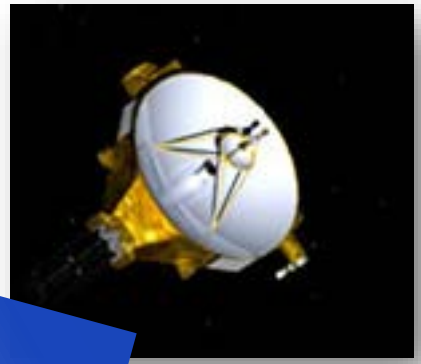
R&D for the Energy Industry

SOUTHWEST RESEARCH INSTITUTE®

Adam L. Hamilton, P.E
President
29 March 2016

Deep Sea to Deep Space

Independent.
Advanced Science.
Applied Technology.
From *Deep Sea*
***To Deep Space*.**
And Everything in between.



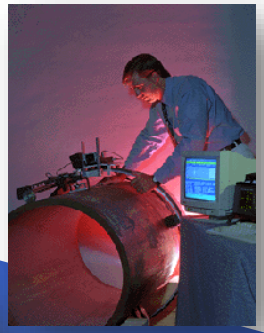
- New Horizons
  - SwRI-lead
  - Launched: January 19, 2006
  - Closest approach to Pluto: July 14, 2015
  - Fastest spacecraft ever: ~30,000 mph

- Alvin
  - Tested at SwRI before first (1964) record-setting dives > 8,000 ft.
  - Redesigned (2013) new Alvin (3" titanium sphere) capable of > 21,000 ft.

