Future-ready refineries for Viksit Bharat

Building resilient, competitive, and sustainable refineries

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Foreword

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India’s refining sector is at pivotal point as the country is on a growth trajectory with rising mobility needs and industrial expansion, reinforcing its position to become a major refining hub while the sector is being reshaped by new set of structural forces: growing petrochemical demand, operational resilience, and net-zero goals. With this context, the growth trajectory is no longer only about whether refineries will transform, but also about how quickly and effectively they can transform.

This paper, ‘Future-ready refineries for Viksit Bharat’, explores this transformation through Indian refiners’ lens—and how they respond to this shift. It is not only about building more capacities but shifting from traditional fuel-focused refinery to integrated petrochemical refineries, to be smarter and future ready through digitally enabled operational excellence and better aligned to lower carbon emissions.

For the sector, this transition brings the set of opportunities along with inherent complexities of the solutions. Brownfield assets must be upgraded with a sharper focus on flexibility, efficiency, and emissions performance, while maintaining cost competitiveness. Greenfield projects should be designed with long-term optionality in focus. This entire transformation is redefined by technologies like advanced digital operations, low-carbon utilities, green hydrogen, and alternative feedstocks.

As Indian refiners seek to balance three priorities that will define the sector’s next chapter: energy security, affordability, and sustainability, the leaders of this transition will be those with a more integrated view of value creation moving beyond the incremental change. This will require coordinated efforts across policy, infrastructure, and technology ecosystems with capital allocation. This needs further push from leadership teams with deliberate choices on partnerships and business model evolutions.

This paper aims to contribute to that conversation by outlining the strategic choices and practical pathways that can help shape the next generation of Indian refineries.

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India's changing refining landscape: Evolving demand and strategic imperatives

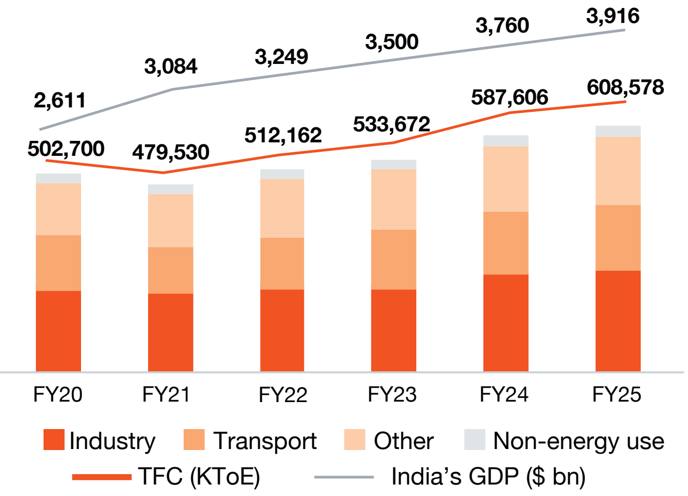
1.1. Setting the context: India's changing refining landscape

India is currently the world's most populous nation, and, as the world's sixth-largest economy,[1] it faces a complex dilemma involving accelerating its economic growth while maintaining the energy transition. Refineries are at the centre of this challenge, as they are both engines of industrial growth for Viksit Bharat and must also evolve to meet the low-carbon future to which India aspires.

1.1.1. Demand growth vs. energy transition paradox/trilemma

India is facing the energy trilemma: pursue energy security with sufficient supply for its growing oil demand from the current 5.6 mbpd[2] in 2024 to 6.6 mbpd in 2030[3]; provide affordable energy to its ~140 crore[4] citizens; and achieve environmental sustainability with net-zero targets by 2070.

Figure 1: India GDP growth vs. energy demand

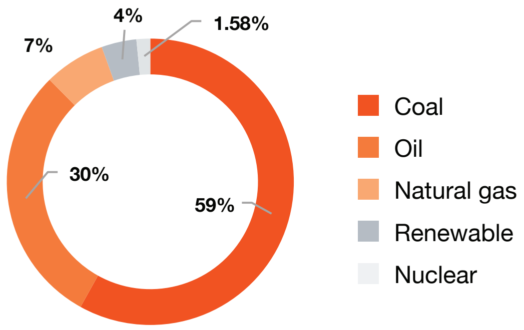


*Projected energy demand in India is to grow from 932 Mtoe in FY25 to 1671 Mtoe in FY2050.

India aims to achieve a sustainable energy mix by reducing its heavy reliance on fossil fuels.[5,6,7,8]

Figure 2: Primary energy mix

India primary energy mix (FY 2025)-932 Mtoe



6.6 mb/d **Oil demand by 2030** (from 5.6 mb/d in 2024)

1.2 mb/d[9] **India's net oil demand addition 2023–2030** (One-third of global growth)

+8mb/d[10] **Oil demand growth by 2050** increase from 2023 levels

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[1] GDP by Country: World Bank

[2] World Bank: Oil Consumption 2024

[3] IEA: India Oil Market Report

[4] World Bank India Population data

[5] India GDP: IMF

[6] Energy Statistics India 2025

[7] IEA World Energy Outlook 2024: 2025 Energy Demand–70EJ, conversion to 1671 Mtoe

[8] Energy Statistics India 2026: TPES % Share FY 25, FY25: 932 Mtoe, TFC Values and share FY 20 with FY 25

[9] IEA: India Oil Market Report

[10] OPEC: World Oil Outlook 2050: 8mb/d increase from 2023 India Oil demand

India's primary demand is driven by urbanisation, industrialisation, growing middle-class consumption, and its emergence as a global manufacturing hub. Even with ambitious climate targets, structural reliance on fossil fuels for transport, industry, and petrochemicals is increasing simultaneously.[11,12]

India's energy transition goals and targets

Energy transition and decarbonisation

- Net-zero emissions by 2070[13]
- Carbon-neutral oilfields and green refineries by 2040

Clean energy shift

- 15% energy share for natural gas by 2030[14]
- By 2030, CNG stations and residential connections are set to nearly double, with the gas grid expanding by 50%.[15]

Renewable energy revolution

- 500 GW (50% of total) of clean energy by 2030[16]
- Emphasis on compressed biogas through the SATAT initiative

Biofuel blending

- 20% ethanol blending with petrol (target achieved by 2025)[17]
- 5% biodiesel blending with diesel by 2030[18]

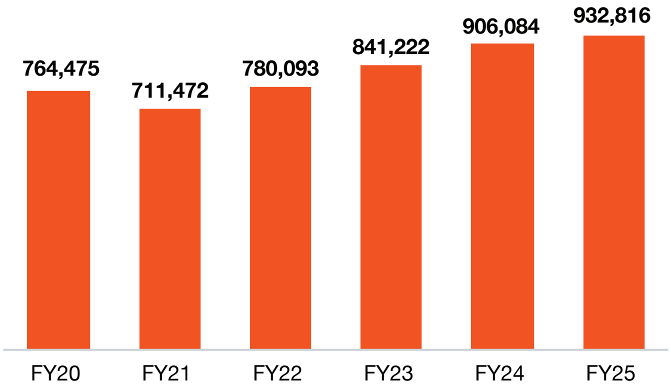
Green hydrogen revolution

- India's National Green Hydrogen Mission (NGHM) targets 5 MMT of green hydrogen per annum by 2030[19]
- PSUs investing in pilot hydrogen production/refuelling stations

EV policies

- FAME India scheme: Encourages the adoption of electric and hybrid vehicles through subsidies
- PM E-DRIVE scheme: Rollout of public EV charging stations across the country and provides a framework for subsidies

Figure 3: Total primary energy supply (TPES) (KT of oil equivalent)



India's energy trilemma

01

Energy security: 90% crude oil import dependence and declining domestic production

02

Energy equity: Energy demand to rise ~35% by 2035

03

Environmental sustainability: Net-zero target by 2070 but 2030 fossil fuel consumption to stay at 2020 levels

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[11] PPAC- 89% crude import in FY 26 (Calculated: Processing 272.110 MMT, imported 245.381 MMT)

[12] IEA World Energy Outlook 2024: India Energy demand rises by 35% by 2035, pg 277

[13] PIB- India net zero targets

[14] PIB- MoPNG

[15] IEA- India Gas Grid Expansion by 2030

[16] Ministry of Power Press Release: PIB

[17] PIB- MoPNG

[18] PIB- natural Policy on Biofuels

[19] PIB- Unlocking India's Green H Potential

Being the third highest globally in CO_2 emissions from fuel, and with an ~8% share of global emissions, India faces a challenge in achieving its environmental pollution and climate commitments.[20] EV penetration is accelerating in India, with YoY growth at 25% in FY26. EVs and energy efficiency improvements together save around 0.48 mb/d of oil demand between 2023 and 2030, whereas, as mentioned in the table below, the Indian oil demand is projected to grow by 1.2 mb/d till 2030 (from 2023), suggesting that oil demand still grows substantially during these years.[21,22,23] This creates a paradox, which defines India's refining strategy. India, while aggressively pursuing a transition to clean energy, needs to increase its refining capacity to meet national demand, as the clean energy transition will not be fast enough to displace oil demand before 2030 and through 2040.

Table 1 India's key energy demand and transition indicators

Indicator	Current (FY25)	2030 Target/factory forecast	2040 Forecast
Total oil demand (mb/d)	~5.6 mb/d[24] (FY24)	6.6 mb/d[25]	+8mb/d addition to 2023 demand[26] (2050)
Refining capacity	258.1 MMTPA[27] (FY26)	310 MMTPA (Govt target)[28]	450–500 MMTPA[29]
Petroleum product consumption	243.1 MMT (FY26)[30]	~335 MMT[31]	~472 MMT[32]
EV sales penetration (% of vehicle sales)	8.27%,[33] up from 7.52% in 2025[34]	30% target (Niti Aayog)[35]	~73%[36]
Renewable energy capacity	~262 GW installed[37]	500 GW (target)[38]	-
Primary energy demand (Mtoe)	932 Mtoe[39]	~1,200 Mtoe[40]	1,671 Mtoe (2050)[41]

1.1.2. India as a global refining hub: Export competitiveness and risks

India has become one of the world's most significant refining nations. India operates 23 refineries with a cumulative installed capacity of 258.1 MMTPA,[42] the fourth largest globally.[43] It is also among the top seven exporters[44] of petroleum products worldwide.

