Strategies on Driver & Compression Flexibility

21st century ideas for increased operating ranges,
lower operating costs and lower emissions.

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Introduction

- **Chris Kapp** has 25+ years experience in the Turbomachinery Industry in all application areas of Oil & Gas in the US, Europe and Asia. Chris has a Msc in aerospace engineering from RWTH University in Aachen.

  Currently Vice President Energy at AFGlobal, a packager of compressors and gas turbine gensets, Chris is also an author of the book focused on rotating equipment "*How to sell Engineered Products*" soon to be published by Pennwell.

- **Mary Beth McBain, Kinder Morgan**

- **Bobby van Borssum, Enbridge Engineer Air Permitting**

- **Elliot Metzger, Williams Engineer AG Development**

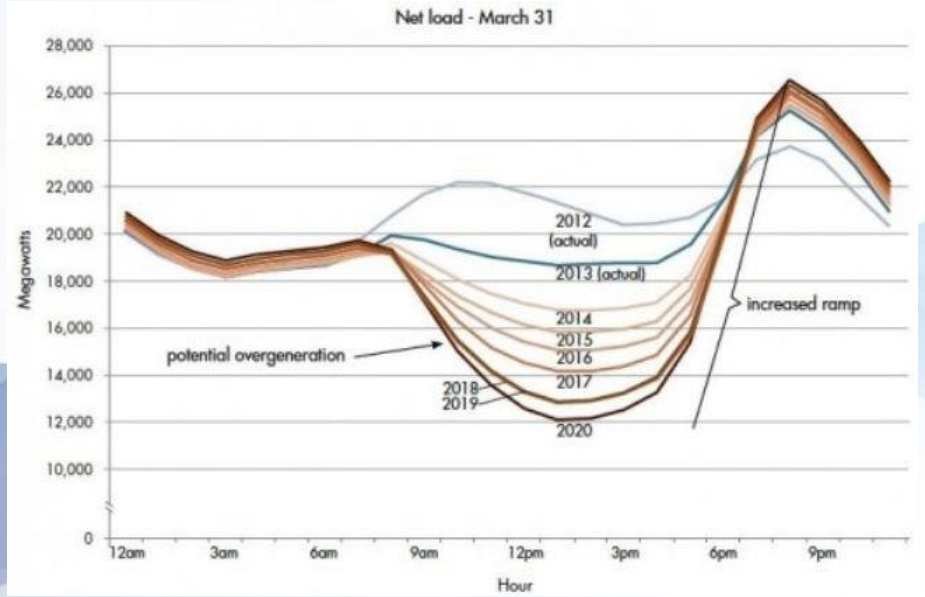
- **Arnold Eisenstein, Universal Pegasus Project Engineering Director**

- **Michael Moses, TransCanada Operations Director**

Problem Statement

- Renewable Electrical Energy production experiences rapid change inducing high volatility.
- Emission Regulations are increasingly a burden to Industry.
- Low operating margins require aggressive ways to reduce CAPEX and OPEX.
- Upstream is doubling and tripling electrical energy demands, absorbing OEM production and crimping Midstream's capabilities to expand.

  At the same time ERCOT's reserve margins are declining with the retirement of old power plants.



DIFFERENT IDEAS ARE REQUIRED

IDEAS

PIPELINE SYSTEMS

COMPRESSION EQUIPMENT

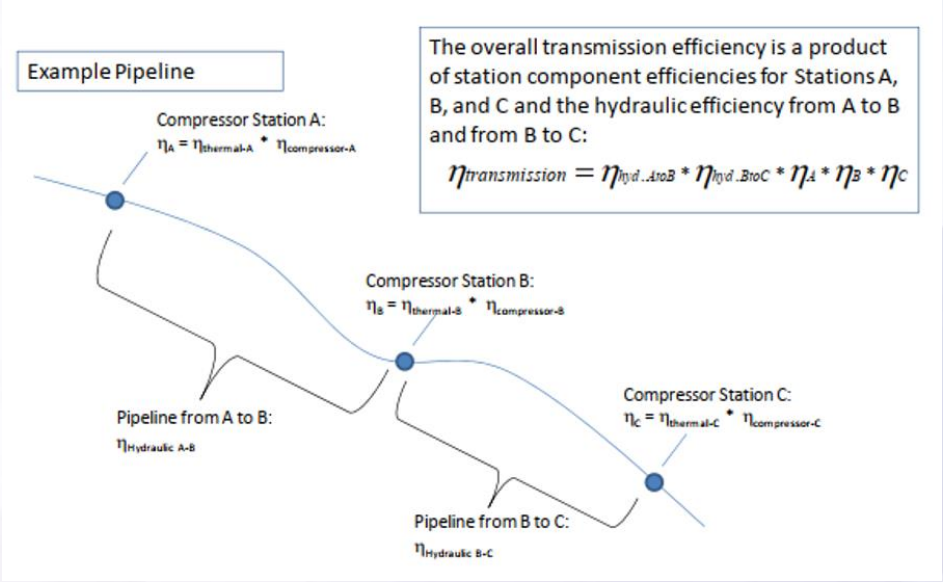
- Reciprocating and Centrifugal Compressors
- Single Large vs Several smaller Compressor Blocks
- Centrifugal Compressors Efficiency & Flow Control Option
- Reciprocating Compressors Efficiency & Flow Control Option
- Drive Behaviors at Full & Part load
- Emissions

