

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

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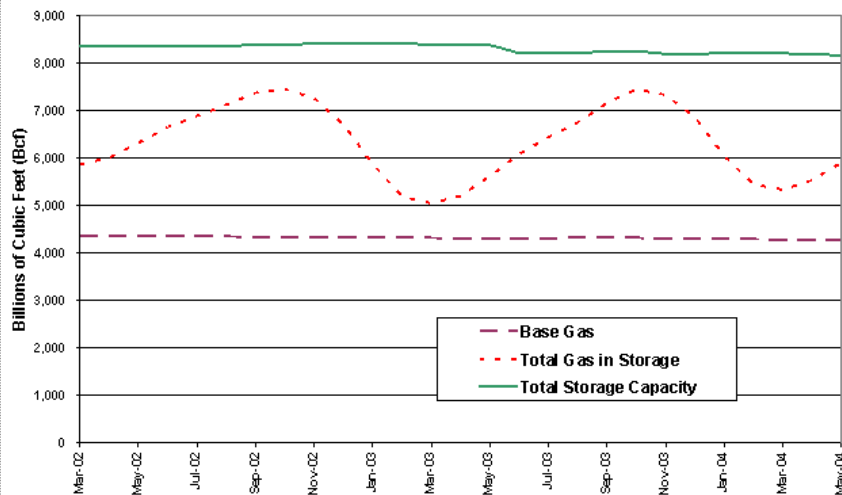
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Gas Storage Ten Year Trend: Seasonal Variation on +/- 1400 BCF natural gas

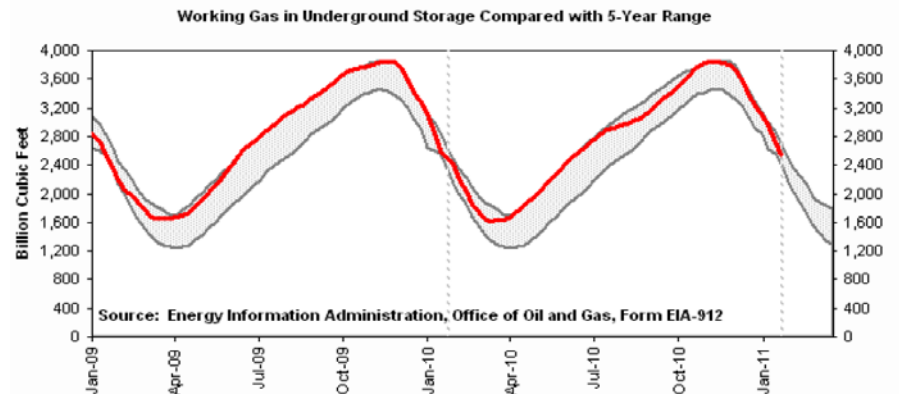
- Seasonal variation for United States on a level of approx. +/- 1400 BCF natural gas, compared to a base gas volume of 4300 BCF.
- Aggregate peak capacity in 2009 estimated at 3890 BCF.
- Last two years shows gas storage volumes on the high side of five year average, possibly due to lower prices for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

