Small-Scale LNG for Expanding Natural Gas Access in India

Sabarish Elango and Hemant Mallya

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Small-scale LNG utilises scalable and flexible infrastructure.

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"Leveraging the scalability, flexibility, and movability of of the small-scale Liquefied natural gas (ssLNG) infrastructure will be vital for providing competition for lower delivered price in India's natural gas markets."

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"Scaling up ssLNG will be essential to fill the access gap for India to reach the 15 per cent natural gas total primary energy share target."

Small-scale LNG distribution is made possible through truck-loading bays in LNG terminals across the country.

Image: Shell LNG Terminal in Hazira (Surat), Gujarat

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Acronyms

CAPEX	capital expenditure
CGD	city gas distribution
CNG	compressed natural gas
CUF	capacity utilisation factor
GST	goods and services tax
HP	high pressure
ISO	International Organization for Standardisation
LNG	liquefied natural gas
LP	low pressure
LPG	liquefied petroleum gas
mmBtu	metric million British thermal unit
mmscmd	million metric standard cubic metres per day
MoPNG	Ministry of Petroleum and Natural Gas
MSME	micro, small, and medium enterprises
mtpa	million tonnes per annum
OPEX	operating expenses
PESO	Petroleum and Explosives Safety Organisation
PNG	piped natural gas
PNGRB	Petroleum and Natural Gas Regulatory Board
scm	standard cubic metres
scmd	standard cubic metres per day
tkm	tonne-km
VAT	value-added tax

Potential gas consumers without pipeline access can be serviced using LNG container trucks.

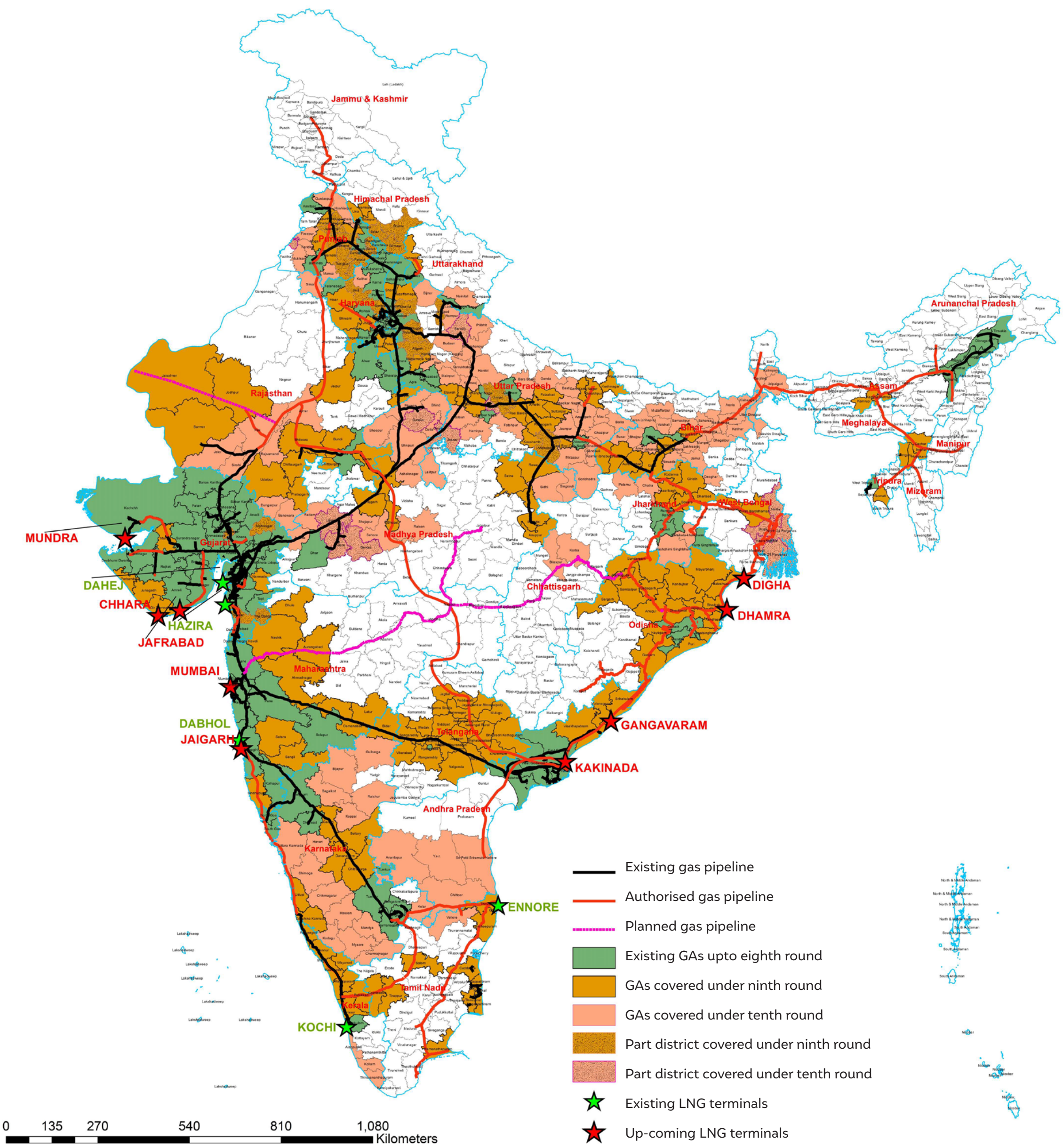
Image: Shutterstock

Executive summary

Natural gas has played an important role in mitigating emissions from several hard-to-abate sectors to address climate change in major global economies. However, natural gas has yet to contribute significantly to the primary energy supply in India, with only a 5.7 per cent share (IEA 2018). Distribution of natural gas in India relies primarily on a 17,000-kilometre network of pipelines for transmission from liquefied natural gas (LNG) terminals and domestic production locations to consumers across different sectors.

However, access to pipelines is limited in several southern and eastern states. Even the planned 15,000-kilometre (approximate) addition to the transmission network will not reach several potential gas consumers (Figure ES1). Transmission pipelines are expensive to construct and often require significant funding from the government to make them viable. Lengthy commissioning times and low capacity utilisation in the initial years of operation (as demand builds), experienced historically, are additional profitability stressors.

Figure ES1 **Limited coverage of natural gas pipeline network in India**



Source: PNGRB 2020a

Small consumers of natural gas rely on city gas distribution (CGD) companies to deliver natural gas from transmission pipelines. CGDs have infrastructure exclusivity in the areas allocated to them. Depending on the CGD pipeline network's reach, consumers may not have access if they are located outside the CGD network's range. Also, since the CGDs are allocated entire districts for gas distribution development, it takes much longer for low-density areas to receive a connection. The gas price charged by CGDs is often uncompetitive with incumbent fuels, considering the investments needed to be made by consumers to switch over to gas. Such issues have prevented the natural gas market from growing as anticipated.

Opportunities for ssLNG

Small-scale LNG (ssLNG) systems transport LNG in cryogenic containers and regasify the LNG at the consumer site. Delivering natural gas as ssLNG could be advantageous for those consumers

I. who are yet to be connected by gas pipelines,

II. whose location lies outside of any proposed coverage area of gas transmission or CGD pipelines,

III. or who cannot procure CGD gas at economical prices.

Small-scale LNG could provide potential consumers with temporary access to gas, thus helping build demand for pipelines. It could also serve as the primary source of gas if no pipeline connection is expected. Small-scale LNG would serve certain users such as large construction sites, mines, and quarries better than piped gas due to their fluctuating fuel needs. Small-scale LNG could also complement existing CGD connections for consumers to diversify supply options and optimise procurement costs. The use of LNG as a transport fuel for heavy-duty vehicles is being encouraged and supported by the Ministry of Petroleum and Natural Gas (MoPNG). Small-scale LNG systems are essential to supply LNG to the numerous refuelling stations being planned across the country.

Business prospects for ssLNG

The ssLNG market could support investments from several stakeholders. LNG terminal operators could benefit by providing the transport and regasification service to enhance their reach and improve their capacity utilisation. Micro, Small and Medium Enterprises (MSMEs) could gain from a commonly managed ssLNG system, with a local micro-grid network for gas delivery. Third-party companies could engage in volume aggregation of small consumers' demand and provide doorstep delivery of LNG from terminal to consumer site, providing natural gas access to the small consumers.

Supply chain configurations for ssLNG

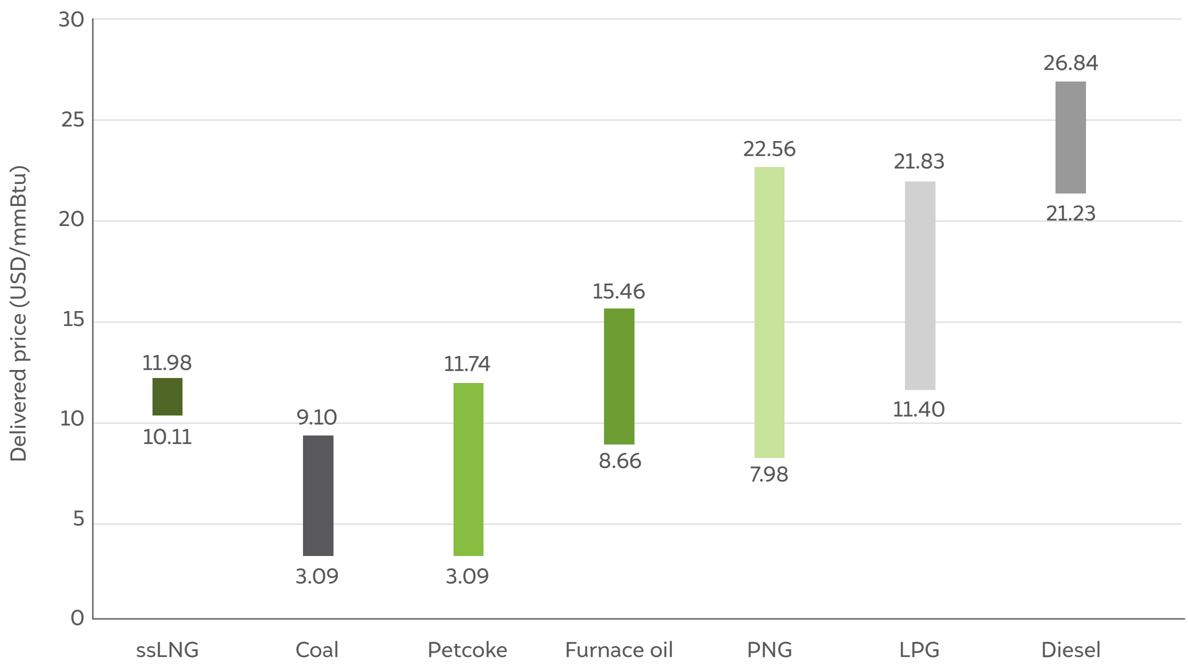
Small-scale LNG can be delivered to consumers in four configurations —by the LNG importing terminal, the consumer's own fleet of vehicles, a third-party logistics service provider, or a third-party aggregator. We evaluated the cost of moving ssLNG from the terminal to the consumer location and subsequently regasifying it for the second configuration. For the other configurations, there are increased efficiencies resulting from servicing multiple consumers. The marketing margins for these configurations are not available in the public domain. Hence, the cost of ssLNG is difficult to quantify. For this study, we calculated the prices for gas delivered through ssLNG systems for a 0.1 million metric standard cubic metres per day (mmscmd) regasification capacity over 20 years at different LNG import prices, for delivery distances from 200 to 1,000 km.

Economics of ssLNG

To estimate the delivered price of ssLNG, we considered the 2017–18 average LNG import price of 7.39 USD (INR 542) per million British thermal units (mmBtu) (PPAC 2020b). For this import price, the delivered price of regasified ssLNG was estimated at 11.11 USD/mmBtu (815 INR/mmBtu) for a one-way distance of 200 kilometres, and 11.98 USD/mmBtu (843 INR/mmBtu) for a one-way distance of 1000 kilometres. The price range of ssLNG is competitive with incumbent fuels such as liquefied petroleum gas (LPG), diesel, and certain petcoke and furnace oil grades as shown in Figure ES2. Gas delivered through ssLNG systems could potentially also be cheaper than CGD gas in many locations due to the high CGD selling price/margins. The price spreads between ssLNG and diesel/LPG are high enough to ensure short payback periods for transport and regasification infrastructure investment.

