PIER 2.0: India's Industry Energy Demand until 2040-41

Perspectives on **I**ndian **E**nergy based on **R**umi **(PIER)**

Prayas (Energy Group)

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Rumi: An open-source Energy Systems modelling platform

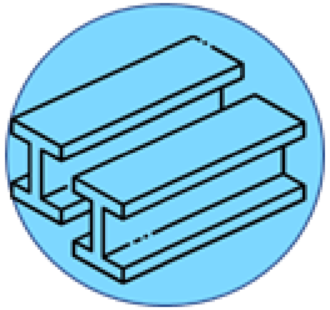
A quick guide to PIER 2.0 Model Documentation

- Please use this document as a primary reference for sector-specific modelling methodology, sources, assumptions, model-results and insights
- Access the “Source Workbooks” for more detailed documentation
- Following is the folder path to the source Excel workbook which can be referred for additional information –
  - `D_IND\IND_Steel_Energy_Demand.xlsx` for Steel
  - Similarly for Cement & Aluminium
- Access the PIER 2.0 files from Zenodo https://doi.org/10.5281/zenodo.14603083
  - Refer Rumi documentation for folder structure (https://github.com/prayas-energy/Rumi/tree/main/Docs)
- Follow the ‘FileInfo’ Sheet in the workbook and respective sheets to access further documentation of assumptions and validation along with citations of sources

Outline

- Industry overview
- Methodology for Industrial energy demand estimation
- Bottom-up Industry Models – Inputs, Results and Insights
    - Iron & Steel
    - Cement
    - Aluminium
- Overall Industry – Results & Insights
- Conclusions
- Appendix – Industry Model details

For ease of reference, slides are marked as below



Steel

Cement

Aluminium

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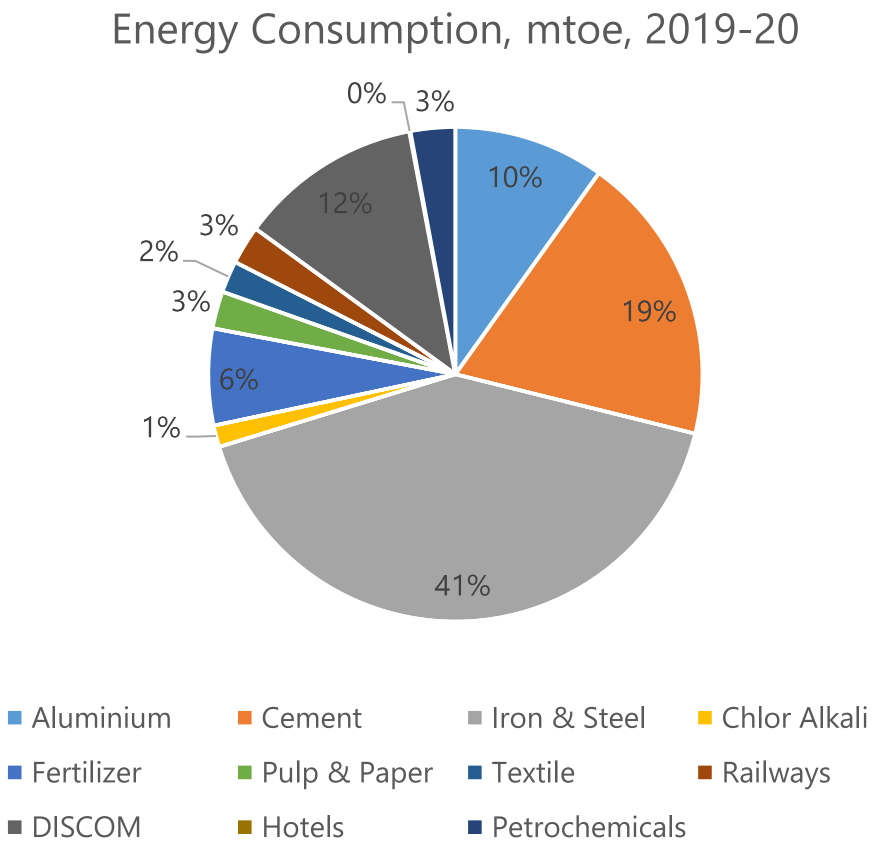
Glossary

AFR	:	Alternate Fuel & Raw material
BF	:	Blast Furnace
BOF	:	Basic Oxygen Furnace
CBAM	:	Carbon Border Adjustment Mechanism
CC	:	Composite Cement
CCUS	:	Carbon Capture, Utilisation & Storage
CDI	:	Coal Dust Injection
CO2	:	Carbon Dioxide
COREX	:	Smelting reduction process for direct iron
DRI	:	Direct Reduced Iron
EAF	:	Electric Arc Furnace
GDP	:	Gross Domestic Product
GH2	:	Green Hydrogen
GHG	:	Greenhouse gases
Gcal	:	Giga calories
IF	:	Induction Furnace
kWh	:	Kilo Watt Hours
LC3	:	Limestone Calcined Clay cement
MT	:	Million Tonne (or million metric-tonne)
mtoe	:	Million tonnes of oil equivalent
NSP	:	National Steel Policy 2017
OPC	:	Ordinary Portland Cement
PJ	:	Petajoules
PPC	:	Pozzolana Portland cement
PSC	:	Portland Slag cement
SEC	:	Specific energy consumption
ST	:	Service Technology
STC	:	Service Technology Category
TWh	:	Tera Watt Hours (same as BU)
tcs	:	tonne crude steel

Sector-wise industrial energy consumption 2019-20

Industry energy consumption excluding Thermal power plants & Refinery (start of PAT-V)



Sector	Energy Consumption, Mtoe	Share
Iron & Steel	54.1	41%
Cement	24.8	19%
Aluminium	12.9	10%
Fertilizer	8.3	6%
Petrochemicals	3.8	3%
Others	26.8	21%
	130.8	100%

Source: BEE 2020

Industry overview

- Industry sector is responsible for over 36% of India's total final energy consumption and 25% of CO_2 emissions
- India 2nd in world production in steel (7.4%) and cement (8%) and set to increase its share over next few decades
- Steel Cement & Aluminium - top 3 energy consuming industries besides thermal power plants
- Consumption of two of the three most abundant man-made bulk materials - Steel & cement – set to rise steeply due to big infra push
- Hard to abate sectors; need rapid decarbonization to achieve climate mitigation goals

Source: IEA India Energy Outlook 2021; Ideas for India 2022; WSA 2024; IEEFA 2023

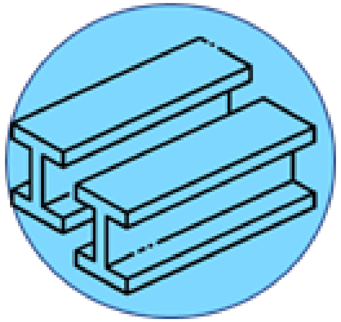
Importance of the industry sector

Industry data	INDIA - INDUSTRY	STEEL	CEMENT	ALUMINIUM
Industry share of total final energy consumption	36%			
Industry share of total CO_2 emissions	25%			
Sector share of Industrial energy consumption		23%	7%	4%
As a share of Industrial CO_2 emissions (end-use)		30%	23%	3%

Source: IEA India Energy Outlook 2021; Ideas for India 2022; IEA Iron & Steel Technology Roadmap 2020

Industrial energy demand estimation

- Energy demand estimated bottom-up for Iron & Steel, Cement and Aluminium
  - Energy demand is determined by estimated trajectories of:
    - State-wise Industrial activity (production) and Technology-wise shares
    - Specific energy consumption (SEC), i.e., efficiency
    - Decarbonisation options
  - Scenarios as defined in PIER2.0
    - Reference, Vikasit Bharat and Vichalit Bharat
    - Industrial production based on GDP trajectories across scenarios
    - Moderate efficiency improvements and decarbonisation measures assumed in Reference
    - Higher efficiency, greater decarbonisation assumed in Vikasit Bharat compared to Reference
    - Conversely, lower efficiency and lesser decarbonisation assumed in Vichalit Bharat scenario
- Energy carrier demand estimation for remaining industries (IND_OTHERS)
  - Energy demand growth rate estimated based on elasticity with GDP growth rate
  - Demand in base year is calibrated based on official data from CEA, MoC, MoPNG, etc.
  - Past trends are assumed to continue with some adjustments based on efficiency improvements, electrification etc.

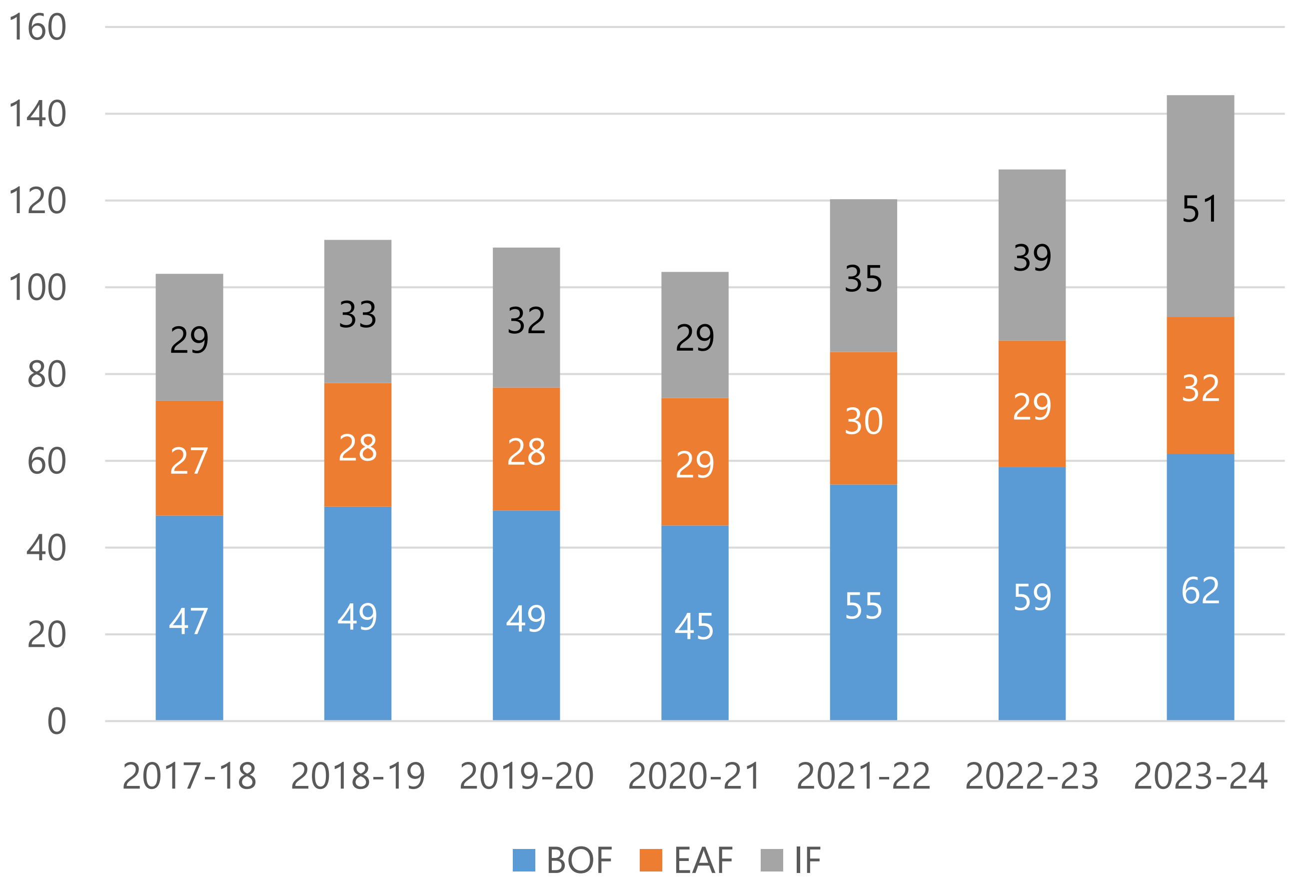


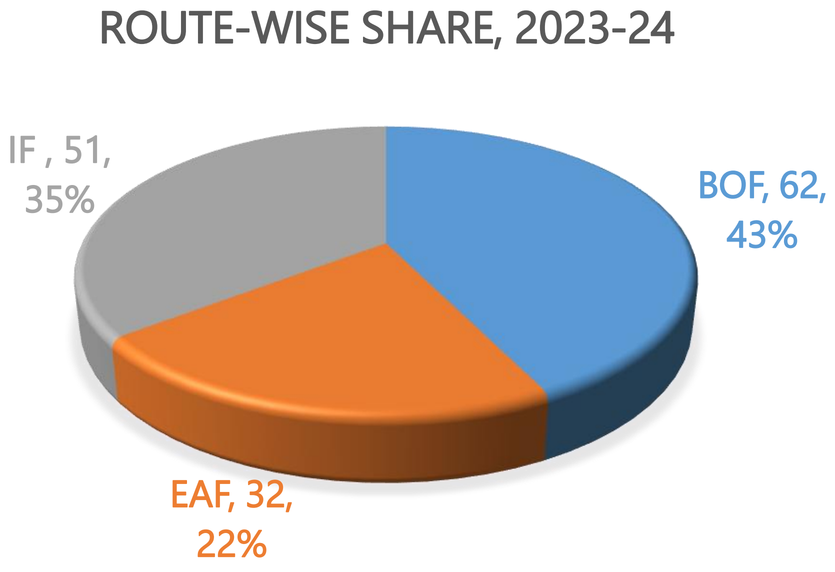
Iron & Steel

PIER Steel model

- Context
- Primary drivers of steel demand
- Model Structure and Inputs
  - Determinants for future steel production
  - Scenario-wise projection basis
  - Scenario-wise production projections
  - Specific Energy consumption & improvement
- Results and Insights

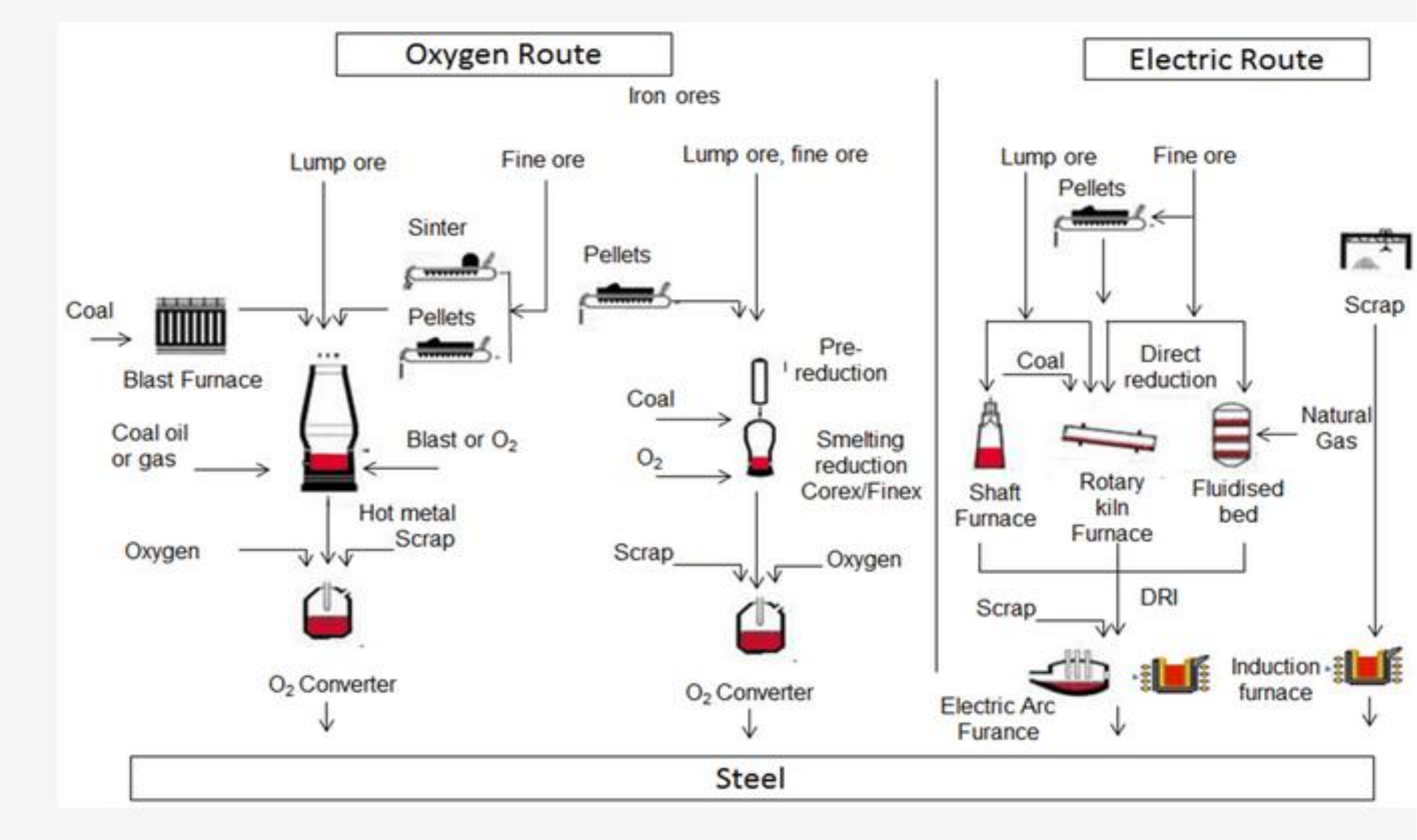
Historical crude steel production & shares





Source: Joint Plant Committee, Ministry of Steel

Key steel making routes – BF-BOF, DRI-EAF & DRI-IF



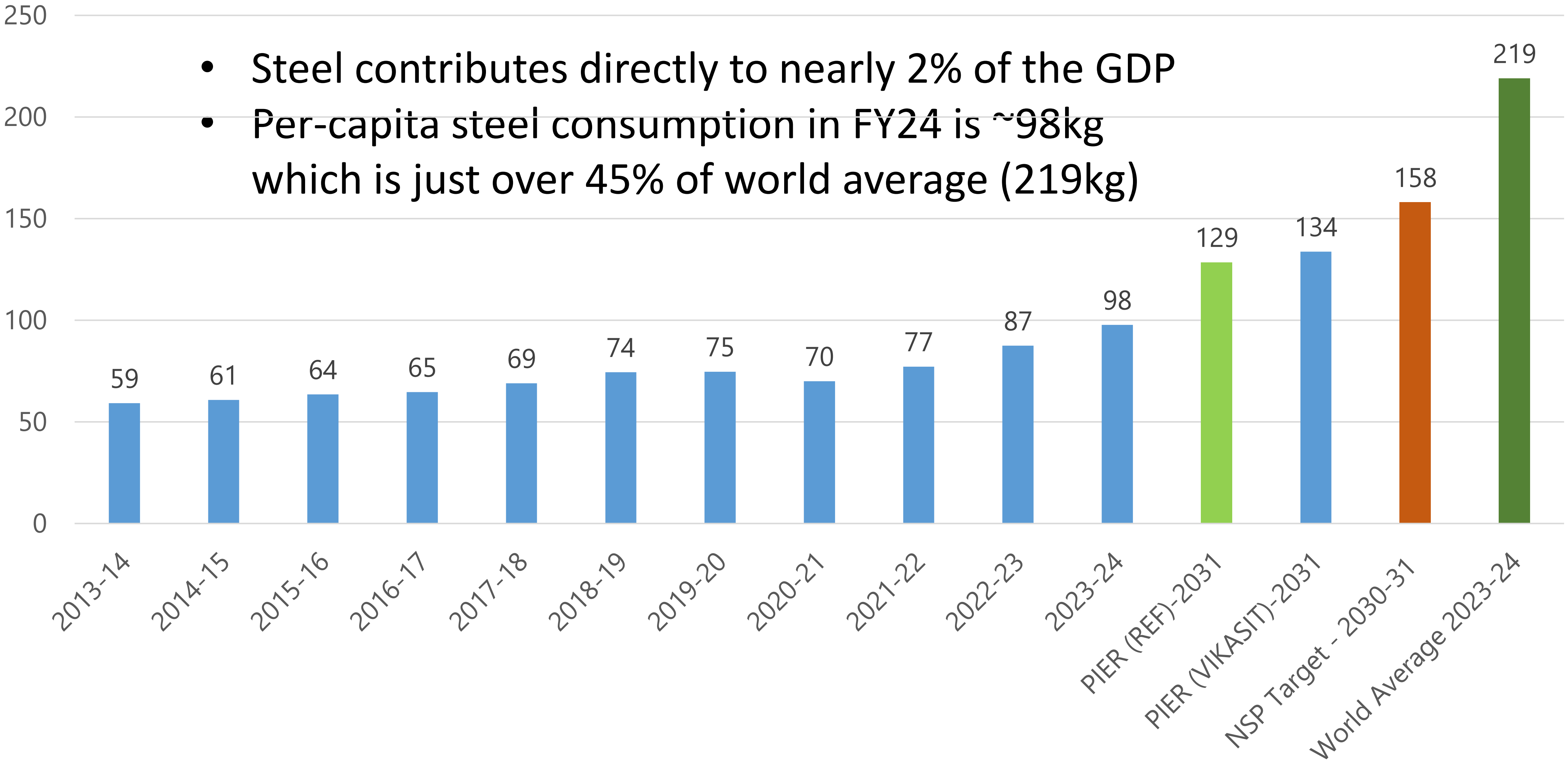
- BF : Blast Furnace
- BOF : Basic Oxygen Furnace
- DRI : Direct Reduced Iron
- EAF : Electric Arc Furnace
- IF : Induction (arc) Furnace

Refer Appendix for details of production routes

Source: Fig.3, Shanmugam et al, Challenges & outlines for steelmaking, 2030 & beyond. https://doi.org/10.3390/met11101654

Steel: Per-capita consumption of finished steel

- Steel contributes directly to nearly 2% of the GDP
- Per-capita steel consumption in FY24 is ~98kg which is just over 45% of world average (219kg)



Primary drivers of steel sector energy demand

Energy Service Demand	Production Routes (Service Technology Category)	Technology trends	Specific Energy Consumption (SEC)
Steel demand or production • Energy demand to meet the domestic steel production • Increase per capita steel consumption to 158 kg	• BF-BOF -> BOF • DRI-EAF-> EAF • DRI-IF -> IF	• Based on decarbonization uptake • Decarbonization levers: Scrap, Green hydrogen, CCUS	• For each of the fuels used in different technologies

Model structure : Steel

Rumi demand components -

- Demand Sector → Industry
- Energy Service → Steel
- ServiceTechCategory (STC)→ BOF, EAF & IF
- ServiceTechnologies (ST) → Sub-process routes within ST Category based on Energy carriers & likely decarbonization levers – Scrap, CCUS, & H2
- Energy Carriers (EC) → Coking & Thermal coal, Natural Gas, Electricity, Hydrogen
- ST_SEC → Specific Energy Consumption for each ST which improves over the years

Steel: Service technologies & Energy carriers

BOF	EAF	IF
Service Technologies BF-BOF BF-BOF-CCUS	**Service Technologies** DRI-EAF-COAL DRI-EAF-NATGAS DRI-EAF-H2 COREX-EAF-COAL COREX-EAF-CCUS SCRAP-EAF BF-EAF BF-EAF-CCUS	**Service Technologies** DRI-IF-COAL SCRAP-IF
Energy Carriers Coking coal, Thermal coal as CDI (coal dust injection), Electricity	**Energy Carriers** Thermal coal, Natural Gas, Electricity, Green Hydrogen	**Energy Carriers** Thermal coal, Electricity

Steel: Determinants for future production (All scenarios)

- Growth rate of steel production is based on elasticity with respect to growth rate of GDP
- Starting elasticity based on past 12-year production. Elasticity changes in future years as per scenario narratives
- Upcoming BOF capacity based on declared expansion till FY2031 & beyond by steel companies
- New production assumed to be distributed across states in same ratio as base year
- No new expansion in COREX. DRI from COREX plant assumed to be processed in EAF plant
- Capacity addition in IF (and its share) likely to stagnate due to quality issues & inefficiencies

Determinants for future steel production….

