converting the assigned emission factor (kgCO<sub>2e</sub>/kg) to gCO<sub>2e</sub>/MJ using the stream's Lower Heating Value, calculated from API gravity and sulfur/hydrogen content where available, or a global default of 43.4 MJ/kg otherwise.

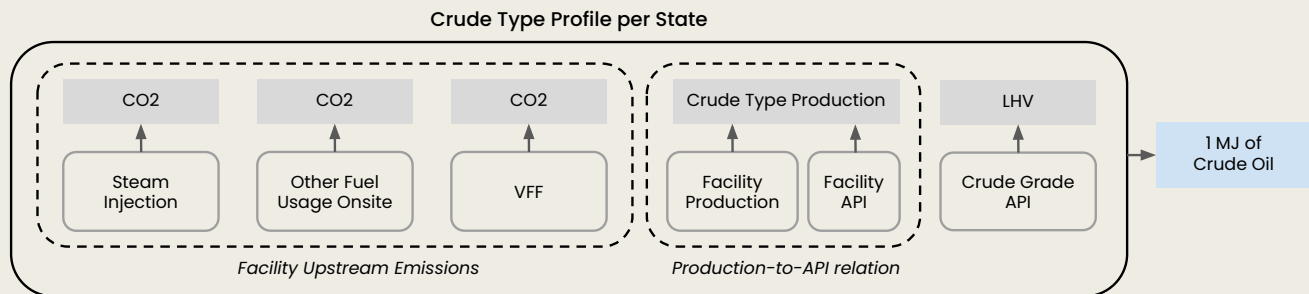
Key assumptions:

- All upstream emissions captured by the Ecolnvent country EF are assumed representative of the crude stream's production geography and method (onshore, offshore, or both).
- Country-level EFs do not capture facility-specific extraction technologies or operator-level practices; they represent an averaged emissions profile across all production within that country and production type.

# US State-level

## CARBON INTENSITY MODELING

US State-level crude streams are modelled using EPA facility-level data, which reports greenhouse gas emissions and production volumes for onshore petroleum and natural gas facilities. These facilities do not report crude-stream-specific carbon intensities directly; instead, CIs are inferred by redistributing facility-level emissions across crude types using API gravity as a weighting mechanism.



## Scoring Logic

Facility-level carbon intensity is calculated by dividing total reported emissions by total production

Methane emissions are restated from AR4 to AR6 ( $\text{CH}_4 = 27.2$ ) to ensure alignment between US facility-reported data and Ecolnvent-based modelling used for non-US crude streams

A Gaussian weighting function assigns each facility's production contribution to a given crude grade based on API proximity to the reference grade – facilities producing oil closer in character contribute proportionally more

The maximum weighted CI per crude type (Heavy 10–22, Medium 23–31, Light 32–50, Condensate >50) within each State is taken as the representative CI, prioritising conservativeness

Scope 2 and Scope 3 emission fractions, not covered by EPA reporting, are added using labelled components from the Ecolnvent country-onshore emission factor to achieve like-for-like comparability with non-US crude streams

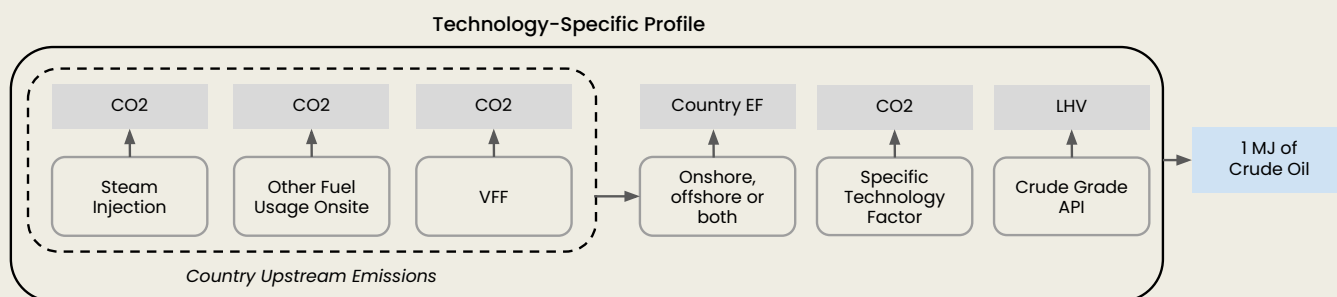
Key assumptions:

- All wells within a facility are assumed to produce at the same rate. API gravity is held constant at the reported average for both facilities and crude grades.
- Scope 2 and Scope 3 additions are sourced from the same Ecolnvent basis used for rest-of-world crudes, keeping the correction internally consistent.

