

The “LMRC”

Linear Motor Reciprocating Compressor

Brief Overview and Development Progress Report

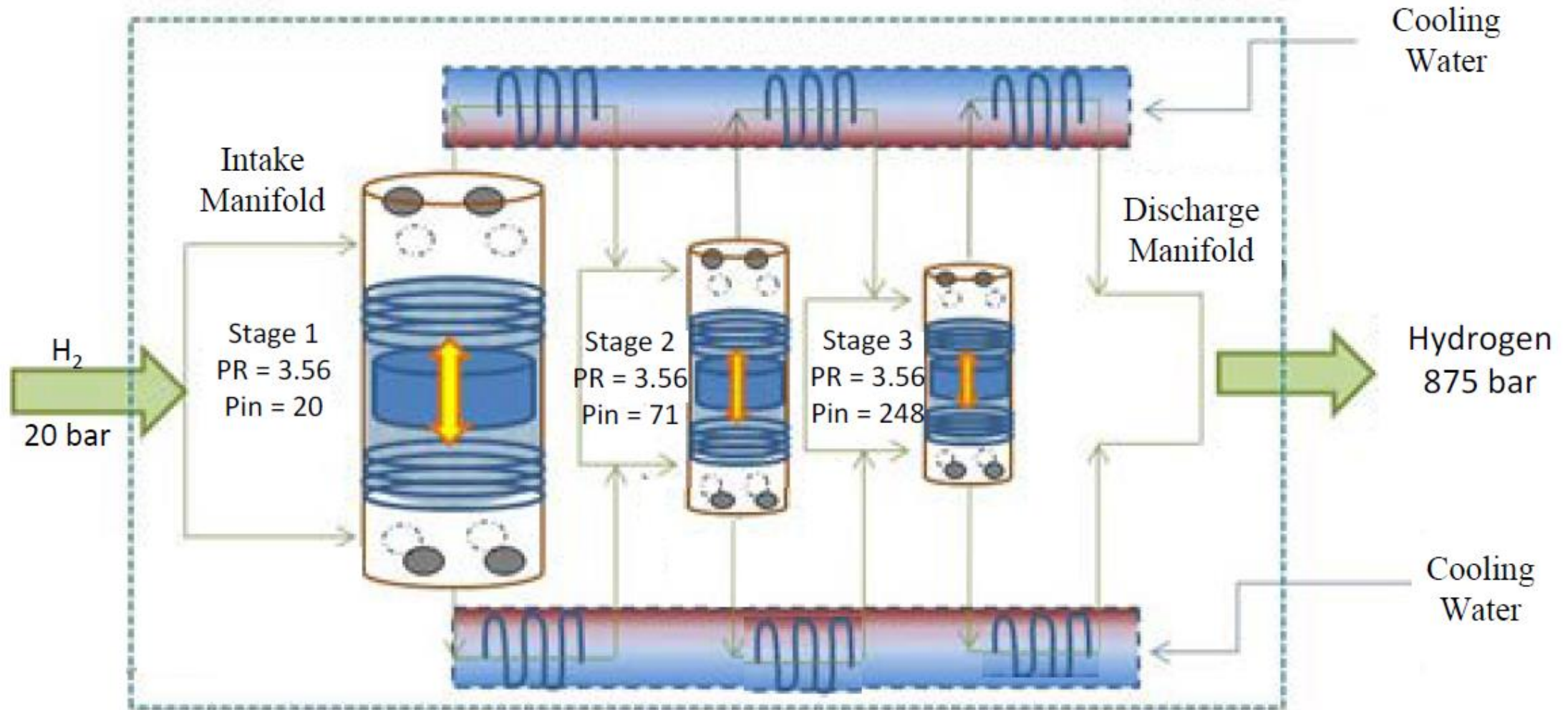
**A collaborative effort by ACI Services Inc., Libertine FPE Ltd.,
Southwest Research Institute, and the U.S. Department of Energy**

Presented by W. Norm Shade, PE

GMRC Gas Machinery *Virtual* Conference – October 12, 2020

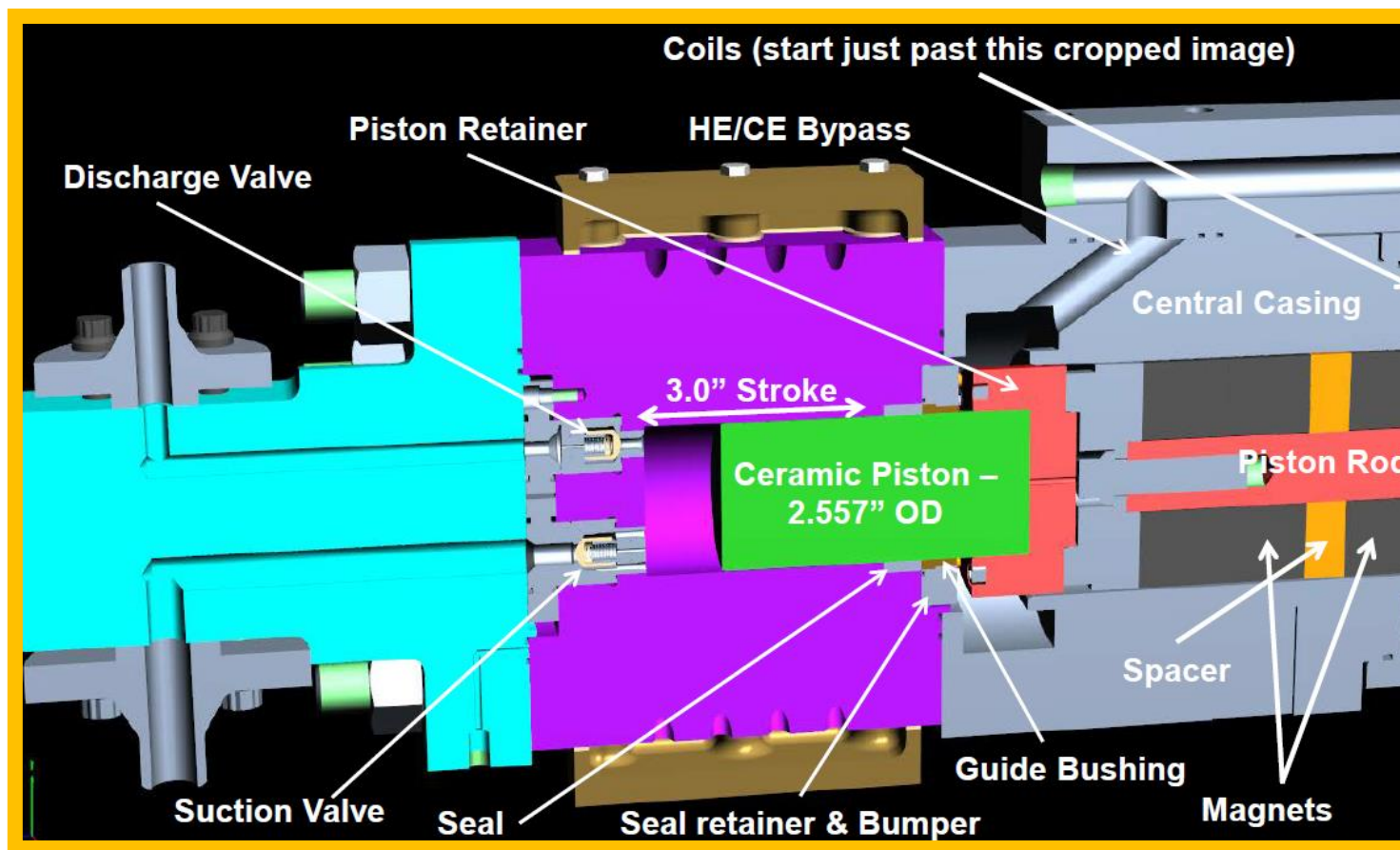
Phases 1 & 2 (2014 – 2018)