EXAMPLE

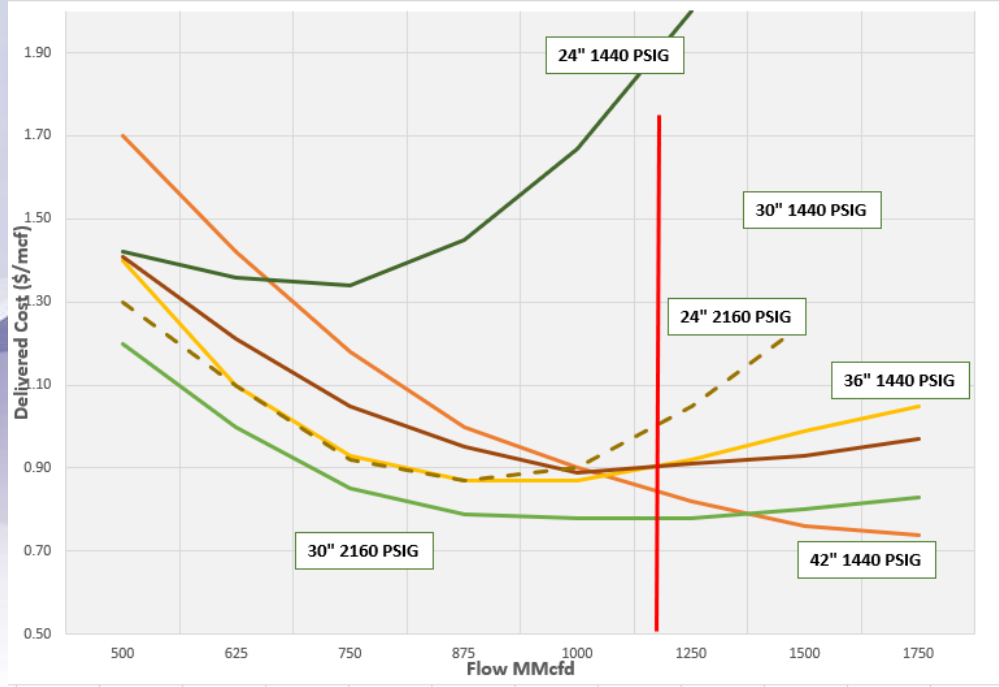
CONCLUSIONS

Pipe & Station Design Considerations

- An overall Pipeline System Efficiency depends on the **thermodynamic (and mechanical) efficiency** of the compressor and its driver as well as its **hydraulic efficiency.**



The hydraulic efficiency has an outsized impact on performance and equipment selection. The two most significant parameters are operating pressures and pipe diameters.



J-Curves which show delivered cost per flow determine an optimum solution for different pipe diameters (compressor stations) and MAWP.

Diagrams courtesy INGAA, Interstate Natural Gas Pipeline Efficiency, Oct 2010

Pipeline Considerations

- Once operating pressures are set there is very little we can do to change the pipe. However increasing pipe diameter can be “virtually” achieved through looping instead of installing new compression.

- Other vital factors to be considered are:

- parallel (and series) compression.

- compressor station spacing: often a function of pipeline hydraulics, right of way and permitting. May be as little as 50 miles apart. Some high pressure pipes have stations up to 150 miles apart. i.e Interconnector 3,500 PSIG, 3-5 BCFD. 4X35 MWe 4 stage compression.

