

Future long distance energy transport in tubes

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Abstract

A need for up to 5000 km long energy connections with capacity of up to 20 GW_e (electric power content) is addressed by comparing known options and by proposing to transport energy reach substances in evacuated tubes. Using example of natural gas, it is shown that evacuated tube transport technologies (ET3) system moving liquefied natural gas (LNG) adds most of the value being economical, flexible, energy efficient, safe, reliable and sustainable.

1. Introduction

Compared below are three options to transport energy over long distance: 1) natural gas by pipeline NGPL, 2) electrical energy by high voltage direct current technology HVDC and 3) liquefied natural gas LNG by ET3. They all have in common the following elements: collection network, processing stations A and B, transport lines, and finally a distribution network.

In option 1a natural gas passes the collecting network at (before) supply site A, is transported via a pipeline from A to B and passes the distribution network at (after) B on the way to consumer (e.g., power plant). For example, a typical 1.2 m diameter, pipeline operated at 120-220 bar, has a capacity of 28 Bm³, energy loss of 2.5% for 1000 km and a typical length of few thousand km. Such pipe matches the flow of electric energy content of 20 GW_e, and three of such pipes in parallel are needed (providing a total of 22 to 66 Mton/year of natural gas in a connection with N-2 to N-0 redundancy). For such connection capital costs typically are: 11 M€/km excluding and 15 M€/km including compressors [1], prices of year 2016. This option uses a proven technology. It is based on the assumption that there is enough of O₂ supply and of CO₂ sink capacities at demand site B, it allows use of co-generation (when both electricity and heat are consumed at the demand site). Economics: assuming 20 and 350 \$ per 1000 m³ of gas price at wellhead and at demand site, said connection generates annually 9 B€ of income, therefore the capital cost of 15 B€ can be returned in estimated 3 years (assuming that 50% of the income is used for the return). Main drawbacks are: gas pipelines are not always possible (e.g., between USA and Europe), they are not flexible enough to provide sufficient level of security required in modern world, total cost increase proportional to connection length (a pressure drop can be as high as 100 bar for 1000 km), relatively high energy loss and environmental concerns: e.g., when energy is realized at B, CO₂ is produced, O₂ is consumed and waste heat is rejected; the additional costs (such as carbon tax) are not accounted above. A related option 1b (to use LNG produced at supply station A, shipped with tankers to and consumed at demand station B, receiving terminal) has comparable (to option 1a) capacity and economics at distances of 3000 km or more. Option 1b as compared to 1a provides additional flexibility and security in gas supply [1].

In option 2 electrical energy is transported instead of gas by using high voltage direct current (proven) technology, where a flow of electrons passes collecting network and up-converter station at (before) A, is transported via an overhead line (OHL) or high temperature superconducting (HTS) underground cables (UGC) between A to B, passes down-converter station B and distribution network at (after) B on the way to consumer. In option 2a for such 1000 km-long, N-2 redundant connection comprised of three times two 10 GW OHLs at ±800 kV extrapolated from [3] capital costs are: 16 M€/km excluding and 25 M€/km including converter costs. The energy loss amounts 2.5 % per 1000 km.

In option 2b for such 1000 km-long, N-2 redundant connection comprised of three 20 GW_e HVDC HTS cables (at ±800 kV) capital costs are: 8 M€/km excluding and 17 M€/km including converters [3]. The energy loss is 0.25 % per 1000 km. For option 2b the converter cost (9 B€) is proportional to the rated power and almost independent on the connection length. Economics: assuming electrical energy market prices at points A and B respectively of 30 and 120 €/MWh, the 20 GW_e connection will generate 15 B€/year of income. Furthermore, assuming 50% of that is return to investors, the capital cost of 17 B€ will be returned in 2-3 years. A clear merit of options 2 (as compared to 1) is that they are compatible with renewable energy sources (wind, solar, hydro) producing electrical energy. Furthermore, in option 2b placing of the energy delivery network fully underground is included.