- SwRI / ACI project to develop a reliable, efficient, cost-effective compressor for hydrogen vehicle fueling
- Compressing 10 kg/hr (103 MSCFD) of hydrogen from 20 to 875 bar (290 to 12,689 psi) in three stages

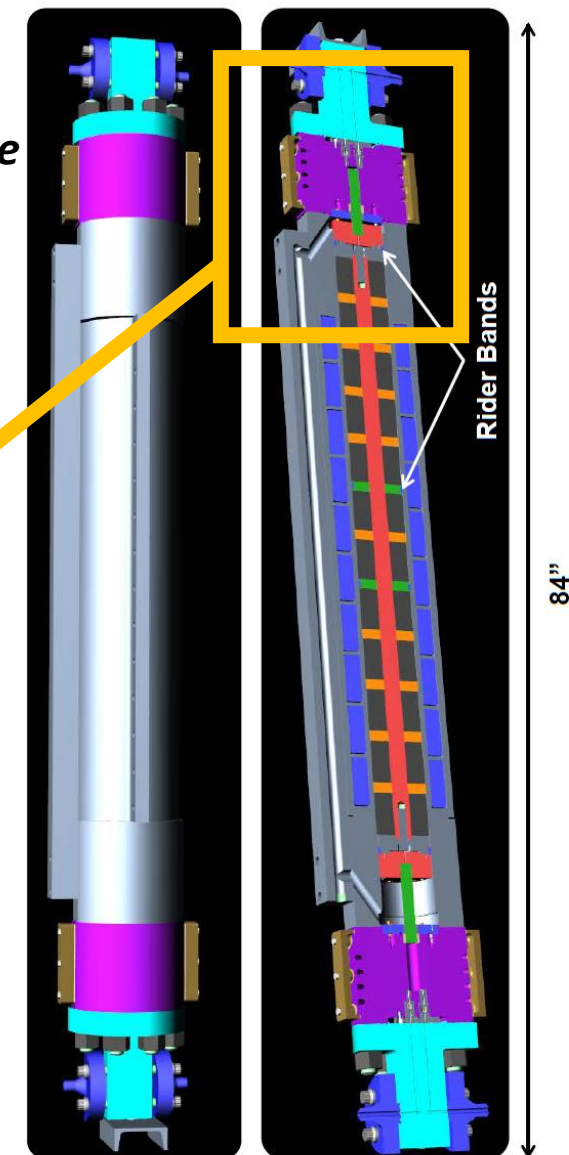


Phases 1 & 2 (2014 – 2018)

- Phase 1 – designed all 3 stages; Phase 2 – built & tested 1st stage
- 3.00" stroke; 2.557/1.537/0.852" bores; 330 rpm; targeted 95% adiabatic efficiency per stage
- 2015 GMC Paper: *Designing a Linear Motor Recip Compressor (LMRC) for 12,700 psi Discharge*

