Underground Storage of Refrigerated Natural Gas in Granites of the Southeastern U.S.

North Carolina Geological Survey
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Abstract

Conventional underground storage sites for natural gas (salt caverns, depleted gas and oil reservoirs, and aquifers) are either rare or absent along the U.S. eastern seaboard. However, the potential exists for underground storage of refrigerated natural gas in mined caverns (RMC) in granite*. We identified eleven pipeline-granite intersections in NC and southern VA along the Williams/Transco pipeline (completed) and the Atlantic Coast Pipeline (initial construction stage).

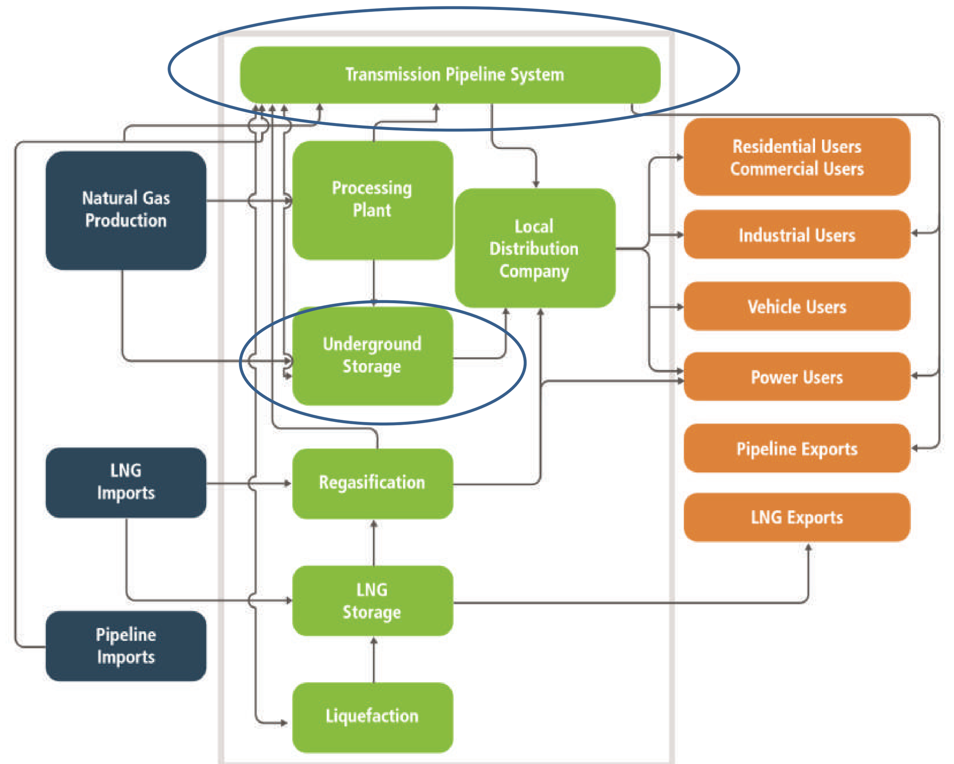
We used the conceptual design for a mined cavern in granite in the Maryland piedmont from PB-KBB (1998) in a DOE sponsored study as an example of the type of natural gas storage cavern that could potentially be adapted for use in the NC and VA granites*. RMC design capacity is 5 BCF at a cost of ~$200 million. Nominal RMC depth is 3,000 ft. RMC facilities provide high security, emergency supplies during natural or man made supply disruptions or peaking demand, and a small footprint. Liquid Natural Gas (LNG) plants are judged to be more competitive at present because of lower capex, but are less secure. RMC plants can meet multiple peak demands per year whereas LNG plants are limited in their cycle time.