Deep Sea to Deep Space

And Everything Between

Nondestructive Evaluation

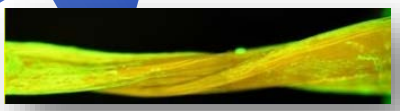


Materials & Engineering

Infrastructure Communications

Robotics, Automation, and Simulations

Water and Geological Engineering



Regenerative Medicine

Engine Design and Optimization

Energy

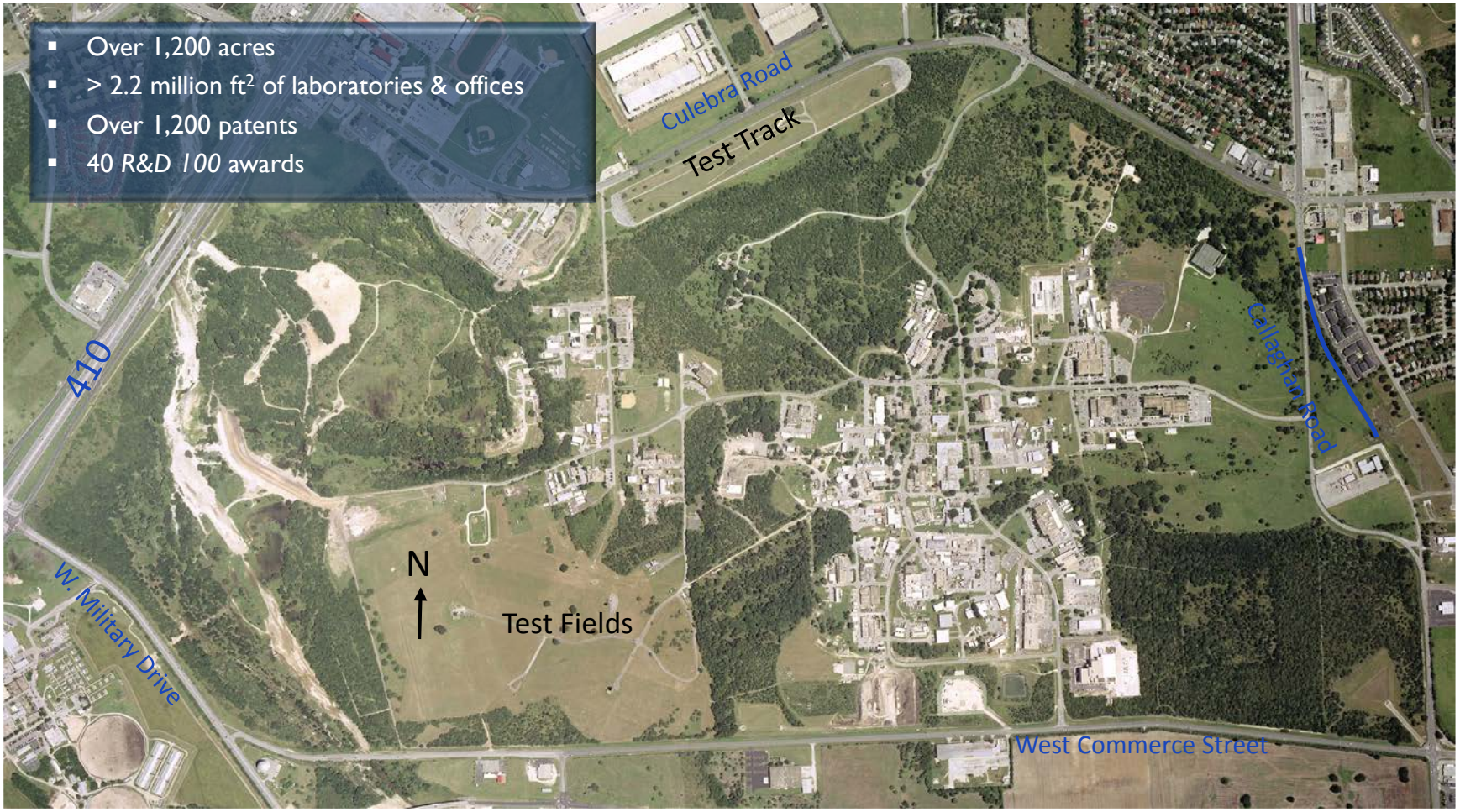
Operational Overview

- 501©(3) non-profit
  - Not-for profit
  - Not-for-loss
- Broad technological base
  - Applied RDT&E services
  - Physical sciences & engineering
- Capital intensive operation