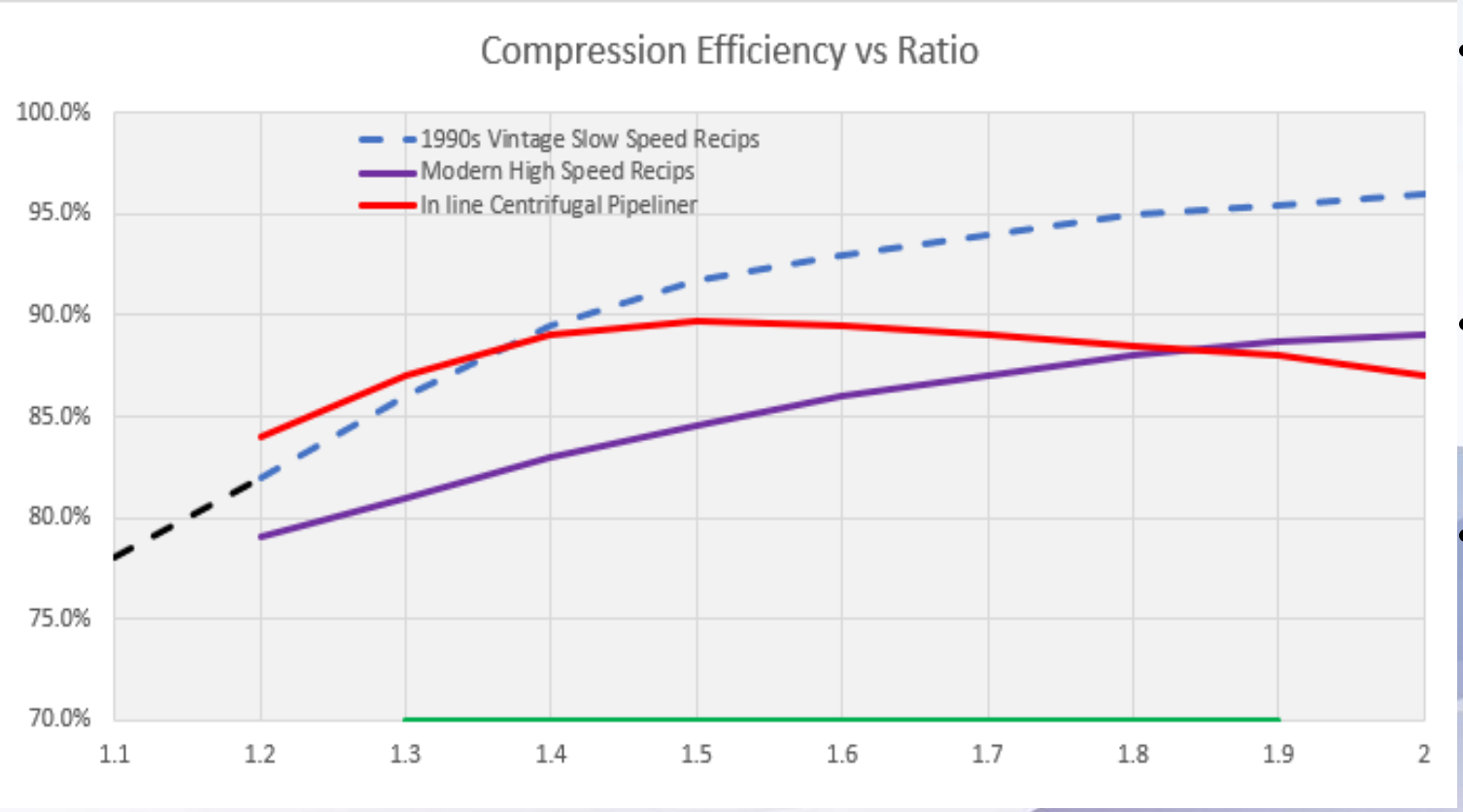
- pipe coatings: expensive, limited reduction of friction, may be subject to wear. Limit<160F.

- gas storage & line packing: eases out peak demands of compression for a limited amount of time. Both solutions require “re-charging” at some point in time.

Midstream Pipeline Considerations

- Lastly solutions are always influenced by
- Capital efficiency
- Emissions
- Financing, interest rates going up…..
- Regulatory Authorities and
- Customer acceptance of gas transportation price and delivery

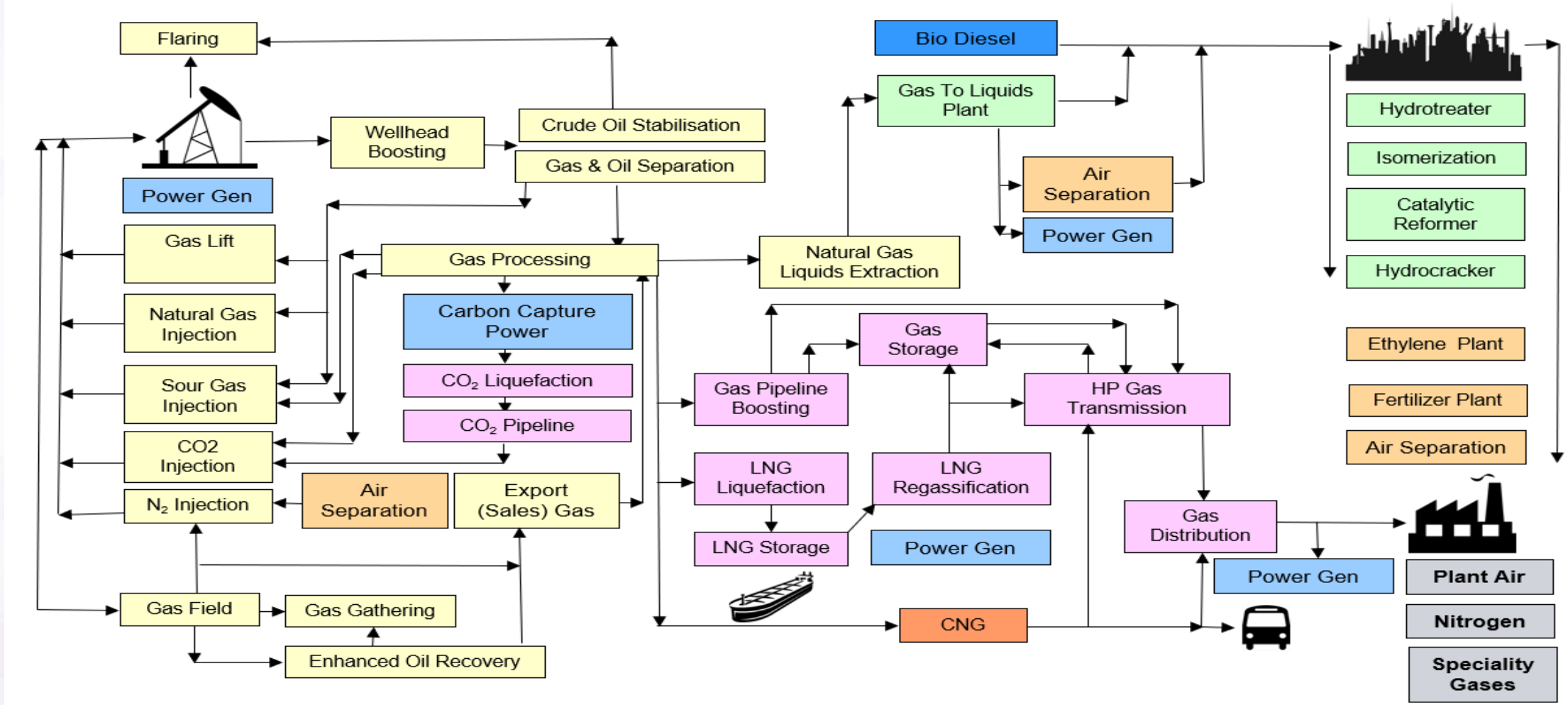
Typical Compressor Efficiencies vs Pipeline Compression Ratios



