
# Low Carbon Intensity Propylene

## A Technoeconomic and Carbon Intensity Study

NexantECA

June 2023

Special Report Prospectus

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# Introduction

# Propylene is one of the most important building blocks in the chemicals industry, the basis for additional chemicals and fuels. Its derivatives have a vital role in enabling a sustainable future

## Propylene is responsible for a significant share of the global emissions from the chemicals industry.

- According to the IEA, the **Chemical sector is the third largest industry subsector in terms of direct $CO_2$ emissions.**
- **Propylene** is the 2nd most important chemical raw material after ethylene, and together are one one of the largest three chemical emitters: ammonia, methanol, and olefins.
- **Propylene** is a major feedstock for additional chemistry, including polymers, surfactants, and more – all impacted by proposed abatement routes.
- Different route options are emerging for **low carbon intensity propylene**, some of which utilize the existing value chain and infrastructure, each with different carbon intensities

**Propylene 2022**

**600+ Global assets**

**approx. 139+ million tons Installed capacity**

**165+ million tons $CO_{2eq}$ annual emissions**

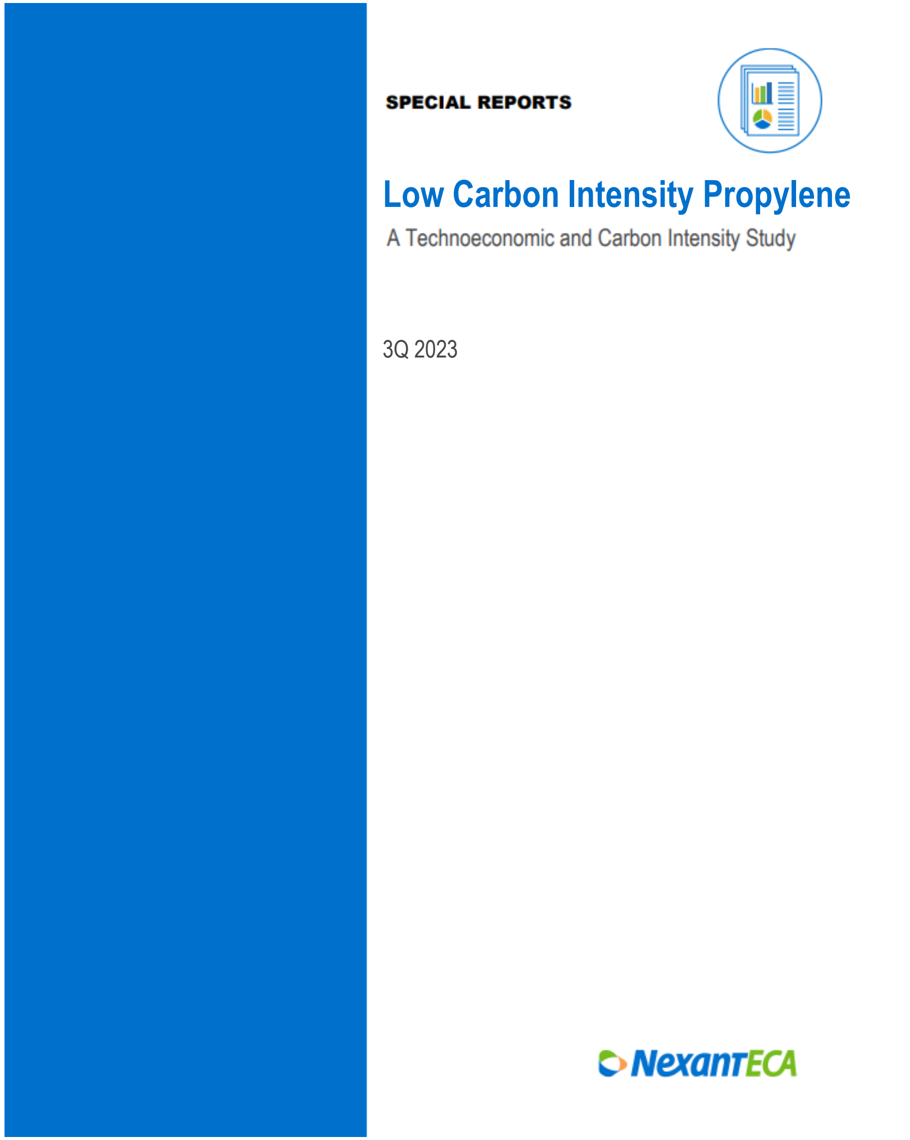
***Propylene derivatives are essential for the low-carbon technologies of the future***

# Objective and Key Questions Addressed

# The objective of this report is to provide subscribers with carbon intensity benchmarking of conventional routes against emerging alternatives backed with technoeconomic analysis

## Carbon intensity benchmarking is an increasingly important consideration, and NexantECA has developed a proprietary methodology for modelling value chains per asset

- In this report, NexantECA covers **alternative production routes** and compares their **relative cost of production and carbon intensities** with conventional routes in various regions.
- Holistic approach to sustainability, of which carbon intensity is becoming an important **measurable metric** that impacts the company **bottom line**
- Specific country level analysis available as an **additional modules** beyond report analysis regions: U.S., Brazil, Western Europe, and China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3Q 2023

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## Key Questions addressed in this Special Report

- What is the **lowest carbon intensity route** to propylene?
- Which make **the most economic sense** currently? How will this change with different **frameworks and instruments** for carbon price? What is **the break-even carbon price** for competitiveness?
- Which of the following **abatement options** will offer the most in terms of carbon intensity reductions, as compared to the conventional benchmarks:
  - Conventional Benchmarks:
    - Conventional Cracking
    - PDH
    - MTP
    - FCC
  - Advances and Alternative Technologies:
    - Hydrogen Firing
    - Carbon capture
    - Low CI Heating
    - Renewable naphtha / feedstock switching
    - rLPG PDH
    - Ethanol-to-Ethylene (E-to-E) + Metathesis
    - Renewable Methanol-to-Propylene (MTP)
    - Other Developing Routes (e.g., direct fermentation)