- FY 2015 Revenue: ~$592MM
  - ~2,700 employees
- FY 2015 Internal Research (IR) program:
  - ~$7.2MM
  - ~180 projects

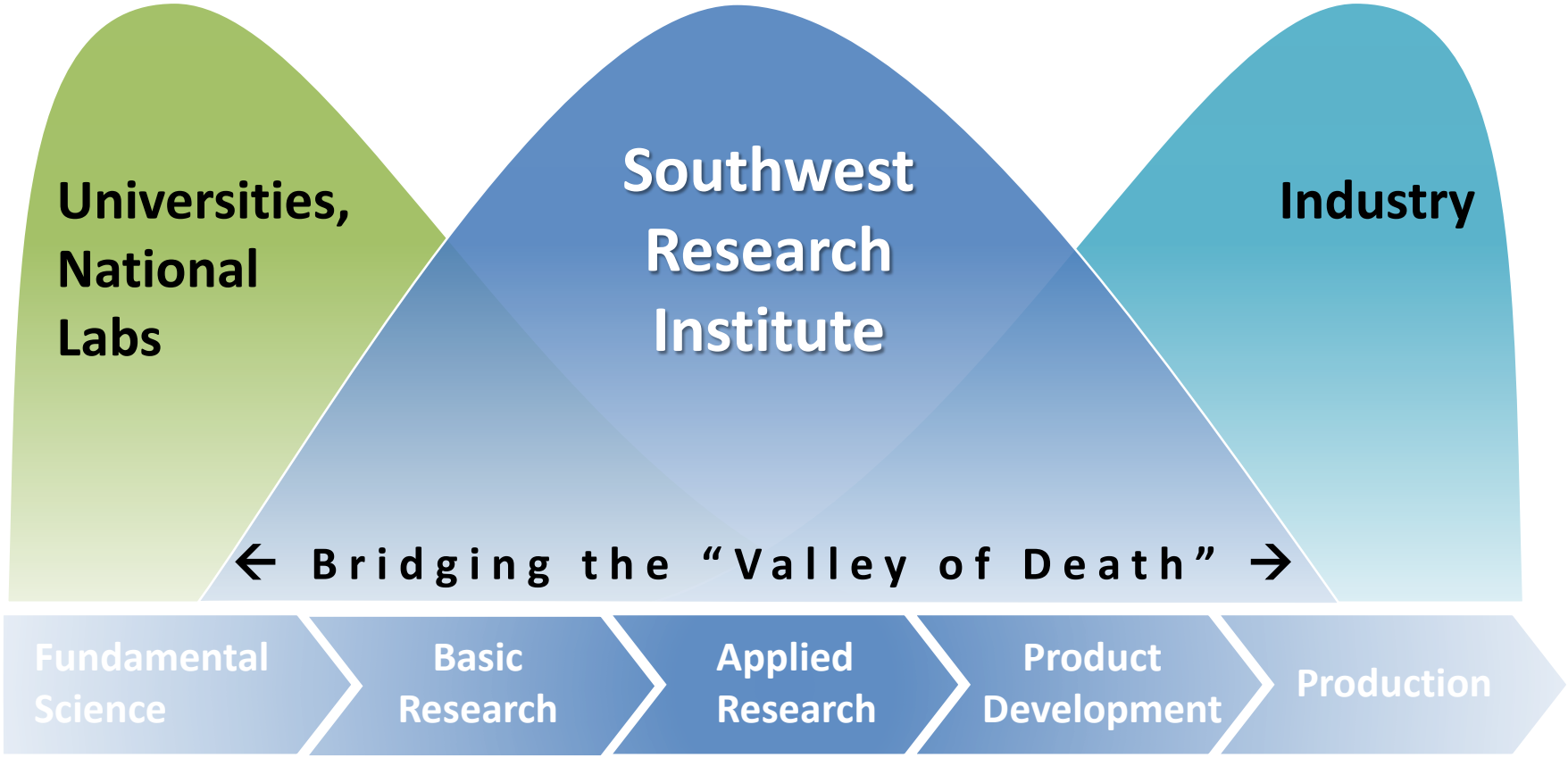
'For nearly 70 years, the Institute has solved some of the most challenging technical problems facing humankind, and answered questions regarding the breadth and depths of our planet as well as the very nature of our universe. Our success has provided results, both visionary and practical, for people around the world. The SwRI "family" has enriched the lives of those around us—practically on every continent.'