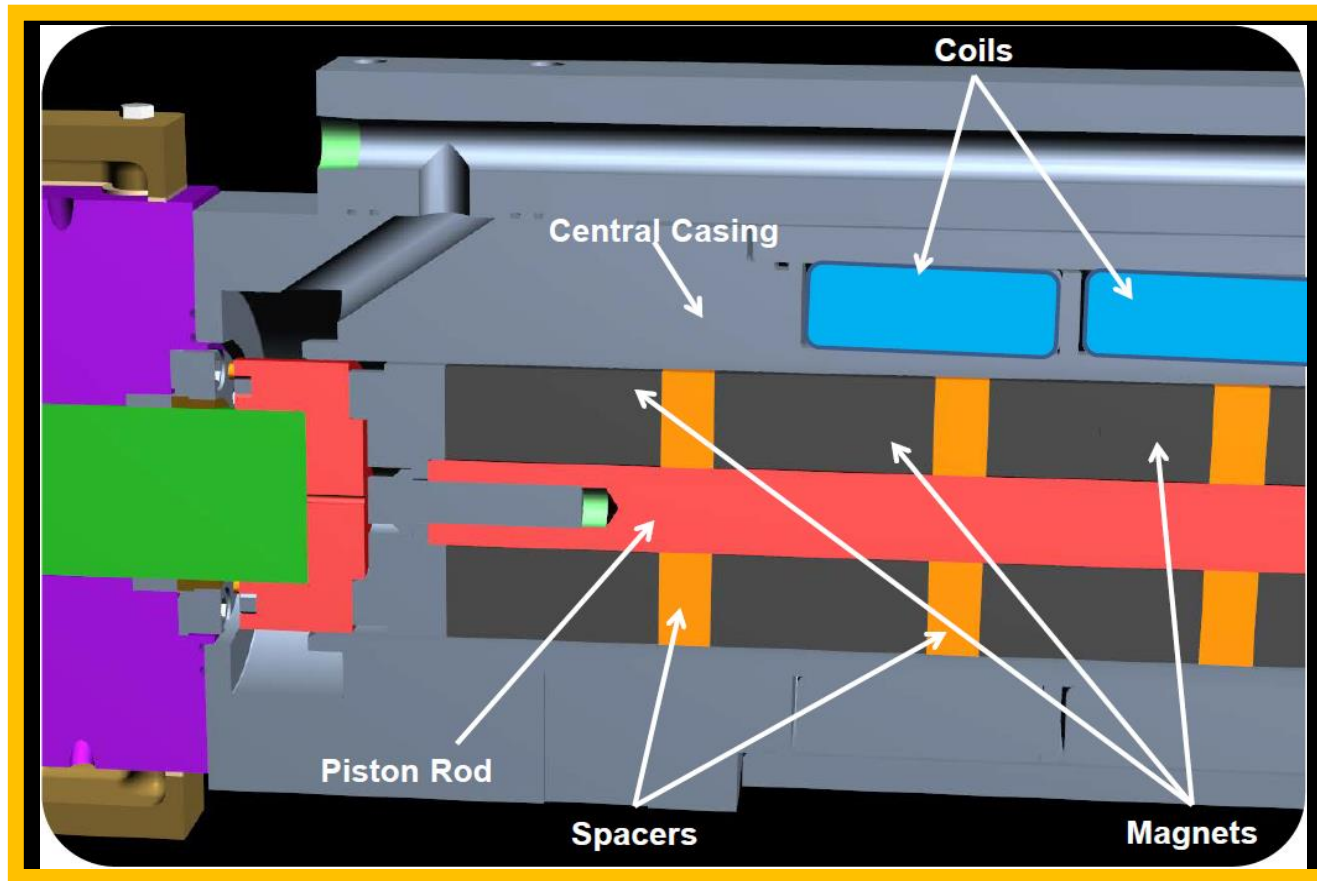


Earlier Project History

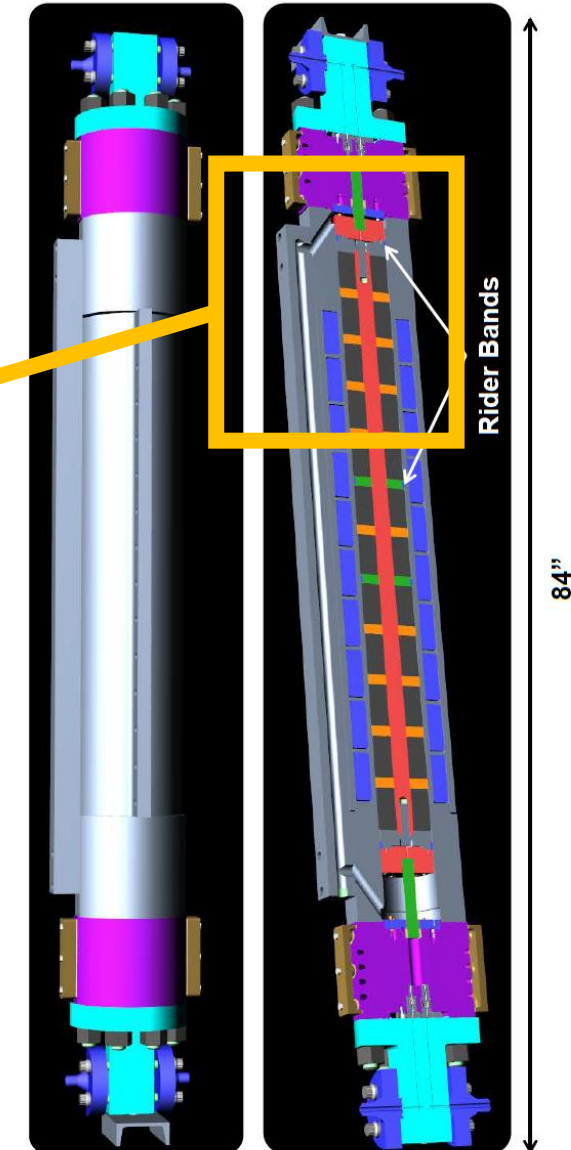


Phases 1 & 2 (2014 – 2018)

- Phase 1 – designed all 3 stages; Phase 2 – built & tested 1st stage
- Double-ended compressor design
- High-strength Neodymium (NdFe_{14}B) permanent magnets
- Electrical coils outside casing

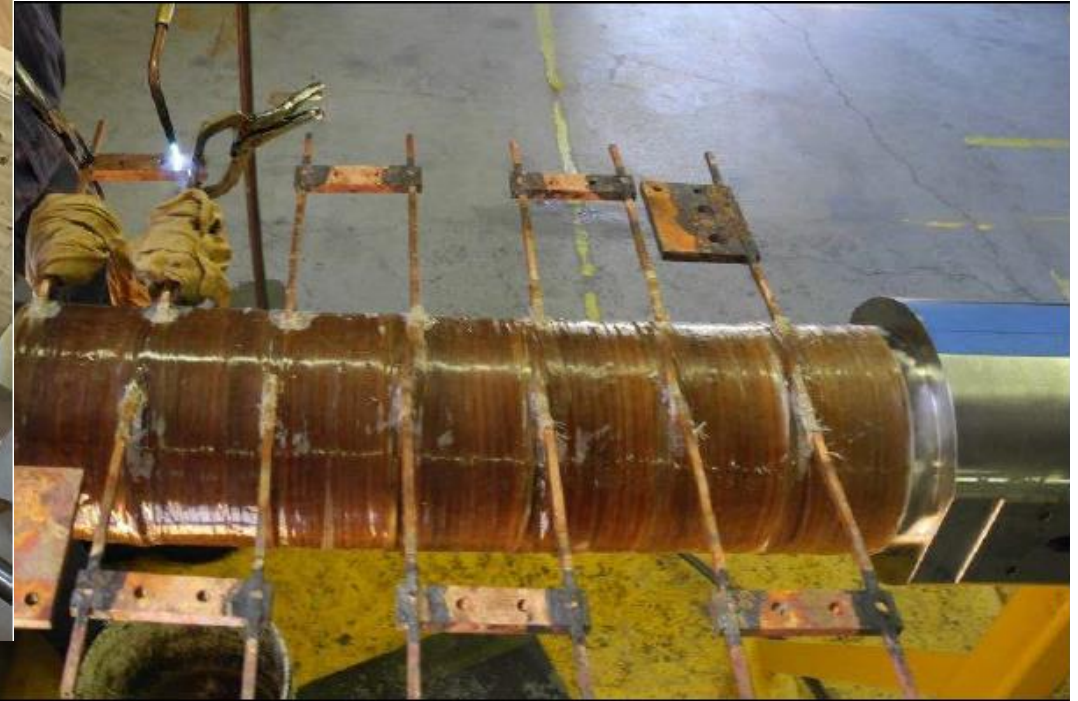


Earlier Project History



Phases 1 & 2 (2014 – 2018)

- Original Stage 1 prototype – stator coils wound on central casing (right) and assembled in cooling jacket (left)