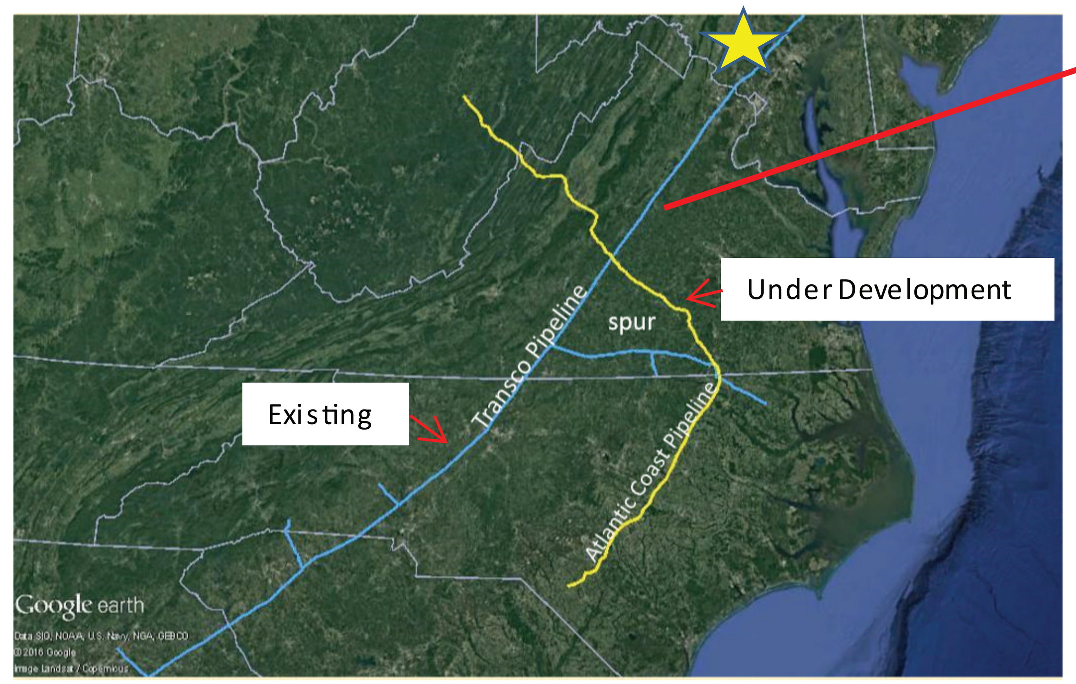
GIS and Google Earth Pro were used to intersect granite outlines from USGS digital state geologic maps with pipelines. USGS search engines provided additional information on the granites identified. The USGS' National Geologic Map Database provided search results for geological, geophysical, and geochemical maps, many that can be downloaded.

Existing geological knowledge of granite rock locations with potentially suitable geotechnical properties in the NC and southern VA region, coupled with modern advances in hard rock excavation technology, argue for the overall technical viability of the RMC concept. Commercial viability will depend on site specific conditions, market analysis, and other considerations requiring additional phased study.

If the need for underground storage justifies the higher costs of underground excavations, such as the type described by PB-KBB corporation, these granites would warrant further consideration as underground storage sites.

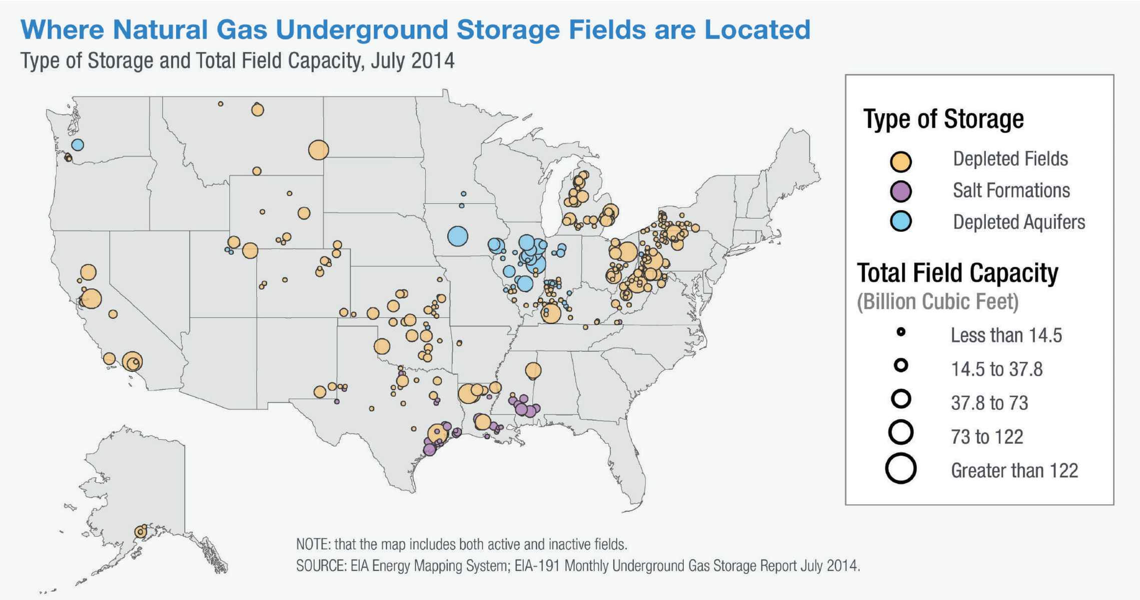
*Granite as used herein is a broad term for massive and isotropic rock bodies with desirable ranges of physical, and mechanical properties that are capable of sustaining large underground openings, with suitable thermal properties.