The price range of ssLNG is competitive with incumbent fuels.

Figure ES2 The delivered price of ssLNG compares favourably with several other fuels



Source: Authors' analysis

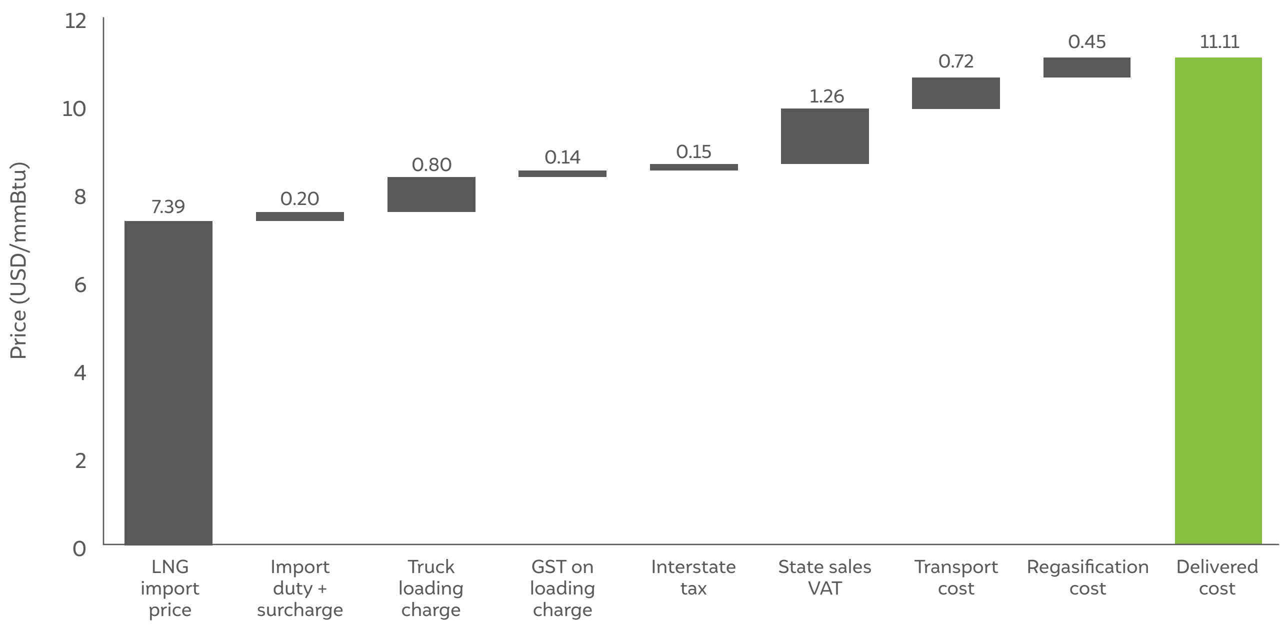
Note 1: Prices for states in proximity to terminals - Tamil Nadu, Kerala, Andhra Pradesh, Telangana, Karnataka, Maharashtra, Odisha, Jharkhand, Chhattisgarh, West Bengal, Gujarat, and Rajasthan.

Note 2: 10th and 90th percentile of prices considered to remove outliers.

Note 3: 2017-18 average LNG import price considered for ssLNG range due to lack of data on individual import cargoes.

The break-up of price for one-way distance of 200 kilometres is shown in Figure ES3. The break-up suggests that, apart from the LNG import price, major contributors are the truck-loading charges levied by the terminal, the value-added tax (VAT) applied on gas in the state of sale, and the cost of transporting LNG.

Figure ES3 VAT, loading charges, abd transport costs contribute significantly to the delivered price of ssLNG



Source: Authors' analysis

We conducted a sensitivity analysis to understand the impact of varying discount rates, the ssLNG system lifetime, terminal loading charges, and VAT (results in Figure ES4). The analysis shows that changes in the discount rate on the capital expenditure (CAPEX) of setting up an ssLNG system do not significantly impact the delivered price of ssLNG. The delivered price of natural gas through ssLNG increases for shorter project lifetimes - those setting up a temporary ssLNG system must pay a marginally higher delivered price. Still, the increase is not significant as the salvage value of the equipment has not been accounted for in this analysis. The delivered price of ssLNG varies proportionally with the changes in terminal loading charges. However, it is still not significant. Finally, reducing the VAT from 14.5 per cent (as in Kerala) to 3 per cent (as in Maharashtra) reduces the delivered price of LNG significantly, by 8–10 per cent.

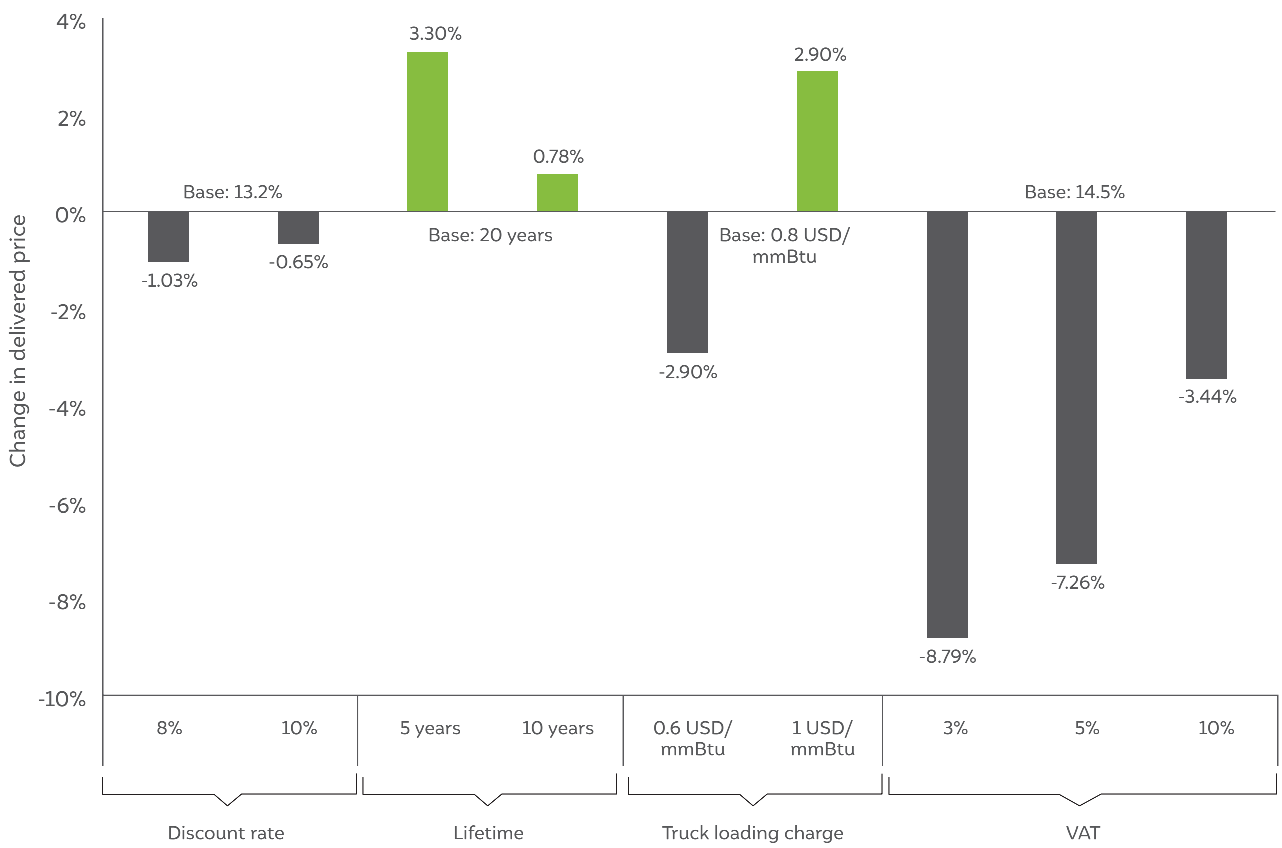
Our analysis suggests that the low initial costs; competitive delivered gas prices; and scalability, flexibility, and movability of ssLNG infrastructure could be very beneficial for improving gas access.

Challenges for ssLNG

There are some challenges associated with ssLNG systems, such as the possibility of transport disruptions (caused by inclement weather, accidents, etc.) and the limited LNG volume that can be supplied. Costs of retrofitting or re-engineering equipment for consumers to use gas, and the logistical and managerial constraints in the case of small industrial consumers, also pose some challenges. However, sound system design, resource management, and policy support can address these issues.

> **The low initial costs; competitive delivered gas prices; and scalability, flexibility, and movability of ssLNG infrastructure could be very beneficial for improving gas access.**

Figure ES4 VAT has the highest impact among the considered sensitivity variables



Source: Authors' analysis

Note: Sensitivities shown for an LNG import price of 6 USD/mmBtu and 200 km one-way distance.

Policy recommendations for ssLNG

Several regulatory and policy actions can provide an impetus through ssLNG for the increased access and utilisation of natural gas. Such actions will allow India to move towards the Ministry of Petroleum and Natural Gas' (MoPNG) stated goal— to increase the share of natural gas in the country's total primary energy supply (TPES) to 15 per cent by 2030.

1. **MoPNG and PNGRB should clarify that ssLNG does not infringe on the infrastructure and marketing exclusivity of CGD on its own networks** (in the geographic area allocated to that CGD), which will result in gas-on-gas competition and better price discovery, providing natural gas access at competitive prices to the consumers.

2. **PNGRB should consider introducing a clause in the PNGRB Regulation G.S.R.198(E) that provides pipeline infrastructure exclusivity to CGDs** for an exception to pipeline/distribution network connectivity within an industrial cluster. This will allow MSME clusters to source ssLNG, regasify it at a single location in the cluster, and distribute it through a pipeline network strictly limited to the cluster without infringing on the exclusivity rights of the CGDs.

3. A vital benefit of the ssLNG system is its standardised and modularised equipment, especially cryogenic tanks. The nodal agency for approving cryogenic tank design, **the Petroleum and Explosives Safety Organisation (PESO), should approve the use of the International Organisation of Standardisation's ISO 1496/3 design**, which allows for the containerisation of tanks for the intermodal transport of LNG. PESO should also approve the transport of these containers on railway wagons.

4. India's railway network is extensive and can potentially reach customers in locations with no existing or planned pipelines. The Dedicated Freight Corridors with faster travel times can significantly reduce the delivered cost of ssLNG. Therefore, the **Indian Railways should develop specific tariffs for LNG transport and provide the necessary infrastructural support to haul LNG freight** containers, both of which do not currently exist.

5. The VAT on natural gas sales varies widely across states. States can choose to reduce VAT on natural gas consumption **(such as the three per cent rate in Maharashtra)** while awaiting the transition of petroleum fuels to the goods and services tax (GST) system. States can selectively reduce VAT for small customers, such that the states' revenue collection is not significantly impacted. Still, small industrial customers will be able to access natural gas.

6. The **Sagarmala initiative should promote and support the use of natural gas as fuel for inland and coastal waterways transport**. Using gas can eliminate fuel spillages from diesel engines in waterways and reduce air pollution in ecologically sensitive areas; ssLNG will play a crucial role by supporting the natural gas refuelling system along the waterways.

1. Introduction

Natural gas plays a significant role as a transition fuel in various sectors as economies shift away from coal and petroleum fuels (International Energy Agency [IEA] 2019). In India, the share of natural gas in the primary energy mix is only 5.7 per cent (IEA 2018). The Ministry of Petroleum and Natural Gas (MoPNG) has set a target of increasing this to 15 per cent by 2030, underscoring the significant potential for a fuel transition in the Indian economy.

