India Coal Mine Methane Market Study

EPA Publication No: 456R19001

May 2019

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This publication was developed at the request of the United States Environmental Protection Agency (USEPA), in support of the Global Methane Initiative (GMI). In collaboration with the Coalbed Methane Outreach Program (CMOP), Advanced Resources International, Inc. (ARI) authored this report under RTI International contract EP-BPA-18-H-0010.

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List of Acronyms and Abbreviations

AERB	Atomic Energy Regulatory Board
BCCL	Bharat Coking Coal, Ltd.
Bcf	billion cubic feet
Bcm	billion cubic meters
Bt	billion tonnes
CAGR	Compound Annual Growth Rate
CBM	Coalbed Methane
CCEA	Cabinet Committee on Economic Affairs
CCL	Central Coalfields Limited
CGD	City Gas Distribution
CIIP	CBM/CMM-Initially-In-Place
CIL	Coal India Limited
CMM	Coal Mine Methane
CMPDI	Central Mine Planning and Design Institute
CNG	compressed natural gas
DRI	direct reduced iron
DVPL	Dahej-Vijapur Pipeline
ECL	Eastern Coalfields Limited
EVs	electric vehicles
FIT	Feed-In Tariffs
ft^3	cubic feet
GDP	Gross Domestic Product
GEF	Global Environmental Facility
GHG	Greenhouse Gas
GJ/t	Gigajoules per tonne
GMI	Global Methane Initiative
GoI	Government of India

GW	gigawatt
HAP	Household Air Pollution
HELP	Hydrocarbon Exploration Licensing Policy
HVJ	Hazira-Vijaipur-Jagadishpur pipeline
IEA	International Energy Agency
kcal/kg	kilocalories per kilogram
km	kilometer
km^2	square kilometer
kWh	kilowatt-hour
LNG	Liquified Natural Gas
LPG	Liquified Petroleum Gas
m^3	cubic meter
MDO	Mine Developer and Operator
Mm^3	million cubic meters
Mmb/d	million barrels per day
MMSCMD	million standard cubic meters per day
Mmt	million metric tons
Mmtce	million metric tons of coal equivalents
Mmtoe	million metric tons of oil equivalents
MoC	Ministry of Coal
MoP&NG	Ministry of Petroleum and Natural Gas
$MtCO_2e$	metric tonnes of carbon dioxide equivalent
MW	megawatt
NPCIL	Nuclear Power Corporation of India
NPIC	National Programme on Improved Chulhas
OIL	Oil India Limited
ONGC	Oil and Natural Gas Corporation
PLF	Plant Load Factor
PMUY	Pradhan Mantri Yojana
Rs/MMBTU	Rupees per million British Thermal Units
SAIL	Steel Authority of India Limited
SCCL	Singareni Collieries Company Limited
SECL	South Eastern Coalfields Limited
SHAKTI	Scheme for Harnessing and Allocating Koyala (Coal) Transparently in India
TAPI	Turkmenistan-Afghanistan-Pakistan-India
Tcf	trillion cubic feet
Tcm	trillion cubic meters
UNDP	United Nations Development Program
USEPA	United States Environmental Protection Agency

1.0 Introduction

India's energy market is marked by high energy demand due to strong industrial, manufacturing and transportation sectors, combined with an increasingly large share of the world's population. Domestic energy supply, largely dominated by coal, has failed to keep up with the high demand, and India has been forced to rely on increasing imports of coal, natural gas, and oil. Investments in clean energy have so far only made a small impact on the domestic energy sector.

As India's coal sector struggles to meet its domestic energy demand, it will need to mine deeper, gassier coal seams to meet its consumption needs. This transition will likely lead to increased methane emissions from active underground coal mines. Coal mine methane (CMM) utilization offers potential benefits to India through emissions reduction opportunities and increased domestic energy security. Multiple feasibility studies have provided valuable information about the technical and economic viability of CMM utilization projects, largely in the eastern portion of the country where there is an abundance of coal resources (Figure ES 1).

The outlook for CMM projects has improved significantly over the past year with important regulatory and market developments. On the regulatory front, the Indian government will now allow Coal India, Ltd. to develop CMM/CBM on their lease block (previously CMM/CBM development required the approval of the Ministry of Petroleum and Natural Gas) and they removed price controls on CMM/CBM production. A significant gas market development is the construction of a 2,000 km pipeline from Jagadishpur to Haldia which will run proximal to the coalfields of the Damodar Valley. The pipeline, constructed by the Gas Authority of India (GAIL), will provide a ready market for the produced gas.

This document serves to provide a national overview of India's energy markets, as well as to identify CMM utilization and emissions reduction opportunities in India. This report is part of a larger initiative funded by the United States Environmental Protection Agency (USEPA) under the Global Methane Initiative (GMI). More information on the GMI can be found at: www.globalmethane.org.

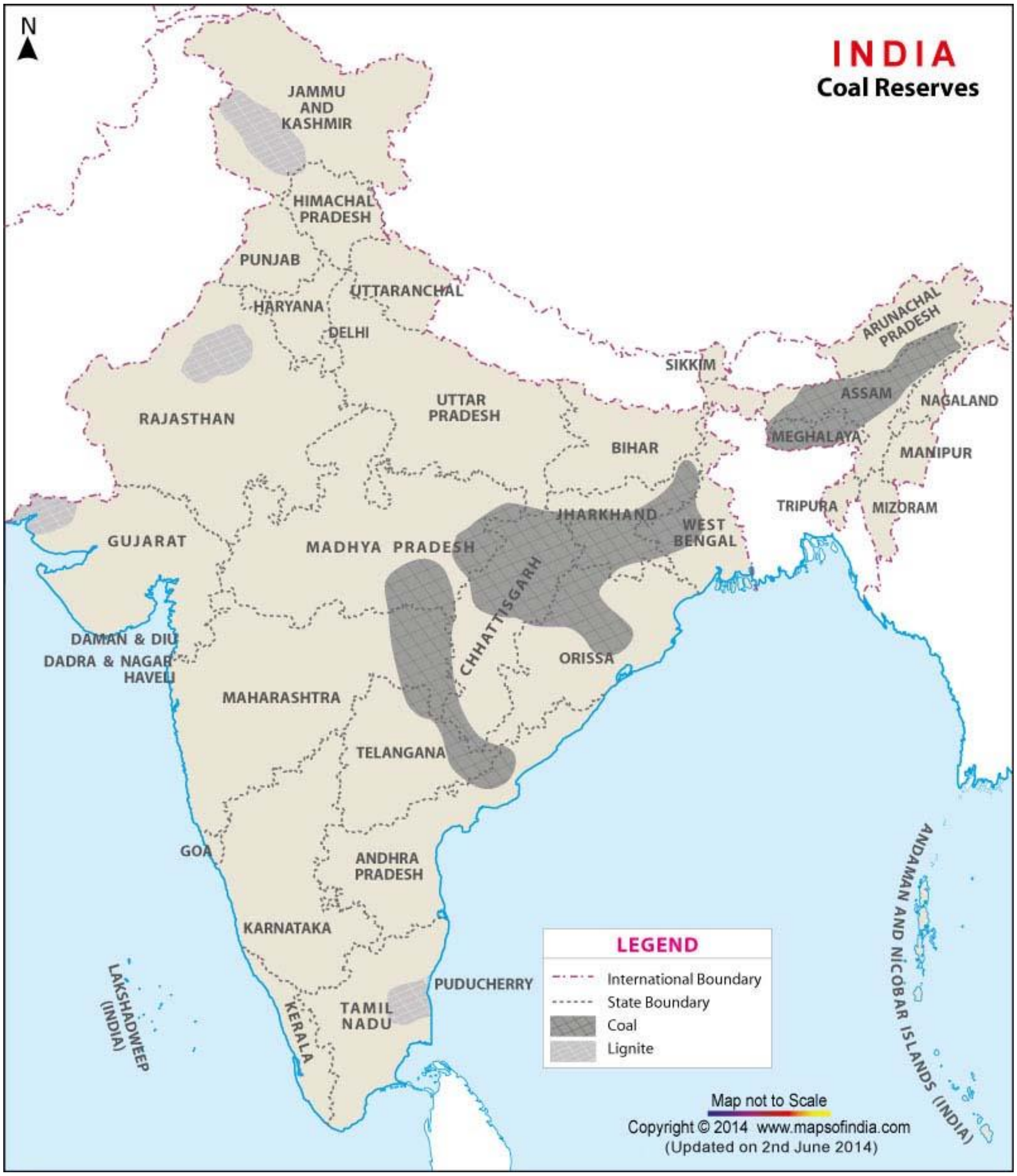


Figure ES 1: Coal Reserves of India.

2.0 India's Coal Mining Industry

2.1 India's Growing Energy Deficit and the Role of Coal

According to recent projections, India's energy consumption is set to grow at the fastest pace among all major economies by 2040; during these years, energy consumption will increase 165% (BP, 2018). In order to meet this future demand, India will have to significantly increase its energy production. As India's coal demand has grown in recent years, however, so too have the nation's coal imports. Over the past decade, coal imports have grown by more than 13% per year (EIA, 2016; USEPA, 2015). Nonetheless, the recent past shows that India has struggled to meet its energy demands, oftentimes resulting in an undersupplied market and power deficits (Figure 1).

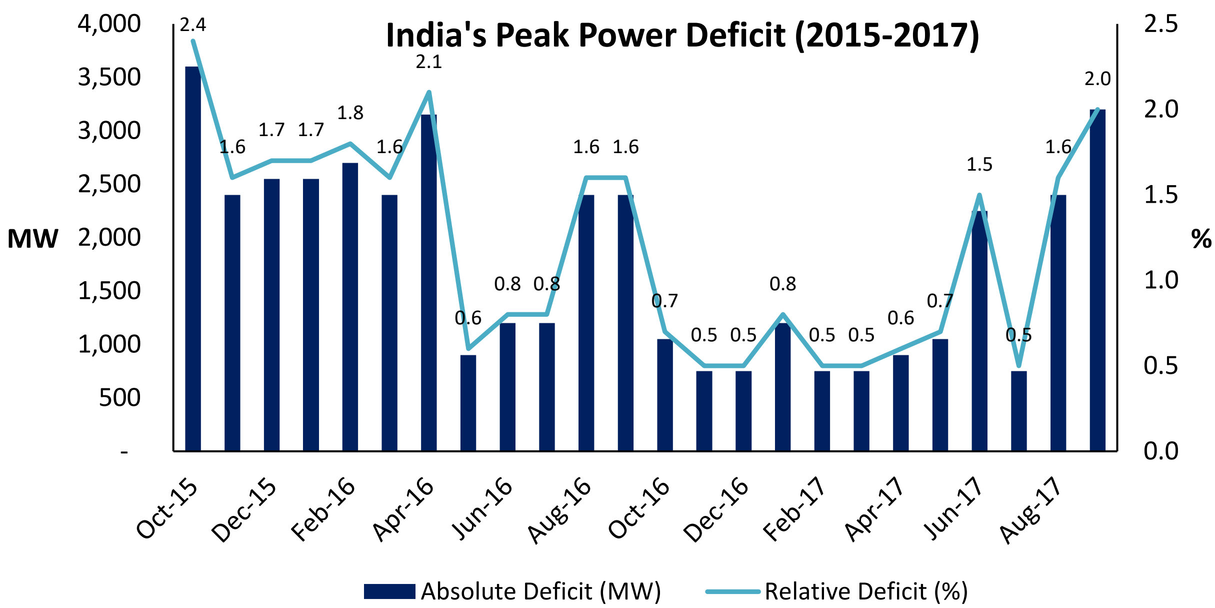


Figure 1: Figure showing India's peak power deficits during the years 2015-2017. The deficit in September of 2017 (2.0%) was the highest in sixteen months (Economic Times, 2017).