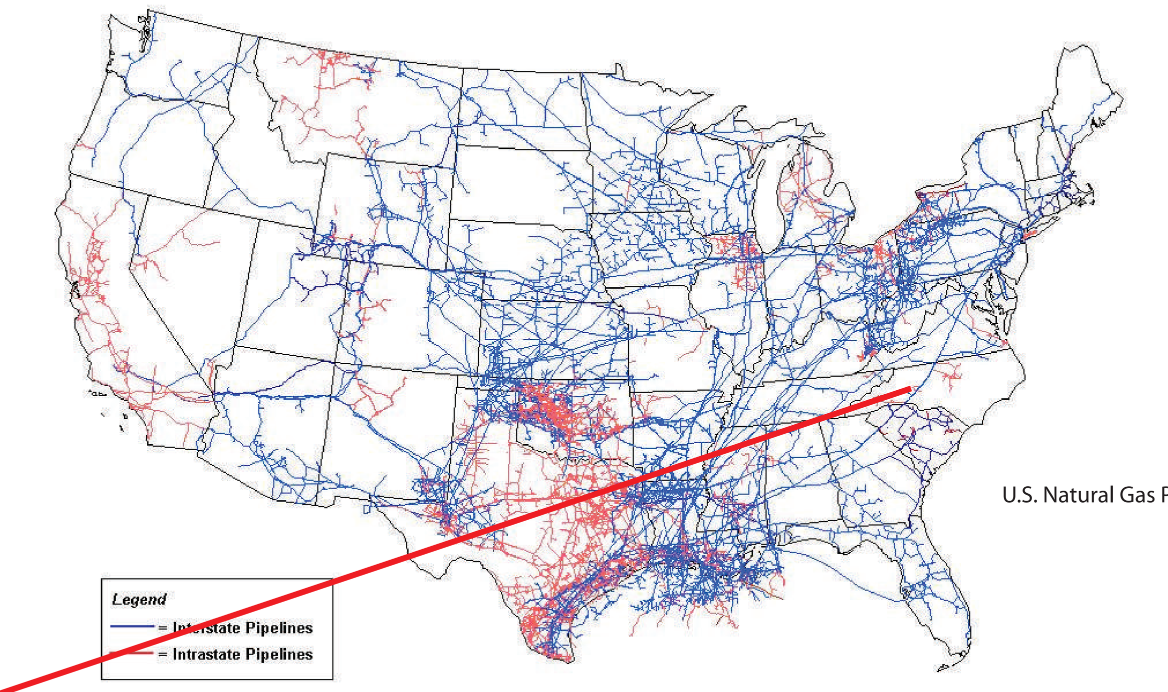


Right - Map showing the distribution of plutonic rocks and general ages in the North Carolina Piedmont and Mountains, and the existing route of the Transco Pipeline (red), and the general route for the Atlantic Coast Pipeline (green). The map was produced using GIS files that were modified from Geological Survey of Canada files: Hibbard *et al*., 2006. The draft plutonic rocks map of NC was prepared by Philip J. Bradley by modifying the Hibbard *et al.*, (2006) map to display only the plutonic rocks of the state.

