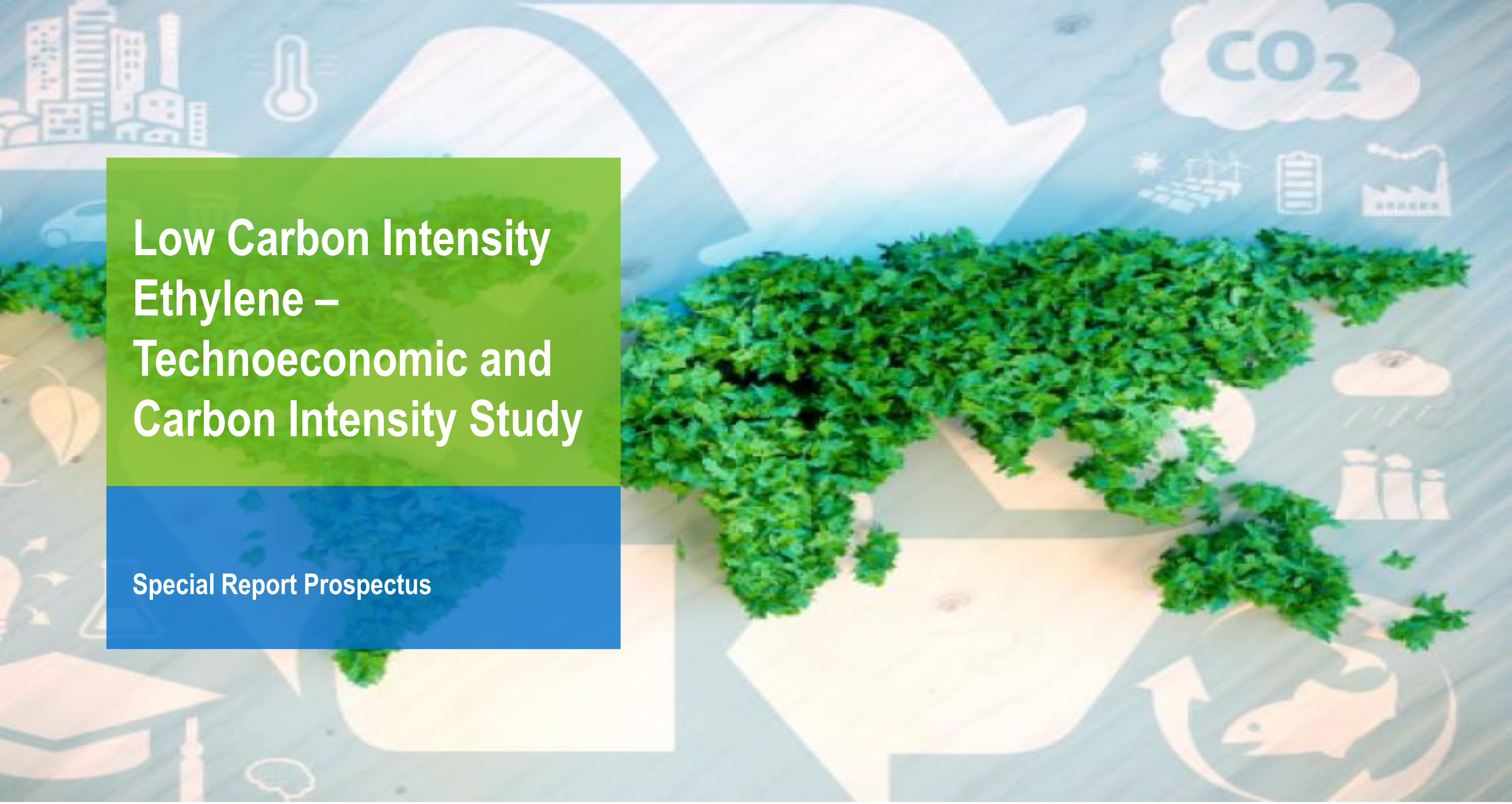


Low Carbon Intensity Ethylene – Technoeconomic and Carbon Intensity Study

Special Report Prospectus

NexantECA

Published August 2022

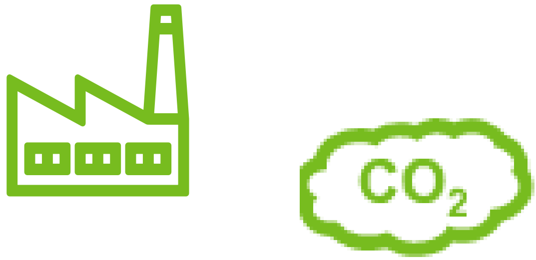
Special Report

Contents

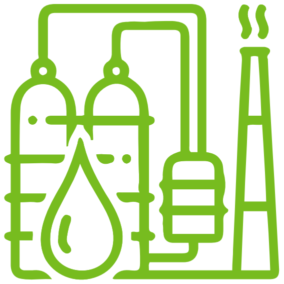
Section

Introduction

The transition towards climate neutrality and circular economy will have a profound impact on existing assets and radically change the economic drivers for the selection of new technologies

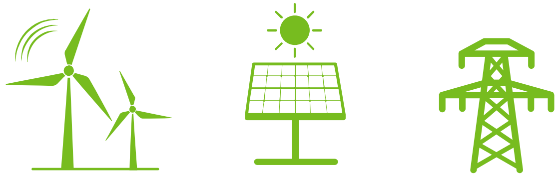


The world is facing unprecedented challenges. The market landscape is evolving with a heightened emphasis on opportunities offered as well as the risks presented by climate change and the need to meet the **increased commitments to achieving net-zero emissions**.



