NATURAL GAS INFRASTRUCTURE R&D AND METHANE EMISSIONS MITIGATION WORKSHOP

November 12-13, 2014

NATURAL GAS PIPELINE AND COMPRESSOR EFFICIENCY

- Overall pipeline efficiency is a complex puzzle that includes both economic efficiency and transportation efficiency.
  - Due to economic efficiency Interstate Natural Gas Pipelines typically do not operate at their optimum design condition.
  - So, most compressor/driver combinations are operated at off-design conditions.
  - In addition, there is a large range of installed compressor efficiencies due to installation effects.

Pipeline Transmission Efficiency Puzzle

The overall pipeline transmission efficiency is a product of compressor station efficiency (engine thermal efficiency times compressor efficiencies times manifold efficiency) and pipeline hydraulic efficiency.

$$\boxed{\eta_{\,trans.} = \eta_{A} * \eta_{\,hyd.\ A\ to\ B} * \eta_{B}}$$

Pipeline from A to B

$\eta_{\,hydraulic\ A\ to\ B}$

Compressor Station A

$\eta_{A} = \eta_{\,\text{thermal-A}} * \eta_{\,\text{compressor-A}} * \eta_{\,\text{manifold-A}}$

Compressor Station B

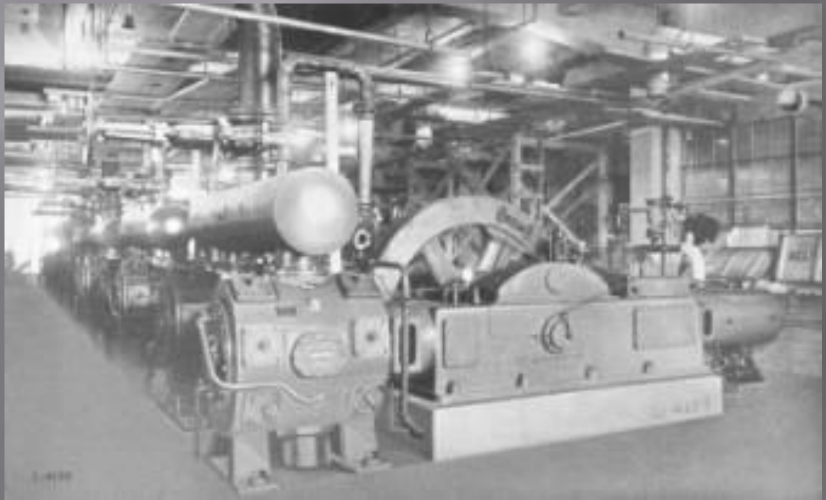
$\eta_{B} = \eta_{\,\text{thermal-B}} * \eta_{\,\text{compressor-B}} * \eta_{\,\text{manifold-B}}$