258.1 MMTPA

Refining capacity (FY26)

Fourth largest globally[45,46]

$41.1 billion

Petroleum product exports in FY26

61.4 MMT volume[47]

1.06 mb/d

Refined fuel exports FY26

3.6% YoY decrease from FY2025[48]

With many global refineries slated for closure by 2035, as European and other advanced economies face climate regulation and declining domestic demand for refinery products, India appears poised to become a major global refiner.[49]

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[20] India CO2 emission worldometer
[21] IEA- Oil Demand Growth
[22] EVindia- 25% growth in sales in FY26
[23] Economic Times- 77% in 2025
[24] World Bank: Oil Consumption 2024
[25] IEA: India Oil Market Report
[26] OPEC: World Oil Outlook 2050: 8mb/d increase from 2023 India Oil demand
[27] PPAC: Installed Refinery Capacity
[28] PIB: Energy Technology Meets 2025
[29] ET: Refining capacity forecast
[30] PPAC- India Current Petroleum Consumption
[31] ET: Refining capacity forecast
[32] ET: Refining capacity forecast
[33] Autocar: EV sales 25% yoy growth in FY26, Penetration% FY26, and FY25
[34] Autocar: EV sales 25% yoy growth in FY26, Penetration% FY26, and FY25
[35] Niti Aayog: Electric vehicles in India
[36] ET: EV penetration 2040
[37] PIB: Renewable energy capacity installed: MNRE
[38] Ministry of Power Press Release: PIB
[39] India Energy Statistics: 2026: TPES FY20–FY25
[40] IEA World Energy Outlook 2024: 2025 Energy Demand–70EJ, conversion to 1671 Mtoe
[41] IEA World Energy Outlook 2024: 2025 Energy Demand–70EJ, conversion to 1671 Mtoe
[42] PPAC: Installed Refinery Capacity
[43] PIB: Energy Technology Meet 2025
[44] PIB: Energy Technology Meet 2025
[45] PPAC: Installed Refinery Capacity
[46] PIB: Energy Technology Meets 2025
[47] PPAC- India Petroleum Products Export
[48] PPAC: converted MMTPA to mb/d
[49] PIB: Energy Technology Meets 2025

Refineries as strategic national assets: Four dimensions of Viksit Bharat

01 **Economic engine:** The refining sector contributes about one-fifth of India's central revenue; petroleum product exports generated $41.1 billion in FY26, which is India's leading export category.

02 **Energy security anchor:** Domestic refining capacity reduces forex outflow and ensures supply chain control.

03 **Industrial feedstock hub:** ~80% of India's petrochemical capacity is integrated with petroleum refineries, which supply the growing chemical industry.[50,51]

04 **Atmanirbhar Bharat Lever:** India achieved ~80% import substitution across the energy value chain, with new refineries planned as integrated complexes that focus on self-sufficiency.[52]

Table 2 Key Indian refiners: Capacity and export profile

Refiner	Capacity[53]	Key refineries	Export role
RIL	68.2 MMTPA	Jamnagar (the world's largest complex)	70% of India's exports in 2025; non-Russian crude
IOCL	70.25 MMTPA	Panipat, Mathura, Koyali, Barauni, etc.	Largest PSU refiner; domestic focus
BPCL	35.3 MMTPA	Mumbai, Kochi, Bina	Expanding petrochemical integration
HPCL	24.5 MMTPA	Vizag, Mumbai	New Barmer refinery (9 MMTPA) under development
HMEL	11.3 MMTPA	Bhatinda, Punjab	Primarily for domestic demand
MRPL	15 MMTPA	Mangalore	Second largest exporter; 121 kb/d FY25[54]
Nayara Energy	20 MMTPA	Vadinar, Gujarat	Third-largest exporter (107 kb/d FY25)

India is on track to become a petrochemical powerhouse by 2030, backed by a $37 billion investment[55] push. New major refineries (HPCL Barmer refinery in RJ and Greenfield complexes in Andhra, and CPCL Nagapattinam refinery in Tamil Nadu) in India are being designed as integrated refinery-petrochemical complexes, **signalling a strategic shift from fuel-only to chemicals-and-fuel production, which is central to achieving Viksit Bharat goals.**

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[50] PIB: MoPNG

[51] PIB: India's Petchem Potential, 2024

[52] PIB: Energy Technology Meets 2025

[53] PPAC: Installed Refinery Capacity

[54] Angel One: petroleum exports 2025

[55] Moneycontrol- India's Petrochemical Investment

1.2. Evolving demand landscape and strategic imperatives

India's petroleum demand is undergoing a structural transformation, redefining the refinery configuration, product slate, and business models for refiners. The last decade of transport fuel growth is leading up to aggressive targets that will take centre stage in the 2030s, which will result in a modal shift, even with demand rising for petrochemical, aviation, and marine fuels.[56,57]

Figure 4: Consumption of petroleum products (mb/d)

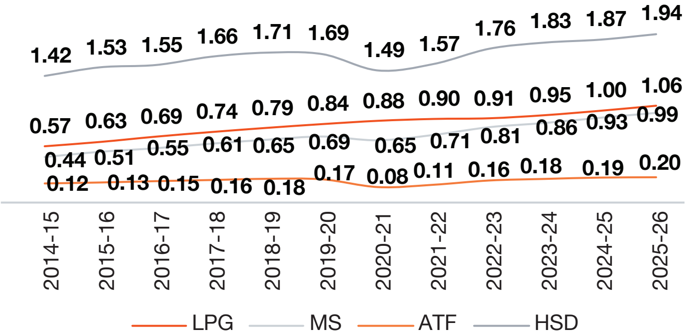

Table 3 India's transport and key fuel demand trajectory

Fuel type	CAGR (FY20-FY26)[58]	Growth	2026 demand (mb/d)[59]	2030 demand (mb/d)[60,61]	Key driver
Diesel/gasoil	2.33%	3.6% over FY25, declining growth	1.94	~2.6 mb/d (IEA)[62]	Industry, HGVs, agriculture
Gasoline (petrol)	6.2%	6.4% over FY25, declining growth	0.99	~1.3 mb/d (IEA)[63]	Car ownership growth
Jet/kerosene (ATF)	2.75%	~5.9% CAGR till 2030[64]	0.20	~0.25 mb/d	Aviation growth
LPG	3.95%	Slow growth	1.06	~1.24+ mb/d	Cooking + petrochem feedstock

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[56] PPAC- India's petroleum demand

[57] PPAC- India's petroleum demand modal shift

[58] PPAC- India's fuel demand trajectory

[59] PPAC- India Diesel Demand

[60] IEA World Energy Outlook 2025

[61] IEA Indian oil market outlook 2030

[62] IEA: Oil analysis and forecast to 2030: calculated diesel demand as 38% of 6.6 mb/d and petrol as 20% of 6.6mb/d

[63] IEA: Oil analysis and forecast to 2030: calculated diesel demand as 38% of 6.6 mb/d and petrol as 20% of 6.6mb/d

[64] IEA: Indian Oil market report

1.2.1. Transport fuels: Diesel and petrol demand are plateauing

EV sales grew from 50,000 in 2016 to 2.45 million in 2026, with 8.27% penetration in 2026, advancing towards Niti Aayog's 30% target by 2030. EV growth beyond 2030 will be aggressive, as seen in India's current goals, which are partly resulting in **a plateauing of demand for diesel and petrol, especially for lighter vehicles. Transport fuels will also see declining growth beyond 2030.**[65,66]

01

Diesel/gasoil: The dominant driver, but facing structural headwinds

In FY 2026, HSD consumption stood at 1.94 mb/d, up from 1.87 mb/d in FY 2025 and representing 3.6% year-on-year growth.[67] Road diesel accounts for 38%[68] of India's projected growth in total oil demand through 2030, driven by heavy goods vehicles (HGVs), buses, agriculture, and commerce. By 2050, HGVs alone are expected to be a major growth in total transport energy demand.

02

Petrol/gasoline: Moderate growth, moderated by EVs

Gasoline demand will grow by 0.7%[69] until 2030, as the electrification of India's vehicle fleet prevents a more substantial rise. FY 2026 shows that Indian MS consumption stood at 0.99 mb/d, up from 0.93 mb/d in FY 2025.[70] EV penetration is already curbing petrol demand, with EVs expected to displace 480 kb/d of extra oil demand between 2023 and 2030.[71]

1.2.2. Petrochemical demand surge[72]

While transport fuels will eventually plateau, growing petrochemical demand represents an explosive growth stream for Indian refineries.

$1 trillion	**Petrochemical industry by 2040** from ~$220 billion today
29.6→46 MT	**Petrochemical capacity 2024→2030** +55% capacity expansion
$87 billion	**Investment in petro-chemicals—next 10 years** Domestic + FDI

80% of India's petrochemical capacity is already integrated with petroleum refineries. Naphtha (for crackers), LPG (for dehydrogenation), and aromatics (for PTA/polyester chains) are refinery byproducts that can be converted into high-value chemical production.[73,74] India currently imports ~45% of petrochemical intermediates; its goal is to reduce this by establishing four PCPIRs and attracting investments to set up domestic plants.

1.2.3. Aviation turbine fuel: India's fastest-growing fuel segment

FY 2026 has seen aviation turbine fuel consumption in India at 0.20 mb/d, up 1.9% from FY 2025,[75] with estimates of 5.9% per year[76] till 2030. This represents the highest growth rate for any fuel category in India, driven by a rising aviation market and a growing number of air passengers supported by government schemes and programmes.[77] Sustainable aviation fuel (SAF) commands significant revenue potential.

The demand for transport fuels is robust but plateauing, while petrochemical feedstocks, aviation, and marine fuel demand are surging, alongside growing demand for green carriers. This creates a complex but urgent need for refinery reconfiguration. The refineries, designed in the 1970–2000s primarily for transport fuels, must evolve into multi-product, flexible, integrated energy and chemical hubs.