The **large-scale and complex nature of climate change** makes it uniquely challenging, especially in the context of economic decision making. The implications of climate change that need to be considered are today as well as long term.

With climate risk affecting asset valuations, the capital market appetite shifted towards **investments with good ESG performance and competitive financial returns**.



Net zero commitments and targets are driving demand in the voluntary carbon market and leading to increasing carbon market activity

Ethylene 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

Ethylene 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**.
- **Ethylene** is the 2nd largest global chemical and one of the largest three chemical emitters: ammonia, methanol, and ethylene.
- **Ethylene** is a major feedstock for additional chemistry, including polymers, surfactants, and higher olefins – all impacted by proposed abatement routes.
- Different route options are emerging for **low carbon intensity ethylene**, some of which utilizing the existing value chain and infrastructure, each with different carbon intensities

Ethylene 2022

371 Global assets

approx. **214.2** million tons Installed capacity

260+ million tons CO_{2eq} annual emissions

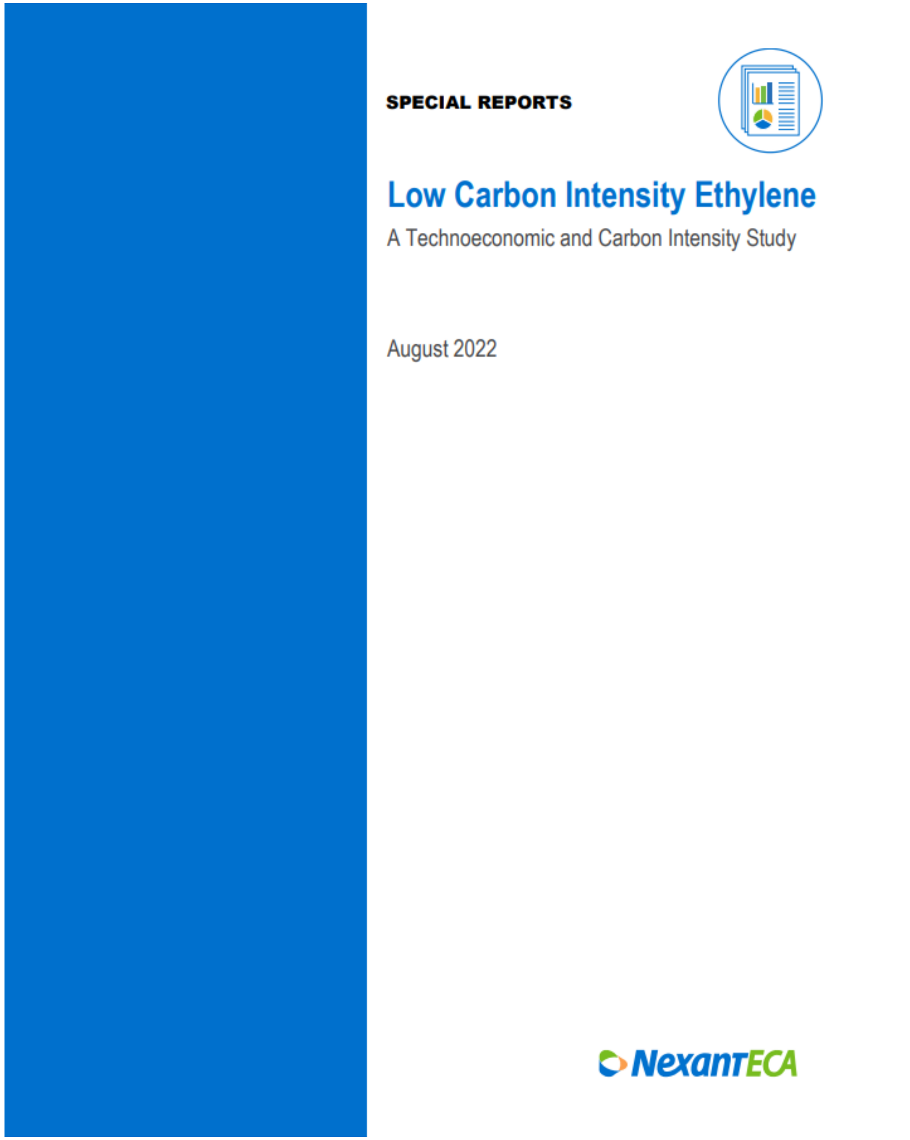
Ethylene derivatives are essential for the low-carbon technologies of the future

Objective and Key Questions Addressed

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

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

- In this report, NexantECA covered **alternative production routes** and compared their **relative cost of production and carbon intensities** with the conventional route 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**


SPECIAL REPORTS

Low Carbon Intensity Ethylene

A Technoeconomic and Carbon Intensity Study

August 2022

NexantECA

Key Questions addressed in this Special Report

- What is the **lowest carbon intensity route** to ethylene?
- 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:
  - Advances in Cracker Technologies:
    - Carbon capture
    - Electric crackers
    - Renewable Naphtha
  - Alternative Ethylene Technologies:
    - Ethanol-to-Ethylene (E-to-E)
    - Renewable Methanol-to-Olefins (MTO)

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

- Add-ons for **other regions** (e.g., Southeast Asia) or specific countries (e.g., Japan or South Korea) are also available for an additional fee.

