WGCPARIS2015
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26th World Gas Conference | 1-5 June 2015 | Paris, France

Small-Scale LNG Supply Chains

Confronting the Diseconomies of Small-Scale LNG

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Background

As the liquefied natural gas ("LNG") industry experiences unprecedented growth in global demand for natural gas, increasingly abundant supplies of LNG and technological advances, we anticipate substantial growth in the demand for small-scale LNG quantities. For the purpose of this paper, small-scale LNG applies to capacities less than one million metric tonnes per year ("MMTPA").

Small-scale LNG supply chains are more complex and offer more combinations due to smaller cargo unit capacities and increased available options for each supply chain component; upstream natural gas supply, liquefaction, storage, sea transportation, overland transportation, unloading facilities, regasification, natural gas fuel to end-users, and end users (e.g. power generation, pipeline distribution, or bunker fuel).

Small-scale LNG projects typically require smaller capital investments, thus lowering entry barriers and offering attractive investments for new investors. The multitude of options and challenges for each supply chain component and the complexities associated with component linkages must all be carefully evaluated for successful project execution.

Current and potential small-scale LNG markets include China, India, Indonesia and other Southeast Asian countries, the Middle East, Northern Europe, USA, the Caribbean, Central America and South America.

Aims

This paper focuses on the sea transportation-related components of the small-scale LNG supply chain, as these often will significantly determine the viability of a supply chain. It develops and compares the cost of service economics for the two most likely sea transportation options, namely containerized LNG transportation and small-scale shipping.

- There is a range of LNG supply capacities where transporting LNG using containerized LNG storage (such as ISO[1] containers) in either tug-barges[2] or container deck vessels[3] is more economical than transportation by bulk LNG

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[1] Containers in compliance with International Organization for Standardization (ISO) standards

[2] Tug-barges refer to both articulated tug barges (AT/B) and traditional tug-towed barges

[3] Container Deck Vessels refer to self-powered vessels where containers are stowed on deck (not below)

carrier ("LNGC") ships. Beyond this range, bulk transportation by LNGC ships becomes more economical. This paper identifies the "breakpoint" supply chain capacity between these two LNG transportation options based on selected "typical" chain assumptions. This breakpoint will vary as the project configurations vary (i.e. shipping distances, LNG sources, target markets, and sea transportation vessel capacities).

- Small-scale LNG supply chains with capacities up to 1.0 MMTPA were evaluated. Containerized LNG storage and transportation is most appropriate at the lower end of the small-scale range, namely up to 100,000 tonnes per year ("TPA"). Beyond this lower end capacity, LNGC vessels become more economical, with optimal vessel sizes depending on required LNG supply and project configuration. Comparison between these additional larger-capacity scenarios is beyond the scope of this paper.

- The small-scale supply chains and the evaluation boundaries for this study are illustrated in **Figure-1** and **Figure-2**. These are graphical representations of the supply chain for both containerized LNG storage/transport options and bulk LNG storage/transport options. Facilities outside of these boundaries vary minimally such that they have little or no impact on economic evaluation or are typically beyond a supply chain developers control, so are excluded from the comparisons in this paper. Facilities within these boundaries vary significantly based on selected methods of LNG storage/transportation and are evaluated in detail.

- LNG supply chain unit costs have been evaluated in $/MMBTU[4] to allow economic comparison across different chain configurations and capacities. Comparisons have only been made between facilities within the scope boundaries, not for the entire supply chain. The key cost measure is the "delta" cost between the scenarios. This delta would not be expected to change if the entire supply chain was considered, as most cost variation occurs within the evaluated chain components.

- Consistent study bases and assumptions were established. These define the range of LNG supply volumes, supply sources, target markets, shipping distances, overland transportation distances, storage capacities, sea transportation methods, overland transportation methods, LNG delivery scenarios to end-user location, and consistent representative commercial parameters.

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[4] US Dollars per million British Thermal Units ($/MMBTU).

- Marine transportation of LNG has the greatest impact on project economics, and multiple shipping options were evaluated. Although shipping costs are minor with respect to total project cost, their impact on the unit delivered cost of each chain configuration is significant.

- Methodologies and evaluations used to support solutions are presented, including illustrations in **Figure-3**. Sensitivity impacts are shown for changes in marine vessel capacities.

- Comparisons of delivered natural gas fuel cost as LNG versus typical local liquid fuels such as diesel and heavy fuel oil ("HFO") are also discussed and presented in **Figure-4** and **Figure-5**. In this case, the total supply chain cost of service was considered rather than just the facilities within study boundaries.to provide a "like" comparison with the local purchase cost of liquid fuels.