Adam L. Hamilton, P.E.

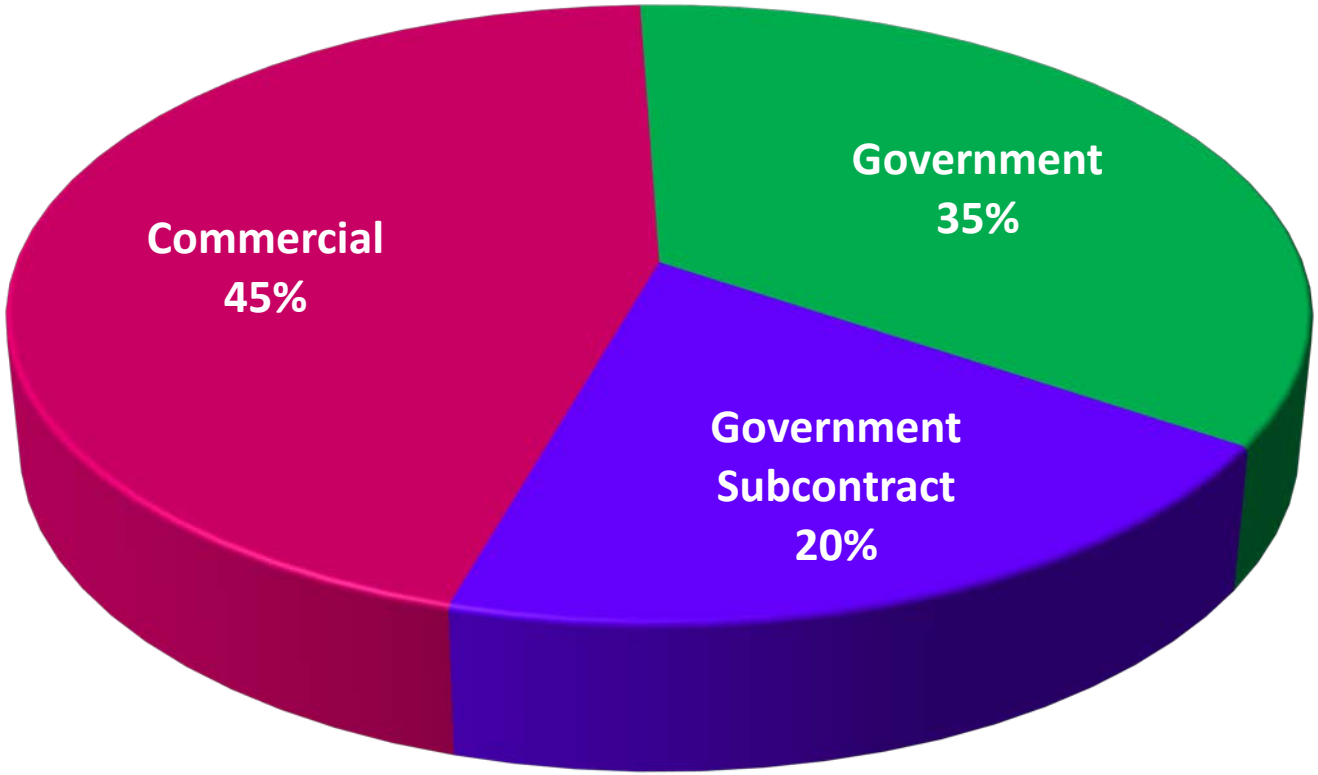
SwRI Campus San Antonio



SwRI® in the Technology Spectrum



2015 Revenue Sources



"…to furnish research and development services to all who can benefit by it."

Harold Vagtborg

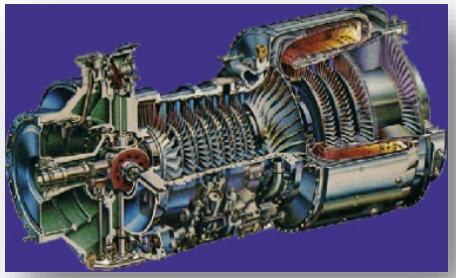
55% "Government"
45% Commercial

Energy Perspective

Sources

- Fossil Fuels
- Renewables
- Nuclear

Conversion



- Combustion
- Chemistry
- Turbomachinery

Use

- Transmission
- Storage
- Distribution

Innovation ◆ Research ◆ Development ◆ Testing ◆ Optimization ◆ Scaling

Major Industry Trends

Alternative Sources

- Concentrating Solar Power (CSP)
- Wind
- Storage and Grids
- Advanced Biofuels

Efficiencies

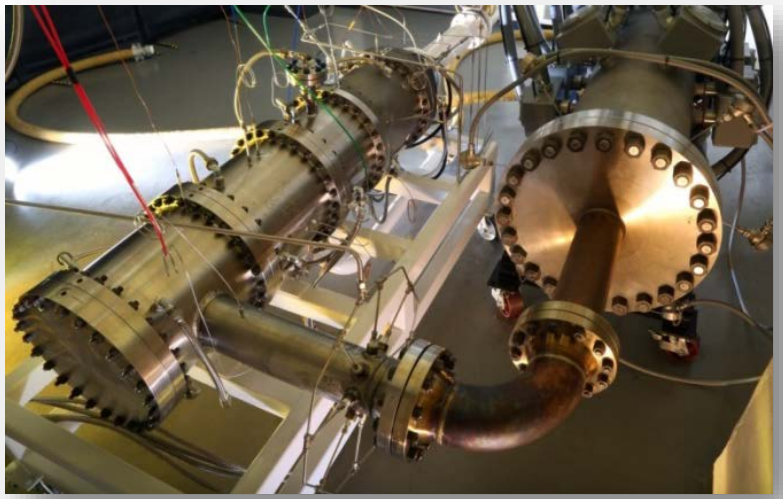
- Improved Processes
- Working Fluids
- Enhanced Materials

