

**Gas Storage:
Trends and Future Projections
Compression Equipment Selection**

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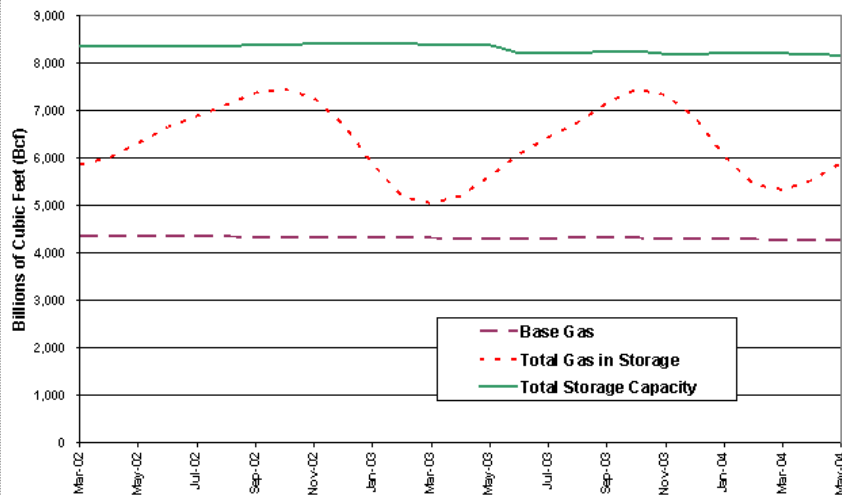
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Gas Storage Ten Year Trend: Seasonal Variation on +/- 1400 BCF natural gas

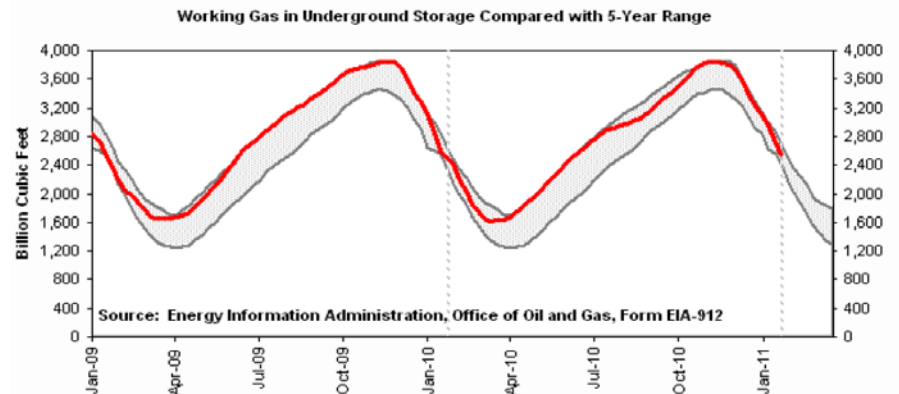
- Seasonal variation for United States on a level of approx. +/- 1400 BCF natural gas, compared to a base gas volume of 4300 BCF.
- Aggregate peak capacity in 2009 estimated at 3890 BCF.
- Last two years shows gas storage volumes on the high side of five year average, possibly due to lower prices for natural gas.

May 2002-May 2004:
Total Gas in Storage compared to storage capacity and base gas



Source: Energy Information Administration, *Natural Gas Monthly* (DOE/EIA-0130), May 2002-July 2004.