# Technology-specific adjustments

## CARBON INTENSITY MODELING

In certain cases, country-level data on extraction technologies identify material deviations from default emission factor assumptions. Where such data exist, technology-specific adjustments are applied to the country-level CI to reflect the actual emissions profile of the crude stream more accurately.



## Scoring Logic

**Norway:** Norwegian offshore extraction is supplied by onshore grid electricity rather than on-site fuel combustion. Norway's grid is sourced almost entirely from renewable generation.

The fuel combustion emissions term is removed from the country-level CI and replaced with an equivalent electricity emissions term based on the Norwegian grid emission factor.

**Canada:** Canadian production encompasses both conventional crude and unconventional oil sands – substantially more energy-intensive due to the thermal energy required for extraction and the dedicated upgrading process for bitumen.

Oil sands CI is scaled by a factor of three relative to the conventional baseline, consistent with values reported in peer-reviewed literature:

*Key assumptions:*

- All technology adjustments are applied relative to the country-level Ecolnvent emission factor used as the baseline.
- Norwegian electrification is modelled as a direct substitution of fuel combustion energy with grid electricity at equivalent energy demand.
- The oil sands multiplier of three is applied uniformly to all Canadian unconventional crude streams and does not capture facility-level variation within oil sands production.

# Confidence Score Logic

## Description

Each carbon intensity (CI) assessment is accompanied by a confidence score that reflects how reliable and complete the underlying data and assumptions are. It indicates how much trust users should place in the analysis, given data availability and quality.

## Scoring logic

The confidence score aggregates across three components:

1. **Completeness** – number of CI drivers considered and their representativeness of the crude grade
2. **Granularity** – granularity level of the emission factor used for the calculation
3. **Reliability** – extraction confidence (reduced weight of 0.3 vs. 1 for other components, as production data has less impact on CI than EF quality)

Each score is reported on a 1-5 scale, where:

- 1 = very high confidence
- 5 = very low confidence

### Very High Confidence

Country EF with validated technology adjustments and full crude properties (API, S, H); compositional LHV (S/H/O); primary-source verified.

### High Confidence

Country EF with technology adjustments, or US state-level data (Subpart W) with API matching and AR6 methane; captures major emission sources.

### Fair Confidence

Country/continent EF with API and sulfur; benchmarked to assay databases; excludes facility and operator-level detail..

### Low Confidence

Country/continent EF with API only; standard LHV assumptions; no technology or operator differentiation.

### Very Low Confidence

Continent EF only; no crude, facility, or field-level inputs; reflects undifferentiated regional averages.

# Estimated Mechanism Eligibility

## Description

Crude oil is one of the primary feedstocks for liquid fossil fuels used across transport, aviation, and shipping. As decarbonisation regulations tighten, the carbon intensity of the crude source is increasingly relevant to compliance outcomes for regulated refiners and fuel suppliers.

Sylvera's Estimated Mechanism Eligibility framework provides an initial screening assessment of crude stream performance across multiple decarbonisation mechanisms. Rather than relying on individual scheme-specific lifecycle assessments, which require granular, facility-level data, Sylvera's framework estimates eligibility likelihood based on the best available public data.

Each crude stream receives a **mechanism-specific eligibility likelihood** rather than a definitive eligibility determination. This reflects the inherent uncertainty in global-scale screening and the data intensity required for formal certification. The output is designed to **support prioritisation and risk identification**, not to substitute for scheme-specific lifecycle assessments.

# Estimated Mechanism Eligibility

## Goal

The goal of the framework is to **estimate which crude streams are likely to be eligible for certification or reduce deficit exposure**, across multiple decarbonisation mechanisms.

The framework provides an alternative to the data-intensive requirements of formal scheme eligibility assessments, **enabling market-wide screening and prioritisation across a large universe of crude streams**. This allows refiners and traders to identify where the strongest compliance opportunities and risk exposures exist across their crude slate.