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[65] Niti Aayog: Electric vehicles in India

[66] Autocar: Penetration of EV in India

[67] PPAC- HSD Consumption Report

[68] IEA: Oil analysis and forecast to 2030: calculated diesel demand as 38% of 6.6 mb/d and petrol as 20% of 6.6mb/d

[69] IEA: Oil analysis and forecast to 2030: calculated diesel demand as 38% of 6.6 mb/d and petrol as 20% of 6.6mb/d

[70] PPAC- MS Consumption Report

[71] IEA: Indian Oil market report

[72] PIB: India's Petchem Potential, 2024

[73] PIB- MoPNG

[74] PIB- India's Petchem Potential, 2024

[75] PPAC- India Aviation Fuel Consumption

[76] IEA- Indian Oil market report

[77] PIB- Ministry of Finance

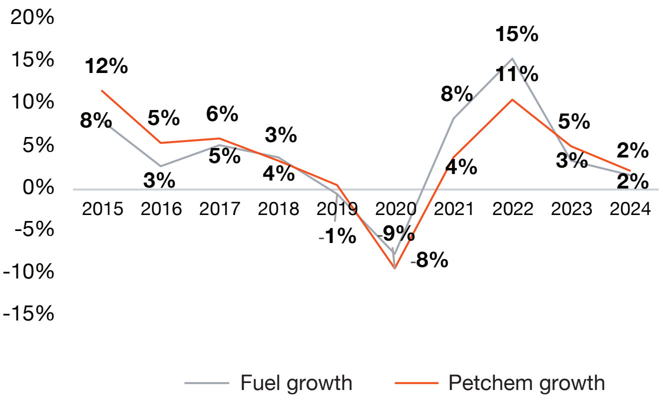
02

Future refinery paradigm: From fuel producer to integrated complex

2.1. Shift from fuels to chemicals and speciality products

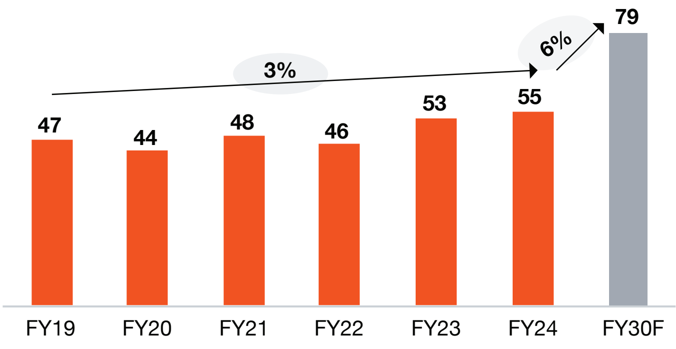
India's refining sector has been optimised for transportation fuels for decades. Structural changes in mobility, energy efficiency, and industrial demand are reshaping the long-term economics of fuel-only refining. For Indian refineries, fuel products, such as HSD, MS, and jet fuel, currently account for ~80% of total refinery output, indicating a high dependence on the transportation and industrial fuel sectors.[78] For fuel products, a short-term growth of 3–4%[79] is expected over the next five years, whereas expected petrochemical growth is projected at 2x that of fuel products.[80]

Figure 5: Fuel vs. petrochemical product growth



While absolute fuel demand in India continues to grow in the near term, long-term growth is expected to moderate as electrification, blending mandates, and efficiency improvements reshape the transport energy mix. Meanwhile, for petrochemicals, India is set to account for over 10% of global demand growth, outpacing the global average by ~1.5x.[81]

Figure 6: Petrochemical demand for MMTPA



2.1.1. India's petrochemical demand and growth

India is the third-largest consumer of petrochemicals after China and the US. Growth in petrochemical consumption will result in an increase in the total crude oil demand. Refinery integration is expected to reach 25% by 2030.[82] Nevertheless, India remains a net importer of petrochemicals, relying on imports for 45% of its intermediates.[83] Bridging the gap between domestic demand and supply through local production remains a top priority.

1.3x faster growth than global due to GDP growth, an underpenetrated market, and a strong end-growth market

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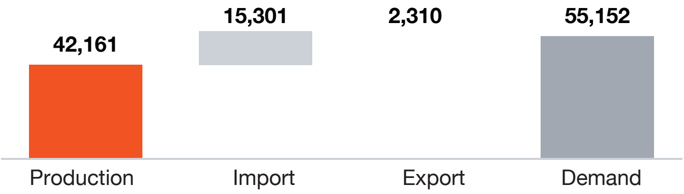
[78] PPAC- Refinery Output
[79] PwC Research and Analysis
[80] PwC Research and Analysis
[81] PwC Research and Analysis
[82] IBEF- Petrochemical Integration
[83] IBEF- Petrochemical Imports

Major imported petrochemical products are polymers (35% import share), fibre intermediates (11% share), aromatics (10%), synthetic rubber (5%), and performance plastics (3%), with other products making up the remaining 36%.[84]

In FY2024, 28%[85] of petrochemical products were imported, with a ~11,000[86] TMT deficit and a net value of imports worth ₹1,33,924 crore.[87]

Figure 7: Supply-demand outlook, petrochemicals, FY24



Key drivers of refinery integration with petrochemicals include:

01 Projected strong demand for petrochemical products and higher import dependency for petrochemical intermediates

02 Probable drop in future fuel oil demand due to:

- Energy-efficient vehicles
- Hybrid vehicles
- Switch from fossil fuels to renewables
- Carbon footprint minimisation

03 Operating refineries have the advantage of feed security and can leverage refinery intermediate streams. Reduced opex due to shared facilities.

04 Demographic advantage for India as a low-cost manufacturing hub and paradigm shift with respect to integrated refinery/petrochemical complexes to hedge cyclic downturns and risks.

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[84] Department of Chemicals and petrochemicals (DCPC), GoI- petrochemicals Import Statistics

[85] DCPC, GoI- Petrochemicals Import Statistics

[86] DCPC, GoI- Petrochemicals Import Statistics

[87] DCPC, GoI- Petrochemicals Import Statistics

Indian refineries are proactively focusing on petrochemical integration by making significant investments and adding capacity. Four types of refinery integration predominate: with a steam cracker; with an aromatics complex; with an aromatic complex and a steam cracker; and direct crude-to-chemical (C2C) plants.

Below are the key leaders and initiatives shaping the Indian refinery-petrochemical integration paradigm.

Table 4 Key Indian refiners and current vs. projected petrochemical capacity

Refinery	Current capacity	Projected capacity	Key expansions
Reliance Industries Limited	~5.8 MMTPA[88] (polymers); 1.7 MMTPA ethylene[89]	>9 MMTPA	Jamnagar O2C Expansion, Gujarat
IOCL	~ 4.5 MMTPA[90]	13 MMTPA	₹61,077 crore petrochemical complex at Paradip (PX/PTA integrated)[91] 150 KTA butyl acrylate plant at the Gujarat refinery[92]
BPCL	0.83 MMTPA[93]	3.2 MMTPA[94]	₹49,000 crore Bina petrochemical park 1.2 MMTPA ethylene cracker[95]
HPCL	2.2 MMTPA[96]	4.6 MMTPA[97]	9 MMTPA Barmer (HRRL) integrated refinery-cum-petrochemical, Rajasthan; includes diesel cracking[98]
ONGC	2 MMTPA[99]	8 MMTPA Opal+ MRPL[100]	₹1 lakh crore proposed 12 MMTPA refinery-cum-petrochemical complex in Uttar Pradesh[101]

2.2. Flexibility, resilience, and optionality as core design principles for India

The refinery-petrochemical integrated model emphasises flexibility in feed and products. New refineries are being designed for wide crude slats and dynamic operation.

Table 5 Key projects indicating refinery flexibility

Refinery project	Key realisations	Type of flexibility enabled
HPCL Visakh Refinery–RUF (commissioned 2025)[102]	First commercial deployment of **the LC-MAX residue hydrocracking technology** globally; achieved **93% conversion rate** post-VRMP[103]	**Feedstock and operational flexibility**
HPCL Rajasthan Refinery	Designed with **26% petrochemical intensity[104]**	**Product-slate flexibility**
HMEL Bathinda Petrochemical Project	Addition of **1.2 MMTPA ethylene cracker** that uses both naphtha and fuel gases[105]	**Feedstock and operational flexibility**

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[88] News Article: Reliance Polymers Expansion Plan
[89] Business Standard- Reliance Ethylene Capacity
[90] IOCL Capacity and Expansion
[91] IOCL Petrochemical Expansion
[92] IOCL- Gujarat Refinery
[93] BPCL capacity and expansion
[94] BPCL capacity and expansion
[95] Economic Times- BPCL Petrochem Park Announcement
[96] HPCL Newsroom
[97] HPCL Investor Presentation FY 2025-26
[98] EC Compliance Report- HPCL Petrochemical Project
[99] Opal Corporate Brochure
[100] PSU Connect- ONGC Petrochemical Expansion
[101] Invest UP Gov- ONGC
[102] HPCL, Investor Presentation
[103] HPCL, Investor Presentation
[104] HPCL Petrochemicals
[105] Indian Chemical News

Technologies enabling refinery flexibility include FCC/HSFCC upgrades (HMEL Bathinda, BPCL Bina upgrade), residue hydrocracking RHC (HPCL Vizag); stream cracker (BPCL Bina); propane dehydrogenation PDH (Gail Usar); aromatics complex (IOCL Panipat aromatics expansion); and COTC (Reliance Jamnagar).

Future standing refineries must provide

Flexibility: The ability to shift the product slate between fuels, feedstocks, and chemicals in response to market signals

Resilience: The ability to maintain cash flow through commodity and energy price cycles; can be achieved through integration, diversified crude sourcing, and domestic demand growth

Optionality: The ability to evolve the facility's configuration; can be achieved through modular design, COTC-ready process units, and digital operations

2.3. Maximising value through C2C configuration: India's roadmap

C2C/COTC represents the most ambitious end of the integration spectrum: rather than processing crude oil primarily to make fuels (with chemicals as a byproduct), it processes crude oil primarily to make chemicals. India aspires to maximise the economic value extracted from each barrel of crude processed by replacing low-margin transport fuels with high-margin chemicals, thereby powering Viksit Bharat manufacturing and the consumption economy. India currently occupies an early integration position on the C2C spectrum. Most PSU refineries are in the 6–15% petrochemical intensity range. A private sector benchmark, Reliance Jamnagar represents the most advanced integration in India and aspires to the 70%+ COTC target. C2C designs improve average realisations and reduce margin volatility.

C2C integration primarily occurs in two phases:

Phase 1 C2C/COTC commercial scale (cracker + RHC)

- RIL Jamnagar operating in a true O2C configuration, with current petrochemical intensity estimated at ~20%[106]
- Haldia Petrochemicals proposed Cuddalore project (Tamil Nadu), an oil-to-chemicals (O2C) facility with a 3.5 MMTPA petrochemical output at an investment of ₹85,000 crore[107]

Phase 2 Advanced technology (TC2C, direct cracking)

- RIL has targeted an ~70% C2C conversion at Jamnagar, phasing out petrol and diesel in favour of jet fuel and petrochemicals
- India currently has no operational COTC complex at frontier conversion levels.
- Reliance Jamnagar leads India's C2C trajectory, both in current operations + future ambitions.