**NexantECA's analysis includes multiple values for emissions reductions along with break-even values required for economic competitiveness in the following regions:**

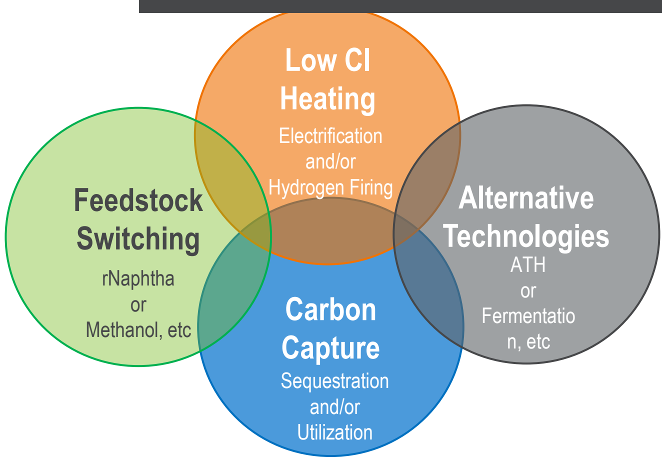
# Routes to Propylene and Low Carbon Intensity Propylene

# There are several primary conventional routes to propylene that the alternatives are compared to as a benchmark

**PRIMARY CONVENTIONAL ROUTES**

| | | |
|---|---|---|
| NGLs | Steam Cracker | Propylene |
| Naphtha | Steam Cracker | Propylene |
| NGLs | Steam Cracker + Olefin Interconversion | Propylene |
| Naphtha | Steam Cracker + Olefin Interconversion | Propylene |
| Methanol | MTP | Propylene |
| Propane | PDH | Propylene |
| Crude Oil | Refinery (e.g., FCC) | Propylene |
| Crude Oil | Enhanced FCC | Propylene |

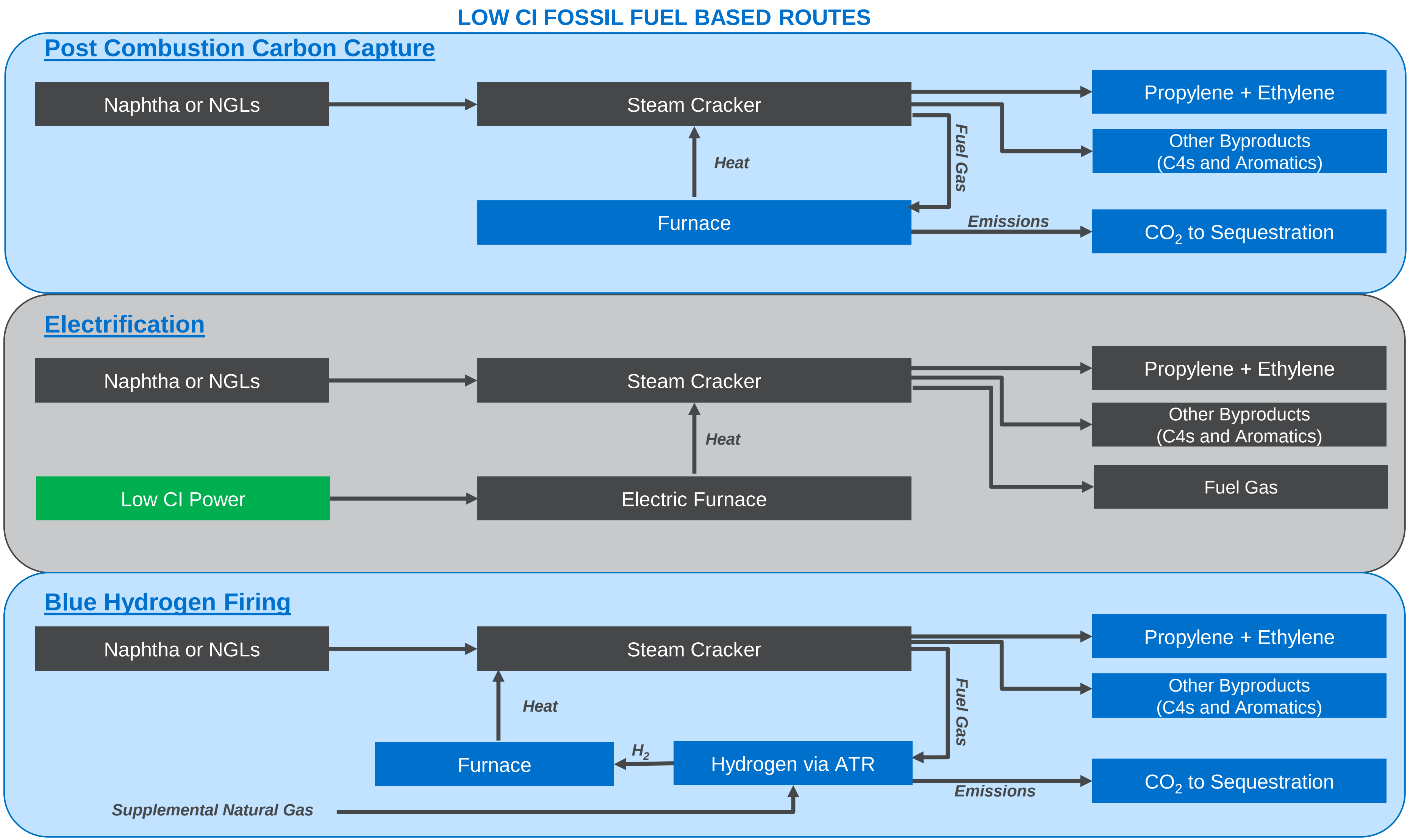
**Options for Reducing Propylene Carbon Intensity with Current Feedstocks**