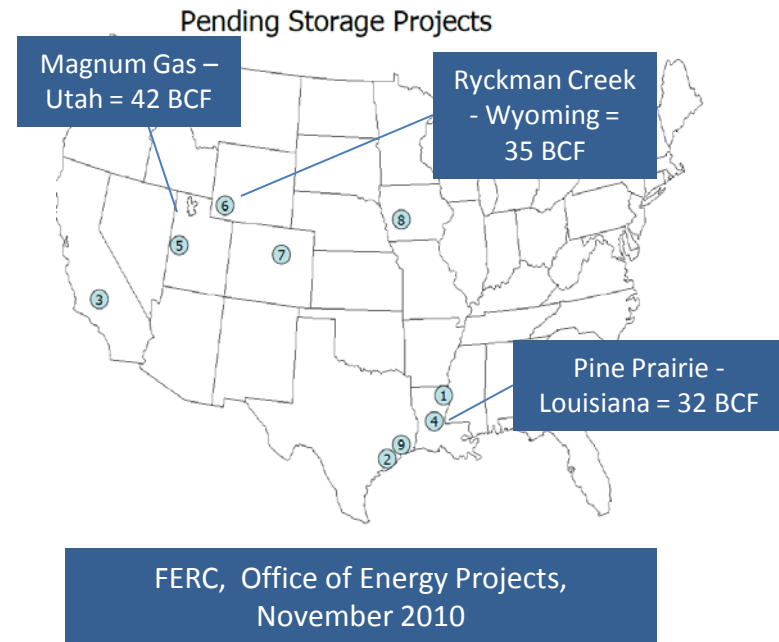
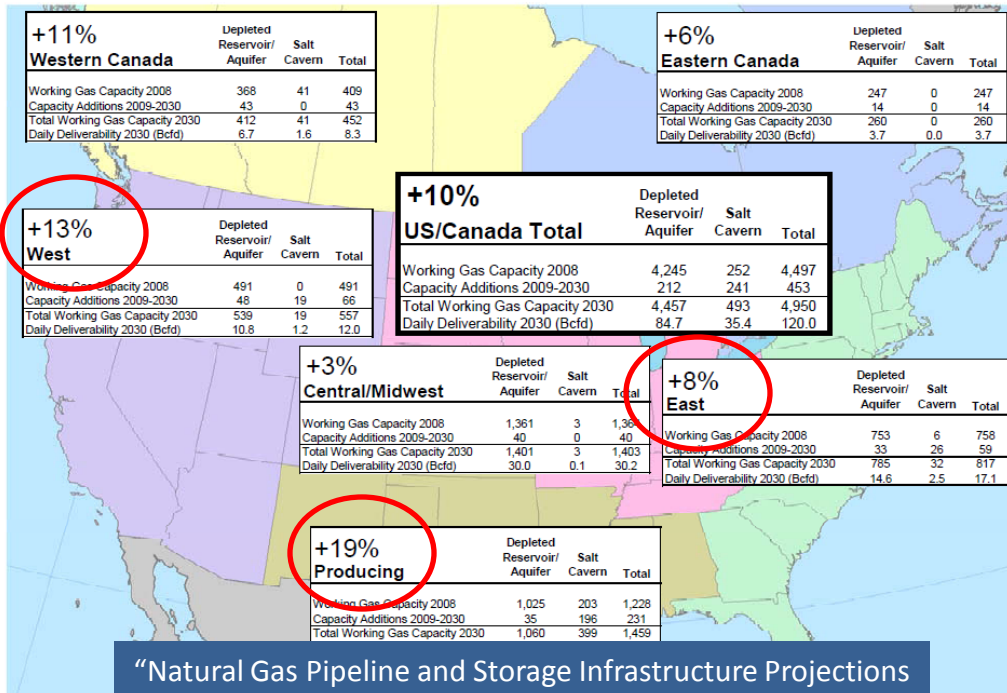
January 2009-January 2011:
Last 2 yr comparison shows gas storage volume at high end of 5-year average



Source: U.S. Energy Information Administration, http://www.eia.doe.gov/pub/oil_gas/natural_gas/analysis_publications/storagebasics/storagebasics.html