Looking ahead to the mid-century, renewable energy consumption is expected to contribute a larger percentage of India's total energy mix, rising to 13% of the portfolio in 2040 from 2% in 2016 (BP, 2018). Coal consumption is projected to more than double from 412 million tons of oil equivalent (Mmtoe) to 995 Mmtoe during the period 2016-2040 (BP, 2018). This increase will account for 28% of India's total energy consumption growth by 2040; although the overall share of coal in the energy mix will drop from 57% to 50%

over this time frame (Figure 2). Nevertheless, coal will remain the major driver of India's energy consumption growth.

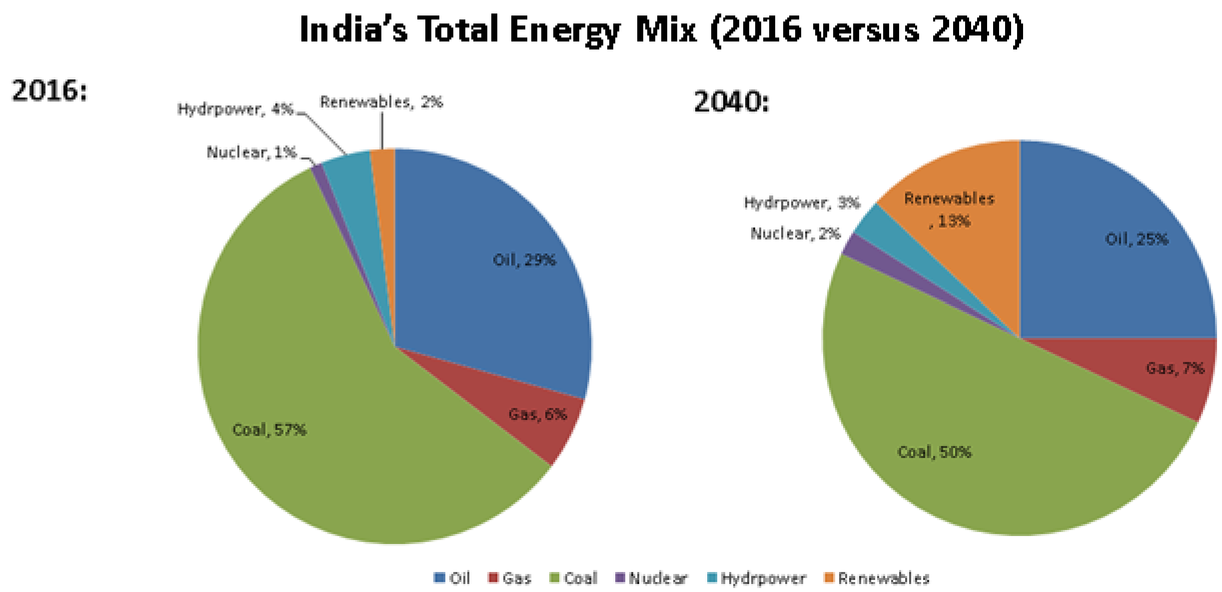


Figure 2: Figure comparing India's total energy mix in 2016 in 2040 (projected). Despite total energy consumption and coal usage increasing, greater contributions from renewable energy technologies result in coal accounting for a smaller share of the nation's total energy mix in 2040 (BP, 2018).

From a supply perspective, India is also expected to increase coal production. Coal production is projected to increase to 734 Mmtoe in 2040, an increase of more than 250% from 2016. Despite this large projected increase in the country's production, India will still be forced to import about 25% of its coal supply to meet the its future energy demands (BP, 2018).

2.2 Structural Changes in India's Coal Mining Industry and the Impact on Methane Emissions

As previously discussed, coal is the largest component of India's energy mix. Currently, India is the world's fourth largest producer of coal and the world's second largest consumer of coal (BP, 2018.1). Structurally, both India's coal supply and coal demand are expected to grow significantly by 2040. Under current projections, the gap between coal production growth and coal demand growth will also force imports to rise. Recent legislation and regulatory reforms, however, are focused on increasing domestic coal production to reduce imports and promote energy security.

In 2015, as part of India's 12th Five Year Plan (2012-2017), the country announced an aggressive coal production target of 1.5 billion tons (Bt) by 2020, which would be double 2015 production levels (EIA, 2016). Coal India Limited (CIL), the company currently responsible for producing about 80% of India's coal, plans to increase annual production to about 1 Bt over the next four years (EIA, 2016; Loh, 2016). Singareni Collieries Company Limited (SCCL) is responsible for another 10% of India's current coal production. The final 10% of production comes from captive producers, which represent private industries mining coal for their own use such as cement and steel production. With close to 90% of India's coal production coming from government-owned entities, India's Ministry of Coal is focusing on bringing private-sector investment to the country's coal industry.

In June of 2016, the Ministry of Coal called for all government owned and operated thermal power producers to halt coal imports and source coal feedstocks from CIL (Daws, 2016). Similarly, in May of 2017, India's Cabinet Committee on Economic Affairs (CCEA) approved a methodology for the auction and sale of coal mine blocks (CRISIL, 2018). Under the new methodology, the highest bidder will be awarded mining rights with no restriction on end-use. The government hopes this move to allow the private sector to commercially mine coal will boost both production and mining efficiency through increased competition and technical capacity.

India's commitment to increased coal production also puts the nation's future methane emissions in the spotlight. Most coal mines in India are classified as Degree I or Degree II gassy mines, indicating that they are moderately gassy, as described in Table 1 (USEPA, 2015). That said, as India's demand for coal continues to increase, mines may be forced to target deeper and gassier seams. Although the number of deep underground coal mines in India is limited, they will eventually have to be developed in order to meet India's rapidly growing coal demand. Furthermore, the Ministry of Coal's ban on thermal coal imports will force domestic producers to ramp up production.

Table 1: Table showing the gassy mine classification system of India. Most currently active coal mines in India are classified as Degree I or Degree II gassy mines.

Class	Emissions Characterization	Number of Mines
Degree I	Percentage of inflammable gas in the general body of air near seam workings does not exceed 0.1% and the rate of emission per tonne of coal produced does not exceed 1 cubic meter (m^3) (35.31 cubic feet, ft^3)	222
Degree II	Percentage of inflammable gas in the general body of air near seam workings is more than 0.1% and the rate of emission per tonne of coal produced does not exceed 1 m^3 (353 ft^3)	102
Degree III	The rate of emission of inflammable gas per tonne of coal produced exceeds 10 m^3 (353 ft^3)	18

In recent years, the government's push to increase domestic production, combined with the depletion of shallow and easy to extract seams, has caused India's coal mine methane (CMM) emissions to rise from 1,007 million cubic meters, Mm^3 (35 billion cubic feet, Bcf) in 2000 to an estimated 1,397 Mm^3 (49 Bcf) at the end of 2015 (USEPA, 2015). Without proper methane mitigation techniques implemented in the future, India's trend of increased methane emissions is expected to continue.

2.3 Benefits of CMM Drainage and Utilization Projects and the Role of USEPA's CMOP

CMM refers to methane released from the coal and surrounding rock strata due to mining activities. In underground mines, it can create an explosive hazard to coal miners, so it is removed through ventilation systems. In abandoned mines and surface mines, methane might also escape to the atmosphere through natural fissures or other diffuse sources. The benefits of CMM drainage and utilization include:

- Conserving a local source of clean-burning energy
- Increasing mine productivity
- Enhancing mine safety by reducing in-mine concentrations of methane
- Providing a secondary revenue stream for the mine
- Reducing GHG emissions

CMM projects deliver direct financial benefits to project operators through the sale of gas to pipelines or the use of gas in applications ranging from electric power generation to industrial uses. In addition, indirect financial and economic benefits may also be realized.

The U.S. Environmental Protection Agency's (EPA) Coalbed Methane Outreach Program (CMOP) is a voluntary program that works cooperatively with the coal mining industry to reduce methane emissions from coal mining activities. Working in collaboration with CMOP, the Global Methane Initiative (GMI) is an international public-private initiative that advances cost effective, near-term methane abatement and recovery projects and the use of methane as a clean energy source. Activities of the GMI are focused on reducing informational, institutional, and market barriers to project development by making available tools and resources, providing training and capacity building, conducting technology demonstrations, and offering direct project support.

Currently, there are no commercial-scale CMM projects in India. Nonetheless, the development of CMM is high on the agenda of the Indian coal mining industry. CMOP and GMI have been partnered with the government of India for a number of years, and the U.S. organizations have conducted several pre-feasibility studies to assess the viability of implementing CMM utilization projects.

3.0 CMM Opportunities in India

3.1 Policy Drivers and Regulatory Response

3.1.1 National Policies

The development and commercialization of CMM technologies has received increased attention from the Ministry of Coal and CIL. If successful, implementation of CMM technologies would be in synergy with three major national policy efforts. First, India stands committed to the global efforts to fight climate change, and as part of the agreement reached at the Paris Climate Summit, the country has pledged to reduce the emissions intensity of its GDP by 33% to 35% by 2030 from 2005 levels (USEPA, 2016). While India is also looking to increase its use of renewable energy sources, the dominance of fossil fuels, and in particular coal, will continue in the near future. The drainage, capture, and utilization of CMM that would otherwise be emitted to the atmosphere would allow India's reliance on coal as a fuel to continue, while also minimizing its associated environmental impacts.

Second, recent regulatory reforms are focused on increasing domestic coal production to reduce imports and promote energy security. In 2015, India announced a coal production target of 1.5 Bt by 2020. Similarly, in June of 2016, the Ministry of Coal called for government owned and operated thermal power producers to halt all coal imports and source coal feedstocks from CIL. Despite these regulatory initiatives, though, much of India's domestic coal resource is gaseous and only considered safe to mine after pre-drainage of methane. Therefore, the implementation of CMM utilization technologies would complement India's recent regulatory efforts and better enable India to sustainably increase domestic coal production.

Finally, India's government has set a goal to reduce the nation's imports of natural gas by at least 10% by 2020 (PTI, 2016). To meet this goal, it is expected that CMM and coalbed methane (CBM) will play an important role. Nevertheless, with coal mines being forced to target ever deeper and gassier seams, CMM utilization will present India with greater opportunities for natural gas production.

3.1.2 CMM Regulations

In recent years, the government of India has supported an "Ease of Doing Business" initiative to improve business conditions, increase domestic unconventional natural gas production, and reduce the supply-demand gap in domestic fuels. India's Cabinet Committee on Economic Affairs did so by approving an amendment to the November 2015 regulations issued by the Ministry of Petroleum & Natural Gas (MoP&NG) under Section 12 of the Oil Field (Regulation and Development) Act, 1948. The amendment relaxes rules facing CIL's extraction of natural gas laying below coal seams in its blocks via CBM and CMM technologies in a move to boost production levels (PIB, 2018). A major breakthrough for CMM and CBM producers came in 2017, when the government of India exempted CMM/CBM production from price controls. The government ruled that CMM/CBM production falls under the new Hydrocarbon Exploration Licensing Policy (HELP), and that prices should no longer be restricted (Ministry, 2016). Increasing realized natural gas prices is expected to accelerate production operations for a number of CBM projects and may also improve the economics of potential CMM projects.

3.2 Current Status of the CMM Industry in India

3.2.1 Coal Mine Emissions

India's carbon emissions have been increasing at the world's second-greatest rate since 1990, second only to China (GMI, 2015). Large increases in emissions from the electricity, cement and waste sectors, along with rises in the transport and residential sectors have made India the world's third largest emitter after China and the U.S. (Reuters, 2017). With more than a third of India's carbon emissions coming from the coal sector, and the high capital cost to replace existing plants, it is likely that coal mines will continue to contribute to significant percentages of India's total carbon emissions. India's estimated coal mine methane emissions estimates are presented in Table 2 below.