Natural gas is currently distributed through a 17,000-kilometre network of transmission pipelines from various production locations and LNG import terminals to residential, commercial, power generation, and industrial consumers (Petroleum and Natural Gas Regulatory Board [PNGRB] 2020b). The existing network primarily covers Maharashtra, Gujarat, Madhya Pradesh, Uttar Pradesh, Haryana, and the National Capital Region in the north and Karnataka and Kerala in the south. Additionally, more than 15,000 kilometres of pipelines are under construction and scheduled for completion by 2023 (PNGRB 2020b). However, even with these additions, the gas network will be unable to service large areas in several states, including Tamil Nadu, Andhra Pradesh, Odisha, Chhattisgarh, and Jharkhand (PNGRB 2020a). These states have significant industrial bases that can potentially switch to natural gas. Still, coverage depends on the construction of spur lines and CGD networks to connect to critical demand nodes, which could take up to a decade.

Gas pipelines have a large CAPEX outlay for construction; the upcoming Jagdishpur-Haldia-Bokaro-Dhamra pipeline (JHBDPL) is estimated to cost USD 0.69 million (INR 5 crore) per kilometre (PNGRB 2019b). Therefore, pipeline projects are unprofitable in many cases, especially without significant viability gap funding from the government (40 per cent of CAPEX for JHBDPL) and the uptake of gas at expected volumes. Low capacity utilisation factors (CUF) further diminish the profitability of pipelines, as is the case in the existing network, which has a CUF of approximately 48 per cent (Petroleum Planning and Analysis Cell [PPAC] 2020a). These issues can restrict the rapid development of pipeline infrastructure, thus limiting access to potential customers. Given these challenges, a solution is necessary to build demand for pipelines while under construction to ensure their profitability when completed and to service those demand nodes that will not be connected by pipeline networks in the near future, or ever.

Access to natural gas depends on the reach of the gas transmission pipelines and access to city gas distribution (CGD) pipeline networks that provide last-mile delivery to customers. CGDs have infrastructure exclusivity over their network in the geographic area allocated to them. Geographic areas are being allocated to CGDs at a district level, which have varying densities of demand. Typically, CGDs prioritise networks in high demand density areas within a district, resulting in delayed access for the remaining areas. Therefore, a CGD may not build a network up to individual demand nodes located far from the primary grid, leaving the latter without access. The ssLNG system could supply gas to such demand nodes.

The transport sector could see a large uptake of LNG for heavy-duty vehicles due to its cost-competitiveness with diesel. To promote the use of LNG-fuelled trucks, MoPNG plans to install a large number of refuelling stations along major highways in the country. These stations will require a regular LNG supply, which natural gas pipelines cannot provide.

Small-scale LNG (ssLNG) could help increase demand for gas and provide sustainable access. By utilising scalable, modular, and movable assets to target small demand nodes, ssLNG can diversify the natural gas consumer base. Doing so can help build demand for future pipeline networks such that the CUF of the network is higher than expected in the initial years. Small-scale LNG can deliver gas to demand nodes located away from existing and future pipeline networks. Small-scale LNG could complement existing CGD connections to diversify supply options and optimise procurement costs. LNG refuelling stations across highways will need to be serviced by ssLNG. Short-term flexible demand requirements of large constructions, mines and quarries could be met through ssLNG systems.

Image: Shell

This brief aims to provide an understanding of ssLNG and the various configurations under which it can operate. It offers a snapshot of the status of ssLNG usage across different countries. We discuss the opportunities for utilisation of ssLNG systems and who should invest in such systems. We also discuss the benefits and challenges of deploying ssLNG systems. The brief includes the economics of delivered prices of ssLNG for various distances and LNG import prices so that end users can determine the viability of ssLNG for their specific cases. Finally, we make recommendations to transcend barriers and explore new avenues for scaling up ssLNG in India.

In this brief, we do not look at the dynamics of demand realisation, which primarily rely on competing fuel prices and switching costs (i.e., retrofitting or replacing) of end-user equipment. The rationale is that once the gas is accessible, market forces will resolve these issues. Since ssLNG is scalable, demand realisation can happen incrementally, and a priori large-scale demand realisation is not necessary as in the case of pipelines.

> **Small-scale LNG could complement existing CGD connections to diversify supply options and optimise procurement costs.**

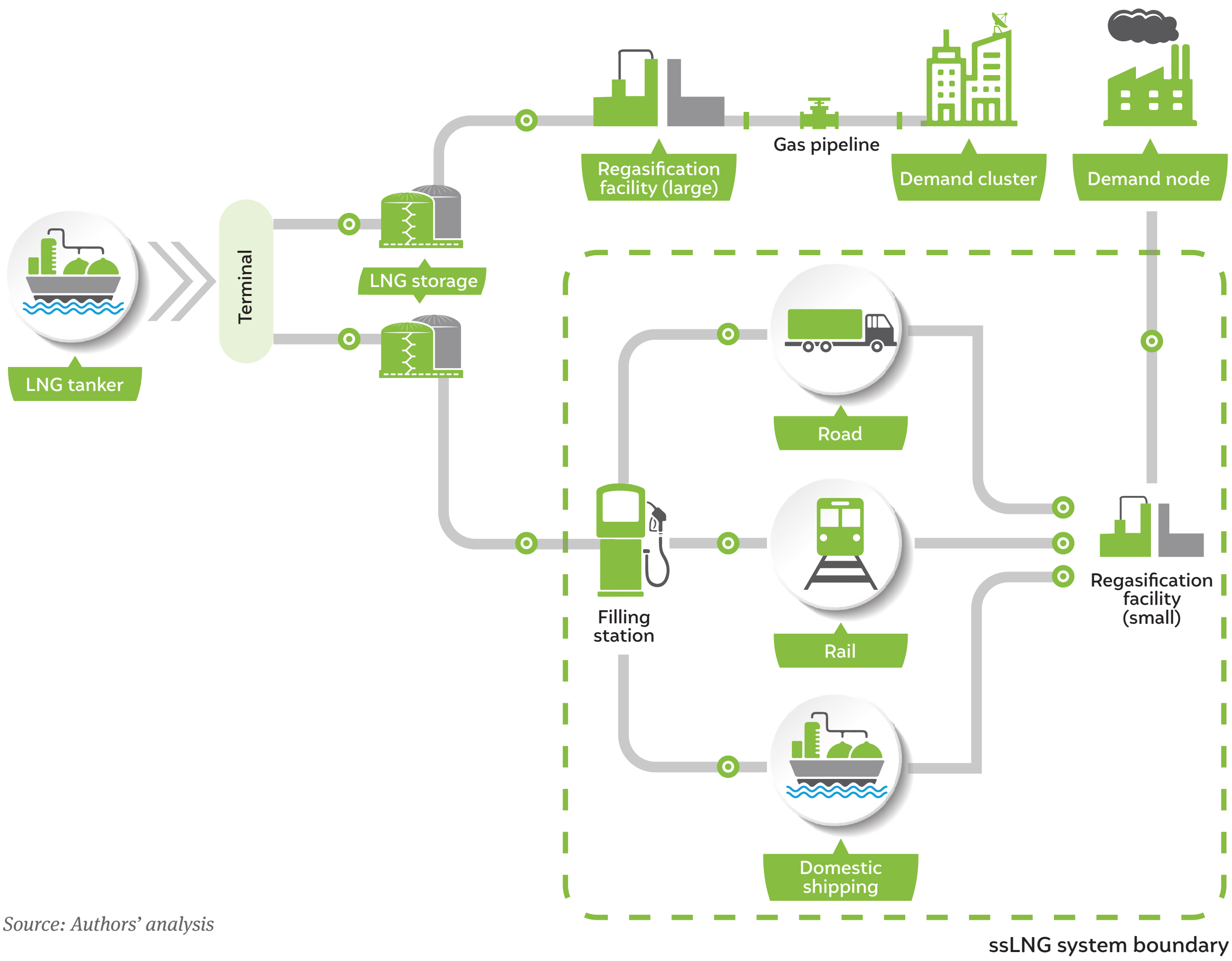
2. What is an ssLNG system?

In an ssLNG system, LNG is transported from one point to another using road, rail, or waterways instead of pipelines. It is then regasified before the point of end-use.

2.1. The ssLNG supply chain

The typical supply chain for an ssLNG system consists of the LNG liquefaction terminal, LNG receiving terminal, transport system, and regasification station. In India, however, all LNG is imported to LNG terminals, which form the starting point of the supply chain depicted in Figure 1.

Figure 1 Small-scale LNG systems use road, rail, or waterways instead of transmission pipelines



Source: Authors' analysis

2.1.1 LNG receiving terminal

Tanker ships carrying LNG arrive at the receiving terminal's offloading jetty, where a transfer system offloads the LNG into large cryogenic storage tanks. The storage tanks usually contain a buffer of 3–4 days' supply to compensate for any supply disruptions. Stored LNG can be regasified to a high pressure onsite and supplied to long-distance gas pipeline networks that feed large demand clusters. In the case of ssLNG, the LNG is loaded at the terminal from truck loading bays into cryogenic containers for transport. As natural gas is imported in a liquid state, liquefaction systems are unnecessary; instead, the LNG is transported directly from the terminal to the consumer's regasification facility. In specific scenarios, small-scale liquefaction of natural gas from pipelines for delivery to remote areas in the form of ssLNG might be feasible; however, this will require a small liquefaction facility that can be expensive.

2.1.2 Transport

Transporting LNG for small-scale consumers is possible via road, rail, or waterways. Road-based transport is common, with trucks hauling LNG containers (20–40 ft long, approximately 16-34 tonnes gross weight, approximately 20-48 kilolitres capacity) from the LNG terminal to the satellite plant. Rail-based transport of LNG using cryogenic tank wagons can help improve efficiency, provided the rail network can connect the LNG terminal and the demand node. Similarly, LNG can be transported by small LNG tanker ships that can either access coastal locations or utilise inland waterways. This solution, too, is limited by the location of the infrastructure. The transport system can be scaled up or down depending on demand and hence is more suited than pipelines for developing demand clusters or meeting peak-shaving demand. In general, the cryogenic conditions of LNG storage in the tanks permit hold times of 60–65 days, with boil-off losses of around 0.2 per cent per day (Chart 2013).

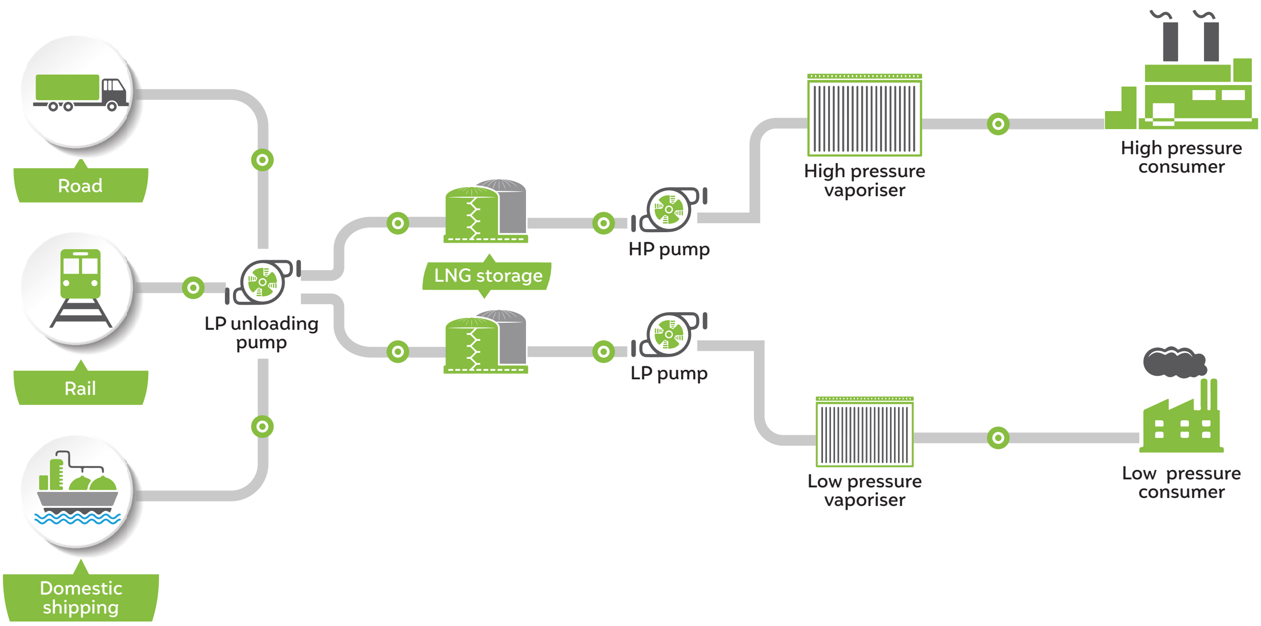
For all the three means of transport, the LNG can also be used as fuel for the prime mover (especially for road and waterways). LNG use instead of diesel in trucks can improve engine efficiency by approximately 15 per cent (Unilever et al. 2017). LNG purchased from the importing terminal also costs significantly less than diesel available at fuel stations. The extended range that LNG offers also minimises the need for fuel stops.

