International Journal of Oil, Gas and Coal Engineering
2023; 11(5): 79-85
http://www.sciencepublishinggroup.com/j/ogce
doi: 10.11648/j.ogce.20231105.11
ISSN: 2376-7669 (Print); ISSN: 2376-7677 (Online)

Economic Comparison of Storage of Natural Gas as Liquefied Natural Gas and Compressed Natural Gas: A Niger Delta Case Study

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To cite this article:
Anthony Ogbaegbe Chikwe, Onyebuchi Ivan Nwanwe, Jude Emeka Odo, Dominic Elechi, Christian Emelu Okalla. (2023). Economic Comparison of Storage of Natural Gas as Liquefied Natural Gas and Compressed Natural Gas: A Niger Delta Case Study, *International Journal of Oil, Gas and Coal Engineering*. *11*(5), 79-85. https://doi.org/10.11648/j.ogce.20231105.11

Received: July 30, 2023; **Accepted**: November 3, 2023; **Published**: December 22, 2023

Abstract: The worldwide demand for a safe and unpolluted climate combined with the need of adapting stranded gas fields to fulfill the developing need for Natural gas on the planet today has required comprehension of the scope of potential for business acknowledgment of Liquefied Natural Gas (LNG) and Compressed Natural Gas (CNG) facilities. This places a significant weight on the monetary assessment measure which will give the most extreme knowledge into the reason for a choice to put or not to put resources into the LNG or CNG. In this study, an economic comparison was conducted between LNG and CNG as gas storage methods. The economic indicators utilized in this project were the Net Present Value (NPV), the Internal Rate of Return (IRR), and the payback period (PBP). The LNG and CNG cases had plant capacities of 5.2MMTPA and 2.6MMTPA respectively, a discount rate of 15 %, and a project life of 24 years. Results from economic analysis depict NPV, IRR, PBP, and profitability index values of $14,000,000, 15%, 7 years 6 months, and 1.76 for CNG and $3,077,000,000, 26%, 5 years, and 4 months, and 1.01 LNG respectively. It can be inferred from the results of this study that when the same amount of feed gas is supplied to an LNG and a CNG facility, an LNG was found to be more profitable than CNG as a gas storage method. This is because the LNG method resulted in a higher NPV, a higher IRR, a lower PBP, and a higher profitability index than that obtained for the CNG method. Based on the results of this study, natural gas should be stored as LNG rather than as CNG.

Keywords: Liquefied Natural Gas, Compressed Natural Gas, Net Present Value, Internal Rate of Return, Payout Period, Profitability Index

1. Introduction

Natural gas can be stored for an extended period in assigned storage facilities for ensuing utilization. Gas storage is essentially used to get together with load fluctuations. During times of low demand, gas is generally infused into storage offices and drawn off when there is popularity or utilization. Underground reservoirs are the most widely recognized techniques for putting away natural gas and it comprises three kinds; exhausted (depleted) oil reservoirs, salt cavern reservoirs, and aquifers. Despite the underground storage techniques, natural gas can also be stored as compressed natural gas (CNG), liquefied natural gas (LNG), hydrates, and liquids. Every one of these storage techniques has discernable monetary value and actual highlights which influences the moderation of a sort of storage for a specific application [1]. At atmospheric pressure, the boiling point of natural gas is -162°C. When natural gas is mixed with air, it burns if the concentrations have a volume that ranges from 5% to 15%. Natural gas is colorless and odorless. The stoichiometric ratio for air fuel is approximated to be around 17.22 based on mass. At Standard Temperature and Pressure natural gas has a lower density than air, the density of natural gas ranges between 0.7 - 0.9 kg/m3. Depending on its composition, the molecular weight of natural gas ranges between 17 and 20 kg/mol. [2]

The worldwide demand for CNG and LNG is right now on the increment, this improvement can be credited to the utilization of LNG and CNG in power generation. As the demand increments and the worth of natural gas stay high, the inspiration to adopt non-customary gas assets likewise increments. A lot of the world's natural gas has a place with the classification known as "stranded gas" where pipeline transportation isn't reasonable or affordable. The production of abundance and the broadening of the economy has been the public authority's significant justification for using natural gas projects in Nigeria and other agricultural nations. Likewise, there has been motivations and demand from ecological bodies to end gas flaring. These components, combined with the expanding homegrown demand for natural gas have now urged financial backers to venture into gas storage projects [3].