- Slow Speed Recips <700 rpm are legacy equipment. Not in new unit production for pipelines.
- Centrifugals indicate efficiencies of dedicated pipeliner types, not barrels.
- Reciprocating Compressors show maximum possible. However unlike centrifugal they are not shop performance tested. True efficiency is lower by up to 3% due to pulsations/interstage losses.
- OEMs guarantee performance based on project specific information.

The change from slow speed to high speed from 1990ish indicates that the pipeline industry once switched from very high performance to a lower cost and “adequate” performance compromise position.

Selected Compressor Applications in O&G and Industry



Centrifugal Compressor Efficiency Options

- Centrifugal OEMs can increase efficiency and often operating range by….

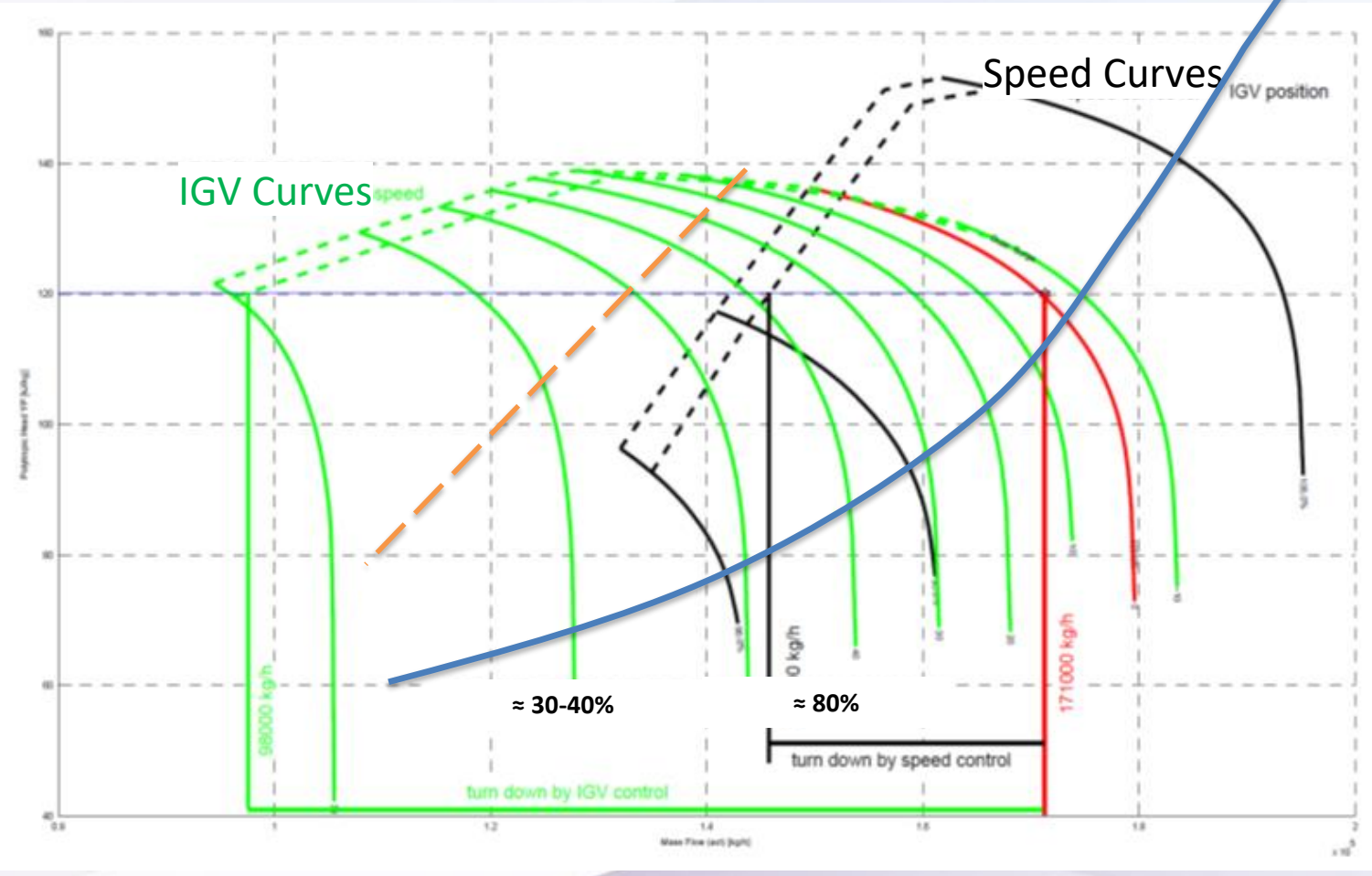
- use of 3-D vs 2-D impellers. Can raise η ≈2-5% in some specific flow ranges or low loss diffusors (larger diameter compressor case/nozzles –common in pipelines reducing flow velocity and losses.