Table 2: Table illustrating India's estimated coal mine methane emissions (USEPA, 2012). *Global warming potential for metric tons of carbon dioxide equivalent ($MtCO_2e$) (100-year) used is 25.

Emission Source	2000	2005	2010	2015
Mm^3 (Bcf)	1,043 (36.8)	1,113 (39.3)	1,324 (46.8)	1,450 (51.2)
$MtCO_2e$*	17.7	18.9	22.5	24.6

3.2.2 CMM Projects

While there is drainage of CMM at some active Indian coal mines, there are currently no commercial CMM recovery and utilization projects. Many project opportunities remain in the feasibility-proving stages. For example, during the period 2014-2016, the EPA published pre-feasibility studies for the Sawang and Chinakuri collieries. The studies examined the economics of utilizing long, in-seam boreholes to drain gas from deeper portions of the mines.

The most advanced CMM project is at the Moonidih Mine owned by Bharat Coking Coal, Ltd. The Moonidih Mine was the first mine in India to introduce fully mechanized, self-advancing longwall technologies, and it remains one of India's most technologically advanced underground mines. The mine, currently producing about 1 Mmt per year, has set a production target of 3.5 Mmt per year. An early CMM demonstration project implemented at Sudamdih and Moonidih mines was funded by the United Nations Development Program (UNDP), the Global Environmental Facility (GEF) and the Indian Ministry of Coal (MoC) (Aminian, 2014). This UNDP/GEF/MoC sponsored project sought to implement in-seam, directional drilling technology at the mine, but due to funding limitations, the project was unable to purchase the down-hole steering equipment, so the project had limited success. Most recently, in September 2018, Bharat Coking Coal Ltd. (BCCL) issued an International Tender for a turn-key project to provide in-mine directional drilling, gas gathering, and the generation of 2-4 megawatts (MW) of power. The introduction of these technologies at the Moonidih mine may spur further CMM drainage and utilization projects in India.

3.3 CMM Resources in India

3.3.1 CMM Sources and Geographic Distribution

India’s enormous coal resources suggest that the country also has large CMM potential. India’s coal deposits are found in 17 major coalfields. The States, coal fields, resources, and proved reserves are illustrated in Table 3. Figure 3 shows the location of India’s major coal deposits.

Table 3: Table detailing India’s coal resources by state, coal field, resources, and proved reserves (Mmt) (GSI, 2010).

State	Coal Field	Resources (Mmt)	Proved Reserves (Mmt)
Orissa	Talcher	43,859	14,240
West Bengal	Raniganj	23,731	11,638
Orissa	Ib-river	22,448	7,267
Jharkhand	Jharia	19,430	15,078
Chattisgarh	Mand-raigarh	22,178	3,881
Andhra Pradesh	Godavari Valley	22,016	9,257
Jharkhand	N. Karanpura	17,073	9,499
Jharkhand	Rajmahal	14,338	2,656
Madhya Pradesh	Singrauli	12,417	4,795
Chattisgarh	Korba	11,705	4,981
Jharkhand	E. Bokaro	8,083	3,352
Jharkhand	S. Karanpura	6,150	2,620
Maharashtra	Wardha Valley	6,044	3,297
Jharkhand	W. Bokaro	5,012	3,629
Chattisgarh	Hasdo-arand	4,994	1,370
West Bengal	Birbhum	5,993	-
Madhya Pradesh	Sohagpur	6,129	1,643
West Bengal	Birbhum	5,993	-
Madhya Pradesh	Sohagpur	6,129	1,643

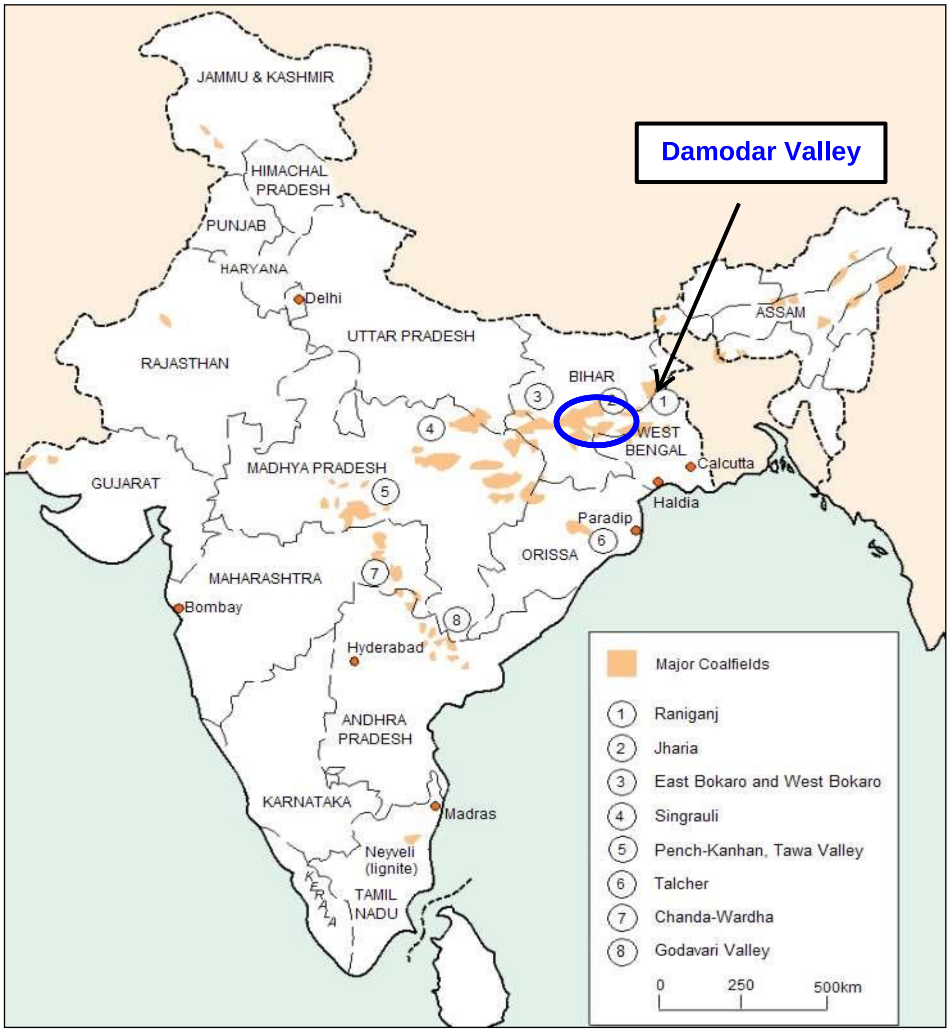


Figure 3: Figure showing the location of India's major coal deposits (Walker, 2000). The Damodar Valley, located in northeast India, is the country's largest coal producing region.

Anthracite and bituminous coals account for approximately 92% of the country's proved reserves (EIA, 2013). The principal deposits of hard coal are in the eastern half of the country. The States of Jharkhand, Orissa, West Bengal, and Chattisgarh, together account for about 70% of reserves (EIA, 2014). The Damodar Valley basins include the significant Jharia and Raniganj coalfields in the east and the Bokaro, Ramgarh, and North and South Karanpura fields in the west. High-rank coal seams in deeper coalfields represent a significant target for CMM development. In some of the coalfields of the Damodar Valley, there can be up to 25 coal seams, and even in excess of 40 in some areas, with a cumulative thickness of over 100 meters (M2M, 2005).

3.3.2 CMM Resource Potential

Many of India's large coal deposits also represent areas with the highest potential for CMM development. In 2015, India emitted an estimated 1,450 Mm^3 (51 Bcf) of CMM. This number is expected to grow, as the country has committed to increasing coal production, but has not yet taken action to reduce methane emissions. Furthermore, as coal mines are forced to target deeper and gassier seams, the opportunities to capture and utilize methane will also increase. Therefore, given the country's large coal deposits and current lack of methane utilization infrastructure, there may be significant CMM resource potential. Table 4 identifies some of India's gassiest underground coal mines and their respective CMM resource potential.

Table 4: Indian underground coal mines that may be suitable for CMM recovery projects, billion cubic meters (Bcm) (Kumar, 2014).

Colliery, Coal Field	Degree of Gassiness	CMM Resource (Bcm)
Amlabad, Jharia	III	0.76
Murulidih, Jharia	III	4.98
Central Purbatur, Jharia	III	5.31
Sudamdih, Jharia	III	0.86
Kalidaspur, Raniganj	III	3.78
Ghusick, Raniganj	III	2.58

3.4 Outlook for CMM Opportunities in India

Similar to India possessing significant CMM resource potential, the country also possesses a positive outlook for CMM utilization opportunities. As discussed above, India's widespread coal deposits will likely serve as a large resource base for CMM. As such, CMM project development hinges on regulatory, economic, and technological forces. India's national policy objectives to reduce carbon emissions, increase domestic coal production, and decrease natural gas imports all suggest a broadly supportive landscape for CMM development. Similarly, the recent decision to exempt CMM from price controls has dramatically improved the economic feasibility of developing CMM projects. Finally, while technical hurdles to CMM project development remain, the establishment of the CMM/CBM Clearinghouse in Ranchi, in conjunction with the Central Mine Planning and Design Institute (CMPDI) has helped develop local expertise in CMM recovery technologies. Taken together, India's large resource base, supported by regulatory, economic, and technological forces suggest a positive outlook for CMM opportunities in India.

4.0 CMM Utilization in India

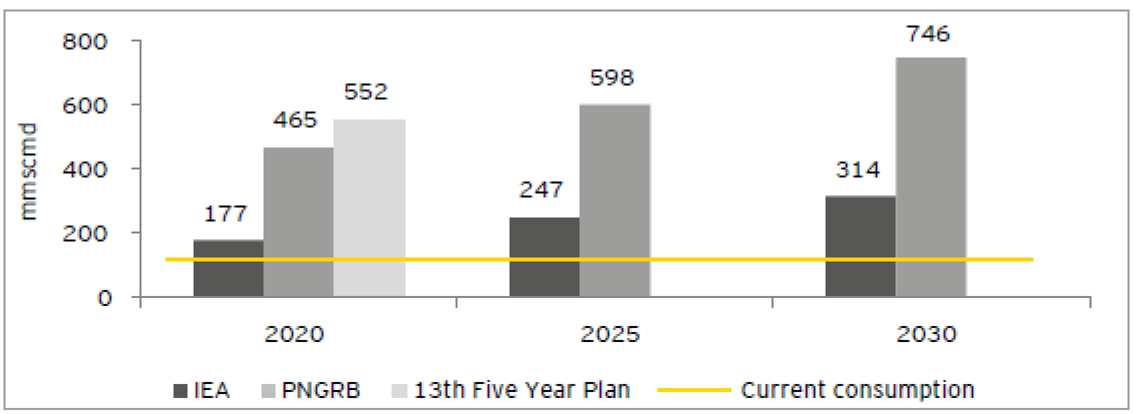
4.1. Pipeline Injection

4.1.1. Use

4.1.1.1. City Gas Distribution (CGD)

Gas supply constraints and inadequate infrastructure have hampered the growth of CGD systems in India to date. The Petroleum & Natural Gas Regulatory Board (PNGRB) projects CGD coverage to extend to 243 cities over the coming decade, thereby creating tremendous business opportunities for potential CGD players and operators in cities like Sonipat, Meerut, Yanam and others in regions across the country (EY, 2010). Natural gas demand is expected to grow rapidly over the next 10-15 years, with differing assumptions around availability, affordability and growth in end-user segments (Figure 4). One persistent issue facing CGD growth is that the power and fertilizer industries get a preferential allotment of domestic gas supplies, leaving less domestic gas for CGD companies (EY, 2011). Government and industry players will continue to play a key role in the development of the CGD market in India as time progresses.