- EAF share – Difference between Total & sum of BOF+IF production
- EAF production likely to increase post 2031 due to increasing pressure to decarbonize (CBAM etc.) & net-zero targets

Options with most potential for decarbonization and likely adoption - Increased scrap share, green hydrogen (GH2) & CCUS

- More scrap likely due to scrap recycling policy
- GH2 which is likely to pick up post 2030, considered for DRI-EAF route
- Use of GH2 in blast furnace not considered for now

CCUS – Potential option for BF-BOF & COREX route, likely to pick up post 2035

- Chemical conversion is considered as the option for PIER
- For Vikasit, it is assumed to kick in from early 2030s

Steel production projection basis – Reference scenario

Medium growth, medium decarb, medium SEC improvement scenario

- GDP growth rate as per IMF projections till FY2028, then 6% assumed
- Production projection as per best guess based on past and future likely trends
- Increase in steel demand mirrors current push in infrastructure & construction
- BOF – Grows at 7% to complete capacity in pipeline till 2031. Grows at 4% post 2031 to clock a 50% share by 2041
- Due to decarbonization and CBAM mandates, EAF capacity & production grow at 7%
- EAF continues to grow at 6% due to higher availability of scrap & lower green H2 prices. EAF share improves from 22% in 2024 to 31% by 2041
- IF grows slower at 2% till 2031 and then shrinks by 1% till 2041. IF share reduces from 35% in 2024 to 19% by 2041
- Improvement in SEC is in line with current trends

Steel production projection basis – Vikasit Bharat

High growth, high decarb, high SEC improvement scenario

- Higher GDP growth (6.8%) so that per capita income becomes USD 5000 by 2041
- Reflects aspirations of ‘Developed India’ but with focus on sustainability
- Higher steel demand in infrastructure & construction
- More investment in new production facilities and R & D
- Higher CUF and uptake for decarbonization pathways
- BOF – upcoming capacity expansion till 2031 + 1/3rd stated expansion post 2031 is commissioned. Grows at 9% p.a. to achieve 55% share by 2035. Drops to 45% share on a slower 4% growth till 2041
- Due to decarbonization, CBAM mandates and increasing natural gas availability, EAF production grows at a brisk 8% till 2031
- Due to drastic fall in prices of Green H2 & greater availability of scrap, EAF grows strongly at 12% in 2030s to improve its share from 22% in 2024 to 45% share by 2041
- IF stagnates and then shrinks by 3% till 2035 and further by 5% to reduce from 35% in 2024 to 10% share by 2041

Steel production projection basis – Vichalit Bharat

Low growth, low decarb, low SEC improvement scenario

- Lower GDP growth (5.3%) assumed for model period
- Lower steel demand in infrastructure & construction
- Less investment in new production facilities and R & D
- Steel production grows at 4.5% till 2031, slows down to 3% in next decade
- BOF – upcoming capacity expansion declared till 2027 is commissioned. Rest till 2031 and beyond does not get completed due to financial difficulties
- IF grows at 3% (higher than Ref) till 2031, slows down to 1% till 2041

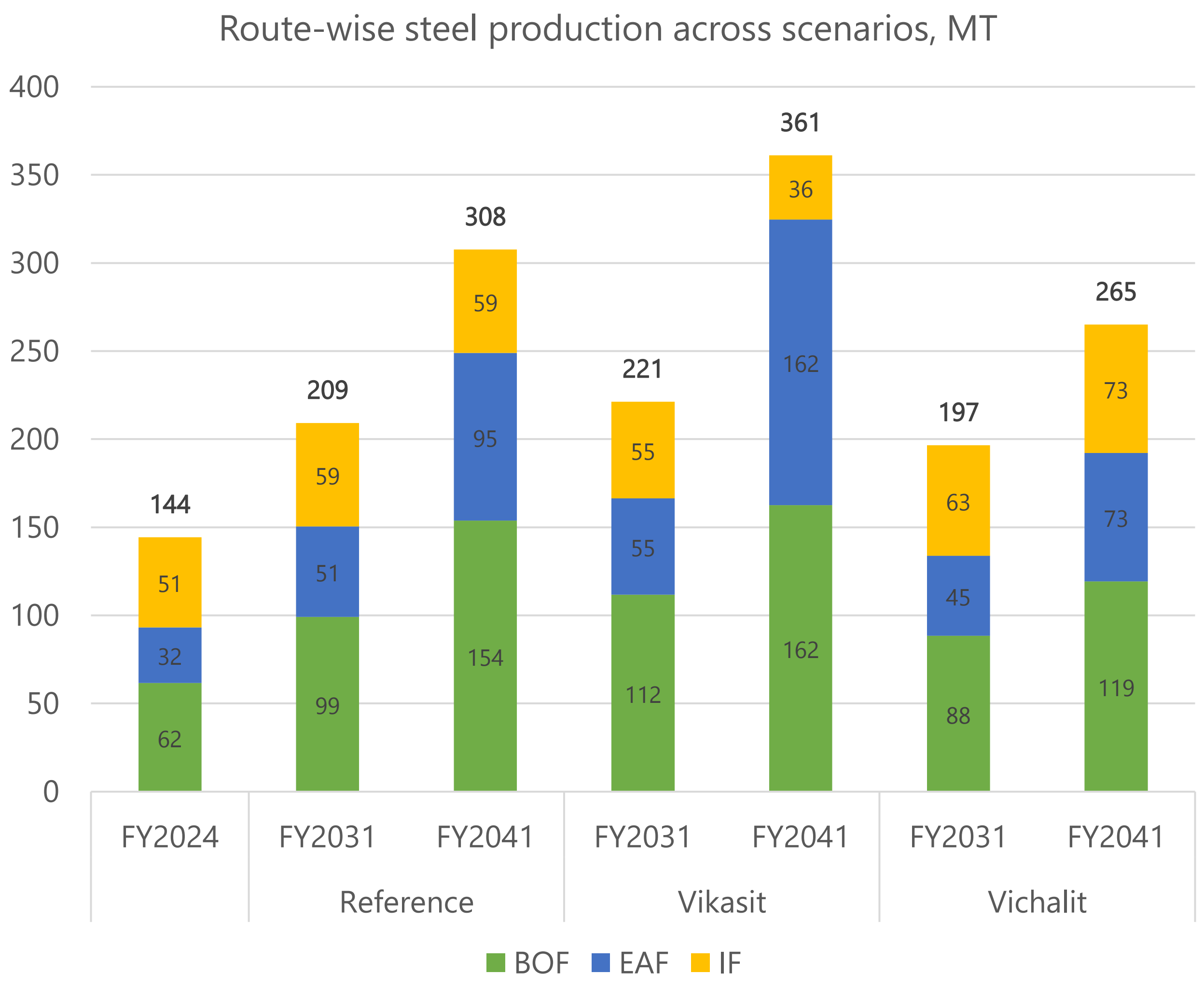
Though there is lower uptake for decarbonization pathways -

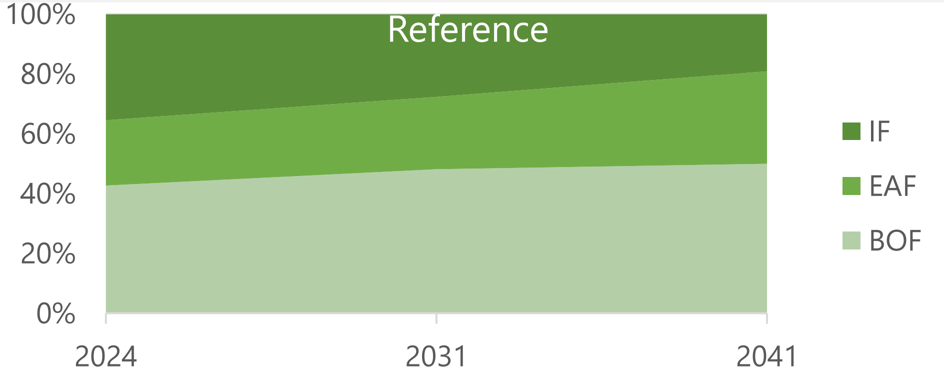
- CBAM and decarbonization mandate force some investment in EAF and it grows at 5.3 % till 2031 and continues at 5% till 2041
- Relative shares of BOF-EAF-IF routes continue to remain in same ballpark range (45%-27%-28%) in 2041

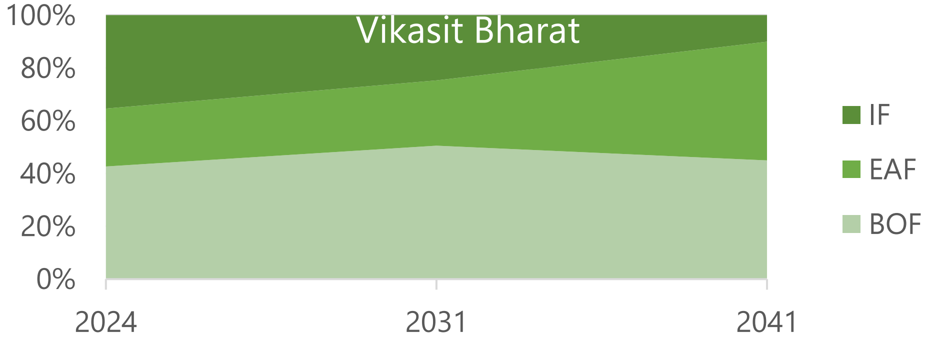
Steel: Comparison of scenarios

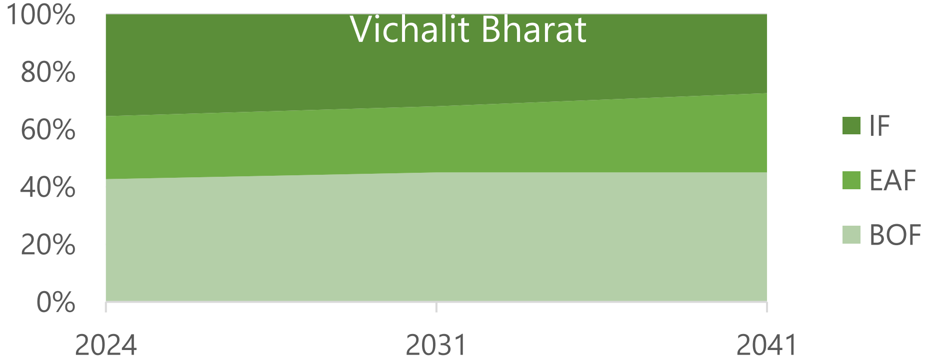
Parameters	Reference	Vikasit	Vichalit
GDP growth rate assumed	As per IMF till FY2028 6% p.a. thereafter	6.8%	5.3%
Overall Steel Growth rate till 2031	5.4%	6.3%	4.5%
Overall Steel Growth rate 2031-41	3.9%	5.0%	3.0%
Steel Production, MT (2041)	308	361	265
Decarbonization adoption pace	Medium	High	Low
Scrap growth rate %	5%	6-8%	4%
Production using GH2, MT (2041)	2.2	9.8	0.7
Production with CCUS, MT (2041)	3.8	9.1	2.3
SEC improvement rate	Medium	High	low

Route-wise steel production & BOF shares across scenarios

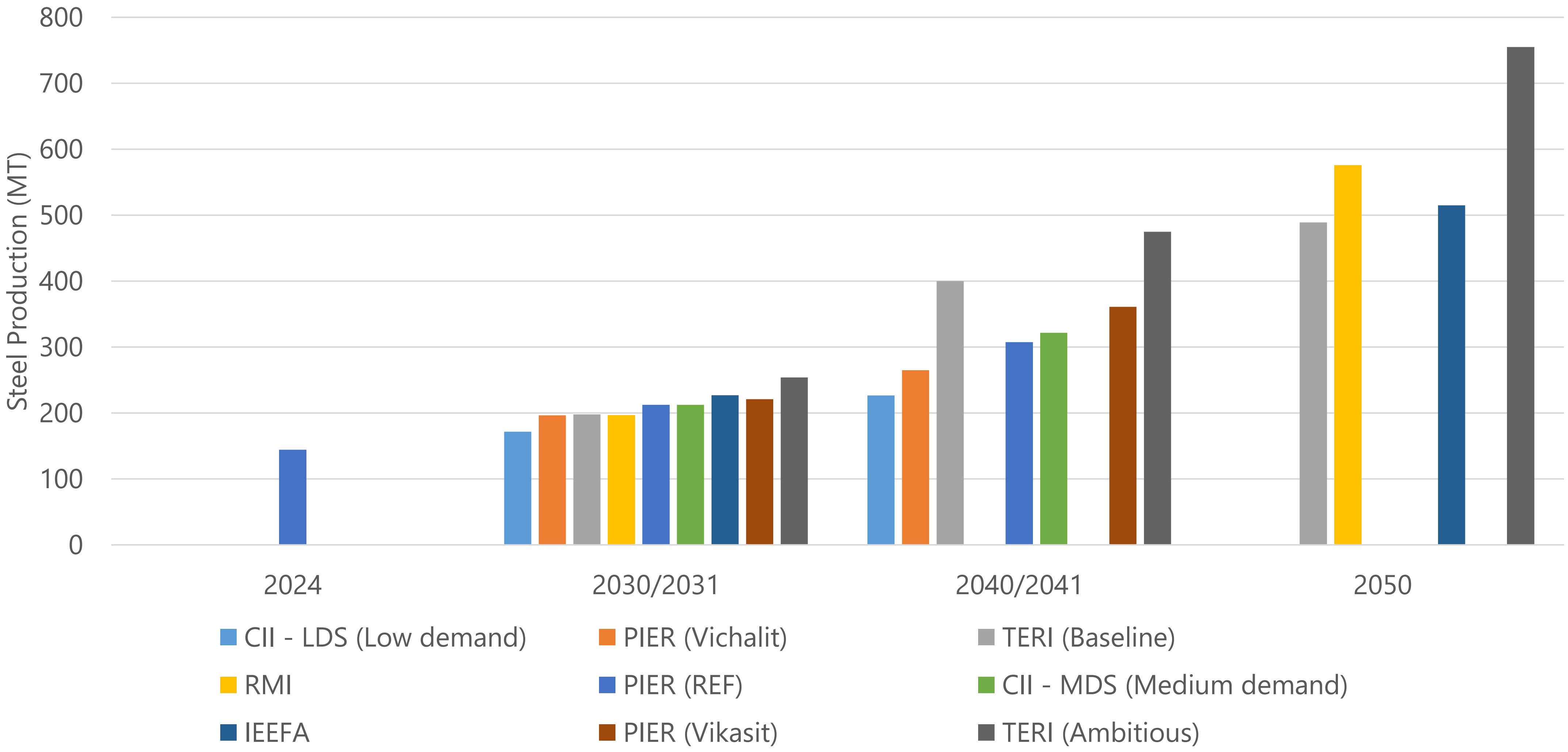






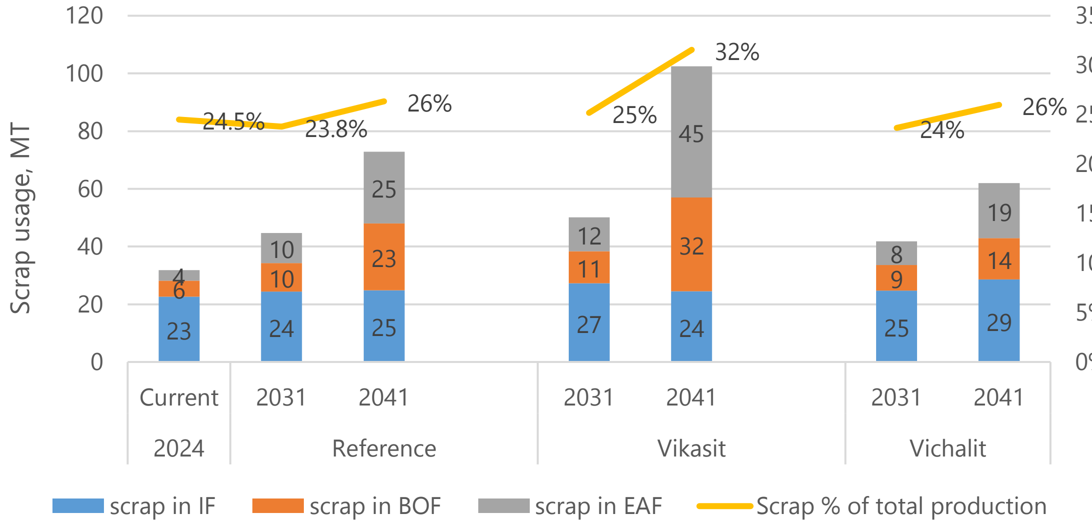


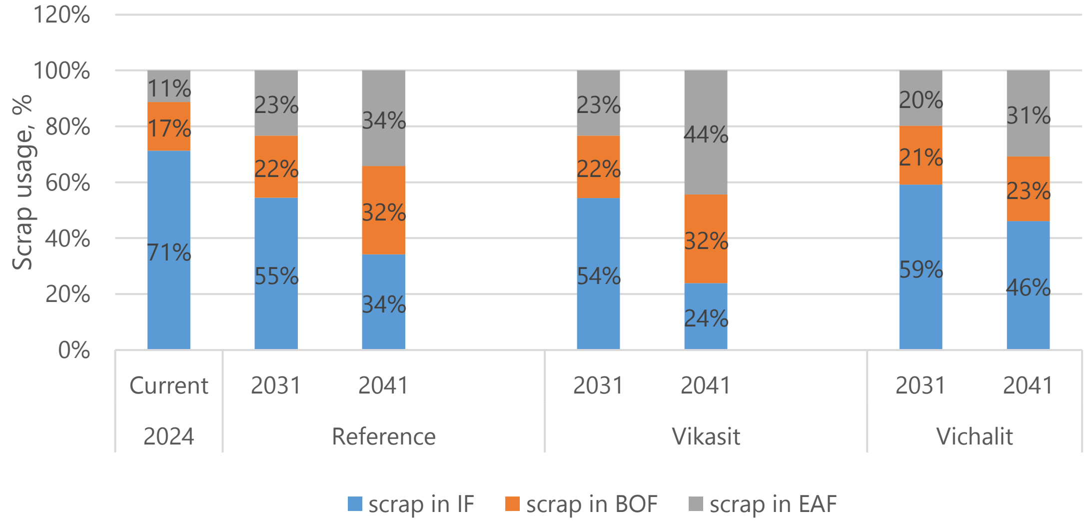
Steel: Comparison of PIER steel production with other sources



Steel: Scrap usage and shares

- Globally 32% steel production from recycled scrap, India : 23% (2022)
- 28 MT scrap used in 2021-22
- Scrap largely used in EAF & IF as raw material, BOF can use scrap up to ~20%
- Scrap availability grows at 5% in Reference & 6-8% in Vikasit.
- Scrap availability increases to 26% in Reference and 32% in Vikasit by 2041





Steel: Specific Energy Consumption (SEC)

- SEC Improvement - Key lever to reduce energy consumption and emissions
- Route-wise current SEC taken as Base SEC (legacy) for each ST based on literature or author's assumptions
- Final target SEC for 2041 assumed for each ST to calculate % improvement
- SEC improvements for legacy & new production follow different trajectory as scope for SEC improvement in legacy capacity is limited. More aggressive SEC improvement assumed for new production by taking lower SEC targets in 2041 (Refer Appendix for more details)
- Final SEC arrived at by taking weighted average of new & legacy production for each ST so that Fleet SEC does not fall below BAT(best available technology) / global best value
- Fuel wise SEC (current) – Thermal & electricity split is difficult to collate. Break-up assumed as per value in LBNL 2008, wherever not available
- Fuel wise SEC (future) - BAT values taken from LBNL 2008 for new capacity in Vikasit Bharat scenario. Reference & Vichalit have less aggressive targets
- Additional energy needed for CCUS is added to electrical SEC for BF-BOF, BF-EAF & COREX

Source : LBNL 2008 (World Best Practice Energy Intensity Values for Selected Industrial Sectors)

Steel: Specific Energy Consumption – Process route-wise

BF-BOF :

- Current SEC taken as per industry averages. Target SEC for 2041 for all scenarios assumed within target range specified in NSP 2017 (Refer Appendix)
- Fuel-wise split (coking, thermal & electrical) for current as well as target SEC taken within the above mentioned range
- Electrical SEC = Total SEC – Thermal SEC (coke rate+CDI rate)
- BAT SEC as per current global best is taken as the target SEC for 2041 for new production in Vikasit scenario.

