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An Overview of Decarbonisation Initiatives for Indian Refineries

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Abstract

Indian Petroleum Industry is aggressively implementing decarbonisation measures in the refineries. These initiatives include (i) Energy reduction from the current assets (ii) Supplementing the power requirement through renewable power (iii) Ramping of the hydrogen production through solar and wind energy (iv) Production of biofuels such as ethanol from municipal waste.

Industry can achieve decarbonisation measures through considering many different pathways supplemented by Digital Technologies for the measurement and control of emission reductions. Through real time process, energy, emissions, economics and multi-period optimisation simulation tools, refineries can integrate both conventional forms of energy and renewables to meet the emission targets in the most economical manner. This paper illustrates some of these benefits.

Introduction

The Indian Petroleum Industry is aggressively implementing decarbonisation measures in its refineries to meet the needs of its growing population. In 2022, India was the fifth largest global economy with GDP of US $3.8 trillion and the second most populous country with about 1.4 billion people. By 2050, India is expected to become the world's second largest economy with over 1.6 billion people, creating a dire need of sustained energy sources. To cater to this growing demand for energy, the government is planning to increase its refining capacity from 5 million barrels/day to about 10 million barrels/day by 2050, using sustainable measures while simultaneously focussing on the existing assets to reduce the carbon footprint. For an emerging economy and the fourth largest carbon emitter in the world, India has committed to reduce its emissions by 33%–35% by 2030 compared to 2005 levels.

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Roadmap Development

As India emerges as a global economic power, how can India achieve a net-zero emissions economy by 2050? After all, economic growth is associated with consumption of natural and man-made resources leading to greenhouse gas (GHG) emissions. Mitigating Scopes 1, 2, and 3 emissions will play a critical role in moving towards zero emissions. The World Resources Institute introduced 3 scopes of emissions. Scope 1 includes the company's direct GHG emissions from fossil fuel combustion. Scope 2 includes indirect GHG emissions associated with the company's consumption of purchased electricity, steam, heat, and cooling from utility providers. Scope 3 includes all the other indirect GHG emission from upstream productions, that is, emissions embodied in trade.

To reach a net zero emissions energy system, India will need to follow a comprehensive roadmap for decarbonisation. The roadmap, as depicted in Figure 1, requires more and faster deployment of solar, wind and hydro power to enable greater electrification across the country. It also requires the development of new fuels. Liquid biofuels and biogas, as well as hydrogen produced from electrolysis are the most promising substitutes to liquid fossil fuels, as they can be obtained

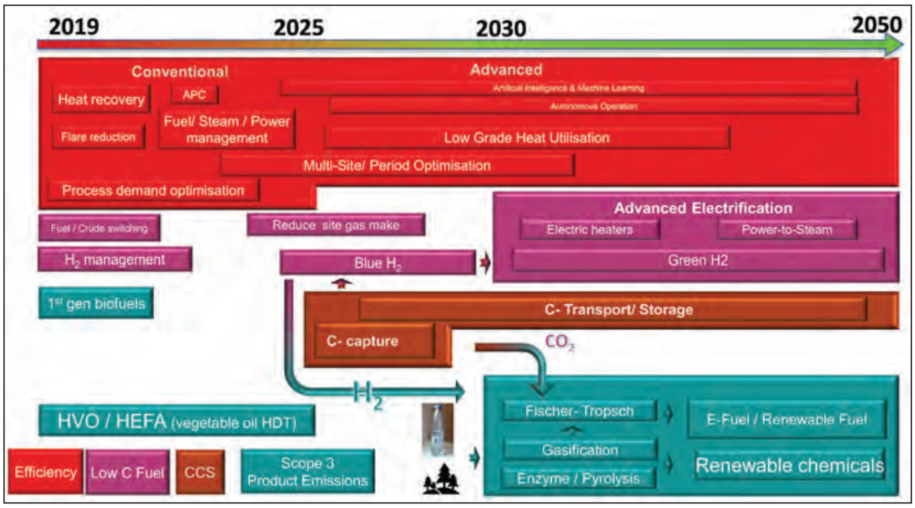

Figure 1. Roadmap for net zero emissions

from locally available feedstocks for replacing or supplementing petrol or diesel to meet growing energy requirements for different economic activities. This plan is back-casted from India's net zero emission goals set at the end-time of 2070 with the following steps:

1. **Identify Net Zero Targets**

   a. Review current and proposed Green House Gas Emissions (GHG) regulations

   b. Establish baseline GHG emissions performance in line with regulatory standards

2. **Create Emissions Modelling and Reporting**

   a. Categorize emissions into Scope 1, Scope 2, and Scope 3

   b. Show how Scope 1 and 2 emissions are linked to energy usage and operations

   c. Provide GHG reporting dashboard design that monitors actual, planned, and future emissions

3. **Develop a Roadmap**

   a. Develop optional actions within the roadmap to achieve net zero emissions targets according to the timeline

   b. Identify technology options for each operating asset to meet the emissions reduction targets

      i. Identify for Scope 1, 2 and 3 GHG reduction impact

      ii. Assess potential capacities and estimated capital costs

The Approach

India has opportunities to chart its own unique development on its pathway to decarbonisation. However, it must ensure that its energy pathway is socially inclusive, economically viable and assures sustainability of resources long-term.

Integrated Process Energy and Economics Model

One of the best ways to reduce Scope 1 and 2 emissions is via early deployment of best available technologies. To help refineries define their baseline emissions, an Integrated Process, Energy, Emissions, and Economics Model (IP3EM) has been developed. With built-in best technology (BT) benchmarking at the process unit level, emission reductions can be integrated into GHG abatement options. The IP3EM model (Figure 2) offers the refiner the following benefits:

- Tracks all major system balances, such as hydrogen, steam and fuel gas and flaring rates.
- Compares baseline emissions with the regulatory standards to accurately identify and quantify the sources of Scope 1 and Scope 2 emissions. This automatically calculates carbon intensities for all refinery products.
- Generates multiple Scope 1 and 2 emissions reduction scenarios that can analyze refinery margins and return on capital, energy reductions, hydrogen firing, electrical heating, and carbon capture – including unit sizing and CO_2 production rates.
- Allows rapid analysis and optimization of renewable power options to further reduce Scope 2 emissions and energy costs.

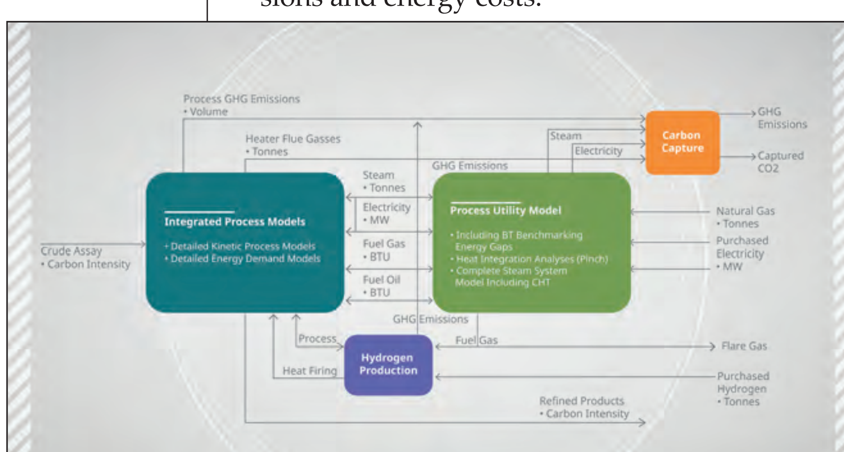

Figure 2. Integrated Process, Energy, Emissions, and Economics Model (IP3EM)

- Incorporates Scope 3 projects, such as renewable diesel plants or sustainable aviation fuel (SAF) production, into the IP3EM tool and analyses.
- Designs and develops emissions management options to clear reporting and certify carbon intensities.