Pipeline Compression Evolution

Legacy Slow-Speed Integral Compression
300 rpm, 1500 to 2500 HP

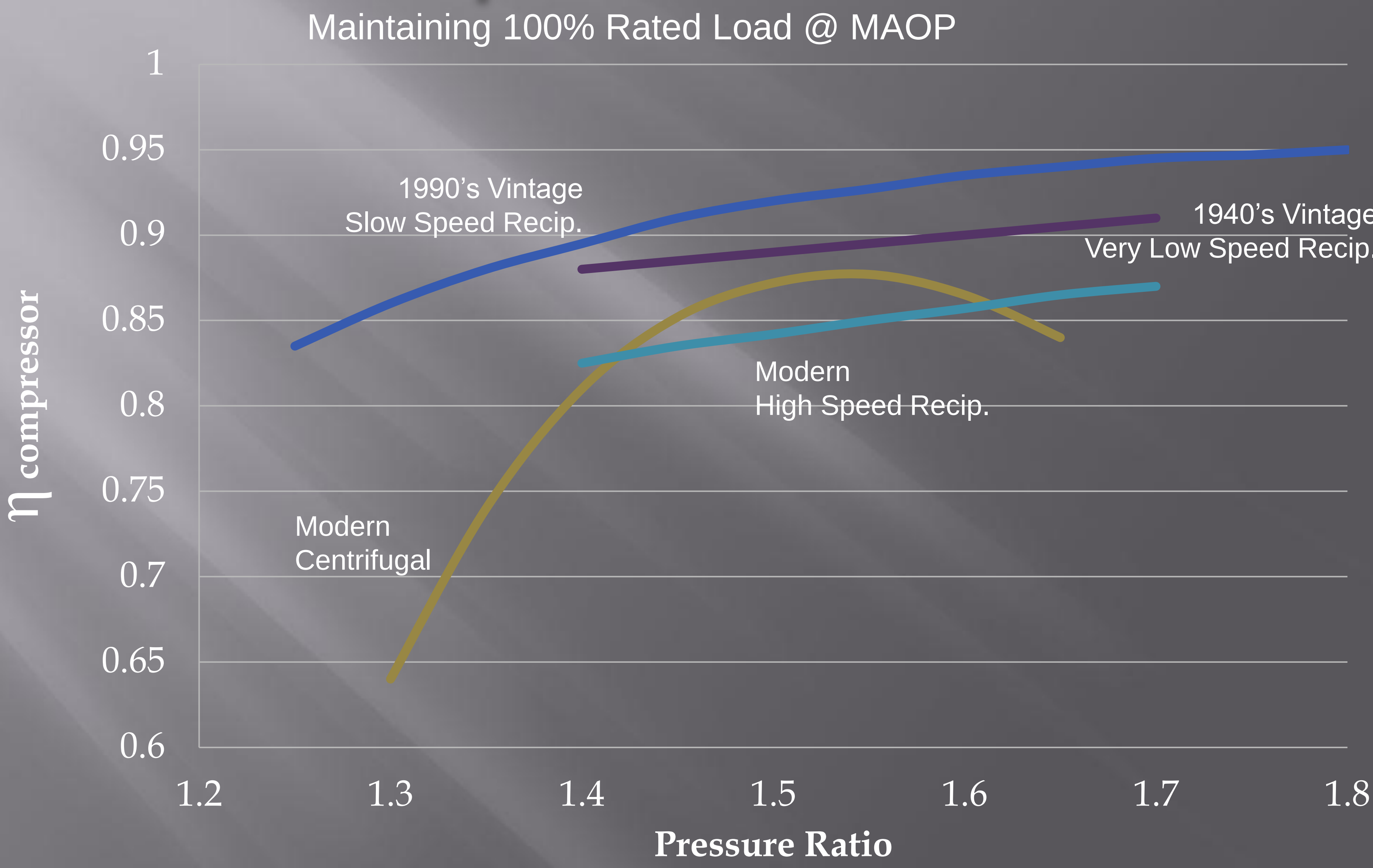
Medium-Speed Separable Compressors
500 to 900 rpm, 4000 to 8000 HP