- We address challenges and potential risk issues and offer mitigation recommendations for investors. These include environmental, safety, and health concerns.

Methods

Our methodology includes (a) establishing a realistic study basis and scope boundaries, (b) evaluating specific supply chain components that affect chain viability, (c) utilizing a computerized model, and (d) illustrating results using industry-recognized measures such as $/MMBTU. Sensitivities are evaluated and results presented illustrating the impact of varying shipping vessel sizes. Finally, we include a discussion of small-scale LNG supply chain challenges and potential risk issues along with recommendations for further study.

Economic/Technical Model

<u>LNG Supply Chain Model</u> – economic evaluations were performed and conclusions reached using the Poten/Merlin proprietary Small-Scale LNG Supply Chain Model.

The model structure consists of multiple supply chain component options. For this comparative study, scope boundaries were drawn as follows:

- Excluded:
    - Upstream natural gas supply
    - LNG liquefaction, LNG storage, marine export facilities
    - LNG regasification to natural gas
    - Power generation
    - Other end-users (pipeline, bunkers, other)

- Included:
    - LNG storage for transportation
    - LNG export & handling facilities
    - Sea transport of LNG
    - LNG import & handling facilities
    - LNG storage at destination
    - Overland transportation of LNG

Study Bases and Assumptions – the following were used:

- LNG supply capacity range: small-scale < 1.0 MMTPA
- LNG supply source (assumed): US Gulf Coast base-load liquefaction plants (supplied from LNG storage tanks)
- LNG supply quality: "Lean" LNG, approximately 1,045 BTU/SCF HHV
- LNG target market: Caribbean Islands (Dominican Republic)
- LNG shipping distance: 1,200 nautical miles
- LNG storage and transportation:
    - ISO-40 containers transported by tug-barges and container deck vessels, ranging from 350 TEU[5], 200 TEU, 100 TEU capacities (time charter basis)
    - Bulk LNG transported by LNG carriers, ranging from 10,000 m^3 to 20,000 m^3 LNG capacities (time charter basis)
- Marine facilities:
    - Export dock and/or berths constructed / modified for small-scale vessels
    - Import dock and/or berths constructed / modified for small-scale vessels
- LNG bulk storage at destination:
    - Import shore-side: ship capacity +20%
    - Inland destination at regasification facility: 14 days storage
- Overland transportation distance from import to user location: 50 km
- Overland truck capacities (tankers & container trailers): 40 m^3
- End-user receives LNG product (not natural gas) for use.
- Commercial/economic assumptions:
    - Project life following start-up: 15 years
    - Required return on investment: 12%
    - Equity only evaluation basis
    - Future escalation (inflation): 2.5% per year

[5] Twenty-Foot Equivalent Units (TEU) – measure of marine vessel capacity in number of 20-foot containers that can be transported or handled

- Specific Exclusions:
    - Cost of natural gas supply (upstream facilities and/or Henry Hub pricing)
    - Cost of LNG liquefaction, treating, storage, marine export facilities
    - Cost of LNG regasification facilities
  - Cost of power generation facilities
  - Taxes, duties, permits
  - Revenues from LNG sales

<u>Methodologies</u>

- LNG supply – MMTPA increments of LNG supply up to 1.0 MMTPA (10 data points) were evaluated, based on the specified LNG source and destination. (0.025, 0.050, 0.075, 0.100, 0.250, 0.500, 0.750, 1.0 MMTPA)

- LNG storage costs – container quantities were calculated based on LNG supply chain capacity, shipping methods (mode, speed, capacity) and vendor pricing for ISO-40 containers.

- Shipping costs – vessel counts and costs were calculated based on LNG supply chain capacity, shipping distances, vessel types and capacities, and time charter rates (assuming full-time charters rather than partial cargoes on scheduled shipping lines).

- Overland transportation costs – trucks/trailers/tankers requirements were calculated based on delivery capacity, trucking distances, truck type, speed, and capacity and costs for applicable trucks (assuming these were controlled by the project rather than public trucking lines).

- LNG storage – bulk storage costs were calculated based on maximum required storage capacities and costs for construction.

- LNG export and import facilities – costs were based on the assumption that upgrades would be required at the both export and import facilities to handle smaller-scale vessels, including container-filling facilities and handling equipment for loading and off-loading.

- Costs of Service was derived as the unit charge required in $/MMBTU to deliver LNG through each supply chain configuration to yield the required project return on investment.