2.1.3 Satellite storage and regasification plant

LNG is transported to satellite storage and regasification plants located at or near the demand node being supplied. The satellite plant has the following major components.

> The transport system can be scaled up or down depending on demand and hence is more suited than pipelines for developing demand clusters.

Figure 2 Major components of the satellite plant



Source: Authors' adaptation from IGU (2015)

Satellite storage tanks

The transported LNG is offloaded (pumped) into small storage tanks at the satellite facility. Satellite storage tanks sizes vary according to daily demand (referred to as 'send-out'); in addition, a buffer amount equivalent to 3–4 days' supply compensates for transport disruptions. Storage systems can be scaled up or down to meet demand and be designed to be movable.

Pumps

The stored LNG is pumped into vaporisers for regasification using cryogenic pumps. Depending on the demand, low-, medium-, or high-pressure pumps may be used.

Vaporisers

Vaporisers regasify the LNG to a suitable delivery pressure—low, medium, or high. In the regasification process, the LNG is heated from cryogenic to atmospheric conditions through a heat exchange process, typically with ambient air. Low-pressure gas is suitable for co-located consumers; medium-pressure gas for commercial and residential gas networks; and high-pressure gas for compressed natural gas (CNG) stations and dense pipeline networks.

There are several variations in the design of satellite plants, depending on demand duration and volume.

i. Stationary systems are semi-permanent structures mounted on rigid substrates, meant to supply medium- to long-term demand nodes.

ii. Skid-mounted systems utilise compact storage and regasification units mounted on skids to meet low-volume, short-term demand; these systems allow for easy relocation.

iii. Containerised systems use small tanks and regasification units that can be hauled by trucks. These can supply remote demand nodes or exceptional use cases, such as mines, on a one-time basis or an irregular schedule.

2.1.4 ssLNG supply configurations

There are four prominent configurations possible for the sale and transport of LNG from terminal to consumer site. The techno-economic assessment in Section 3 considers these options:

i. **Configuration 1**: In the first configuration, the terminal operator uses its fleet of vehicles to transport and deliver LNG to the consumer's doorstep. The terminal charges a bundled price for the LNG, including the LNG and transport costs. The consumer bears the CAPEX and OPEX of the regasification equipment.

ii. **Configuration 2**: In the second configuration, the consumer purchases the LNG at the terminal (referred to as 'ex-terminal') and arranges their own transport to move the LNG to their site and subsequently regasifies it for end-use.

iii. **Configuration 3**: In the third configuration, the consumer purchases the LNG at ex-terminal prices and contracts a logistics service provider to arrange LNG transport to their site.

iv. **Configuration 4**: In the fourth configuration, a third party buys the gas from the import terminal and sells it to the end-use consumers. This third party may also lease out regasification equipment to consumers. The difference between Configurations 3 and 4 is that in Configuration 4, the third party owns the gas, whereas in Configuration 3, the third party only provides transportation as a service.

The first configuration is more common among Indian consumers, as they can avoid subcontracting a logistics service or maintaining a fleet of vehicles. The second configuration is feasible for mostly mid-sized long-term customers willing to invest in a logistics system. The third configuration is a classic logistics service relevant for irregular or one -time deliveries. The fourth configuration is in a nascent stage, but the most promising as it will allow for bundling of smaller demand nodes, which terminals may not be willing to serve. In Configurations 1-3, the consumer owns and operates the satellite plant for regasifying the LNG.

A CGD can rely on ssLNG (in Configuration 2) to cater to demand in the early days of infrastructure development while waiting for access to a transmission pipeline. This will also help CGDs prioritise grid development to areas when the built-up demand exceeds a certain economic threshold. Finally, CGDs can use ssLNG to service areas which cannot economically be connected by pipelines.

2.2 Opportunities for ssLNG

Small-scale LNG systems are applicable in several areas and sectors, and the prominent ones are discussed below,

i. **Areas without pipeline access**: While several public and private stakeholders are involved in increasing gas pipeline coverage, numerous states and districts will remain without pipeline access in the next decade. Despite extensive trunk pipeline construction (in states like Chhattisgarh, Jharkhand, Tamil Nadu, Andhra Pradesh and Karnataka), spur lines and city gas networks are yet to materialise. Even in those regions with piped natural gas (PNG) availability, the delivered price of gas is often very high due to high selling prices (unregulated end-customer prices & marketing margins) on CGD supplied gas. Thus, significant demand exists for more expensive fuels such as furnace oil, diesel, LPG and CGD gas (see Figure 7). Small-scale LNG could spur industries and small commercial and industrial clusters to switch from these fuels to natural gas. The gas demand equivalent to LPG use by industries is significant, at 5.8 mmscmd (as calculated from Petroleum Planning and Analysis Cell [PPAC] 2020b, 2020c) for states that can access terminals through ssLNG. Further, there is a demand of 7.3 mmscmd gas equivalent for diesel in power generation and transport in industries. However, this requires retrofitting or replacement, the economics of which are difficult to quantify.

ii. **Fuel stations**: Heavy-duty transportation could benefit greatly from switching to LNG from diesel – the lower fuel costs and potential increase in fuel efficiency would allow increased margins for logistics companies or lower transportation costs for consumers. The MoPNG expects a demand of 25-30 mmscmd by 2035, with 10 per cent of trucks switching to LNG (Ministry of Petroleum and Natural Gas [MoPNG] 2020b). The Ministry has already planned a network of 50 LNG refuelling stations along the Golden Quadrilateral network of national highways, targeting an increase to 1,000 stations in the next three years (MoPNG 2020b). Using ssLNG systems to service these stations with fuel could become the norm, similar to conventional fuel stations. This provides an excellent opportunity for third party operators to aggregate fuel station and consumer gas demand to optimise their systems.

iii. **Mines, quarries and large construction sites**: Certain locations such as mines and construction sites could benefit from ssLNG distribution systems since such sites are usually not suited to pipeline connections. A large quantity of energy is consumed in the form of diesel by heavy-duty machinery operating at such sites, which could benefit from cheaper and more efficient LNG fuel delivered by ssLNG systems.

iv. **Consumers seeking competitive and diversified supply source**: Several consumers, specifically in the industrial sector, are currently buying expensive CGD supplied gas (with high marketing margins). These consumers can consider ssLNG as a viable and potentially cheaper alternative to CGD supplied gas or to supplement their CGD volumes.

2.3 Who should invest in ssLNG?

Sections 1 and 2.2 show the potential of ssLNG to be an effective means of distributing gas for various end-use cases. As such, different stakeholders can consider investing in ssLNG systems.

i. **Industrial consumers**: Industries consuming expensive fuels such as petcoke, diesel and LPG could have a net benefit by investing in ssLNG systems for sourcing natural gas. Section 3 shows the economics of ssLNG and compares prices of gas (delivered through ssLNG) with incumbent fuels (see Figure 6). The techno-economic assessment shows that investing in and managing transport and regasification systems (as in Configuration 2) could provide a net cost-benefit to the consumer depending on gas demand. Large industrial consumers can also utilise ssLNG as a temporary arrangement while pipelines get built.

ii. **Service providers**: Logistics companies could explore the ssLNG business for transporting gas between the LNG terminal and the consumer. They could operate in Configuration 3 as a logistics provider or in Configuration 4 as an aggregator, thus commanding higher margins on the gas delivered.

iii. **CGD operators**: Existing CGD network operators could expand the reach of their network within a geographic area using ssLNG, thereby avoiding the need to rely on pipelines for areas which do not have a significant gas demand. CGDs can also develop ssLNG systems to supply gas to their pipeline networks that are still waiting for connections to a trunk transmission pipeline.

> **The gas demand equivalent to LPG used by industries is significant, at 5.8 mmscmd for states that can access terminals through ssLNG.**

2.4 Benefits and challenges of ssLNG

As mentioned in Section 2.2, there is a distinct market for ssLNG distribution owing to the limitations and issues with pipeline distribution. However, certain circumstances compromise the reliability of ssLNG. Here are some benefits and challenges associated with ssLNG.

Benefits

i. Small-scale LNG **can compete in many cases with CGD delivered piped gas because of high CGD marketing margins** that result in a higher delivered price of natural gas.

ii. An ssLNG system allows demand centres (such as mines and factories, typically located away from populated areas) that are not connected to pipeline networks to access natural gas.

iii. It is **cost-competitive with various incumbent fuels such as LPG and diesel** (see Figure 6) despite the lower efficiency of ssLNG transport vis-à-vis pipelines.

iv. Multiple ssLNG players servicing the same area will bring about competition and better price discovery for end users.

v. **CAPEX requirements for an ssLNG system are** significantly lower than the costs of pipeline development. Multiple operators can serve the same area, leading to CAPEX distribution among multiple entities, thus de-risking systemic CAPEX allocation. Therefore, ssLNG systems can expand more quickly than pipelines.

vi. Pipelines typically experience low demand in the initial years of operation, reducing the project's overall profitability. Such a lack of demand visibility also hinders future expansion. **An ssLNG system can be utilised to build anchor demand while pipelines are in the development phase**, thereby improving their overall viability and profitability when completed.

vii. Since pipelines are fixed, non-scalable assets, they must be sized appropriately to have sufficient capacity to meet any increases in demand for a few decades. However, **there is the risk of demand stagnating at a lower capacity and pipeline assets getting stranded.** Small-scale LNG systems can mitigate this risk, as it is movable and scalable.

> **Small-scale LNG can compete in many cases with CGD delivered piped gas because of high CGD marketing margins.**

viii. Facilities that have a pipeline connection and fixed contract volumes can be supplied with ssLNG for peak-shaving demand. There are sections of pipelines currently running at near-full capacity, so ssLNG distribution will have to deliver additional volumes.

ix. Small-scale LNG better serves consumers with intermittent, irregular, or seasonal requirements.

x. Piped gas relies primarily on long-term contract prices; however, **ssLNG can exploit the spot market and leverage dips in short-term prices**.

xi. Opting for ssLNG to supplement their existing PNG connections would allow consumers to optimise their supply chain and procurement costs better.

Challenges

i. As ssLNG systems rely on road, rail, or waterway transport, **they are susceptible to disruptions to any of these modes of transport resulting from natural events** (flooding, cyclones, and earthquakes); accidents that delay travel; or human-made events such as strikes or public disorder. Such disruptions can be mitigated to a large extent by maintaining a sufficient LNG inventory that covers consumption or send-out for 3–5 days without needing replenishment.

ii. **Small-scale LNG primarily benefits end-users who require only a small volume**. However, such end users typically do not have the sophistication to manage their own fuel supply chain, as discussed in Configuration 2. Even if the end-user relies on the Configuration 1 approach (where the terminal supplies the LNG), they may not be able to secure long-term contracts. Thus, they will become susceptible to price movements in international markets and price changes in the terminal's LNG supply contracts. However, this is not significantly different from piped natural gas, which is susceptible to the international LNG market's vagaries.

iii. **Utilising natural gas in existing industrial or commercial facilities often requires some retrofitting of equipment or re-engineering of**

processes. This warrants some upfront capital investment to enable the switch from the incumbent fuel to natural gas. Also, industrial operations are designed to use a specific fuel which provides process stability. Changes in fuel type and the associated uncertainty is undesirable. These issues may dissuade consumers in the industrial sector from switching to LNG.

iv. **Stakeholders misinterpret the regulation of PNGRB offering marketing exclusivity to CGD operators** (exemption from permitting third-parties to use CGD pipeline network) to include natural gas supply through ssLNG. Some CGD operators hold and propagate the view that small-scale LNG storage and regasification infrastructure (even for consumers' captive consumption) is an integral part of the CGD network and hence eligible for infrastructure exclusivity, implying that ssLNG sourcing is illegal. Therefore, consumers are hesitant to contract ssLNG and invest in regasification equipment – they would prefer certainty on the policy/regulatory position before committing investments to avoid potential legal disputes with the CGD operators in the respective authorised areas, if already licensed.

v. Several clusters of micro, small and medium enterprises (MSMEs) in the industrial sector could potentially be good candidates for ssLNG. However, these clusters often comprise of dozens, if not hundreds, of small units. In such cases, there is no single entity that can be held responsible for the logistics, common storage and regas infrastructure and management of gas supply. Also, because multiple units are involved, a microgrid distribution pipeline network is necessary to move the gas from the common receiving site for storage and regasification and the end consumers' sites.