- Using Axial Inlet impellers, larger range and head but limited expansion capability.

- Inlet Guide Vanes, provides significant boost to off-design efficiencies.

- Individually designed impellers to minimize stall limits. Eliminate the “kink”
- Lower Mach numbers to maximize distance to stall… Eliminate “walking stick”
- Last but not least: **A great Application Engineer** ! Communicate !

Centrifugal Compressor Control Options

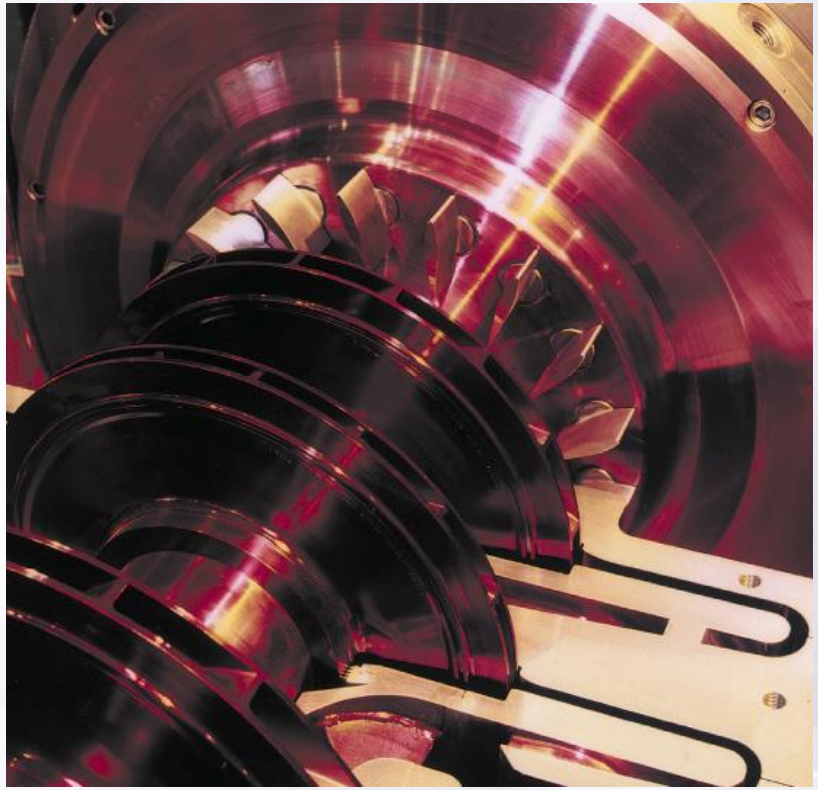


- Suction (or discharge) throttle pretty much the worst option on power consumption. Does not improve turndown
- Variable Speed drives shows dramatic improvement but limited to 50 or 70%-105%. Expensive (VFD and MVSD).
- Variable Inlet Guide Vanes provide a credible option and have been used in O&G. Low CAPEX. But not every OEM offers this technology.

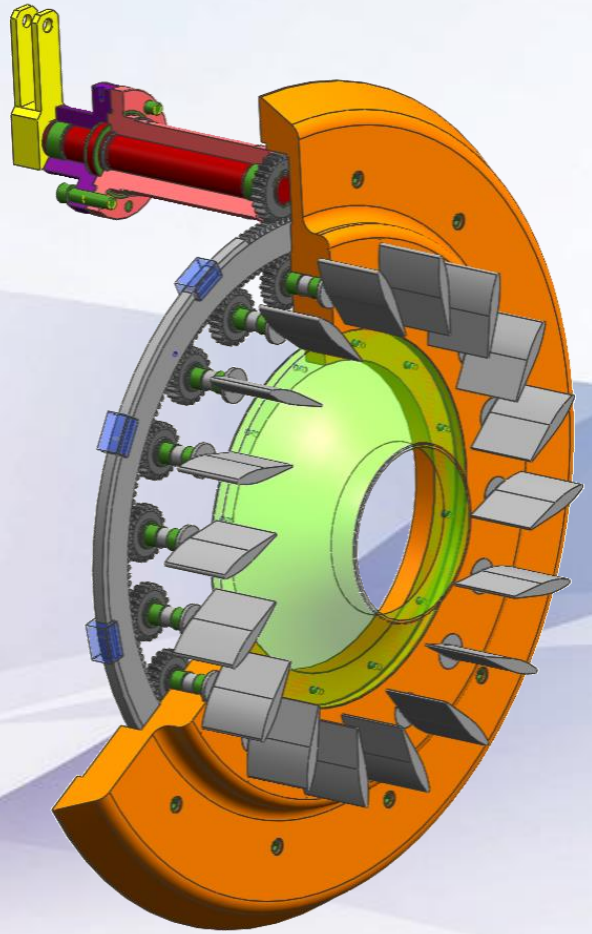
IGV's are a superior way to obtain range.
The motor or turbine is also operating at full speed at best efficiency. This is also a great low emissions solution.