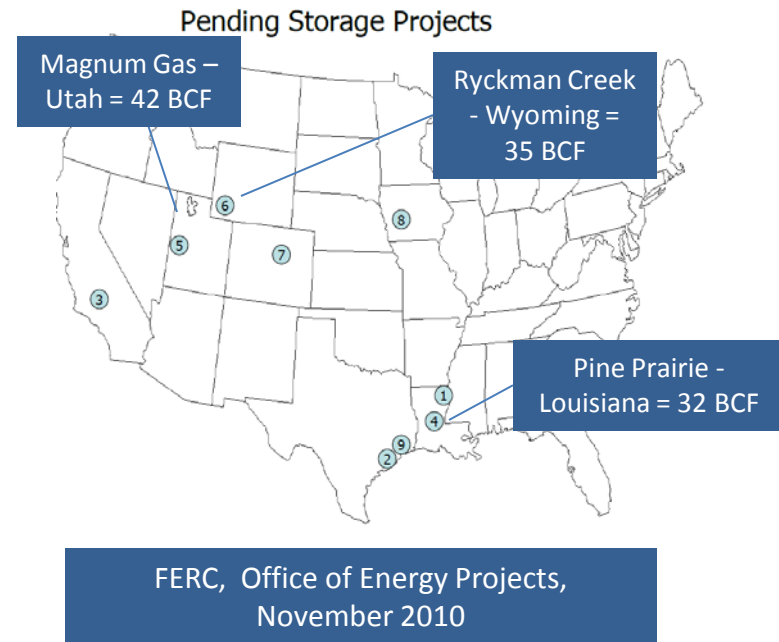
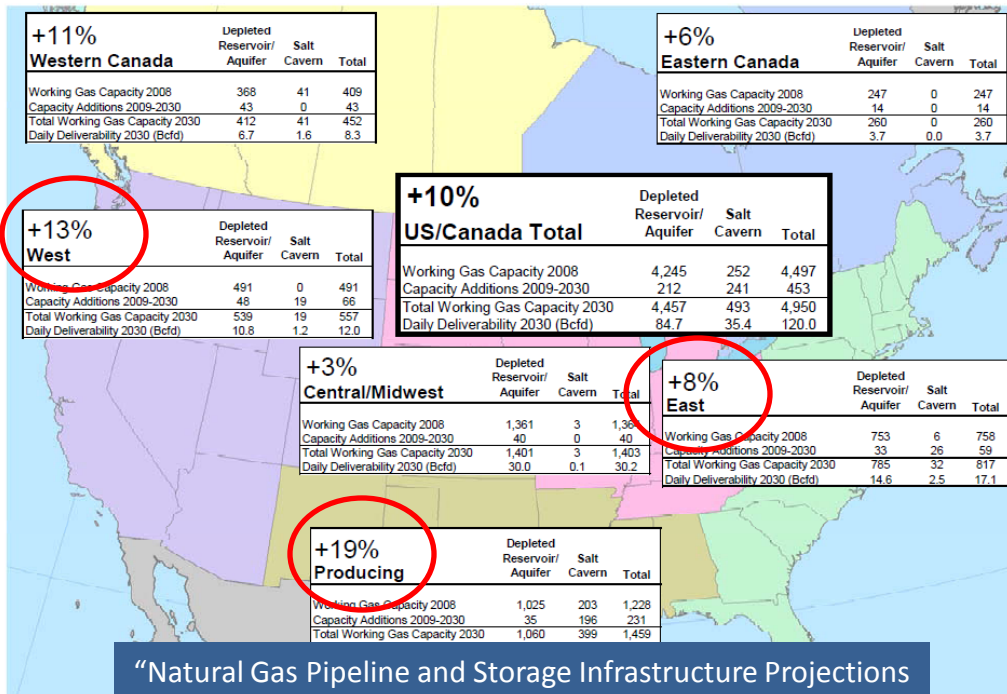
January 2009-January 2011:
Last 2 yr comparison shows gas storage volume at high end of 5-year average