2.5 Small-scale LNG across the world

Small-scale LNG is still a developing system, with an estimated global capacity of only 30 mtpa in 2020 (PricewaterhouseCoopers [PwC] 2017). However, ssLNG capacity could double or triple by 2030, owing to its significant potential in remote power generation applications and the transport sector (PwC 2017). Typical ssLNG markets include countries with a vast spatial distribution of populations/industrial activity (e.g., China, India, and the United States of America [USA]) or challenging geography that limits the potential for pipeline construction (e.g., Indonesia and Japan).

2.5.1 ssLNG in India

Small-scale LNG presently has very little penetration in India. As the natural gas market is comparatively small in India, a paucity of information, visibility, and policy support compound the nascency of ssLNG. Major

Image: Shutterstock

gas consumers are traditionally supplied by pipeline networks, the development of which the government continues to prioritise.

Small-scale LNG was pioneered in India by Indian Oil Corporation Ltd in 2007 (Indian Oil Corporation Ltd [IOCL] 2020). In 2019, the company sold 36.12 thousand tonnes of ssLNG (IOCL 2019) and was the market leader in the supply of LNG by trucks (IOCL 2015).

Small-scale LNG could precede pipeline construction to build demand for the latter; Gail (India) Limited has established this configuration in India. To enhance demand in the city of Bhubaneswar, where Gail has been allocated the development of CGD, the company is transporting LNG from Dahej on the west coast (1,700 kilometres away) using trucks. The LNG is regasified to low pressure for city gas users and high pressure for CNG vehicles (Press Trust of India 2020). This configuration intends to create demand and make the upcoming long-distance pipeline more profitable. Similar systems could supplement future city gas networks catering to smaller towns so that distributors can use ssLNG systems instead of relying on third-party pipeline development.

Currently, the LNG import terminals (Dahej, Hazira, Kochi and Ennore) supply ssLNG to a small number of industrial consumers. A lack of awareness and a limited supplier base which can offer flexible and customised price constructs to manage volatile gas prices also limit such applications. Expanding such ssLNG systems through third party or terminal networks will help increase the CUF of underperforming LNG terminals (such as the one in Ennore), where a lack of demand and pipeline construction delays affect handling and loading charges.

2.5.2 ssLNG in China

China is by far the largest market for ssLNG, with an estimated capacity of approximately 20 mtpa (in 2020), predominantly in the northern and western provinces (IGU 2015). Drivers of ssLNG in China include policy concerns surrounding air pollution, which prompted coal-to-gas switching in 2017 (APEC Energy Working Group 2019). Various sectors consume ssLNG; however, transport demand will be significant in the future. The use of LNG and CNG vehicles (especially for heavy-duty transport) is on the rise because they are more fuel-efficient (Unilever et al. 2017) and LNG costs less than diesel.

> **Small-scale LNG presently has very little penetration in India.**

LNG is distributed predominantly by trucks; an estimated fleet of 1,300 LNG delivery trucks was functional in China in 2016. The country has adopted waterway transport using small LNG tankers (which deliver LNG from large terminals to smaller ones) at a limited scale; only two such ships were in operation as of 2018. There are more than six million natural gas vehicles in China, of which around 200,000 are heavy-duty trucks (APEC Energy Working Group 2019). Strong governmental intervention and control of prices have ensured the prevalence of ssLNG in the Chinese market (International Gas Union [IGU] 2015).

2.5.3 Other markets

Countries such as the USA and Japan consume large quantities of natural gas and are developing ssLNG infrastructure. In both Japan and the USA, ssLNG is partially transported by train, using either cryogenic railway wagons (in the USA) (Levy 2020) or intermodal ISO containers (in Japan) (JAPEX 2020). Iran is also developing its ssLNG distribution network; moreover, the low price of domestic gas enables the country to meet demand in remote regions (Shirazi et al. 2019). Similar developments are taking place in South America, with limited small-scale distribution in countries like Argentina (Garcia-Cuerva and Sanz Sobrino 2009). Small-scale LNG is used in Indonesia to support gas power plants, and in Europe to reach remote demand centres, CNG stations, and ship refuelling (APEC Energy Working Group 2019).

3. The economics of ssLNG

We assessed the techno-economic feasibility of ssLNG distribution by comparing the delivered prices of LNG with those of other fuels such as coal, petcoke, LPG, and diesel, as well as that of gas delivered through pipelines. We considered a baseline demand of 0.1 million metric standard cubic metres per day (mmscmd) for one-way distances between 200 and 1,000 kilometres (the total distance is double for the return trip of empty containers). This volume represents the demand of a small township or a mid-sized industrial cluster or individual unit (using fuel for process heat).

3.1 Methodology

Depending on the delivery configurations mentioned in Section 2.1.4, the delivered price for the consumer includes the following components:

i.

i. **LNG landed cost:** The price at which the terminal imports the LNG. We considered a range of 4–10 USD/mmBtu for the landed cost of LNG, which can be either a spot price or long-term contract price.

ii. **Import duties and other surcharges**: Imports of LNG carry an import duty of 2.5 per cent, with an additional surcharge of 10 per cent applied on the duty component.

iii. **Loading charges**: The terminal levies a charge to load the LNG into cryogenic or ISO containers; this is a typical tolling charge in LNG sales comparable to the regasification charge levied for pipeline injection. We considered a charge of 0.8 USD per million British thermal units (mmBtu), including a 0.2 USD/mmBtu (typical) margin.

iv. **GST on loading charges**: The loading charges are liable for a goods and services tax (GST) of 18 per cent, as a tax on service that the terminal renders.

v. **Transport cost**: This is the total cost in USD/mmBtu of transporting the LNG (by road or rail) from the terminal to the consumer site (Section 3.1.1). In Configurations 1, 3 and 4, the taxable delivered price of gas includes this cost; in Configuration 2, the consumer bears this cost, which is not taxed.

vi. **Transport margins**: In Configurations 3 and 4, the price paid to the service provider or aggregator, respectively, for transporting LNG from the terminal to the consumer location will include a margin (on an average at 20 per cent).

vii. **GST on transport cost**: A GST of five per cent (without input tax credit) is applied to the transport cost in Configurations 1, 3 and 4 (and rail transport in Configuration 2), as it is a service provided to the consumer.

viii. **Central sales tax**: If LNG is sold in a different state, a two per cent central sales tax is levied on the LNG import price. Our analysis included this tax for distances greater than 600 kilometres, assuming such distances mean that ssLNG is delivered in a different state from the one in which the terminal is located.

ix. **State taxes on natural gas**: For Configuration 1, the value-added tax (VAT) is applied in the state in which the terminal delivers the LNG. In Configurations 2 and 3, the sales VAT is applied in the state in which the terminal is located. In Configuration 4, VAT is paid at the terminal (by the service provider) and the delivery state (by the consumer). The VAT varies among different states (e.g., 5 per cent in Tamil Nadu and 14.5 per cent in Kerala).

x. **Satellite plant costs**: This refers to the USD/mmBtu for installing and operating a satellite storage and regasification plant at the consumer site (see

Table 1 Key assumptions of road transport costs

Assumption	Value	Reference
Availability	0.9	Authors' assumption
Fuel consumption (diesel truck)	35 litres (l)/100 km (loaded)	(International Council on Clean Transport [ICCT] 2017)
	30% less (empty)	(Maynus and Sheckler 2009)
Fuel consumption (LNG truck)	15% less than that of diesel trucks	(Unilever et al. 2017)
Average speed	40 km/hr	(ICCT 2017)
Loading/unloading	1 hour each	Authors' assumption
Lifetime	10 years	Authors' assumption
Working hours	12 hrs/day	Authors' assumption
LNG capacity	48,000 l (tank trailer)	(Chart 2021)

Source: Authors' analysis

Section 3.1.2). The consumer bears this cost in all the configurations.

3.1.1 Transport cost

Road transport

Transportation costs involve the cost of purchasing and operating trucks (fuelled by diesel or LNG) and trailers. Table 1 shows the key assumptions.

i. We calculated the operating expense (OPEX) of trucks based on typical costs such as maintenance, wages, and tolls per tonne-km (tkm) (Transport Corporation of India [TCI] and IIM Calcutta 2016). The costs were scaled (to the tonnage/mileage of a specific case from those of the base case) and inflated (from 2015 values) (Reserve Bank of India [RBI] 2020).

ii. Freight rates were scaled based on distance (Rivigo 2019) and LNG price (for LNG trucks).

iii. We estimated the cost of diesel based on average prices in June 2019.

iv. We assumed the cost of LNG as fuel for trucks to be the same as the LNG price ex-terminal.

v. We considered 40-foot tank trailers to transport the LNG from the terminal to the consumer.

Table 2 gives the cost of road-based transport.

Rail transport

The Indian railway system is not yet equipped to transport LNG via intermodal containers or railway wagons. We estimated rail transport costs by assuming that intermodal ISO containers would be transported as Class 180 cargo (Indian Railways Conference Association [IRCA] 2012) under the assumptions in Table 3. The rail transport costs are provided in Table 4.

Table 2 Road transport costs

Component	CAPEX	OPEX
Truck (diesel)	USD 32,732 (INR 2.4 million) each (IndoTrux 2020)	0.03–0.04 USD/tkm (2.12–3.02 INR/tkm)
Truck (LNG)	30% more than diesel truck CAPEX (Barnett 2018)	0.013–0.026 USD/tkm (0.98–1.92 INR/tkm) (Configuration 2)
Truck (trailer)	USD 136,836 (INR 10 million) each (industry sources)	5 per cent of CAPEX/year (assumed)

Source: Authors' analysis

Table 3 Key assumptions of rail transport costs

Assumption	Value	Reference
Availability	90%	Authors' assumption
Average speed	23.20 km/hr	(Indian Railways 2020)
Loading/unloading	8 hours each	Authors' assumption
Lifetime (container)	10 years	Authors' assumption
Working hours	24 hrs/day	Authors' assumption
LNG capacity	43,500 l (ISO container)	(Chart 2013)

Source: Authors' analysis

Table 4 Rail transport costs

Component	CAPEX	OPEX
Train	Not applicable	0.025–0.03 USD/tkm (1.82–2.22 INR/tkm) (Ministry of Railways 2020)
ISO container	USD 122,748 (INR 9 million each)	5 per cent of CAPEX/year (assumed)

Source: Authors' analysis

3.1.2 Satellite plant cost

The satellite plant costs primarily include the cost of the storage tanks and regasification system (pump, vaporiser, and piping) to meet the consumption or send-out requirement of 0.1 mmscmd. We made the following assumptions:

i. The vaporiser operates at a CUF of 80 per cent.

ii. The storage system includes a buffer of approximately two days' demand (Shirazi et al. 2019, numbers scaled to 0.1 mmscmd).

iii. A factor of 1.94 is applied to convert equipment costs to engineering, procurement, and construction costs (Shirazi et al. 2019).

iv. We considered a lifetime of 20 years for the satellite plant.

3.1.3 Delivered price calculation method for ssLNG

Figure 3 gives an overview of the price build-up for all four configurations. The delivered price of regasified ssLNG considers import costs, terminal charges, transport costs, regasification costs and all applicable taxes and duties at each stage. The calculation does not include profit margins for the transport of LNG. This assumption is valid for Configuration 2, in which the end-user owns and operates the transport system. Therefore, we presented the results for Configuration 2 only. For Configurations 1, 3 and 4, since the transport system's utilisation is dependent on multiple consumers, it is not easy to calculate a representative delivered cost. However, one can approximately calculate the cost by considering an applicable transport tariff, a transport margin (of approximately 20 per cent) and a goods-and-services tax (GST) on transportation.