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[106] Economic Times- Reliance Petrochemical Intensity Index

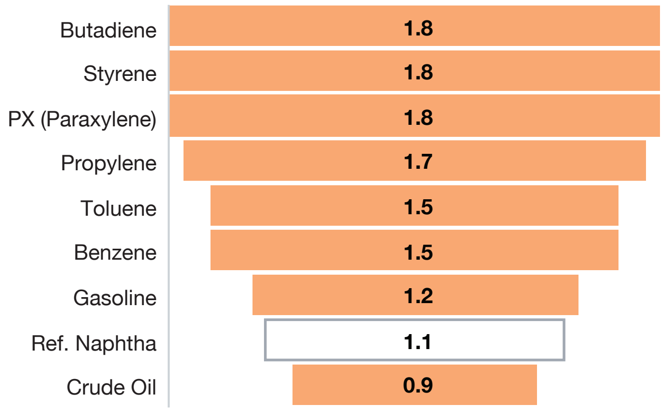
[107] Indian Chemical News- Haldia Petrochemical Project Brief

2.4. Maximising value through C2C configuration: India’s roadmap

Petrochemical products (butadiene, styrene, PX, propylene, and ethylene) command 1.5–1.8x higher prices than naphtha, whereas crude oil trades at ~0.9x the price of naphtha. This price differential is the key economic driver of refinery-petrochemical integration.[108]

Speciality chemicals command EBITDA margins of 18–30%, compared with 3–8% for commodity fuels and 10–15% for commodity petrochemicals.[109] The speciality chemical sector in India is also experiencing an ~12% CAGR.[110] Some of the most relevant speciality high-value segments include:

Figure 8: Price ratio (relative to naphtha)



Electronic chemicals

Ultrapure solvents, photoresists, and CMP slurries

Feedstock: Aromatics, IPA, and acetone derivatives

Demand driver: Semiconductor demand

Performance elastomers

Key elastomers: SBR, NBR, and EPDM

Feedstock: C4 butadiene

Demand driver: Strong automotive demand

High performance and speciality polymers

Key polymers: PC, PA, and PEEK

Feedstock: BTX aromatics, benzene

Demand driver: End-industry growth

Lubricant additives and synthetic base oil

Demand driver: Strong automotive demand

Feedstock: Toluene, benzene, xylene, and cyclohexane

Demand driver: 7.8% YoY growth in 2025[112]

Agrochemical intermediates

Feedstock: Chlorine, phenol, and BTX derivatives

Demand driver: 9% CAGR from FY25 to FY28[111]

Pharma and fine chemical intermediates

Key category: API, solvents

2.5. Current positioning and outlook

India today operates 258 MMTPA[113] of refining capacity with a national petrochemical intensity of around 13%.[114] Most PSU refineries remain fuel-heavy, with petrochemical intensity in the 6–15% range, while Reliance Jamnagar leads the domestic frontier through its O2C configuration.

The country’s import dependence indicates a significant gap for refiners to capture. Several projects are underway; however, scale, depth, and execution velocity remain critical gaps.

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[108] PTQ Magazines- HMEL Specialty Chemicals Price ratio relative to Naphtha – Price Ration Graph
[109] PwC Research and Analysis
[110] PIB- India Specialty Chemicals Growth Rate
[111] IBEF- India Agrochemical Sector Growth Rate
[112] PIB- India Lubricants Growth Rate
[113] PIB- India Current Refining Capacity
[114] IBEF- India Petrochemical Intensity

03

Driving operational excellence through digitalisation and AI: Building the 'last refinery standing'

3.1. The inflection point

Indian refining is at an inflection point that is both structural and strategic. On the one hand, an accelerating energy transition—EV penetration, biofuel mandates, and net-zero pledges—is reshaping long-run product demand. On the other hand, the operational reality of refineries involving ageing DCS vintages, siloed historians, paper-based shift logbooks, and periodic LP runs remains the norm rather than the exception. The refineries that will remain commercially viable through this decade will not be the largest or the most complex—they will be the most intelligent. This article presents the argument that the path to being the 'last refinery standing' runs through two interdependent enablers: a robust digitalisation stack and embedded, enterprise-wide AI—neither alone is sufficient.

3.2. Layered digital architecture

Digitalisation in a refinery is not a single system—it is a layered architecture in which each tier generates data that feeds the layers above it while also deriving value from the layers below. Over the past decade, Indian refineries have made significant investments at Levels 1 and 2, connecting DCS to historians, deploying advanced process controls (APCs) and real-time optimisers, and standing up energy management systems (EMS) and digital twins. BPCL's IRIS platform remotely monitors thousands of sensors across its supply chain, while Reliance has built a gigawatt-scale AI-ready data infrastructure at Jamnagar in partnership with Google. These investments were necessary, and many refineries have realised significant value. One limitation, however, has become very evident— digitalisation at its core makes data available and provides analysis, but does not take decisions. That gap is bridged precisely by AI.

The refinery digital-AI stack

AI/agentic layer ← Cuts horizontally across all tiers; consumes data and generates prescriptive decisions

Level 4 Enterprise intelligence: ERP, LIMS, KPI dashboards, sustainability, and carbon reporting

Level 3 Operation management: Digital logbook, CMMS, EMS, etc.

Level 2 Process optimisation: APC, RTO, digital twins, and predictive analytics

Level 1 Field instrumentation and control: SCADA, DCS, IIoT sensors, data historian

Most Indian refineries have invested in pieces of this stack that are technically live but operationally underutilised. Very few have a coherent architecture, comprising a deliberate design of how Level 1 data feeds Level 2 optimisation, which feeds Level 3 operational management, which in turn feeds Level 4 enterprise intelligence—with AI spanning all of it. Without that architectural view, every new digital investment is a point solution that delivers only a fraction of its potential because it cannot exchange data with the surrounding systems.

3.3. Solution stack for refineries

01 IOT, SCADA, and historian

A historian is already present in most Indian refineries. It should not be treated solely as an archive, but as an operational asset. Data quality should be governed. An AI model trained on a patchy historian produces patchy predictions, causing operations teams to lose confidence in AI. While fixing the historian is not a glamorous task, it is the highest-leverage investment available to an Indian refinery today. Refineries with a structured, integrated historian platform compound their AI advantage with each passing year.

02 Advanced process control and real-time optimisation

APC—based on model predictive control algorithms—continuously adjusts setpoints to push operations towards constraint limits. RTO sits above APC, solving the plant-wide economic optimisation problem—crude blend, unit operations, product quality, and energy cost—against real-time market prices. Indian refineries should now move from siloed, unit-level RTO to site-wide RTO. A common data backbone enables the CDU, VDU, hydrotreaters, reformer, hydrocracker, and utilities to optimise to a single margin objective, avoiding local optima and reducing giveaway, energy use, and variability. Companies like HPCL are already evaluating the adoption of site-wide RTO programmes to capture the full value from the CDU, crackers, gasoline, and diesel blending. This closes the loop with APC, enabling every unit to pull in the same direction and turning real-time data into refinery-wide profit.

03 Digital logbook and electronic shift handover

The most undervalued—and most consequential for safety—tool in the stack is digital logbooks and e-handovers. Structured logbook data becomes a training corpus for AI, with patterns invisible to any individual operator becoming visible and actionable at scale.

3.4. Why digitalisation alone is insufficient: The AI imperative

As seen above, digitalisation in Indian refineries is centred on connectivity—linking DCS to historians and deploying APCs, real-time optimisers, digital twins, and EMSs. Investments such as BPCL's IRIS platform and Reliance's AI-ready infrastructure at Jamnagar represent notable progress in this area. With the adoption of digitalisation worldwide, one limitation has become very evident—at its core, digitalisation makes data available and can perform analysis but does not take decisions.

That is where AI intervenes. The evolution from traditional AI to generative AI, and now to agentic AI, has fundamentally transformed how refiners approach process control, safety, and operational efficiency. AI's true value is not in replacing human control—it lies in improving decision quality throughout the refinery value chain, helping organisations make faster, better, and economically more viable decisions at each step. Refinery margins that surged in 2022 have now normalised, highlighting the need for sustainable efficiency improvements rather than cyclical gains. In this context, AI has emerged as a critical enabler for refinery leaders and policymakers in India, shifting from just another technology investment to a strategic imperative. Refineries that combine digitalisation with AI-driven decision-making in this decade will be the last ones standing as the global rationalisation process is finalised.

3.5. The AI landscape in global refining

Industry leaders have already documented the benefits and gains of adopting AI in the following ways

- AI-enabled predictive maintenance across pieces of critical equipment, processing huge data points annually achieving reduction in unscheduled downtime and a decrease in maintenance costs.
- AI-integrated refining operations yielding improvement in throughput efficiency while reducing maintenance-related disruptions.

The evidence is consistent. Refiners must focus on specific use cases within their organisation that measurably impact the bottom line, including improving margins, lowering operating costs, enhancing reliability, and increasing plant operational flexibility. For today's refiners aspiring to be the 'last refinery standing', AI must become embedded in day-to-day operations across the refinery value chain, helping organisations make faster, better, and more economically viable decisions at each step.

3.6. High-value AI use cases across the refinery value chain

3.6.1. Predictive maintenance and asset reliability

AI-driven predictive maintenance has moved from a proof of concept to an operational necessity in leading refineries. By analysing real-time sensor data and historical trends, AI can forecast failures weeks or even months in advance—enabling proactive maintenance in scheduled outages and eliminating unplanned shutdowns. AI and machine learning monitor critical rotating equipment (pumps, compressors, and heat exchangers) in real time, significantly reducing downtime and extending asset lifespans. AI-enabled drones are also used for inspections, enabling remote monitoring and early issue detection. While Indian refineries have already started deploying these solutions, the question is not whether AI-driven predictive maintenance works, but how much margin is left unrealised each year without it being deployed at scale.

3.6.2. Energy and process optimisation

AI can be deployed across various production stages to improve efficiency and reduce operating costs. Since refinery processes are highly energy intensive and AI systems can identify patterns and inefficiencies, they have the potential to unlock many opportunities for improvement in energy usage. Generative AI models can also be used to optimise CDU distillation cut points, particularly in older units where RTOs are absent or poorly calibrated, reducing energy consumption and increasing product yields.[115] In the context of Indian refiners, the math is straightforward; for companies like IOCL, processing approximately 80 MMTPA across its refinery network, even a 10-cents-per-barrel improvement applied to a small portion of this volume and sustained over time translates into hundreds of millions of dollars annually. The major benefit for such organisations is that, once AI use cases are built and embedded in operations, the gains will keep coming with almost no additional capital expenditure.