## Scope

The framework covers the likelihood of favorable performance under **three major regulatory mechanisms** that directly link crude carbon intensity to compliance obligations or credit generation opportunities:

- **CORSIA Lower Carbon Aviation Fuel (LCAF)**
- **California's Low Carbon Fuel Standard (LCFS)**
- **Canadian Clean Fuel Regulation (CFR)**

The framework *does not* model:

- Facility-level credit generation
- Formal lifecycle certification
- Refinery throughput or total fuel pool weighting

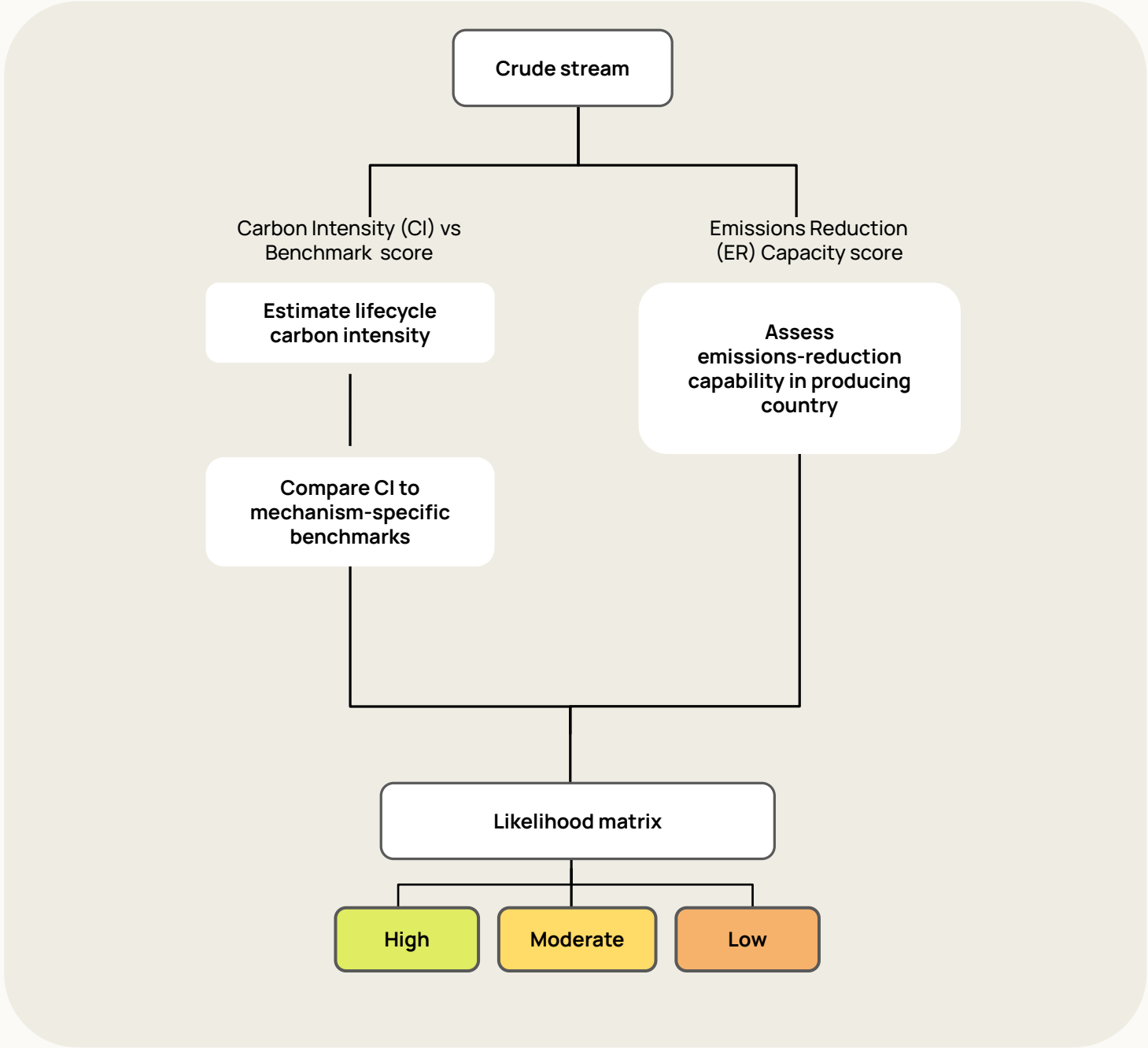
# Schemes covered

## Estimated Mechanism Eligibility

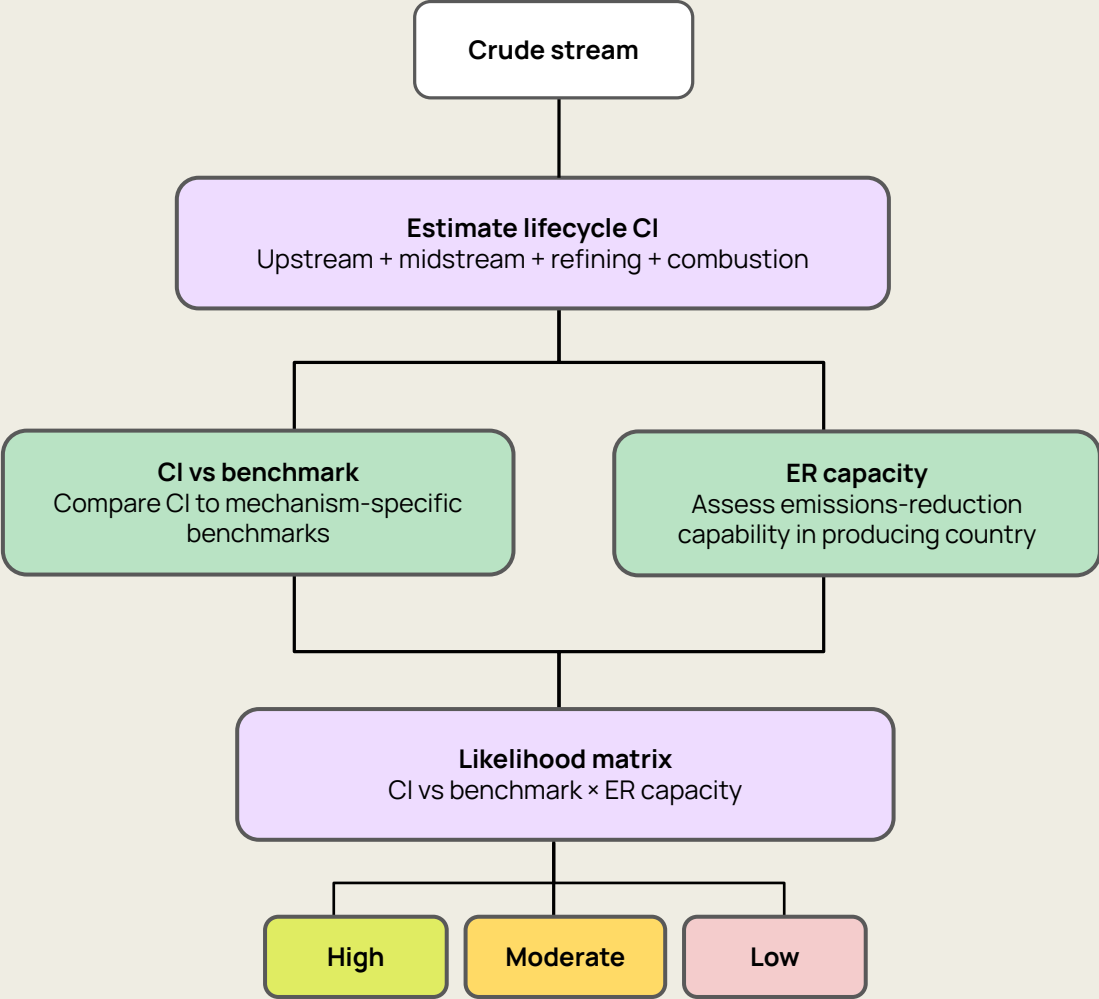
### Schemes

Scheme	Relevance to crude
CORSIA Lower Carbon Aviation Fuel (LCAF)	CORSIA governs carbon offsetting obligations for international aviation, with <b>eligibility</b> for lower-CI aviation fuels ("LCAF") <b>determined partly by the lifecycle carbon intensity of the crude feedstock.</b>
California Low Carbon Fuel Standard (LCFS)	California's Low Carbon Fuel Standard (LCFS) creates deficits or credits for fuel suppliers based on the <b>carbon intensity of fuels</b> relative to a benchmark. Crude selection affects <b>incremental deficit exposure.</b>
Canadian Clean Fuel Regulation (CFR)	Canada's Clean Fuel Regulation (CFR) assigns <b>carbon-intensity limits to liquid fossil fuels.</b> Crude streams with lower lifecycle CI have potential to generate compliance credits.