Transportation

Marine transportation methods using small container deck ships, small LNG carrier ships[6], and articulated tug/barges (AT/B) present logistical challenges. As ISO-40 containers have working volumes of approximately 40 m^3, the supply and handling logistics to remote locations create challenges, requiring dedicated container shipping, container handling equipment, overland transportation, container storage, and inventory management.

Commercial

Small-scale LNG project capital investments are lower and payback periods are shorter than for base-load LNG projects. This creates new supply chain and market dynamics enabling LNG industry newcomers and a mix of participants.

Challenges & Potential Risk Issues

Issues that present challenges and risks to successful project execution and remedial actions that can be taken:

- Small-scale LNG markets remain in their infancy. There appears to be a growing demand for small-scale LNG from markets and investors with little or no LNG experience and with limited understanding of the technical, commercial, safety, and operating issues that LNG presents. <u>Recommendations</u>: considerable effort toward early stage project evaluation and planning; take advantage of industry leaders' expertise and experience; educate investors seeking to enter the LNG market; study target market areas for needs, infrastructure, laws and regulations.

- Reliable LNG supply – reliable and secure LNG sources are crucial for buyers to move forward with a small-scale LNG supply chain. On the other hand, LNG suppliers need to secure a market before they commit investments to construct a liquefaction project. This results in LNG opportunities being deferred while suppliers are searching for buyers and buyers are searching for suppliers, thus creating a paradox. <u>Recommendations</u>: the most effective solution would result from closer collaboration between the supply-side (liquefaction) and the demand-side entities (natural gas end-users) during project planning. Early project coordination and agreements could ensure security for both the supply-side and demand-side participants. Supply diversification could also mitigate risk, with buyers relying on small LNG quantities from multiple sources including both base-load plants and small-scale plants.

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[6] Small-scale LNG transportation vessels are defined as those with a capacity of under 18,000 m^3

- Adequate LNG small-scale export facilities – base-load LNG plants are not constructed until they have long-term large-scale LNG buyers. This results in no pre-investment in small-scale related facilities, such as the smaller marine docks and berths to accommodate smaller vessels and facilities for shore-based filling and handling of containers. Recommendations: No easy and economical "after the fact" solution is universally applicable to this issue other than budgeting to appropriately modify or build new facilities to accommodate small-scale LNG on a project-by-project basis.

- Adequate LNG small-scale import facilities – facilities for unloading LNG at the buyer's dedicated location, whether for containerized or bulk LNG, will have to be newly constructed. If existing port facilities are utilized for containerized LNG import, infrastructure modifications, container handling equipment, and storage areas may be required. For bulk LNG, totally new import infrastructure will be required such as unloading berth and LNG storage. Recommendations: budgeting small-scale projects for these facilities appears to be the best option.

- Future expansion – the demand for small-scale LNG is expected to grow. As supply chain and distributor infrastructure is further developed, there may be opportunities for "hub and spoke" supply chains. Recommendations: Advanced planning and pre-investing for future supply chain facilities such as increased shipping quantities, plan for flexible and expandable storage hubs and distribution, creating "hub and spoke" distribution networks, permitting, financing, providing for diversified fuel markets beyond power generation, such as transportation fuels, bunker fuels and industrial fuels.

- LNG storage containers – containerized storage is a proven product with various models for different capacities, shipping distance, boil-off gas "hold times"[7], and working pressures. These are available from multiple vendors. Challenges include supply lead time, ability to obtain large quantities, and managing LNG boil-off gas. Recommendations: advance planning and purchase commitments; diversify purchases to multiple suppliers; consider container leasing options that some companies offer which include routine maintenance and inspections

- Managing heat leak – heat leak into LNG containers results in pressure build-up while in transit. Containers are designed for a maximum allowable working

[7] Container "hold time" is specified in days of LNG storage until the container's designed maximum allowable working pressure (MAWP) is reached, typically 60-85 days for ISO-40 containers.

pressure which dictates the "hold time" until the container must be unloaded to prevent safety issues. Recommendations. Purchase containers specified for anticipated "hold times" and crucial monitoring and adherence to transportation schedules.

- Bulk LNG marine transportation – dedicated bulk LNG ships on time-charter basis is preferred over scheduled carriers as this permits more control over handling and scheduling during shipping. Availability of dedicated small-scale carriers presents challenges as there are not many ships available due to lack of demand, other than a few shuttle vessels. Recommendations: budget for time-chartering of vessels and order new-build vessels to meet demand. Should scheduled carriers be utilized instead of dedicated charter vessels, schedule contingencies need to be included for fixed shipping schedules, multiple ports, additional shipping times, and customs services.