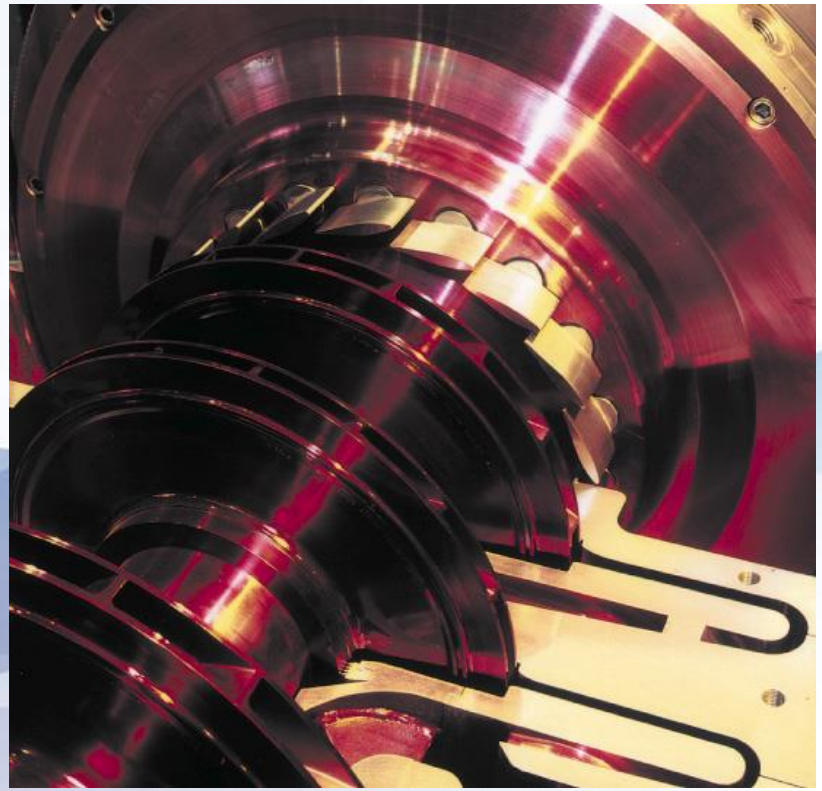
Courtesy Siemens

Actual IGV hardware pictures.



Max. pre-swirl +75°





Max. counter swirl -10°

IGV technology is nothing new, many gas turbines and compressors in LNG and elsewhere already use it.

Images Courtesy Siemens

Reciprocating Compressor Efficiency Options

- Reciprocating Compressors, have opportunities to improve and loose efficiency

- Providing easier flow through large cylinders and flow passages (cost),

- Compressor valve type, optimum valve timing, valve lift, large valve areas (cost)
  This is a small overall extra cost with noticeable benefits . However an incorrect design may reduce reliability as compressor valves have limited “operating range”.
  There is steady improvement in this field.

- Pulsation. Pressure losses are often underestimated, remedies to fix potential damage to pulsation may be costly and inefficient and are known post order.
  Interesting developments such as PAN offer a potential improvement.

- Part load controls such as automatic variable control pockets or reverse flow stepless suction unloaders are excellent for part load efficiency and operating range but do not come cheap….

Reciprocating Compressor Control Options

All-Electric Reverse Flow Stepless Control

- Capacity control by stepless unloading of suction valves
- In general suitable for multistage control
- Control range 100 to 25% (typically)

Electric Stepless Clearance pocket

- Capacity control by automatic adjustment of cylinder clearance on head end-side
- Electrically driven
- Suitable for cylinder with > (9.5”) diameter.
- Control range 100 to 70% typically

- Suction throttle control may raise or lower horsepower demand but costs money too.
- Bypass controls are common and grossly inefficient.
- Manual variable control pockets are very common but underutilized.
- Valve Stepped On-Off controls may be used but are expensive as throws may have to be duplicated to achieve 0/25/50/75/100% versus just 0/100% flow.

Reciprocating compressors are suitable for flexible operation but need to be paired with automatic controls to be useful.

Images Courtesy HOERBIGER

Drive Behaviors at Variable Load and Speeds

- Whether engine or turbine, there are minimum speed and loads that ensure safe operation and emissions compliance. Typical minimum values are between 50-90% depending on model and OEM.