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[115] Business AI for Oil and Gas: Unlocking Efficiency Across the Value Chain, Authored by Rajeshwar Guggilla, CC BY 4.0

3.6.3. Crude basket and value chain optimisation

Indian refiners operate one of the world's most complex crude slates—Russian ESPO, heavy sour Middle Eastern grades, and African opportunity cargoes—with buying decisions shifting weekly on price, geopolitics, and freight. Every crude switch has ripple effects across multiple downstream units, including CDU cut points, FCC performance, hydrogen demand, and product yields. Value chain optimisation COTS solutions have already shown significant benefits but when combined with AI-integrated end-to-end value chain optimisation, the value potential could be much greater.

AI-driven algorithms can further determine optimal blending ratios for petroleum products, ensuring consistent product quality while reducing waste and costs. Generative AI in particular has the potential to reduce fuel giveaways in gasoline blending, generating significant savings for refineries that handle large volumes of gasoline daily.[116] Another valuable application of AI is strengthening refinery margins.[117] By analysing operational parameters, feedstock characteristics, and market demand, generative AI can recommend process adjustments to maximise the production of high-value products and improve refinery margins.

The refineries that will dominate India's diesel, jet fuel, and petrochemical intermediate markets in the future will be those that convert today's untapped potential into real margins through AI-driven crude-to-product optimisation.

Table 6 Generative AI-driven improvements in refinery operations[118]

Refinery process area	Metric	Min	Max
Crude oil distillation	Energy consumption reduction	2%	5%
Product blending	Blending giveaway reduction	5%	10%
Yield optimisation	Refinery margin increase	1%	3%
Predictive maintenance	Unplanned downtime reduction	20%	20%
Predictive maintenance	Maintenance cost reduction	5%	10%
Real-time monitoring	Process variability reduction	10%	15%

3.7. The pilot trap: Why intention is not implementation

Many energy companies expect AI to deliver results within a year, but most fail or stall. This disconnect has contributed to a growing perception that AI is not delivering value. The problem, however, is not in the technology or the models themselves; rather, it lies in the organisational readiness and system architecture.

For Indian refineries, three specific components pose a barrier to AI implementation.

3.7.1. Data architecture fragmentation

In most Indian refineries, core systems such as DCS, SCADA, LIMS, Historian, and ERPs were implemented over several decades by different vendors and do not share a unified data layer. AI models require clean, continuous, and tagged time-series data across all systems simultaneously. Where platforms like Historian are deployed, the foundations for AI are already in place. The task is to connect all datasets through a unified data layer, enabling successful enterprise-wide AI implementation and building real operational intelligence. Otherwise, AI initiatives are likely to stall at the data preparation stage.

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[116] Business AI for Oil and Gas: Unlocking Efficiency Across the Value Chain, Authored by Rajeshwar Guggilla, CC BY 4.0

[117] Business AI for Oil and Gas: Unlocking Efficiency Across the Value Chain, Authored by Rajeshwar Guggilla, CC BY 4.0

[118] Evaluating Cost Benefit Implications of Ai Driven Predictive Analytics for Environmental Compliance and Sustainability in Oil and Gas Refinery Operations, authored by Charles Bom, CC by 4.0

3.7.2. Organisational change barriers

To become an AI-first organisation, the industry requires a significant shift not only in technology but also in how teams are structured and workflows managed, challenging the traditional ways of working. In Indian refining, a major gap is the lack of people who understand both refinery operations and basic data science. When AI recommendations are routinely overridden by operators implementing their traditional ways of working or maybe reviewed only in weekly planning meetings instead of being acted on in real time, the value of AI is never fully realised.

3.7.3. The problem of plenty

The AI boom in the industry has introduced the challenge of too many choices. Refinery leaders are often overwhelmed by vendor propositions, multiple use cases, and platforms and end up implementing multiple POCs simultaneously without clear prioritisation. The result is a portfolio of promising proof-of-concept solutions that deliver no enterprise-scale value. AI deployment demands a prioritisation-first approach: identify two or three use cases with the clearest bottom-line impact and the cleanest data foundation and drive those to full adoption before expanding scope. In India's refining industry, the value of AI is hindered not by doubt but by poorly scoped efforts that chase activity rather than measurable impact.

3.8. The last refinery standing

For today's refiners aspiring towards the 'last refinery standing' philosophy, adopting AI alone will not be sufficient to reach their goal. AI must be tightly integrated with digital foundations and embedded in day-to-day operations across the refinery value chain. India sits in a geography of survival, but geography is not destiny. The decisions made in the next three to four years—on data architecture, integrated digital solutions with an enterprise approach, AI use case prioritisation, and talent—will determine which Indian refineries hold that position. Those that fail to make this transition will be left with state-of-the-art infrastructure without the intelligence required to remain competitive. The window is open, but it will not remain so indefinitely.

04

Decarbonising the refinery: Pathways to greener operations

Indian refineries are responsible for 60–80kg CO_2/tonne throughput of Scope 1 emissions,[119] which is 5–7% of national GHG emissions, while targeting net-zero target commitments by PSUs such as IOCL/BPCL/HPCL in their roadmaps. However, these decarbonisation efforts towards net-zero targets must balance near-term margin pressure with Viksit Bharat's energy demand, prioritising low-capex efficiency gains before scaling up decarbonisation pilots. The following pathways offer a practical approach tailored for Indian brownfield refineries:

a. Utility and energy-supply decarbonisation

i. Combined heat and power (CHP) or cogeneration expansion

ii. Renewable electricity procurement and captive solar for utilities

iii. Fuel switching in boilers: From coal/fuel oil to PNG or refinery fuel gas (RFG)

iv. CBG plants: Paddy straw or waste to CBG

b. Hydrogen and carbon management

i. Green hydrogen plants: Electrolyser-based hydrogen for hydrotreaters

ii. Blue hydrogen with CCUS: Carbon capture post-blue hydrogen production plants and flue gases

iii. Hydrogen blending in fuel gases

c. Alternative feedstocks and low-carbon products

i. Bio-feedstock co-processing: Palm stearin or used cooking oil (UCO) in hydrotreaters

ii. SAF production

iii. Renewable diesel: Hydro-processed esters and fatty acids (HEFA) units using waste oil and animal fats

d. Efficiency and operational measures

i. Flare-gas recovery systems

ii. Furnace efficiency optimisation

iii. Heat exchange network improvements: Additional heat recovery to preheat crude streams

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[119] MoEF, GoI

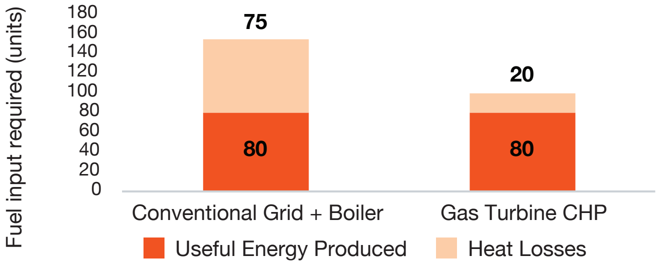
4.1. Utility and energy-supply decarbonisation

4.1.1. CHP or cogeneration expansion

Traditionally, steam and electricity for energy in refineries are produced separately—steam from fuel-fired boilers and electricity from the grid or inefficient captive units. This approach is costly and thermodynamically wasteful. CHP, or cogeneration, addresses this by generating both electricity and heat from a single gas turbine system, capturing exhaust heat that would otherwise be lost.

Envisaged benefits of CHP over traditional grid and boiler supply are as follows:[120]

Figure 9 Fuel input to produce the same useful energy output



- Fuel savings of 30s–40% compared to operating a traditional separate generator and steam boiler
- CO_2 emission reductions from 8,300 tonnes/year (2,100 from boilers and 6,300 from power plants) to 4,200 tonnes/year
- Elimination of 7.5% of electricity consumed as grid losses due to on-site generation

A comparative snapshot: What are refiners doing?

To address electricity and steam needs, the ONGC Hazira Gas Processing Complex runs a cogeneration plant with a maximum capacity of 61.5 MW.[121] In a CHP setup, HPCL's Vizag refinery runs a power plant with a minimum capacity of 60 MW.[122] The sector-wide picture, however, depicts a partial and inadequate deployment of CHP. Some significant deficiencies remain in Indian PSU refineries:

- **Ageing and undersized steam generation units:** Many PSU refinery steam systems were built for simpler, older processing designs. Steam demand has increased as hydro-processing capacity for BS-VI fuels has increased, but CHP capacity has not increased accordingly.
- **Grid dependency:** Many PSU refineries are still largely reliant on state grid power, exposed to India's average grid emission factor of ~0.716 kg CO_2/kWh,[123] which is far higher than the emission intensity achievable with on-site gas turbine CHP.
- **Capital-intensive projects:** The substantial capital expenditure required for CHP, in the range of thousands of dollars per kW, competes with other investment priorities.
- **Fuel gas supply reliability:** Stable CHP operations may be hampered by fuel gas composition (varying crude slates) and pressure variations in Indian PSU refineries.

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[120] US Environmental Protection Agency- Benefits of CHP

[121] Directorate General of Hydrocarbons, GoI

[122] Global Energy Monitor - GEM Wiki: HPCL CHP Station

[123] Central Electricity Authority, GoI

4.1.2. Renewable electricity procurement and captive solar for utilities

Why refinery operations must rethink energy sourcing

Indian refineries are among the most energy-intensive industrial assets, consuming almost one-third of total energy allocated to the industrial sector. Refineries draw electricity primarily from the grid or captive sources, about 70% of which is coal-based,[124] making it a major driver of Scope 2 emissions.

Why renewable power makes strategic sense for refineries

Beyond decarbonisation, renewables provide cost-saving opportunities while reducing net CO_2 emissions.

01

Scope 2 emission reduction

Renewable integration can reduce Scope 2 emissions linearly depending on penetration and grid displacement.

02

Cost savings

40–60% long-term electricity cost savings as renewable tariffs showcase a clear long-term decline.

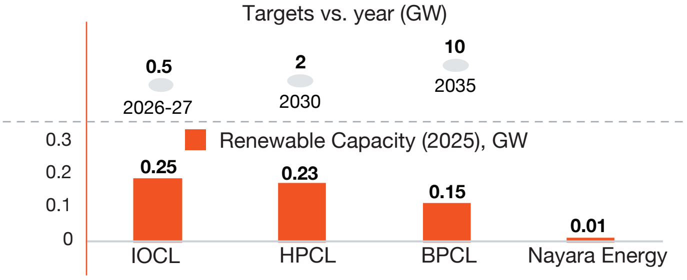
03

Energy security and price hedging

Over 65% of power generation is still coal-based.