Scope 1 and Scope Reduction Pathways

Indian refiners have an opportunity to transition to a lower-carbon economy. Managing energy consumption via energy reduction, carbon capture, utilization, transportation and storage, as well as green hydrogen production and optimization will help the country reach its proposed emission targets and provide greater energy security.

Energy Reduction

While most refineries aim for reaching first quartile goals, most Indian refineries are currently reporting second, third, and fourth quartile energy consumption performance. A fourth quartile refinery emits 65% more CO_2 than its 1st quartile competitor. If the site improves by one quartile, emissions can be expected to drop around 15% as shown in Table 1. Emissions can be further reduced by approximately 3% via digitalisation with an energy management system that monitors the various energy-carrying utilities such as steam, electricity, fuel, hydrogen, and CO_2.

Table 1. Percentage of energy consumption by quartile

Quartile	1st	2nd	3rd	4th
Energy Consumption (%)	20	35	50	65

To reach top quartile performance, refiners can reduce their energy consumption by taking the following steps:

i. Benchmark energy usage to best-in-class performance.

ii. Using the benchmarks, identify opportunities to reduce Scopes 1 and 2 emissions through revised operating practices, adopt heat integration techniques and deployment of capital.

iii. Prioritize a list of projects, including potential timing, capital, expected returns, and impact on GHG emissions for each asset.

iv. Identify and assess opportunities to reduce Scope 2 emissions with the use of renewable energy sources such as wind, solar, biomass, and geothermal energy.

Carbon Capture

With 23 refineries in the Indian oil market, carbon capture, utilisation and storage (CCUS) is a current priority as part of the decarbonisation roadmap. Carbon capture is viewed as a key technology with potential to remove significant GHG emissions from fossil fuel sources such as refineries. Without the use of CCUS technologies, the 2017 emission reduction target could be extremely difficult to achieve.

For instance, a decarbonisation study took place in one of Japan's major industrial clusters. Figure 3 illustrates the approach taken by the researchers. A key focus of the study was the financial modelling of multiple assets and options related to CCS. The research was conducted to make the industrial area net carbon neutral by 2050, preferably using carbon utilisation. The assessments considered the following carbon capture technologies:

- Amine and other chemical solvents
- Physical solvents
- Cryogenic
- Membrane / PSA

Carbon Utilisation

Carbon Utilisation (CU) involves converting CO_2 into useful raw materials such as fuels and chemicals while reducing CO_2 into the atmosphere.

A major challenge facing the clean energy community is the urgency to evaluate and select the most cost-effective CU options. The techno-economic evaluation of CU encompasses major parameters like market demand, product and feed delta pricing, CO_2 pricing, H_2 costs, utility and operating costs, capital cost estimates,

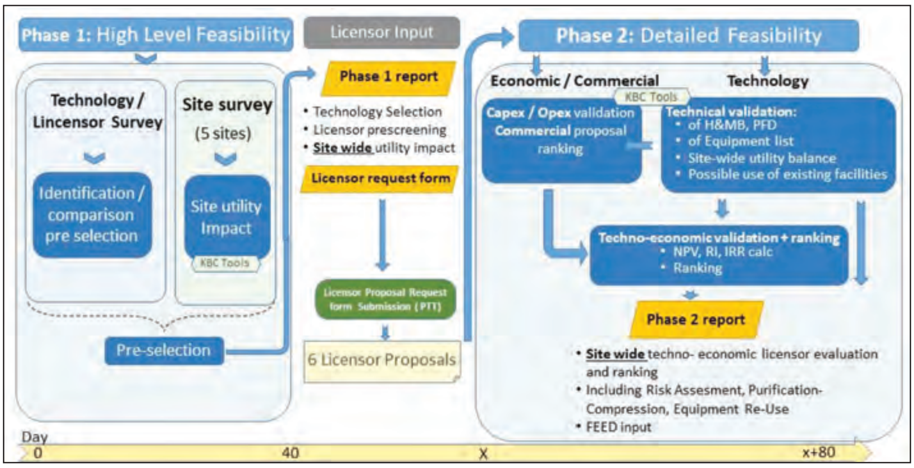

Figure 3. Techno-economic assessment of CCUS technologies

and technology readiness level.