The expansion of Greenhouse gases which has been on the increase since the pre-industrial period has played a major role in global warming. Other than having a global effect, air contamination is likewise influencing the climate and human well-being on a provincial and local scale. An example of this was seen when pollutants like Nitrogen oxides and oxides of sulfur were discovered to be responsible for the answerable for the eutrophication and acidification of normal ecosystems and freshwater and for the development and movement of ozone at ground-level [4].

According to Hönig et al [5], there is a predetermined need to supplant 20% of fuel utilization with alternate fuels. As of now, alternative fuels are generally utilized in electricity generation and transportation. It is feasible to utilize the following alternative energy sources for transportation; Liquefied Natural Gas (LNG), Liquefied Petroleum Gas (LPG), biodiesel, Compressed Natural Gas (CNG), hydrogen, and electricity. Among all the referenced alternate energy sources, natural gas ends up being quite possibly the most harmless to the ecosystem because of its verifiable clean combustion measure. The International Energy Agency (IEA) examined prospects and inferred that the natural gas demand should encounter a speedy growth rate. Broad accessibility, Compatibility with combustion motors, and Lower functional expense are direct results of the associated benefits of natural gas.

Natural gas associated with crude oil is called associated gas. Information from the EIA has uncovered that the world's gross natural gas reserves are around 6200 TCF. Albeit, various examinations have shown that the assessed global associated commercial gas reserves with no commercial worth is around 1000 TCF which is about 17% of all gas reserves.

The World Bank's Global Gas Flaring Reduction (GCFR) in conjunction with the National Geographic Data Center (NGDC) is doing an expedition to foster a methodology that will predict global volumes of flared gases based on satellite observations. The NGDC claimed that the global volume was to be about 4.9-6.1 TCF per annum between 1994 and 2008 alongside the highest volume of 6.1 TCF in 2005 and the least volume in 2008 which was 4.9 TCF. This measure of gas represents more than 5-6% of the whole world's utilization of gas. It is estimated that three times the yearly flared gas volume is re-injected into depleted reservoirs without Enhanced Oil Recovery requirements, this also serves as a better alternative to flaring and venting.

The impact of global warming is another major problem with gas flaring. It was reported by the World Bank that flaring of associated gas releases over 300 MTPA of carbon dioxide. When gas is vented, the effect of global warming gets more serious because methane has 21 times the power than Carbon dioxide as a greenhouse gas. Consequently, the oil and gas industry appears to have gotten to the stage where innovative field advances will not be attainable until the problem of associated gas is solved with the present carbon tax legislation [6].

1.1. Liquefied Natural Gas

Liquefied natural gas (LNG) is a form of natural gas that has been cooled to a liquid structure, it is generally made of methane, with little hints of ethane. Natural gas is changed over to a fluid structure for safety and rearrangements for storage and transportation. After cooling, it is decreased to around 1/600 of its original volume in a gaseous state at standard conditions for pressure and temperature. LNG exists as a colorless, scentless, non-corrosive, and non-harmful form of natural gas. Combustibility, asphyxia, and freezing are common dangers associated with LNG. The process of liquefying natural gas entails the removal of certain components such as acid, gases, water, helium, dust, and heavy hydrocarbons, which could lead to difficulty downstream. The gas is then condensed into liquid form at near-atmospheric pressure by cooling it to about -162°C (-260 °F). The maximum pressure for transportation is set at 25kPa (4 psi). The gas obtained from hydrocarbon deposits mostly contains a high number of hydrocarbon products, which normally include methane (CH_4), ethane (C_2H_6), propane (C_3H_8), and butane (C_4H_{10}). These products have wide-ranging physical properties such as boiling points and heating value, which permits various channels for commercialization and various uses. Acidic compounds like carbon dioxide CO_2, H_2S, oil, water, mud, and mercury are extracted from gas to produce a sweet gas stream. If the mercury, acidic molecules, and additional impurities are not removed, they could damage the equipment. The amalgamation of mercury to aluminum and corrosion of steel pipes in the cryogenic columns could also result in costly damages. Natural gas is regarded as an economically insignificant product of crude oil production whenever a production field was far from the gas pipelines or located offshore where pipelines were not available. This implied that the produced gas was flared, especially as there was no feasible means of storage or transportation besides pipelines that involves abrupt use by the final consumers. This also implied that in the past, natural gas marketers were exclusively local and all products produced were consumed on local grounds. The evolution of the production processes, storage facilities, and transportation has provided the requirements for the commercialization of natural gas into the global markets, which enables it to compete with other fuels. The dependence on networks that were said to be unachievable was made possible by the development of LNG storage facilities. Several months' supply could be placed in storage facilities, given that storing other fuels could easily be done comparatively using simple tanks. The introduction of large-scale storage facilities has made it feasible to develop reserves for gas storage, which could store gas for a long time. The reserves of LNG could be used at any time through the process of regasification and are the main methods for networks to handle peak shavings requirements [7].