1940's Vintage Very Low Speed Compression
180 RPM, 500 to 750 HP

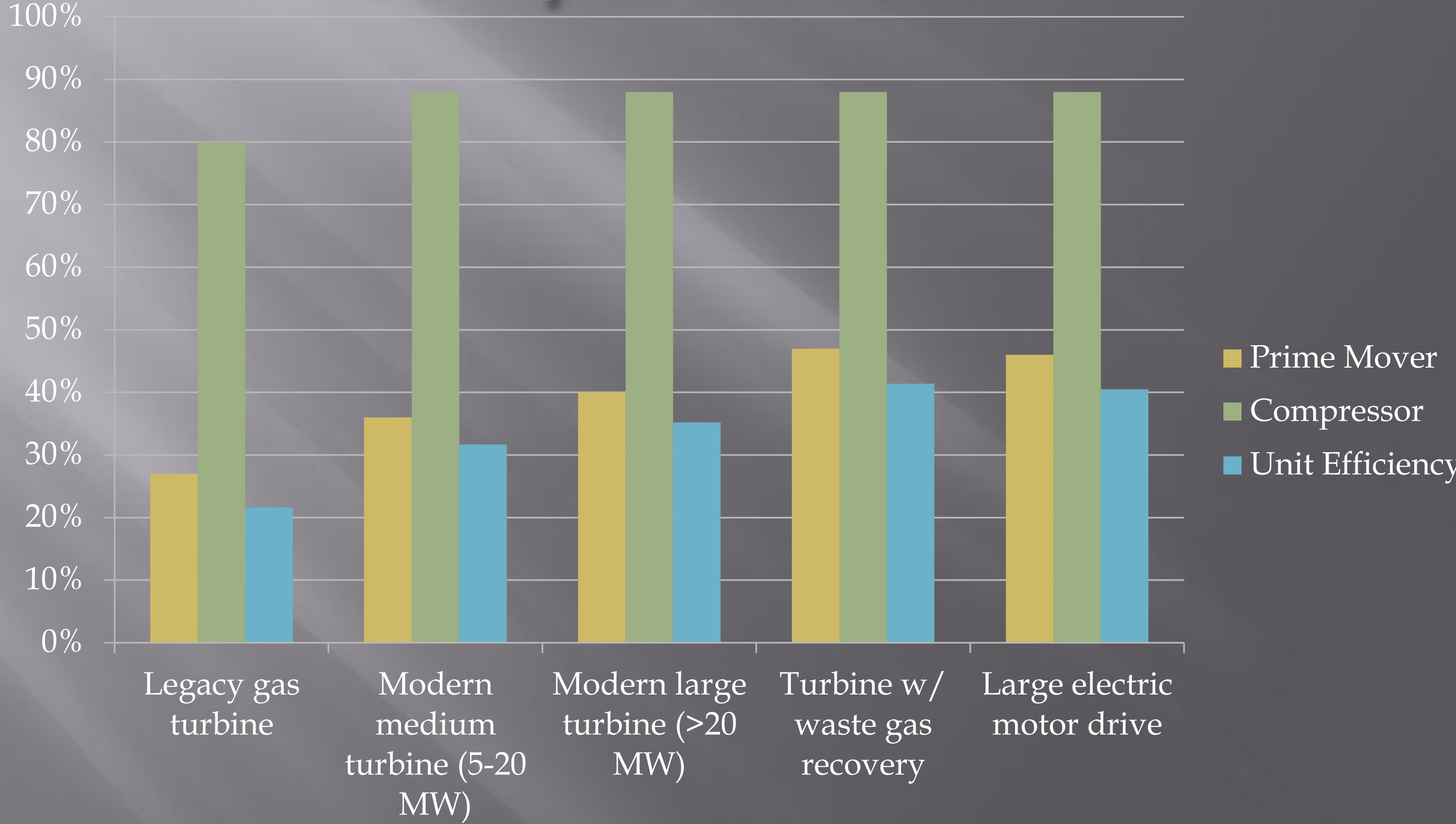


Modern Turbine, Centrifugal Compressor

Compressor Efficiency (η) vs Compression Ratio



Turbine/Centrifugal Compressor Peak Efficiency Comparisons

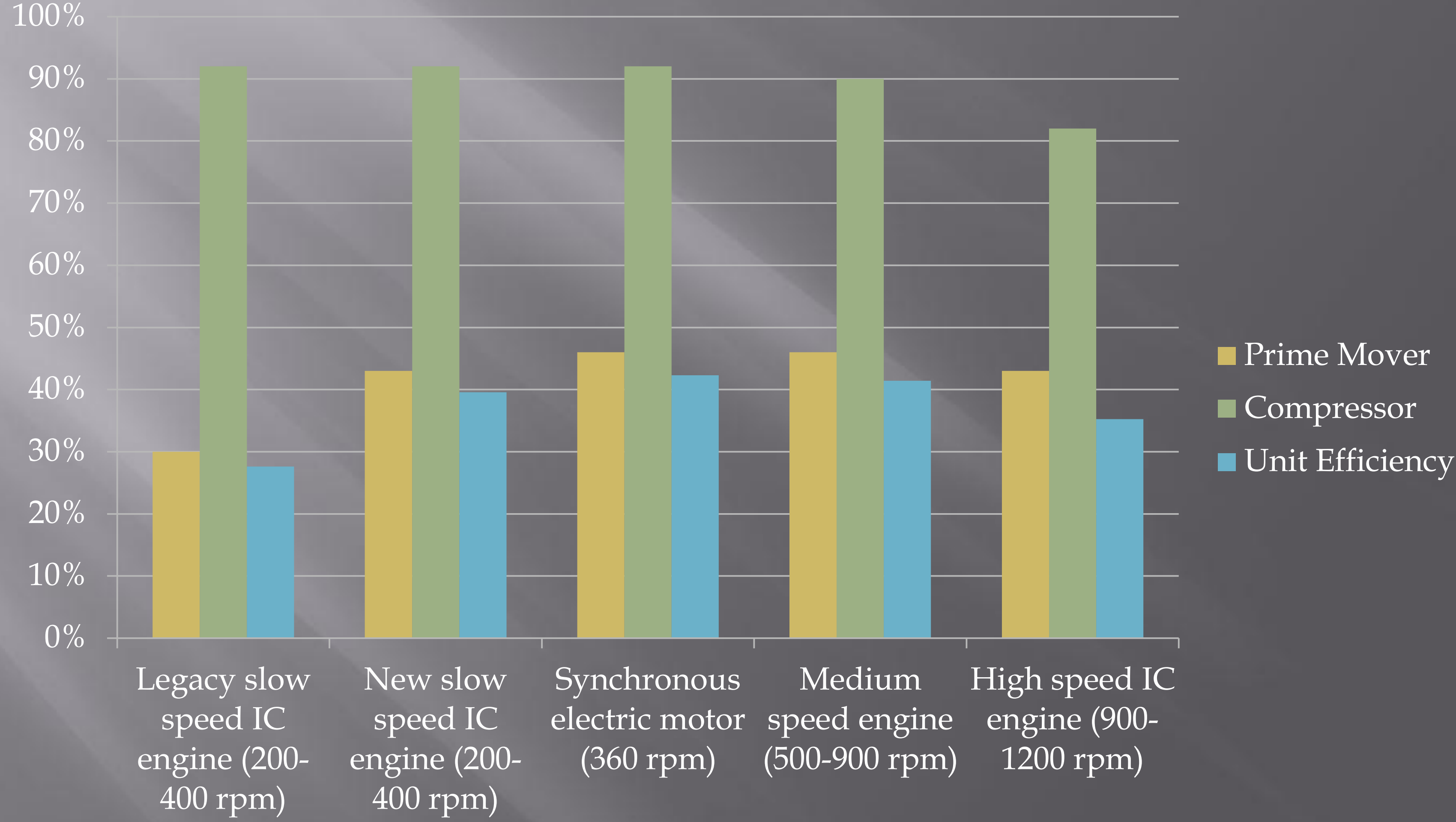


DOE Project for the Development of Isothermal CO_2 Compression

- Pilot-scale demonstration of an internally-cooled compressor design
- Compressor specs…
  - 6-stage, back-to-back
  - 4,000 hp
  - 10,000 acfm flow capacity
  - 1,200 psi case rating
- Demonstrated 3 to 9% improvement in energy cost to power plants.