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

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

Entry to Gate = On-site

Scope 3 Downstream

Indirect after the gate

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

Scope 3

All other indirect

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

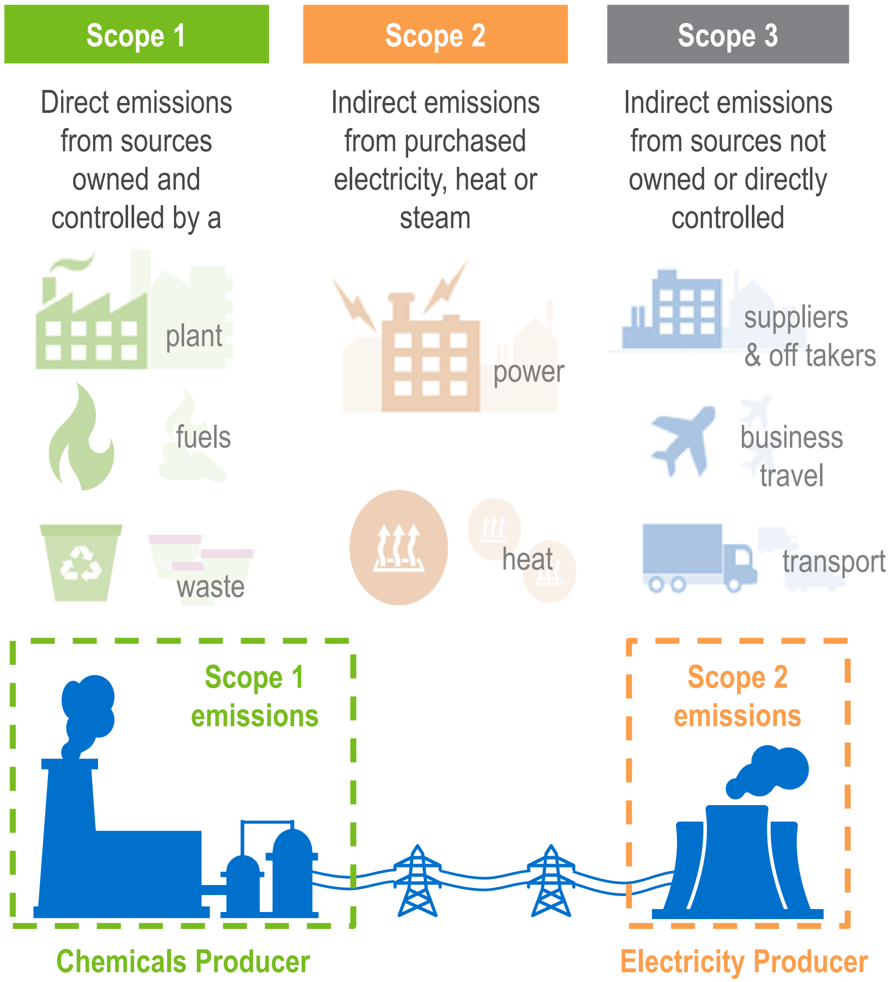
Cradle to Gate = Ex-works

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

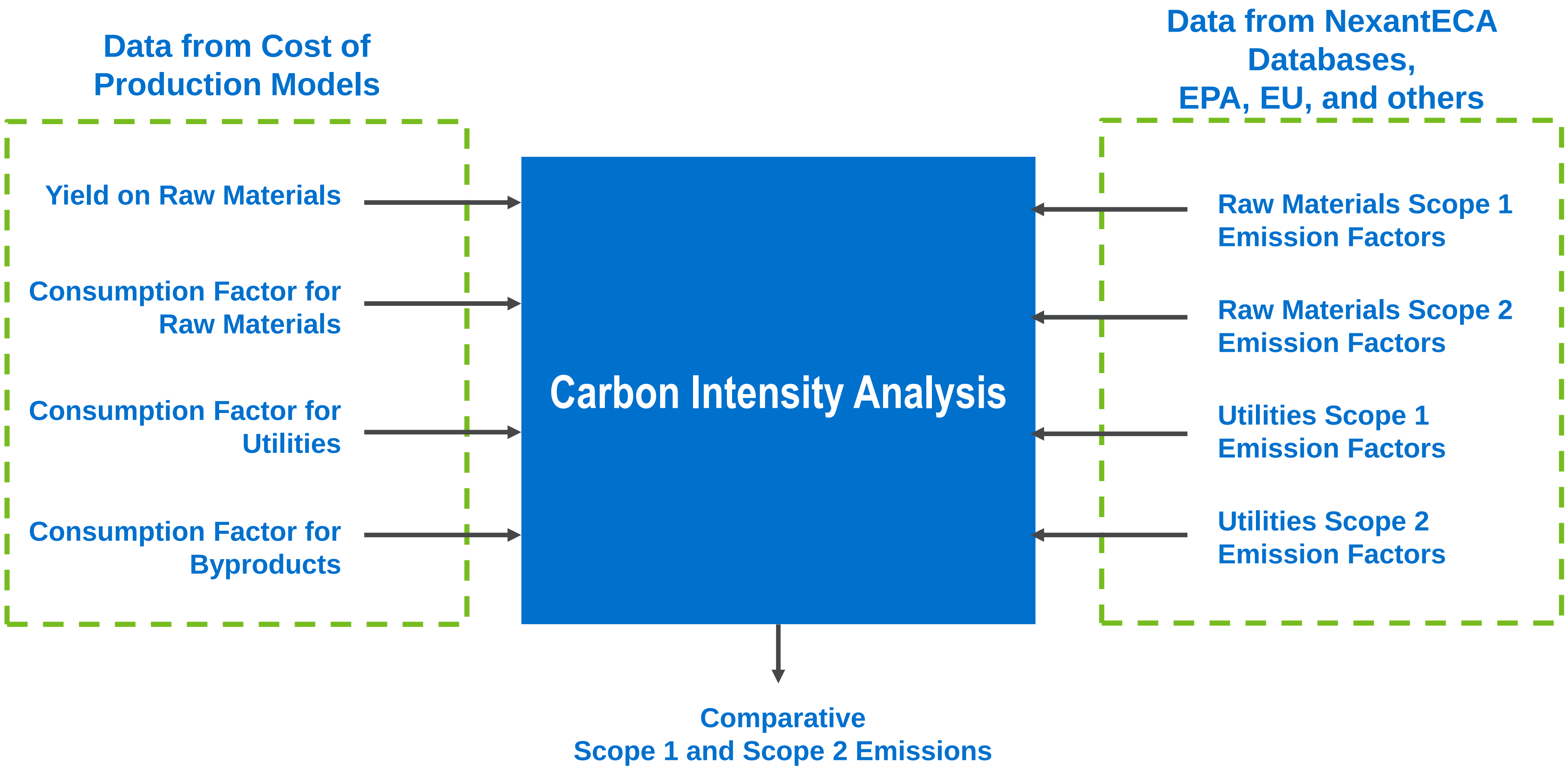


- **Scope 1** emissions are direct emissions that occur from sources controlled or owned by the reporting company
  - These can be the emissions from combustion of fuels, process emissions or fugitive emissions
  - The GHG Protocol does not include biomass combustion in Scope 1
- **Scope 2** emissions 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