1.2. Compressed Natural Gas

CNG is gotten from natural gas, which primarily comprises of methane (CH_4). CNG is made by compressing natural gas to less than 1% of the original volume occupied at standard atmospheric pressure. CNG is stored and dispersed via hard containers usually in spherical or cylindrical shapes at a pressure of 2,900-3,600 psi (20-25 MPa). CNG can be used in combustion engines and reformed vehicles, and also in automobiles that have been specially designed and manufactured to run on CNG. CNG in combustion engines can be used either alone, or with an isolated liquid fuel system to widen the range or in aggregation with another fuel. It can be used as a substitute for petrol, diesel, LPG, LNG, etc. The cost of storage containers is usually the key challenge to a faster implementation of CNG as a fuel. This is why metropolitan governments and municipal transportation automobiles were the earlier users of CNG, as they could rapidly repay the money spent in the new and inexpensive fuel. Despite these situations, the global number of CNG vehicles has gradually increased. Due to the steady growth in the industry, the cost of fuel storage cylinders has been reduced to a much more satisfactory level [8]. At the receiving station, the CNG vessel offloads gas via pipeline. The terminal is designed to be straightforward and contains a dock that has pipelines with pipeline connections meant for high-pressure transports. The terminal also has an expander which permits energy to be acquired from high-pressure gas. Ships that have pressures below that of the pipeline make use of a scavenging compressor to offload the ships. This results to a shipment of larger amounts of gas, thus reducing the number of ships needed to transport gas. Storing gas at the production and receiving phases are required for activities to go on nonstop. If the time between successive shipments is not favorable to the parties involved, the ideal thing to do would be to keep additional ships in the ports to serve as storage mediums [9].

1.3. Screening Criteria

LNG projects with base load plants need gas reserves, purchasers, and funding. The use of recognized machinery and contractors are particularly essential for buyers and stakeholders. 1 TCF of natural gas is necessary per MTPA of LNG for over 20 years. Due to economies of scale, LNG is most cost-efficiently created in rather large facilities at locations with oceanic access which allows regular large bulk cargoes through to the markets. This involves a steady gas supply for the respective production capacity. Preferably, plants are situated near the source of the gas, to decrease the cost of intermediary transport facilities and gas liquefaction. The high cost of constructing large LNG facilities creates the advanced growth of gas sources to maximize facility utilization indispensable, in addition to the life addition of present, economically devalued LNG facilities cost-effective. Principally when joined with lower sale prices as a result of the large capacity that is installed and the increasing costs of construction. This causes the financial screening to advance new and improved LNG facilities, even if they might be greener than already existing facilities with all investor concerns fulfilled. It is customary to contractually secure gas supply and gas trades for prolonged phases before making decisions, this is because of the high financial risk of LNG investments [10].

To promote LNG investments, an effective and vigorous risk outlining becomes a necessity. The risk of the price will keep changing basics for crucial decisions for LNG investments. In the presence of the recent price-varying conditions, circumventing and management of LNG price risks become increasingly complicated for project execution. Unexpected upstream activities, pipelines, and transport charge increments or plan holdups can have an impact in the original volumes of gas presented to the facilities. This can also be related to price behaviors if the price of the transfer is a factor for a non-integrated commercial model that could ascertain if an LNG facility carries risk for investments in the capital upstream [11].