A comparative snapshot: What are refiners doing?[125,126]

Figure 10 Current vs. projected renewable capacities



Public sector refiners—HPCL, IOCL, and BPCL—are leading this shift through on-site and off-site renewable procurement, reducing grid exposure and emission intensity. Several investments and planned capacity expansions are ongoing to reduce Scope 2 emissions. Additionally, Reliance Industries has also actively integrated solar capacity as a broader energy transition, which also includes renewable integration at Jamnagar refinery.

Barriers to renewable adoption

- **Requires high upfront capital:** Indian refiners face substantial upfront investment while entering the renewable sector, but they often prioritise core investments in opportunistic markets that provide higher profit.
- **Land availability in certain cases and securing grid or open access approvals.**
- **Limited immediate impact on refinery emissions:** Even after integrating renewables, technologies such as carbon capture and electrification are required to meet decarbonisation goals.

Despite the high initial capex, integrating renewables significantly lowers the cost per tonne of CO_2 avoided by displacing grid electricity and fossil-based captive power, reduces emissions, and lowers operating costs. At the same time, renewables are positioned as an early, defensive, low-cost decarbonisation lever.

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[124] EIA, Energy mix of India

[125] HPCL Capacity Projected, HPCL current capacity, BPCL, IOCL, Nayara

[126] BPCL sustainability report

4.1.3. Fuel switching in boilers

In a typical refinery set up, ~75% of energy consumption is attributed to hydrocarbon fuel used in steam boilers and fire heaters, making boiler fuel choice a significant contributor to Scope 1 emissions. Currently, boilers are ignited primarily using RFG, with petcoke and coke-derived gases forming a major secondary fuel. Natural gas and liquid fuels are used only selectively or as a backup. RFG is the major fuel for boilers due to its low marginal cost. Fuel switching means replacing high-CO_2 fuels in boilers (e.g. residual fuel oil, petcoke, or coal) with lower carbon alternatives, with the goal of reducing direct emissions from fuel consumption.

Table 7 Alternative fuels for boiler fuel switching

Alternate fuel[127,128]	Integration approach	Status
Natural gas	Replacing fuel oil/pet coke; burner retrofits	Early stage
Hydrogen blends (H_2–NG)	Low percentage co-firing	Pilot/early trials
Green hydrogen	Dedicated burners or progressive blending	Planned
Biomass/biogas	Limited use in auxiliary boilers	Niche
Electrified steam (eboilers)	Electric boilers using renewable power	Conceptual

Benefits of boiler fuel switching

- **Scope 1 emission reduction:** Gas burns 25–30% less CO_2 (kg) than diesel/oil per MMBtu, whereas sustainably sourced biomass can be near carbon neutral on a lifecycle basis. As a result, switching a 100-t/h industrial boiler from fuel oil to natural gas can typically reduce CO_2 emissions by 25–30%, whereas a switch to sustainable biomass can achieve even higher levels, depending on feedstock sourcing and supply chain emissions.
- **Lower air pollutant emissions:** Gas has negligible sulphur levels and particulate emissions.
- **Strategic alignment with the green H_2 mission.**

Technology adoption by Indian refiners

Indian PSU refiners have incorporated fuel switching and efficiency improvement plants, yet boiler fuel transition has been a secondary lever. Most refiners still prioritise RFG over renewable sources.

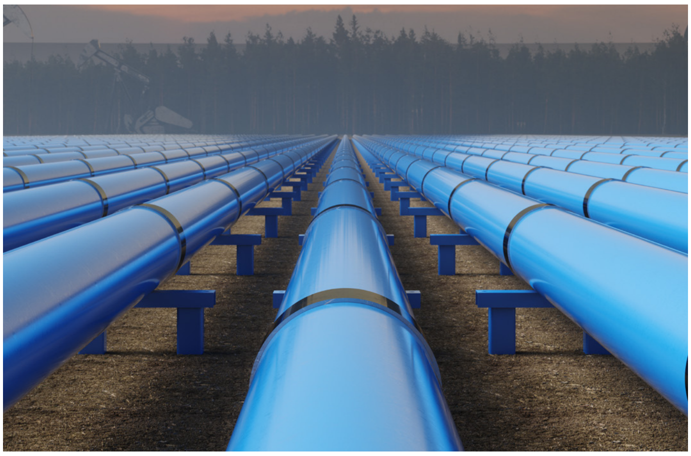
All PSU refiners are investing in green hydrogen for hydrotreating and as a potential replacement for grey H_2-rich RFG in boilers and process heaters. With India's NGHM requiring refiners to meet 50% of their hydrogen needs with green H_2 by 2030, the carbon intensity of RFG will decline structurally.

Major barriers to adoption

The major constraints on adoption are fuel availability and economics.

- **Natural gas:** Domestic gas production meets <50% of total gas demand, increasing the ongoing reliance on imports. LNG is also more expensive. Many boilers require dual-fuel burners and pipeline connection upgrades.
- **Biomass:** Underdeveloped supply chain and seasonal production
- **Safety and regulatory approvals** under the OISD, the PESO, and the Boiler Act norms

Fossil fuels remain a cheaper option, limiting wide-scale adoption so far.



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[127] Centre for High Technology, GoI- Oil and Gas Technical Journal, 2nd Edition

[128] US Environmental Protection Agency- Emission factors Hub

4.2. Hydrogen and carbon management

India is among the world's largest producers and consumers of hydrogen today, only behind China and the US. The current demand stands at 6.76 MMTPA, with almost 99.5% of hydrogen consumed in refining and ammonia production.

Currently, all the hydrogen used in Indian refining is grey hydrogen produced via steam methane reforming (SMR) from natural gas or naphtha, which is deceptively carbon intensive.

6.76 MMT

Hydrogen demand[129]

42 MMT

Green hydrogen demand potential by 2070 in industry[130]

₹19,744 crore

NGHM total policy outlay[131]

309.5 MMTPA

India's planned refining capacity by 2030[132]

₹20,000 crore

Union Budget 2026–27 CCUS allocation[133]

Net-zero 2070

India's binding climate commitment

The policy framework for hydrogen production is provided by the NGHM, authorised by the Union Cabinet in January 2023 with an initial investment of ₹19,744 crore (~$2.4 billion). By 2030, the Mission aims to produce 5 MMTPA of green hydrogen annually, with a production cost target of $1.5/kg, and the ability to prevent over 50 MMTPA of CO_2 emissions nationwide—with refineries being the primary off-takers.[134]

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[129] PNGRB Press Note

[130] Niti Aayog

[131] MNRE National Green Hydrogen Mission

[132] PIB MoPNG Announcement

[133] Union Budget FY2026-27

[134] MNRE, GoI-National Green Hydrogen Mission Overview

4.2.1. Green hydrogen plants

The electrolyser-based green hydrogen plant provides a long-term solution for refinery hydrogen decarbonisation. It produces hydrogen by splitting water using electricity generated entirely from renewable sources.

Envisaged benefits

- Major CO_2 reduction against grey hydrogen
- Higher H2 purity (>99.95%) than SMR reformate, which improves hydrotreater yields
- Creates domestic electrolyser manufacturing through PLI and SIGHT schemes

Projects

NGHM presents both an opportunity and an obligation for Indian refiners. To reduce dependence on Chinese electrolysers (which in 2024 cost $600–1,200/kW versus $2,000–2,600/kW for non-Chinese units[135]) and position Indian manufacturers to compete globally, NGHM incentivises electrolyser manufacturers (3,000 MW/year capacity awarded to 15 companies, with ₹4,440 crore in incentives[136]). A total of 42 KTPA tenders have been floated by PSU refineries and are to be awarded by March 2025,[137] such as the IOCL green H_2 plant at the Panipat refinery with a capacity of 10 KTPA (to be commissioned in 2027).

Current barriers

- Green hydrogen costs more than grey hydrogen ($3.08/kg or ₹279/kg[138] from a recent tender for supply to NRL with government intervention vs. $1.2–1.8/kg of grey hydrogen) due to unsubsidised costs. NGHM partially addresses this gap; however, long-term cost economics depend on electrolyser scale-up and continued reductions in renewable costs.
- Problems such as land, water access, and single-window approvals are causing delays in project mobilisation for green hydrogen.
- India's electrolyser production capacity is currently in a nascent stage, which leads to high import dependence. Electrolyser delivery lead times can affect commissioning schedules and geopolitical supply chain risks.
- The lack of a mandatory hydrogen purchase obligation makes hydrogen offtake a major problem without subsidised cost, if production costs do not match the lowest alternative available.

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[135] IEA Global Hydrogen Summary: Electrolyzer Costs

[136] NGHM- Overview and Incentives Status

[137] PIB Press Release

[138] PSU Watch News- NueEN wins NRL green hydrogen tender at a record low Rs 279/kg

4.2.2. Blue hydrogen with CCUS

Blue H_2 is at core a grey H_2 plus carbon capture produced using the same SMR process, yet most of the CO_2 is captured, conditioned, and either stored geologically or utilised for industrial purposes that would otherwise be vented to the atmosphere. Blue hydrogen offers a near-term, commercially viable pathway to dramatically reduce the carbon intensity of the hydrogen supply.

The Union Budget 2026–27 has allocated ₹20,000 crore over five years for CCUS technology deployment across five industrial sectors—power, steel, cement, refineries, and chemicals.

India's first industrial post combustion capture plant (Tuticorin Alkali Chemicals, Tamil Nadu) has been operational since 2016, validating the CCUS commercial model. The IOCL Koyali–ONGC Gandhar CO_2-EOR project captures CO_2 from IOCL's refinery and pipes it approximately 80 km to ONGC's Gandhar oilfield.

Benefits

- Carbon intensity is significantly reduced from grey hydrogen (9–12 kg CO_2/kg hydrogen[139]) to 1–3 kg CO_2/kg hydrogen for blue hydrogen.
- Preserves the existing SMR capital investment.
- CO_2 EOR generates incremental oil recovery revenue that partially offsets capture costs.

Current barriers

- A significant barrier is the high cost, with flue gas capture post combustion being more expensive than precombustion or high-purity capture.
- Blue hydrogen with CCUS requires verified geological storage; however, India's subsurface characterisation for dedicated storage is in a very early stage. Neither is a comprehensive CCUS regulatory framework yet in place.
- The lack of CO_2 pipeline right-of-way approvals and the PNGRB tariff framework for CO_2 transport further impedes project development.
- Carbon credit verification for CCUS projects is not yet embedded in India's CCTS framework, which can help to compete with the prices of low-carbon hydrogen alternatives available.