Gas Storage Planned Projects

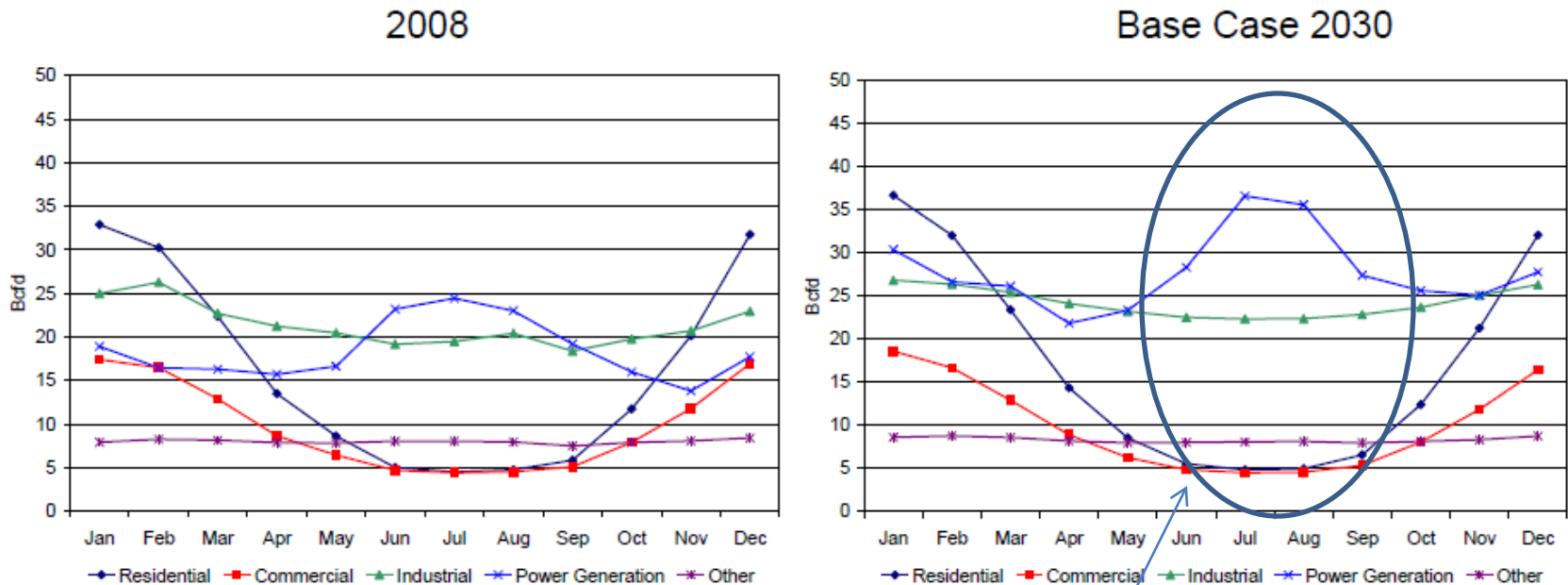
- INGAA study reports that more than half of future storage projects through 2030 will be development of salt caverns over depleted reservoirs.
- INGAA pipeline efficiency study notes, "Because it generally is more economical in providing short-term delivery... storage has become an increasingly important way for pipeline companies to meet customers' peak day capacity requirements and to accommodate outages."
- Important Variable: Effect of new gas shale production of natural gas / storage sites if gas prices rise again.



"Natural Gas Pipeline and Storage Infrastructure Projections Through 2030," INGAA Foundation Report October 2009.