- When engines and turbines are operated at part load, benefits in reliability through extended maintenance can be achieved but they are often purchased with higher fuel burn due to lower efficiencies.

- Engines and turbines are already in part load when not operating at the specified maximum ambient! Power output at all ambients have to be checked and compared to absorbed compressor power.

- Variable Frequency Drive efficiencies are robust (95-98%) through a wide operating range however electric motor efficiencies fall sharply at part load and speed. Motor efficiencies stay robust at full speed and part load (MVSD) !

- The drive solution is always an integral part of the compressor technology solution, it is never independent.

Large vs Small Compression (Typical)

What is better, a large compressor or 2 -3 smaller compressors for the same purpose ?

- CAPEX. Costs do not scale proportionally.
  2 X 50% units will cost more than 1 X 100% unit from an OEM (app. 120-150% more).

- Fuel Burn. Smaller units typically are less efficient at design point but as small units are switched on and off they provide much better operating range and off-design efficiencies.

- Operating range: Most units cannot turn down below 50-70% effectively. Very few solutions offer 20% turndown. Those may be suitable for single unit installation and operation if high availability and reliability requirements are met.

- Reliability: Centrifugal Compressors and Electric Drives enjoy very high reliability. Gas Engines in particular require frequent maintenance. Setting up a “+1” (1+1) or (2+1) unit philosophy is very expensive. The more units you have the more maintenance needs to be done.

Emissions

- CO_2 emissions are directly related to combustion efficiency and power.
- Any device or object that reduces power, just increased your CO_2 output!
- a) Engine/Turbine Low No_x & CO systems and catalysts
- b) VFD or MSDS introduce a minimum 3-5% losses at full load.
- c) Any extra valve or pipe before or after the compressor (or inefficient suction valve)

- NO_x or CO emissions typically are affected by fuel/air mixtures and part load behavior. The same emissions may rise several orders of magnitudes during starts, stops and equalization phases (catalysts). Shutting down compressors frequently is not a good environmental issue and may lead to permitting problems! Blowdowns are to be avoided.

- Combustion By Products & Fugitive Flare Emissions are Volatile Organic compounds (VOCs)!

- Methane emissions can be influenced by the sealing system of the compressor (gas seal/packing). On multiple unit sites leads to significant air emission issues.

Midstream Gas Compressor Stations for High Reliability and Flexibility

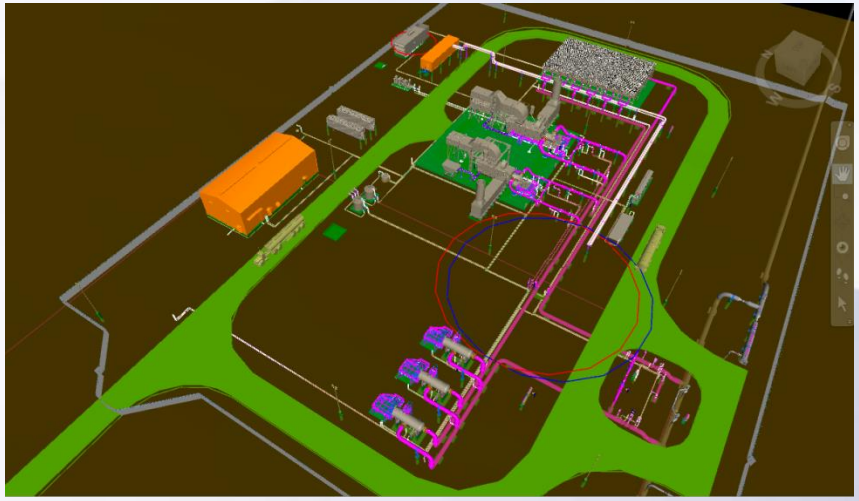
- Head station is composed of multiple smaller units.
- Intermediate stations are two unit stations with individual recycle per unit and cooled recycle for overall station.
- Compressor maps are designed for at least 30% turndown per unit and +85% isentropic efficiency
- Enclosures preferred in some locations – gas turbine completely enclosed, shipped in one skid, equipped with CO2 fire suppression system.
- 14-day pressurized hold for quick-start up (limit blow down on unit down time)
- Ability to start under load **ISSUE for Larger HP RECIPS > 2000 hp**
- Turbine exhaust constructed on site with silencer and test ports in vertical stack.
- Gas fuel conditioning – Peco two chamber coalescing filter, robust seal gas filter, added FG heater after regulation.
- Heated IG supply posts.
- Air compression reliability for Solar IA systems.
- Emergency generators (2 x 750 KW) sized to handle full station power load, dominated by gas process coolers
- Non-manned stations: LCC and O&M costs minimized with more remote monitoring.