Figure 4: Varying estimates for India's future gas demand (EY, 2016).



Source: IEA World Energy Outlook 2015, PNGRB Vision 2030, 13th Five Year Plan source through Petroleum Planning and Analysis Cell website

**For PNBRG and 13th Five Year Plan, data represent the years ending March*

4.1.1.2. Interstate Transmission

India's pipeline network is crucial to the development of CMM resources as well as other conventional forms of energy. Project economics including the price, quality and availability of gas, demand and loan terms all factor into the feasibility of transmittable CMM. A pre-feasibility study of Jharkhand's demand for CMM showed energy consumption constrained by inadequate supplies amid plentiful markets for locally produced energy. The primary markets for a CMM utilization project at the Sawang Colliery are power generation using internal combustion engines and pipeline sales for CGD or use in the fertilizer or industrial sector. Given the small production volume and need for gas-quality upgrading, the construction of a pipeline for transport to a demand center was deemed impractical. Based on discussions with the CMPDI, local consumption is the preferred end-use option for the mine's 4.4 MW electrical capacity of drained gas (USEPA, 2015). Each scenario must be evaluated on a case-by-case basis to determine the best use for CMM. India's plans to build out their pipeline network allows CMM utilization projects to better evaluate the costs associated with particular projects and may open up opportunities for development in areas previously believed unprofitable.

S. no.	Transporter	Length in KM	Percentage share
1	GAIL	11410	68.04%
2	RGTIL / RGPL	1784	10.64%
3	GSPL	2618	15.61%
4	AGCL/DNPL	817	4.87%
5	IOCL	140	0.84%
	Total	**16770**	**100.00%**

Figure 5: India has three major pipeline entities engaged in natural gas transportation across India. These pipelines transport domestic gas as well as imported RLNG (PPAC, 2018).

GAIL India Ltd. is the country's largest gas pipeline operator and currently operates about 11,000 km of gas pipelines in the country that can distribute 210 Mm^3 (7 Bcf) of gas a day (Reuters, 2018). As of 2016, GAIL operated two major natural gas pipelines in northwestern India: the Hazira-Vijaipur-Jagadishpur (HVJ) line running from Gujarat to Delhi, and the Dahej-Vijapur (DVPL) line (EIA, 2016). The HVJ line is the longest natural gas pipeline in the country and is close to 3,750 km in length (EY, 2010). The state-run company has laid out plans to develop more pipelines across the country, one of which is 2050 km in length and will connect Jagdishpur to Haldia. GAIL's planned pipelines will be proximal to the Jharia mines in the Dhanbad district and other coal fields within Jharkhand, West Bengal and Odisha. Proximity to pipeline infrastructure bodes well for CMM project economics.

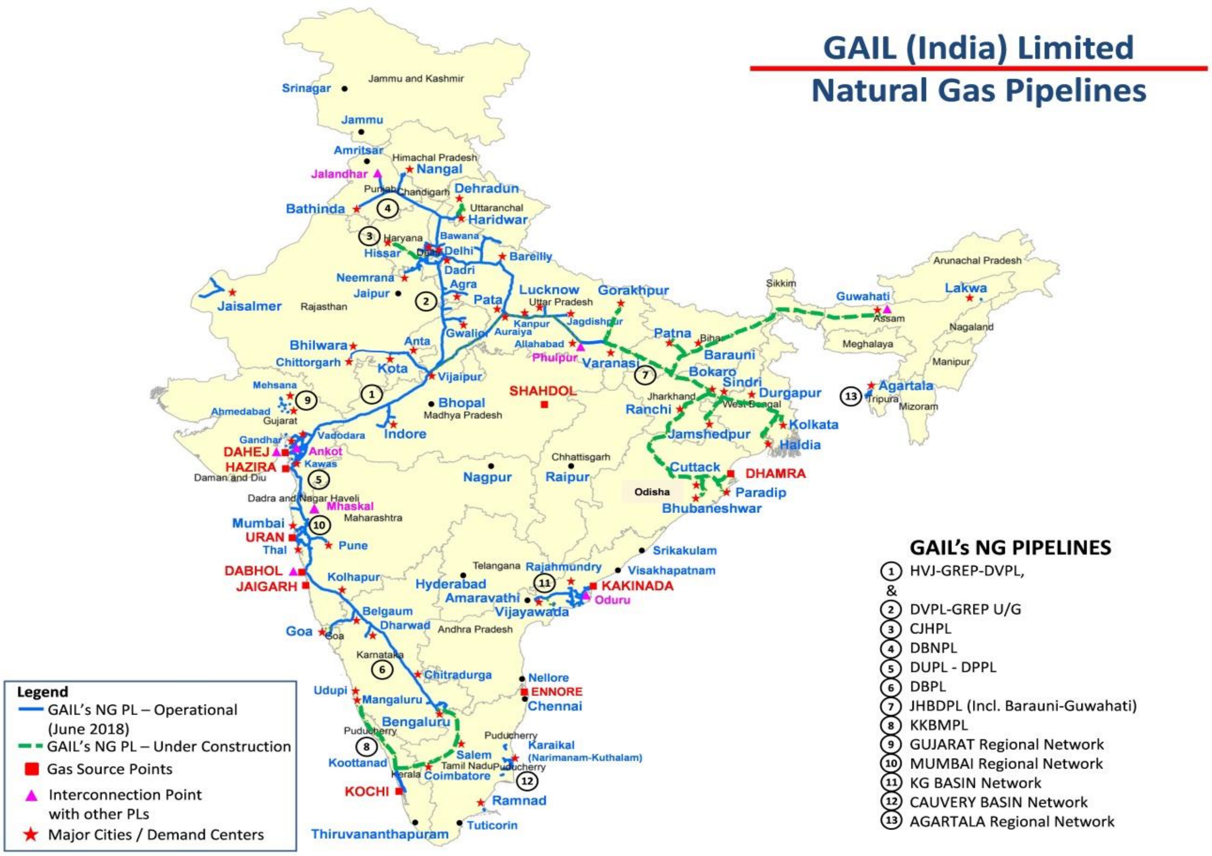


Figure 6: Map of state-owned GAIL pipelines in India, existing and proposed (GAIL, 2018).

Natural Gas Pipeline Capacity and Zonal Tariffs (as on August 2018)									
S.NO	Name of NG Pipeline	Sub Network	Capacity In (MMSCMD)			Tariff In Rs/MMBTU #			
			Total Capacity*	Total Common Carrier Capacity*	Available Common Carrier Capacity*	Zone 1	Zone 2	Zone 3	Zone 4
1	DVPL-GREP Upgradation	NA	54	13.5	7.890	42.46	48.14	53.76	59.32
2	Dahej-Uran-Dabhol-Panvel	NA	19.9	4.98	0.000	24.41	24.65	NA	NA
3	Dadri-Bawana-Nangal	NA	31	7.75	6.000	14.04	14.06	NA	NA
4	Chainsa-Jhajjar-Hisar	NA	35	8.75	8.750	7.85	NA	NA	NA
5	Dabhol-Bengaluru	NA	16	4	3.890	40.82	40.86	40.86	NA
6	Kochi-Koottanad-Bengaluru-Mangaluru	NA	16	4	2.150	42.78	42.2	NA	NA
7	Dukli-Maharajganj	NA	0.075	0.019	0.019	6.13	42.82	NA	NA
8	Agartala Regional	NA	2	0.5	0.500	5.8	NA	NA	NA
9	KG- Basin	NA	15.997	4	3.890	45.32	NA	NA	NA
10	Cauvery Basin	Narimanam - Kuthalam	2	0.5	0.500	17.41	NA	NA	NA
		Ramnad	2.33	0.58	0.510	16.63	NA	NA	NA
11	Mumbai Regional	Uran-Thal-Usar	3.543	0.89	0.550	5.7	NA	NA	NA
		Trombay	3.494	0.87	0.870	1.04	NA	NA	NA
12	Gujarat Regional P/L Network	South Gujarat Main	3.25	0.81	0.760	7.81	NA	NA	NA
		Motwan	0.0855	0.02	0.020	0.78	NA	NA	NA
		Kadi-Kalol	0.128	0.03	0.030	1.84	NA	NA	NA
		Kalol-Ramol	0.666	0.17	0.170	6.86	NA	NA	NA
		Mehsana	0.235	0.06	0.060	1.86	NA	NA	NA
		Paliyad	0.068	0.02	0.020	0.58	NA	NA	NA
		Ex-Hazira (GGCL)	3.88	0.97	0.970	0.42	NA	NA	NA

Table 5: Corresponding information to Figure 5 regarding pipeline capacity and zonal tariffs (GAIL, 2018).

Proposals for an international pipeline, namely the Turkmenistan-Afghanistan-Pakistan-India (TAPI) project, have been discussed for more than a decade with little progress due to major geopolitical risks, technical challenges and lack of financial backing.

4.1.2. Competition

4.1.2.1. Domestic Gas (Conventional, CBM, and Shale)

The natural gas sector is fully regulated in India, involving preexisting price setting mechanisms and tax subsidy structures. This has created substantial distortions in the market and disincentives for increased energy efficiency and usage of cleaner fuels. Natural gas faces disadvantages relative to cheaper coal in the Indian energy system on strictly market-based terms (Boersma, 2017). However, Gujarat and other regions have experienced meaningful growth in natural gas demand. Growth has been driven by Gujarat's local authorities' incentives for infrastructure expansion and construction of gas-fired electricity generation capacity and fertilizer plants, along with conditions of a large population and accessible offshore natural gas reserves.

India is not known for its shale reserves, but it believed to have at least 2.6 trillion cubic meters (Tcm) (91.8 trillion cubic feet, Tcf) of CBM reserves throughout its provinces (Joshi, 2016). As mentioned in section 3.1.2., the Indian government further relaxed rules for CBM development earlier in 2018 by way of removing state-owned Coal India's responsibility to apply for a license to extract CBM from its coal blocks (Rakshit, 2018). India's upstream oil and gas industry faces issues including ageing infrastructure, shortage of skilled human resources and increased competition to acquire oil assets abroad, namely from China (EY, 2011). The aforementioned mandates and regulation relaxations are consistent with India's desire to reverse their high dependence on imported crude oil and LNG and increase their domestic energy security.

4.1.2.2. Imported Gas (LNG)

India's primary natural gas supply sources are conventional domestic production and LNG imports. Low price affordability of gas imports combined with a fall in domestic gas production resulted in under-utilized, gas-based power plants. Effective plant load factor (PLF) was 21% during 2015 (EY, 2016). LNG imports stepped in to play a significant role and helped bridge gas supply deficits in India and increased LNG's share of overall gas supplies in India from 20% to 38% during 2010-2015. LNG trade is becoming more flexible as well, with close to 30% of trade done under short-term contracts, allowing India to benefit from profitable ephemeral trading opportunities. However, India has struggled to source long-term LNG supplies due to competition from other LNG-importing countries. India is the world's fourth-largest importer of LNG, behind Japan, South Korea and China. The government has assisted the stranded gas-based capacities of the power and fertilizer sector by helping make LNG more affordable (EY, 2016), but other sectors and regions struggle to have all their energy needs met by LNG alone largely due to issues with cost and price uncertainty.