Carbon Mitigation

- Carbon Capture and Storage (CCS)
- Carbon Emission Reduction

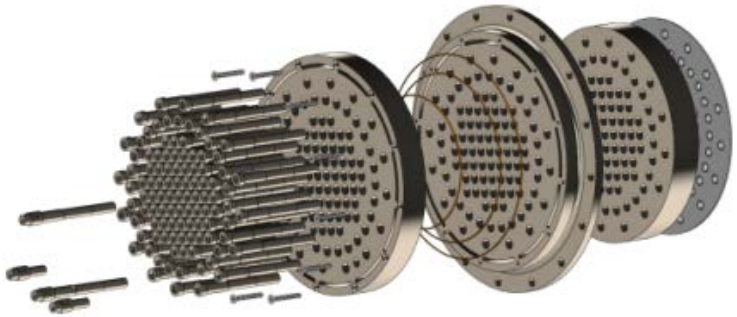
Concentrating Solar Power

- Using solar energy for efficient combustion
  - High (~1,000°C) inlet temperatures
  - Stable ignition control
  - Reduced emissions levels



High Temperature Injector Testing

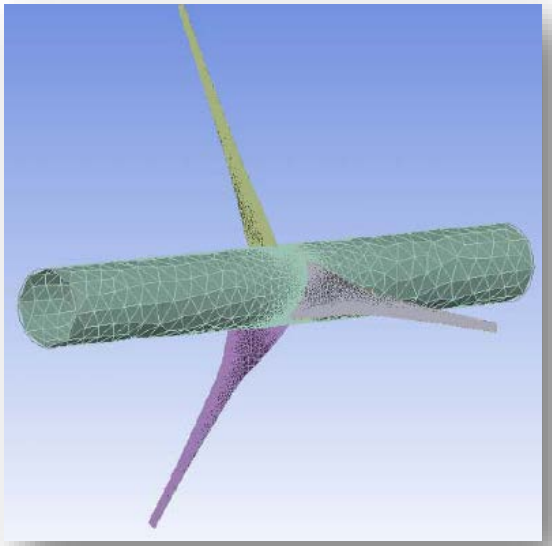
Concentrating Solar Power Array and Tower