FERC, Office of Energy Projects, November 2010

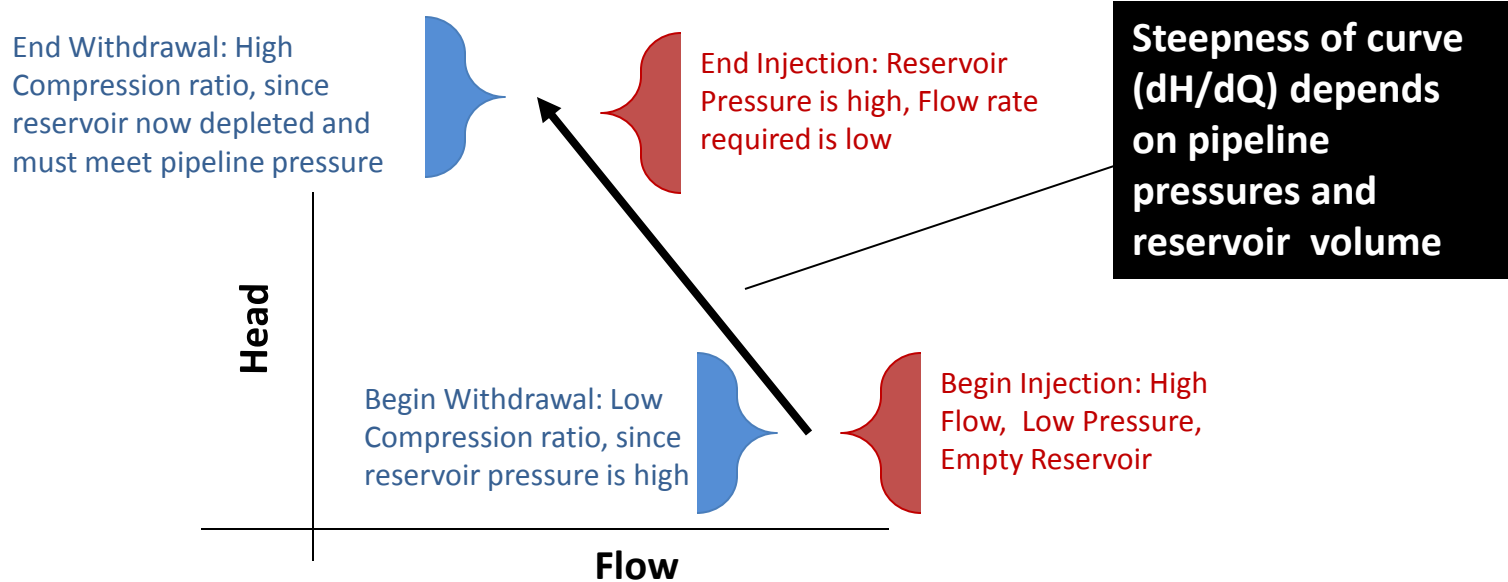
Potential Increase in Storage Needs through 2030



- Storage compression has relied on seasonal demand swings (decreased summer residential demand) to build up the reservoir through compression for storage injection in the summer months.
- Depending upon power generation with natural gas forecast, this summer “low demand” compression availability could change.

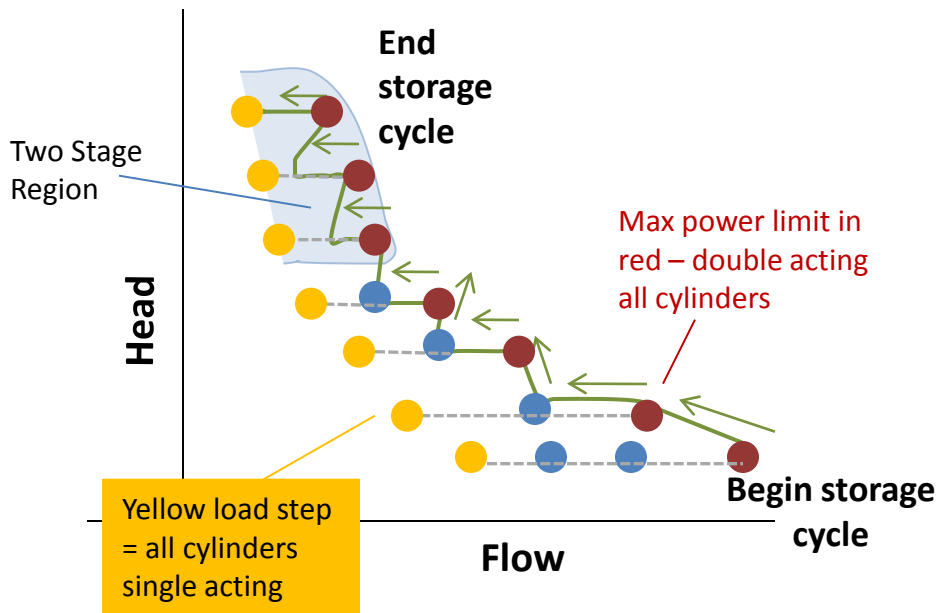
Compression Equipment Selection

- Compression storage must meet low pressure ratio, high flow rates in beginning of cycle (initial injection or withdrawal)
- Must also meet high pressure ratio, low flow during end of cycle for injection or withdrawal.
- Centrifugal compressors will follow continuous curve to support storage cycle, to the left of max power line and to the right of the surge line.
- Reciprocating compressors will follow stair-stepped approach, using combinations of unloading and staged compression.