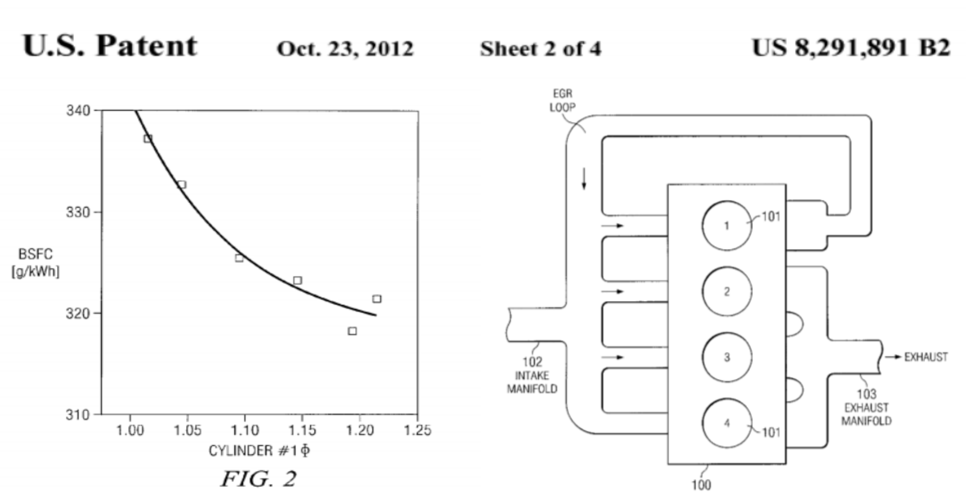
U.S. DEPARTMENT OF ENERGY

Engine/Reciprocating Compressor Peak Efficiency Comparisons



D-EGR Applied to Natural Gas Engines

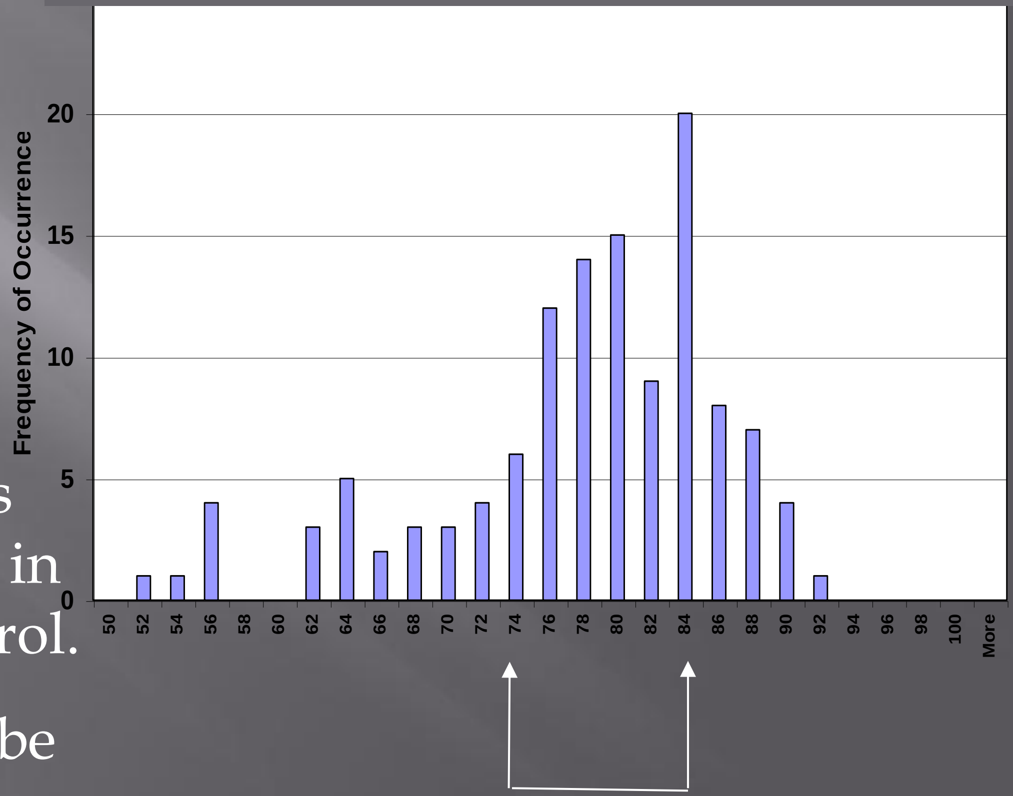
- Dedicated EGR Cylinder: Fuel-rich combustion process, yielding reformer gas, including H2 and CO.
- Reformer gas reduces fuel consumption in the main combustion cylinders leading to improved efficiency by 15%.
- SwRI currently building and testing heavy-duty Natural Gas D-EGR demonstration engine.
- Goal of the program is to demonstrate fuel consumption improvement, with simultaneous improvements to emissions of NOx and Methane emissions.



Survey & Field Tests of Slow-Speed Integral Infrastructure Fleet

- DOE/GMRC/PRCI (2006) Study Slow-Speed Integral Compressors:
  - Majority of slow-speed compressor cylinders operate from 74-84% efficiency. Best at 92%.
  - Primary installation losses are due to pressure losses in valves and pulsation control.
  - If bottom half of fleet can be modified to the "best" performers, pipeline capacity can be increase by 10%.