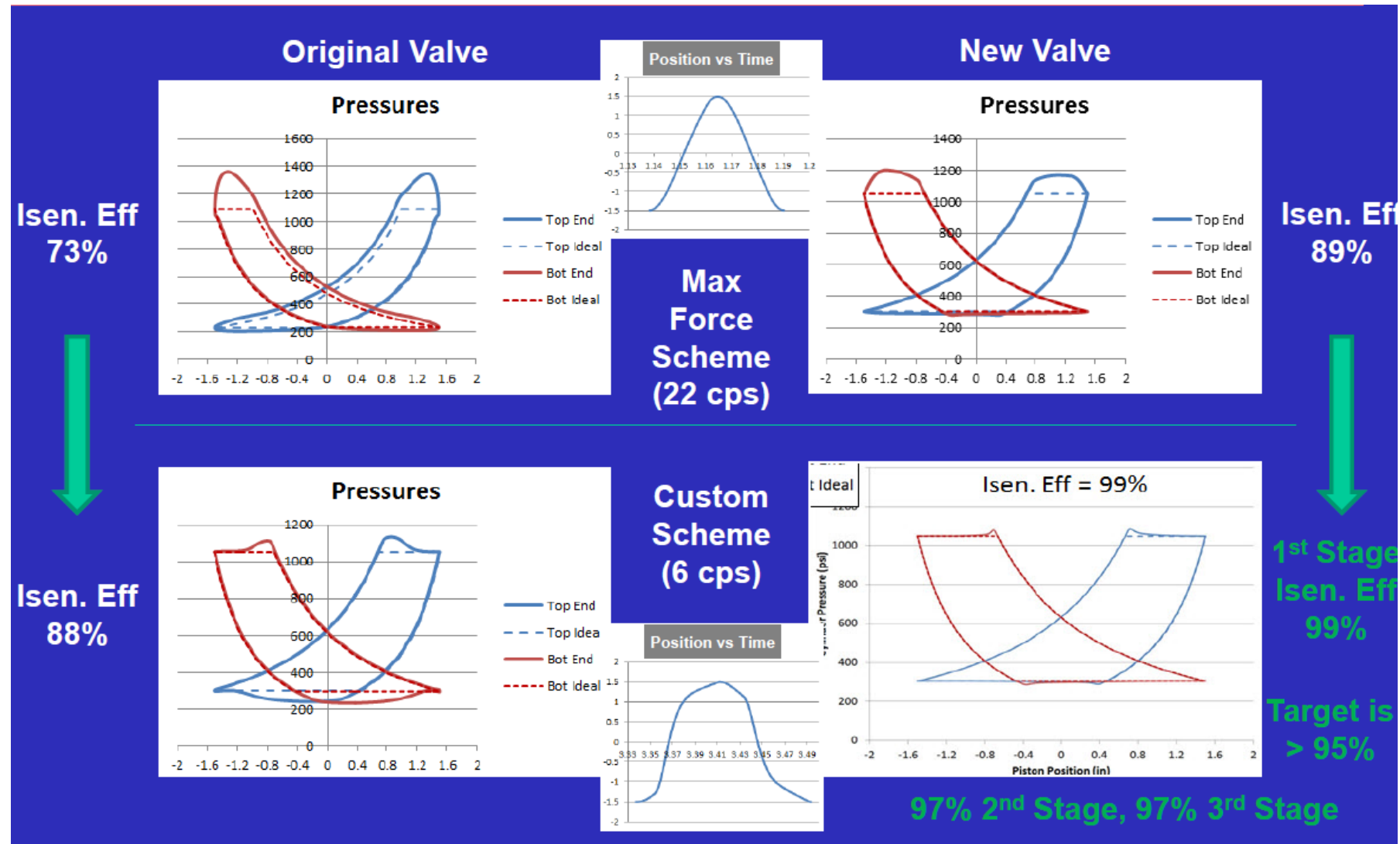
Phases 1 & 2 (2014 – 2018)

- Original Stage 1 prototype – magnet assembly (left); zirconia pistons (right); compressor cylinder & head (center)



Phases 1 & 2 (2014 – 2018)

- Original Stage 1 prototype – control scheme & valve optimization for high efficiency (based on simulations)



Phases 1 & 2 (2014 – 2018)

- Original Stage 1 prototype – testing results at SwRI



Successes:

- Operated on helium and hydrogen
- Mechanically sound
- Minimal vibration
- No leakage to atmosphere
- Internal seals performed as intended
- Proof of concept
- Significant learning!

Disappointments:

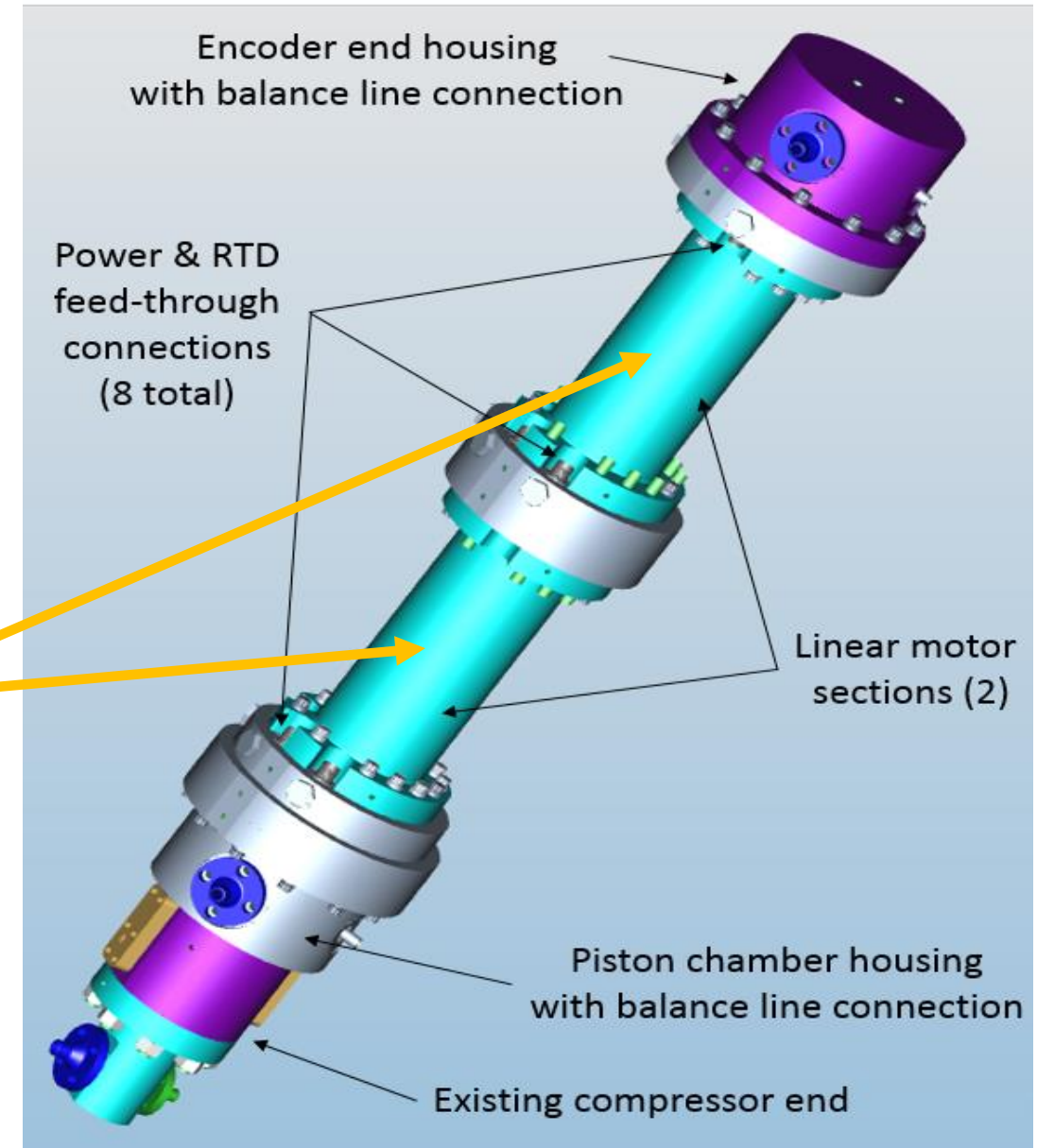
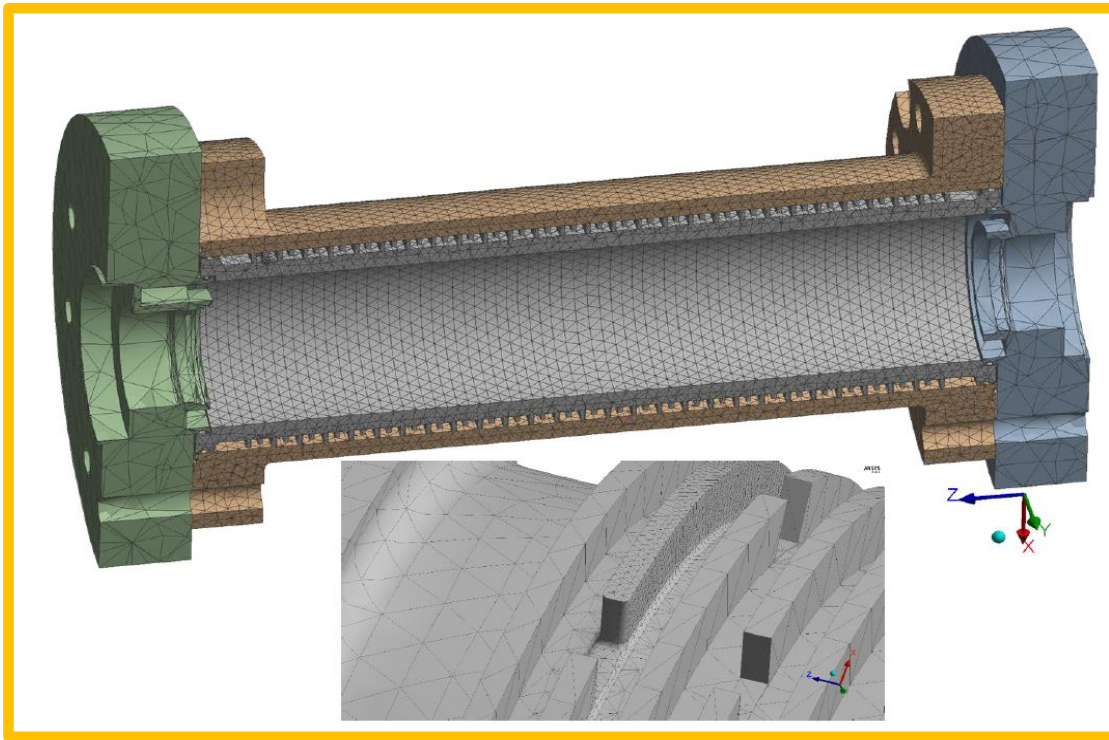
- Testing limited by control system, position sensor & instrumentation problems
- Magnets may have deteriorated with time in hydrogen environment
- Coils located outside casing caused low motor efficiency
- Learned that different motor & control designs necessary to achieve goals