4.1.3. Outlook of CMM for Pipeline Injection

As mentioned earlier in the report, there are currently no commercial CMM recovery and utilization projects in India, with many project opportunities still in the feasibility-proving stages. For the development of a robust CGD market in India the country must have an adequate supply of natural gas, which can only be used if the country has integrated gas infrastructure with uniform natural gas pricing, affordable end-user prices and regulatory policies that support project frameworks (EY, 2010). CMM has the potential to play a more significant role in India's energy mix with a developed CGD market, especially in cities located in the Damodar Coalfield region. If India wants to stimulate energy security while promoting cleaner alternatives alongside coal, it should evaluate the incorporation of CMM into pipeline systems.

4.2. Electricity Generation

4.2.1. Use

4.2.1.1. Fuel for Base Load Power

Base load power plants typically provide a continuous supply of electricity throughout the year that the amount of power on the grid should not go below. While CMM has not yet made its way into the mainstream energy mix, there are opportunities for insertion due to high levels of energy demand. India's estimated 2.6 Tcm (91.8 Tcf) of CBM/CMM reserves provide ample opportunity for resource extraction via CMM technologies (Joshi, 2016). India suffered from an electricity blackout lasting from several hours to days in certain areas in July of 2012, which affected close to 680 million people across the northern regions of the country (EIA 2016). Plant Load Factor in the country (Coal and Lignite based) from 2017-2018 only reached roughly 61%, a notable decline from 78% in the 2009-2010 period (CEA, 2018).

4.2.1.2. Fuel for Peak Load Power

Peak load refers to the daily fluctuation of electricity use and represents one of the bigger issues facing the renewable energy industry. Domestic natural gas has more commonly filled India's peak load needs as a cheaper and more flexible-use fossil fuel. Gas offers a cleaner alternative to coal for electricity generation and CMM has the potential to provide methane resources to peaker plants under the right circumstances.

4.2.1.3. Fuel for Captive Power

Captive power plants provide a localized source of power for energy use while being capable of operating parallel to or independent of electricity distribution systems. Power intensive industries such as fertilizer and aluminum plants use captive power projects as a back-up source of power to protect them against unreliable grid power. Typically used for industrial facilities, captive power plants serve as a good end-use for coal mine methane. Local consumption allows for gas use as-is, with minimal processing and transportation. Generating sets can be cheaply installed with the plant infrastructure and distribution center already planned. 85% of the total captive capacity additions are expected to be coal-based, but there are synergies available in certain scenarios in utilizing CMM. A study by Shukla et al. (2004) showed the growth of captive plants in India is attributable to the need for backup power arrangements, requirements for better quality supply, the co-generation benefits of steam and electricity from production process of industries and the need to generate electricity at costs lower than the high industrial tariffs (Nag, 2010).

4.2.2. Competition

4.2.2.1. Fossil Fuels (Coal, Natural Gas, Diesel)

Fossil fuel generation accounted for roughly 81% of India's net electricity generation in 2014, with coal-fired plants dominating the resource mix. In India, where the country holds the fifth-largest coal reserves in the world, coal plants accounted for almost 186 GW, or 62% of the utility-based installed capacity in 2016. Natural gas-fired generation capacity was roughly 25 GW in 2016, representing 8% of total generation capacity. Natural gas serves as a supply source for peak load power requirements, but the country has struggled to keep up with energy demand, which has spurred investment in imports of natural gas. Utilization rates in India's power plants using fallen fuels have steadily dropped since 2007 from 79% to less than 65% in 2014. This decline largely caused by disruptions in fuel supplies, transmission and distribution restraints, and financially strained distribution companies declining to purchase electricity generation (EIA 2016). India's government has made attempts to improve utilization of resources with initiatives such as the Scheme for Harnessing and Allocating Koyala (Coal) Transparently in India (SHAKTI). The new methodology's objective is to centralize the process of allocating coal to thermal plants based on bids, but winners have not been getting desired coal supplies months after bids are awarded (Business Line). The Indian government addressed falling domestic gas output through its aforementioned HELP initiative and price premiums for new gas discoveries in difficult areas (CRISIL, 2018.1). On the private side, proponents of the sector argue that a move to allow the private sector to commercially mine coal will boost mining production and efficiency, while saving roughly Rs 30,000 crore ($4.1 billion) of coal imports (CRISIL, 2018). While there is still a need for more organization surrounding electricity generation in the country, India's current demand ecosystem is heavily reliant on fossil fuels and will be for the foreseeable future.

4.2.2.2. Nuclear

Nuclear power is India's fifth-largest source of electricity after coal, gas, hydroelectricity and wind power. Its 21 operational nuclear reactors at 7 nuclear power plants provide a net generation capacity of 5.3 GW, which represents roughly 2% of total utility-based generation capacity with an 8% share of installed power capacity in 2016. The Nuclear Power Corporation of India (NPCIL) supplied India's 5.3 GWe nuclear capacity with an overall capacity factor of 83% and availability of 88% (WNA, 2018). The government intends to increase the nuclear share of total generation to 25% by 2050 to meet growing energy demand (EIA, 2016). India became a party to the Nuclear Suppliers' Group agreement, which opened access to nuclear technology and expertise through a number of cooperative agreements to further its nuclear programs. Along with historically limited access to uranium, India met challenges to nuclear development following protests of nuclear plants in the aftermath of the Fukushima disaster in Japan. In response the Atomic Energy Regulatory Board (AERB) conducted safety audits for the existing reactors per the government's request (EIA, 2016). India plans to shift its reactors power source to the much more abundantly available thorium through a three-stage nuclear development plan.

4.2.2.3. Hydro and Other Renewables

India's plan to install 175 GW of renewable energy by 2022 is consistent with their pledge as a country in the Paris Agreement to reduce emissions intensity of GDP by 33%-35% below 2005 levels by 2030 (USEPA, 2016). The Prime Minister launched the International Solar Alliance (ISA) to help meet targets for some of the country's renewable energy goals alongside an overall $42 billion invested in India's renewable energy sector since 2014 (DIPP, 2017).

India's geography and climate are quite favorable for renewable energy technologies and 13.42% and 18.75% of the country's installed power capacity is sourced from hydro and renewable energy resources respectively (Mercom, 2017). Solar makes up a large percentage of the renewable energy mix and India plans to add 44-46 GW of solar capacity from 2018 to 2022. Wind energy resources are more localized within the states such as Karnataka, Rajasthan and Gujara. The wind-rich regions will decline feed-in tariffs (FiT) from the government and procure energy through a competitive bidding route in the future. The government plans to bid out 9 GW in 2019 and will likely create a low-tariffs environment, which supports buying (CRISIL, 2018.2). India has a diverse set of renewable resources that have not been fully exploited to date, mainly because of an abundance of coal resources within the country, but environmental concerns and decreasing costs of renewable technologies may push policy towards furthering the development of cleaner sources of energy.

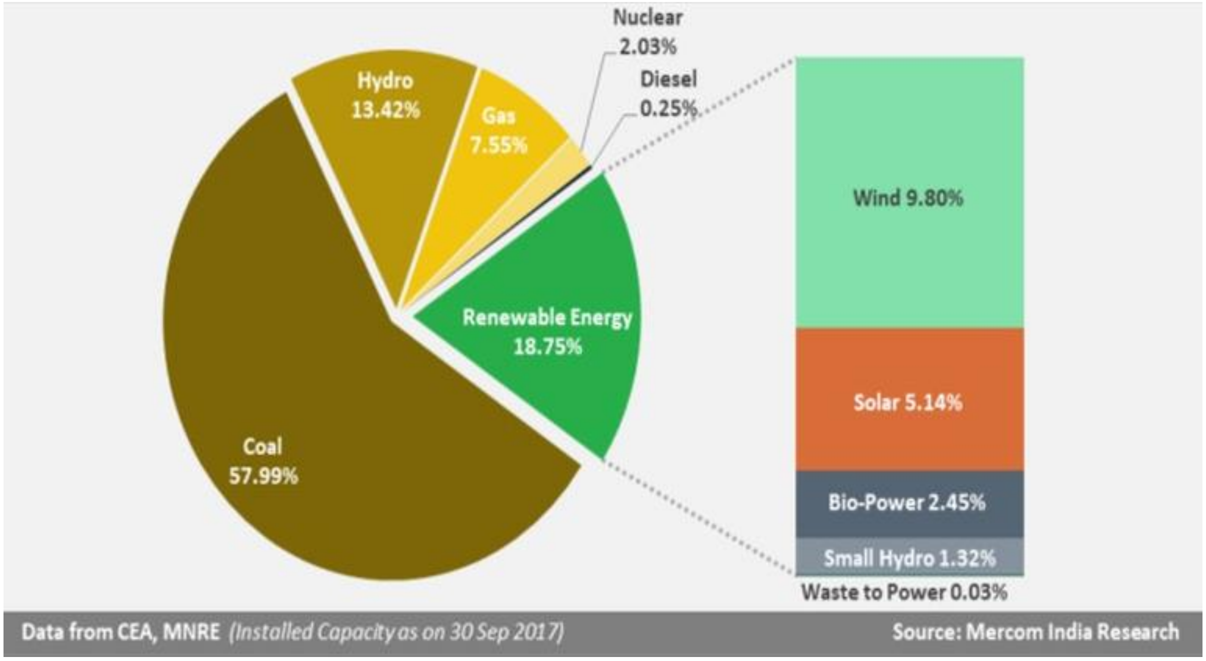


Figure 7: India's cumulative installed power capacity mix (%) as of 2017 (Mercom).

4.3. Domestic and Commercial Use

4.3.1. Use

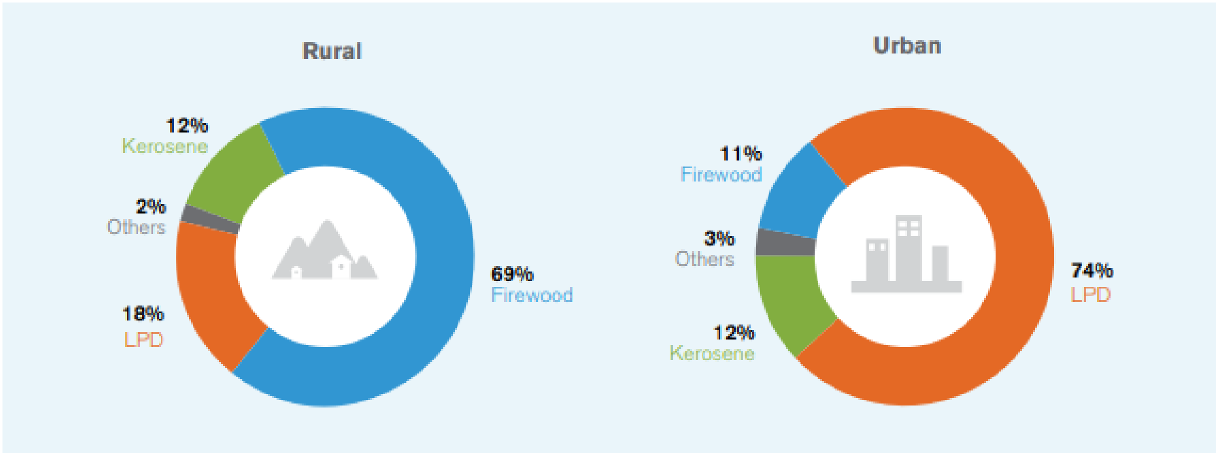
4.3.1.1. Cooking

The resources used for cooking vary greatly between rural and urban residents. A majority of urban residents use liquefied petroleum gas (LPG) (74%) for cooking, while rural residents use firewood (69%), as depicted in Figure 8. Incorporation of CMM into domestic use would likely come via CGD systems, but there is currently very little use of CMM on the domestic side in India. Only 0.01% of households use electricity for their primary cooking energy and only 3% of households had PNG connections, largely as a factor of cost and regional imbalances in the pipeline infrastructure.