BF-EAF :

- Thermal SEC for BF portion taken same as in BF-BOF. Elec SEC is taken as 4% of BF SEC as per BAT value
- For Steel, heat from hot metal is used in EAF – so no thermal portion considered, only Electrical SEC

Source : TERI 2020; NSP 2017; WSA 2021; LBNL 2008

Steel: Specific Energy Consumption : Process route-wise

DRI – EAF / IF

- Current SEC is compiled with individual SEC (thermal & electrical) for iron making & steel making

DRI

- Current SEC is taken as 4.5 Gcal/thm (hot metal) based on literature
- For Vikasit, BAT SEC of 3.4 Gcal/thm is assumed as target in 2041 for new capacity

EAF -

- Electrical SEC current value taken as per MoS 2024 report with a 60% electrical / 40% thermal break-up
- For Vikasit, BAT SEC taken as the 2041 targe with a 3:1 Electrical : thermal break-up

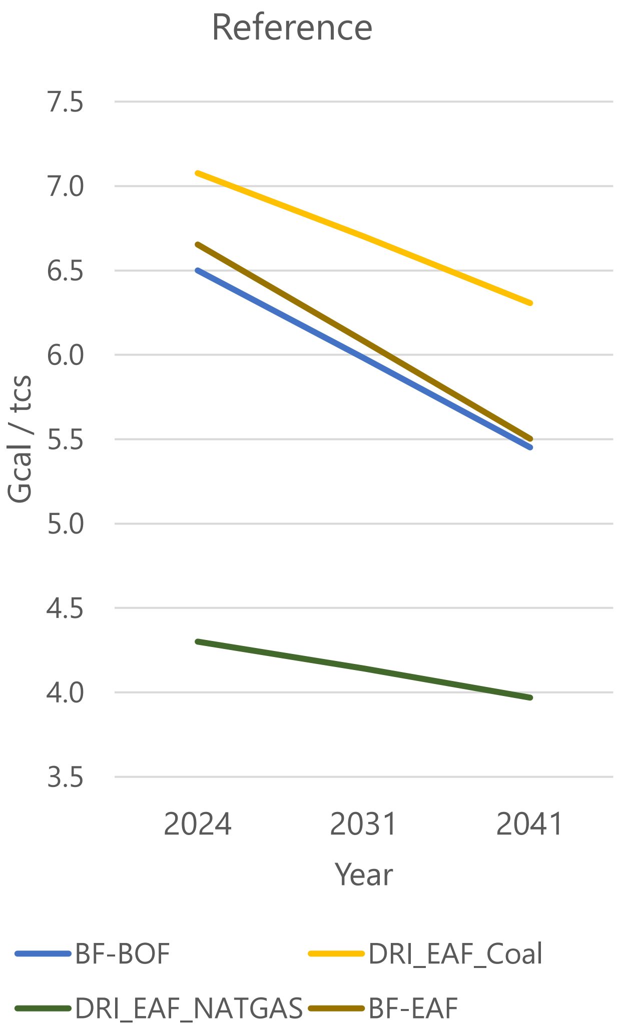
IF

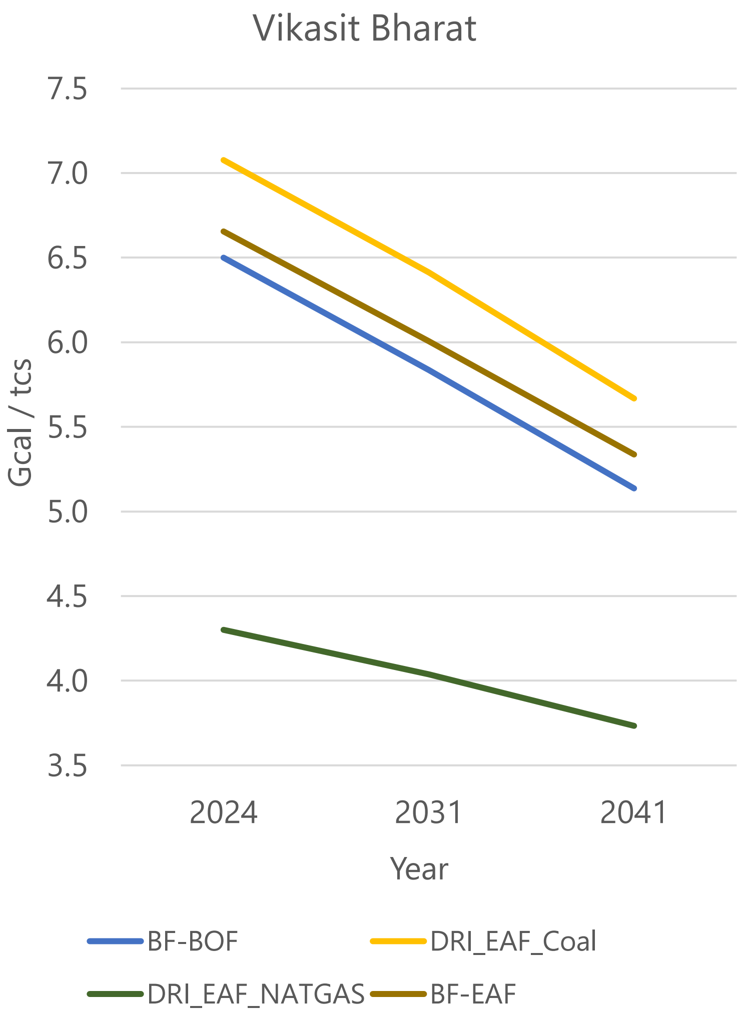
- IF - Elec SEC current value taken as per MoS 2024 (limited SEC data for Induction furnace) and no thermal SEC is considered.

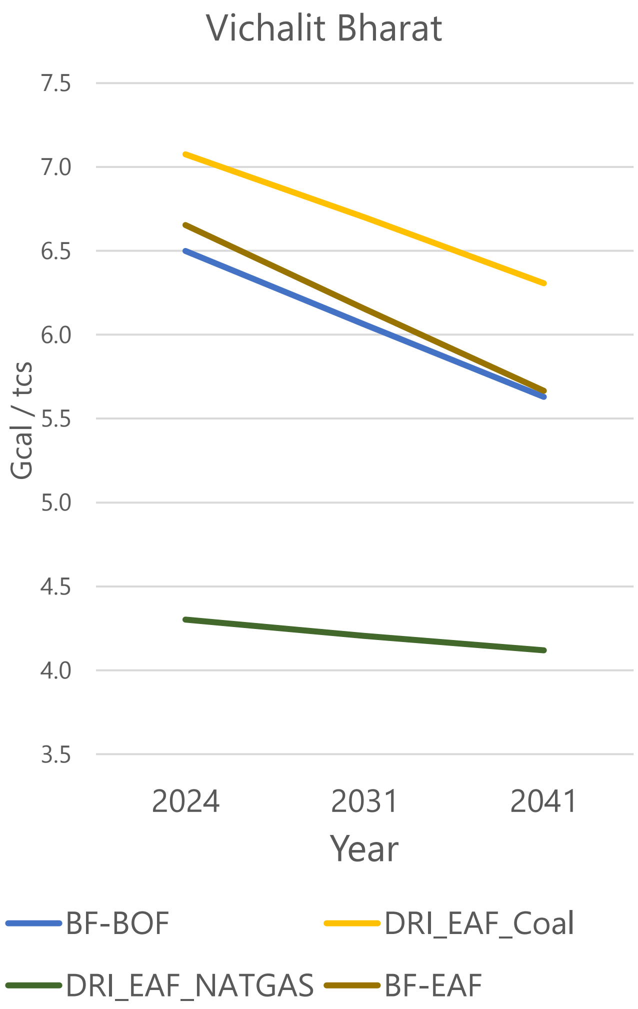
Source : TERI 2021; LBNL 2008, MoS 2024(Greening the Steel Sector in India-Roadmap and action plan); Bedarkar et al 2020

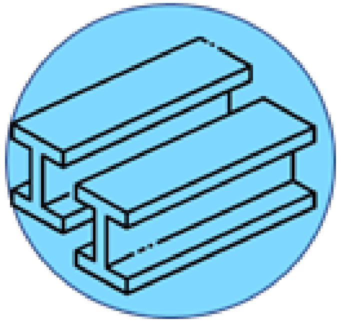
(Refer to Appendix for SEC details of other STs)

Steel: SEC improvement trends (process-wise)





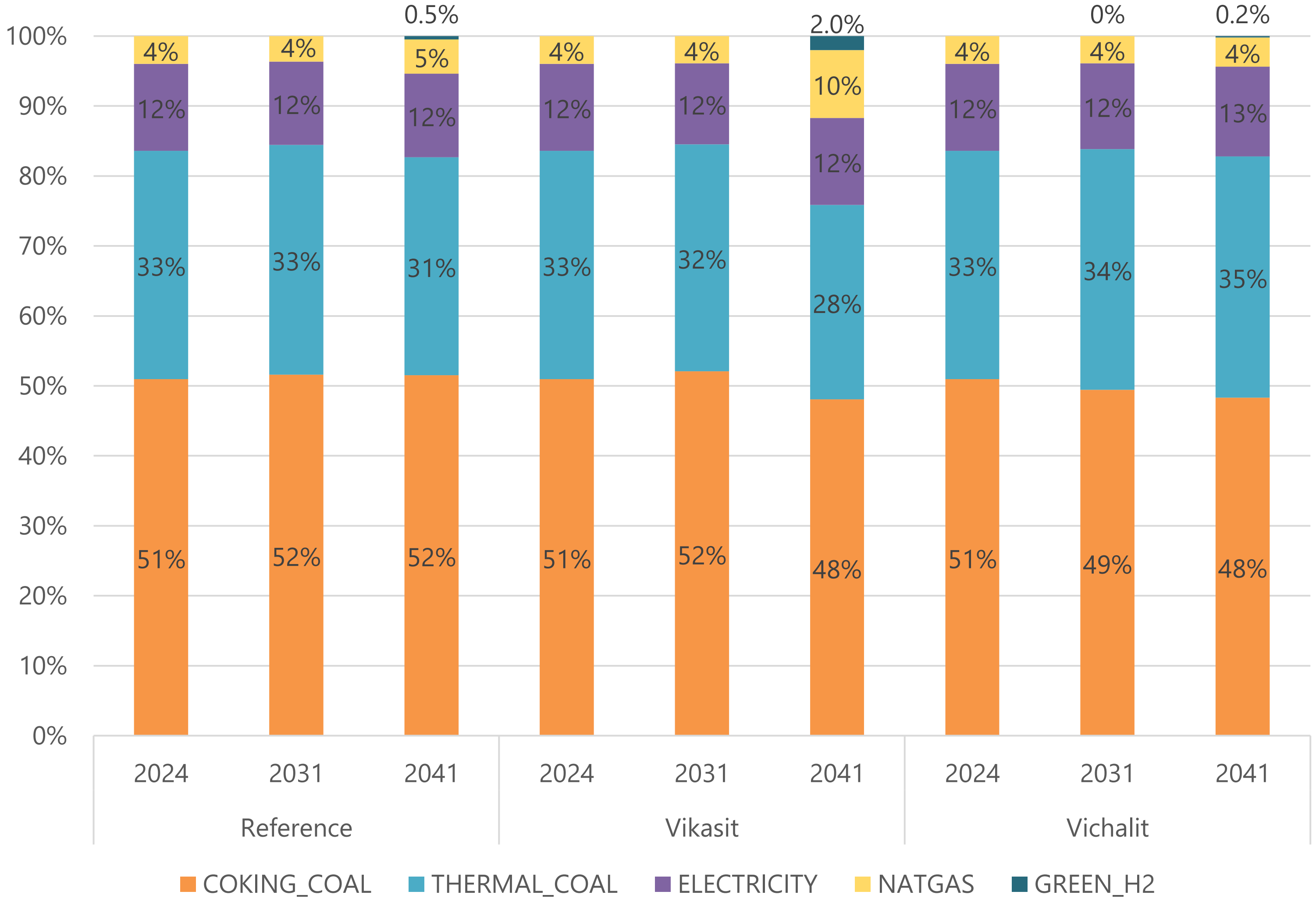




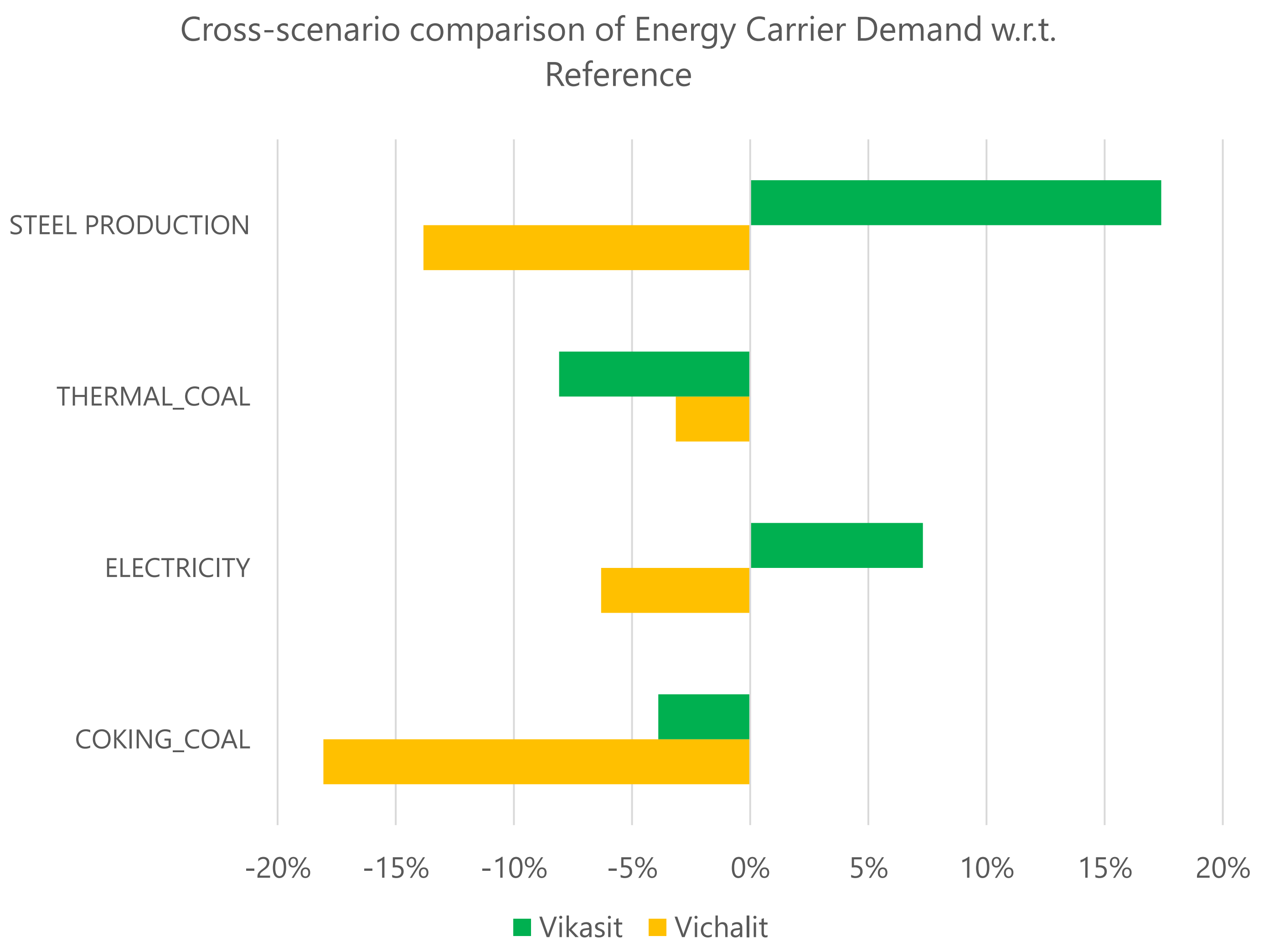
Steel : Results & Insights

Steel: Changing shares of energy carriers across scenarios

- Share of coal (coking + thermal) in 2041 in Vikasit is only 76% compared to 83% in Reference
- Combined share of Natural gas, Electricity & Green H2 increases from 16% in 2024 to 24% by 2041 in Vikasit
- Electricity share remains constant at 12-13% across all scenarios
- Natural gas share goes up from 4% in 2024 to 10% & Green H2 to 2% in Vikasit by 2041

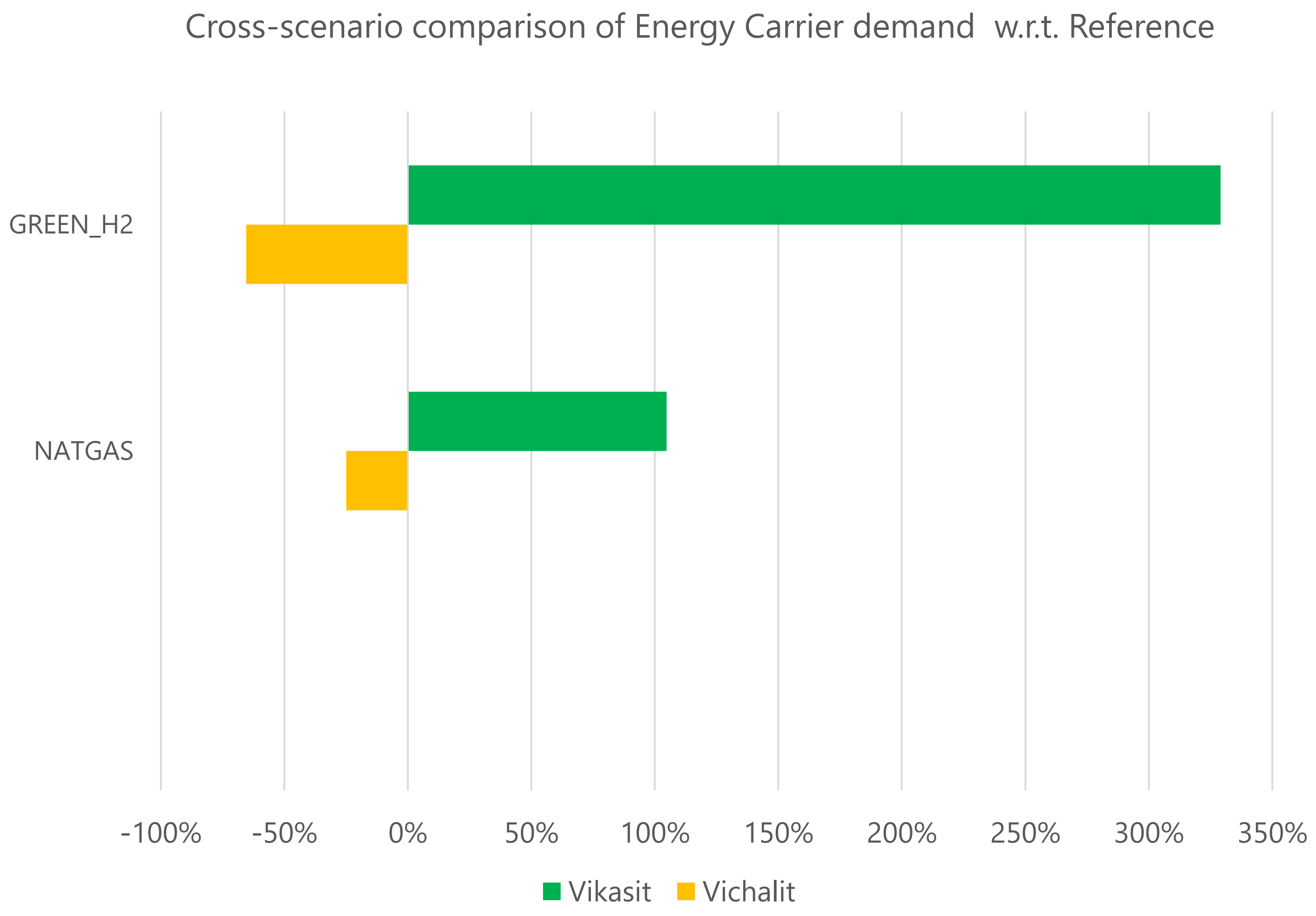


Steel : Comparison of EC Demand across scenarios



- Steel production is 17% higher than Reference in Vikasit and 14% lower in Vichalit in 2041
- However, coking coal demand is lower by 4% & thermal coal is lower by 8% in Vikasit due to better efficiency improvement
- In Vichalit, coking coal is 18% lower while thermal coal is only 3% lower than Reference
- Electricity is 7% higher in Vikasit and 6% lower in Vichalit