Need for natural gas storage - Southeastern U.S.

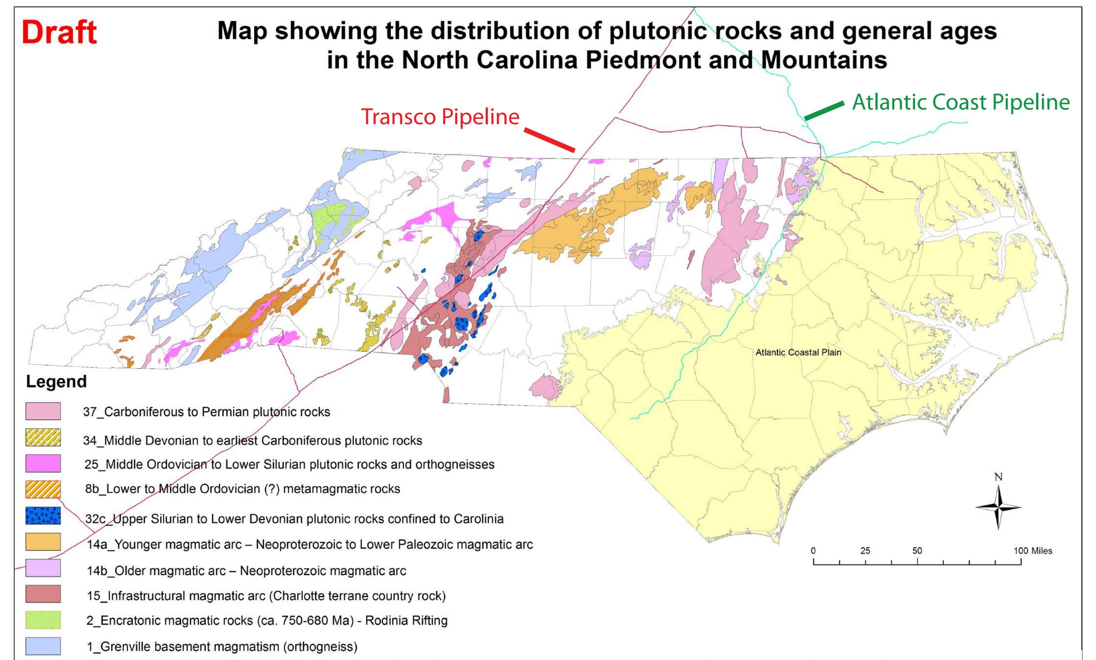


The Southeastern U.S. lacks traditional natural gas storage facilities (salt caverns, depleted gas and oil reservoirs, and aquifers) (Source: EIA Energy Mapping Ssystem; EIA-191 Monthly Underground Storage Report July 2014.