**Conventional Technologies may use carbon capture, low CI heating or both as a solution while not changing the feedstock and getting some significant carbon intensity reductions**

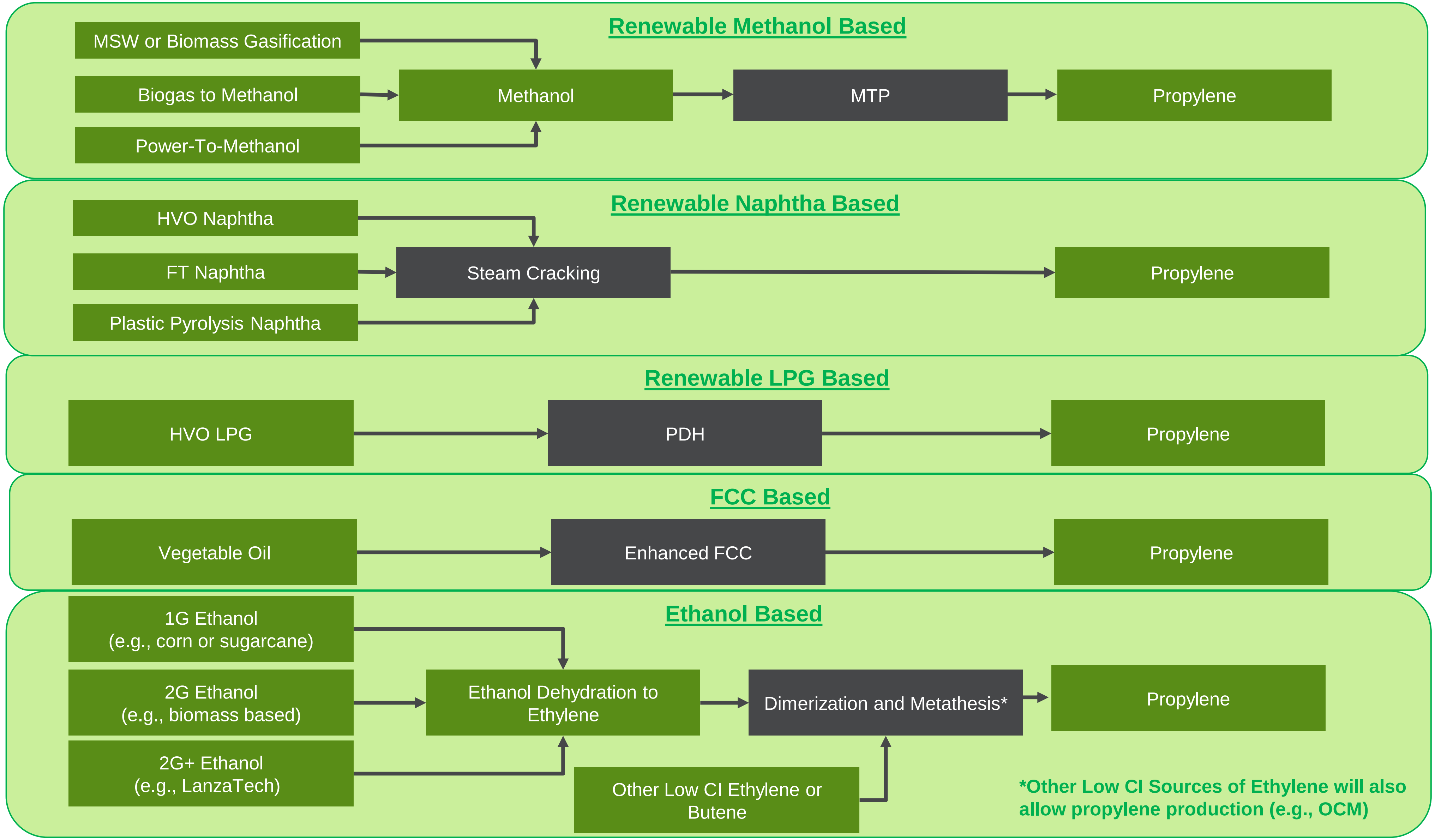
***A significant proportion of propylene's emissions are scope 1 emissions due to the heating required, making it a good potential candidate for carbon capture, or switching to low CI heating and renewable power while continuing to utilize the same feedstock***

# There are several options for dramatically reducing cracking carbon intensity with current feedstocks - NexantECA is investigating the following cases