4.2.3. Hydrogen blending in RFG

The rerouting of H_2 through refinery off gases is rarely considered a decarbonisation lever. The current level of use with increasing concentration of H_2 in the blend of RFG represents a near-term pathway without fundamental process changes to reduce the carbon intensity of refinery equipment.

Injecting hydrogen into the RFG header is a straightforward principle: hydrogen combustion produces only water vapour without any CO_2 emissions. The initiative spans three progressive stages:

- **Phase 1 Optimise existing H_2 content (0–10 vol%):** The current refinery off-gas already contains around 25-30%[140] hydrogen by volume, which can be preferentially fed to the fuel gas header rather than to lower-value use cases, capturing immediate carbon reductions with negligible capex.
- **Phase 2 Incremental blend increase (10–20 vol%):** Pressure safety valve recalibration, materials assessment, and targeted burner re-rating will allow the system to operate with higher H_2 concentrations, with piping integration and better leak detection procedures, as hydrogen is an odourless and colourless gas.
- **Phase 3 High-blend pathway (>20 vol%):** In the long run, as the economics of blue and green hydrogen improve, distribution and storage supply chains mature, allowing refiners to target higher blends. Ultimately, refinery off-gas could serve as a stable anchor for demand, making the case for on-site hydrogen production.

Among PSU refiners, IOCL has started studies on hydrogen management at the Panipat refinery as part of its broader energy transition programme. MRPL's Phase 4 expansion also involves better recovery of hydrogen from refinery off-gases. However, no Indian PSU is committed to blending hydrogen in the RFG network as a standalone decarbonisation effort.

Benefits

- No product specification changes and no customer-facing modifications
- Double decarbonisation effect when green H_2 replaces grey as it reduces both SMR process CO_2 and furnace combustion CO_2

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[139] Canada Energy Regulator, 90 g CO2e per MJ of grey H_2 produced

[140] PwC Insights

Current barriers

- Materials compatibility: Higher hydrogen blends in RFG may lead to the embrittlement of carbon steel piping elements, which need to be analysed, yet it is a costly programme for older facilities.
- Burner compatibility: Existing burners are designed for specific flame-speed characteristics and Wobbe Index and are affected by H_2 blending, requiring burner redesign/replacement beyond certain blending volumes of H_2.
- Safety and leak detection: Hydrogen's greater flammability and lower minimum ignition energy require revised emergency procedures and upgraded leak detection systems.
- Hydrogen supply availability: Phase 2/3 blending requires more hydrogen in the range of 20% by volume, beyond the current hydro processing capacity. Hence, there is a need for technology upgrades, such as optimised recovery through PSA or a new H_2 production plant/external supply.
- Absence of regulatory framework: Currently, there are no regulatory standards addressing the hydrogen blending requirements/limitations or associated material changes in the ecosystem and safety protocols for RFG systems.

4.3. Alternative feedstocks and low-carbon products

India's refineries are transitioning from single-feedstock fossil processors to multi-feedstock platforms that convert waste oils, agricultural residue, and organic waste into low-carbon fuels.

4.3.1. Bio-feedstock co-processing: Palm stearin or UCO in hydrotreaters

Co-processing is the integration of bio-based and waste-derived feedstocks directly into existing refinery process units, principally palm stearin and UCO, with existing hydrotreating units, with blending up to 5%. Through HEFA chemistry, triglycerides are deoxygenated and then hydro-isomerised to produce renewable diesel and SAF-range paraffinic hydrocarbons. ASTM D1655 permits co-processing of biomass feedstocks in petroleum refinery hydrotreaters for up to 5% blending.

Table 8 ASTM D7566 approved SAF production pathways[142]

Pathway	Blending limitation	Feedstocks
Fischer-Tropsch (FT)	50%	Municipal solid waste and biomass
Hydrotreated esters and fatty acids (HEFA)	50%	UCO, animal fats, and nonedible oils
Power-to-liquid (PtL/e-SAF)	50%	Green hydrogen biogenic CO_2
Alcohol-to-jet (ATJ)	50%	Sugarcane, grain ethanol; cellulosic ethanol
HC-HEFA	10%	Algal oil
Co-processing	5%	UCO/vegetable oil/animal fat blended with petroleum

The IOCL Panipat Refinery is India's first ISCC CORSIA Certified SAF producer. Axens and Praj signed an MOU to work in India to produce SAF utilising alcohols through the ATJ pathway. A Praj-IATA-ISMA MoU has developed lifecycle assessment certification for sugarcane ethanol ATJ-SAF for CORSIA compliance.

Benefits

- SAF blended with conventional jet A fuel can be used in existing infrastructure without additional capital expenditure, leading to 80% lower carbon emissions compared to conventional jet fuels.

Current barriers

- No commercial-scale standalone unit of HEFA and ATJ has been commissioned in India as of April 2026.
- UCO collection remains constrained by a weak aggregation system and fragmented collection infrastructure, driven by the commercial reuse of cooking oil in India.

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[141] National Renewable Energy Laboratory (NREL)

[142] US Department of Energy

4.3.3. Renewable diesel

Renewable diesel, also called hydrotreated vegetable oil, is produced primarily by the HEFA process. Unlike conventional (FAME) biodiesel, HVO is a paraffinic hydrocarbon fuel that can be used in 0–100% blends in most diesel engines and is generally transportable through existing petroleum pipelines in India. HVO typically has a higher cetane number than that of conventional diesel.

India's commercial-scale HVO production was negligible as of April 2026. No PSU refinery has yet commissioned a dedicated HEFA unit.

Benefits

- HVO is compatible with existing engines and infrastructure, allowing it to be used in existing blending and distribution infrastructure.
- HVO use leads to less pollution and reduced nitrogen oxide emissions compared to conventional diesel.

Current barriers

- UCO collection infrastructure is currently absent at a commercial scale. Also, there are issues of adulteration with the quality of UCO.
- The supply of animal tallow is fragmented because of the scattered feedstock, which makes it difficult to gather in large volumes.

4.4. Efficiency and operational measures

4.4.1. Flare-gas recovery system

Flaring is defined as controlled waste/excess hydrocarbon combustion at a refinery flare stack. It serves as the last line of defence against the release of unwanted gases into the air during equipment upsets, overpressure events, and startup or shutdown transients.

A large portion of flare gases across refineries is routine flaring arising from process inefficiencies, sub-optimal performance of pressure controls on gas headers, leakages from fuel gas systems or process units, and inadequate vapour unit recovery capacity. This is called operational/non-emergency flaring, which FGR systems are designed to eliminate. Below is the list of expected benefits of FGR systems:

- Reduced GHG and pollutant emissions, with a 90–98% emission reduction in flare-related CO_2, VOCs, and other emissions.
- Reducing mechanical and thermal stresses in the flare extends flare tip life and lowers maintenance frequency.
- Recovered gases can be used as cracking feedstocks or upgraded to LPG, CNG, or LNG, creating additional revenues.
- Improvement in the ESG profile with reduced flaring helps in meeting methane and flare-gas reduction targets. Lower emissions and visible flames improve community perceptions and improve relations.

Four projects were commissioned for flare-gas recovery systems at Digboi, Haldia, Barauni, and Gujarat refineries by IOCL.[143] BPCL has implemented partial FGR at its Mumbai refinery, with a two-liquid ring vacuum pump compressor system on the HP flare header. Bina and Kochi refinery has implemented the FGRS system by carrying out daily flare emission monitoring with dedicated metres and conducting routine PSV leak surveys.[144] HPCL has implemented FGR units for minimising flaring and utilising process gas for heating in the furnaces/boilers in the Mumbai refinery.[145] Current barriers to wider adoption include the following:

- Unlike the EU and the US, India lacks a time-bound binding regulation mandate.
- Indian PSU refineries prioritise petrochemical integration, crude throughput expansion, and mandated fuel quality upgrades (BS-VI) due to budget constraints.
- The flare headers were designed for safety relief, not for continuous low-pressure gas recovery. Hence, retrofitting FGR requires significant engineering effort and experienced technology partners.
- FGR projects are eligible for carbon credits under the Clean Development Mechanism, Verified Carbon Standard, Gold Standard, and India's Carbon Credit Trading Scheme under the Indian Carbon Market. However, the Indian Carbon Market is in a nascent stage, with credit prices insufficient to drive investment decisions.

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[143] IOCL Media Announcement

[144] BPCL Sustainability Report 2024-25

[145] HPCL Sustainability Report 2024-25

4.4.2. Furnace efficiency optimisation

Furnaces and fired heaters are the single largest energy consumers in the refining industry, typically accounting for up to 50% of the total refinery energy consumption, with process heating using two-thirds of total fuel use; inefficiencies arise from poor combustion, fouling, and heat loss, driving excess fuel burn. Core intervention areas for furnace efficiency optimisation include the following:

- Combustion air control: Minimising excess air by maintaining optimal air-fuel ratio with the help of O_2/CO sensors and automated controls reduces stack losses, boosts efficiency and cuts Nox emissions.
- Heat recovery: This can be achieved by installing economisers (flue gas to boiler feedwater) or recuperators/air preheaters to capture waste heat from high-temperature exhausts.
- Maintenance techniques: High-emissivity coatings of Cetek to refractories and tubes increase radiant heat transfer by 10–12%; online tube cleaning/repairs avoid the buildup of fouling, resulting in a 1–2% reduction in annual loss.
- Burner upgrades: Retrofitting low-Nox, high-efficiency burners for uniform flames and up to 10% less excess air improves the turndown ratio for variable loads.

IOCL has achieved considerable furnace efficiency improvements at Panipat and Baruani. BPCL has implemented APC on crude distillation units at Mumbai and Kochi, and many other PSUs are engaged in similar initiatives. However, the sector average remains below global benchmarks for the following reasons:

- Delays in capital deployment on refractory and convection section repairs during high utilisation periods.
- Inadequate availability of instruments at secondary furnaces such as FCC, hydrocrackers limit APC deployment.
- Absence of equipment that monitors temperature and O_2 at furnace exists in many facilities.

4.4.3. Heat exchanger network improvements

Heat exchanger trains—shell and tube, plate-type, and other equipment—recover and recycle energy across process streams, with the crude preheat train alone being the single largest heat-recovery block in atmospheric distillation units. Thus, optimising the heat exchanger network (HEN) is a high-impact lever to cut heater duty, fuel use, and carbon footprint. Core interventions include:

- Crude oil fouling is the main driver of heat exchanger performance loss, significantly reducing heat transfer over time. Solutions like helical baffles, twisted tubes, online chemical cleaning, and fouling-resistant materials help extend clean-run periods.
- Providing additional surface area for better heat transfer between hot and cold streams as it increases the thermodynamic efficiency of heat recovery.
- Continuous monitoring of U-valves, exchanger duty, and pressure differentials using process data historians enables the identification of fouling much before the actual impact on preheat temperatures.