A study that evaluated nine CU technologies was recently conducted. These technologies and feeds, other than CO_2, are listed in Table 2.

Table 2. Carbon utilisation technologies

#	Name	Main Product	Non-CO_2 feeds
1	Methanation	Methane	H_2
2	Methanol	Methanol	H_2
3	Fischer-Tropsch	Syncrude / SAF	H_2
4	Oxo Synthesis	Butanal	Propylene, H_2
5	Carbonation	Building material	Steel slag
6	Xylenes	Mixed Xylenes	H_2
7	Urea	Urea	Ammonia (NH_3)
8	Polyols	Polyether carbonate polyol	Propylene oxide (PO)
9	Polymeric Carbonates	Polypropylene carbonate (PPC)	Propylene oxide

The findings revealed that carbon capture technologies are moving toward technological maturity. A large amount of hydrogen is needed to produce fuels and other oxygen-free products, making the technology impractical expensive in the short- and medium-terms. Viable candidates for CU include high-value niche chemicals, especially those containing oxygen. In addition, building materials produced from CO_2 and slag use relatively limited amounts of CO_2 and are expected to be economically viable with limited support.

Overall, CU pathways may have a key role to play in India, consistent with international energy outlooks, and may be a natural step towards a blue hydrogen economy.

CO_2 Transportation and Storage

While identifying carbon capture opportunities is the first step in considering the CCS technology as an attractive carbon emission mitigation option, the next step is to link those opportunities with other conditions such as CO_2 transportation and storage.

The flow continuity across the refineries for CO_2 capture, as well as transport to terminal and injection, may make it difficult to determine the requirements of the CO_2 gas system in isolation. Moreover, the transport facilities capacity, the pressure and capacity of the storage site, the effect of impurities in the mixture and more may vary. Ultimately, this may affect the sustainability of the initiative over time. Today, advanced technologies can simulate full compositional details and with highly accurate thermodynamic models across the entire supply chain from carbon capture to injection.

Green Hydrogen Production and Optimisation

Most of the Indian refineries are preparing to produce green hydrogen in electrolysers, which may depend on different (intermittent) energy sources such as solar, wind, energy storage, and the national power grid.

The hydrogen electrolyser operator's main objective is to fulfil the demand of green hydrogen on time, at the lowest costs, and on specification while accounting for all operating constraints (e.g., min/max electrolyser capacity, min/max storage capacity, electric grid contracts, and more). Additionally, the operator may also need to handle a surplus of renewable energy production via hydrogen generation and storage in the most economical way. Typical variables to consider include:

- the amount of hydrogen to produce at a given time,
- the amount hydrogen to store, and
- the amount of electric power to import from the grid.

Power market system operator requirements and hydrogen require planning while accounting for the weather and power grid price forecasts.

A multi-period optimiser solution for monitoring, optimisation, and scheduling of hydrogen electrolyser systems, and any other related energy vectors, has been developed. The system evaluates how to allocate the generation and storage of hydrogen based on expected power prices and planned hydrogen demands from other sources like ammonia production.

Under a poorly managed operation, green hydrogen is produced under the premise to satisfy production at the ammonia plant, without considering electricity prices. This operation will satisfy demand and system requirements. However, it may be suboptimal and lead to higher hydrogen production costs.

If the system is managed by an optimiser, it will consider power price variability, storage capacity and constraints, and electrolyser operating efficiencies to determine when to produce hydrogen while satisfying demand.