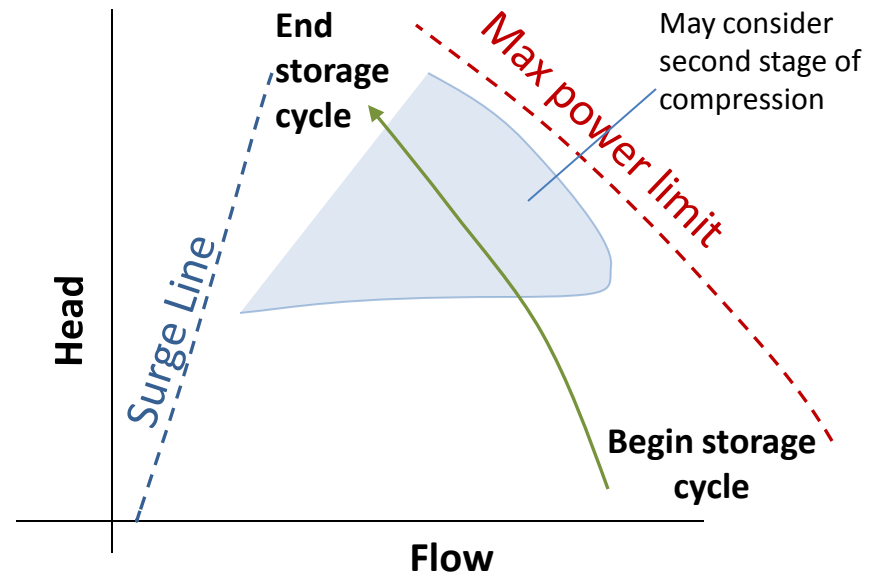
Operation to Meet Storage Cycle Pressure Ratio and Flow

**Reciprocating Compressor
operation for storage**



Reciprocating compressor uses incremental load steps – limits are amount of unloading and number of cylinders, effects on pulsations, and more narrow two stage region. As load steps and staging increases = complexity increases!

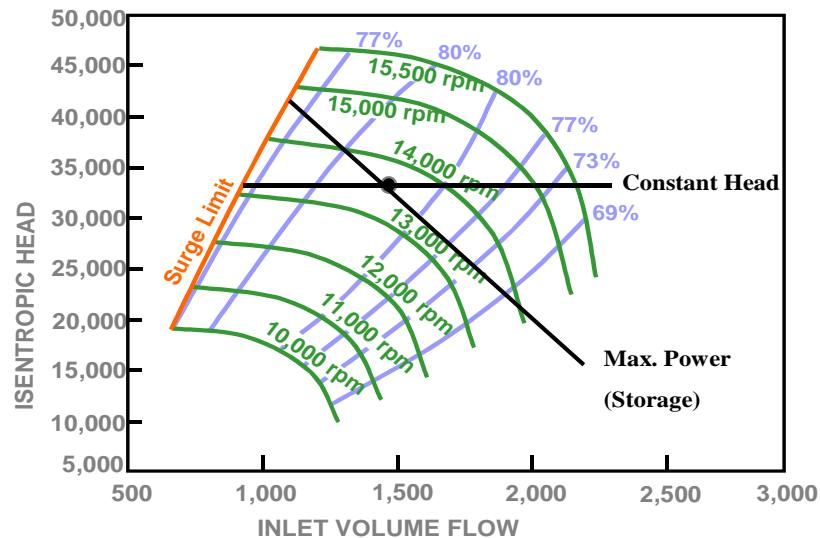
**Centrifugal Compressor
operation for storage**



Centrifugal compressor operating curve is continuous – and limited only by max power limit of driver and surge region