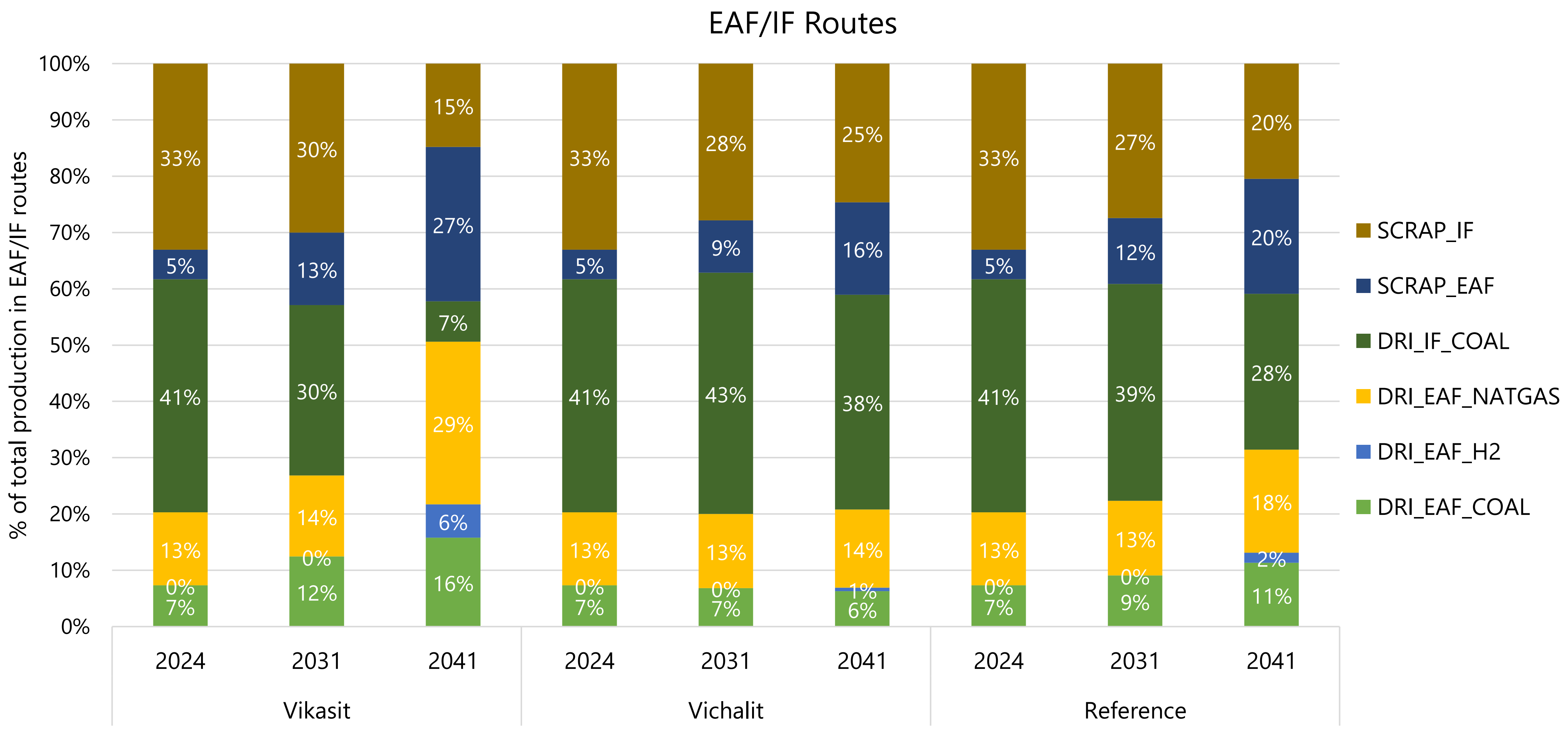
Steel : Comparison of EC demand across scenarios



- Natural gas demand is more than 100% higher than Reference in Vikasit by 2041. In Vichalit, it is 25% lower
- For Green H2, demand is over 300% higher than Reference in Vikasit by 2041. Conversely, in Vichalit, Green H2 demand is 65% lower than Reference

Steel: Decarbonisation in EAF / IF routes

Main decarbonizing levers for DRI-EAF : Green H2, Natural gas and increasing scrap share



Cement

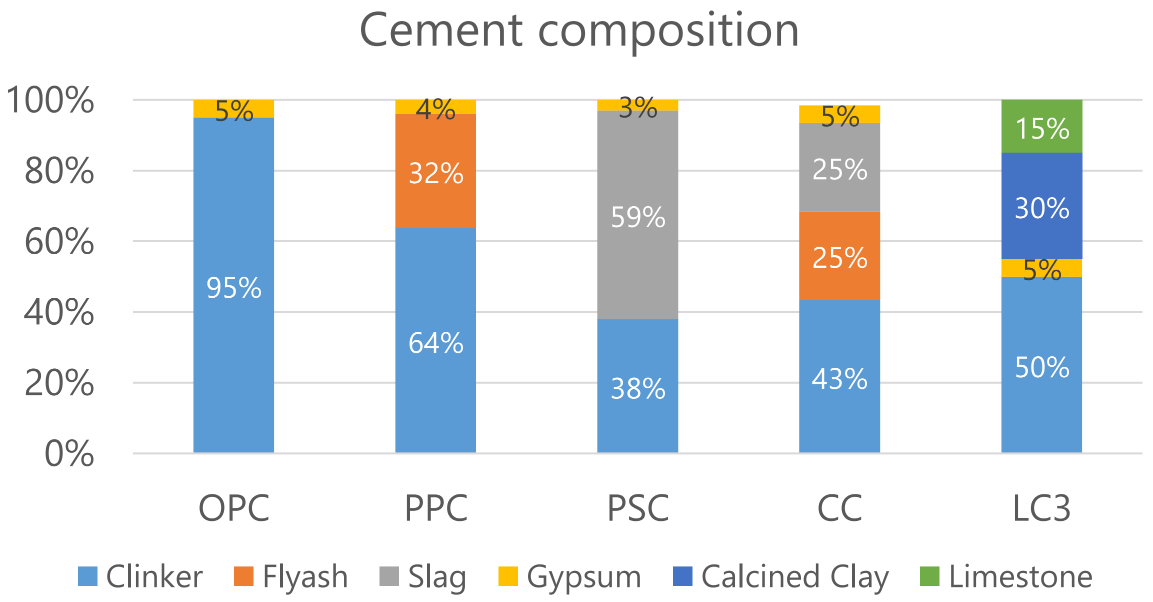
PIER Cement model

- Context
- Cement types, composition and energy use
- Model Structure and Inputs
  - Scenarios
  - Cement demand projection
  - Levers affecting cement energy consumption and emissions
  - Clinker ratio
  - Specific Energy consumption
- Results

Cement model structure : cement types

Cement Types

- **Ordinary Portland Cement (OPC) (~27% production share in 2022)**
- **Blended cements (~73% production share):**
  - Pozzolana Portland cement (PPC)
  - Portland Slag cement (PSC)
  - Composite cement (CC)
  - Limestone Calcined Clay (LC3) cement



Source: Compiled by PEG from various sources

Service Tech Categories	Service Technologies	Energy Carriers
OPC	OPC_NORM / OPC_CCUS	Heat: THERMAL_COAL, PETCOKE,
PPC	PPC_NORM / PPC_CCUS	BIOMASS_WASTE
PSC	PSC_NORM / PSC_CCUS	
CC	CC_NORM	ELECTRICITY
LC3	LC3_NORM	

Energy use in cement production

Raw Material Preparation	Clinker Production	Clinker Grinding
Limestone, chalk or similar sources of calcium carbonate are the primary raw materials for cement	Calcination is decomposition of limestone into lime to produce clinker. Fuel is fired directly into the kiln to reach temperatures of up to 1450°C.	Clinker is ground with other supplementary cementitious materials
30% of Electrical Energy	100% of Thermal and 25% of Electrical	40% of Electrical Energy

Distribution of energy in cement production:

- 80-90% : Thermal energy
- 10-20%: Electrical energy

Clinker production is the most energy intensive stage of cement production, involving high application of heat

- Reduction of clinker for energy reduction
- Waste heat recovery for energy reuse

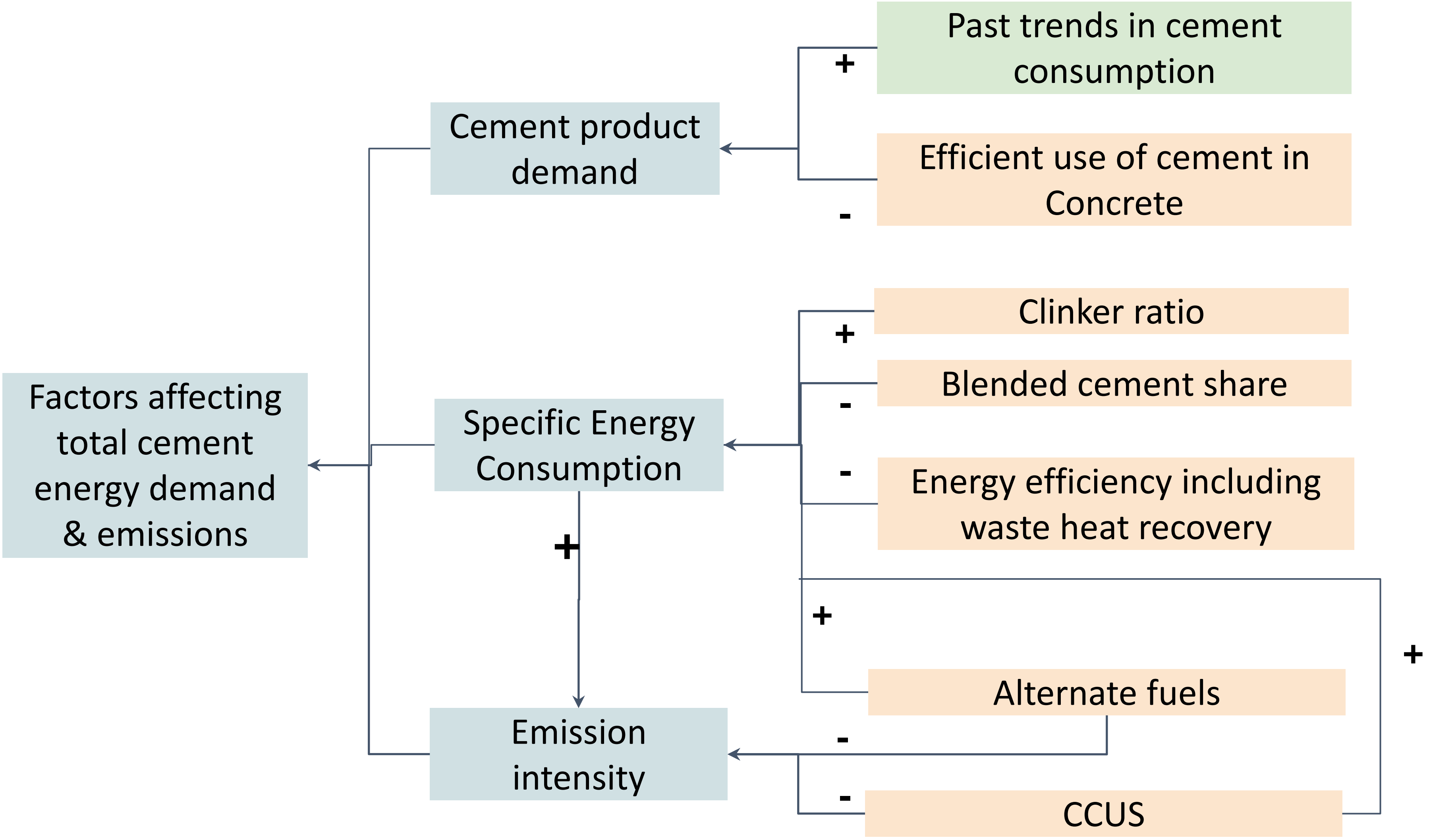
Energy reduction strategies:

- Higher share of blended cement
- Reduction in clinker ratio
- Energy efficiency
- Waste heat recovery

Decarbonisation options:

- Use of alternate fuels (biomass, waste)
- Carbon capture, utilisation and storage (CCUS)

Factors affecting cement energy demand and emissions

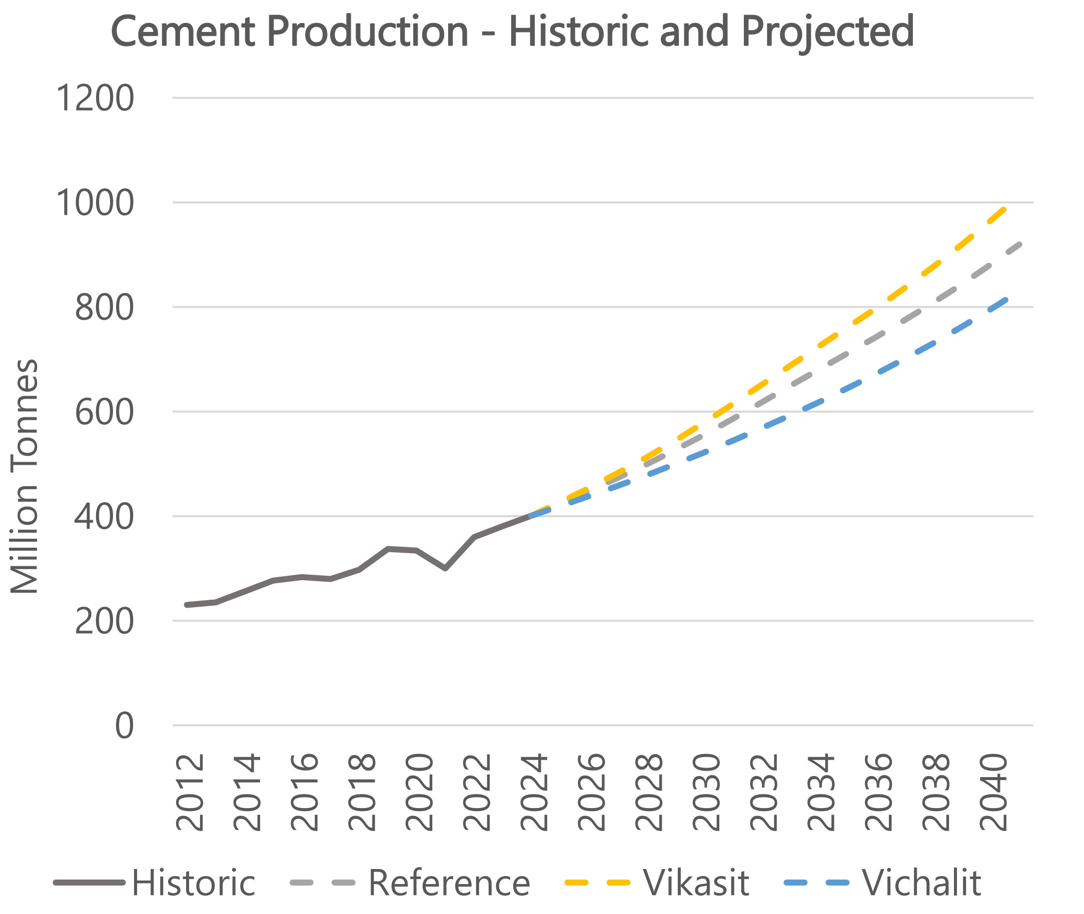


Cement: Scenarios

Scenario	Description
All	Growth rate in production based on elasticity with GDP growth rate. Elasticity same across scenarios, but growth rates vary.
Reference	Elasticity based on past trends and higher weightage to recent trends; Limited efficiency and decarbonisation measures, based on past trends.
Vikasit	Higher share of low carbon/blended cements, reduction in clinker ratio, efficiency improvement and use of alternate raw materials Decarbonization measures gain pace - alternate fuels (biomass_waste), CCUS
Vichalit	Slower reduction in clinker ratio No active measures for decarbonization - slower uptake of biomass, no investments in CCUS in the model period.

Scenarios: Cement production

Year	GDP Elasticity	Assumptions
2014-2024	0.83	Historical elasticity with respect to GDP
2024-2031	0.915 (10% higher than past)	Continued construction and infrastructure expansion
2031-2036	0.89-0.76	Transition to lower elasticity
2036-2041	0.73	Lower demand growth rate due to saturation



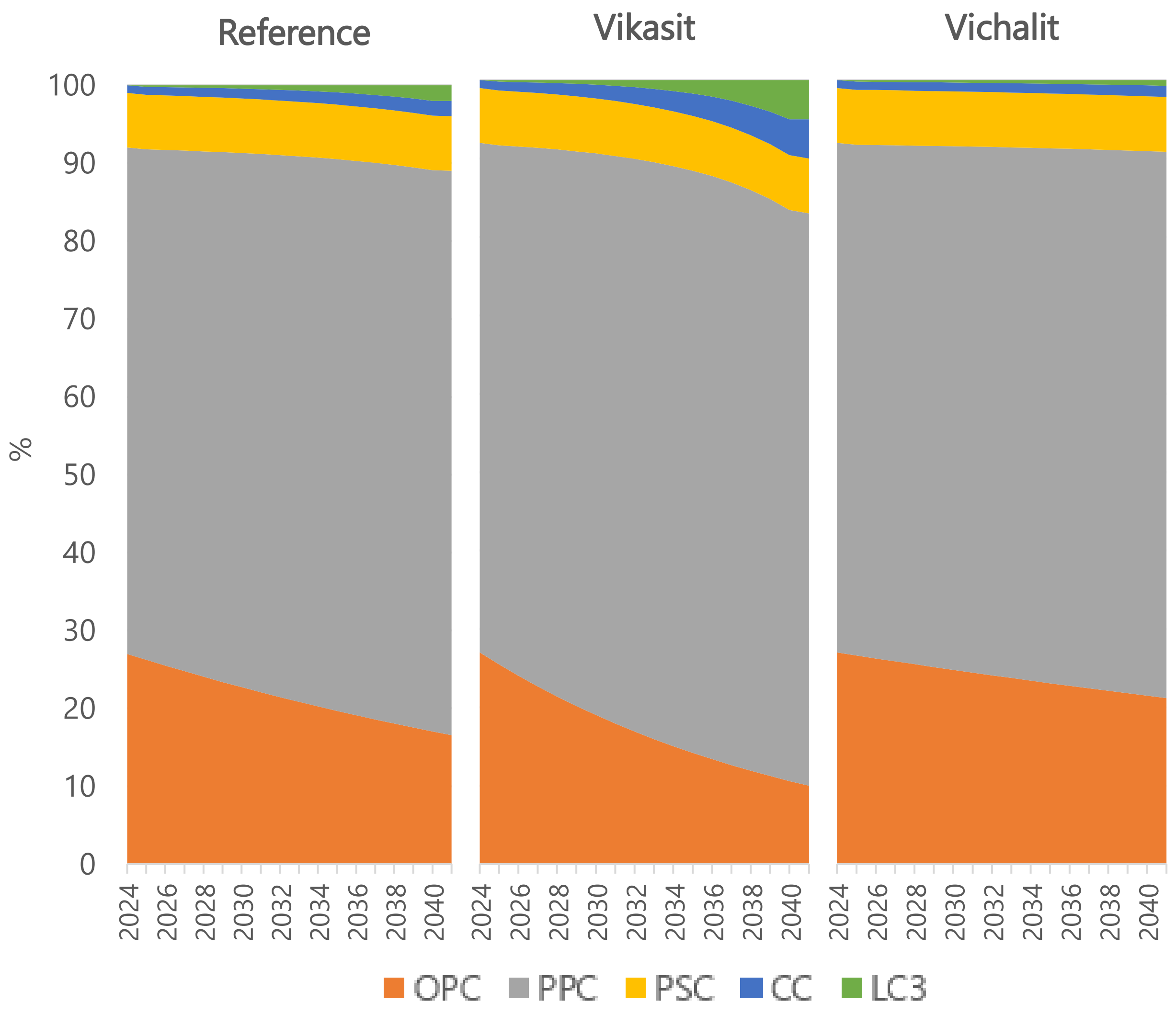
Sources:

Historic production compiled from Indian Mineral Yearbooks

Future year projections from PIER model inputs

Cement: Scenario-wise change in cement type shares

- OPC : Reduction in share due to its higher clinker ratio from 27% in 2024 to 16.5% by 2041 in Reference, 10% in Vikasit, and 21% in Vichalit
- PSC : Share constant at 7%
- CC : Flat growth in the past, share 1% in 2024, and grows marginally to 2% in Reference, to 5% in Vikasit and to 1.4% in Vichalit by 2041
- LC3 : 0% in 2024, grows to 2% in Reference, to 5% in Vikasit and to 0.7% in Vichalit by 2041
- PPC : Difference between total production and sum of (OPC+PSC+CC+LC3). 65% in 2024, increasing to 72.5% in Reference, to 73% in Vikasit and to 70% in Vichalit by 2041