CNG is viable for transportation to markets within a distance of less than 1000 km. other forms of gas storage such as GTL and LNG become better options for gas transportation as the distance increases. The volumes needed for CNG transports are smaller when compared to LNG and GTL. The fuel consumption needed for the compression of the gas at the plants is estimated to be between 0.5 and 1.0% of the feed gas. Extra fuel consumption in the course of transportation is based on the distance between the market and the source of the gas. The transportation cost depends on the different conditions of the project, the number of vessels, and the distance to the market. A study carried out with Coselle showed that the cost of transporting 300 MMscf/D of CNG over 1,100 miles is $1.4/MMBtu [9].

It has been proven from studies conducted by researchers that lower CO_2 production and lower vehicle noise can be achieved when operating vehicles with LNG [12]. This is advantageous when operating vehicles in cities. In their study, comparison was made between LNG and standard diesel in operating vehicles, in which LNG was found to be more viable.

2. Methodology

Table 1. *Parameter Assumption for LNG.*

PARAMETER	VALUE
Plant Capacity	5.2 MMTPA
Natural Gas Price	$ 1/MMBTU
LNG Market Price	$ 320/ton
LNG FPSO Capital Cost	$2,284,000,000
Feed Gas Volume	5.3 TCF
Operating Cost	4% of CAPEX
Project Life Span	24 YEARS
Construction Period	4 YEARS
Discount Rate	15%

The economic analysis was carried out using Microsoft excel to find the NPV, IRR, payback period and profitability index for both LNG and CNG. Various parameters and assumptions were carried were used to find the CAPEX, OPEX, and revenue.

CAPEX for the LNG and CNG methods were calculated using equations 1 and 2 respectively while calculation of OPEX for LNG and CNG methods are depicted in Tables 1 and 2 respectively. Revenue obtained for using the LNG and CNG methods are calculated using equation 3.

Table 2. *Parameter Assumption for CNG.*

PARAMETER	VALUE
Plant Capacity	2.6 MMTPA
Natural Gas Price	$ 1/MMBTU
CNG Market Price	$ 190/ton
Plant Cost	$515 MILLION
Total Shipping Cost	$360 MILLION
Feed Gas Volume	5.3 TCF
Operating Cost	15% of Capex
Project Life Span	24 Years
Construction Period	4 Years
Discount Rate	15%

$$LNG\ CAPEX = LNG\ FPSO\ CAPEX + Cost\ of\ Feed\ Gas \tag{1}$$

$$CNG\ CAPEX = Compression\ CAPEX + Shipping\ CAPEX + Cost\ of\ feed\ gas \tag{2}$$

$$REVENUE = Market\ price\ for\ LNG\ or\ CNG * Plant\ capacity \tag{3}$$

3. Results and Discussion

3.1. Results

Table 3 shows CAPEX, OPEX, and revenue obtained from LNG and CNG methods.

The data shown in table 1 were used to perform cash flow analysis for each of the gas storage methods and are presented in Tables 4 and 5 respectively for LNG and CNG.

Table 3. *Comparison of CAPEX, OPEX, and Revenue for LNG and CNG methods.*

	LNG Method	CNG Method
CAPEX	$2,552,000,000	$1,142,000,000
OPEX	$91,360,000	$171,300,000
REVENUE	$1,664,000,000	$494,000,000

Table 4. *Cash flow analysis for LNG.*

YEAR	CAPEX (MM$)	REVENUE (MM$)	OPEX	NCF	CUMM NCF	PV @5%	PV @15%	PV @30%	PV @50%	PV @100%
0	(2552)	0	0	(2552)	(2552)	(2552)	(2552)	(2552)	(2552)	(2200)
1	0	0	0	0	(2552)	0	0	0	0	0
2	0	0	0	0	(2552)	0	0	0	0	0
3	0	0	0	0	(2552)	0	0	0	0	0
4	0	0	0	0	(2552)	0	0	0	0	0
5	0	1664	(91)	1573	(979)	1232	782	424	207	49
6	0	1664	(91)	1573	594	1174	680	326	138	25
7	0	1664	(91)	1573	2167	1118	591	251	92	12
8	0	1664	(91)	1573	3740	1065	514	193	61	6
9	0	1664	(91)	1573	5313	1014	447	148	41	3
10	0	1664	(91)	1573	6886	966	389	114	27	2
11	0	1664	(91)	1573	8459	920	338	88	18	1
12	0	1664	(91)	1573	10032	876	294	68	12	0
13	0	1664	(91)	1573	11605	834	256	52	8	0
14	0	1664	(91)	1573	13178	794	222	40	5	0
15	0	1664	(91)	1573	14751	757	193	31	4	0
16	0	1664	(91)	1573	16324	721	168	24	2	0
17	0	1664	(91)	1573	17897	686	146	18	2	0
18	0	1664	(91)	1573	19470	654	127	14	1	0
19	0	1664	(91)	1573	21043	622	111	11	1	0
20	0	1664	(91)	1573	22616	593	96	8	0	0
21	0	1664	(91)	1573	24189	565	84	6	0	0
22	0	1664	(91)	1573	25762	538	73	5	0	0
23	0	1664	(91)	1573	27335	512	63	4	0	0