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

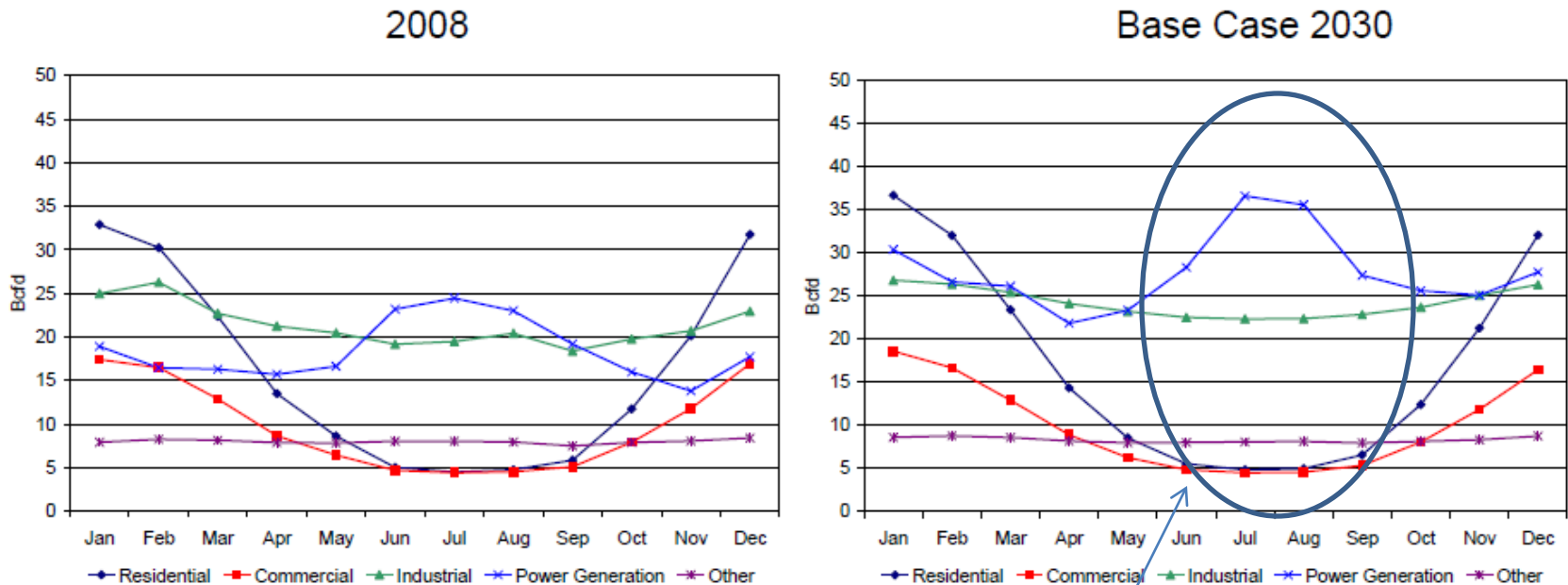
Gas Storage Planned Projects

- 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.

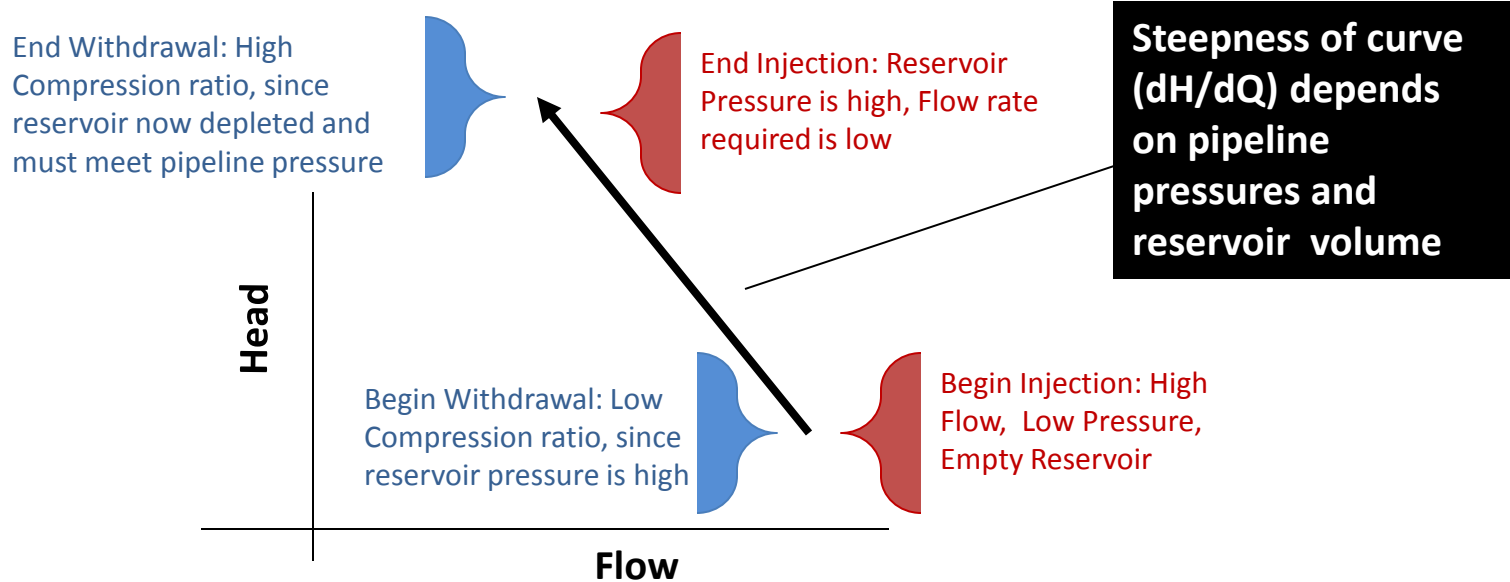
Potential Increase in Storage Needs through 2030



- 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.