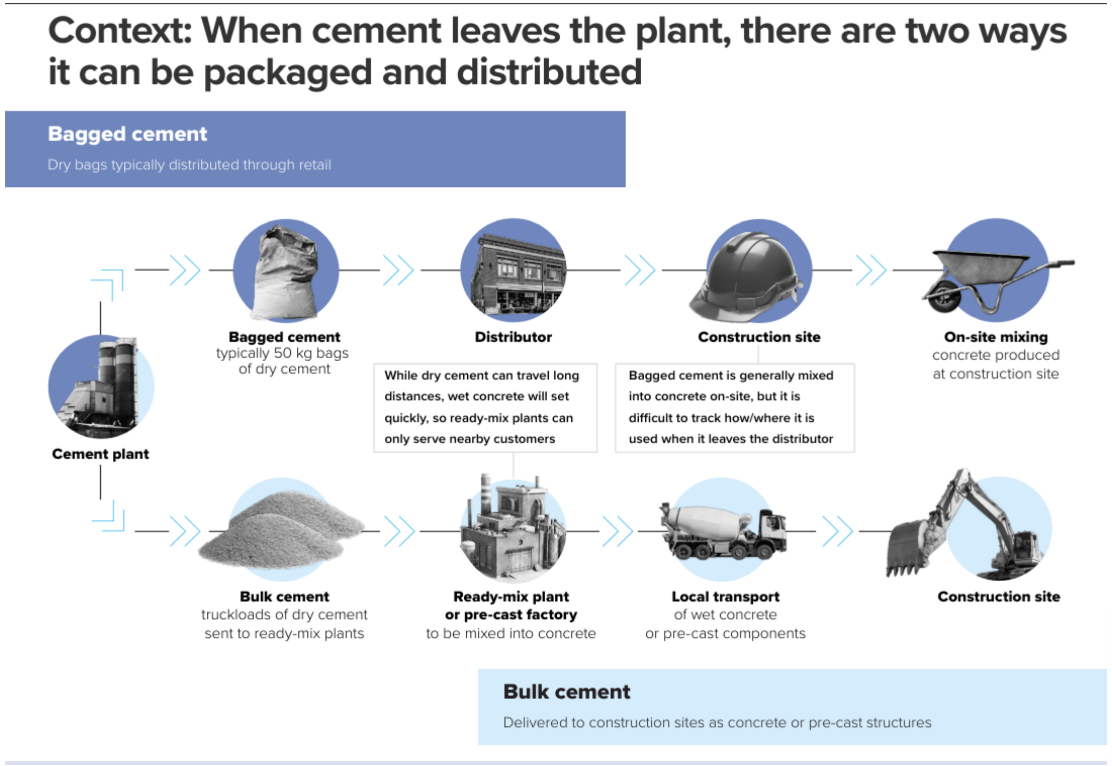
Cement: Changes in clinker ratio over model period

Type	Reference FY41	Vikasit Bharat FY41	Vichalit Bharat FY41
PPC Fly ash proportion	Increases from 31% to 35% (Indian limit in base year)	Increases to 40% (Indian limit assumed to be revised upwards)	Increases to 33%
PSC Slag proportion	Increases from 57% to 64%	Reaches Indian limit of 70%	Increases to 60%
CC Clinker ratio	Reduces from 45% to 40% (halfway to lower bound of BIS standards)	Clinker ratio reduces to 35% (lower bound of BIS standards)	Clinker ratio reduces to 42%

Clinker ratio assumptions across scenarios

Year	Scenario	OPC	PPC	PSC	CC	LC3
2017		95%	65%	40%	45%	
2041	Reference	95%	61%	34%	40%	50%
	Vikasit	95%	56%	27%	35%	50%
	Vichalit	95%	63%	37%	42%	50%

Cement: Efficient use of cement in concrete

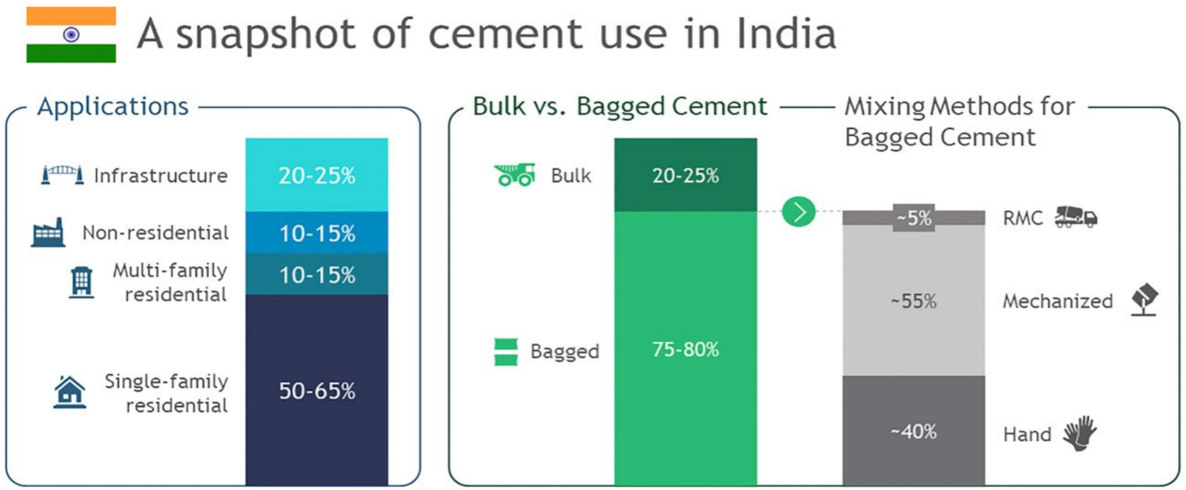


Source: BCG, Paving the Way for a Better Future: Cement Decarbonization in Emerging Markets

A shift from bag to bulk cement reduces cement wastage by 30%.

Assumptions made in PIER

Current share of bulk cement	23%
Bulk cement in Reference 2041	30%
Vikasit scenario	50%
Vichalit scenario	25%



Source: https://www.weforum.org/stories/2022/12/here-s-how-india-cement-net-zero/

Cement: Thermal specific energy consumption (SEC)

- Step 1: Calculation of thermal SEC (kcal/kg cement) for all types of cement
- Step 2: Add the incremental energy consumption caused due to AFR (& CCUS)
- Calculated based on the clinker factor of each cement type as thermal energy is used only in clinkerization. (Assuming 740 kcal/kg of clinker)

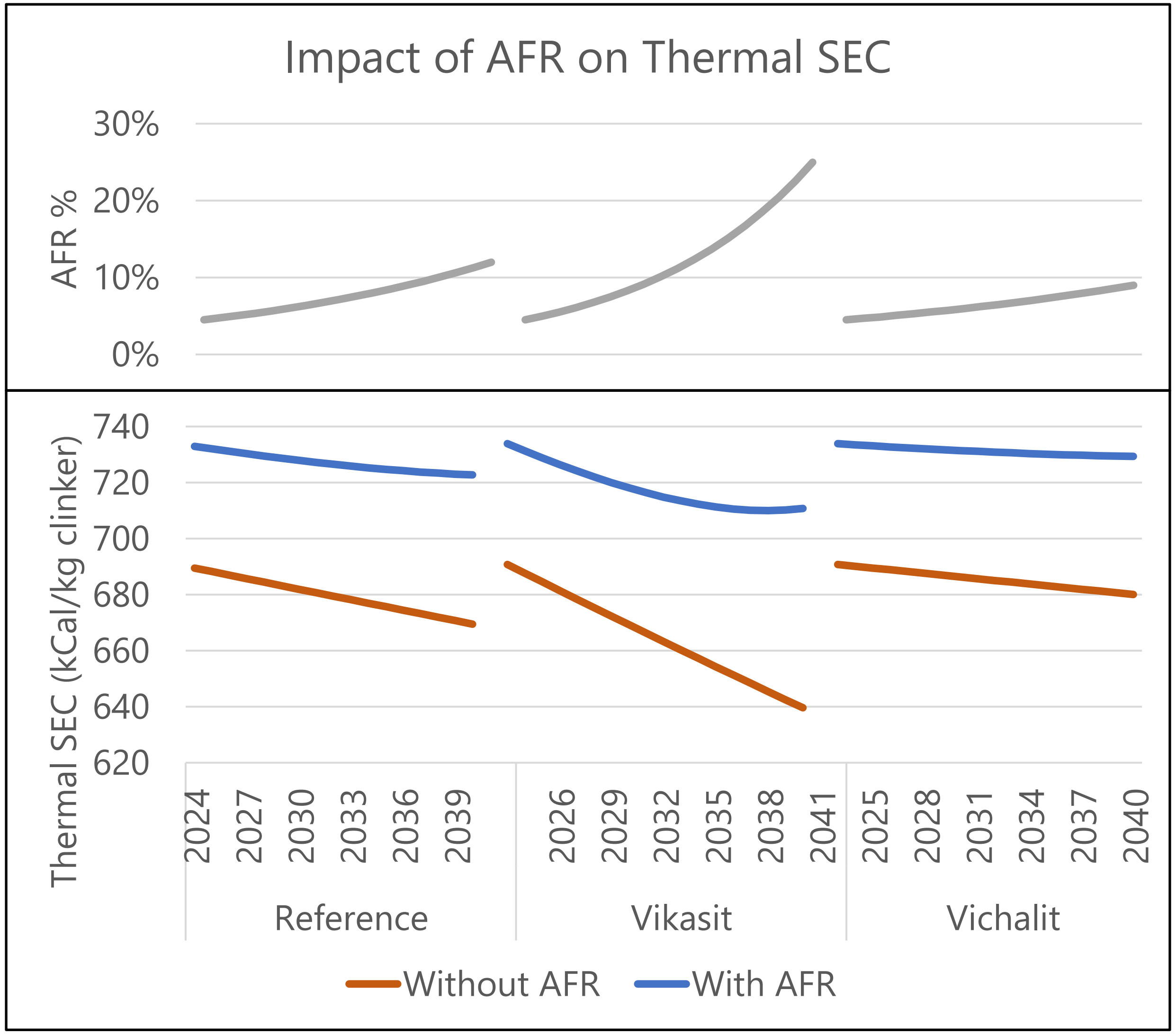
Thermal SEC	OPC	PPC	PSC	CC
Typical Clinker ratio	95%	65%	41%	45%
Thermal SEC in kcal/kg cement	703	481	303.4	333

Scenario	Thermal SEC improvement
Reference	Historical rate of improvement (CMA, 2021)
Vikasit	India’s best by 2041 (680 kCal/kg of clinker)
Vichalit	Half of Reference improvement rate

Cement: Thermal SEC and Impact of AFR

- Share of AFR in 2024 is 4%, and this is assumed to increase over time given past trends
- For every 1% increase in alternative fuels and raw materials (AFR), thermal SEC increases by 1.5 Kcal/kg of clinker to account for the lower energy content of AFR and pre-processing needed

AFR share	AFR Share 2041
Reference	12%
Vikasit	25%
Vichalit	9%



Cement: Electrical Specific Energy Consumption (SEC)

- Step 1: Calculation of Electrical SEC for all types of cement across scenarios
- Step 2: Add the incremental energy consumption caused due to CCUS
- Step 3: Subtract the energy saved through Waste Heat Recovery

Elec SEC (kWh/t)	2022	2031	2041	SEC Improvement	Basis
Reference	80.0	76.1	72.4	-0.5%	Historical trend
Vikasit	80.0	71.3	65.0	-1.1%	Global best
Vichalit	80.0	78.3	76.0	-0.25%	Half of Reference

Source: CMA 2021; TERI 2018; NPC 2017

Carbon Capture Use and Storage (CCUS) potential

- CCUS has potential to capture 90% of the emitted CO_2
- CCUS proportions are determined based on clinker proportions
- Additional electricity per tonne of CO_2 captured - 630 KWh/ tCO_2

CCUS share	2041
Reference	2%
Vikasit	5%
Vichalit	0%

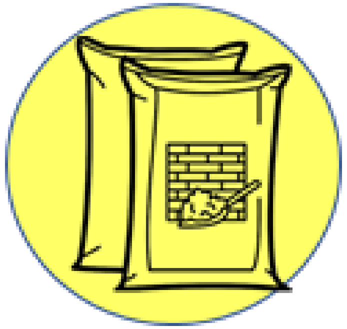
Cement: Waste Heat Recovery (WHR)

WHR potential per tonne clinker - 4 MW/ MT clinker
Source: CII 2009

Year	Installed capacity (MW)	Potential (in MW)	% of potential tapped
2021	538	1100	49%
Source: CMA 2021			

WHR (in MW)	Reference	Vikasit	Vichalit
2041	1414	2059	1122

- WHR tapped potential in 2041
  - Reference – 60%
  - Vikasit – 90%
  - Vichalit – 50%
- WHR savings are split across cement types based on cement type-wise clinker proportions
- WHR savings subtracted from Electrical SEC across years



Cement Model Results

Energy demand across scenarios

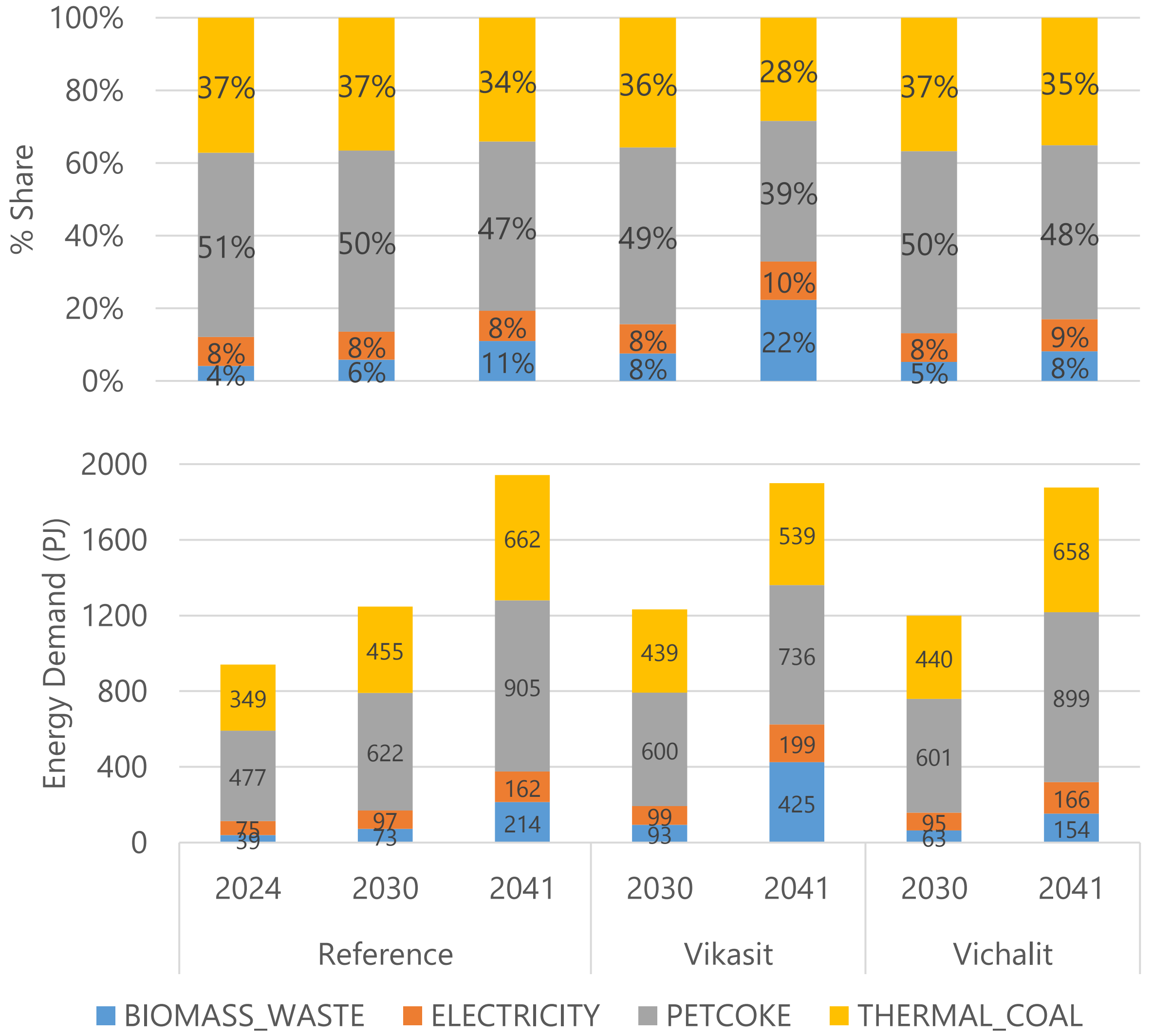
Coal and Petcoke:

Fossil fuel demand lower in Vikasit compared to Reference in spite of higher cement production due to cumulative effect of the following:

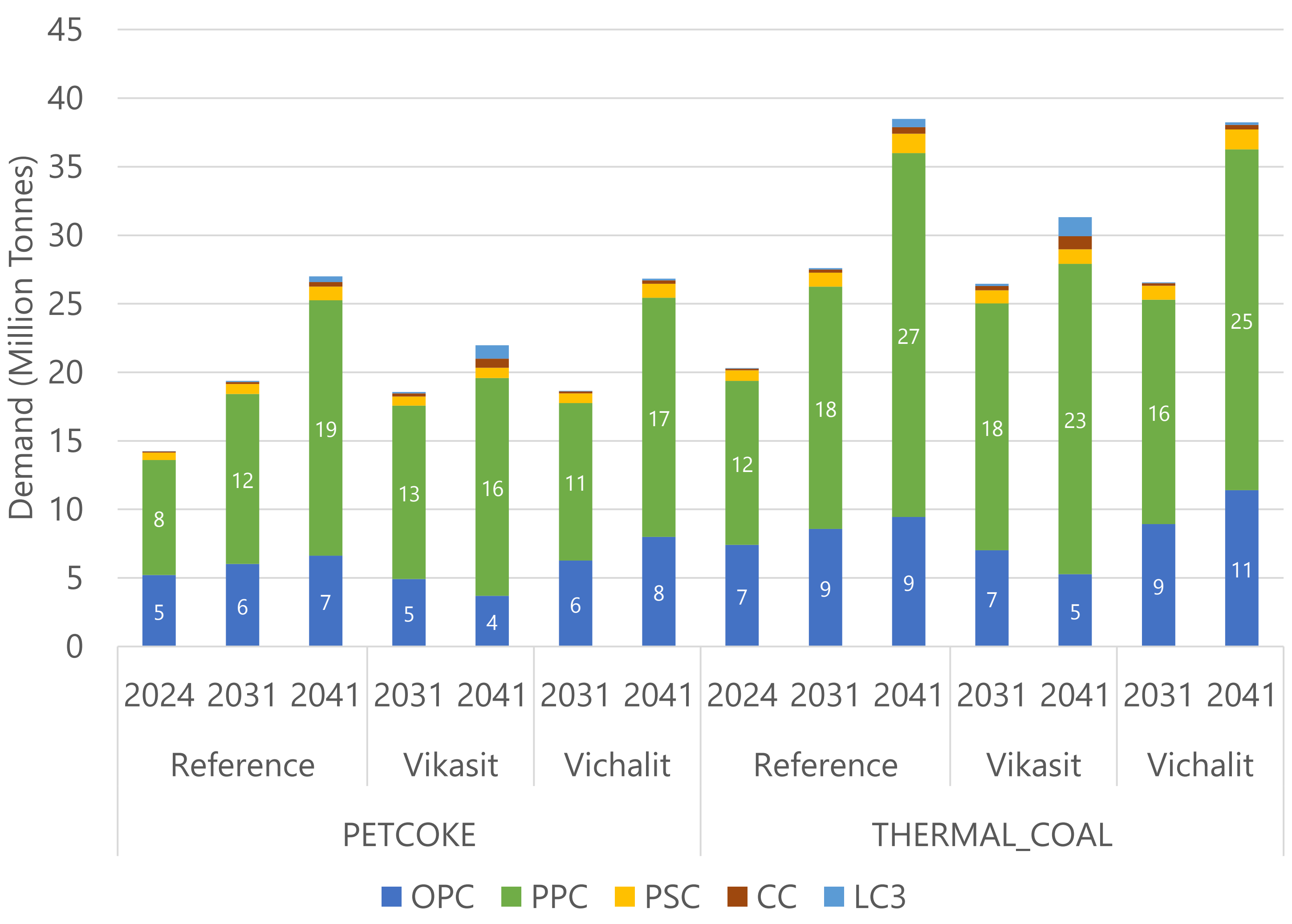
- Energy efficiency measures
- Higher use of AFR in Vikasit
- Higher use of blended cements

Electricity :

Significant rise in electricity demand post 2035 is due to the uptake of CCUS.