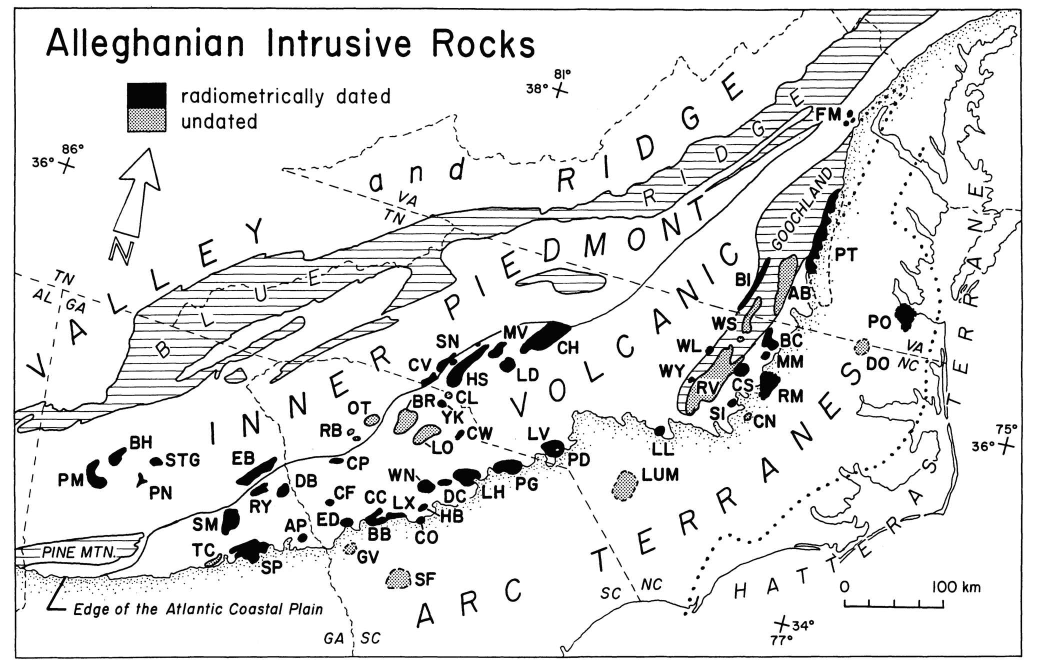


U.S. Natural Gas Pipeline Network, 2009

Source: Energy Information Administration, Office of Oil & Gas, Natural Gas Division, Gas Transportation Information System. Available on-line at . URL https://www.eia.gov/naturalgas/archive/analysis_publications/ngpipeline/ngpipelines_map.html



Data source: Modified from Hibbard *et al.*, 2006. Figure modified from Bradley *et al.*, 2012.



Location map of Alleghanian plutons in the southern Appalachians (from Speer *et al.*, 1994). The granites are crossed by the existing Transco Pipeline and along the route of the Atlantic Coastal Pipeline that is now in construction. The granites may be sites for RMCs.

Statement of Problem

Two or more additional liquefied natural gas storage facilities with capacities of ~5+ BCF might be needed along the routes of the Transco and Atlantic Coast pipelines in NC and VA for supply backup and to balance pipeline supplies (U.S. Energy Information Administration, 2015), to supply growing seasonal and peaking demand to nearby natural gas power plants and nearby metropolitan areas, and to attenuate price fluctuations.

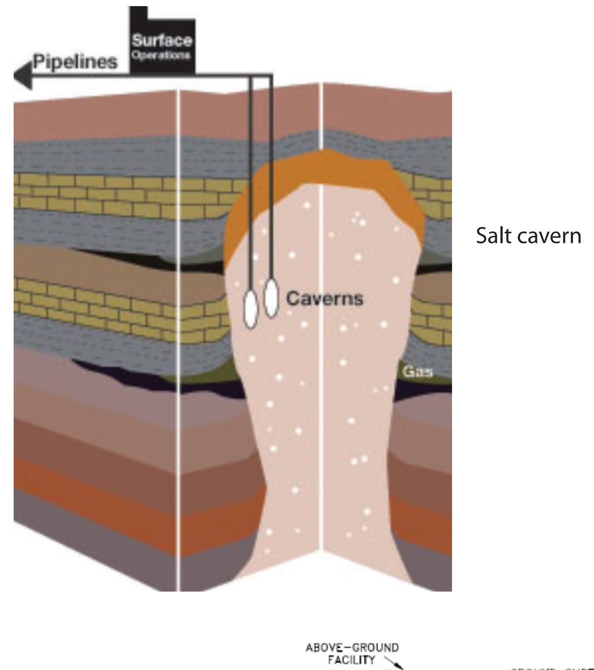
Underground storage instead of surface storage is preferred to prevent emergency shortages in the event of natural disasters or terrorist attack and underground storage requires less surface land. But conventional underground storage sites (depleted oil and gas reservoirs, aquifers and salt caverns) are absent in NC and VA. However, storage in lined or unlined caverns excavated in hard rock (e.g., granite plutons) is a possibility.

Our previous contributions on this topic include: Carpenter *et al*., 2017a,b; Myers, 2017; Myers and Reid, 2018, and Reid *et al.*, 2016, 2018.