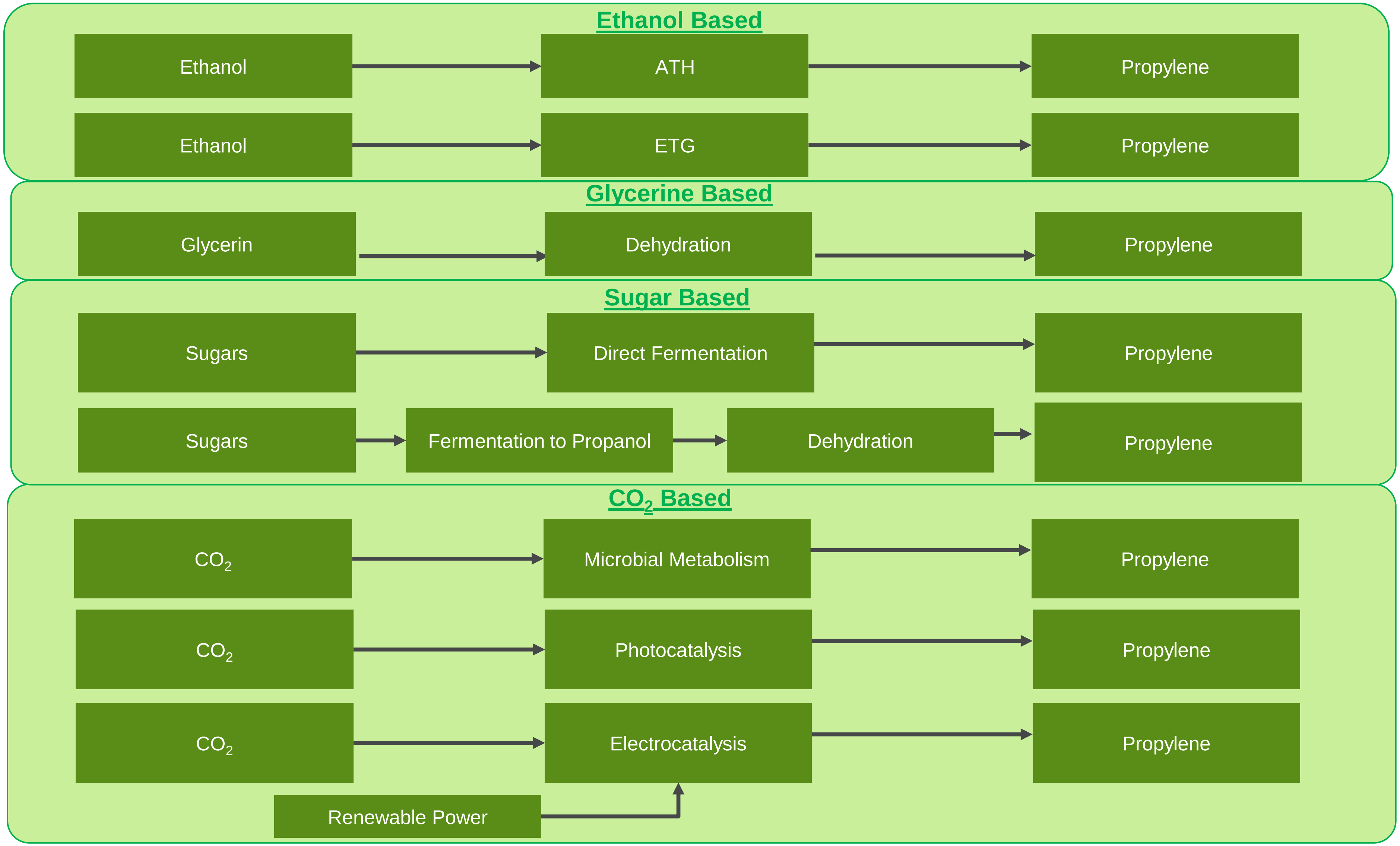
# The propylene story is even more complex than ethylene because of the various options – many of which can use the existing value chain and substitute biomaterials:

## RENEWABLE FEEDSTOCK SWITCHING



# The propylene story is even more complex than ethylene because of the various options – several routes are still in developmental stages

## ALTERNATIVE ROUTES TO LOW CARBON INTENSITY PROPYLENE IN DEVELOPMENTAL STAGES



# What is Carbon Intensity

NexantECA

# Carbon Intensity is viewed by Scope 1, Scope 2, and Scope 3 Emissions – this study is concerned with Scope 1 and Scope 2 emissions, and raw materials Scope 3

Cradle | Entry | Gate

**Scope 3 Upstream**

**Indirect before entry**

- Raw Materials
- Water
- Inert Gas
- Freight
- Fugitive

**Scope 1**

**All direct onsite**

- Process
- Fuel Gas
- Steam
- Vehicles
- Offices
- Fugitive

**Scope 2**

**Purchased energy**

- Electricity

*Scope 2 can include steam, heating or cooling if purchased from third party*

**Scope 3 Downstream**

**Indirect after the gate**

- Freight
- Product manufacture
- Product Sale
- Product Use
- Customer activities
- Product End of life

Entry to Gate = On-site

**Scope 3**

**All other indirect**

- Investments
- Capital Goods
- Leased Assets
- Business Travel
- Commuting
- Purchased Services
- Waste