4.3.1.2. Heating (Space and Water)

Given India's geographical positioning and climate, heating space is typically less sought after compared to cooling. Cooling appliances are set to increase 17% in share of the sectors total consumption by 2040 (IEA, 2015). Energy demand and peak demand will only be more stressed with intense heat waves and increased ownership of cooling appliances. The IEA projects that by 2040 more than 60% of the 299 Mtoe used in the sector will be either electricity (45%) or oil (16%) (2015). Urbanization will assist in accessing modern fuels, only if urban development is well planned.

Figure 8: Breakdown of fuel source used for cooking in India's rural and urban populations (CEEW, 2017).



**Others include biogas, agro residue, coal/charcoal and cow dung cakes*
Source: Census, 2011[12]

4.3.2. Competition

4.3.2.1. Wood/Biomass

The World Energy Outlook estimates that 244 million people in India go without access to electricity, while 819 million people rely on traditional biomass for cooking (Boersma, 2017). Biomass cookstoves create household air pollution (HAP), causing close to one million premature deaths per year across the country. Further, women are disproportionately affected as they spend the equivalent of 2 weeks each year collecting firewood (CEEW, 2017). The government worked to provide improved biomass cookstoves, known as chulhas, through the National Programme on Improved Chulhas (NPIC), which distributed 35 million chulhas in the 16 years following its launch in 1986. One of the reasons that households rely on traditional biomass is because of its cost; over 43% of households across the most energy deprived states do not spend any real money to obtain cooking fuel.

4.3.2.2. LPG

According to a survey, over 88% of respondents cited high recurring costs as one of the barriers to adoption of Liquefied Petroleum Gas (LPG) for cooking purposes (CEEW, 2017). However, India recently became the second largest importer of LPG in the world, behind China, as part of a larger effort to replace biomass cooking fuel. India's average monthly imports of about 1.7 Mmt in 2017 trailed China's 2.2 million and surpassed Japan's 1 Mmt figure. The mixture of propane and butane is also used for transport and the petrochemical industry (Reuters 2017.1). The Indian government has attempted to expand the network of rural LPG distributors and the Pradhan Mantri Yojana (PMUY) has distributed about 30 million connections to poor households at reduced up-front costs (CCEW, 2017).

4.3.3. Outlook of CMM for Domestic Use

One of India's main forms of energy transmission to domestic and commercial demand-hubs occurs via the national grid. The Power Grid Corporation of India owns, operates and maintains five regional network zones, connected to each other, that form the grid. India's network suffers from one of the highest shares of loss in electricity generation in the world. Issues arising from harsh climates affecting ageing and poorly maintained networks, theft, unmetered consumption and inadequate revenue collection all contribute to the 20% network loss in 2013 (IEA, 2015). The domestic and commercial consumption of energy is complex, uncontrolled and under development. CMM has the opportunity to progress alongside India's energy system into a modern, sophisticated provider to domestic users if the correct policies are instituted to improve energy suppliers and brokers ability to meet demand.

4.4. Industrial Fuel

4.4.1. Use

4.4.1.1. Fuel for Steam Production

India produced roughly 340 million tons of coal equivalents (Mmtce) in 2013, with 291 Mmtce of that used as steam coal. Almost 50% of total industrial energy use is sourced from coal, and it is projected to grow to 56% by 2040 alongside increasing demand from different branches of industry. According to the EIA, the production of 1 kilowatt hour (kWh) of power from coal generates over 80% more carbon dioxide than the same electricity production from natural gas.

4.4.1.2. Fuel in Furnaces and Heating Applications

4.4.1.2.1. Iron and Steel (Fuel for Blast Furnaces)

India is the fourth-largest producer of steel in the world. According to the World Steel Association in 2016, 57% of India's steel was produced under electric-based methods, which represents the second-highest proportion of electric-based steel production among major producers (EIA, 2017). The majority of the remaining 43% is made via oxygen-based processes. It is the only country to use coal instead of natural gas for large-scale direct reduced iron (DRI) production (IEA, 2015). Their reliance on coal-based sponge iron manufacturing is a product of easy-to-build DRI facilities, India's lack of access to cheap, domestic natural gas and the fact that domestic coking coal, which is necessary for pig iron production, is relatively lower quality. The rapid production growth of the industry was driven by expansion in capacity and improved capacity utilization. The iron and steel sector are considered crucial to economic growth, and a linear relationship has been proven to exist between steel production and national gross domestic product (GDP).

Most iron and steel plants in India are located in the state of West Bengal, Jharkhand, and Orissa due to the availability of iron ore, limestone and coal- the main raw materials needed for the production of iron and steel. India's steel plants are very energy intensive overall due to their use of coal instead of natural gas. India's three major DRI gas-based producers ran at a utilization rate below 30% in 2013 because of low availability of domestic natural gas (IEA, 2015).

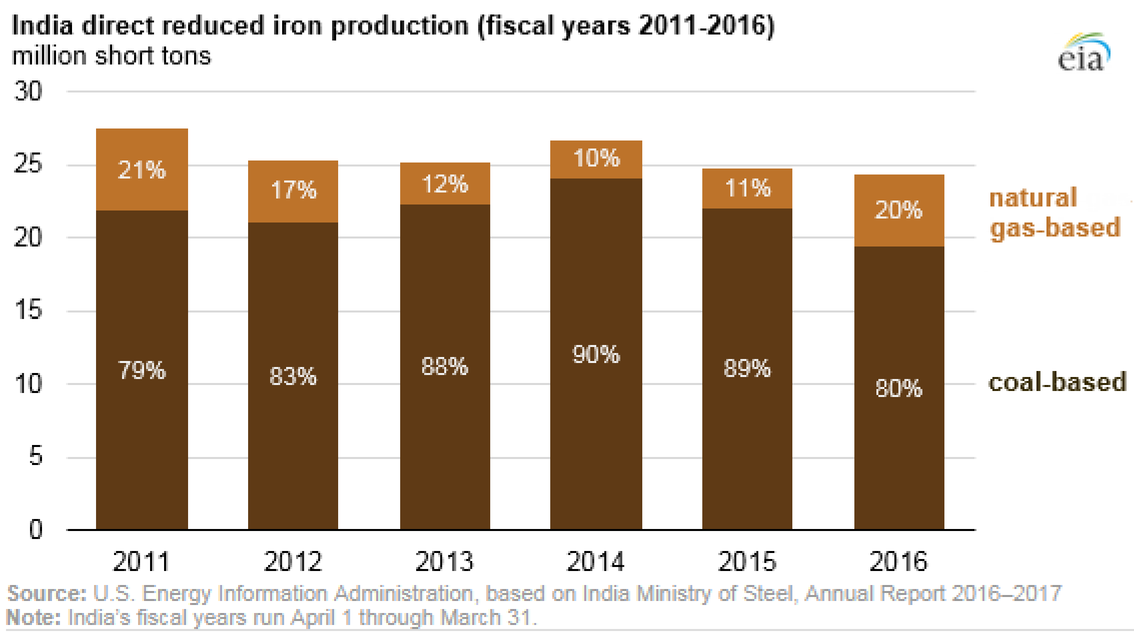


Figure 9: India's mix-use of fuel consumption for DRI production (EIA, 2017).

4.4.1.2.2. Aluminum (Smelters)

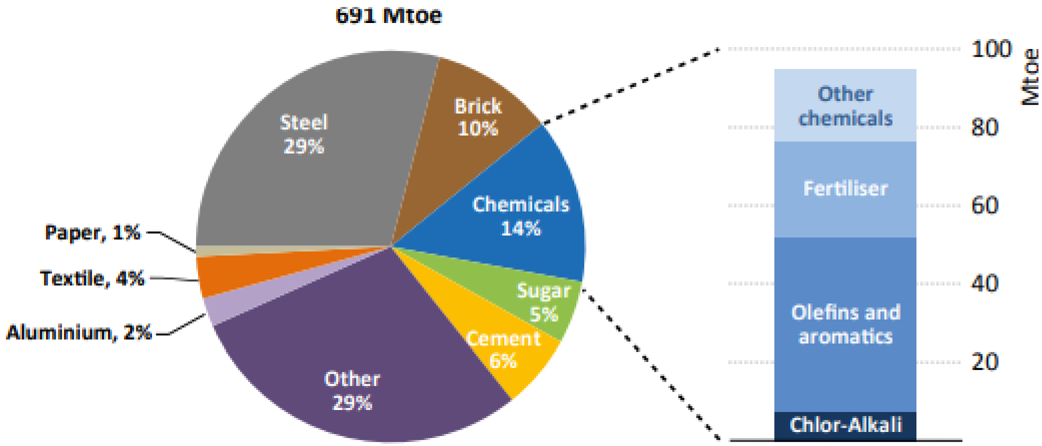
Aluminum production involves the electrolytic reduction of alumina, which is a very energy intensive process that uses electricity. India ranks fourth in the world in terms of alumina production. It has abundant bauxite reserves and comparatively low labor costs, which has driven the country to become a net exporter of alumina and bauxite. The Bayer and Hall-Héroult processes are the major industrial processes that transform the resource into a useful product through the course of refining bauxite and smelting aluminum. Both are very energy intensive and rely heavily on energy to power the process. The average electricity consumption for the production of 1 ton of aluminum is roughly 15,000 kWh. Raw materials used in the manufacturing process include calcined petroleum coke, caustic soda, aluminum fluoride, fuel/oil and steam/anthracite coal (CARE, 2017). Because the cost of power is such a large component of the manufacturing process, aluminum producers are located near cheap, abundant sources of power. In India, aluminum manufacturing companies have their own coal-fired captive power plants to reduce costs and serve as a source of energy for manufacturing.

4.4.1.2.3. Cement (Kilns)

The cement industry is expected to triple its energy demand by 2040 in order to meet the growing demands of urbanization across the country. Large production units and the use of modern technologies have made India’s cement industry one of the most efficient in the world. The relatively high use of fly ash and blast furnace slag as a substitute for the more energy-intensive clinker, the output of the cement kiln, is an example of some of the industry’s innovation. Energy intensity of cement production is expected to decrease 13% by 2040 due to a decline in the clinker-to-cement ratio (IEA, 2015). Small-scale cement industries in India consume an average fuel consumption of 3.7 GJ per tonne of clinker and electricity consumption of 104 kWh/t of cement, while the average fuel consumption for large cement industries was 3.29 GJ/t and electricity consumption was 92 kWh/t (IIASA, 2011).

India’s brick industry is unlike most other countries and does not rely on tunnel kilns for the production of hollow or perforated bricks. Rather, it is an extremely labor-intensive industry that is spread out over more than 100,000 small plants and makes use of biomass as its main source of fuel. The brick industry has significant potential for better energy efficiency. CMM would be a good option to fire small kilns, as there are also many small-scale cement plants located throughout the Damodar Valley coal region.

Figure 10: Projected (2040) industrial energy consumption by sector in India in the New Policies scenario (IEA, 2015).



4.4.2. *Competition*

4.4.2.1. Coal / Pet-Coke

India lays claim to over 87 Bt of proven coal reserves, roughly equivalent to 140 years of current output. Most coal can be found in the eastern regions of the country, two-thirds of it in the states of Jharkhand, Odisha and Chhattisgarh. Exploited Indian coal reserves are largely shallow in depth, but technologies like CBM and CMM will become even more attractive once mining operations migrate to deeper, gassier seams to meet increasing demand. While India's CMM emissions are currently low, the EPA projects India's emissions will grow 34% between 2017 and 2030 as a result of high rank and gassier coal production (2012). On a granular level, most Indian coal falls in a range of 3,500 kcal/kg to 5,000 kcal/kg, which is markedly lower than coal in other major producing countries. This is attributable to the high-ash content in the coal, which reduces its calorific value (IEA, 2015). Indian miners have to extract around 1.5 tons of coal to get the same amount of energy as 1 ton of Australian coal as a result of this calorific value difference. Nevertheless, coal dominates the energy mix in India as a result of its accessibility and cost. Non-coking coal consumption is expected to increase at a CAGR of 5% to roughly 960 Mmt in 2022 from 742 Mmt in 2017. Domestic supply is estimated to increase at a CAGR of 7% to 846 MT from 598 MT over the same period (CRISIL, 2018).