Options for Natural Gas Storage in NC and VA

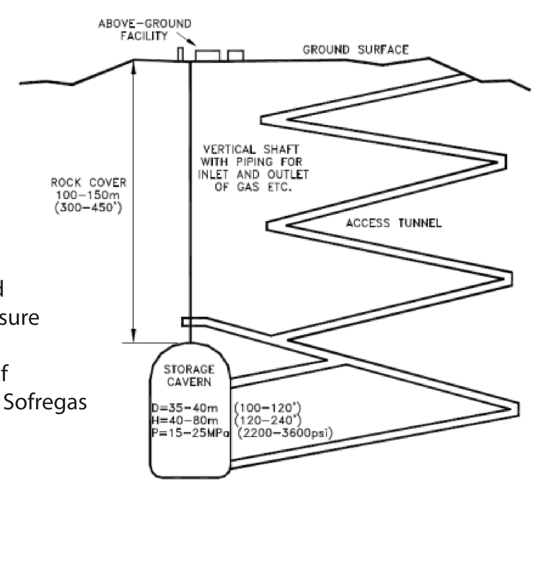
	Desirable Features				
	~5+ BCF capacity	High level of physical security	Multiple withdrawal cycles, high deliverability rate	Favorable candidate sites	Relative capital / operating cost
Above ground					
- Liquefied Natural Gas	Yes	No	No / No	Yes	See 'Preferred storage option' to the right.
Underground					
- Depleted oil / gas reservoir	Yes	Yes	No / Yes	No	
- Aquifer	Yes	Yes	No / Yes	No	
- Salt cavern	Yes	Yes	Yes / Yes	No	
- Excavated hard rock cavern (lined)	Yes	Yes	Yes / Yes	Yes	
- Excavated hard rock cavern (unlined)	Yes	Yes	Yes / Yes	Yes	

Liquefied Natural Gas (LNG)



Lined Rock Cavern (LRC)

- Steel liner used to seal cavern.
- Concreted between the liner and mass used to transfer gas pressure load to the rock mass.
- Est. construction cost for a 5.2 Bcf facility = $345 million ($1999); Sofregas US Inc., 1999.