As seen in Figures 4 and 5, the key element in this system is appropriately managing hydrogen inventory (i.e., green area in both Figures). As expected, hydrogen production (red bars) is more economical when electricity prices are low (blue curve) and recommend the proper use of the storage tank. To optimise the

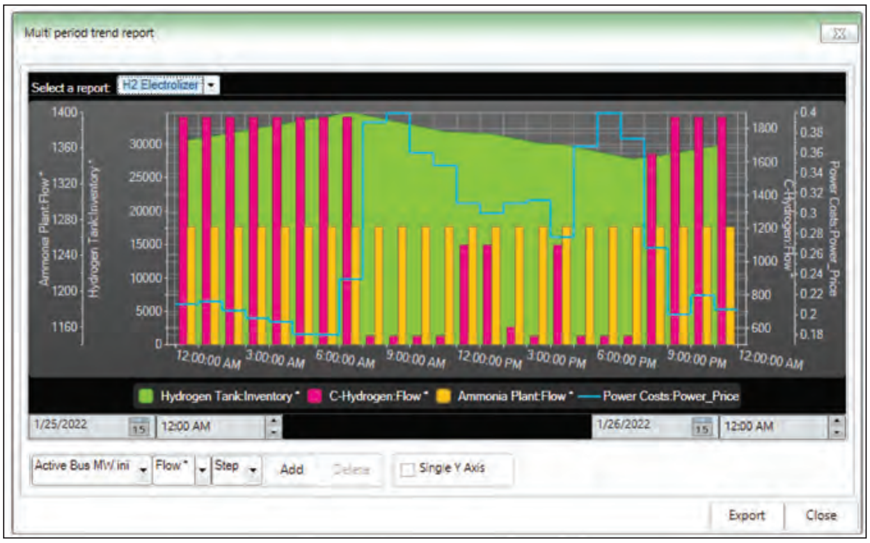

Figure 4. H_2 management by optimiser

Figure 5. H_2 unmanaged operation

green hydrogen, electricity prices, storage conditions, electrolyser operating efficiencies, demand forecast, and renewables are taken into account.

The comparison of optimally managed versus unmanaged operations is shown in Figures 4 and 5.

Reducing Scope 3 Emissions

According to researchers, Scope 3 emissions account for about 75% of the total industrial carbon footprint. With better insight, refiners can pursue Scope 3 emission reduction projects not just within their own plants but across their supply chain.

Ethanol Blending and Bio Diesel

Because India has significant potential to expand its modern bioenergy sector using organic waste generated by the agricultural sector and municipal solid waste, one measure being pursued by the government involves increasing ethanol blending by up to 20% by 2025. This initiative not only reduces the CO_2 emissions but also helps improve energy security and air quality. Furthermore, agricultural wastes can be used to develop indigenous technologies. Various technologies have been evaluated such as cooking oil, animal fats, forestry / mill waste, husks, straw, cobs, municipal to opti-