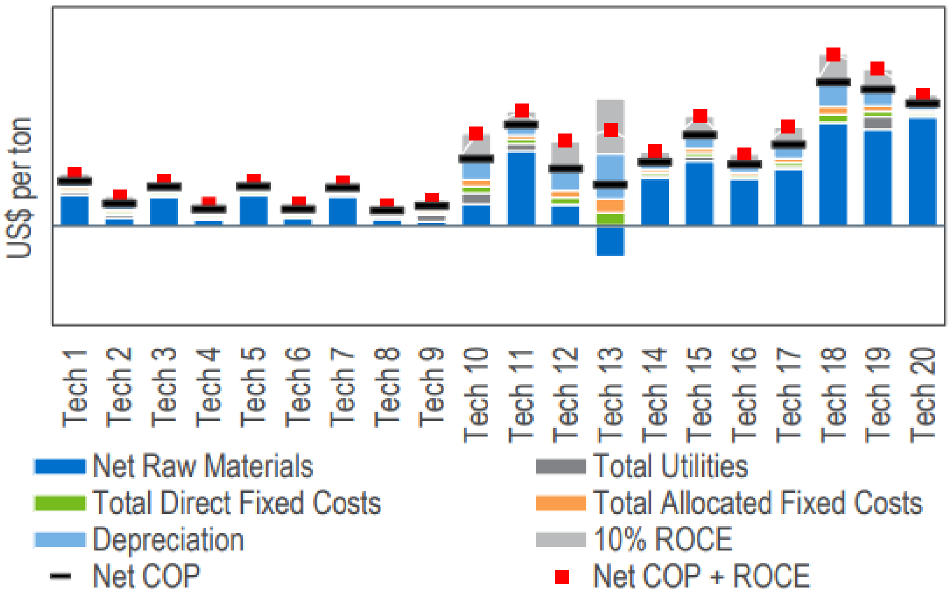
The outputs for the various routes can be compared on an even basis to determine the carbon intensity reductions possible and comparative sustainability

Illustrative Cost of Production Model for Chemical X

Plant Start-up	1Q2010		
Analysis Date	2010		
Location	USGC		
Capacity	274.6 Thousand Tons/yr		
Operating Rate	100 percent		
Throughput	274.6 Thousand Tons/yr		

CAPITAL COST	MILLION U.S. $
ISBL	61.4
OSBL	12.2
Total Plant Capital	**73.7**
Other Project Costs	18.4
Total Project Investment	**92.1**
Working Capital	9.2
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



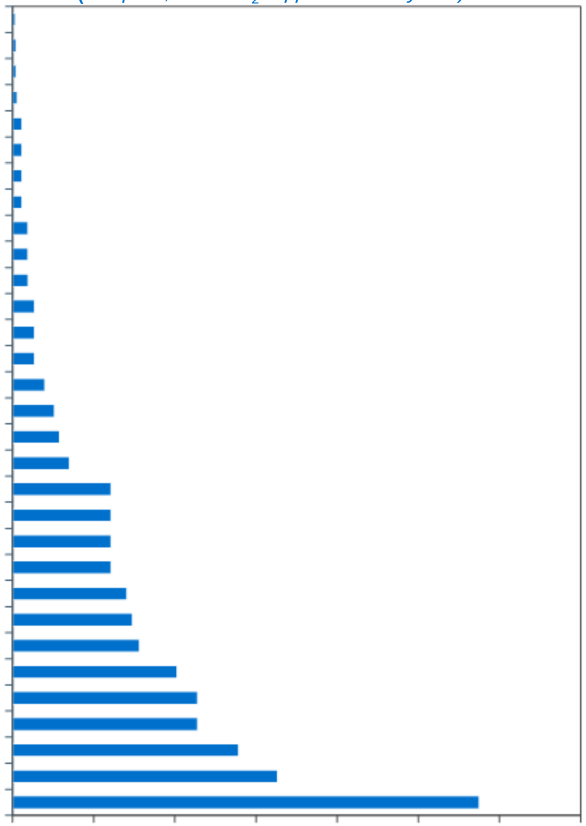
The outputs for the various routes can be compared on an even basis to determine the baseline competitiveness— a value to carbon emissions can add to the competitiveness of the lower carbon intensity routes