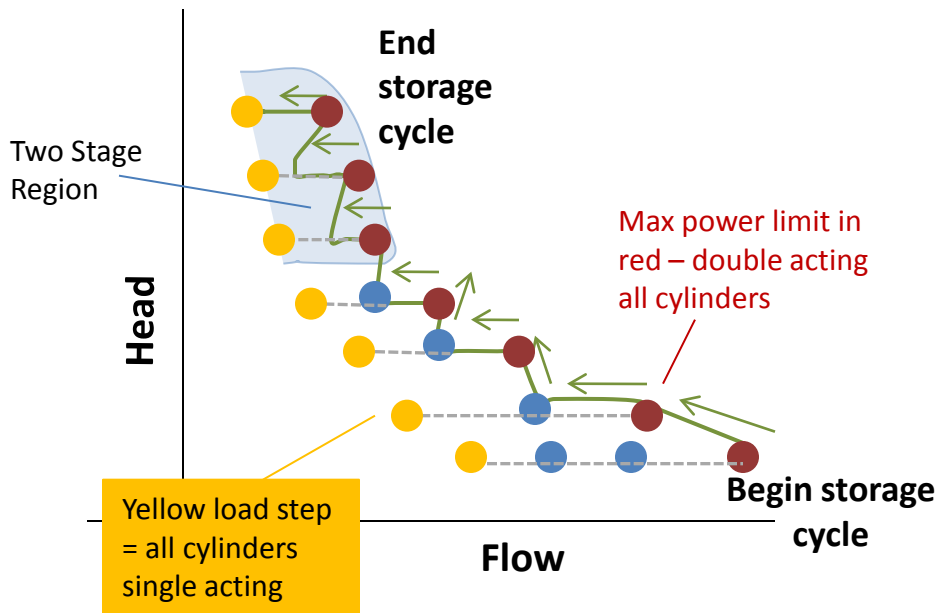
Compression Equipment Selection

- 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.



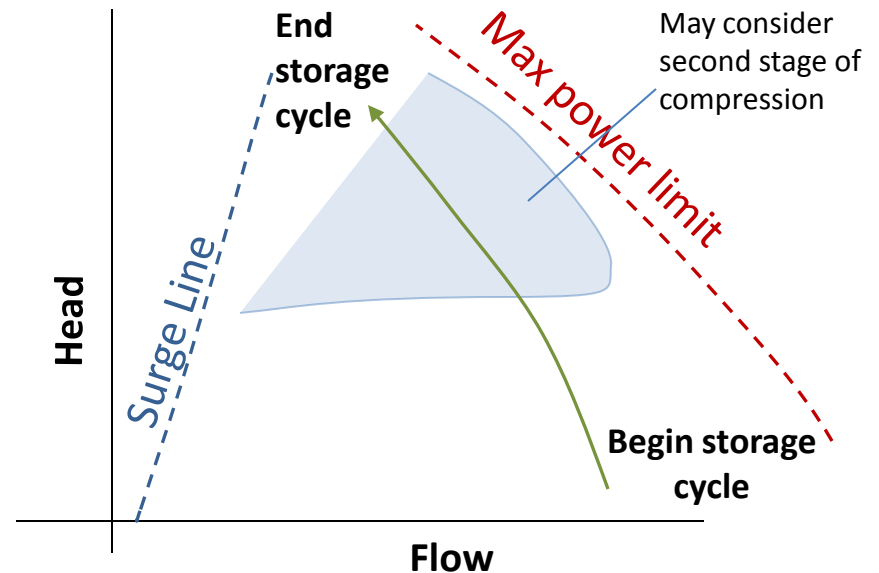
Operation to Meet Storage Cycle Pressure Ratio and Flow

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!