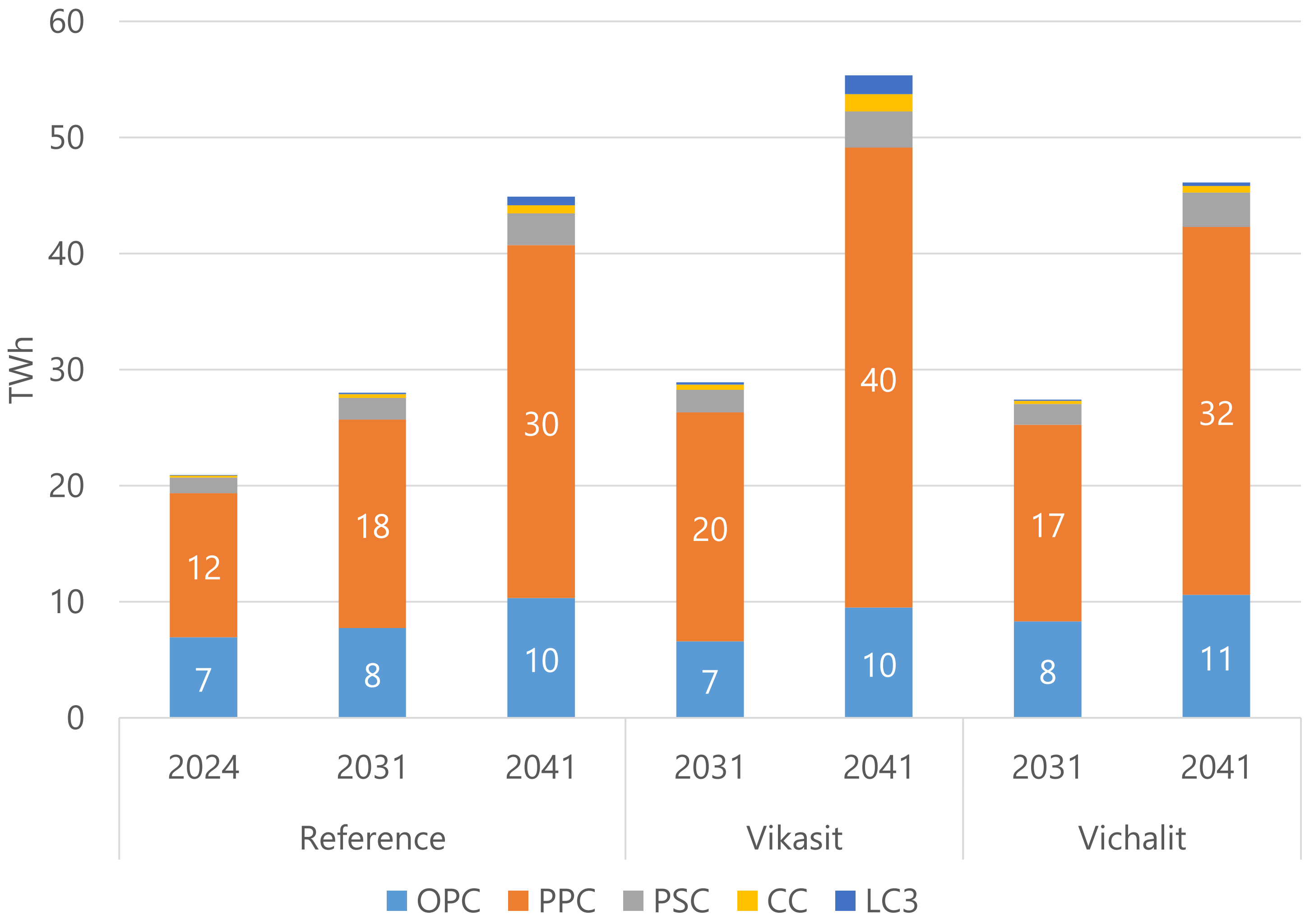


Cement: Coal and Petcoke demand (MT) across scenarios



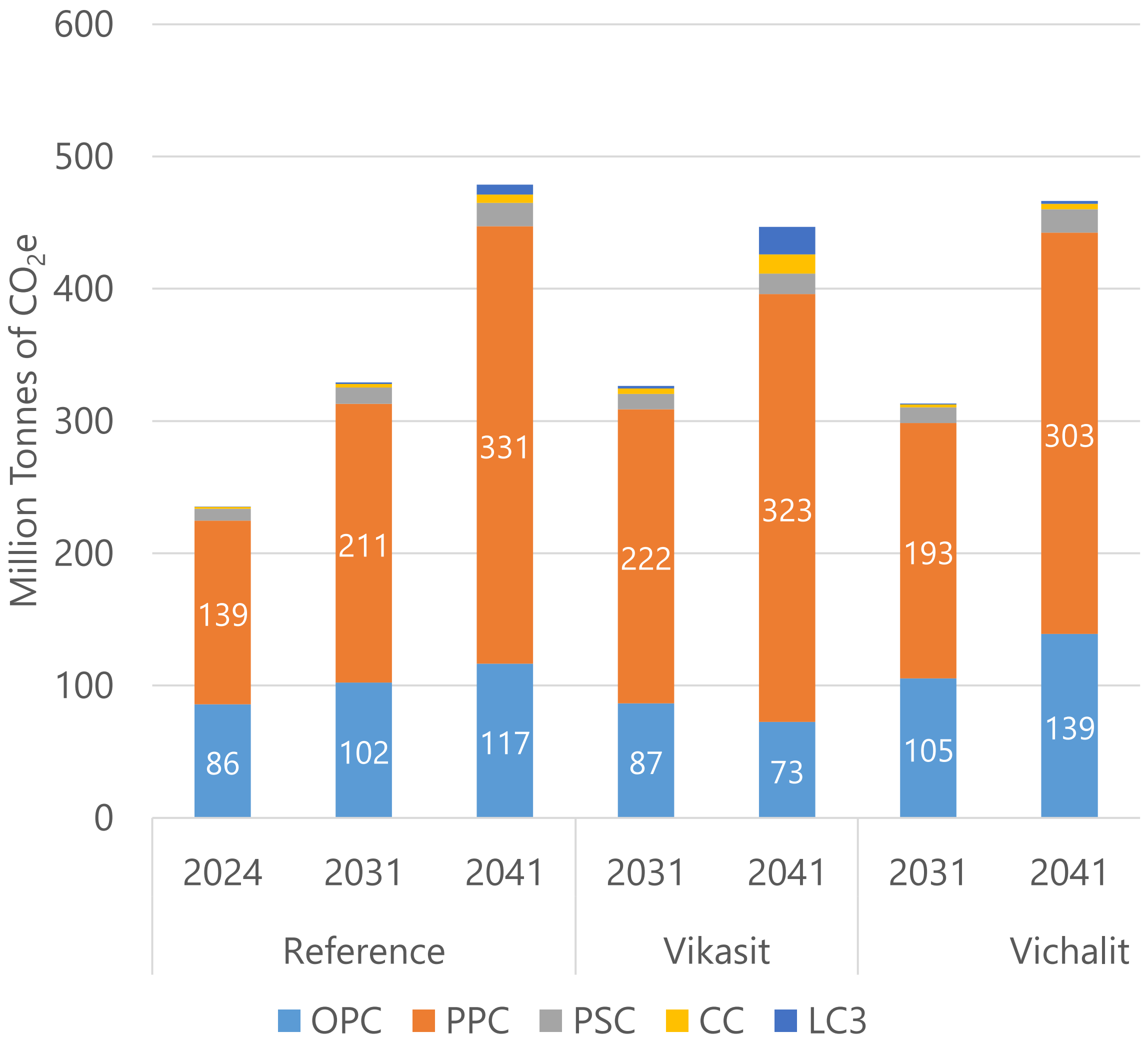
- Significant reduction in demand for coal and petcoke in Vikasit scenario by 2041 due to improved efficiency and switch to AFR
- Conversely, demand remains the same as Reference in Vichalit scenario despite lower production
- Dominant energy use in OPC and PPC production in line with their production shares

Cement: Electricity demand (TWh) across scenarios



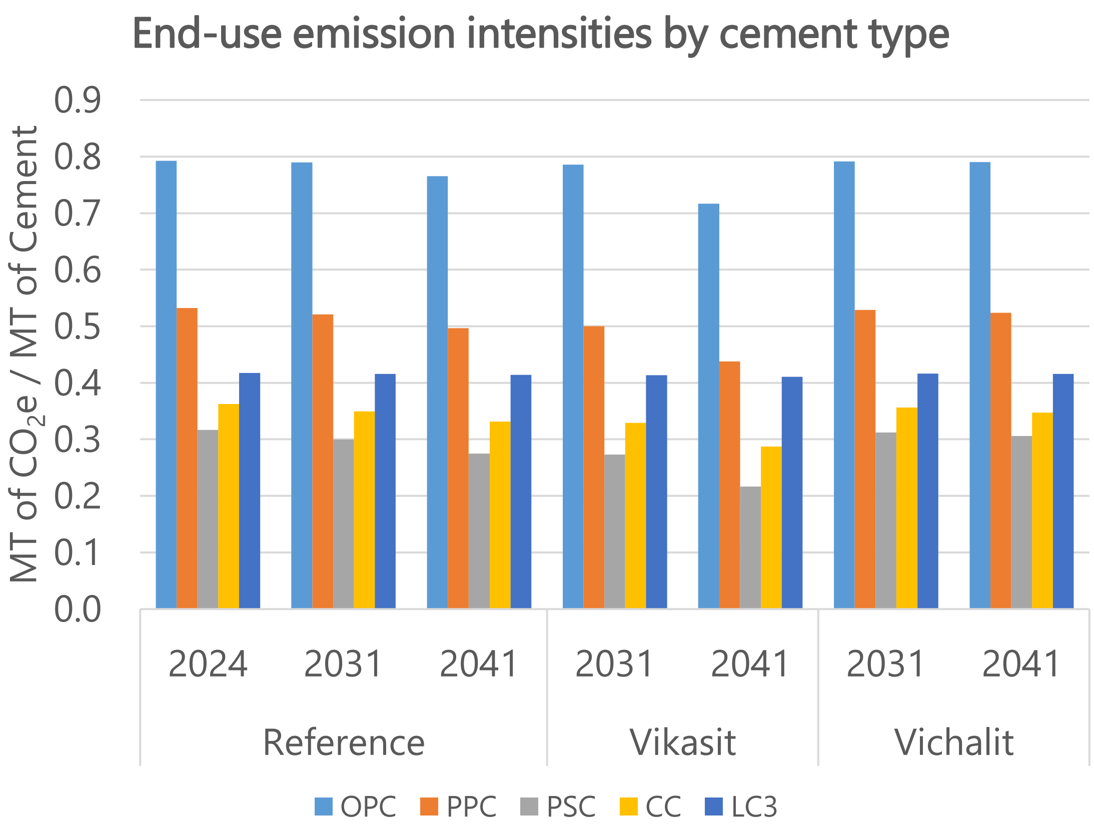
- Electricity demand grows over the years in Reference and Vikasit scenarios, but not as fast as production, due to efficiency improvements and waste heat recovery
- However, when CCUS is introduced in the 2030s, electricity demand grows in a significant manner

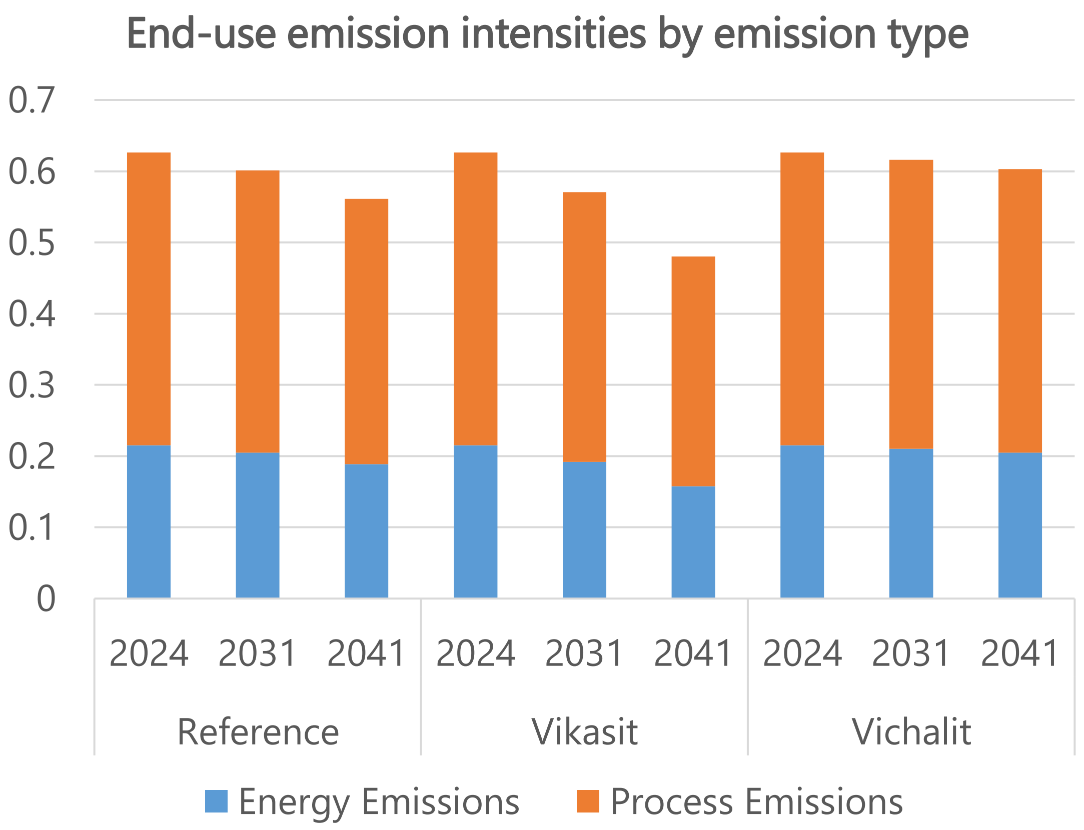
Cement: End-use emissions across scenarios



- End-use emissions are lower in Vikasit scenario than Reference due to
  - Higher use of blended cement and lower clinker ratio
  - Higher use of AFR
  - Higher CCUS penetrations in 2041

Cement: End-use emission intensities





- Blended cements play an important role in reducing the emissions intensity
- Process (non-energy) emissions are significant (>50%) in cement production
- CCUS only option to mitigate process emissions

Aluminium

PIER Aluminium model

1. Context – Drivers and production process
2. Model Inputs and Assumptions
   - Production and Technology
   - Fuels and Specific Energy Consumption (SEC)
   - Key differences across scenarios
3. Results and Insights

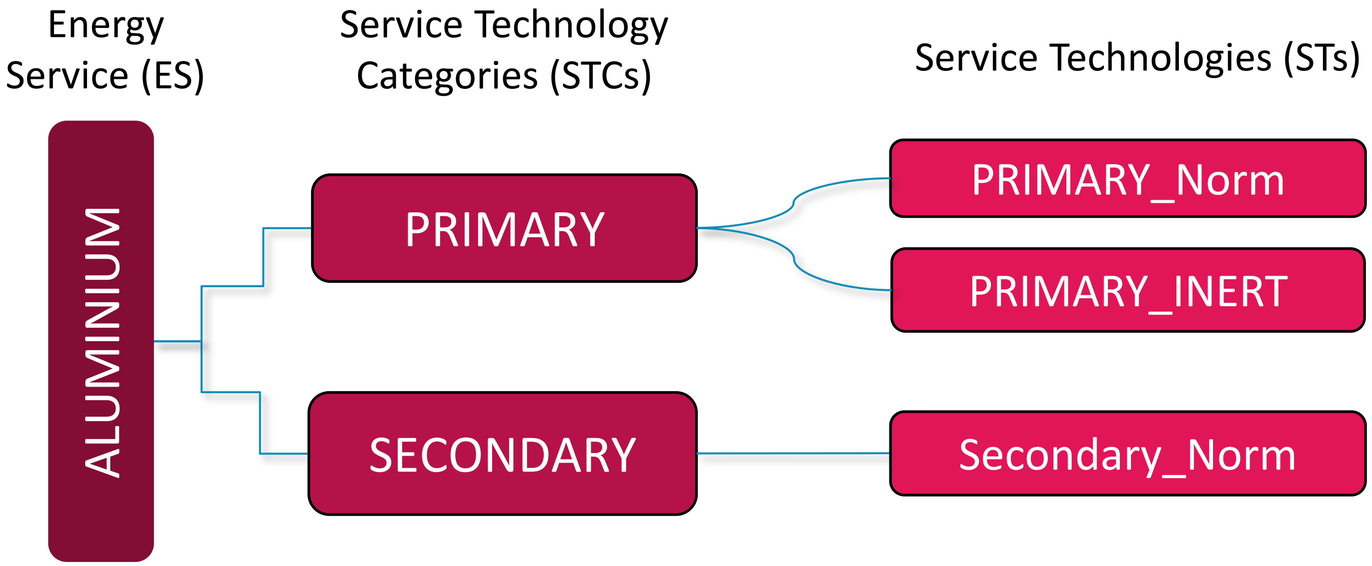
Drivers of energy demand in the Aluminium industry

- Drivers for energy demand are Aluminium production and specific energy consumption (SEC – determined by efficiency measures)
- Aluminium production growth rate is projected based on elasticity with GDP growth rate, which changes across scenarios
- Primary and Secondary Aluminium production are projected separately
- Secondary Aluminium production involves recycling of used Aluminium, and is an important decarbonizing lever due to significantly lower energy requirement
- Most scrap processing is in the informal sector, and secondary Aluminium production happens largely in the smaller units (MSME)
- Scrap imports are a key driver for growth in secondary Aluminium production
- For detailed understanding of Assumptions, please check Appendix and the source workbook (IND_Aluminium_Energy Demand.xlsx) located at: Default Data\Demand\Source\D_IND).

Energy use in Aluminium production

PRIMARY ALUMINIUM PRODUCTION

REFINERY BAUXITE → ALUMINA	SMELTING ALUMINA → ALUMINIUM
Refinery (Bayer) process involves conversion of Bauxite to Alumina, where thermal energy is required	Smelting involves use of electricity for electrolysis (Hall-Heroult) process to extract Aluminium



Service Technologies (STs)

- **PRIMARY_Norm**: Refining Bauxite ore + electrolysis with carbon anodes to obtain Aluminium
- **PRIMARY_INERT**: Same process as PRIMARY_Norm, but using inert anode to reduce CO_2 emissions
- **SECONDARY_Norm**: remelting and refining of Aluminium Scrap

Aluminium: Production and Technology Assumptions

Production Assumptions

- Elasticity for Primary Aluminium production is constant across scenarios. Since GDP growth rate varies across scenarios, production also varies.
- Elasticity for Secondary Aluminium production changes based on expected decarbonisation across scenarios
- Per-capita aluminium consumption of 2 kg in 2024 increases to 10.5 kg in Reference scenario, to 12.8 kg (world average in 2024) in Vikasit, and to 8.7 kg in Vichalit by 2041

Technology Assumptions

- Inert anode assumed post 2035 by when it is assumed to be commercially viable. Additional energy needed considered for inert anode based on literature.