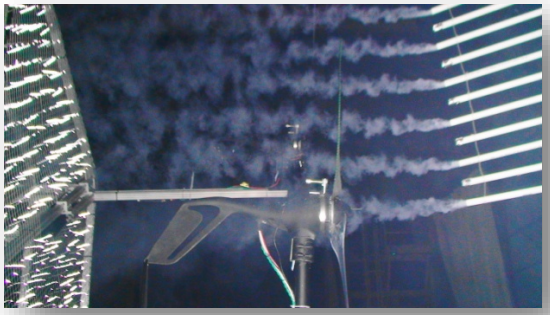


SwRI's High Temperature Natural Gas/Heater Air Injector

Wind

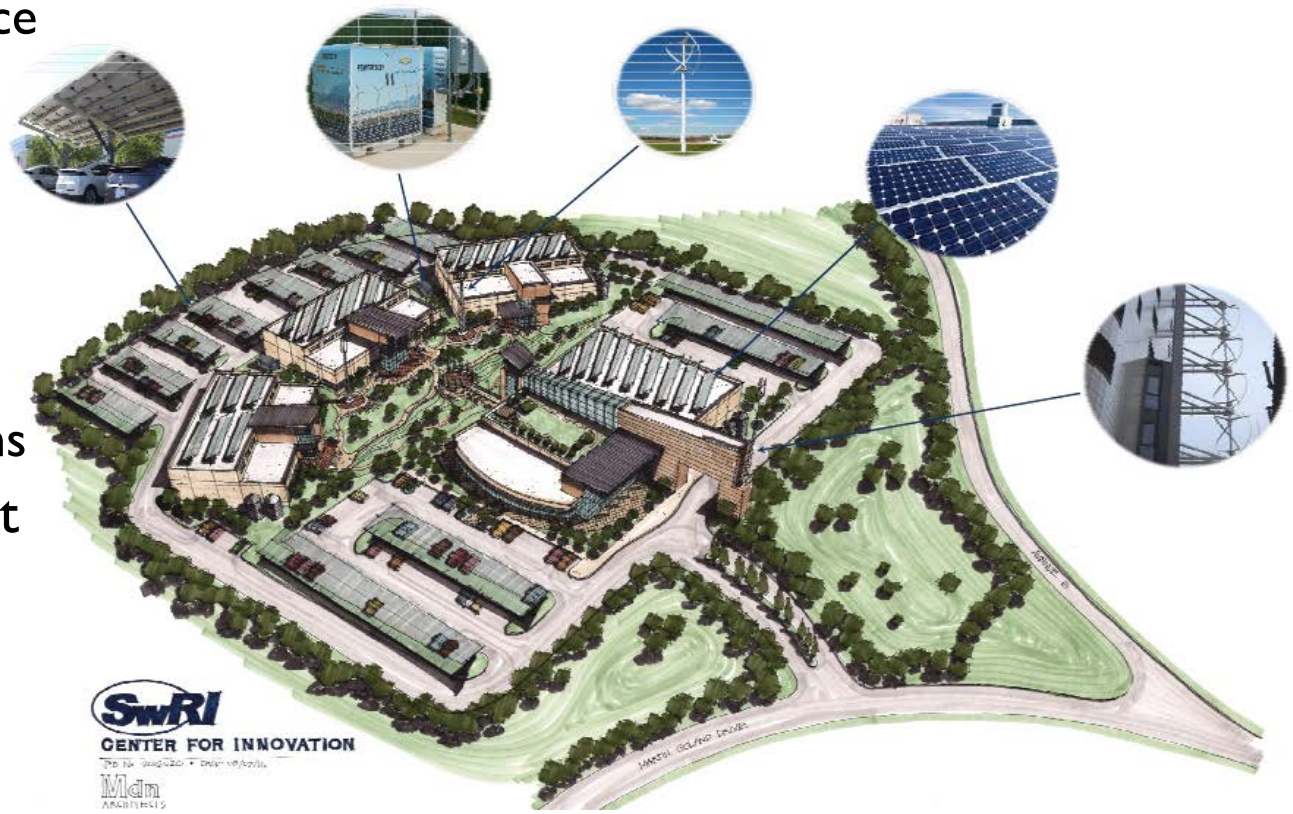
- Turbine gearbox torsional analysis and optimization
- Blade dynamics
  - Modeling
    - Computational Fluid Dynamics
    - Finite Element Modeling
  - Measurements and Instrumentation
- Wind-tunnel testing





Energy Storage and Grids Research

- Multidisciplinary expertise
  - Materials science
  - Chemistry
  - Power systems
  - NDE
  - Fire Testing
  - Manufacturing
  - Control systems
- Internal investment
  - Facilities
  - Innovation
- External research
  - Client-directed
  - Consortia



Advanced Biofuels

From Rudolph Diesel's use of peanut oil in 1900 to the future of biofuel production

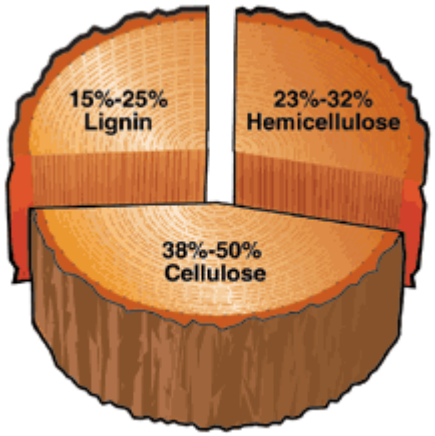
- Renewables and Alternatives
  - Crops
  - Agricultural waste
  - Municipal waste
  - Animal fat
  - Vegetable oil
  - Waste cooking oil
  - Algae
  - etc.

Advanced biofuels from almost any source of carbon material for today's engines and infrastructure

Lignin to High-Octane Liquid Fuel

- Lignin: underused byproduct of paper manufacturing (and other processes)
- Two-step conversion process:
  1. Lignin depolymerization in ionic liquids
  2. Hydrodeoxygenation with bifunctional nonprecious metal catalysts to produce hydrocarbons
     - Octane numbers > 100