# Scoring Logic



# Scoring Logic



# CI vs Benchmark

## ESTIMATED MECHANISM ELIGIBILITY

### Description

The **CI vs Benchmark score** is the primary driver of the eligibility likelihood assessment. It reflects how the crude stream's estimated life cycle carbon intensity compares to the threshold defined by each decarbonization scheme.

Crude streams with a lower CI relative to the benchmark are more likely to meet certification requirements, generate credits, or reduce compliance deficits, depending on the mechanism.

### Scoring Logic

#### 1. Estimate full lifecycle CI

The total lifecycle CI is estimated by summing contributions across **four stages**, to system boundaries with scheme benchmarks.

- **Upstream CI**
  - Represents emissions from crude extraction and production.
  - Sourced from Sylvera's upstream CI.
- **Midstream CI**
  - Represents transport emissions from production site to refinery.
  - Estimated using simplified trade scenarios based on CORSIA transport emission factors. A conservative, "worst-case" midstream scenario is used.
- **Refining CI**
  - Represents emissions associated with crude processing.
  - Modelled using a global average, derived from peer-reviewed literature of lifecycle analysis across crude oil refineries.
- **Combustion CI**
  - Represents end-use combustion of refined fossil fuels.
  - Held constant across crude streams using CORSIA default values for combustion.

If facility-specific CI at any stage are known, the assumptions are overridden.

# CI vs Benchmark

## ESTIMATED MECHANISM ELIGIBILITY

### Scoring Logic

#### 2. Compare to scheme-specific benchmarks and assign category

Each crude stream is classified based on its **CI position relative to the scheme benchmark**:

- **Below benchmark** - CI is comfortably below the scheme threshold
- **Near benchmark** - CI is close to the benchmark, within a defined tolerance band
- **Above benchmark** - CI is clearly above the benchmark

### Scheme-specific assumptions

#### **CORSIA**

The model compares estimated lifecycle CI to the latest (2025) CORSIA baseline carbon intensity of 80.1 gCO<sub>2e</sub>/MJ. A ±5 gCO<sub>2e</sub>/MJ band is applied to define the "Near benchmark" category, reflecting uncertainty in lifecycle CI calculations.

#### **California LCFS**

California LCFS uses pre-determined upstream CI values from the California Air Resources Board's (CARB) regulatory lookup table (Table 9). Where a crude stream is listed, Table 9 values are used directly; otherwise, a default CI of the California baseline crude average applies. Streams are classified against the latest (2025) California baseline crude average of 12.61 gCO<sub>2e</sub>/MJ (upstream and midstream only). Because LCFS values are drawn directly from a regulatory lookup table, a binary classification is applied, and no "Near benchmark" band is used.

#### **Canadian CFR**

The Canadian CFR sets annual carbon-intensity limits for liquid fossil fuels. A conservative diesel benchmark is used, applying the current year's limit (85.0 gCO<sub>2e</sub>/MJ for 2026). Canada-specific midstream scenarios applied based on region of origin. A ±5 gCO<sub>2e</sub>/MJ band is applied to define the "Near benchmark" category, reflecting uncertainty in lifecycle CI calculations.

# CI vs Benchmark

## ESTIMATED MECHANISM ELIGIBILITY

### Scoring Logic

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#### Scheme-specific assumptions

##### CORSIA

The model compares estimated lifecycle CI to the CORSIA baseline carbon intensity of 80.1 gCO<sub>2</sub>e/MJ. A ±5 gCO<sub>2</sub>e/MJ band is applied to define the "Near benchmark" category, reflecting uncertainty in lifecycle CI calculations. Worst-case midstream scenario is used to be conservative.

##### California LCFS

California LCFS uses pre-determined upstream CI values from CARB's regulatory lookup table (Table 9). Where a crude stream is listed, Table 9 values are used directly; otherwise, a default CI applies. Streams are classified against the California baseline crude average of 12.61 gCO<sub>2</sub>e/MJ (upstream only).

Because LCFS values are drawn from a regulatory lookup table with limited estimation uncertainty, a binary classification is applied – no "Near benchmark" band is used.

##### Canadian CFR

The Canadian CFR sets annual carbon-intensity limits for liquid fossil fuels. A conservative diesel benchmark is used, applying the current year's limit (85.0 gCO<sub>2</sub>e/MJ for 2026). Canada-specific midstream scenarios applied based on region of origin.

# Emissions Reduction (ER) Capacity

## ESTIMATED MECHANISM ELIGIBILITY

### Description

Pathways to eligibility or credit generation under each scheme also depends on the capacity of a crude production facility to implement and demonstrate emissions-reduction (ER) measures. Several mechanisms require evidence of emissions reductions relative to a baseline, and/or the deployment of specific abatement technologies, as a condition of eligibility.