Carbon Intensity is compared across the different scope emissions, and the different regions

Regional Comparisons

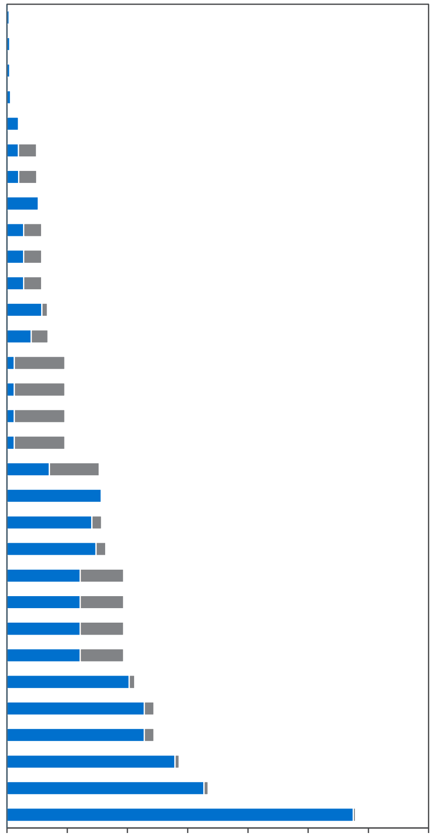
Direct Emissions Comparison

(Scope 1, Ton CO_2 eq per Ton Ethylene)



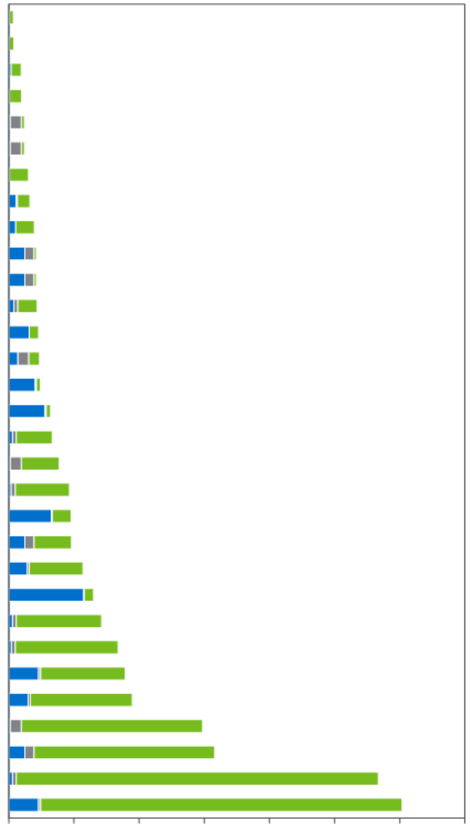
Process Emissions Comparison

(Scope 1 and 2, Ton CO_2 eq per Ton Ethylene)



Value Chain Comparison

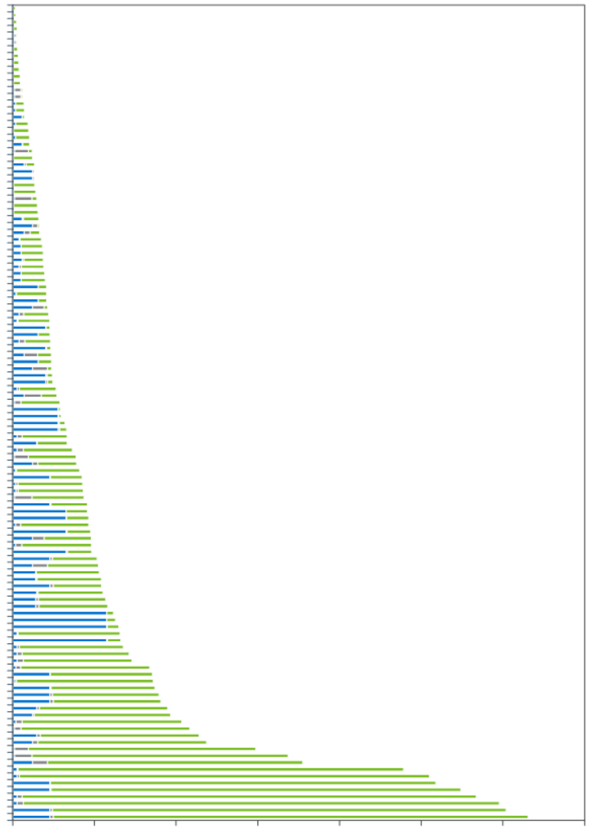
(Scope 1,2 and 3, Ton CO_2 eq per Ton Ethylene)



Global Comparisons

Value Chain Comparison

(Scope 1,2 and 3, Ton CO_2 eq per Ton Ethylene)



■ Scope 1 ■ Scope 2 ■ Scope 3

Routes to Ethylene and Low Carbon Intensity Ethylene

NexantECA

There are three primary conventional routes to ethylene that the alternatives are compared to as a benchmark

PRIMARY CONVENTIONAL ROUTES

NGLs (e.g., ethane / propane)	→ Steam Cracker	→ Ethylene
Naphtha	→ Steam Cracker	→ Ethylene
Methanol	→ MTO	→ Ethylene

Methanol and the utilities for the downstream MTO processes (e.g., power and steam), depending upon the region can be produced from natural gas or coal (e.g., including CTO in China), which can make the carbon footprint vary widely