- Containerized LNG marine transportation – dedicated container vessels (container deck ships and tug-barges) on a time-charter basis would be preferred over scheduled carriers as this permits more control over handing and scheduling during shipping. Numerous container vessels are in operation but additional vessels may be required depending on the required chain capacity. Recommendations: budget for time-chartering of vessels and order new-build vessels to meet demands. Should scheduled carriers be utilized instead of dedicated charter vessels, schedule contingencies would need to be included for fixed shipping schedules, multiple handling of containers, multiple ports, additional shipping times, and customs services.

- Overland transportation – local infrastructure may be inadequate for trucking LNG quantities, thus requiring upgrade investments and/or smaller vehicles. Recommendations: early project survey of transportation infrastructure and local regulations such as load and size limits, permits, operating hours.

- Local opposition to LNG – public pre-conceptions toward LNG supply may create opposition from residents and community leaders. Recommendations: campaigns to educate residents and community leaders, stressing LNG's safety track record and safety measures to be put in place; work closely with local community to earn their confidence.

- Operational & security risks – shortage of skilled transportation, handling, and operations personnel. Recommendations: hire and train quality personnel with industry expertise; budget projects for hiring and retaining higher-salaried personnel. Plan to secure required staff early in the project development process.

- Environmental, safety, & health (ES&H) issues – with the small-scale LNG industry in its infancy, it lacks expertise and experience addressing ES&H issues related to small-scale LNG transportation, handling, and operations that take place within small-scale markets. Recommendations: hiring and training quality personnel by experienced LNG industry leaders; place ES&H issues as the "number one" priority.

Results

The supply chain analysis results are discussed below and graphically presented on **Figure-3** (comparing LNG supply methods) and **Figure-4** (comparing LNG-based natural gas supply to liquid fuel fuels).

Comparisons: Cost-of-Service for LNG Supply

Figure-3 illustrates unit cost comparisons for transportation between (a) containerized supply of LNG using ISO containers transported by tug-barges / container deck vessels and (b) bulk supply of LNG transported in small LNG Carriers. Unit transportation costs were calculated as Cost of Service" for each LNG supply chain components based on a 12% return on investment. This was done for a 0-200,000 TPA range of LNG supply. Higher LNG supply capacities up 1.0 MMTPA were evaluated but only the bottom end of this range was illustrated as higher chain capacities strongly favoured bulk supply over containerized supply. Results are expressed in $/MMBTU.

The "solid blue graph" in **Figure-3** represents LNG bulk delivery unit costs in $/MMBTU using 20,000 m^3 vessels. The "solid red graph" represents containerized LNG delivery unit costs for 200 TEU container vessels.

For sensitivity analyses, dashed graphs show ranges above and below the solid graphs. The "dashed blue graph" represents LNG delivery using smaller 10,000 m^3 vessels, which indicates lower costs in the lower LNG supply range but increasing as the LNG supply increases. The two "dashed red graphs" represent LNG delivery using 100 TEU and 350 TEU container vessels, while smaller 100 TEU vessels indicate lower costs than the 200 TEU vessels. This is due to lower ISO containers purchase requirements as fewer containers are loaded on the smaller vessels (i.e. smaller batch sizes lower the supply chain inventory requirements). Total ISO containers requirements were generally about three times the vessel capacity, plus a four-day operating safety buffer. For the chains evaluated in this study, the three-times factor is a result of having one vessel load in transit while one vessel load is being filled at the liquefaction plant and one vessel load is being consumed at the regasification plant.

To summarize results, containerized LNG delivery on 200 TEU capacity container vessels is more economical than bulk LNG delivery in 20,000 m^3 vessels for LNG supply chain capacities up to 85,000 TPA. This graphical point is shown in **Figure-3** as the intersection of the "solid blue graph" and "solid red graph". For smaller and larger capacity container vessels, the intersection point varied as follows:

- Using smaller 100 TEU capacity container vessels increases the applicable range for containerized deliveries to 92,000 TPA. This ship size requires purchasing the fewest ISO containers thus a lower capital investment.
- Using larger 350 TEU capacity container vessels, the applicable range of LNG supply decreases to 64,000 TPA.
- Using smaller 10,000 m^3 bulk delivery vessels instead of 20,000 m^3 vessels lowers costs slightly at the lower end of LNG supply range.