GMRC Survey of Slow Speed Compressors

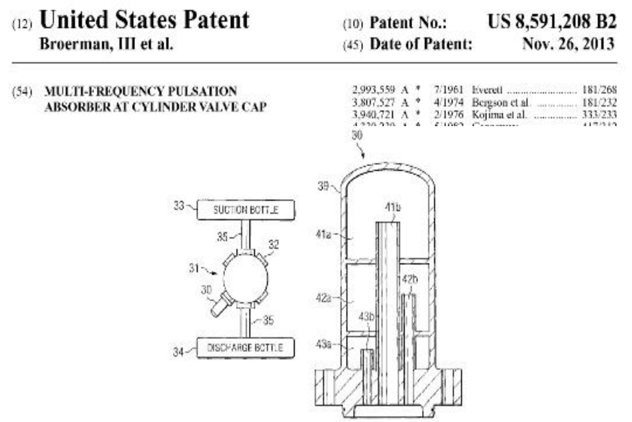


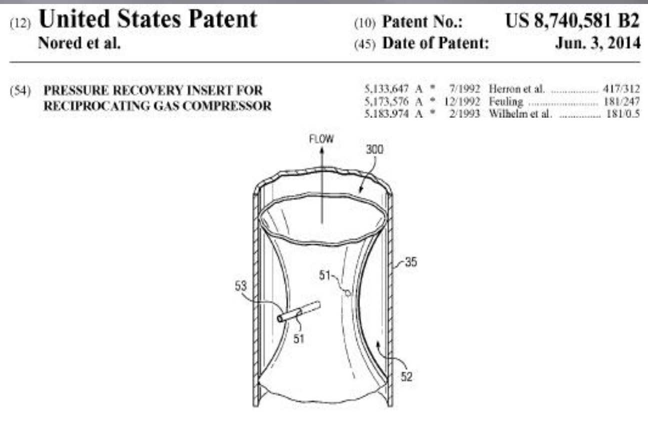
74-84% Thermal Efficiency

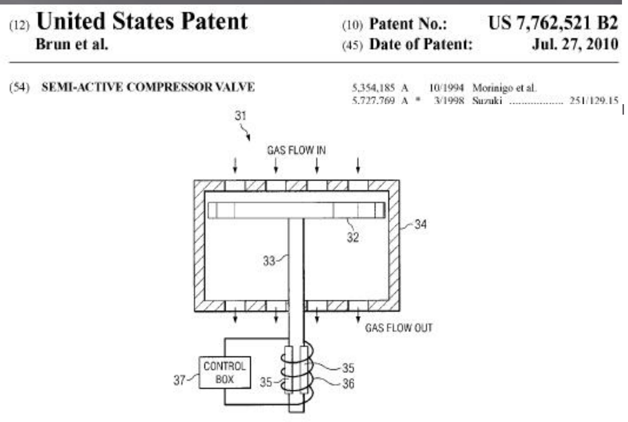
DOE/GMRC/PRCI 2006 project, "Technologies to Enhance the Natural Gas Compression Infrastructure," Smalley, Harris, Bourn. Phillips and Deffenbaugh

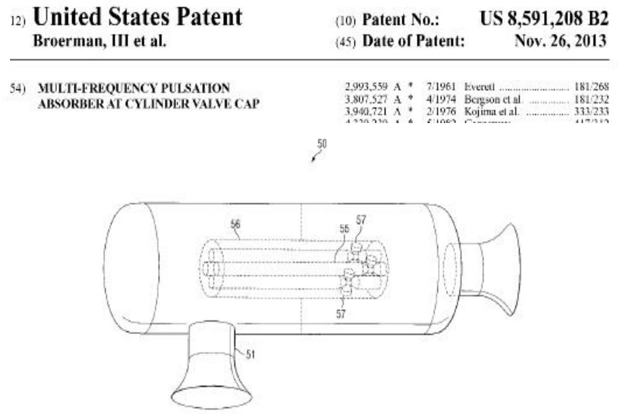
Advanced Reciprocating Compressor Technology

- ARCT Compression Goals:
  - Flexibility – 50% turndown
  - Efficiency > 90% over full range
  - Reliability – 10x valve life
  - Valve Losses - ½ ΔP
  - Integrity – vib. < 0.75 in./sec.


