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# Distributed Compressed Natural Gas Sea Transport

Michael Nikolaou and Michael J. Economides, SPE, University of Houston; Xiuli Wang, SPE, XGas; and Matteo Marongiu-Porcu, SPE, Texas A&M University

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## Abstract

While liquefied natural gas (LNG) is the dominant technology for marine transport of natural gas, compressed natural gas (CNG) is an economically attractive alternative for transportation of relatively small amounts of natural gas over short distances (up to 6 Bcm/year transported over 2000 km, respectively). Because the main capital expenditure in a CNG project is on marine transport vessels, careful design of CNG transport fleets and compatible distribution schedules is important. Design through solution of an all-encompassing optimization problem would be desirable but complicated and intuitive unappealing. In this work, a structured optimization framework is applied to potential marine CNG transport from a source in the Trinidad/Venezuela area to island countries in the Caribbean. Two general patterns emerge in the results: A "hub-and-spoke" pattern for servicing of the largest four consumption markets (Puerto Rico, Dominican Republic, Jamaica, and The Bahamas) and a cyclical "milk-run" pattern for the remaining (smaller) markets.

## Introduction

The role of natural gas as a fuel is slated to increase dramatically in the coming decades, owing to the efficiency and environmental friendliness of natural gas in comparison to other fuels. However, transportation of natural gas from points of production to consumption markets remains a challenge. Two well established gas transportation technologies currently dominate the market: Pipeline and liquefied natural gas (LNG) accounting for 70 and 30 percent of transported gas, respectively. Pipelines generally offer the most economically attractive solution and are the preferred choice whenever feasible, such as for land transport. Subsea pipelines are restricted by the distance and terrain they can traverse. As a result, transport of natural gas by sea vessels is favored for transport over long distances spanning sea water. While LNG is currently the dominant technology used for sea transport of natural gas, a number of recent studies have shown that compressed natural gas (CNG) is economically more attractive than LNG for sea transport of relatively small volumes of natural gas over small distances (Marongiu-Porcu, et al., 2008, Wang and Marongiu-Porcu, 2008). In comparison to LNG, which requires costly liquefaction and regasification facilities at the shipping and receiving sites, respectively and is energy-intensive, CNG requires minimal investment in facilities at the shipping and receiving sites and uses less energy. The main capital cost for CNG is incurred for transportation vessels. Although the cost for transportation vessels is higher for CNG than for LNG (stemming from corresponding gas compression ratios of 300:1 vs. 600:1, respectively), overall economics favor CNG for short distances and small loads, as summarized in Figure 1. Finally, because the demands for the entire chain of operations to be well coordinated and in place are easier to meet for CNG (compression / transportation / distribution) than for LNG (liquefaction/transportation/regasification), the former provides an additional degree of flexibility that is welcome in situations of changing market conditions.

Even though CNG is used widely in land applications (buses, passenger cars) and a proof-of-concept for sea transport of CNG has existed since the 1960s (Broeker, 1969), CNG has yet to make inroads into the transportation market for natural gas. Three factors have contributed towards that. First, investment emphasis internationally has been primarily on LNG, for understandable reasons (see Figure 1). Second, CNG vessel designs and projects have been envisioned to eke a bite out of the LNG pie, which is not necessarily a good approach. Third, innovative CNG vessel designs for low cost and high efficiency have become available only in recent years. There are certainly several regions worldwide whose energy needs, geography, and access to natural gas sources would make them good candidates for application of CNG sea transportation (Figure 2). For each of these regions there exist multiple scenarios for CNG distribution, in terms of number of vessels, vessel capacities, and itineraries. Identification of promising scenarios is necessary to determine project economics and possibly guide future technological developments.