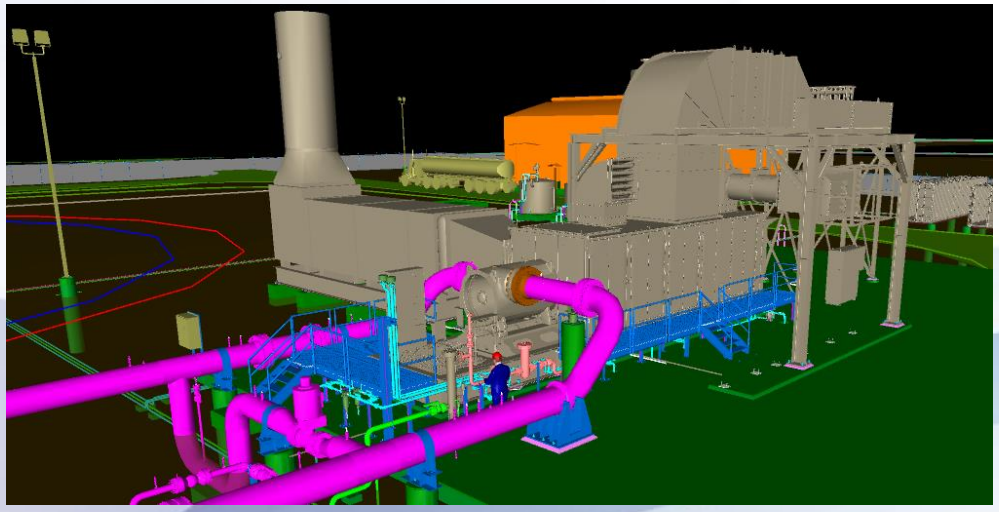
Courtesy Kinder Morgan

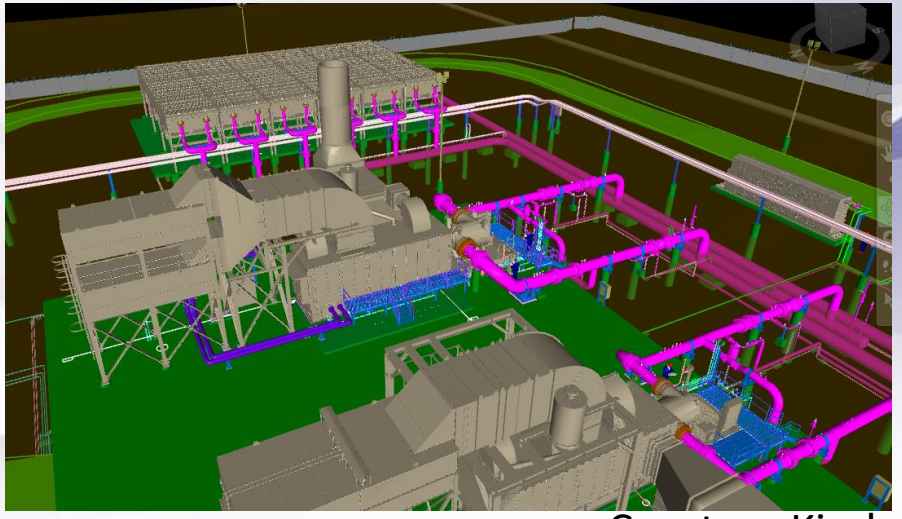
Example gas turbine site for pipeline transmission compression

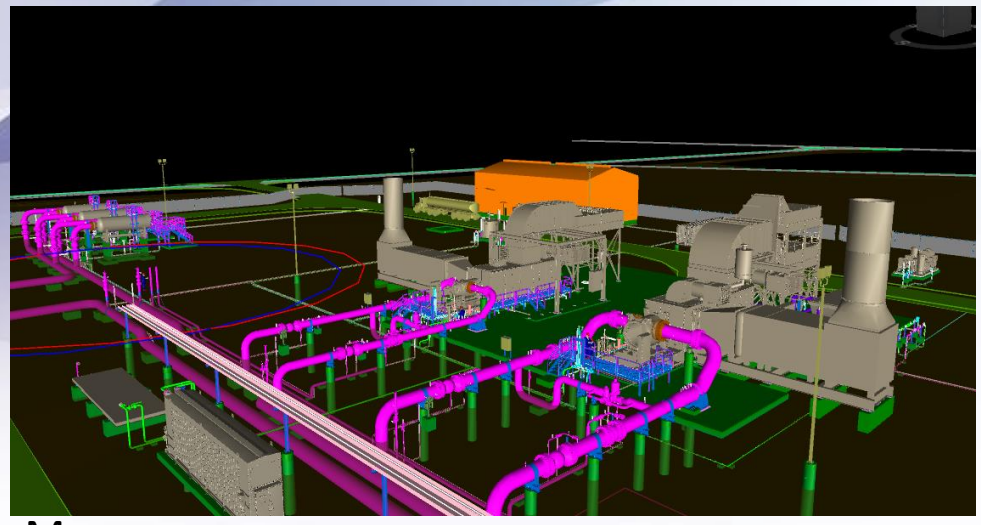
Courtesy Kinder Morgan

Example gas turbine site for pipeline transmission compression









Courtesy Kinder Morgan

Conclusion for Pipelines

Almost all compressors and drives can be controlled,
Many lack automatic part load controls for a wide operating range.

Regardless of technology there are usually distinct limits that are either drive or compressor imposed. A practical low limit is between 50-70% flow but this can be improved to 20-40%.

Multiple medium size compressors in one station or split between up- and downstream stations may be required to provide all flow variation.

Emissions permitting isn’t trivial: starts, stops, blowdowns fugitive emissions are major problems.

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