(12) United States Patent
Broerman, III et al.
(10) Patent No.: US 8,591,208 B2
(45) Date of Patent: Nov. 26, 2013
(54) MULTI-FREQUENCY PULSATION ABSORBER AT CYLINDER VALVE CAP


(12) United States Patent
Nored et al.
(10) Patent No.: US 8,740,581 B2
(45) Date of Patent: Jun. 3, 2014
(54) PRESSURE RECOVERY INSERT FOR RECIPROCATING GAS COMPRESSOR


(12) United States Patent
Brun et al.
(10) Patent No.: US 7,762,521 B2
(45) Date of Patent: Jul. 27, 2010
(54) SEMI-ACTIVE COMPRESSOR VALVE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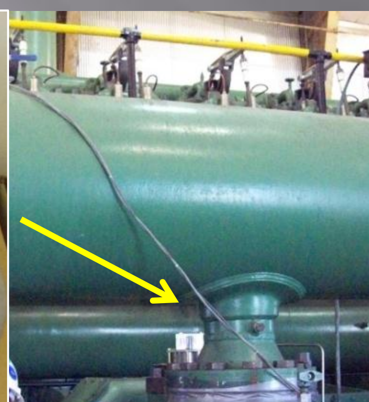
Efficiency Improvement Technology

Dominion Groveport Station, Low Speed Compressor Operating @ 300 RPM

Overall Efficiency ~ 75%, Primary losses: 10% valves, 13% pulsation control

The Solutions:



Replace Orifice w/ Venturi: Installed at El Paso Elk Basin Station

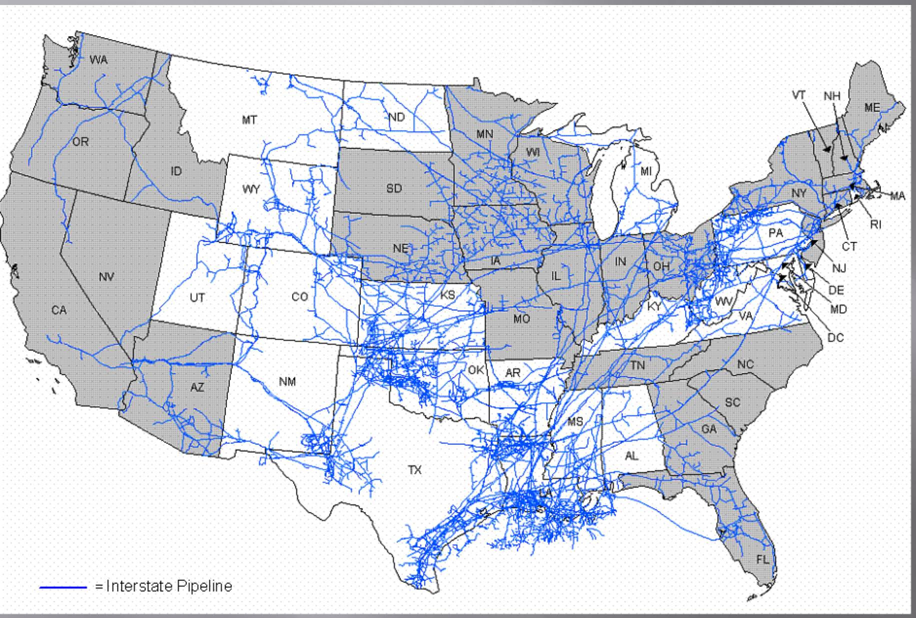
Reduced pressure drop from 2 psi to 0.4 psi per cylinder for 80% improvement in pressure losses

Replace Orifice w/ Helmholtz Resonator on the Valve Cap at El Paso Baxter Station

Eliminated nozzle pulsations and dynamic losses

Improves efficiency by 4-5%

Summary Points



REDUCED PRESSURE DROP = REDUCED HORSEPOWER = REDUCED EMISSIONS =

IMPROVED EFFICIENCY

- Greatest opportunity for maximizing transportation efficiency with advanced technology is at the initial design stage and the associated state of the technology at the time.
- Due to economic efficiency Interstate Natural Gas Pipeline compression does not normally operate at optimum design condition.
- Need for technology advancements to optimize performance over the full compressor operating range:
  - Novel compressor/driver concepts
  - Advanced turbine/engine technology
  - Advanced high-speed motors
  - Advanced waste heat recovery
  - Advanced capacity control
  - Advanced manifold technology and
  - Advanced compressor valves.