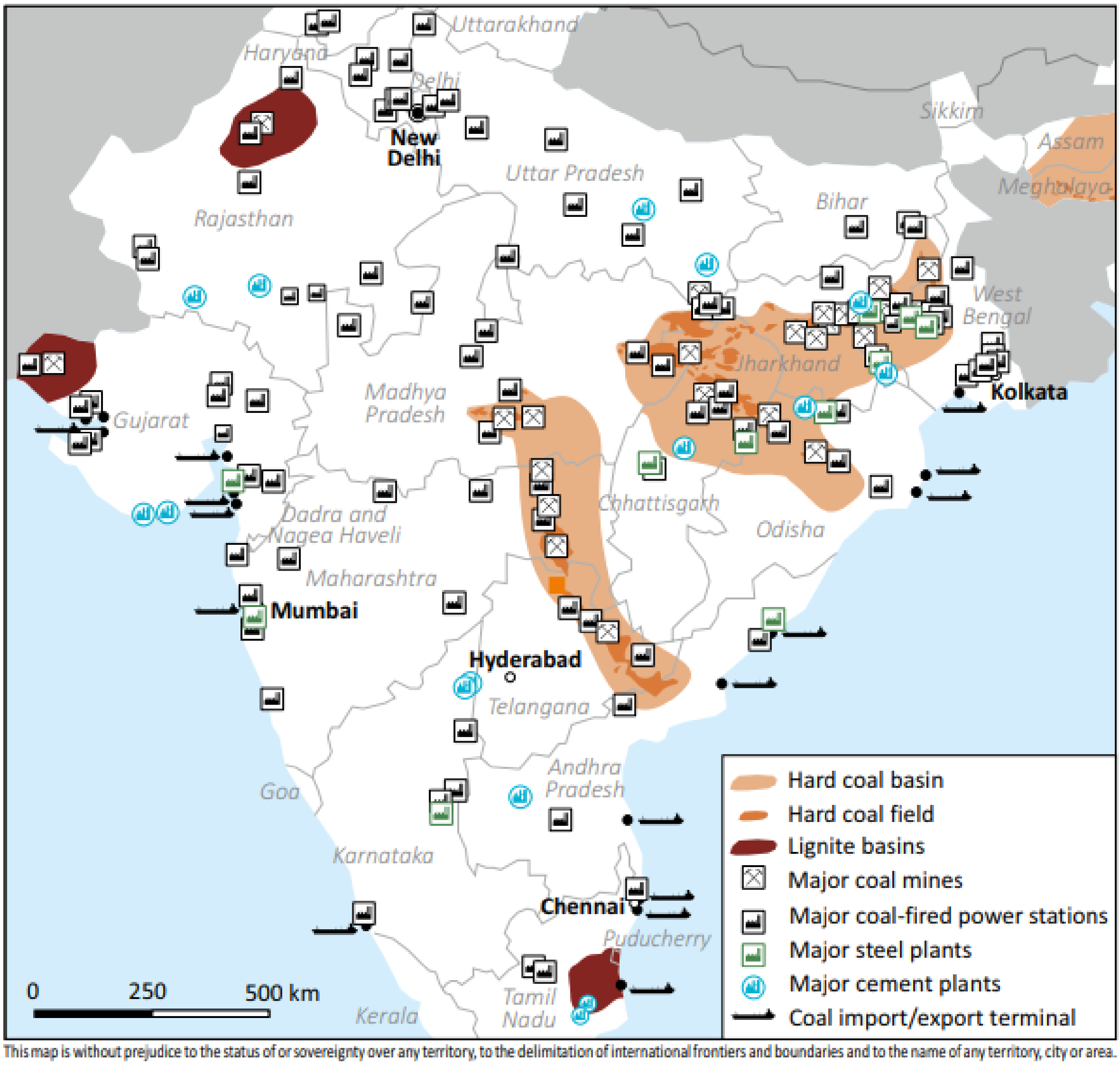


Figure 11: Map of India's coal reserves and industrial hubs (IEA, 2015).

India recently banned the import of petcoke for use as fuel, while imports for cement, lime kiln calcium carbine and gasification industries, when used as feedstock or in the manufacturing process are still allowed. India is the world's largest consumer of petcoke, and imports over half its annual consumption, amounting to 27 MT, from the United States (Reuters, 2017.2). Rising consumption of petcoke is attributable to increased demand from the cement industry and favorable logistics in areas where domestic coal supply has been constrained by holdups in rail networks (Gordon, 2017).

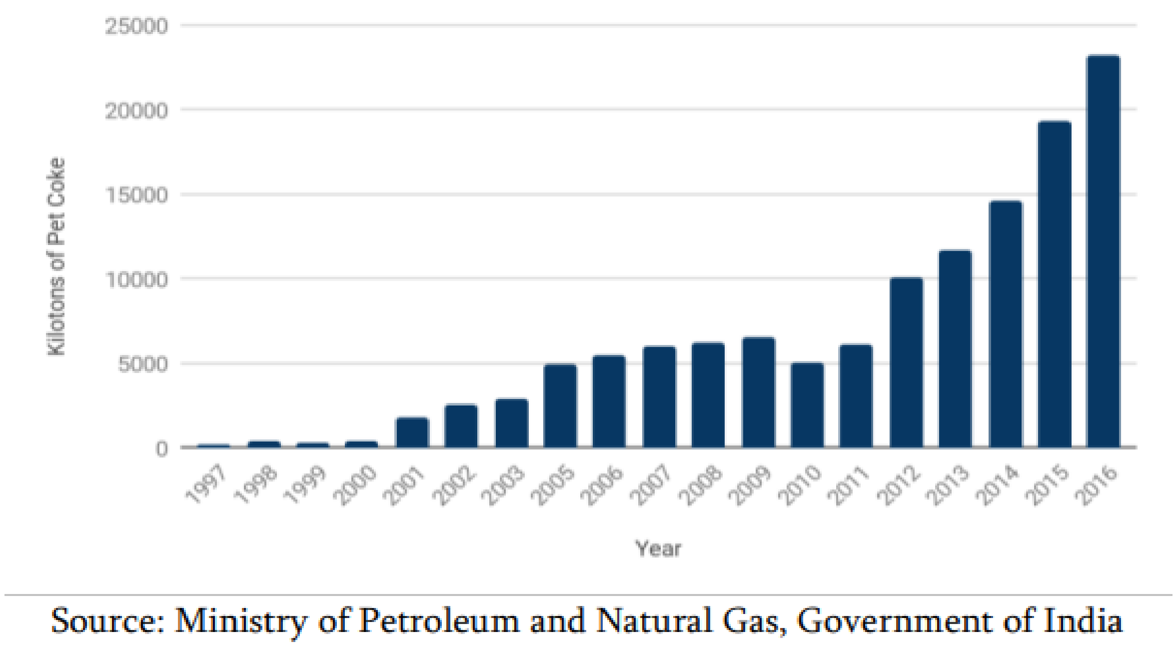


Figure 12: India Petcoke Consumption, 1997- 2016 (Gordon, 2017).

4.4.2.2. Electricity (Electric Arc Furnaces)

Electrical arc furnaces heat charged material by way of an electrical arc, which creates an electrical breakdown of gas that produces an ongoing electrical discharge. As mentioned earlier, 57% of India's steel was produced under electric-based methods, representing the second-highest proportion of electric-based steel production among major producers. Half of the electric-based process steel is made by the use of electric induction furnaces rather than the more internationally common electric arc furnaces. Electric induction furnaces use induction to convert materials into steel. Induction furnaces differ from arc furnaces in that they can operate on much smaller scales, around 20 tons per batch (EIA, 2017). Compared to blast furnaces, electric furnaces produce much lower carbon emissions overall.

4.4.3. Outlook of CMM as Industrial Fuel

While coal still dominates the industrial energy mix, government mandates will create a need to use more efficient, cleaner sources of energy to meet climate goals and rising demands for power in the future. Widespread use of electric-based furnaces illustrates India's willingness to utilize energy-efficient technologies at the industrial level. Cost of fuel plays a huge factor in the industrial sector's choice of their energy source, so CMM will need to be available as a cheap and abundant resource to initiate adoption at a large scale. As India develops its pipeline infrastructure to transport natural gas across regions of the country, it will travel through major supply and demand hubs. CMM will inherently be located near the coal supply hubs as well as the industrial demand centers which have set up near the historical supply of energy.

4.5. Industrial Feedstock

4.5.1. Use

4.5.1.1. Fertilizer Industry (Ammonia and Urea)

India's domestic fertilizer industry is a major consumer of energy that is critical to India's efforts to ensure food security. Most of the phosphorus and potassium-based fertilizers are imported, while roughly three-quarters of the nitrogen-based urea fertilizers are produced domestically. The fertilizer industry consumed 15.8 Bcm of natural gas for use as feedstock in 2013. It is one of the sectors with priority access to domestically produced gas, which is obtainable at a regulated price. The agriculture industry is heavily subsidized and has led to the over-consumption of urea relative to other fertilizers. However, urea's energy use is projected to decrease to 0.55 toe/ton by 2040, representing a 4.8 Bcm reduction in the amount of natural gas required as a feedstock (IEA, 2015). The Steel Authority of India Limited (SAIL) announced plans to build a urea-based fertilizer plant near Sindri, which is likely to spur infrastructure investment and increase demand for natural gas in the long term (USEPA 2015.1).

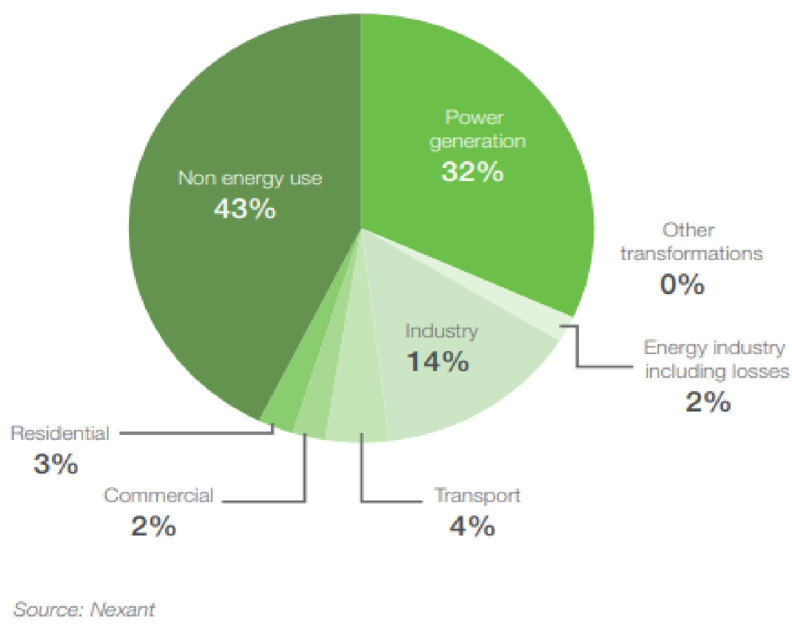


Figure 13: India's natural gas demand by sector (Non-energy use is largely dominated by fertilizer and petrochemical industries) (GPCA, 2017).