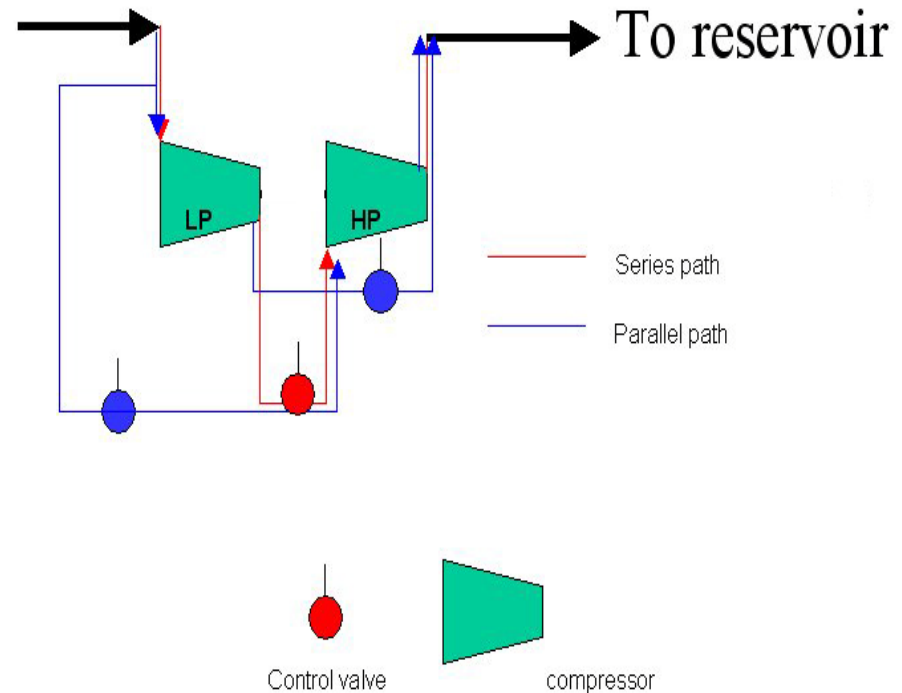
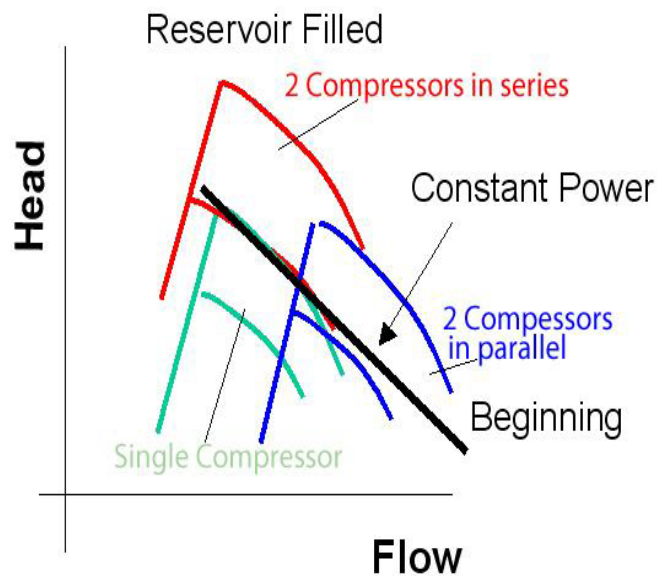
Centrifugal Compressor Storage Curve

- Centrifugal compressors can meet the injection / withdrawal curve naturally by following a constant power line.
- Design can be either single stage or two stage.
- Need to match power requirements of compressor to operating map and storage reservoir capacity.



Centrifugal Compressors: Use of Series and Parallel Operation to Accommodate Storage Needs

- Most storage applications can be fit with a single centrifugal unit.
- Adding option for using low pressure and high pressure stage in series will add flexibility.