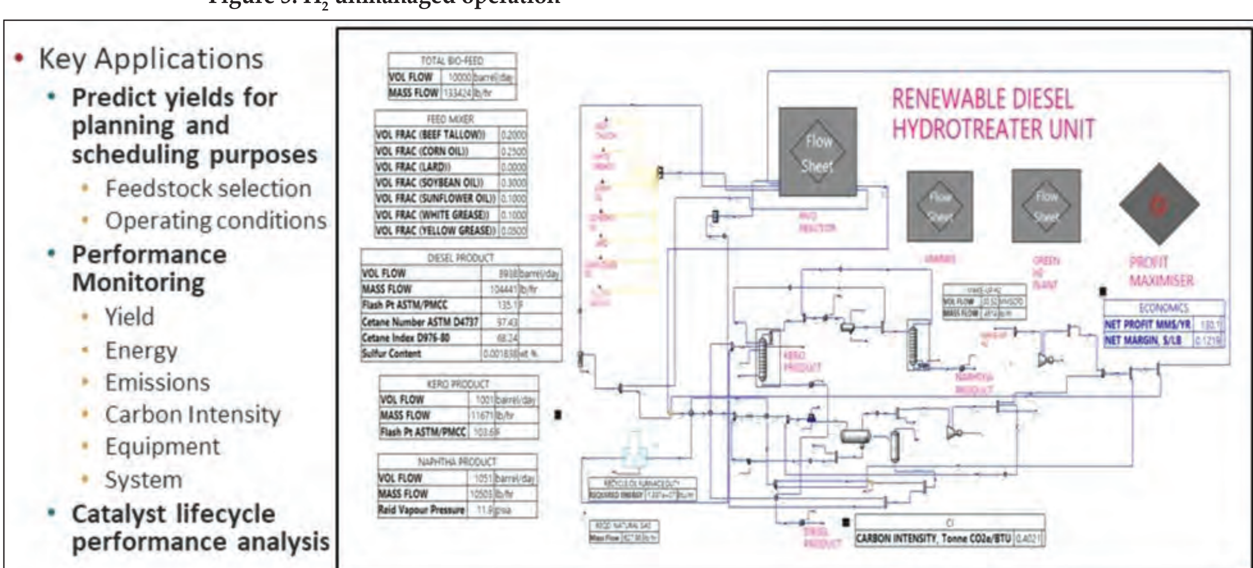

Figure 6. Scope 3 reduction modelling

mise the yields and energy consumption. Using process simulation, blending quantities and blend properties can be optimised to meet the specifications. A typical flowsheet to analyse various feeds and yields appears in Figure 6.

These site-wide process simulations will help evaluate co-processing of bio-feeds to produce biodiesel and SAF.

Conclusion

India's growing economy and increasing levels of trade have led to the growing demand for fossil fuels. While the refining of crude oil offers many useful products and services, the industry has also created a significant amount of GHG emissions. Thus, the industry must fundamentally alter its production practices and business models to decarbonise its operations and support the decarbonisation efforts of the sectors it empowers. Following is a recap of the decarbonisation measures that Indian refineries can implement such as:

(i) Establish baseline emissions and identify the measures to contain the Scope 1, Scope 2 and Scope 3 emissions using an Integrated Process, Energy, Emission and Economic Model tool.

(ii) Reduce emissions through comprehensive energy reduction program covering benchmarking, gap analysis, and implementation of opportunities through no investment, low investment and capital investment. Through this approach, refineries can improve their energy efficiency quartiles by reducing current emissions in the range of 20% to 30% based on their current status. The reduction in emissions can drop further by 3% by adopting digital technologies for measurement and control.

(iii) Use carbon utilization for high-value niche chemicals, especially those containing oxygen. Additionally, building materials produced from CO_2 and slag use relatively limited amounts of CO_2 but are expected to be economically viable with limited support.

(iv) Simulate the CO_2 network from carbon capture to injection, including full compositional details and with highly accurate thermodynamic models.

(v) Implement multi-period optimiser solutions to monitor, optimize, and schedule electrolyser systems and any other related energy vectors. The system evaluates how to allocate the generation and storage of H_2 based on expected power prices and planned H_2 demands from other demand sources like ammonia production.

(vi) Employ simulation models to optimise the ethanol blending quantities and blend properties to meet necessary specifications.

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Editors Note: KBC has been helping industry to achieve decarbonisation measures through its flagship "Energy Improvement Programs" supplemented by Digital Technologies for the measurement and control of emission reductions through its proprietary real time tools.

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Roadmap to Net Zero

KBC’s digital energy management technology and expertise in energy & process management will help achieve your Scope 1, 2 and 3 emissions goals. Wherever you are on your decarbonization journey, our experts will work with you to identify energy saving opportunities and reduce emissions at your plant. We know how to roadmap to net zero and beyond and how to deliver it.

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