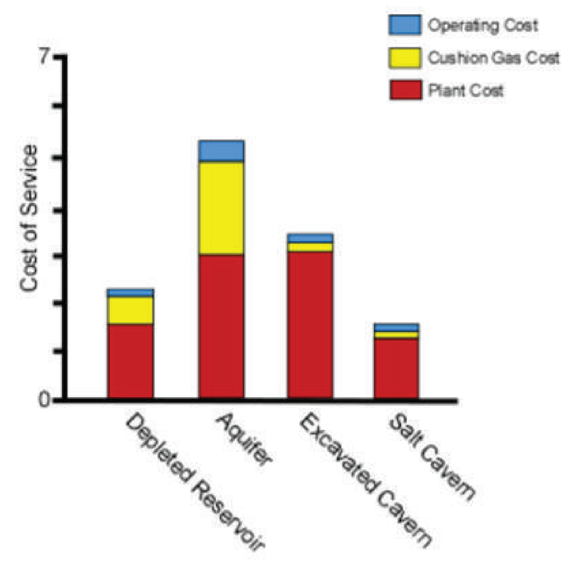


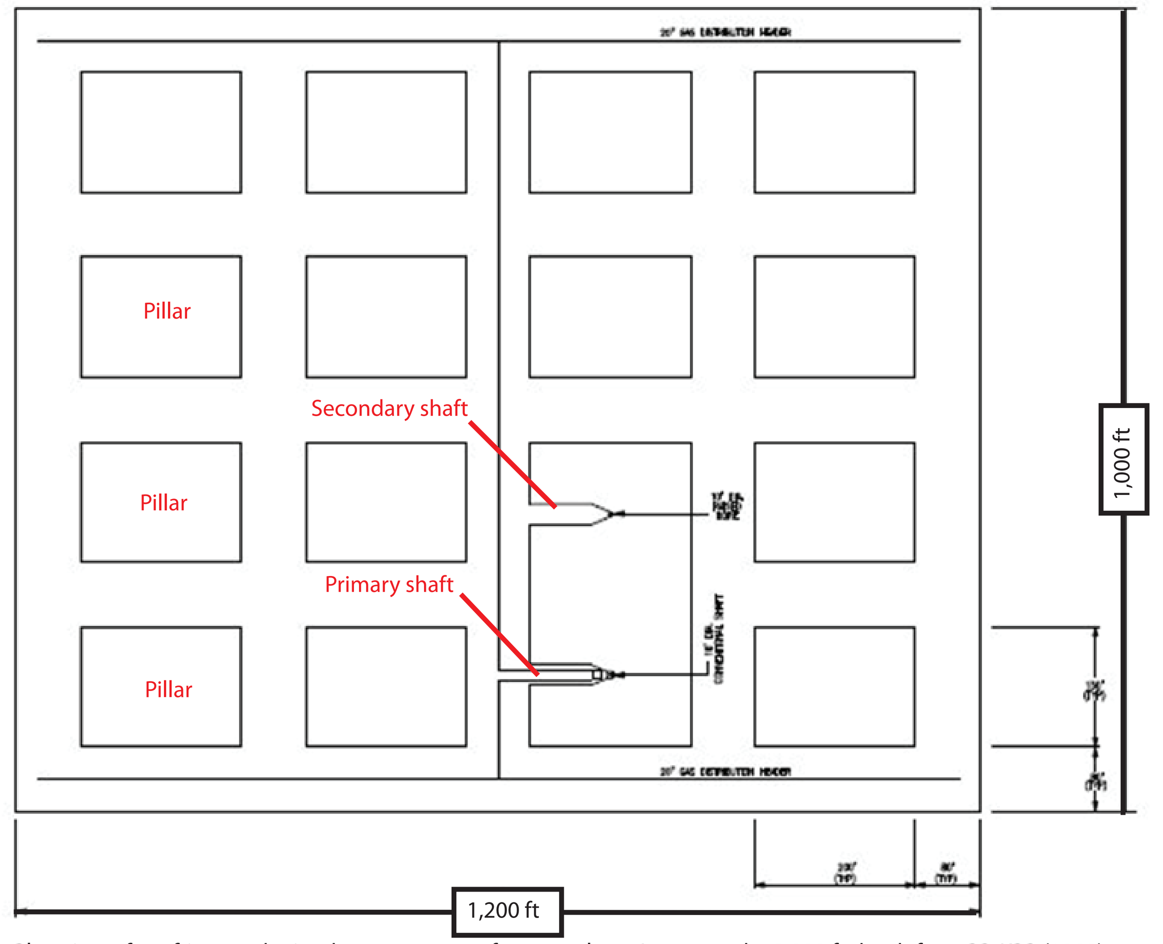
Preferred Storage Option

Excavated (mined) caverns have cycle time and deliverability advantages similar to salt caverns, and comparable operating cost of the salt cavern - but about twice the construction cost (Lord, 2009).

Refrigerated Mined Cavern (RMC)

-- The impermeable, high strength rock mass eliminates the need for liner and concrete.
- Est. construction cost for a 5.0 BCF facility = $173 million ($1998) (PB-KBB, 1998).



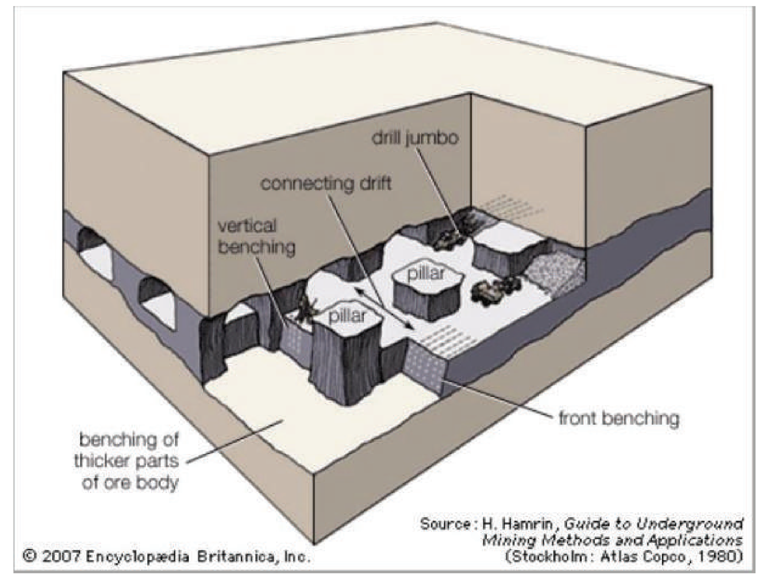


Plan view of a refrigerated mined storage cavern for natural gas. Layout at the 3,000 ft depth from PB-KBB (1998).