Phase 3 (2019 – 2020)

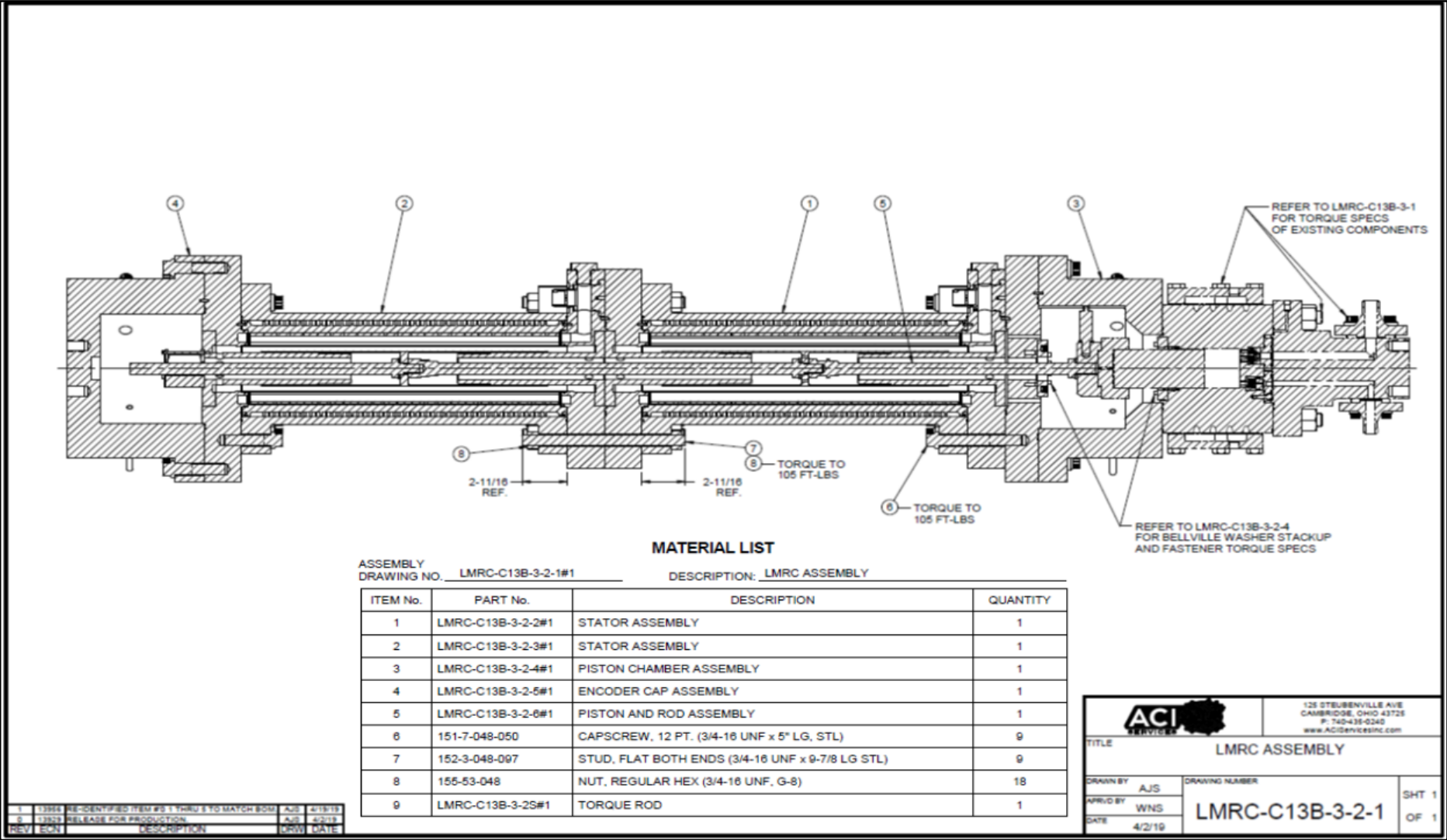
➤ New LMRC Design

- Single-ended design employing proven Libertine technology
- Retained one compressor end of original LMRC
- Completely new motor section with coils inside casing
- Novel stator housing cooling chambers