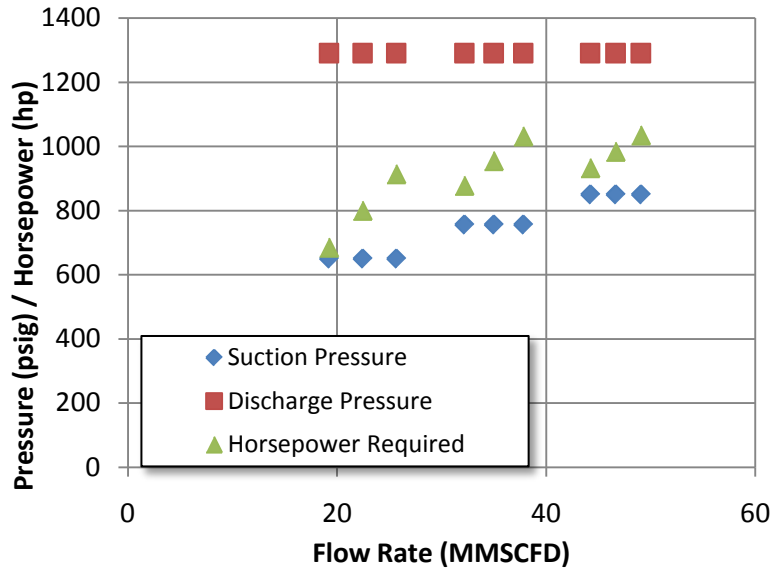


Source: Solar Turbines, Kurz and Brun, "Assessment of Compressors in Gas Storage Applications," Turbomachinery Symposium 2009.

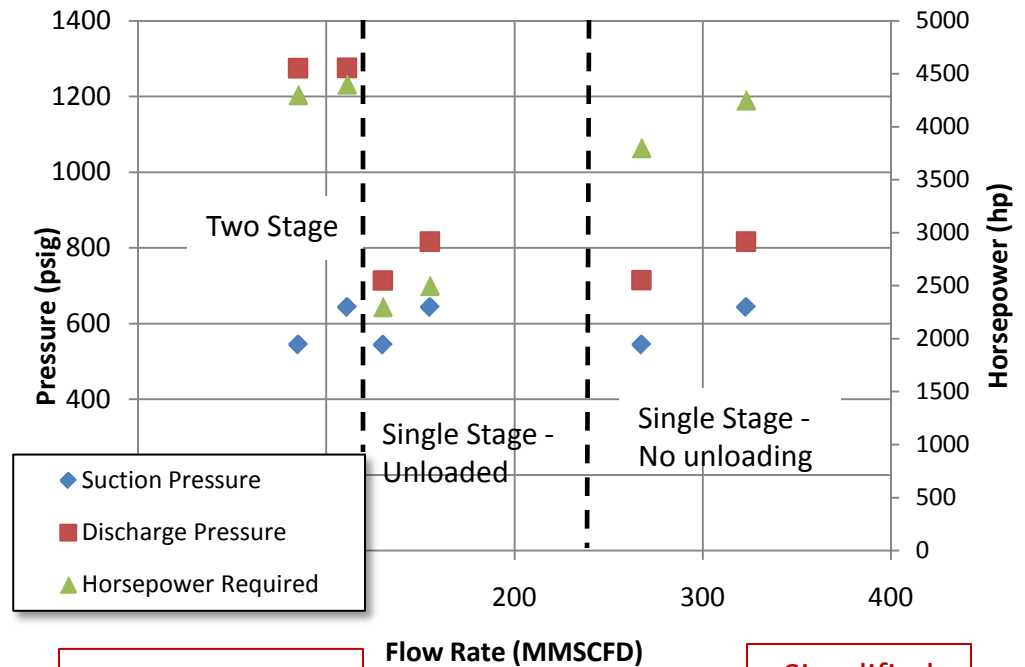
Surge control, check valves and coolers not shown.

Reciprocating Compressors: Transmission vs Storage Compression

Transmission Application:
Discharge Pressure is constant.
Loading and HP are varied to meet flow rate and suction pressure



Storage Application:
Much more varied. Discharge and Suction pressure can vary, Staging and unloading used to match storage curve



Increasingly more complex pulsation study

Simplified Pulsation Analysis



Reciprocating Compressors:

Use of Unloading and Single / Two Stage Designs

- In beginning, a 6-cylinder reciprocating compressor can meet lower pressure ratio required with single unit operating at fixed speed and many load steps - to match flow rate.
- Towards end of cycle, must switch to two stage operation to meet pressure ratio.
- May need to add second unit to meet flow rate.
- Unloading and staging will add more cost and complexity to pulsation filter bottles and station design.