PB-KBB Design
Underground Storage (plan view)

Design features:

Depth: 3,000 ft
Volume: 7 million cubic feet
Storage temperature: -20 degrees F.
Maximum pressure: 1,250 psig
Storage capacity: 5 BCF
Plant cost: $173 million or $34.50 per standard thousand cubic feet stored
Surface footprint: 4 acres with an additional 2-3 acres for mine shafts and mining operation
Shafts: 2 shafts - one 18-20 ft diameter for moving equipment underground and lifting rock during operation; and one 10 ft in diameter to serve for ventilation and escape route in case of accident during construction



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Source: H. Hamrin, *Guide to Underground Mining Methods and Applications* (Stockholm: Atlas Copco, 1980)

Comparative Cost and Schedule of Cavern Location

	Shaft Depth 1500 ft	Shaft Depth 2000 ft	Shaft Depth 2500 ft	Shaft Depth 3000 ft
Mobilization	7,215,000	7,215,000	7,212,000	7,212,000
Sink & line 18 ft shaft	10,003,500	13,330,000	16,672,000	21,813,000
Rise-bore shaft	3,897,000	5,196,000	6,495,000	8,393,000
Material handling eqpt.	4,123,000	4,123,000	4,120,000	4,120,000
Assembling mining eqpt.	2,695,000	2,695,000	2,693,000	2,693,000
Cavern Exc.	181,714,000	104,197,640	82,227,000	64,998,500
Total mining cost	209,647,500	136,764,640	119,419,000	109,229,500
Contingency	31,447,125	20,514,696	15,994,000	14,629,000
Total cavern development cost	241,094,625	157,279,336	135,413,000	123,858,500
SCHEDULE	80 months	59 months	48 months	47 months

Cost Summary of Refrigerated Mined Cavern Project
(3,000-Foot Deep Mine)

Working Gas Storage of 5.0 Billion Standard Cubic Feet
Maximum Injection Rate of 250 MMSCFD
Maximum Withdrawal Rate of 250 MMSCFD
Injection Cycle - 20 Days
Withdrawal Cycle - 20 days

Conventional Mining and Shaft Sinking (6,292,335 barrels of space)			112,346,209
Refrigeration System, Compressors, and Process			31,971,424
Electrical and Instrumentation Equipment			2,243,333
Compressor Building (210-feet X 50-feet) and Control			903,540
Compressor Building Foundation and Slab			68,064
Concrete Supports for Compressor Station Piping			19,698
Control Building Foundation			153,256
Mechanical Separators Foundations			5,570
Mole Seives Foundations			4,999
Pressure Reducing Station Foundations			4,999
Gas Storage Facility Final Design (Eight Months)			1,078,342
Gas Storage Facility Construction & Commissioning			4,815,600
SUBTOTAL			**153,615,034**
Contingency on All Costs @ 10%			15,361,503
SUBTOTAL			**168,976,538**
Contractors' Profit at 10% on Surface Facilities			3,537,488
TOTAL PROJECT COST			**172,514,026**
COST OF FACILITY PER MSCF OF BASE GAS STORAGE			**$34.50**
MINING COST PER BARREL OF MINED SPACE			**$20.00**

Maryland Piedmont study area is underlain by crystalline igneous-metamorphic rock, portions of which are high strength and low permeability. PB-KBB (1998) studies indicate a room-and-pillar, refrigerated mined cavern at a depth of 3,000 ft is optimum.

PANEL #1 - Need for natural gas storage in the Southeastern U.S., and preferred storage option.