YEAR	CAPEX (MM$)	REVENUE (MM$)	OPEX	NCF	CUMM NCF	PV @5%	PV @15%	PV @30%	PV @50%	PV @100%
24	0	1664	(91)	1573	28908	488	55	3	0	0
						13575	3077	(726)	(1931)	(2102)

Table 5. *Cash flow analysis for CNG.*

YEAR	CAPEX (MM$)	REVENUE (MM$)	OPEX (MM$)	NCF	CUMM NCF	PV @5%	PV @15%	PV @30%	PV @50%	PV @100%
0	(1142)	0	0	(1142)	(1142)	(1142)	(1142)	(1142)	(1142)	(1142)
1	0	0	0	0	(1142)	0	0	0	0	0
2	0	0	0	0	(1142)	0	0	0	0	0
3	0	0	0	0	(1142)	0	0	0	0	0
4	0	0	0	0	(1142)	0	0	0	0	0
5	0	494	(171)	323	(819)	253	161	87	43	10
6	0	494	(171)	323	(496)	241	140	67	28	5
7	0	494	(171)	323	(173)	230	121	51	19	3
8	0	494	(171)	323	150	219	106	40	13	1
9	0	494	(171)	323	473	208	92	30	8	1
10	0	494	(171)	323	796	198	80	23	6	0
11	0	494	(171)	323	1119	189	69	18	4	0
12	0	494	(171)	323	1442	180	60	14	2	0
13	0	494	(171)	323	1765	171	52	11	2	0
14	0	494	(171)	323	2088	163	46	8	1	0
15	0	494	(171)	323	2411	155	40	6	1	0
16	0	494	(171)	323	2734	148	35	5	0	0
17	0	494	(171)	323	3057	141	30	4	0	0
18	0	494	(171)	323	3380	134	26	3	0	0
19	0	494	(171)	323	3703	128	23	2	0	0
20	0	494	(171)	323	4026	122	20	2	0	0
21	0	494	(171)	323	4349	116	17	1	0	0
22	0	494	(171)	323	4672	110	15	1	0	0
23	0	494	(171)	323	4995	105	13	1	0	0
24	0	494	(171)	323	5318	100	11	1	0	0
						2170	14	(767)	(1014)	(1122)