Using a simple discounted cash flow method, we determined the cost per mmBtu of transporting and regasifying ssLNG. The expenses (or cash outflow) consist of (a) the capital investment for the satellite station, LNG containers, and trucks in the case of road transport, and (b) the operating costs for the satellite station and truck or rail tariff as applicable. We estimated the tariff by setting the net present value of the cash flows to zero, such that the expenses break even with the corresponding transport and regasification tariffs. We made all calculations on a real currency basis.

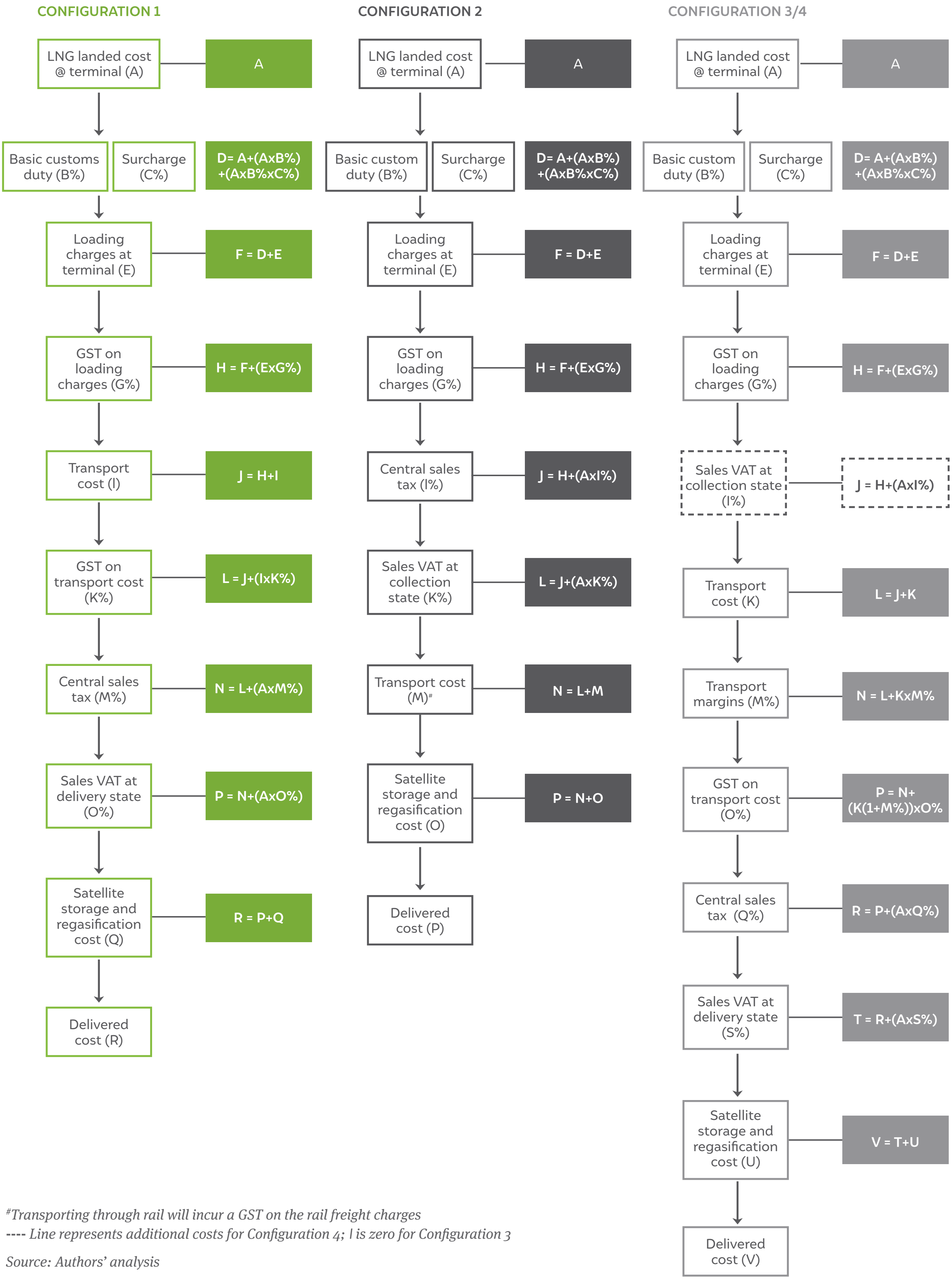
Our tariff calculations include determining the right number of containers and trucks in the case of road transport, and the size and costs of the satellite station based on the daily natural gas demand. The calculations also scale the cost of transport based on the round-trip distance involved in LNG delivery. We developed all estimates using real currency values (with 2019 as the base year) and a discount rate of 13.2 per cent (State Bank of India [SBI] 2019). We assumed the satellite station and trucks' lifetimes to be 20 years and 10 years, respectively.

Table 5 Costs of a satellite plant

Component	CAPEX	OPEX
Satellite plant	USD 2.14 million (INR 156.7 million) (Shirazi et al. 2019)	USD 0.24 million (INR 17.8 million) per year (Garcia-Cuerva and Sanz Sobrino 2009)

Source: Authors' interpretation of given references (numbers scaled to 0.1 mmscmd)

Figure 3 **Delivered price formulae for the four configurations**



#Transporting through rail will incur a GST on the rail freight charges
---- Line represents additional costs for Configuration 4; I is zero for Configuration 3

Source: Authors' analysis

3.2 Baseline delivered prices and sensitivities

We made base case calculations for a natural gas send-out of 0.1 mmscmd. We estimated the delivered price of gas for various transport distances between 200 and 1,000 kilometres (one-way) and import prices in the range of 4–10 USD/mmBtu (282–704 INR/mmBtu). Taxation for natural gas is still based on the value added tax system; a basic customs duty of 2.5 per cent with a social welfare surcharge of 10 per cent currently applies to imported LNG (IANS 2019). We considered the highest state sales VAT of 14.5 per cent (of Kerala) for states with an LNG terminal (MoPNG 2020a). We assumed a truck-loading charge of 0.8 USD/mmBtu (59 INR/mmBtu) at the terminal, with 18 per cent GST on this service.

Configuration 1

We have not presented the tariff and delivered price calculations for Configuration 1 in this analysis. The costs and margins for the transport of LNG by the terminal are not in the public domain. Each terminal in the country has a portfolio of long-term LNG contracts that influence the price they charge consumers. The volume uptake by consumers and the duration of supply can also influence margins. Finally, the terminal's transport fleet would have a higher utilisation factor if it serviced multiple consumers; it is challenging to consider this in the analysis. Therefore, any estimated delivered prices for Configuration 1 would not reflect reality and the wide range possible.

Configuration 2

In Configuration 2, the transport fleet serves only the consumer who owns it. Therefore, we can calculate the cost of owning and operating the vehicles as a part of the tariff. Table 6 shows the delivered prices of LNG for various import prices and transport distances. The cost of owning and operating the transport system and the satellite storage and regasification plant is included in the delivered gas price, as mentioned in Section 3.1.3.

Configuration 3

The Configuration 3 tariff and delivered price would be similar to Configuration 2, except that since a third party would carry out the logistics, there will be a GST component on the customer's transport charge. The GST has a minor impact on the overall delivered price of gas, and hence we did not calculate this component separately.

Configuration 4

Similar to Configuration 1, an aggregator can optimise the number of customers it can service and the margins it can charge in this configuration. Hence this configuration was also not evaluated separately. However, typical margins of aggregators are in the range of 20 per cent over the price of gas (as calculated for Configuration 2) – one can use this amount to approximate the incremental cost over the Configuration 2 estimate of the delivered price of gas.

Table 6 Configuration 2 delivered prices for different LNG import prices and transport distances

One-way distance (km)	Import prices (USD/mmBtu)											
	4			6			8			10		
	Diesel truck	LNG truck	Rail	Diesel truck	LNG truck	Rail	Diesel truck	LNG truck	Rail	Diesel truck	LNG truck	Rail
200	6.95	6.72	6.59	9.30	8.66	8.96	11.66	11.04	11.32	14.01	13.42	13.67
400	7.19	6.89	6.71	9.54	8.85	9.09	11.89	11.24	11.44	14.24	13.62	13.79
600*	7.40	7.09	6.88	9.80	9.10	9.30	12.20	11.53	11.70	14.60	13.97	14.10
800*	7.74	7.34	6.98	10.14	9.36	9.40	12.54	11.81	11.80	14.94	14.25	14.20
1000*	7.91	7.47	7.04	10.31	9.50	9.46	12.71	11.95	11.86	15.11	14.41	14.26

Source: Authors' analysis
**Distances for which a central sales tax of two per cent is applied.*

Table 6 shows that tariffs and delivered costs are lowest for rail transport. Such low costs are because transporting via trains does not require capital investment for vehicles as in road transport. Also, rail transport is generally more cost-efficient, although it is not necessarily more time-efficient. Transport using LNG trucks is inherently cheaper (see Section 2.1.2). Finally, the tariffs and delivered prices increase non-linearly with the increase in the import price of LNG. This is due to the cascading effect of taxes levied on the LNG through the value chain.

Figure 4 shows the build-up of the delivered price of regasified LNG for a typical case. Considering a one-way distance of 200 kilometres and the average 2017–18 import price of 7.39 USD/mmBtu (542 INR/mmBtu) (Petroleum Planning and Analysis Cell [PPAC] 2020b), the delivered price amounts to 11.11 USD/mmBtu (815 INR/mmBtu). Evidently, for a given import price, the state sales VAT forms a significant part of the final delivered price, as in this case with a VAT of 14.5 per cent as applied in Kerala. The transport cost will double if the one-way distance increases to 1,000 kilometres.

3.2.1 Payback periods

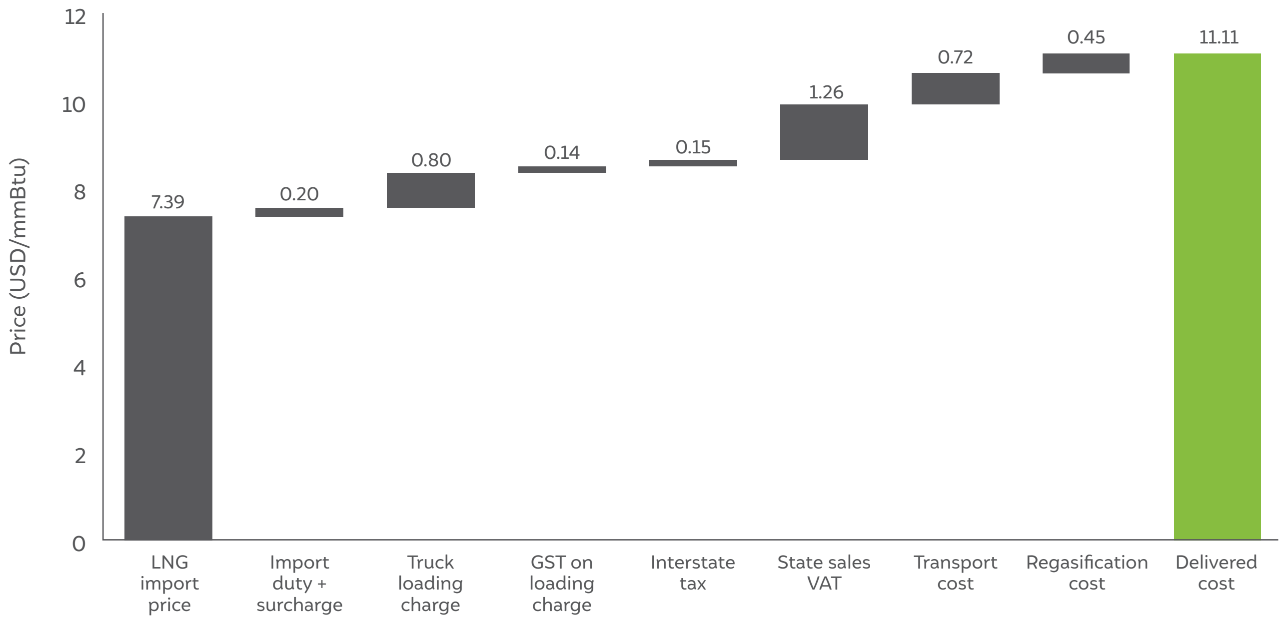
A critical decision for consumers of ssLNG is whether to invest in the regasification equipment (and trucks as well, in the case of Configuration 2) and more importantly, how long it will take to recover the investment. One easy way to evaluate the recovery is to determine the price spread (or difference)

Considering a one-way distance of 200 kilometres and the average 2017–18 import price of 7.39 USD/mmBtu (542 INR/mmBtu) the delivered price amounts to 11.11 USD/mmBtu (815 INR/mmBtu).

between the delivered price of incumbent fuel and natural gas required to recover the investments in the regasification equipment (and trucks if needed) in a certain time frame.