ALTERNATIVE ROUTES TO LOW CARBON INTENSITY ETHYLENE USING CONVENTIONAL PETROCHEMICAL FEEDSTOCKS

|----Carbon Capture----|	NGLs (e.g., ethane and/or propane)	→ Steam Cracker with Carbon Capture	→ Ethylene
	Naphtha	→ Steam Cracker with Carbon Capture	→ Ethylene
	Methanol	→ MTO with Carbon Capture	→ Ethylene
|----Electric----| |---Crackers---|	NGLs (e.g., ethane and/or propane)	→ Electric Cracker with Renewable Power	→ Ethylene
	Naphtha	→ Electric Cracker with Renewable Power	→ Ethylene

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

Many options exist for the reduction of carbon intensity of ethylene production, in three other categories based upon renewable feedstocks: renewable-methanol-, ethanol-, and naphtha-based

ALTERNATIVE ROUTES TO LOW CARBON INTENSITY ETHYLENE USING RENEWABLE FEEDSTOCKs AND THE EXISTING VALUE CHAIN

Renewable-Methanol-Based			
MSW or Biomass Gasification	→ Methanol	→ MTO	→ Ethylene
Biogas SMR + Methanol Synthesis	→ Methanol	→ MTO	→ Ethylene
Power-To-Methanol via CO_2 + H_2	→ Methanol	→ MTO	→ Ethylene

Renewable-Naphtha-Based		
HVO Naphtha	→ Steam Cracker	→ Ethylene
Renewable Naphtha from Plastic Waste Thermolysis	→ Steam Cracker	→ Ethylene
Renewable Naphtha from MSW or Other Biomass Gasification and FT Synthesis	→ Steam Cracker	→ Ethylene

ALTERNATIVE ROUTES TO LOW CARBON INTENSITY ETHYLENE NOT USING THE EXISTING VALUE CHAIN

Ethanol-Based		
1G Ethanol (e.g., corn or sugarcane)	→ Ethanol Dehydration	→ Ethylene
2G Ethanol (e.g., biomass based)	→ Ethanol Dehydration	→ Ethylene
2G+ Ethanol (e.g., LanzaTech)	→ Ethanol Dehydration	→ Ethylene

Carbon capture and/or electric heating with renewable power can also be combined with these routes (e.g., renewable naphtha) to further reduce the carbon intensity of ethylene production

Analyses Performed and Deliverables

Key Analyses Performed

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

- Process Descriptions
- Process Chemistry
- Process Flow Diagrams

Carbon Intensity Analysis: A carbon intensity analysis with an output of tons CO_2eq per ton ethylene (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:

- 3 Primary Incumbent Ethylene production routes:
  - NGL Steam cracking
  - Naphtha Steam Cracking
  - MTO
- Identified alternatives for low carbon intensity ethylene production in 5 categories:
  - Carbon Capture
  - Steam Cracking with Electric Heating with Renewable Power
  - Renewable Methanol-Based MTO
  - Gasification-based
  - Biogas-based
  - Power-to-Methanol via H_2 and CO_2
- Renewable Naphtha-Based Steam Cracking
  - HVO Naphtha-Based
  - FT Naphtha Based
  - Waste Plastic Thermolysis-Based
- Renewable Ethanol Dehydration
  - 1G Ethanol (e.g., corn and sugarcane)
  - 2G Ethanol (e.g., cellulosic)
  - 2G+ (e.g., LanzaTech)

Economic Review – A cost of production (COP) analysis with an output of COP models and comparative economics 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 all identified Routes, including:

- Current economic competitiveness vs the incumbent and market prices

Strategic Review – A high level review of current status of development, potential impacts on the industry, SWOT analysis including

- 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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Other Offerings

For other individual chemicals or whole value chains, NexantECA can offer further analyses

Cost of Production Models:

- Many cost of production models for renewable or low carbon intensity chemicals and fuels can be found in NexantECA's Biorenewable Insights program, including:
  - Feedstocks
  - Polymers
  - Fuels
  - Base Chemicals
  - Solvents
- Many cost of production models for conventional petrochemicals and fuels, in NexantECA's TECH program (formerly PERP)

Carbon Intensity Analysis

- For any chemical currently covered at the Cost of Production model level in the Biorenewable Insights Program and/or the TECH Program, a carbon intensity model in a desired region or regions is available, as an add-on.

Market Analysis

- For many chemicals featured in the Biorenewable Insights and TECH programs, there is also market coverage (supply, demand, pricing) for the same chemicals in the Market Insights program, which has history and scenario-based forecasts of key market data

For more information:

TECH
mcesar@nexanteca.com

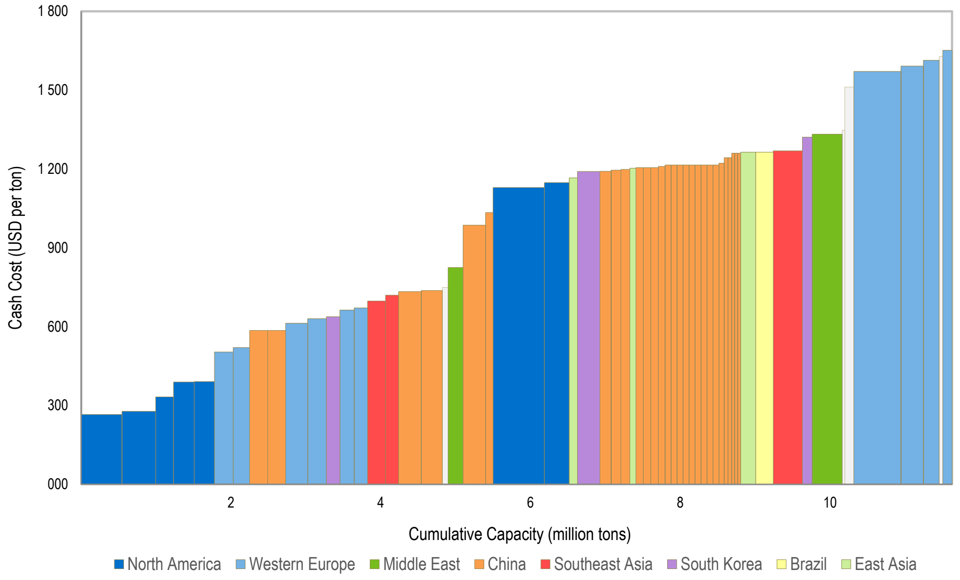
Biorenewable Insights
sslome@nexanteca.com