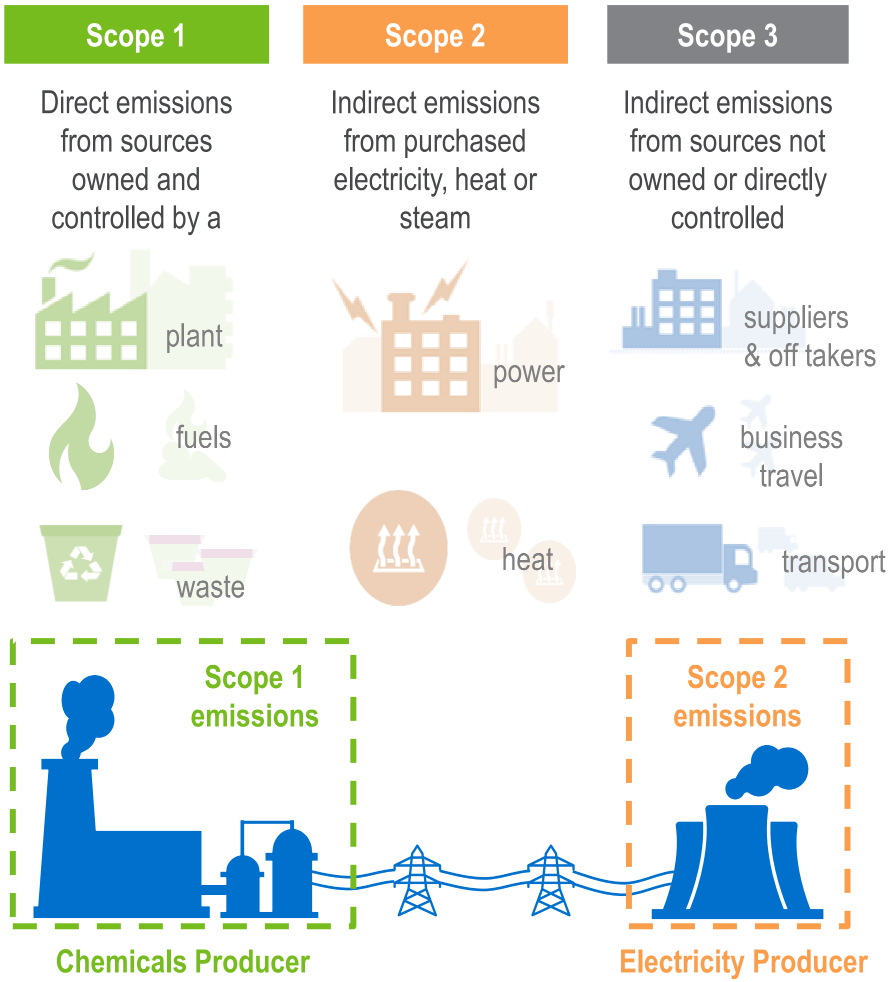
Cradle to Gate = Ex-works

Ex-works plus freight = Delivered

***Many players Net-Zero by 2050 plans are focused on Scope 1 and Scope 2 emissions***

# Scope 1, Scope 2 and Scope 3 emission categories are used to differentiate between direct and indirect emissions with standards and certifications having been developed for reporting

**To improve transparency and completeness in reporting, the Greenhouse Gas Protocol established corporate standards and the concepts of Scope 1, 2 and 3 emissions**

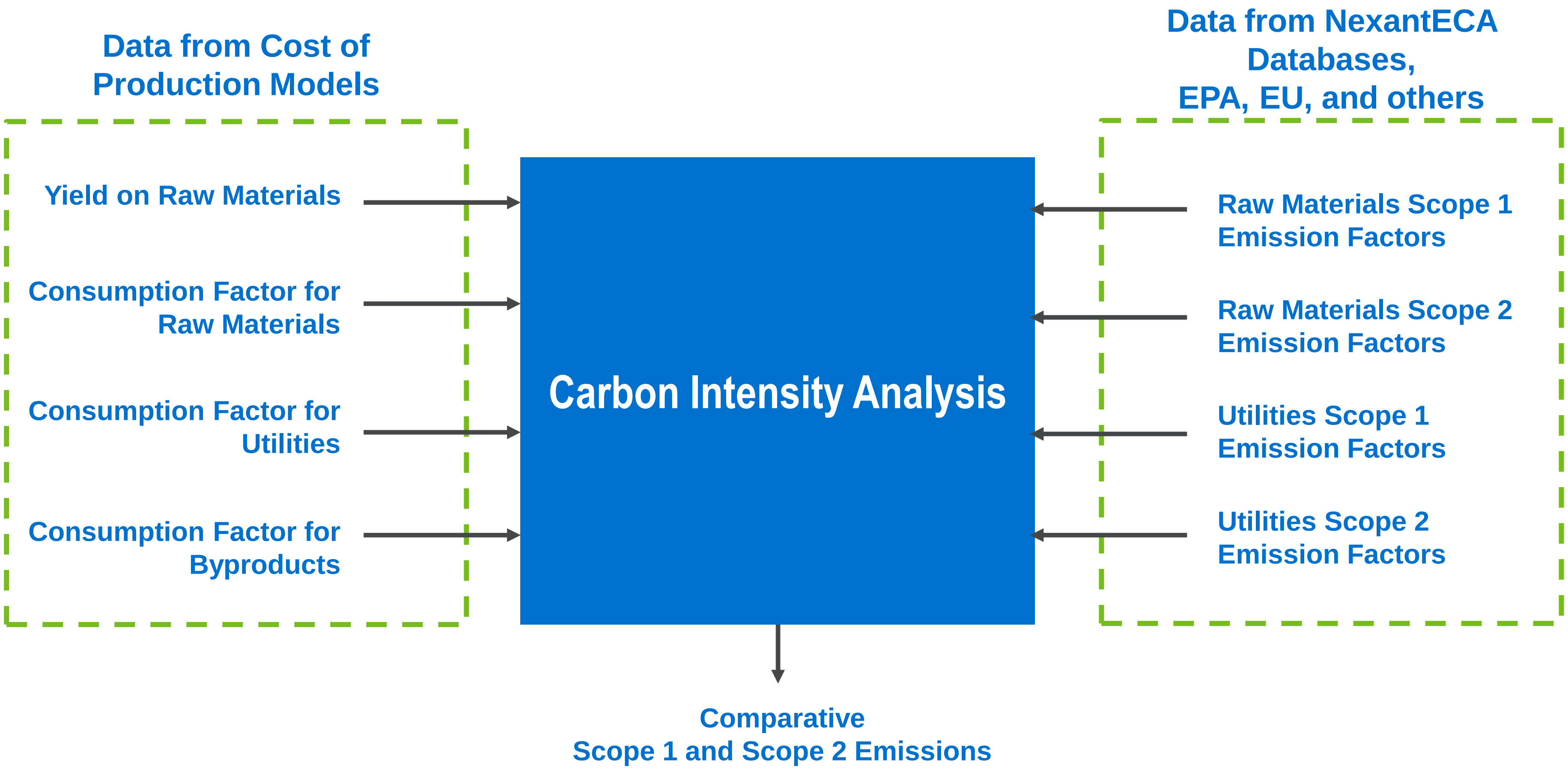



- **Scope 1** emissions are direct emissions that occur from sources controlled or owned by the reporting company
  - These can be the emissions from combustion of fuels, process emissions or fugitive emissions
  - The GHG Protocol does not include biomass combustion in Scope 1
- **Scope 2** emissions include the indirect emissions from the generation of purchased electricity consumed by the company
  - Purchased electricity is defined as electricity that is purchased or otherwise brought into the organisational boundary of the company
  - These emissions occur at the facility where the electricity is generated
- **Scope 3** includes all other indirect emissions, the emissions which are a consequence of the activities of the company but occur from sources not owned or controlled by the company
  - Scope 3 emissions are optional to report under the GHG Protocols reporting standard. Entities often narrow the inclusion criteria for Scope 3 emissions to allow for calculability