A less explored option 3 of energy delivery is with unconventional modes [2], namely evacuated tube transport technologies ET3 [4] considered here. When operated at up to 1300 km/h, pairs of the “go” and “return” tubes can be elevated, on- or underground. Estimated capital cost for such N-2 redundant ET3 system using evacuated tubes of 1.5 m diameter are 10 M€/km excluding and 15 M€/km including stations. Each ET3 capsule can transport 0.3 ton of LNG and at the moderate capacity of 9250 capsules/hour (load factor of 0.097) a pair of evacuated tubes can deliver 22 Mton/year of natural gas (thus matching the capacity of 20 GW_e). The estimated energy loss is just 0.03% per 1000 km. Furthermore transport capacity of such connection can be increased (up to 10 times) with modest additional investment in the connection itself.

Where it is applicable, only a fraction of the total system cost (proportional to the time spent for transporting LNG, just 0.1 of the total available time) can be charged to the energy transporting company making the relevant total capital costs as low as 1.5 B€ for N-2 redundant connection. Economics: assuming 20 and 260 \$ per 1000 m³ of gas price at wellhead and at the demand site (400 \$/ton of LNG), said connection generates annually 11 B€ of income, therefore the relevant part of connection capital cost (1.5 B€) can be returned in estimated 0.3 years, assuming that 50% of the income is used for the return. In other words, a similar gain can be obtained in cost-price of LNG delivery. Where applicable, evacuated tube transport system with smaller tube diameter (than 1.5 m for ET3, e.g., matching the actual transport capacity) offers even lower capital cost (than 15 B€), however it brings a disadvantage of defragmenting the market.

Table 1. Comparative costs of selected options for a 20 GWe, 1000 km-long, N-2 redundant energy link

Option nr.		1a	2b	3
Specification	Transmission by:	NGPL	HTS UGC	ET3 LNG
Reference		[1]	[3]	[2, 5]
Pressure, bar (Voltage, ±kV for option 2b)		220	800	10
Flow, Mt/year (Current, kA for option 2b)		22	12.5	22
Capital costs of the link:				
full length, B€		11.1	8.4	9
full length with stations, B€		14.7	16.6	15
as addition to that of power plant, €/W		0.7	0.8	0.8
Technology status		proven	unproven	unproven
Energy loss, % (excl. converters for opt. 2b)		2.5	0.24	0.03
Load factor		1	1	0.1
Min. width x height of the installed link, (m x m)		3 x (2 x 2)	3 x (2 x -1.5)	3 x (2 x 4)
Conductor and cooling detail				
Conductor and cooling		30 mm thick pipe	ReBCO+LN2	LNG in vacuum
Operating temperature core, K		300	66.5	300
Max. spacing of two stations, km		1500	2000	1500

Table 2 Further details

Option	1a (NGPL)	2b (HTS)	3 (ET3 LNG)
Number of tubes	3 x 1	3 x 1	3 x 2
Outer diameter (of one tube), m	1.2	0.4 m	1.5 m
Full undergrounding of the connection possible	Excluded	Included	Excluded
Power plant at site	B	B	A
Cogeneration (at demand site) is possible	Yes	No	Yes
Offers delivery of O ₂ to site B	No	Yes	Yes
Offers return of combustion products to site A	No	Yes	Yes
Security of supply	Limited	Limited	Limited

Conclusions

A (N-2)-redundant energy connection to deliver over long distance 20 GW_e is considered. At the length of 1000-2000 km, connections transporting natural gas by pipeline, LNG by evacuated tube and electrons by HVDC HTS cable have comparable capital costs. To our opinion, option 3 to transport LNG or other energy reach substance by ET3 in many cases will add most of value being economical, flexible (power capacity can be increased, other cargoes and even passengers can be transported), energy efficient, safe, reliable and sustainable.

References

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