Market Insights
xpeng@nexanteca.com

For other individual chemicals or whole value chains, NexantECA can offer further analyses

Cost Curves

- The NexantECA ***Cost Curve Analysis*** program provides comparative cost positions of individual producers within the global chemical industry. Carbon intensity curves highlight regions and/or technologies that offer small carbon footprints.
- Builds upon our well-known ***Markets and Profitability*** program and ***Technology and Costs*** programs including TECH and ***Biorenewable Insights***.
- Coverage includes major petrochemical value chains, gas-based chemicals, and renewables.



For more information:

Cost Curves
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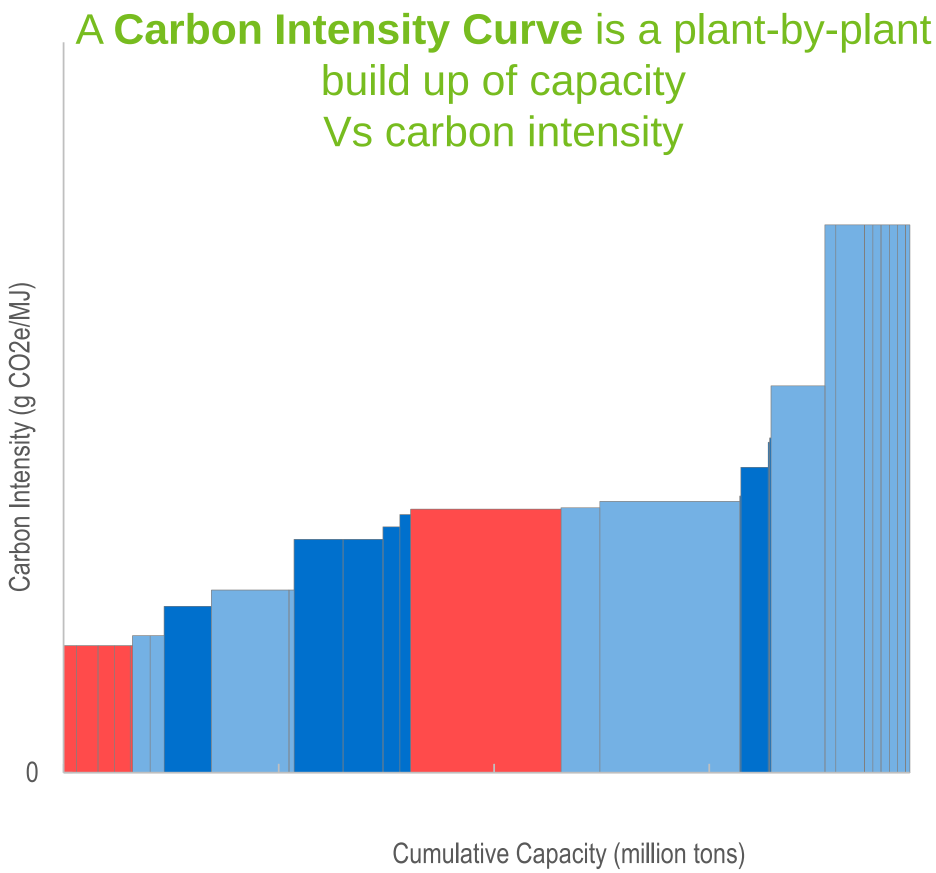
NexantECA is also able to provide Carbon Intensity Curves for any product covered in the Cost Curves program, as an add-on for an additional fee

Illustrative Carbon Intensity Curve for Chemical X



- A carbon intensity curve highlights the regions and/or production processes that offer the lowest carbon intensity and, conversely, which have the highest carbon intensity, and further allows for benchmarking regional carbon intensity
- The carbon intensity curve shows where leading producers are located and illustrates the impact of feedstock selection on CI
- When coupled with cost curves, CI curves can identify low cost-low CI producers and high cost-high CI producers—the former of which will offer long term competitiveness, while the latter are more likely to struggle in the long term.