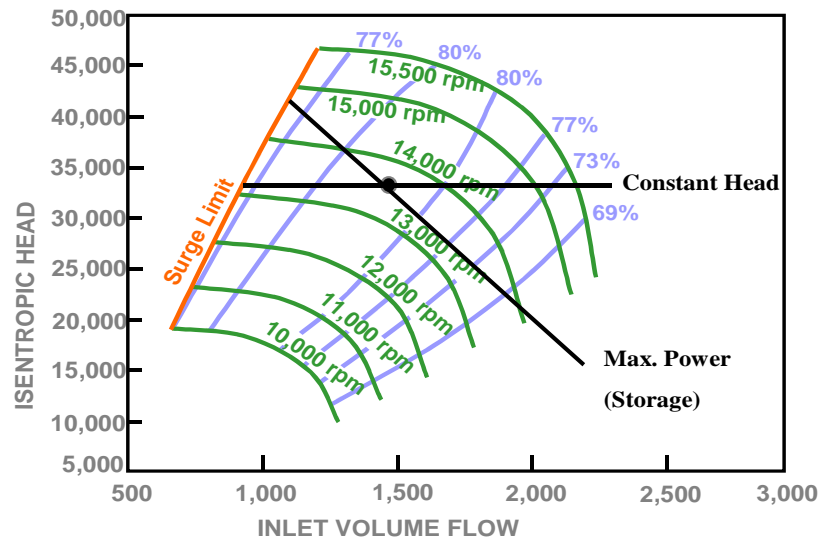
Centrifugal Compressor
operation for storage



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

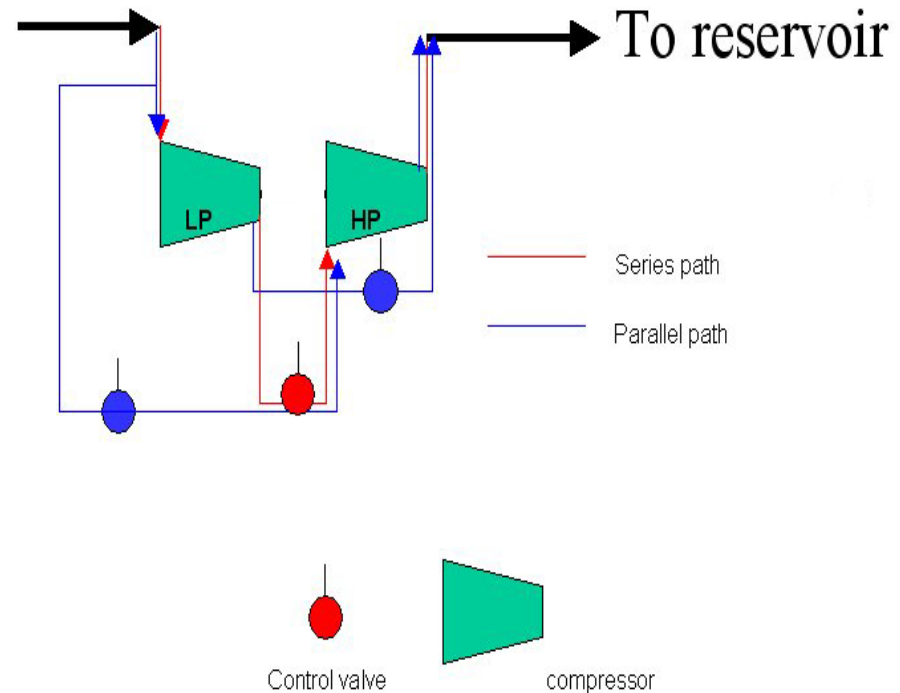
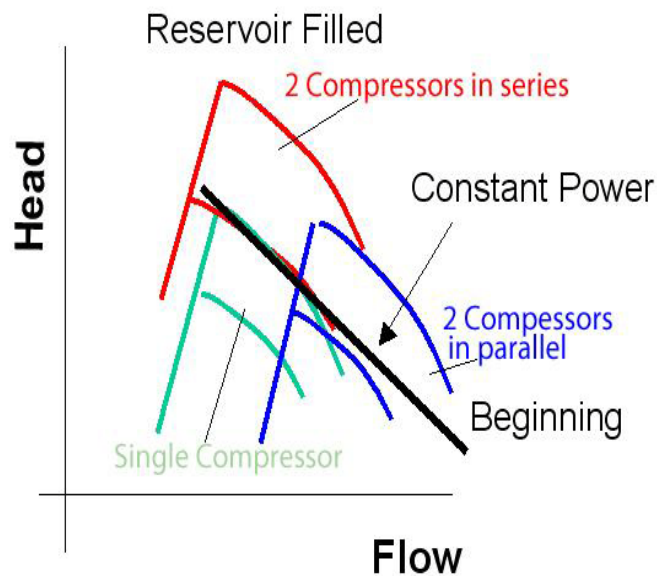
Centrifugal Compressor Storage Curve

- 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.