Comparisons: LNG-based Natural Gas vs. Liquid Fuel Supply Costs

Figure-4 and **Figure-5** illustrate unit cost comparisons in $/MMBTU between natural gas fuel (from LNG) and liquid fuels for the specific target market (Caribbean Islands) for the following range of LNG supply / power generation capacity: 50,000 TPA (40 MWe), 100,000 TPA (75 MWe), 500,000 TPA (400 MWe). For a "like comparison" against liquid fuels such as diesel and heavy fuel oil (HFO), the entire supply chain cost was estimated for each fuel, with representative public domain sources used to estimate LNG supply chain component costs for components outside the analysis boundaries.

Diesel fuel cost was based on current fuel costs at the target market of $17.38/MMBTU, while heavy fuel oil cost (HFO) was estimated at $10.88/MMBTU. These liquid fuel costs were estimated using an $80/bbl Brent long-run crude oil pricing benchmark.

Natural gas fuel cost was based on combining each supply chain component cost for US Gulf Coast LNG transported to the Caribbean Islands and regasified into natural gas for power generation fuel. A cost for converting power plants from diesel / HFO to natural gas fuel has been included, assuming power generation drivers (typically reciprocating engines for small-scale power generation) can be modified from diesel or HFO to natural gas fuel without replacing entire power generation units.

Overall, LNG-based supply chains were competitive with diesel over the entire analysed supply chain range, becoming increasingly competitive with scale. LNG showed unit cost advantages over diesel supply ranging from $4.13/MMBTU (savings) at 50,000 TPA LNG chain capacity equivalent to as much as \$7.23/MMBTU (savings) for a 500,000 TPA LNG chain. However LNG proved somewhat less competitive against lower-cost HFO. For the 50,000 TPA supply chain, LNG was some \$2.37/MMBTU more expensive than HFO supply, and \$1.37/MMBTU more expensive for a 100,000 TPA chain. LNG was more competitive with HFO at larger scale showing a \$0.73/MMBTU savings for a 500,000 TPA chain. **Figure-4** and **Figure-5** illustrates these savings.

Note that costs are conceptual grade accuracy, but do provide an indicative comparison of unit costs between the fuels. Although not developed for this paper, total fuel cost comparisons (savings) could be developed for a time-based range of fuels required for the subject markets.

Summary & Conclusions

Rather than address the entire small-scale LNG supply chain, this paper focuses on where small-scale diseconomies of scale can be confronted to create optimal solutions. A comparison of unit costs between containerized LNG transportation versus bulk LNG transportation across a range of "small-scale" LNG supply capacities showed containerized LNG transportation to be the most economical solution for the smallest LNG supply chain capacities (generally below 100,000 TPA). Increased supply chain scale beyond this level favours bulk shipping in small-scale LNG vessels. Further optimizations could be accomplished by utilizing "hub and spoke" and "sequential" ("milk-run") supply and distribution logistics, but these refinements are beyond the scope of this paper.

When the entire supply chain is considered, small-scale LNG-based natural gas supply can be considered competitive against diesel fuel for small-scale power generation chains. However, LNG-based natural gas supply is less competitive against less expensive HFO with cost advantages only becoming available at higher supply chain capacities.

Finally this paper included a brief discussion of small-chain challenges and potential risks along with recommendations for further study.

In conclusion, to meet the rising global demand for energy, we must move forward with all sources of energy with a goal of achieving a sustainable energy supply. Natural gas is abundant, global, secure, safe, economical, versatile, and easily transported not only through pipelines but also as liquefied natural gas which can be regasified back into natural gas for fuel. The large-scale LNG industry has created a supply chain providing LNG in large volumes to major users, but inadequate for small-scale users. We anticipate the current expansion of the industry will be able to provide LNG to meet smaller-scale customer requirements for smaller quantities in remote locations, particularly for power generation through small-scale LNG supply chain options that are currently available or under development. Continued technological innovation and a growing understanding of LNG chain requirements are making this concept increasingly environmentally friendly, safe, and economical.

References

Refer to footnotes on individual pages.