Source: CRISIL 2022; CEEW 2024

Aluminium: Fuels and Specific Energy Consumption (SEC)

Fuel Assumptions

- Thermal coal is a key fuel for Primary Aluminium production. Natural gas is assumed to replace coal after 2035 to aid decarbonisation
- Fuel for Secondary Aluminium production is assumed to be Furnace Oil (considered as PP_OTHER- i.e. other petroleum products)

Specific Energy Consumption (SEC) Assumptions

- Legacy Primary Aluminium plants are assumed to undergo moderate SEC improvement over the model period.
- SEC for Secondary Aluminium assumed to be 10% of Primary Aluminium SEC
- New capacity post-2024 assumed to have improved SEC, but maintain the same SEC for the rest of the model period without further enhancements.
- Fleet-level SEC remains above the global best (or technical minimum efficiency)
- For secondary Aluminium production, SEC improvement is assumed across the fleet

Source: CRISIL 2022; CEEW 2024

Key differences in inputs across scenarios

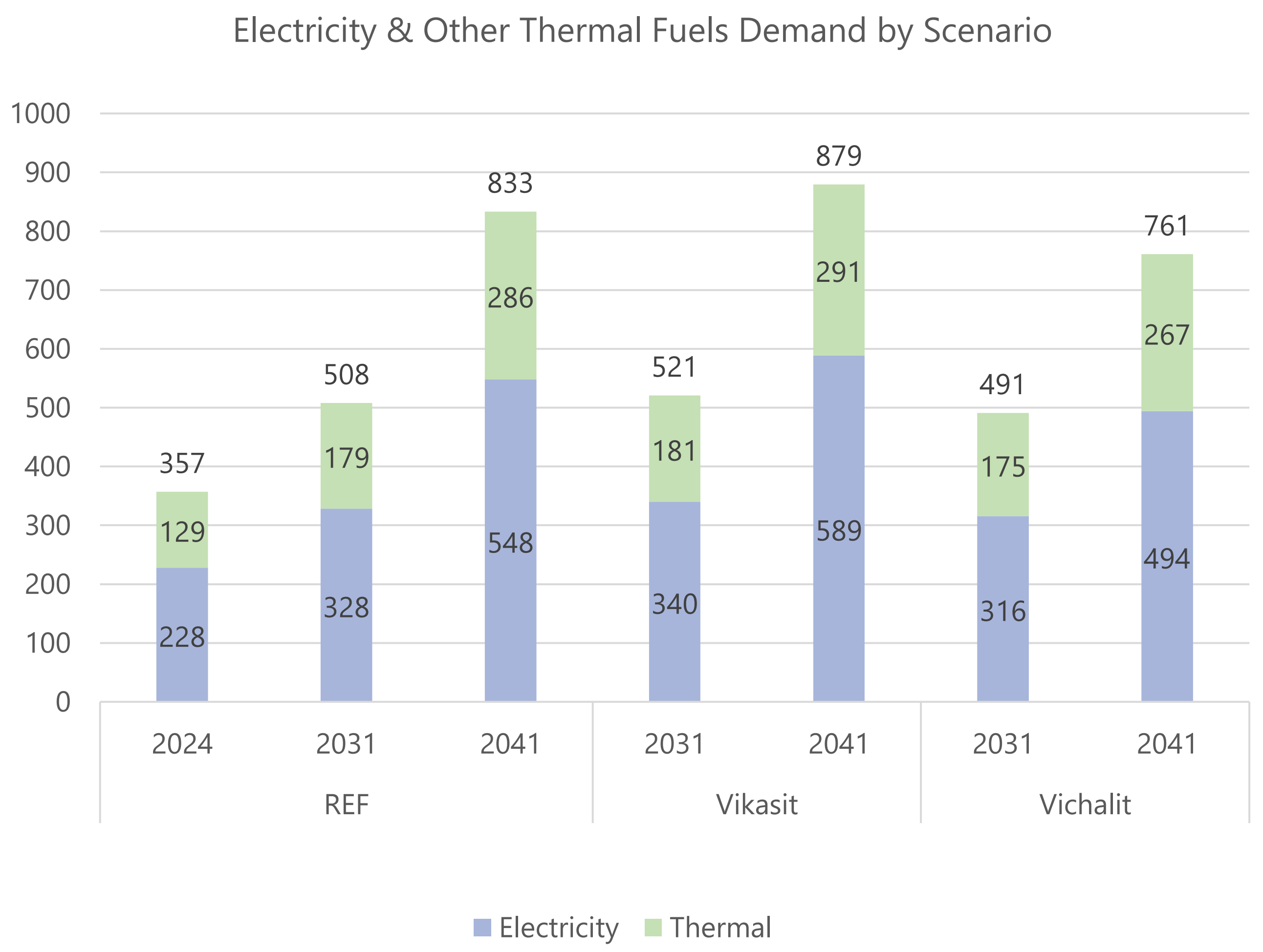
Parameters	Reference (REF)	Vikasit Bharat	Vichalit Bharat
GDP Elasticity	Primary (0.90) Secondary (1.20)	Primary (0.90) Secondary (1.40)	Primary (0.90) Secondary (1.0)
Aluminium production (in MT) in 2041	16.4	20.0	13.7
2041 Share of primary production technologies	Primary_Norm (95%) Primary_INERT (5%)	Primary_Norm (90%) Primary_INERT (10%)	Primary_Norm (97.5%) Primary_INERT (2.5%)
Share of thermal energy fuels in primary production	Coal (90%) Natural gas (10%)	Coal (85%) Natural gas (15%)	Coal (95%) Natural gas (5%)
SEC Improvement	Medium	High	Low

Source: BEE 2015; BEE 2018; CEEW 2024

Aluminium : Results & Insights

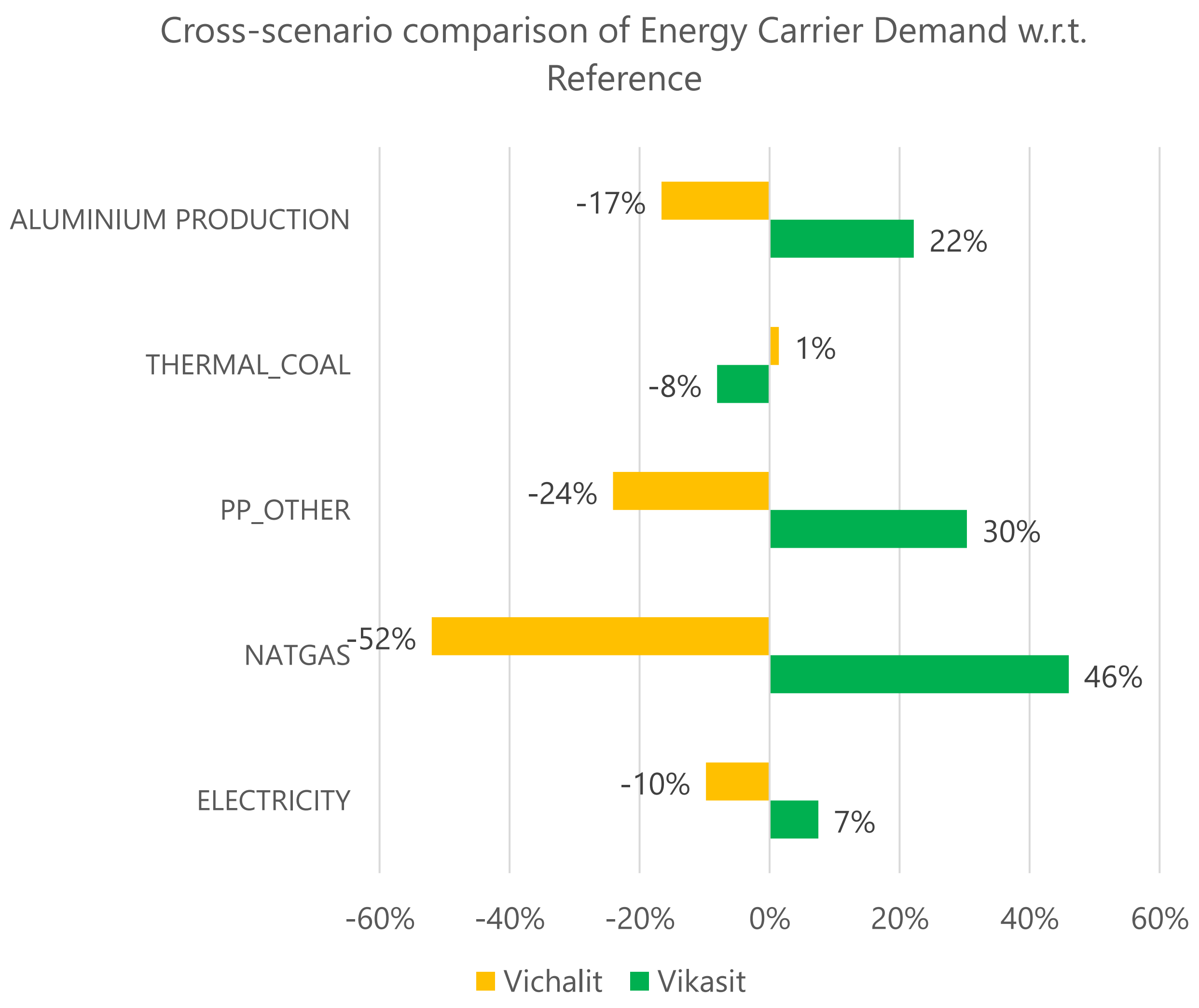
Aluminium - EC wise Energy Demand

- Electricity retains around 2/3rd share in overall energy demand in aluminium production across all scenarios
- Overall energy demand in Vikasit is 879 PJ which is just 6% higher than Reference (833 PJ), though the production is 22% higher in 2041 (refer slide 64)

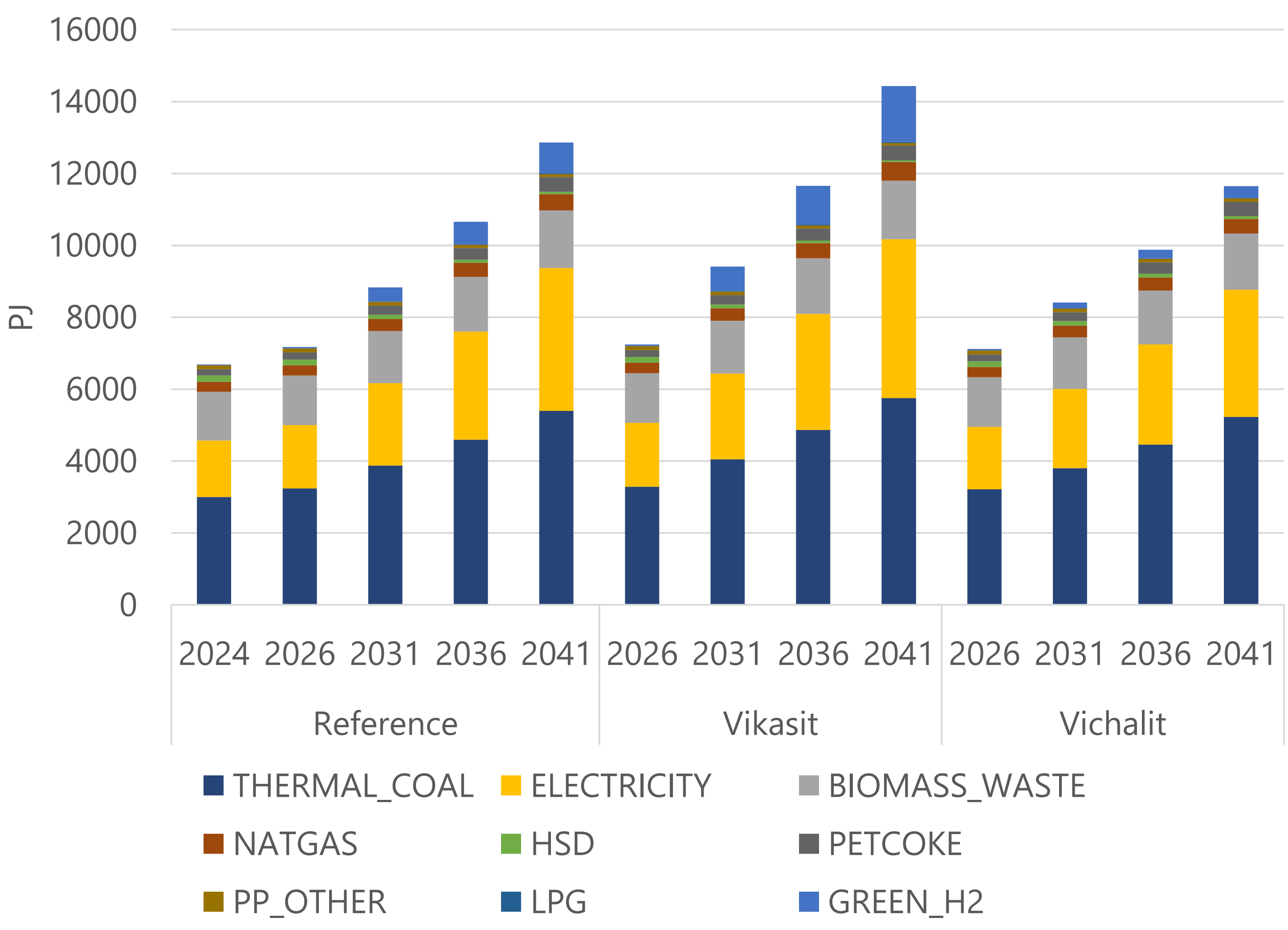


Comparison of EC Demand across scenarios

- Aluminium production is 22% higher than Reference in Vikasit and 17% lower in Vichalit for FY41
- However, thermal coal demand falls by 8% in Vikasit while Natural gas demand increases by 46% by 2041 due to better efficiency improvement and use of gas as an intermediate decarbonising lever
- In Vichalit, thermal coal demand is higher by 1% and Natural gas demand is lower by 52%.
- Electricity is 7% higher in Vikasit and 10% lower in Vichalit



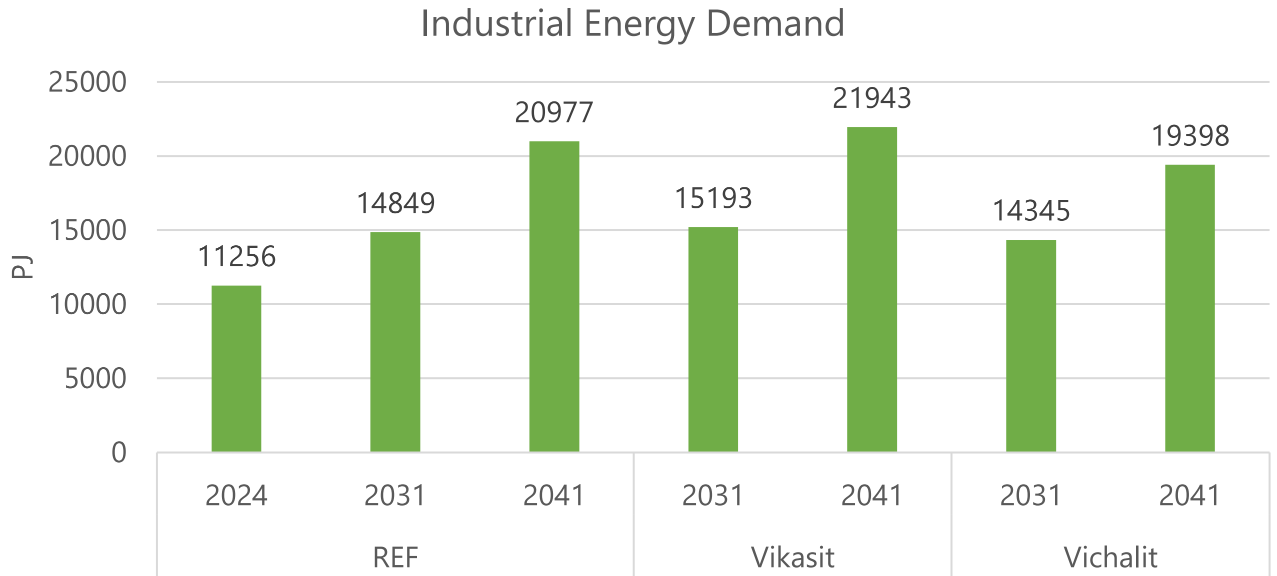
IND_OTHERS: Estimated energy carrier demand over the years

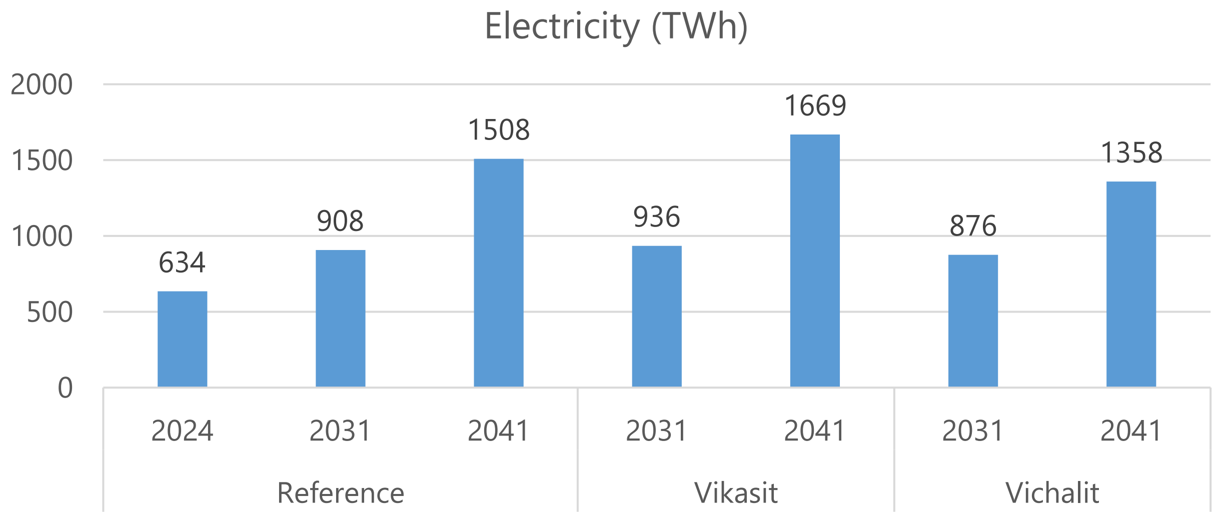


- Energy demand from industries other than Steel, Cement and Aluminium is estimated in a top down manner using GDP elasticity
- Coal, Electricity and Biomass+Waste serve majority of the energy needs
- Green H2 demand, mainly as feedstock for fertilizer production and refineries, plays a prominent role in 2030s in Vikasit

Overall Industry - Results & Insights

Industry : Overall Energy & Electricity demand

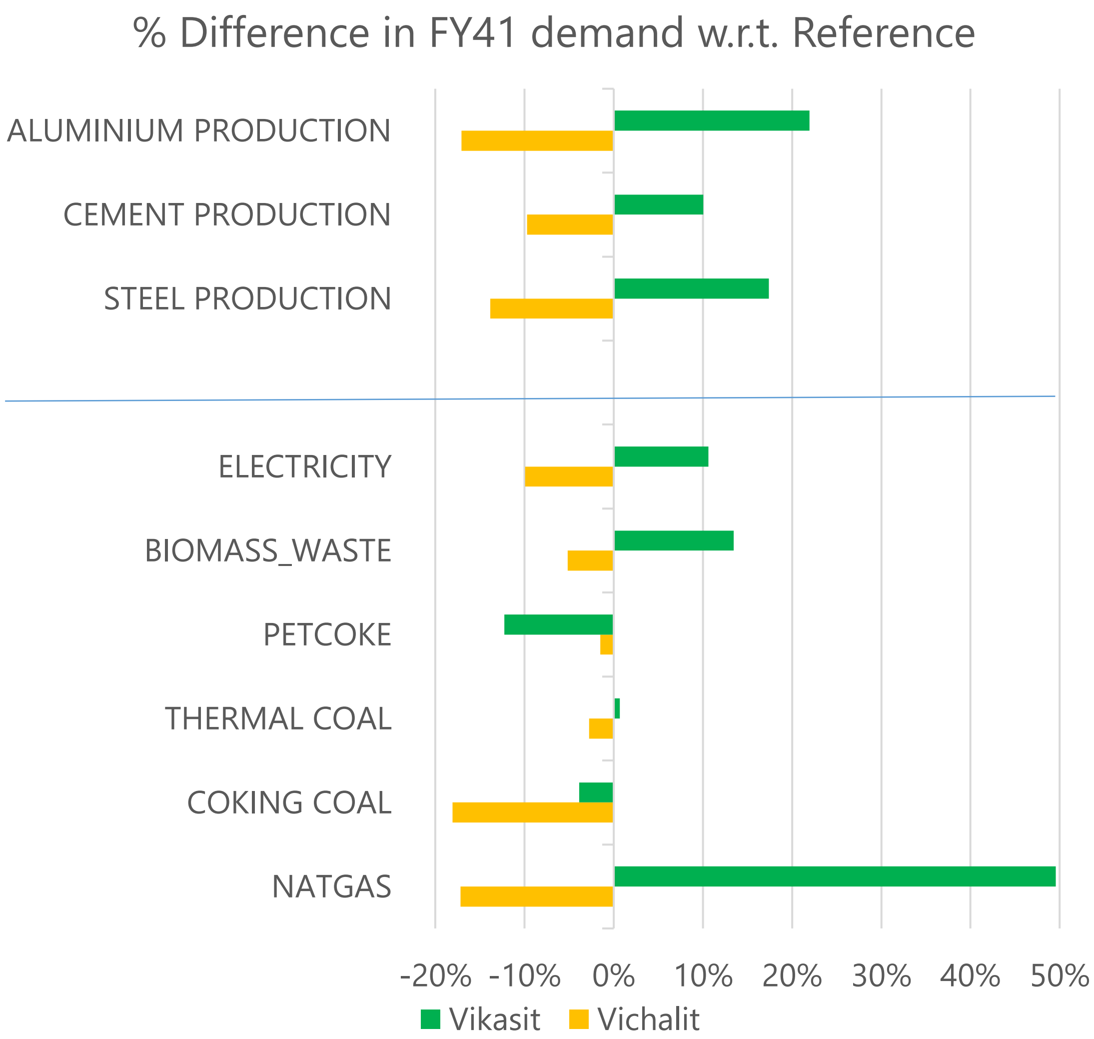




- Industry energy demand grows at 3.7% from 11256 PJ in 2024 to 20977 PJ in 2041 (Reference)
- Vikasit demand grows at 4% to 21943 PJ.
- Growth is slower at 3% in Vichalit to 19398 PJ.

- Electricity demand grows at over 5% from 634 TWh in 2024 to 1508 TWh by 2041 in Reference.
- In Vikasit demand is 11% higher at 1669 TWh while it is 10% lower at 1358 TWh in Vichalit.