Test-tube scale

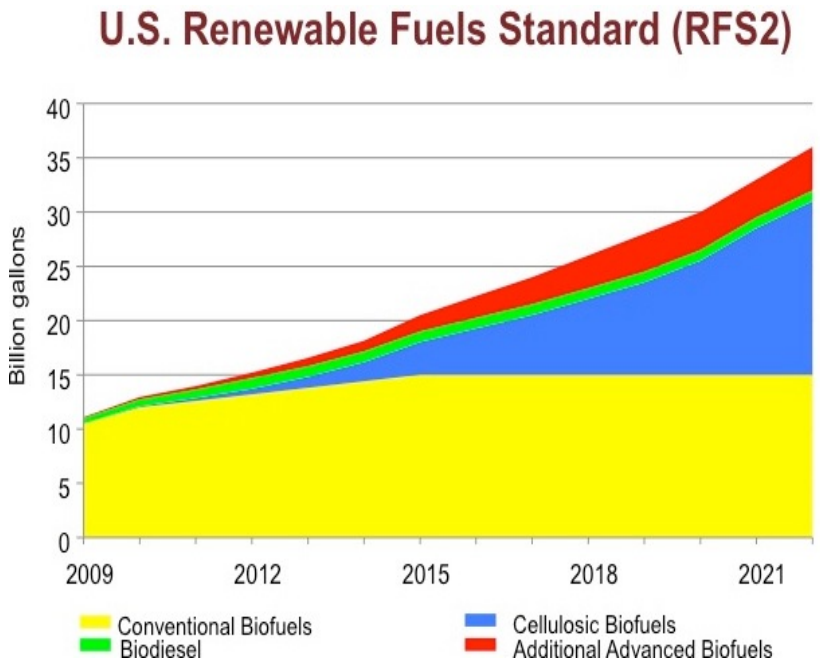


P. Daniel Cassidy, Sarah F. Ashton, Univ. of Georgia

Lignin the second most abundant renewable carbon source on Earth, following cellulose