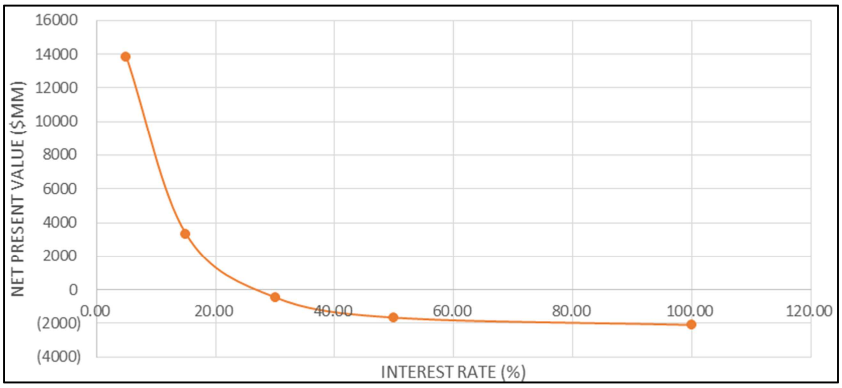

Figure 1. *Variation of Net Present Value with interest rate for LNG.*

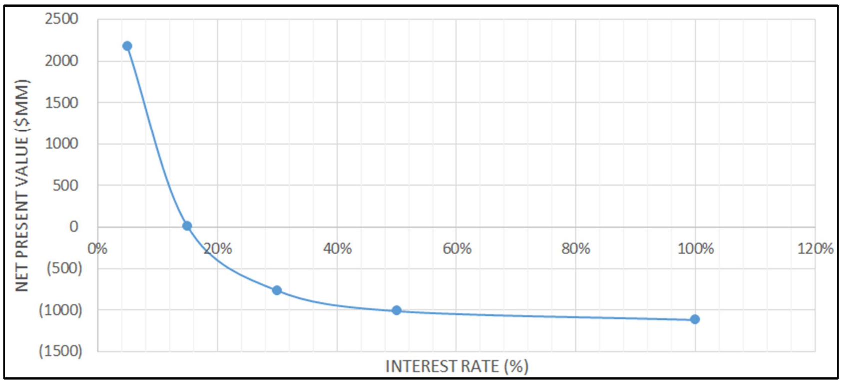

Figure 2. *Variation of Net Present Value with interest rate for CNG.*

Net present value at each interest rate for LNG and CNG were obtained from Tables 4 and 5, and shown in Table 6 and illustrated by Figures 1 and 2 for the calculation of the internal rate of return (IRR) for the two cases.

Table 6. *Variation of NPV for LNG and CNG at different interest rates.*

INTEREST RATE	NPV for LNG	NPV for CNG
5%	13575	2170
15%	3077	14
30%	(726)	(767)
50%	(1931)	(1014)
100%	(2102)	(1122)

NPV, IRR, and Payback period results for the two cases are shown in Table 7.

Table 7. *Comparison of NPV, IRR, and Payback period for LNG and CNG.*

	LNG	CNG
NPV	$3,290,000,000	$14,000,000
IRR	26%	15%
PBP	5 years 5 months	7 years 6 months

3.2. Discussion of Results

As earlier stated, the capital expenditure for an LNG project is typically higher than that of CNG with the same relative capacity. Despite having a higher capital expenditure, the LNG project had a higher NPV which was affected by the market pricing and demand for the LNG commodity. The discount rate of 15% was used to derive the NPV as seen in Table 4 and Table 7. The NPV for LNG and CNG are $3,077,000,000 and $14,000,000 respectively. The NPV for CNG at a 15% discount rate is far lower than that of LNG at the same discount rate, however, the NPV for CNG at a discount rate of 5% is seen as a more presentable figure. This implies that CNG requires a lower discount rate to be more economically viable. The IRR for both projects was found by plotting a graph of the NPV against the interest rates which resulted in the IRR curve. The IRR for LNG and CNG are 26% and 15% respectively, this implies that the LNG has a higher rate of return than that CNG. The payback period was calculated using simple interpolation and it was 5.45 and 7.54 years for LNG and CNG respectively.

4. Conclusion

In this project, an economic analysis of the gas storage methods (LNG & CNG) was carried out. Case studies with a project life of 24 years were used having assumed parameters that were utilized in the evaluation of the economic indicators. The economic indicators used in this project were the Net Present Value (NPV) which is the difference between the cash inflow and outflow, the Internal Rate of Return which indicates the cost-effectiveness of a project was used, the Payback Period was also used, the payback period indicates how long and investment attains break-even cash flow. The case study analyzed for the LNG had a plant capacity of 5.2MMTPA while the CNG plant capacity was 2.6MMTPA. In the economic analysis of the LNG and CNG projects of the case study, the discount rate of 15% was used to find the NPV, the NPV for the CNG project was $14,000,000, and the IRR was obtained from the NPV curve at 15% while the payback period was 7 years 6 months. The discount rate of 15% was also used to find the NPV, the value of the NPV was given as $3,077,000,000 while the IRR was obtained from the NPV curve and has a value of 25% while the payback period for the LNG project 5 years and 4 months. From the analysis carried out, it can be concluded that the LNG project is more lucrative than the CNG project when subjected to the same amount of feed gas.

Further work in this regard would focus on investigating other types of gas storage methods such as storage of natural gas with carbon nanotubes (CNT) [13] and absorbed natural gas [14] with CNG and LNG.

Conflicts of Interest

The authors declare no conflicts of interest.

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