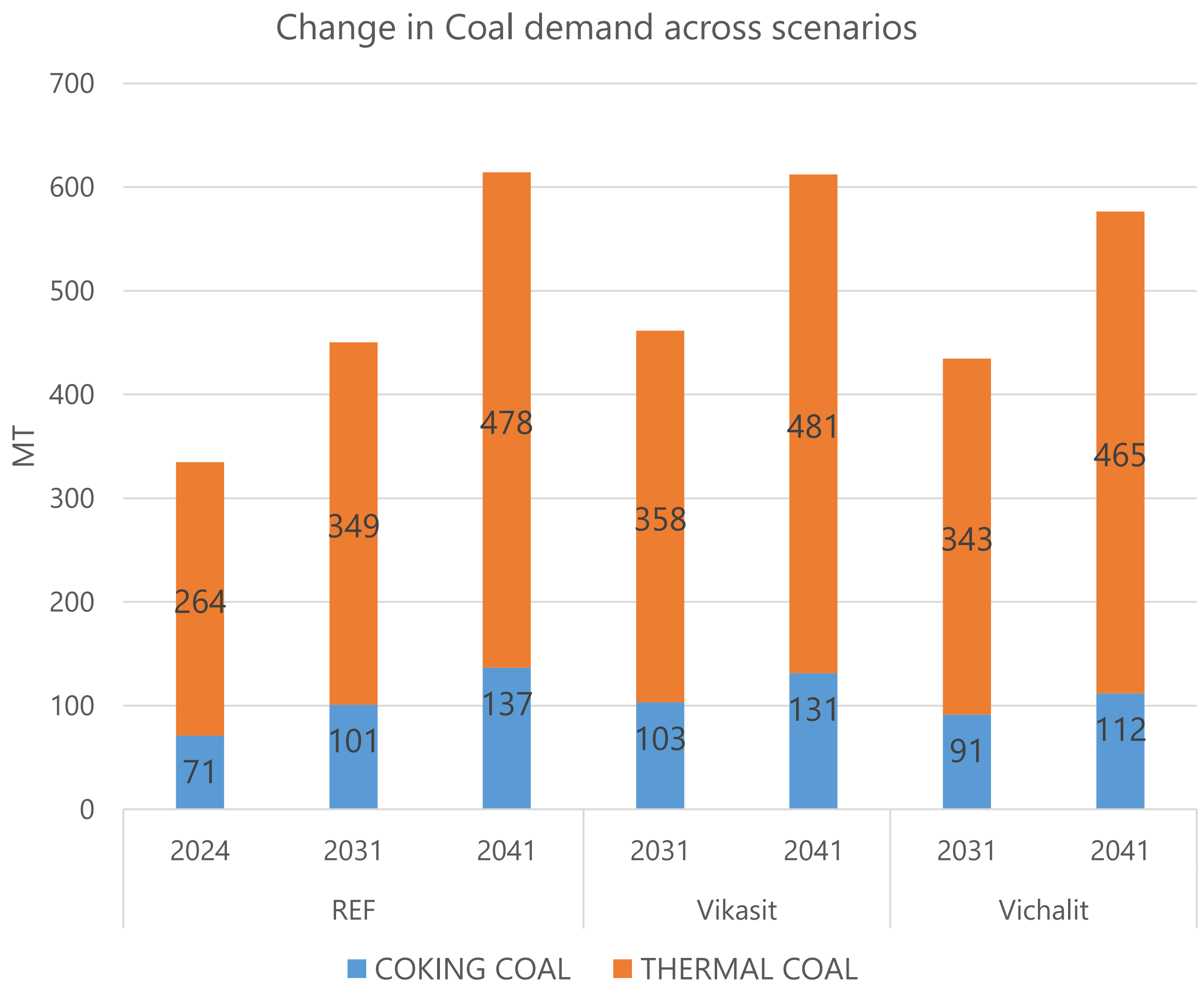
Cross-scenario comparison of service vs EC demand



- Despite 17% more steel, 10% more cement & 22% more aluminium produced in Vikasit w.r.t. Reference in 2041,
  - Coking coal demand *reduces by 4%*
  - Thermal coal increases by just 0.7%
  - Petcoke demand is less by 12%, while Biomass-waste (AFR) is 13% higher
  - Natural gas demand is up 50%
  - Electricity increases by 11%

  This is on account of better efficiencies & greater decarbonisation uptake
- In Vichalit, steel, cement & aluminium production is 14%, 10% & 17% lower than Reference respectively. However,
  - Coking coal is 18% lower, thermal coal 3% & electricity is 10% lower than Reference
  - Petcoke is 2% & biomass_waste is 5% lower
  - Natural gas demand 17% lower

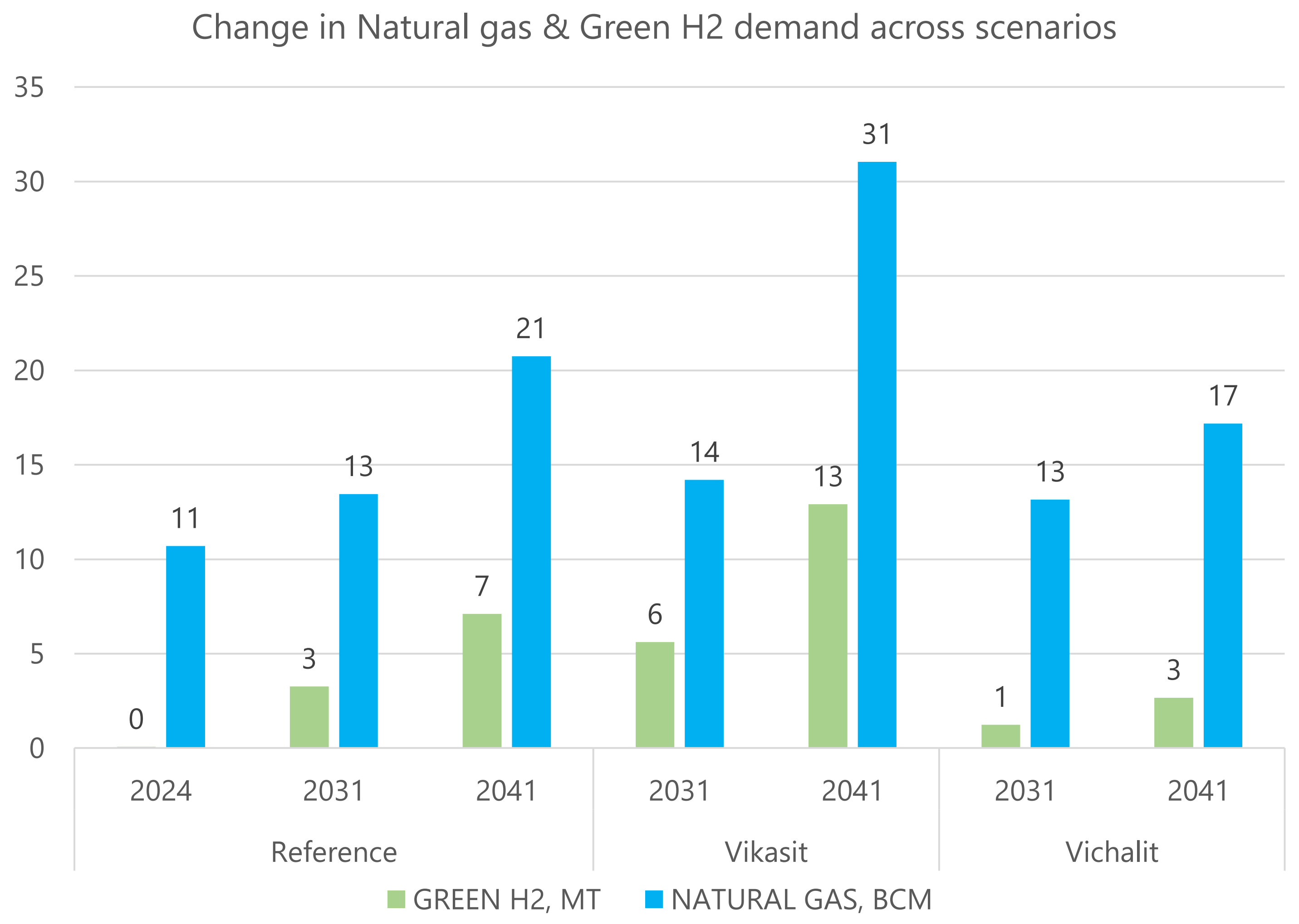
Industry: Coal demand across scenarios



- Coking coal demand grows at 4% from 71 MT(#) in 2024 to 137 MT in 2041 in REF & 131 MT in Vikasit. In Vichalit growth is slower at 3% to 112 MT.
- Thermal coal demand increases at 4% from 264MT to 478MT in 2041 (REF) & 481 MT in Vikasit. In Vichalit, it grows to 465 MT at 3% p.a.

Weighted GCV of coking coal – 5608 Kcal/kg

Industry: Natural gas & Green hydrogen demand



- Natural gas demand nearly doubles from 11BCM in 2024 to 21 BCM in Reference & nearly triples to 31 BCM in Vikasit by 2041. It increases to 17BCM in Vichalit.
- Green H2 demand increases from 0 to 7 MT in REF & 13 MT in Vikasit by 2041. Vichalit demand is 3 MT.

Conclusions

Industry: Conclusions

- Despite 17% more steel, 10% more cement & 22% more aluminium produced in Vikasit than Reference in 2041,
  - Coking coal demand *reduces by 4%*
  - Thermal coal increases by just 0.7%
  - Petcoke demand is less by 12%, while Biomass-waste (AFR) is 13% higher
  - Natural gas demand is up 50%

  This is due to better efficiency improvement and higher decarbonisation uptake
- Blended cements and use of AFR play an important role in reducing the emissions intensity
- Process (non-energy) emissions are significant (>50%) in cement production and CCUS only option to mitigate process emissions
- Natural gas demand triples from 11BCM in 2024 to 31BCM in Vikasit by 2041 due to greater uptake in Steel production and partial replacement of coal in Aluminium.
- Green H2 demand increases from 0 to 7 MT in Reference & 13 MT in Vikasit by 2041

Download PIER 2.0 from: https://doi.org/10.5281/zenodo.14603083

Suggested Citation:

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Appendix – Industry model details

Steel Production routes - 1

Blast Furnace – Basic Oxygen Furnace (BF-BOF)

- Material preparation –
  - Sintering - Agglomeration of ore fines to form nodules (sinter)
  - Coking to produce coke (from coking coal)
- Iron making – BF → Hot metal / pig iron (~ 3.5-4.5% carbon)
  - Reduction of iron oxide by carbon in coke (~1600deg C) in presence of Flux (limestone)
  - Coke partly replaced with PCI (pulverized coal injection)
- Steel making – BOF → Crude steel (Iron-carbon alloy : 0.25–2%C - CS)
  - Hot metal charged with additives & O2 injected, oxidizing remaining C, Si, Mn, P & S
  - Liquid steel & BF slag
- Casting & Rolling → Crude steel products
  - Continuous casting → ingots, slabs, blooms, billets
  - Hot rolling → Sheets, strips, bars or wires

Steel Production routes - 2

Direct Reduced Iron (DRI) – Electric Arc furnace (EAF) / Induction Furnace (IF)

- Material preparation –
  - Sintering / Pelletizing - Agglomeration of ore fines to form nodules (sinter) or pellets
- Iron making – DRI → Sponge iron (~ 800-1000deg C)
  - Iron oxide reduced to solid iron from ore in reducing atmosphere of CO & H2 without melting
  - CO produced either from burning of coal or natural gas / coke oven gas
- COREX (Smelting reduction) → DRI (no coking, no sintering)
  - Iron ore reduced in Reduction shaft by reduction gas (H2+CO) to DRI (95%)
  - Melter-gasifier – gasification of coal, iron & slag melted & refined (byproducts captured in slag)
- Steel making – EAF → Crude steel
  - Electric arc provides heat to melt sponge iron / hot metal / scrap + additives to produce steel
- Steel making – IF → Crude steel
  - Eddy currents generated by alternating magnetic field around a coil provide heat
- Casting & Rolling → same as BF-BOF

National Steel Policy targets FY2031

Target for techno-economic performance as per NSP, 2017				
Parameter	Unit	International Best practices	Current value	Target 2030-31
Coke rate	kg/thm	275-350	400-600	300-350
CDI rate	kg/thm	200-225	50-200	180-200
BF productivity	tonnes/m3/day	2.5-3.5	1.3-2.2	2.5-3.0
SEC	Gcal/tcs	4.5-5.0	6.2-6.7	5.0-5.5

NSP Targets MT (except per capita)	
Parameters	Projections (2030-31)
Total crude steel capacity	300
Total crude steel demand / production	255
Total finished steel demand / production	230
Per capita steel consumption	158 kg
Coking coal requirement	161
Non-coking coal requirement for PCI	31
Non-coking coal requirement for DRI	105
Capacity target for 2047	500

Assumptions -	
BF-BOF route	60-65%
EAF / IF route	35-40%
Coal based DRI	70%
Natural Gas based DRI	30%
Capacity Utilization (for all technologies)	85%
GDP growth rate (y-o-y)	7.50%
Elasticity of steel demand with GDP	0.8 (till FY2020)
	1.0 from FY20 onwards

Steel: Adoption of CCUS & Green Hydrogen

Green H2 considered for DRI-EAF (gas based) route as it is technically feasible to replace natural gas based DRI with H2. Hydrogen is adopted post 2030 (with shares differing within scenarios)

- Use of green H2 in blast furnace to partially replace coal not considered for now.

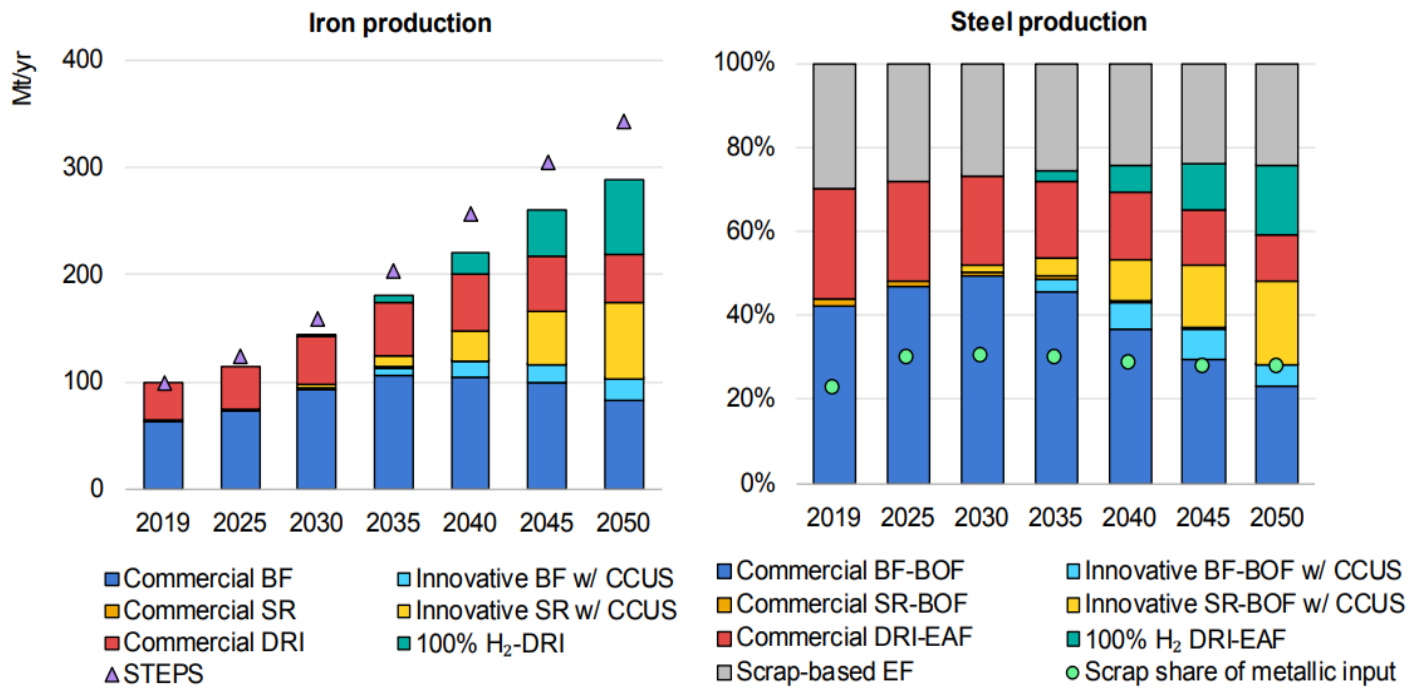
CCUS – Principal potential option for decarbonization for BF-BOF & COREX route, likely to pick up post 2035.

- For PIER, it is assumed that CCUS kicks in from later half of 2030s for the REF & Vichalit scenarios and from early 2030s for Vikasit scenario.
- Various methods being tried – Enhanced oil and coal bed methane recovery; Storage in saline acquifers & basalt formations; Chemical conversion to ethanol, methanol, ammonia etc.
- Chemical conversion is considered as the option for PIER

Steel Basis for deciding shares of decarbonizing levers

IEA's Sustainable Development Scenario

Figure 3.7 Production of iron and steel by route in India in the Sustainable Development Scenario



Source: IEA's Iron & Steel technology roadmap

Steel Specific Energy Consumption (SEC)

- Production process wise SEC – partly based on literature, part assumptions
- Improvement % in SEC over model period based on some literature and author's assumptions.
- For Vikasit, more aggressive SEC improvement assumed by taking final SEC for 2041 as BAT (Best Available Technology) SEC or global best for all new production
- For Reference & Vichalit scenarios, SEC improvement is less aggressive than Vikasit, improvement rate is medium for REF & low for Vichalit

Conversion factors / ratios assumed (tcs : tonne crude steel; thm : ton hot metal)

- Coking coal / coke ratio : Imported coal – 1.5; Domestic coal – 3.0
- 1 tcs = 1.1 thm
- 1 tcs = 1.25 t coal DRI
- 1 tcs = 1.1 t gas DRI
- 1 tcs = 1.1 t scrap

Source : CEEW 2023; LBNL 2008; NSP 2017; WSA 2021

Steel Specific Energy Consumption: Fuel-wise

BF-BOF : For BF-BOF split taken as per current range given in NSP 2017.

- Current SEC (6.5 Gcal/tcs) assumed as per current industry averages. (CDI refers to thermal coal dust injection).
- CV of Imported coking coal calibrated based on actual consumption for 2022.
- For Ref, SEC improves at -0.9% to achieve SEC of 5.4 Gcal/tcs by 2041
- For Vikasit scenario, higher rate of -1.3 % assumed to achieve SEC of 5.1 Gcal/tcs by 2041
- Vichalit has a slower SEC improvement of -0.7% to reach 5.6 Gcal/tcs
- Electrical SEC = Total SEC – Thermal SEC (coke rate+CDI)

Target for techno-economic performance as per NSP, 2017				
Parameter	Unit	International Best practices	Current value	Target 2030-31
Coke rate	kg/thm	275-350	400-600	300-350
CDI rate	kg/thm	200-225	50-200	180-200
BF productivity	tonnes/m3/day	2.5-3.5	1.3-2.2	2.5-3.0
SEC	Gcal/tcs	4.5-5.0	6.2-6.7	5.0-5.5

Source : TERI 2020; NSP 2017

Steel Specific Energy Consumption: Fuel-wise

DRI -

- Coal-DRI & Gas-DRI have multiple data sources with large variances. Current SEC is based on individual SEC for iron making & steel making
- DRI (Direct reduced Iron) – Current SEC is taken as 4.5 Gcal/thm (hot metal) based on TERI 2021
- BAT SEC of 3.4 Gcal/thm as per LBNL 2008 report is assumed for new capacity in Vikasit scenario for 2041

EAF -

- EAF - Elec SEC current value (664 kWh/t) taken as per MoS's Greening steel report 2024
- Overall SEC calculated assuming a 60% electrical / 40% thermal break-up
- BAT SEC (540 kWh/t) taken as per LBNL 2008 report with a 3:1 Electrical : thermal break-up for the Vikasit scenario for 2041
- Accordingly, DRI-EAF SEC reduces from 7.1 to 6.3 Gcal/tcs in REF scenario & 5.7 Gcal/tcs in Vikasit

Source : TERI 2021; LBNL 2008; MoS 2024 (Greening the Steel Sector in India-Roadmap and action plan)

Steel Specific Energy Consumption: Fuel-wise

Not much data available for split for Scrap based EAF & IF as well as COREX

COREX

- Current SEC (6.75 Gcal/tcs) taken as per weighted average from PAT data. SEC improves at -0.2% to reach 6.47 Gcal/t and is assumed same for all scenarios. This is because no new capacity is expected as per industry feedback.

IF

- Electrical SEC current value (825 kWh/t) taken as per MoS's Greening steel report 2024. Reduces to 673 kWh/t in Vikasit and 749 kWh/t in REF.
- Only Electrical SEC (no thermal) assumed for Induction furnace (IF)

SCRAP STs

- For SCRAP_EAF & SCRAP_IF, BAT SEC is taken as per LBNL 2008 report for new production in 2041 in Vikasit scenario and the same shares (thermal & electrical) assumed for current SEC.
- For casting & rolling, current SEC of 0.5 Gcal/tcs is taken which reduces to 0.47 Gcal/tcs in REF & 0.44 Gcal/tcs in Vikasit

Source : BEE 2018; LBNL 2008; MoS 2024 (Greening the Steel Sector in India-Roadmap and action plan); Bedarkar et al 2020; TERI 2020

Aluminium: SEC Improvement – Scenario wise targets

PRIMARY SEC

SEC Targets: REF scenario: Achieve "India Best" SEC by 2041.

Vikasit scenario: Achieve "Global Best" SEC by scenario 2041.

Vichalit scenario: Achieve SEC half of the REF.

Starting Point:

2018 "India Average" SEC from the 2008 BEE report and extrapolated to 2024 for each scenario (while keeping 2023 & 2024 as same across scenarios for calibration).

Approach for SEC Improvement Rates: Calculated 2024 Thermal and Electricity SEC.

Using CAGR based on difference between India Average and India Best, projected 2041 target.

Inert Anode: Reduces energy consumption by 1000 kWh/Ton compared to Carbon anode (based on literature).

Source: BEE 2015; BEE 2018; CEEW 2024; CRISIL 2022; LBNL 2008

Aluminium: SEC Improvement – Scenario wise targets

SECONDARY SEC

SEC Targets and Starting point:

Same approach as PRIMARY.

Approach for SEC Improvement Rates:

•assumed improvement rates as → REF -0.5%, Vikasit -1% and Vichalit as half of REF i.e., -0.25%.

Thermal and Electricity SEC Split:

•As per CRISIL report, Secondary Aluminium saves 90-95% energy. Hence we have taken the upper bound i.e., assumed 10% of primary total SEC (Thermal + Electricity).

Energy Carrier wise SEC Split: 10% Electricity and 90% Thermal (OTH_PP).

Source: BEE 2015; BEE 2018; CEEW 2024; CRISIL 2022; LBNL 2008