In the absence of facility-level data, this score provides **country-level context on emissions-reduction capability** as a proxy, enabling differentiation between crude streams produced in countries with strong versus limited abatement infrastructure.

### Scoring Logic

#### Country level database

A database of **country-level implementation of low-carbon technologies in the oil sector** was assembled from peer-reviewed literature and industry sources, covering 93 countries. For each country, the database records whether the following technology types have been deployed in the oil sector, based on technologies permitted under each scheme:

- **Methane abatement** - Detection, capture, and reduction of upstream methane emissions
- **Renewable electricity / electrification** - Use of low-carbon energy to power upstream operations
- **Carbon capture and storage (CCS)** - Capture and permanent storage of CO<sub>2</sub> from upstream or associated operations

The presence of evidence for **each technology type** contributes +1 to the country-level score.

**If facility-specific practices are known, the country-level score can be overridden.**

# Emissions Reduction (ER) Capacity

ESTIMATED MECHANISM ELIGIBILITY

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## Scoring Logic

**A category is assigned based on the sum of technology types with evidence**

- **High** - Evidence of 3 technology types exists, indicating strong evidence of low-carbon technology adoption
- **Moderate** - Evidence of 1-2 technology types exists, indicating some evidence of technology adoption
- **Low** - No evidence of technology adoption found

### Assumptions

Technologies are considered transferable once demonstrated domestically. The presence of at least one project is treated as evidence of national feasibility.

# Likelihood Matrix

The scores for **CI vs Benchmark** and the **Emissions Reduction (ER) Capacity** are combined using the matrix below to assign a **final eligibility likelihood** for each crude stream under each mechanism.

**Interpretation of the category depends on how each scheme operates.**

	ER Capacity: High	ER Capacity: Moderate	ER Capacity: Low
Below benchmark	High	Moderate	Moderate
Near benchmark	Moderate	Moderate	Low
Above benchmark	Moderate	Low	Low

## Scheme-specific interpretation

### CORSIA

Eligibility is determined by whether a fuel meets the CORSIA CI threshold and associated certification requirements. The likelihood score reflects the **likelihood that the crude stream could meet certification requirements for Low Carbon Aviation Fuel (LCAF) status**.

High	The crude CI is below the mechanism threshold and there is strong evidence of emissions-reduction (ER) capability in the producing country, indicating a high likelihood of meeting certification requirements.
Moderate	The crude CI is near the mechanism threshold, or emissions-reduction (ER) capability in the producing country could enable emissions reductions sufficient to meet certification requirements.
Low	The crude CI is above the mechanism threshold and there is limited evidence of emissions-reduction (ER) capability, indicating a low likelihood of meeting certification requirements.

# Likelihood Matrix

## Scheme-specific interpretation

### California LCFS

All petroleum-based fuels incur a base deficit under LCFS. Crude selection affects incremental deficit exposure. Base deficits and fuel pathway emissions are assumed constant across crude streams and are not modelled. Therefore, the likelihood score reflects the **expected improvement in compliance deficit resulting from crude selection**.

High	The crude CI is sufficiently low to likely reduce compliance deficits under the mechanism, supported by evidence of emissions-reduction (ER) capability in the producing country.
Moderate	The crude CI is near the benchmark and is likely to have a limited compliance impact, or emissions-reduction (ER) capability in the country could enable reductions that improve performance.
Low	The crude CI is above the benchmark and is likely to create high compliance deficits, with limited evidence that emissions-reduction (ER) capability in the producing country would materially improve performance.

### Canadian Clean Fuel Regulation

Under the Canadian CFR, crude CI affects credit generation potential; the base compliance deficit obligation is determined separately. Higher-CI crude does not increase deficits but reduces the opportunity to generate credits. The likelihood score reflects the **likelihood that a crude stream could generate credits under the mechanism**.

High	The crude CI is sufficiently low to likely generate credits under the mechanism, supported by evidence of emissions-reduction (ER) capability in the producing country.
Moderate	The crude CI is near the benchmark and may generate credits, or emissions-reduction (ER) capability could enable reductions that improve credit generation potential.
Low	The crude CI is above the benchmark and is unlikely to generate credits, with limited evidence that emissions-reduction (ER) capability would materially improve performance.

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