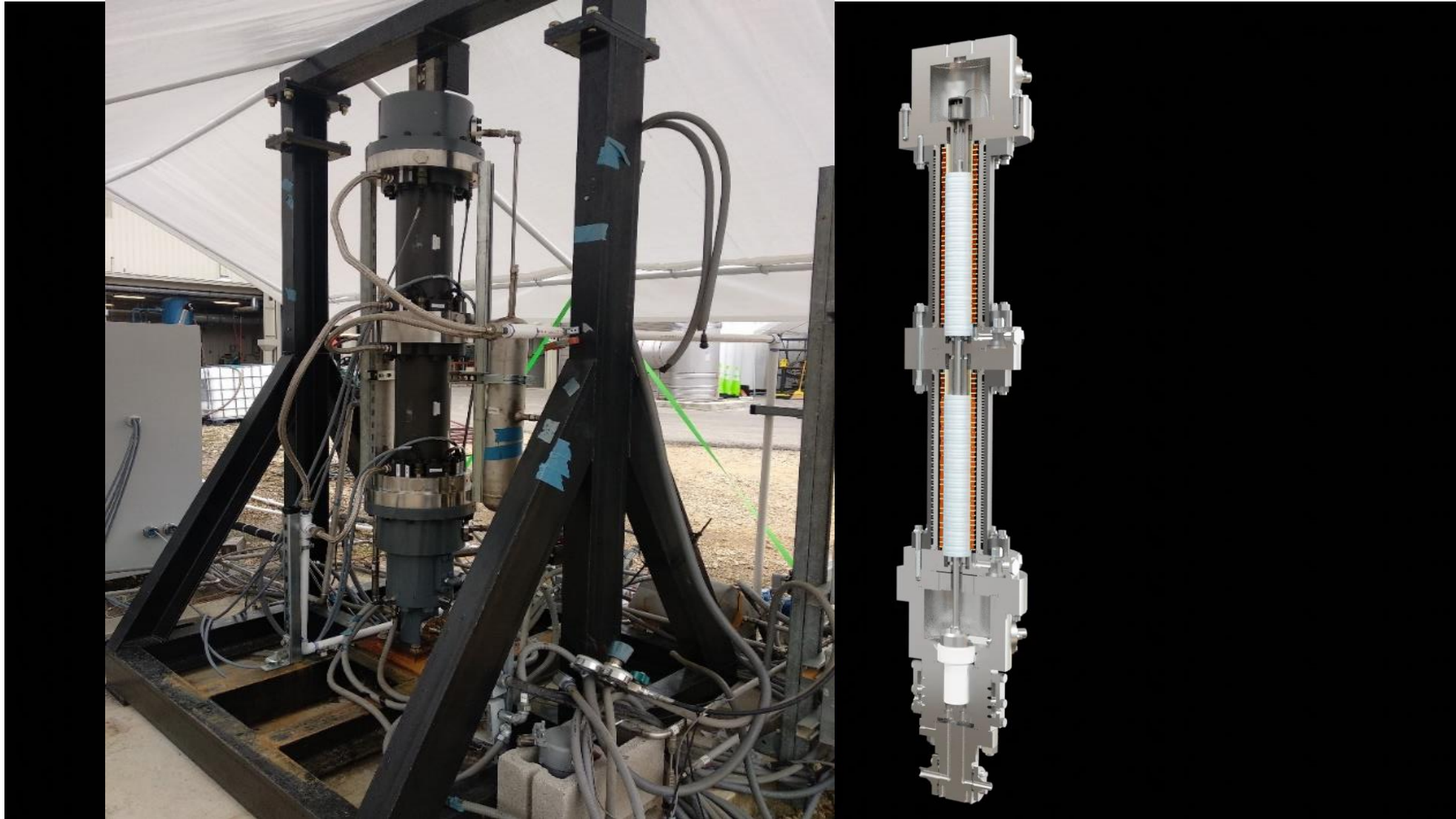
Phase 3 (2019 – 2020)

➤ New LMRC Design



Phase 3 (2019 – 2020)

- New Stage 1 prototype – testing results at SwRI

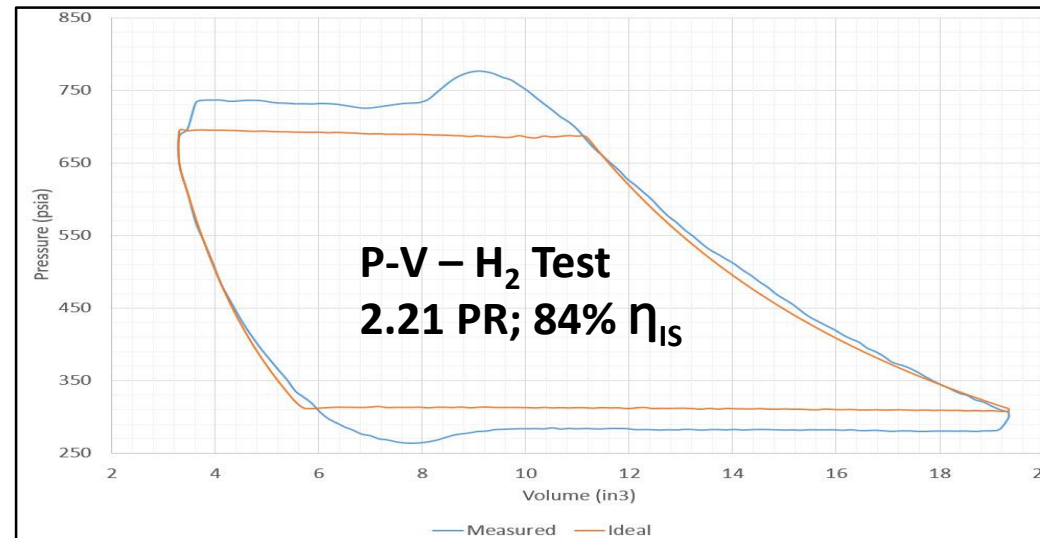
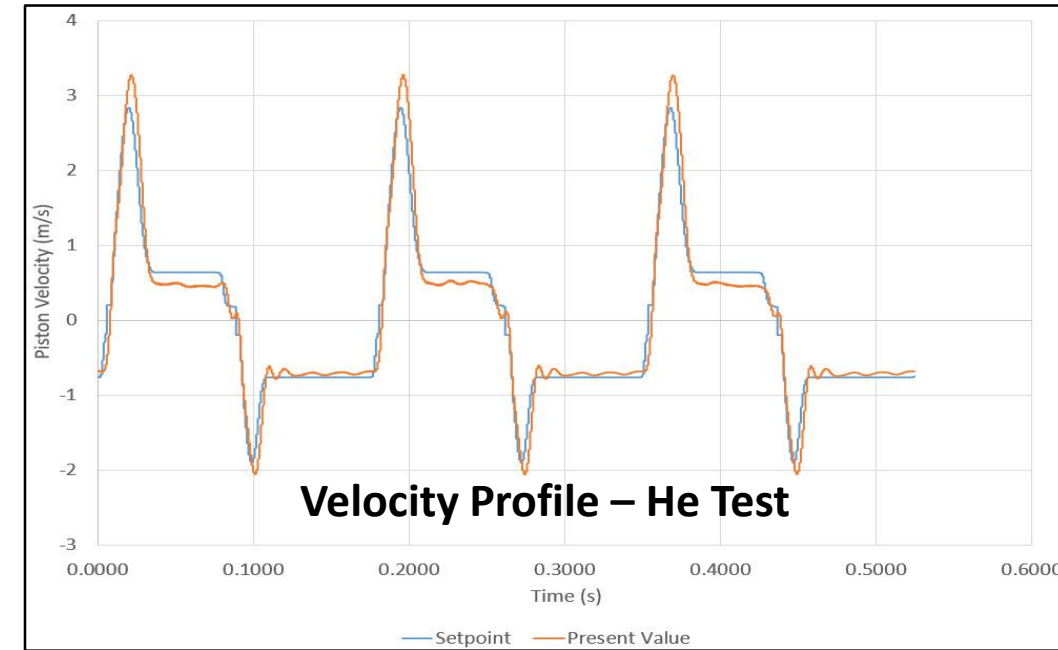