We calculated the required price spread between the delivered incumbent fuel and gas procured as ssLNG for specific target payback periods of two, three, four and five years for any equipment purchased. Table 7 gives the required price spread in USD/mmBtu for different targeted payback periods. For Configurations 1, 3 and 4, the consumer would purchase only the satellite unit's equipment (storage and regasification). Thus, the price spreads are smaller since transportation costs would be included in the fuel's delivered price. In this case, the price spread is independent of the consumer's distance from the LNG terminal. For Configuration 2, the consumer would purchase equipment for both the satellite unit and the transportation (trucks and tank trailers). Here, the spreads are larger for a 200-kilometre one-way distance as the transport systems' added cost affects the payback period.

Figure 4 Build-up of the delivered price for the average case



Source: Authors' analysis

Table 7 Price spreads for early paybacks are small

Payback period (years)	Price spread required (USD/mmBtu)	
	Configuration 1, 3 and 4 (distance independent)	Configuration 2 (200 km one-way)
2	0.71	1.04
3	0.50	0.74
4	0.40	0.59
5	0.34	0.50

Source: Authors' analysis

3.2.2 Sensitivity analyses

To understand the effect of certain variables on the delivered price of regasified ssLNG, we carried out some sensitivity analyses using the base case parameters. Figure 6 summarises the effects of these parameters.

Effect of the project lifetime

In the base case analysis (an import price of 7.39 USD/mmBtu and a one-way distance of 200 kilometres), we considered a lifetime of 20 years for the ssLNG infrastructure. However, to understand the economics of shorter lifetimes, we conducted sensitivity analyses for lifetimes of ten years (for future gas transmission pipeline access) and five years (in case transmission pipelines are already under consideration). Table 8 shows the comparison; the increase in costs is consistent across different distances.

Halving the lifetime to ten years results in a negligible difference in the delivered price. As the cost of vehicle fleet replacement is avoided in the tenth year, transport costs remain constant, and only regasification costs increase. However, a five-year lifetime produces a noticeable increase in both transport and regasification costs. Note that the analysis considers all costs as sunk costs; we did not include any salvage values. However, in reality, all equipment has resale potential and could significantly mitigate the increased delivered price resulting from a shorter lifetime.

Effect of truck-loading charges

Loading charges differ between terminals and are a function of capacity utilisation. Figure 5 illustrates the significant share of the loading charge levied by the LNG terminal in the delivered price. We varied the loading charge from 0.8 USD/mmBtu (59 INR/mmBtu) in the base case to 0.6 and 1 USD/mmBtu (44 and 73 INR/mmBtu) to determine the impact on the delivered price of LNG. Table 9 shows the resulting percentage increases. The delivered price significantly increases only at lower LNG import prices, and when the loading charge is a substantial part of the overall delivered price.

Table 8 Effect of lifetime on delivered price (%) is marginal

LNG import price (USD/mmBtu)	10 years	5 years
4	+1.04	+4.42
6	+0.78	+3.30
8	+0.62	+2.63
10	+0.52	+2.19

Source: Authors' analysis

Table 9 Effect of loading charge on delivered price (%) is modest

LNG import price (USD/mmBtu)	0.6 USD/mmBtu	1 USD/mmBtu
4	-3.89	+3.89
6	-2.90	+2.90
8	-2.32	+2.32
10	-1.93	+1.93

Source: Authors' analysis

Effect of discount rate

We applied a discount of 13.2 per cent in our base case analysis to calculate the delivered price of LNG (SBI 2019). A reduction in the discount rate is likely in the current economic circumstances; hence, we carried out sensitivity analyses on lower discount rates of ten per cent and eight per cent. Table 10 gives the results of these analyses.

Table 10 Effect of discount rate on delivered price (%) is negligible

LNG import price (USD/mmBtu)	8%	10%
4	-1.38	-0.87
6	-1.03	-0.65
8	-0.82	-0.52
10	-0.68	-0.43

Source: Authors' analysis

Table 11 Effect of VAT on delivered price (%) can be significant

LNG import price (USD/mmBtu)	3%	5%	10%
4	-8.36	-6.91	-3.27
6	-8.79	-7.26	-3.44
8	-9.04	-7.47	-3.54
10	-9.21	-7.61	-3.60

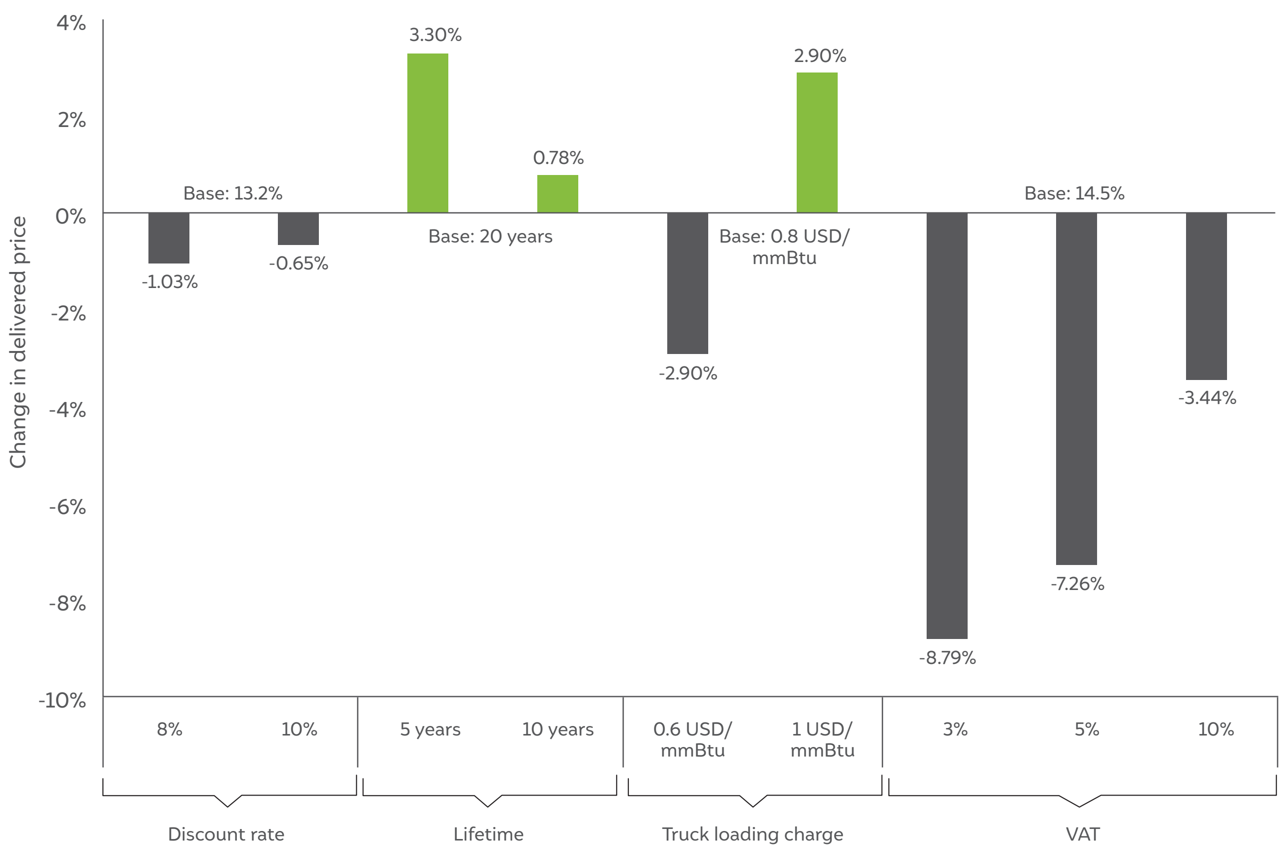
Source: Authors' analysis

Effect of VAT

The VAT that the state applies to LNG price accounts for more than 11 per cent of the delivered price in the base case (see Figure 4). The base case assumes a 14.5 per cent VAT, which is the highest among states with currently operating LNG terminals. Due to the large disparity in VATs on natural gas among different states, we tested lower VAT rates of ten per cent and five per cent. Table 11 shows the effect of the lower VATs—lowering VAT can significantly impact LNG's delivered price.

The magnitude of effects of lifetime, truck loading charge, discount rate, and VATs can be observed in Figure 5, for an import price of 6 USD/mmBtu and 200-kilometre one-way distance.

Figure 5 Changes in delivered prices according to sensitivity variables



Source: Authors' analysis

Note: Sensitivities shown for an LNG import price of 6 USD/mmBtu and 200 km one-way distance.

3.2.3 Comparison of delivered prices of regasified ssLNG and other fuels

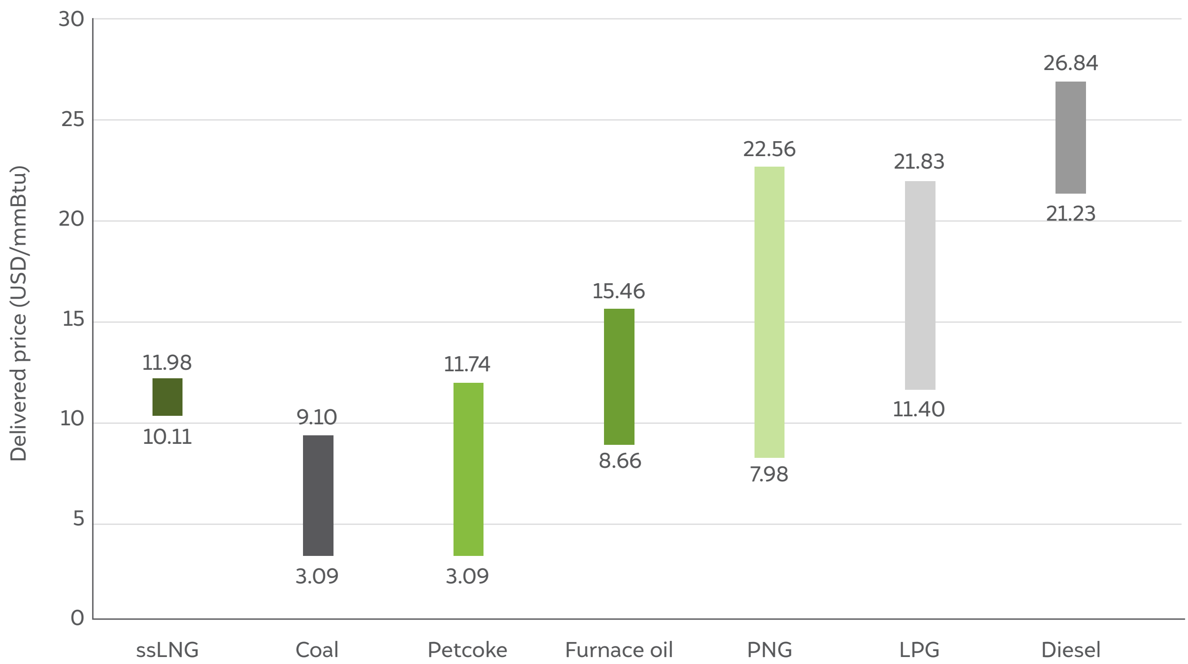
The overall economic benefit of using natural gas depends on the cost of retrofitting/replacing existing equipment. However, regasified ssLNG can compete on a delivered price basis with other petroleum fuels such as furnace oil, diesel, liquefied petroleum gas (LPG), petcoke (mostly imported grades), and higher grades of coal. To provide a comparison on an equitable basis, Figure 6 shows a plot of ranges of 2017–18 prices of regasified ssLNG and other petroleum fuels delivered to industrial consumers across the country (Ministry of Statistics and Programme Implementation [MoSPI] 2018). For 2017–18, we used the actual average price of imported LNG, 7.39 USD/mmBtu (542 INR/mmBtu) (PPAC 2020b), to estimate the delivered price of ssLNG for a range of distances, from 100 to 1,000 kilometres. Figure 6 displays the resultant ranges of delivered prices for LNG and competing fuels. The lowest and highest state VATs (for Maharashtra and Kerala) for states having LNG terminals were considered for estimating the ssLNG price range.