**Certifications have developed to cover the full spectrum of emissions**

- The **GHG Protocol** establishes comprehensive global standardised frameworks to measure and manage GHG emissions from private and public sector operations, value chains and mitigation actions
- **CDP** is a not-for-profit charity that runs the global disclosure system to assist entities in managing their environmental impacts
- The **ISCC's** objective is to contribute to the implementation of environmentally, socially and economically sustainable supply chains

# The Carbon Intensity Analysis includes consumption factors from our cost of production models along with emissions factors

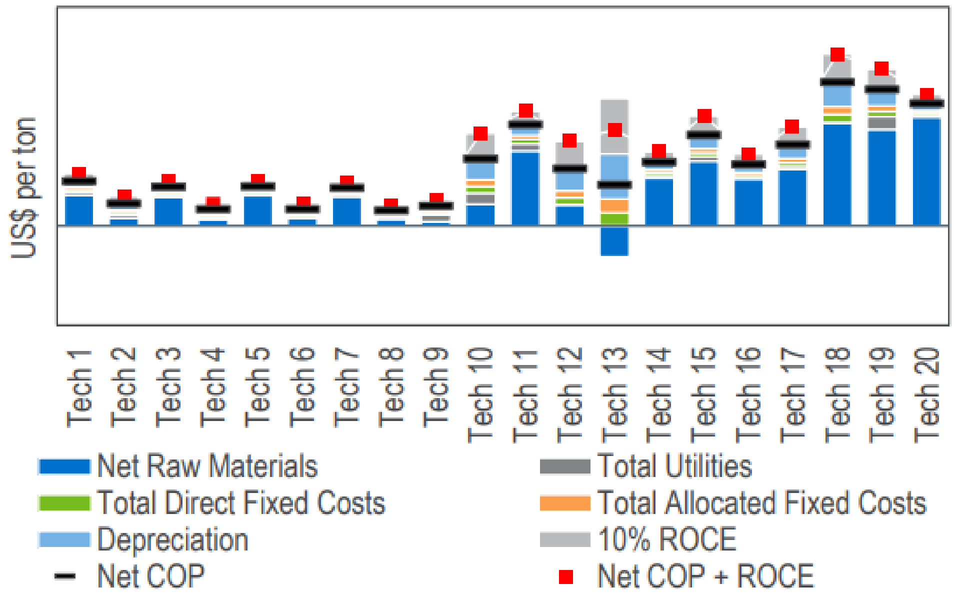



***The outputs for the various routes can be compared on an even basis to determine the carbon intensity reductions possible and comparative sustainability***

# Illustrative Cost of Production Model for Chemical X

| | | | |
|---|---|---|---|
| Plant Start-up | 1Q2010 | **CAPITAL COST** | **MILLION U.S. $** |
| Analysis Date | 2010 | ISBL | 61.4 |
| Location | USGC | OSBL | 12.2 |
| Capacity | 274.6 Thousand Tons/yr | **Total Plant Capital** | **73.7** |
| | | Other Project Costs | 18.4 |
| | | **Total Project Investment** | **92.1** |
| Operating Rate | 100 percent | Working Capital | 9.2 |
| Throughput | 274.6 Thousand Tons/yr | **Total Capital Employed** | **101.3** |