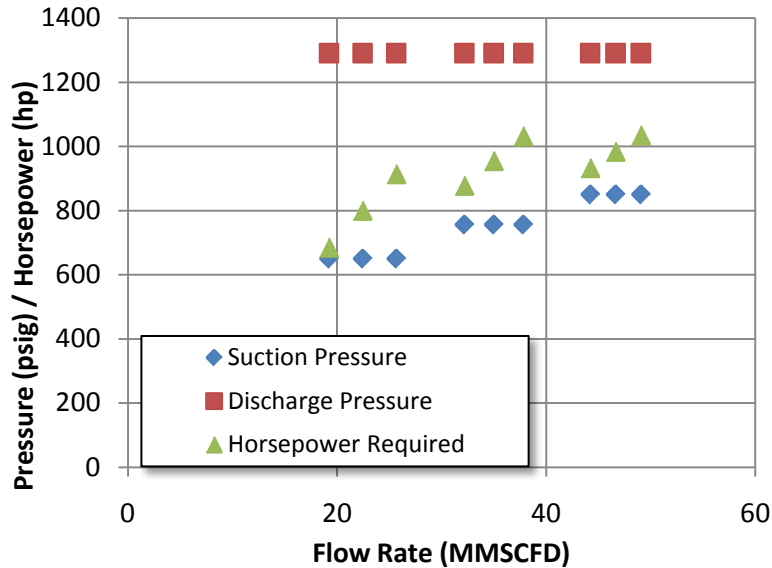


Source: Solar Turbines, Kurz and Brun, "Assessment of Compressors in Gas Storage Applications," Turbomachinery Symposium 2009.

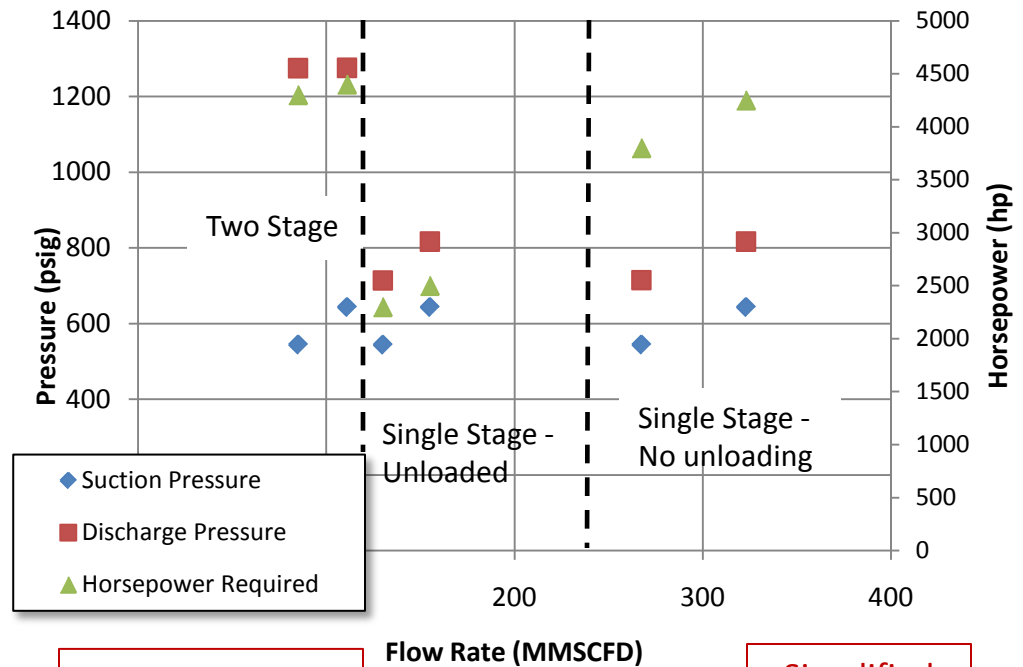
Surge control, check valves and coolers not shown.

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.