IOCL's R&D centre at Faridabad has developed a proprietary formulation for fouling inhibitors and conducted HEN studies for several of its refineries. BPCL has also engaged process consultants for pinch studies for HEN projects at Mumbai and Kochi refinery. However, the presence of cross-unit heat integration is limited in PSU operations for the following reasons:

- A high capex for redesigning projects based on pinch analysis may require piping rerouting, additional surface area for heat transfers, and potential shutdown work.
- The HEN monitoring process requires the feeding of reliable, calibrated data across the instrumentation network of exchangers. Fragmented process historical data are of no use with dependence on external agencies for pinch analysis, creating cost barriers.
- Refinery operations are generally optimised for varying crude slates according to crude availability; hence, optimising HEN studies for single design is futile, driving up costs and reliability further.

4.5. Potential pathways for refinery decarbonisation

India’s refinery decarbonisation landscape presents a multidimensional transition, with low-capex near-term operational levers, such as flare-gas recovery, furnace optimisation, and CHP, forming the foundational layer of the decarbonisation roadmap. Long-term structural shifts towards green hydrogen, SAF, and renewable feedstocks determine whether India’s refining sector can credibly align with the net-zero 2070 commitment and the NGHM 2030 milestones. While PSU refiners have initiated meaningful interventions, adoption remains uneven and fragmented. The pathway is constrained by structural barriers, including high capital allocation, immature regulatory frameworks, underdeveloped supply chains for bio-feedstocks and electrolysers, and the absence of binding mandates. Bridging these will require coordinated action, including time-bound mandates with compliance pathways, maturation of the carbon market under CCTS, and the development of an integrated feedstock ecosystem. Early adoption of these measures by Indian refineries in their capital planning cycles will reduce emissions and operating costs.

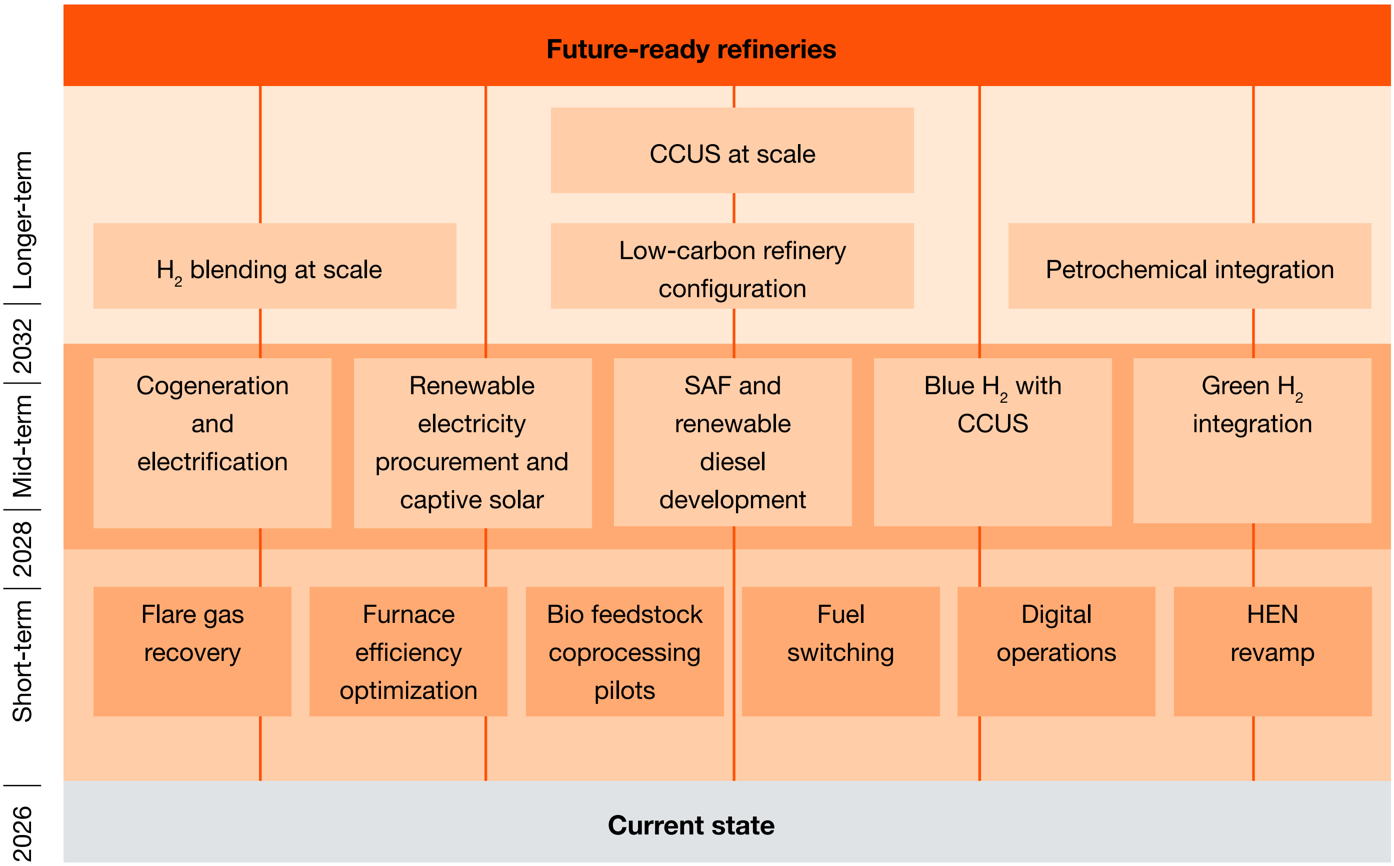
05

Execution roadmap, policy enablers and building resilient, competitive, and sustainable refineries for Viksit Bharat

5.1. Roadmap for Indian refineries

The evolution of Indian refineries to be future-ready requires a long-term structured strategy that addresses the energy trilemma of energy security, sustainability, and equity to provide universal access to reliable, affordable, and abundant energy. The roadmap must recognise that different refineries are at different maturity levels with different emission profiles and complexities; hence, there is a need for diverse customised strategies. Brownfield refineries will be decarbonised through operational upgrades and retrofits, whereas upcoming newer refineries will be designed with flexibilities to integrate, absorb, and produce low-carbon products from the start.

Figure 11 Future-ready roadmap for refineries



The near-term initiatives are characterised by low-capex investments with high returns. They deliver immediate emission reductions while being cost competitive and reliable. Meanwhile, this window gives refiners the breathing room to lay the groundwork for investing in capital-intensive projects, such as blue/green hydrogen readiness, renewable power procurement, and advanced analytical capabilities.

The medium-term initiatives focus on making structural changes to refinery operating models, such as deep petrochemical integration, cogeneration and electrification of equipment, and increased blending of green hydrogen. Refineries should also look for opportunities for alternative feedstock processing in the surrounding environment in proximity to industrial clusters, feedstocks, and logistics.

The long-term focus is on maintaining strategic relevance in a low-carbon economy and reducing emissions, which requires continuous investments in digital intelligence, product diversification, and deeper collaborations across the entire refining value chain.

5.2. Policy and ecosystem enablers

Indian refineries are entering a new era, with operational excellence, capacity growth, and decarbonisation initiatives advancing in tandem. This requires a comprehensive policy and ecosystem response that brings digital transformation, greenfield and brownfield expansion, and decarbonisation under a single, integrated framework. Success in executing these initiatives largely depends on the right policy support, infrastructure ecosystem, market support, and capital to execute at scale.

The foremost priority is to support complex upgrades and refinery capacity expansions. As India seeks to strengthen its position as a global refining hub, expansion plans and major projects underscore the ongoing need for investment in new capacity additions, integrated complexes, utilities, and pipeline connectivity. Hence, policy measures should try to facilitate faster approvals, environmental clearances, infrastructure access with logistics connectivity, and industrial cluster development, ensuring that both greenfield and brownfield expansions are delivered simultaneously at pace.

Digital and operational enablement represents another vital enabler. As refineries become more data-driven, there is a need to develop an ecosystem for industrial AI, automation, digital twins, workforce development, and cybersecurity. Policy interventions should focus on establishing standards for digital infrastructure, promoting smart manufacturing, and creating mechanisms to drive the adoption of APCs, predictive analytics, and digital execution tools across the entire value chain.

A third priority is the decarbonisation enabler. This includes incentives for green hydrogen, biofuel co-processing, renewable diesel, SAF, access to renewable power, and circular feedstocks. The frameworks supporting the offtake of these products with blending mandates and clear standards will boost investor confidence by providing demand visibility, leading to improved bankability of such projects. Simultaneously, policy measures should foster the growth of domestic technology and supply chains, particularly for carbon capture technology, electrolyser production, and renewable energy integration.

The final pillar is partnerships for shared infrastructures. No refinery can decarbonise or expand in isolation; their success depends on the close collaboration with feedstock suppliers, technology providers, power producers, EPC firms, logistic providers, and hydrogen producers. Cluster-based models are particularly important to drive transition as they enable sharing utilities, hydrogen networks and pipelines, carbon infrastructure, and waste-to-energy systems to reduce costs and unlock scalability.

5.3. Conclusion and the way forward

Indian refineries are at a strategic inflection point—they must meet the country's increasing energy needs to maintain energy security while adapting and integrating low-carbon alternatives. Going forward, the success of refineries will no longer be measured by throughput but by how effectively they integrate emissions reduction, digital intelligence, product diversification, and operational excellence.

The transition will not be uniform across the sector. Some refineries will move faster in terms of efficiency and digitalisation, whereas others may lead in petrochemical integration, green hydrogen, or low-carbon product development. The key to success lies in identifying the most suitable approach for each asset and phasing investments strategically while protecting margins and strengthening long-term competitiveness. A portfolio-based flexible approach will therefore prove more effective than a uniform, one-size-fits-all model.

For Indian refiners, the near-term focus should be on achieving operational excellence and digital integration while capturing low-cost emission reductions. In the medium term, the emphasis must shift towards hydrogen and low-cost product integration, requiring more project development time and partnering. Over the long term, this should be followed by full refinery reinvention through integration with petrochemicals, CCUS, and circular feedstock adoption to support Viksit Bharat's energy and sustainability goals.

The central message is clear: Indian refiners will not just respond to the energy transition to achieve net-zero goals; they will drive it. By enabling policy support, infrastructure development, and strategic investments, Indian refiners can emerge stronger, cleaner, and more globally competitive going forward.

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