Phase 3 (2019 – 2020)

➤ New Stage 1 prototype – testing results at SwRI

Successes:

- Operated on helium to 750 psig discharge (temperature limited)
- Operated on hydrogen to 3.18 max PR; 686 psig max discharge
- 84% isentropic efficiency at 2.21 PR with non-optimized profile
- Internal seals performed as intended
- Precision control demonstrated
- Demonstrated ability to idealize piston motion profiles
- Coils located inside casing improved motor efficiency
- Minimal vibration
- Minimal to zero leakage to atmosphere
- Proof of concept

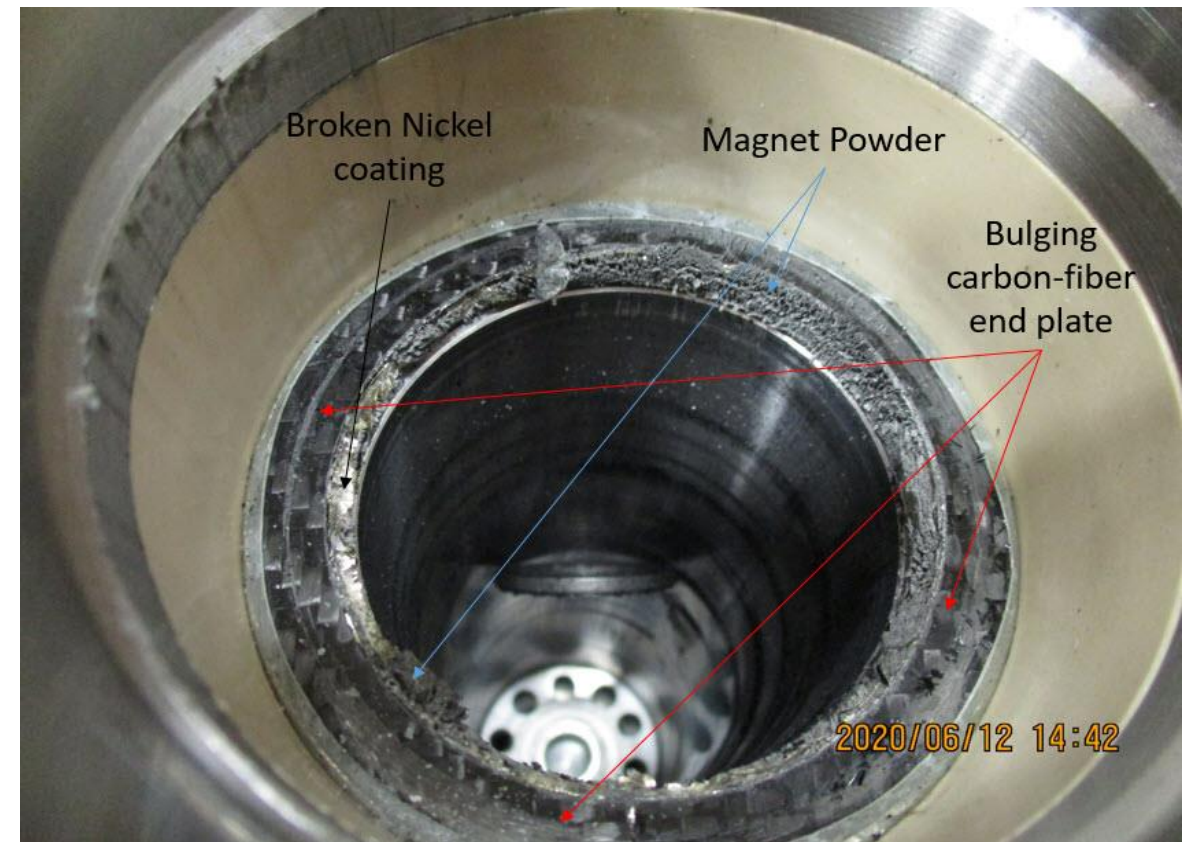
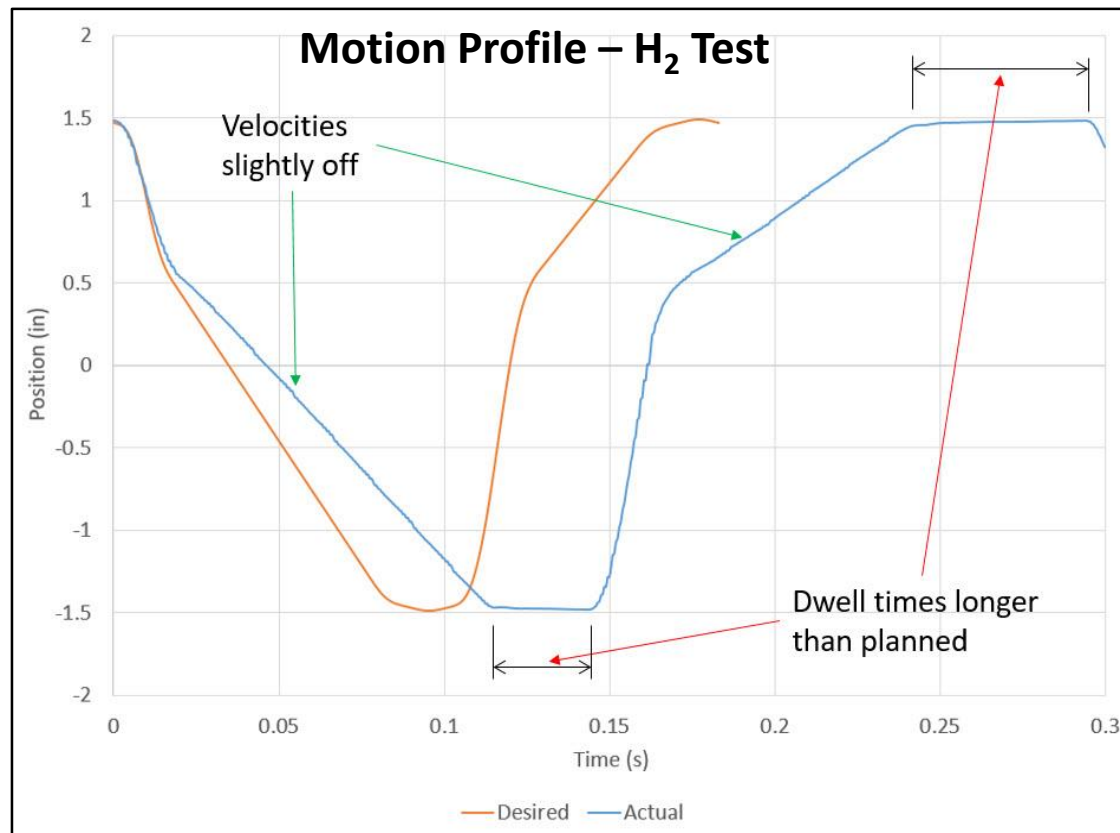


Phase 3 (2019 – 2020)