One can observe that the delivered price of ssLNG is competitive with that of LPG and diesel; in the case of PNG, coal, petcoke, and furnace oil, ssLNG is competitive depending on the fuel quality and location. LNG prices are expected to remain tepid, so it may be feasible for consumers of the incumbent fuels to switch to regasified LNG.

3.3 Different potential applications of ssLNG

We tested the applicability of ssLNG by calculating the delivered price of gas to existing facilities of different industries that are not presently serviced by gas pipelines. Then, we compared this price with that of the incumbent fuel(s) being used (MoSPI 2018). We employed the 2017-18 average LNG import price of, 7.39 USD/mmBtu (542 INR/mmBtu) (PPAC 2020b). MoSPI's Annual Survey of Industries 2017–18 provided the volumes and prices of incumbent fuels. We compared these prices with the delivered price of ssLNG in the historic year 2017–18. Table 12 provides some examples of ssLNG applications in real-world cases. We estimated the payback periods for the ssLNG equipment needed in each case based on the price spread between ssLNG and the incumbent fuels.

Figure 6 The delivered price of regasified LNG compares favourably with several incumbent fuels



Source: Authors' analysis

Note 1: Prices for states in proximity to terminals - Tamil Nadu, Kerala, Andhra Pradesh, Telangana, Karnataka, Maharashtra, Odisha, Jharkhand, Chhattisgarh, West Bengal, Gujarat, and Rajasthan.

Note 2: 10th and 90th percentile of prices considered to remove outliers.

Note 3: 2017-18 average LNG import price considered for ssLNG range due to lack of data on individual import cargoes.

Table 12 Case studies for ssLNG show its competitiveness

Category	Case 1	Case 2	Case 3	Case 4	Case 5
Facility type	Manufacture of articles of concrete, cement, and plaster	Manufacture of non-metallic products	Cutting, shaping, and finishing of stone	Manufacture of glass and glass products	Manufacture of basic chemicals
Expected location	Erode, Tamil Nadu	Jalgaon, Maharashtra	Palakkad, Kerala	Sriperumbudur, Tamil Nadu	Ernakulam, Kerala
Nearest LNG terminal	Ennore LNG terminal	Dahej LNG terminal	Kochi LNG terminal	Ennore LNG terminal	Kochi LNG terminal
Distance from terminal	400 km	430 km	150 km	75 km	50 km
Demand	0.013 mmscmd equivalent	0.004 mmscmd gas equivalent	0.016 mmscmd equivalent	0.16 mmscmd equivalent	0.043 mmscmd equivalent
Incumbent fuel(s)	High-speed diesel, furnace oil, and other oil products	Diesel and furnace oil	High-speed diesel	Furnace oil	LPG and furnace oil
State sales VAT on natural gas	5%	3%	14.50%	5%	14.50%
Weighted average incumbent fuel price	21.99 USD/ mmBtu	22.37 USD/ mmBtu	22.32 USD/ mmBtu	10.96 USD/ mmBtu	13.01 USD/mmBtu
Delivered price of gas as ssLNG	10.51 USD/ mmBtu	12.50 USD/ mmBtu	11.28 USD/ mmBtu	10.17 USD/ mmBtu	11.00 USD/mmBtu
Payback period for ssLNG equipment	<1 year	<1 year	<1 year	3 years	1 year
Annual expenditure on incumbent fuels	4.72 million USD	1.56 million USD	5.65 million USD	27.73 million USD	9.05 million USD
Annual expenditure on ssLNG	2.25 million USD (2.46 million USD saved)	0.87 million USD (0.69 million USD saved)	2.85 million USD (2.79 million USD saved)	25.72 million USD (2.01 million USD saved)	7.65 million USD (1.40 million USD saved)

Source: Authors' analysis; MoSPI 2018

From the case studies, it is clear that ssLNG can be as competitive as, or cheaper than, incumbent petroleum fuels. However, it is worth noting that there could be costs involved in retrofitting combustion equipment necessary to switch from a liquid or solid fuel to natural gas. One must evaluate these added costs against the savings and reduced maintenance resulting from using cheaper natural gas instead of coal and petroleum fuels.

4. Recommendations

Small-scale LNG systems can significantly increase natural gas usage in the Indian economy. However, mentioned below are some measures to enable access to natural gas through ssLNG systems.

Misinterpretation of CGD exclusivity

The regulation of PNGRB titled 'Petroleum and Natural Gas Regulatory Board (Exclusivity for City or Local Natural Gas Distribution Network) Regulations, 2008' provides infrastructure and marketing exclusivity to CGD operators. The PNGRB Act and related regulations do not mention LNG transport by road, rail, or ships and ssLNG infrastructure. But some CGD operators contend that ssLNG infrastructure (storage and regasification) at the consumer end should also be considered a part of the authorised CGD infrastructure, thereby under the exclusive domain of CGD operators. This discourages the industrial consumers interested in developing ssLNG storage and regasification infrastructure at their sites for captive consumption.

Additionally, the regulation on marketing exclusivity (i.e., exemption from permitting access to third-party marketers/consumers to use the CGD pipeline network for a certain number of initial operational years as decided by PNGRB) is often misinterpreted to mean that only CGDs can supply gas to consumers (with a consumption of less than 50,000 scmd) if the CGD has a pipeline network in their area. The ssLNG consumers do not breach the CGD marketing exclusivity as ssLNG is transported using roads, rail, or ships up to the consumer gate without using the CGD pipeline network. This perception of the extent of CGD exclusivity has somewhat impeded the expansion of ssLNG systems. The resulting lack of competition to the unregulated CGD supplied gas keeps gas prices at an uncompetitive level.

Lack of competition to the unregulated CGD supplied gas keeps gas prices at an uncompetitive level.

Legal issues regarding the use of ssLNG, such as the case of Saint Gobain India Private Limited vs Gujarat Gas Limited where the latter has asserted that the former's use of ssLNG violates their exclusivity rights, could significantly limit investment in ssLNG systems (PNGRB 2018). The risk of legal disputes and challenges regarding the clarity of existing regulations would turn away potential gas consumers, leaving CGD operators with the position of a monopoly. The MoPNG and PNRGB should put out a public note clarifying that the exclusivity of CGD networks is limited to their own pipeline infrastructure and that ssLNG does not impinge upon this exclusivity. Such clarity on the regulations would instil confidence in the consumers and potential third party ssLNG suppliers to invest in ssLNG.

Use of ssLNG by MSMEs

The MSME sector consumes 30 per cent of the energy consumed by the industrial sector. Much of this is coal, furnace oil, diesel, and petcoke, which are ideal candidates for replacement by natural gas. Many of these MSMEs are ripe candidates for utilising natural gas through ssLNG as they are not connected to any pipeline grid. Many of the MSME clusters with access to piped natural gas are unwilling to switch due to uncompetitive gas pricing. Hence, MSMEs can benefit from ssLNG.

However, in most cases, MSME units are small consumers of natural gas and may not be able to source and store LNG at a unit level. One option is to source LNG through ssLNG and regasify it collectively at a cluster level and distribute it to all the units through pipelines. However, such an arrangement will violate an existing CGD network's exclusivity or the exclusivity rights of a yet-to-be-built CGD network. PNGRB could consider making an exception to pipeline connectivity within an MSME cluster in the CGD exclusivity regulation, thus allowing MSME clusters to source ssLNG collectively.

Utilising the modularity of ssLNG equipment

A vital benefit of the ssLNG system is its modular equipment. For example, the tanks used to transport LNG can also act as storage units at the regasification site. The ISO 1496/3 standard provides specifications for a modular standalone tank to be used as a freight container. This containerised design allows for tank prefilling while the truck is en route to the LNG receiving site. Then, the tank can be offloaded at the regasification site and used as a storage unit. The containerised tank is also intermodal – the transporter can transfer the tank from one mode, say rail, to another, say a truck, for road transport.

The nodal agency that approves such containerised LNG tanks in India is the Petroleum and Explosives Safety Organisation (PESO). Indeed, the Static and Mobile Pressure Vessels (Unfired) Rules, 2016 has a reference to ISO 20421 as an option for cryogenic pressurised tank specifications (Petroleum and Explosives Safety Organisation [PESO] 2016). However, ISO 20421 is not meant for containerised tanks; it generally deals with cryogenic vessels with a capacity greater than 450 l, without referring to an upper limit on the volume. ISO 1496/3 compliant containers have a capacity of over 20,000 l for 20-ft long containers and over 40,000 l for 40 ft long containers. We recommend that PESO approve and include the reference to ISO 1496/3, or equivalent, in its rules for pressure vessels and, specifically, LNG transport and storage.

Development of rail tariffs specific to LNG containers

The current and planned natural gas pipeline networks still leave several demand pockets without access. Meanwhile, the Indian Railways comprehensively covers much of India's geography. In fact, the Dedicated Freight Corridors (DFC) will significantly reduce the time, and hence the cost of ssLNG delivery. In combination with intermodal ISO containers, the railway network can efficiently supply LNG (and hence natural gas) to demand nodes without pipeline access. However, the Indian Railways does not have specific tariffs for flatbed wagons suitable for ISO container transport as it does for hydrogen and petroleum liquids. Therefore, the Indian Railways should develop specific tariffs for LNG transport and provide the infrastructural support necessary for hauling LNG freight containers.

> **The Indian Railways should develop specific tariffs for LNG transport and provide infrastructural support.**

Reduction of VAT to promote natural gas

The timeline for the introduction of GST to replace VAT on petroleum fuels (including natural gas) remains elusive since state governments rely heavily on VAT collected from petroleum fuels for revenue. Hence, until GST is applied, states can consider reducing the VAT on natural gas to promote its usage. For example, the VAT on natural gas "as a raw material or fuel in the manufacture of goods" is only 3 per cent as per Schedule A of the Maharashtra Value-Added Tax Act. However, Kerala applies a 14.5 per cent VAT on natural gas. To limit the revenue shortfall from VAT reduction, states may provide a concessional VAT to end consumers,

a. Using less than a stipulated volume of natural gas (for instance, less than 0.01 mmscmd), or

b. generating a lower turnover than a particular threshold amount. This will support the growth of MSMEs while lowering the effect of air pollution from this sector.

States can also consider reducing the GST on the following to make ssLNG attractive.

a. On service charges of third-party ssLNG suppliers (Configuration 3 and 4)

b. On purchase of LNG-fuelled trucks for ssLNG transport

c. On purchase of regasification equipment by MSMEs

Small-scale LNG for waterways

The Ministry of Shipping's Sagarmala national initiative intends to unlock the potential of coastal ports and inland waterways by promoting the transport of goods via waterways. It also aspires to reduce the CO_2 emissions from the transport sector by 12.5 mtpa (Ministry of Shipping 2019). Natural gas is cleaner than diesel in terms of criteria pollutants and greenhouse gas emissions. Also, since it is a gaseous fuel, there is no possibility of water contamination. Therefore, natural gas is much better suited to power water transport. Fuelling infrastructure of inland waterways can utilise small-scale LNG systems. We recommend that the

Sagarmala initiative make provisions for the use of ssLNG to support the bunkering of natural gas along waterways such that ships, barges, and boats can easily access CNG or LNG as fuel.

There are four active LNG import and regasification terminals in India, and several more in the planning and development phases. The development of pipelines to connect these terminals to demand nodes will take time. There is potential for LNG from these terminals to be cost-effectively transported to other ports via coastal waters, and from there to demand nodes via inland waterways. We recommend that the Sagarmala initiative also promote and support the transport of ssLNG as freight via coastal and inland waterways.

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LNG terminals could benefit from increased capacity utilisation through ssLNG without depending solely on pipeline connections.


Image: Shell

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