4.5.1.2. Petrochemicals (Chemicals like Methanol, etc.)

Petrochemicals are an essential part of the chemical industry where the choice of feedstock for plants is governed by four major factors: availability, cost, power consumption and the product portfolio to be produced. Key application industries for petrochemicals include packaging, construction and automobiles. Local initiatives that will likely result in new opportunity for industries and push the demand for petrochemicals are: the rapid expansion of Metro Rail Projects, the construction of 15,000 km of new highways, the launch of Smart Cities and an emphasis on rural development (APIC, 2017). The "Make in India" initiative will continue to contribute to domestic industrial and manufacturing production after its implementation in 2014. The petrochemical industry is expected to reach $100 billion in value by 2020, growing at a CAGR of 14%, which is roughly double the country's GDP (ASSOCHAM, 2015).

Depending on the end-use for petrochemicals, there are a variety of fuel resources that the industry consumes. Natural gas can be used as the feedstock for hydrogen production and is competitive with other feedstocks due to advances in catalysis, energy efficiency and process design optimization.

4.5.2. Competition

4.5.2.1. Natural Gas/Hydrogen

Current reserves of natural gas stand close to 7.9 Tcm (277 Tcf), with that figure split between conventional, mostly offshore, and unconventional, in the form of shale and CBM (IEA, 2015). Close to half of production for domestic natural gas was contributed by state-owned Oil and Natural Gas Corporation (ONGC) and Oil India Limited (OIL). ONGC's Bombay High and South Bassien field and onshore fields in Dahej are the only sources of rich gas in India. Economically feasible ethylene cracking requires natural gas that contains 10%-15% of C2-C3 streams by weight. Rich gas (containing greater C2+ contents) is preferred by the petrochemical industry.

India's 39 m^3 (1,377 ft^3) per capita consumption of natural gas lags far behind the worlds average of 469 m^3 (1656 ft^3) per capita (EY, 2015). This is in part due to lower availability and price affordability; inadequate transmission and distribution infrastructure and limited gas import facilities. As mentioned, the demand for natural gas has far outpaced domestic supply, which has led to increasing amounts of imported LNG.

4.5.2.2. Non-Gas Fuels (Naphtha and Fuel Oil)

The petrochemical industry relies heavily on naphtha for its important refining industry. Secondary uses of naphtha include use as a feedstock for steam cracking to produce petrochemicals and the production of aromatic petrochemical products. Naphtha demand is expected to increase to 0.5 million barrels per day (Mmb/d) by 2030 from 0.3 Mmb/d in 2014 (IEA, 2015). State-run Bharat Petroleum currently uses a mix of 20% domestic and 80% imported crude oils but was planning to expand its naphtha production by 10%-15% after finishing work on its 15.5 million-ton refinery expansion (APIC, 2017).

4.5.3. Outlook of CMM as Industrial Feedstock

Lucrative opportunities are available in specialty chemical segments, which cater to huge emerging domestic demand and manufacturing sectors. There is clearly an unfulfilled market with such high demand coupled with availability of resources. If CMM resources are able to meet unique requirements of an industry such as petrochemicals, they have the ability to be a major supplier to plants not near current sources of natural gas and other non-gas fuels. The few suitable domestic gas producers for the petrochemical industry are located in the western regions of the country, while the east has abundant coal, CMM and CBM resources. With a more advanced infrastructure system, the transportation of CMM resources to provide fuel as industrial feedstock might be feasible given the large resource base and lower cost compared to imports of LNG.

4.6. Transportation

4.6.1. Use

4.6.1.1. CNG Vehicles

India’s transportation sector is unique in that it was once dominated by rail, but is now dominated by road transport, which accounts for 86% of passenger and almost two-thirds of freight movements (IEA, 2015). CNG use in vehicles has already been adopted in major cities like New Delhi and is expected to increase after the recent ban on petcoke imports for use as fuel in India. Stricter emissions standards (BS-VI) will be rolled out from April 2020 in an effort to curb sulfur emissions. The standards are expected to increase the costs of petrol and diesel-powered trucks and buses. India could potentially scale up the total number of CNG stations from the current 1,349 to 5,000 by 2025 (NRI, 2018).

More recently, Dharmendra Pradhan, the minister of petroleum and natural gas, announced a rollout of 10,000 CNG gas stations over a decade as a push to reduce India’s dependence on oil imports. That transition could potentially save over 2 Rs lak crore ($27.8 billion) if prospective buyers make the transition to CNG vehicles (Economic Times, 2018). The country could have 10 million CNG vehicles on the road by 2025 depending on how India provisions an effective public transport system and road quality improvements. Petronet LNG Limited, the New Delhi-based major energy company and LNG distributer, entered an agreement with the Indian Government to establish LNG for transportation applications following approval by the Ministry for Road, Transport and Highways for it to be used as a road fuel (NGV, 2017). CNG technology reduces emissions and lowers the cost of importing crude oil.

4.6.2. Competition

4.6.2.1. Petrol/Gasoline and Diesel

Transport is currently controlled by oil for the most part, with a relatively high share of diesel in overall transport demand. The same high mix of diesel is present in the European Union and its high share of diesel-fueled passenger cars. However, India’s high share of diesel consumption is attributable to the large number of freight vehicles and buses. The railway sectors energy consumption is two-thirds diesel, despite efforts to electrify railways. Diesel is expected to dominate energy use in the future, backed by a strong increase in freight activity (IEA, 2015). A number of factors will control the demand for fuel including type of transportation method that sees significant growth over the years, cost of fuel, infrastructure development and emission-curbing policies.

4.6.2.3. Electric Vehicles

Some regions of India that are adversely affected by pollution have already implemented stricter fuel standards for vehicles, while other mandates have attempted to make new vehicles more fuel efficient in the coming years. Cost and convenience will have to be favorable for consumers to make the switch to electric vehicles. Some estimates only recorded 2,000 electric vehicles sold in India in 2017, compared to the 579,000 sold in China during the same year (Lekach, 2018). Electric vehicles will put an increased demand on India’s already strained grid. However, EV’s could find their way into the mainstream, with cities like New Delhi leading the way, if the government continues to roll out favorable policies.

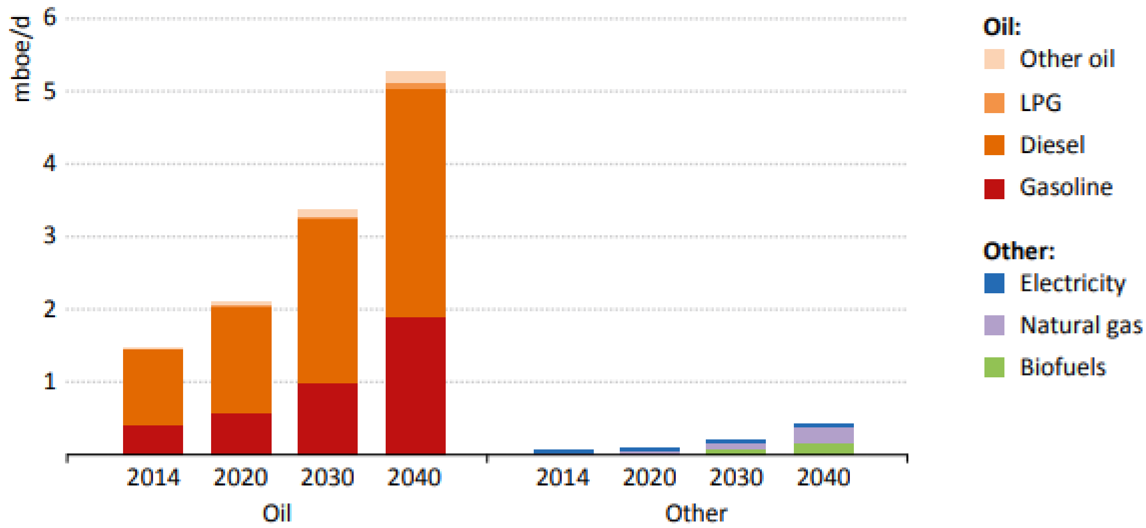


Figure 14: Transport fuel by type in the new policies scenario (IEA, 2015).

4.6.3. Outlook for CMM as Transportation Fuel

Widespread adoption of CNG and grid-powered electric cars will need to occur for CMM to find its way into the transportation sector. That adoption is largely contingent on cost, availability, convenience and government policy to support purchases of those vehicles. As CGD operations start to materialize on a broader scale, CNG stations provide resource distribution opportunities that will effectively reduce the cost of access to CNG for demand centers. There is potentially a market opportunity for CMM utilization projects to provide energy to CGD centers, which are largely driven by demand from CNG cars, as almost three-quarters of demand of the CGD originates from CNG (Economic Times, 2018). India will need to cultivate a sustainable transportation system with such high quantities of transport demand in the future, of which CMM may have the capability to supply given the right conditions.

5.0 Potential CMM Project Barriers and Solutions

5.1. Barriers

CMM utilization project barriers in India are important to consider with the most prominent of them being the issue of inadequate infrastructure. India has dealt with the "chicken or the egg problem" regarding decisions to develop its pipeline infrastructure or its natural gas reserves, when it requires concurrent progress on both fronts. There is a serious demand for gas and methane products, but the delivery of energy resources to end users is contingent on India's ability to develop an adequate energy transmission system. Secondly, CMM faces barriers relating to its extraction and its marketability. CMM is in its emerging stages, and it is still being proven as a resource that can be profitable for producers. So far, methane production levels in mines are relatively low, which means there may be a limited market demand unless technology is developed to better capture and utilize CMM. Policymakers also need to provide incentives to energy producers for capturing GHG emissions to spur interest in CMM. Lastly, CMM must prove itself as a cost-competitive source of energy for adoption. Energy-consumers demand resources like coal because it is relatively cheap compared to other energy sources. CMM will have to be competitive with resources like LNG and other domestic forms of gas for acceptance as a resource.

5.2. Potential Solutions

Wide-scale CMM utilization in India cannot succeed without help from policymakers and technological advancement. It has already received support due to such high levels of demand for energy in India. GAIL's plan to develop more pipeline infrastructure paired with India's large investments in energy infrastructure will improve accessibility to CMM. In addition to macroeconomic factors, CMM utilization projects must provide benefits at the micro-level. CMM utilization improves mine workers' safety, prevents gas from escaping into the atmosphere, reduces ventilation requirements and improves mine productivity. CMM is versatile in that it can be used for pipeline injection, fuel needs of local industries, power generation (on-site or to grid), feed for fertilizer plants and other onsite uses such as drying coal. Identifying key factors affecting methane emissions, such as permeability, will help when making production estimates. Lastly, India needs to further characterize its CMM resources by measuring critical reservoir parameters governing the flow of methane in coal seams. These parameters include gas content/gas saturation, permeability, reservoir pressure and others. The CMM/CBM Clearinghouse at CMPDI, in partnership with GMI, continues to explore opportunities to fully develop India's CMM/CBM potential.

6.0 Conclusions

India's projected demand for energy will likely lead to continued coal exploration and production on an increasing scale. As production continues, the country will need to mine deeper for its coal, where gassier seams exist, which will lead to higher methane emissions unless the CMM is recovered and utilized. Economic, regulatory and technological developments in recent years have significantly improved the potential for CMM utilization projects from India’s extensive coal deposits. Over the last year, India has opened-up development of CMM/CBM on lease blocks operated by Coal India, Ltd., removed price controls on CMM/CBM production, and begun construction of a network of pipelines that will route near major coalfields and provide a ready market for the produced gas. National policy objectives to decrease natural gas imports, increase domestic coal production, and reduce carbon emissions further support a positive landscape for CMM development in the future.

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