| **PRODUCTION COST SUMMARY** | | | **UNITS Per Ton Product** | **PRICE U.S. $ /Unit** | **U.S. $ Per Ton** | **ANNUAL COST U.S.$ millions** | **U.S. $ Per Lb** |
|---|---|---|---|---|---|---|---|
| **RAW MATERIALS** | Natural Gas | Gcal | 6.320 | 21.93 | 138.58 | 38.06 | |
| | Oxygen | ton | 0.642 | 64.90 | 41.67 | 11.44 | |
| | Catalysts & Chemicals | | 1.000 | 0.70 | 0.70 | 0.19 | |
| | | **TOTAL RAW MATERIALS** | | | **180.96** | **49.69** | **0.08** |
| **NET RAW MATERIALS** | | | | | **180.96** | **49.69** | **0.08** |
| **UTILITIES** | Power | MWh | 0.004 | 57.36 | 0.25 | 0.07 | |
| | Cooling Water | kton | 0.057 | 29.04 | 1.67 | 0.46 | |
| | Boiler Feed Water | ton | 1.385 | 0.55 | 0.76 | 0.21 | |
| | Steam (MP) | ton | (0.498) | 20.21 | (10.07) | (2.76) | |
| | Inert Gas | ton | 0.067 | 52.60 | 3.50 | 0.96 | |
| | Fuel | Gcal | 0.382 | 21.93 | 8.38 | 2.30 | |
| | | **TOTAL UTILITIES** | | | **4.49** | **1.23** | **0.00** |
| **NET RAW MATERIALS & UTILITIES** | | | | | **185.44** | **50.92** | **0.08** |
| **VARIABLE COST** | | | | | **185.44** | **50.92** | **0.08** |
| **DIRECT FIXED COSTS** | Laborer | 12 employees | 48.23 Thousand | U.S. $ | 2.11 | 0.58 | |
| | Foremen | 4 employees | 54.74 Thousand | U.S. $ | 0.80 | 0.22 | |
| | Supervisor | 1 employees | 66.05 Thousand | U.S. $ | 0.24 | 0.07 | |
| | Maintenance, Material & Labor | | 3 % of ISBL | | 6.71 | 1.84 | |
| | Direct Overhead | | 45 % Labor & Supervision | | 1.42 | 0.39 | |
| | | **TOTAL DIRECT FIXED COSTS** | | | **11.27** | **3.10** | **0.01** |
| **ALLOCATED FIXED COSTS** | General Plant Overhead | | 60 % Direct Fixed Costs | | 6.76 | 1.86 | |
| | Insurance, Property Tax | | 1.5 % Total Plant Capital | | 4.02 | 1.10 | |
| | | **TOTAL ALLOCATED FIXED COSTS** | | | **10.79** | **2.96** | **0.00** |
| **TOTAL FIXED COSTS** | | | | | **22.06** | **6.06** | **0.01** |
| **TOTAL CASH COST** | | | | | **207.50** | **56.98** | **0.09** |
| Depreciation @ | | 10 % for ISBL & OPC | | 5 % for OSBL | 31.30 | 8.60 | 0.01 |
| **COST OF PRODUCTION** | | | | | **238.80** | **65.58** | **0.11** |
| Return on Capital Employed (Incl. WC) @ | | | | 10 Percent | 36.89 | 10.13 | 0.02 |
| **COST OF PRODUCTION + ROCE** | | | | | **275.70** | **75.71** | **0.13** |



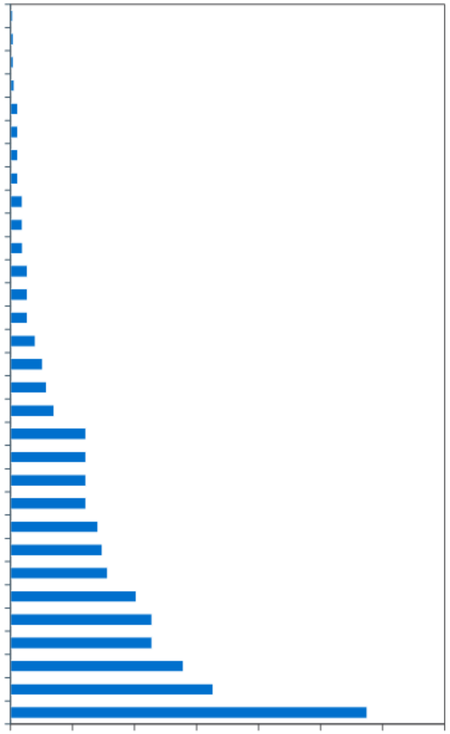

***The outputs for the various routes can be compared on an even basis to determine the baseline competitiveness—a value to carbon emissions can add to the competitiveness of the lower carbon intensity routes***

# Carbon Intensity is compared across the different scope emissions, and the different regions and against regional benchmarks