For more information:

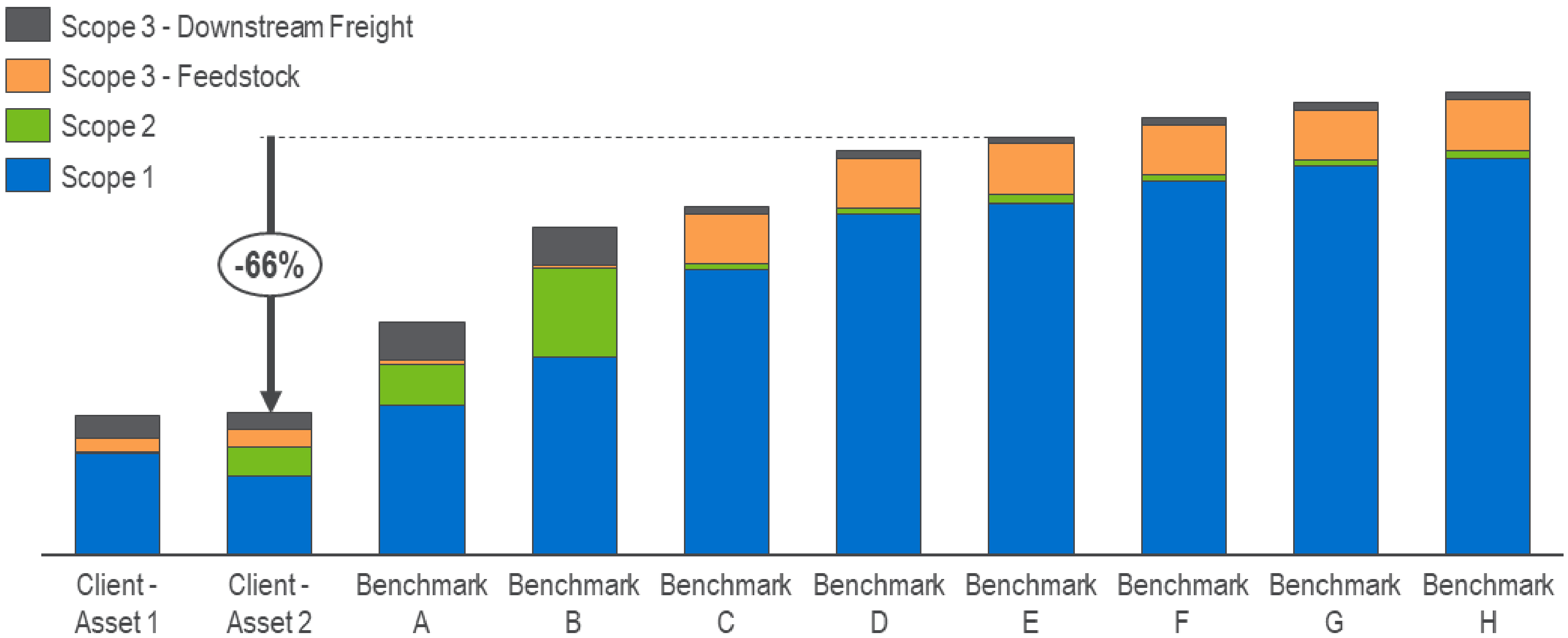
Cost Curves

achan@nexanteca.com

Cost curves and CI curves for ethylene production and other chemicals are available for an additional fee

Carbon intensity is an increasingly important consideration. NexantECA is supporting global leaders quantify the carbon intensity of their proprietary processes relative to other value chains

Carbon intensity benchmarking



Emissions were modelled across the value-chain to factor in raw materials and transportation to customers I.e. upstream and downstream Scope 3 emissions, respectively

For more information:

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NexantECA
Energy and Chemicals Advisory

www.NexantECA.com

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SUBSCRIPTIONS AND REPORTS

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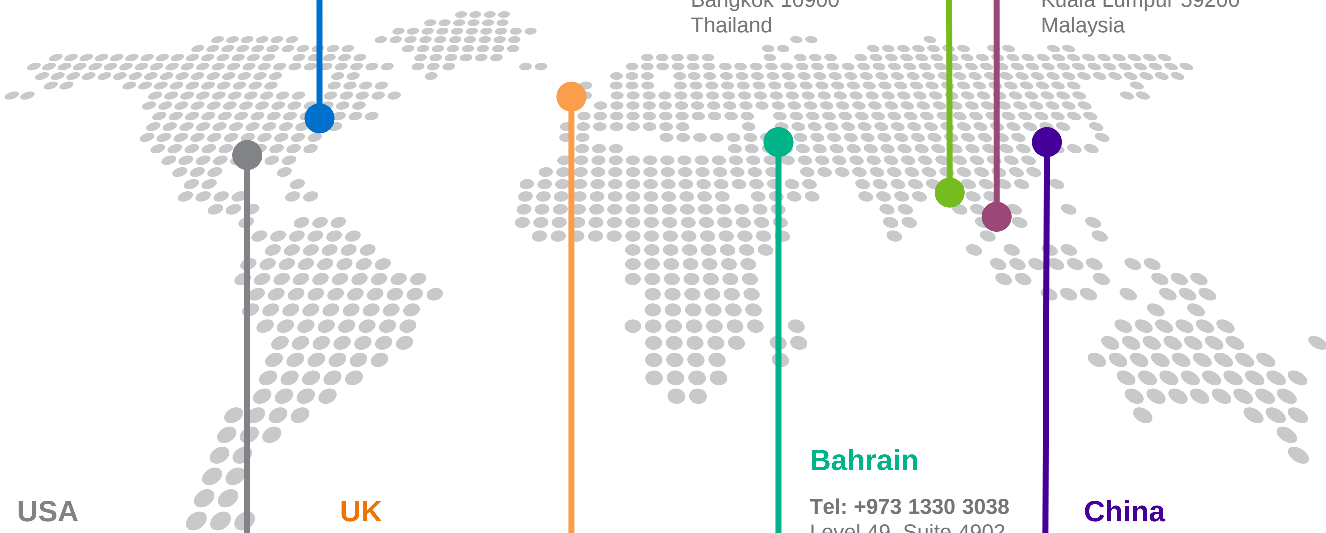

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