Attachments

- Figure-1 Small-Scale LNG Supply Chain – Containerized LNG Storage & Transportation
- Figure-2 Small-Scale LNG Supply Chain: Bulk LNG Storage & Transportation
- Figure-3 LNG Supply & Transportation: Containerized vs Bulk Results
- Figure-4 LNG–based Natural Gas vs Liquid Fuels Cost Comparisons (Table)
- Figure-5 LNG–based Natural Gas vs Liquid Fuels Cost Comparisons (Chart)

Figure-1
Small-Scale LNG Supply Chain
Containerized LNG Storage & Transportation

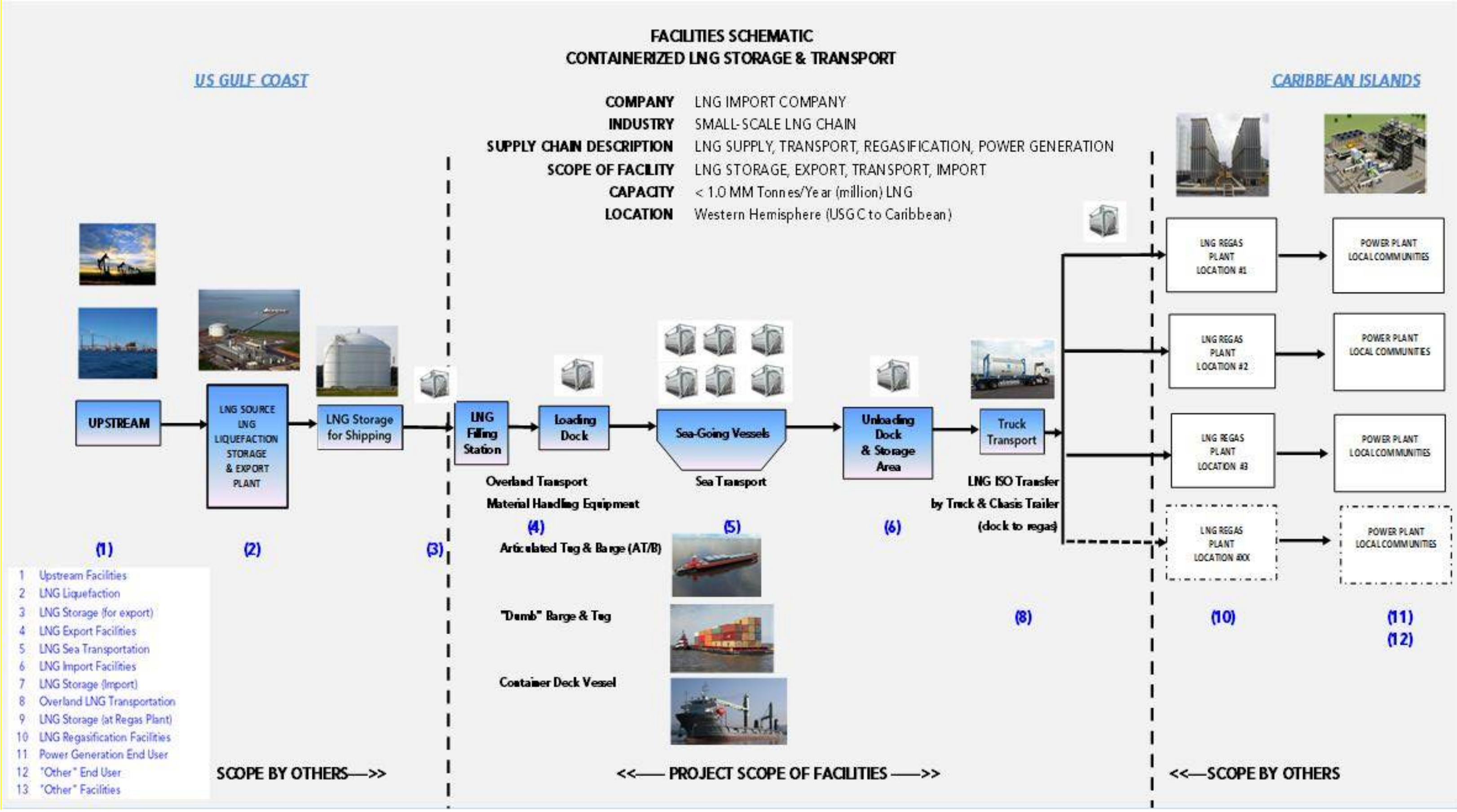

Figure-2
Small-Scale LNG Supply Chain
Bulk LNG Storage & Transportation

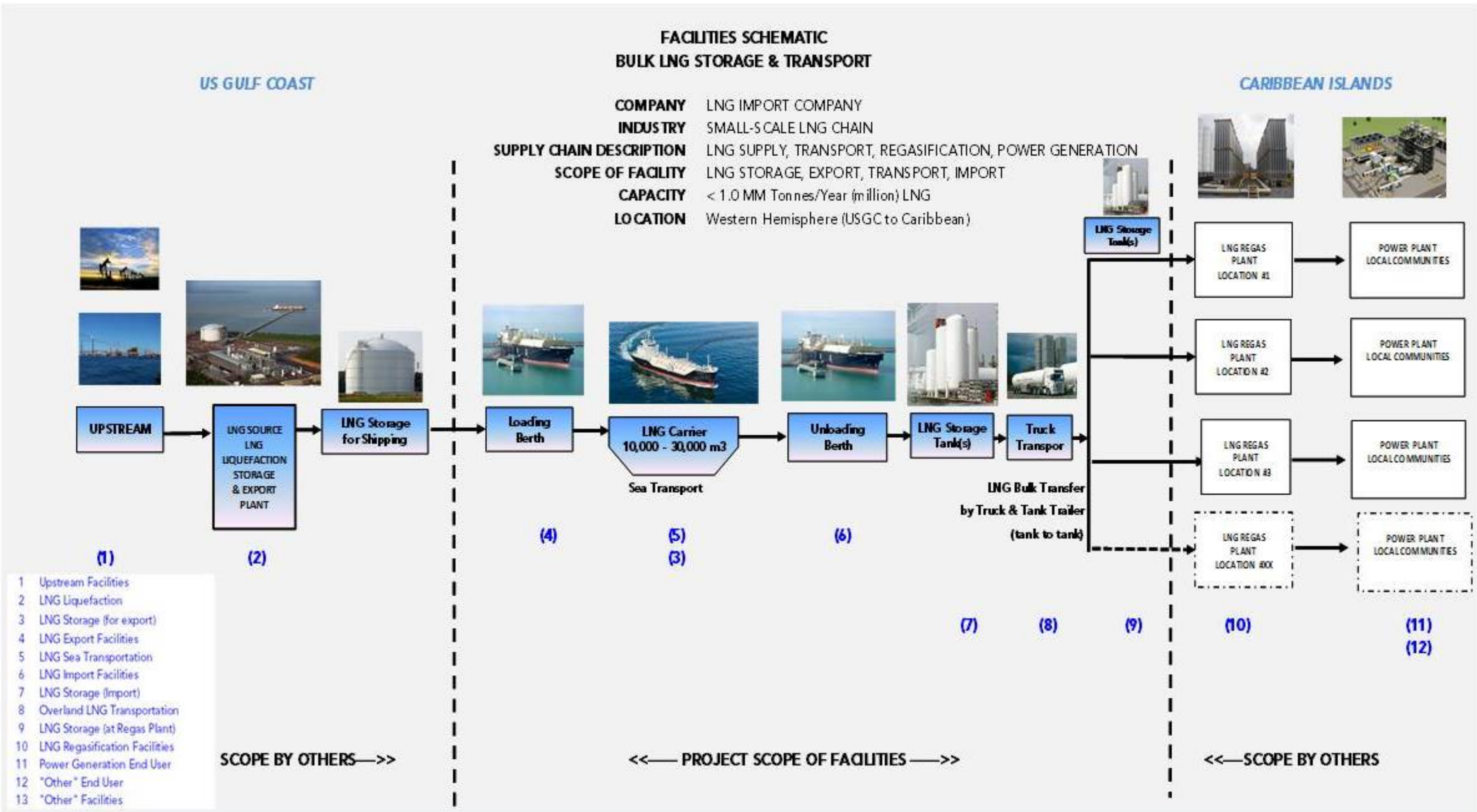

Figure-3
LNG Storage & Transportation
Containerized vs Bulk