## Regional Comparisons

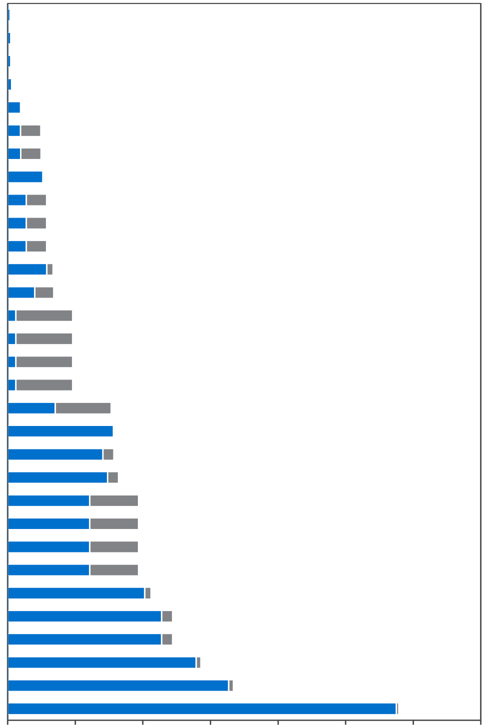
### Direct Emissions Comparison

*(Scope 1, Ton $CO_2$ eq per Ton Propylene)*



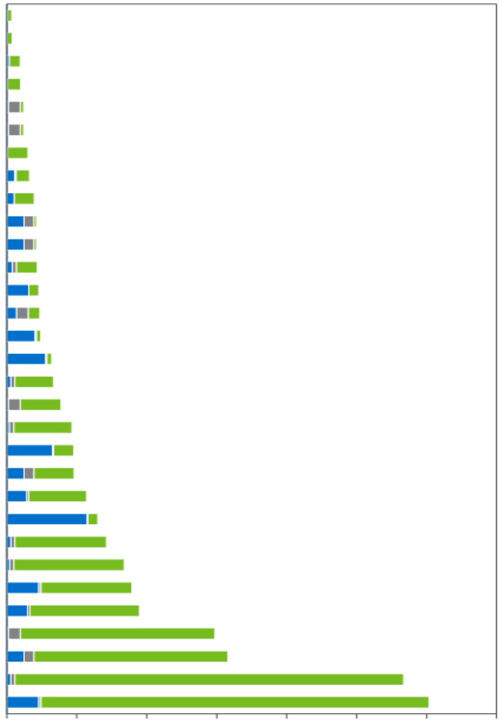
### Process Emissions Comparison

*(Scope 1 and 2, Ton $CO_2$ eq per Ton Propylene)*



### Value Chain Comparison

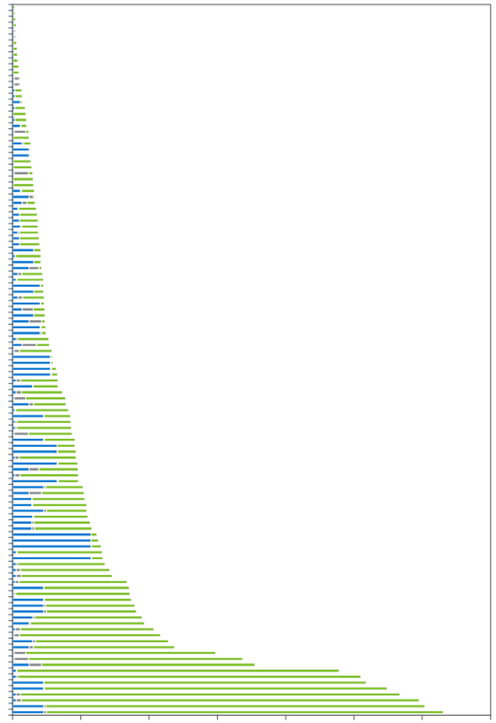
*(Scope 1,2 and 3, Ton $CO_2$ eq per Ton Propylene)*



## Global Comparisons

### Value Chain Comparison

*(Scope 1,2 and 3, Ton $CO_2$ eq per Ton Propylene)*



■ Scope 1 ■ Scope 2 ■ Scope 3

# Analyses Performed and Deliverables

# Key Analyses Performed

**Technical Review** – Technical review of incumbent and alternative low carbon intensity routes to propylene. Analysis includes:

- Process Descriptions
- Process Chemistry
- Technical Overviews

**Carbon Intensity Analysis:** A carbon intensity analysis with an output of tons $CO_2$eq per ton propylene (comprising scope 1 and scope 2 emissions)will be performed for the US Gulf Coast, Western Europe, Asia, and South America, as regionally relevant(other regions and specific countries are available as an add-on for an additional fee) for:

- 6 Primary Incumbent Propylene production routes:
  - NGL (E/P) Steam cracking
  - Naphtha Steam Cracking
  - Steam Cracking with Olefin Conversion
  - MTP
  - PDH
  - FCC
  - Enhanced FCC
- Identified alternatives for low carbon intensity propylene production in several categories:
  - Electric Heating with Renewable Power
  - Blue Hydrogen Firing
  - Renewable Methanol-Based MTP
  - Steam Cracking with Renewable Feedstocks
  - Ethanol-Based Metathesis
  - Developmental Routes, as available and reasonable
  - Carbon Capture as a second case for all Base Cases
- Economic Review – A cost of production (COP) analysis with an output of COP models and comparative economics will be performed for the U.S. Gulf Coast, Western Europe, Asia, and South America, as regionally relevant(other regions and specific countries are available as an add-on for an additional fee) for all identified Routes, including:
- Current economic competitiveness vs the incumbent and market prices

**Strategic Review –** A high level review of current status of development, key players, and capacity plans for plants of alternative low carbon intensity propylene production, and potential impacts on the industry

- Breakeven value for $CO_2$ emissions reduction required for economic competitiveness
  - Based-upon direct emissions (Scope 1)
  - Based-upon processing emissions (Scope 1+2)
  - Based-upon value chain emissions (Scope 1+2+3)

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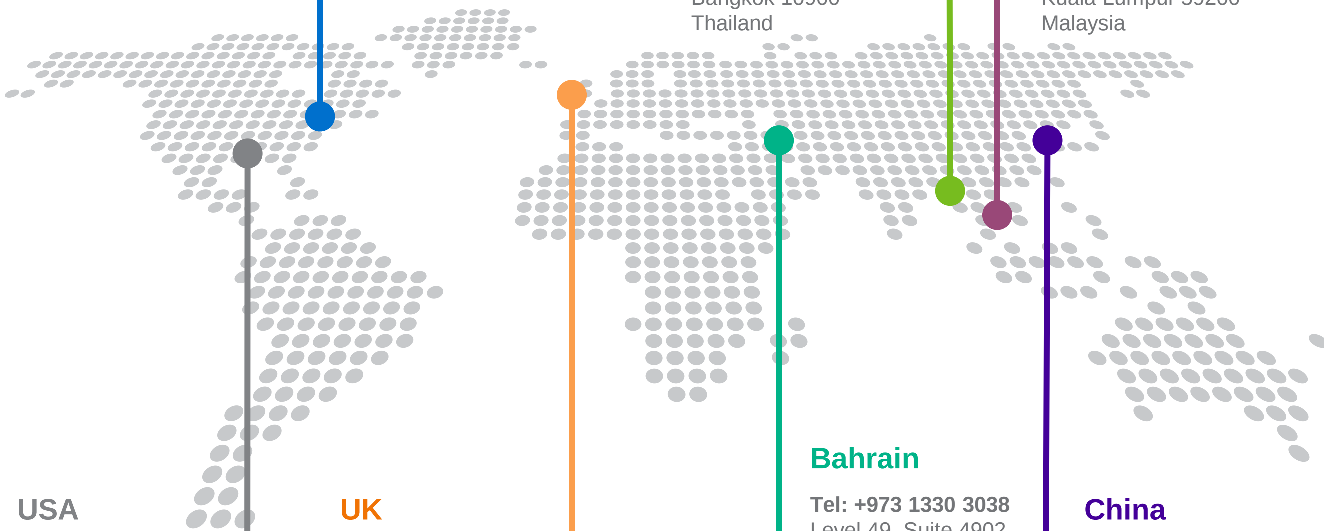


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