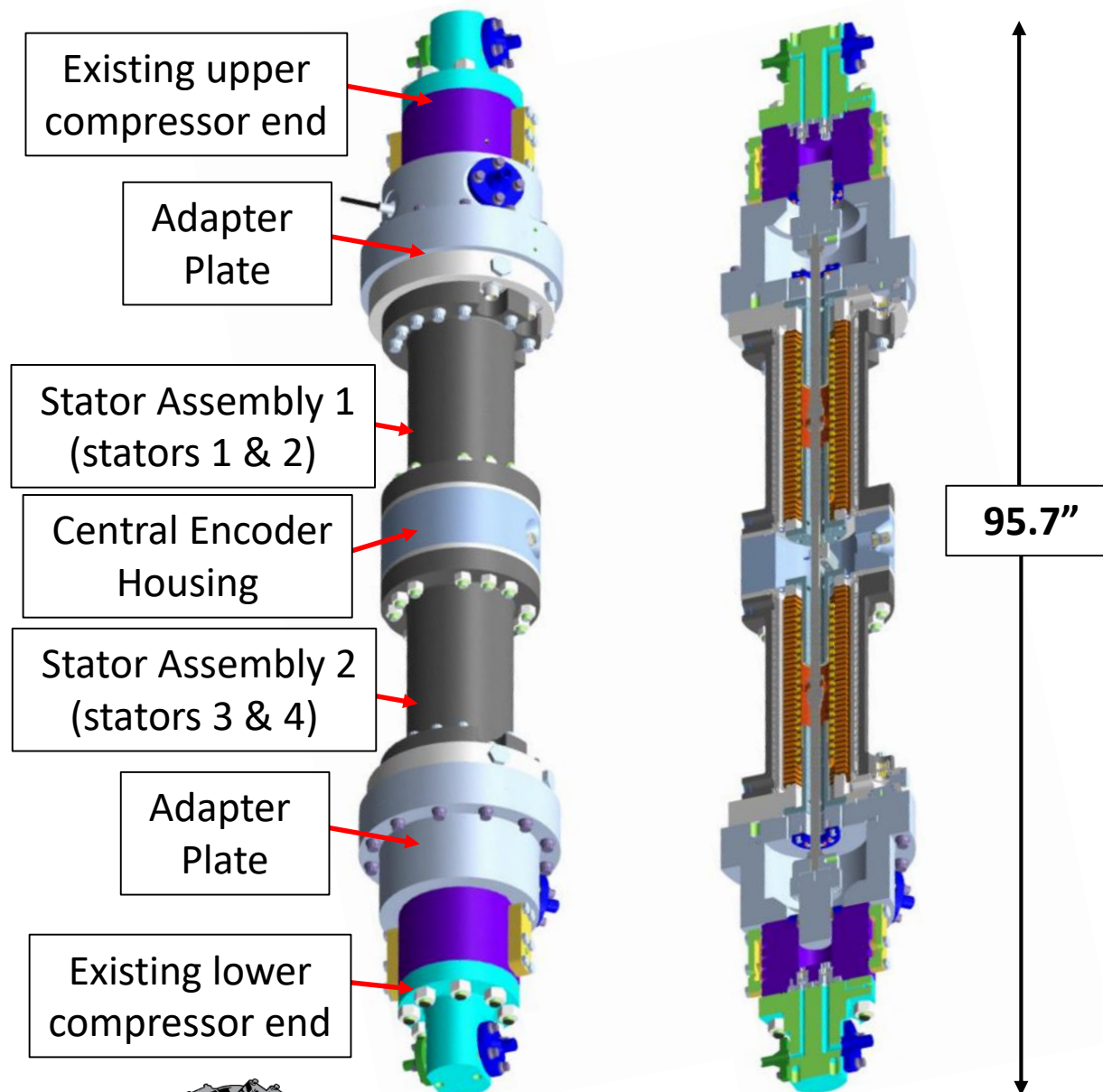
➤ New Stage 1 prototype – testing results at SwRI

Disappointments:

- Suction valve assembly misalignment initially caused poppet leakage (design change defined)
- Longer than desired dwell times at ends of piston stroke (additional control tuning is needed with extended testing)
- Nickel plating problems led to hydrogen attack of multiple magnets (suspended testing before optimization finished)

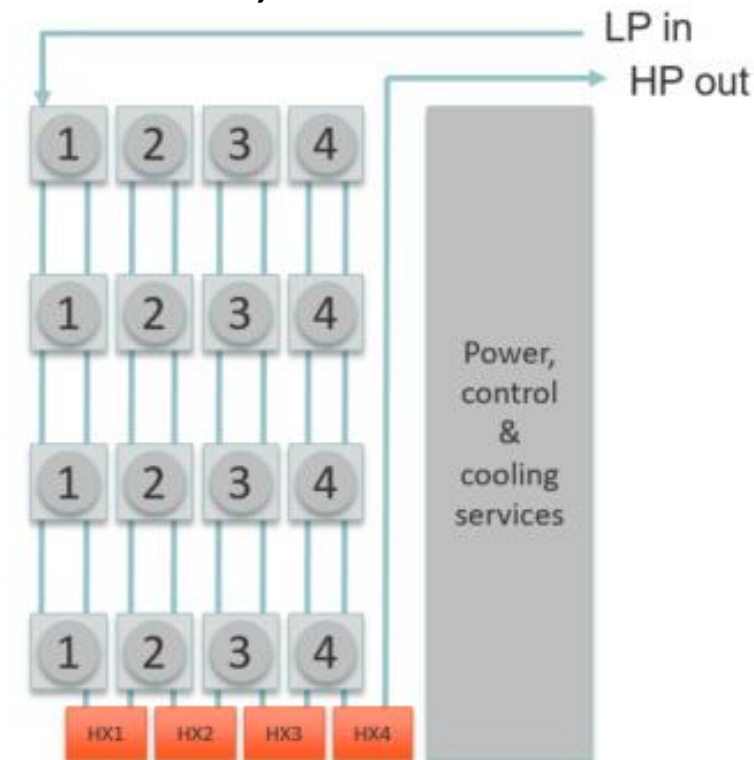


Next Phase (2020 –)



➤ Design Enhancements

- Double-ended compressor (increased output)
- Slotted stator motor (increased efficiency)
- 3x speed and 2x stroke uprate (increased output)
- Integrated modular packages for applications needing
 - higher flow,
 - higher pressure ratio, or
 - both



Next Phase (2020 –)

- **Potential Applications**
 - **Hermetically sealed (zero emission) compression**
 - **Vapor recovery**
 - **Toxic gases**
 - **Any other gases that are compatible with magnet materials**
 - **Hydrogen (after process quality improvements on Nickel barrier plating)**

- **SwRI, ACI and Libertine want to continue developing this technology for commercial applications**
 - **But.....need additional funding for continuing the development**
 - **Project proposals currently before DOE and a major end user for hydrogen fueling applications**
 - **Welcome discussion with interested parties for hydrogen or other compression applications**

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Or contact:

W. Norm Shade, PE
ACI Services Inc.
nshade@aciservicesinc.com
713-206-9651



Eugene L. (Buddy) Broerman
Southwest Research Institute
eugene.broerman@swri.org
210-522-2555



Sam Cockerill
Libertine LPE
sam.cockerill@libertine.co.uk
+44 7740 488130