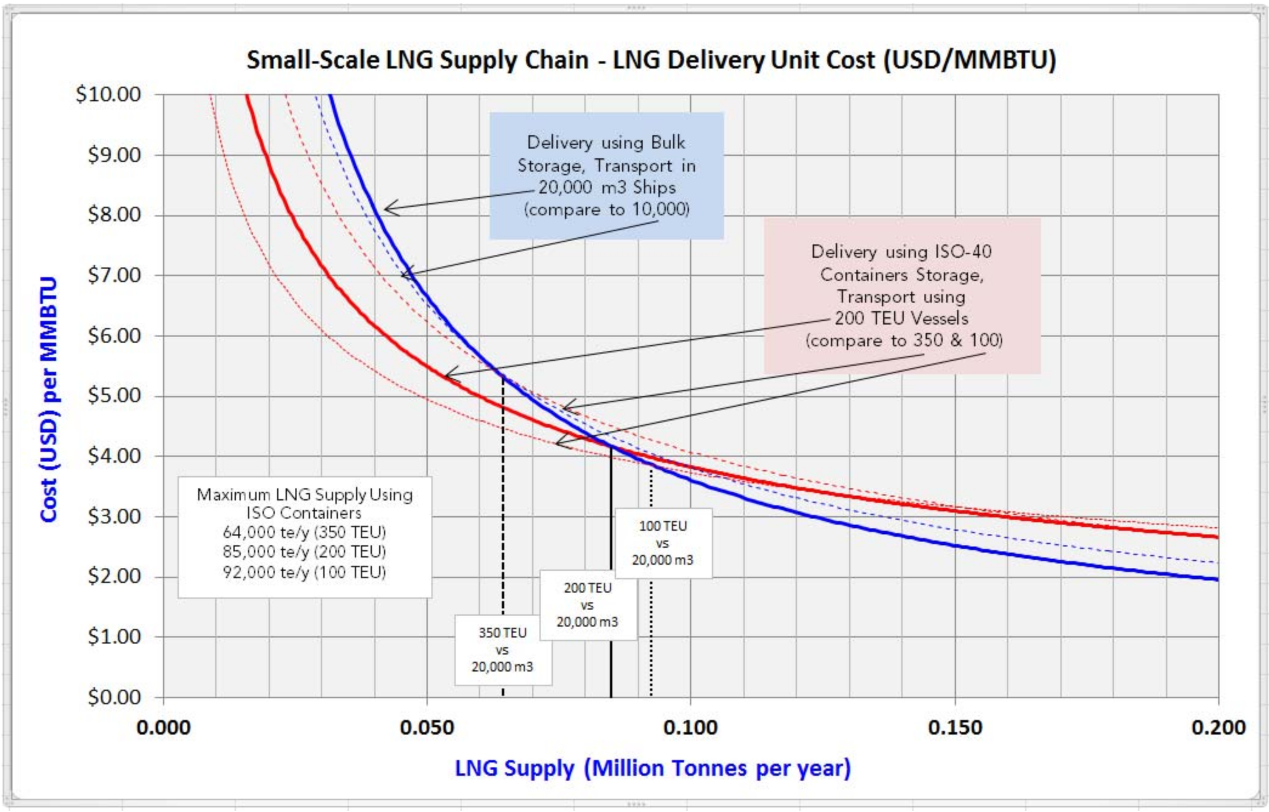

Figure-4
LNG-Based Natural Gas vs Liquid Fuels Costs

Small-Scale LNG Supply Chain
Comparison: Natural Gas vs Heavy Fuels
Caribbean Islands (Domican Republic)
Costs: USD/MMBTU NOTE-1,2

		Power Generation Small-Scale < 50 MWe ISO Transport	Power Generation Mid-Scale 75-300 MWe ISO Transport	Power Generation Large-Scale 300-500 MWe Bulk Transport
	Power Generation (installed MWe)	40	75	400
	LNG supply (te/year)	50,000	100,000	500,000
Diesel Fuel NOTE-3		$ 17.38	$ 17.38	$ 17.38
Heavy Fuel Oil (HFO) NOTE-3		$ 10.88	$ 10.88	$ 10.88
Natural Gas Fuel (LNG source)				
Natural Gas Supply	Henry Hub +15% NOTE-2	$ 3.45	$ 3.45	$ 3.45
LNG Liquefaction	USGC-Sourced LNG	$ 3.50	$ 3.50	$ 3.50
LNG Transportation	Storage, Sea, Trucking	$ 4.80	$ 4.20	$ 2.50
LNG Regasifcation	Ambient Air Vaporizers	$ 1.20	$ 0.85	$ 0.50
Power Plant Conversions	Diesel/HFO to Natural Gas Fuel	$ 0.30	$ 0.25	$ 0.20
Total		$ 13.25	$ 12.25	$ 10.15
Savings with Natural Gas (LNG Source) vs Diesel		$ (4.13)	$ (5.13)	$ (7.23)
Savings with Natural Gas (LNG Source) vs HFO		$ 2.37	$ 1.37	$ (0.73)

Basis Notes

Note-1 Excludes Local Taxes
Note-2 15-year project operating basis
Note-2 $3.00/MMBTU Natural Gas Cost (Henry Hub) plus 15%
Note-3 Diesel & HFO pricing based on $80/bbl (Brent Crude)

Figure-5
LNG-based Natural Gas vs Liquid Fuels Costs