Ready for Bench Scale Testing

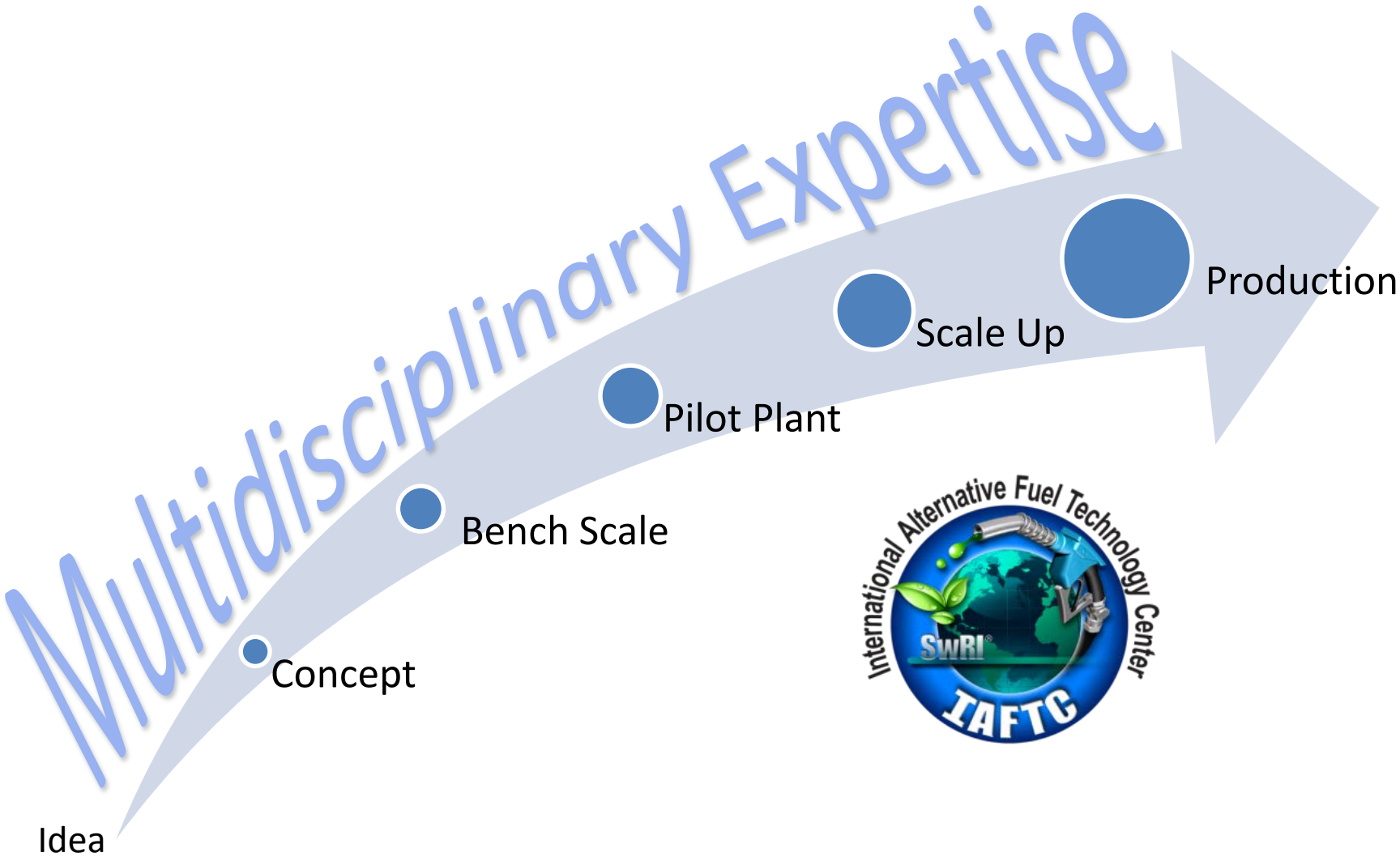
Renewables and Alternatives



- Emissions Testing
  - Component testing and in-vehicle performance measurements
  - Fuels and additive registration

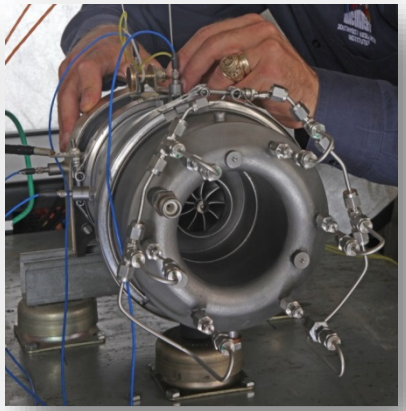
- International Alternative Fuels Technology Center (IAFTC)

International Alternative Fuel Technology Center

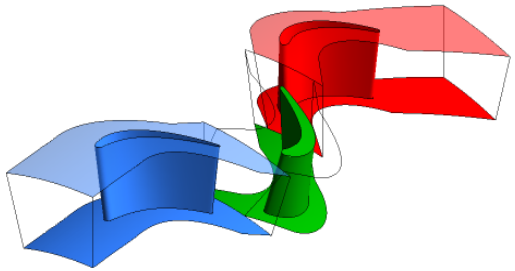


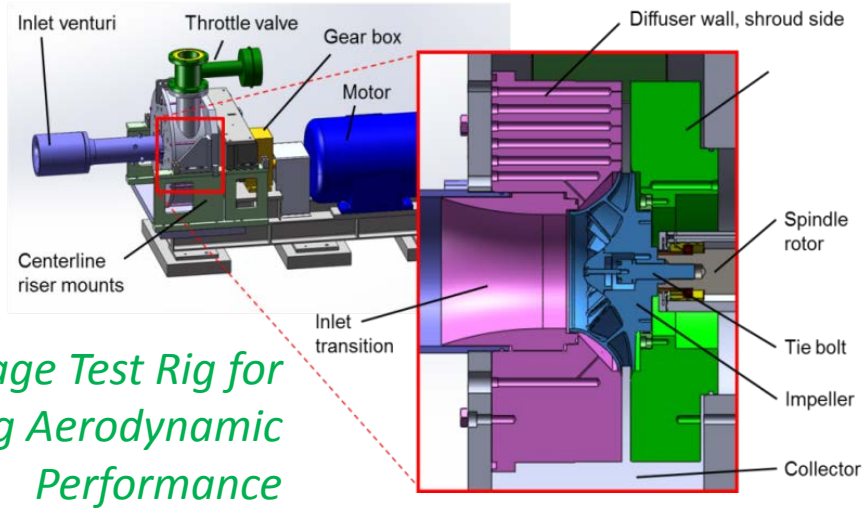
Turbomachinery Design, Analysis, & Testing

7KW Gas Turbine for Hybrid UAV



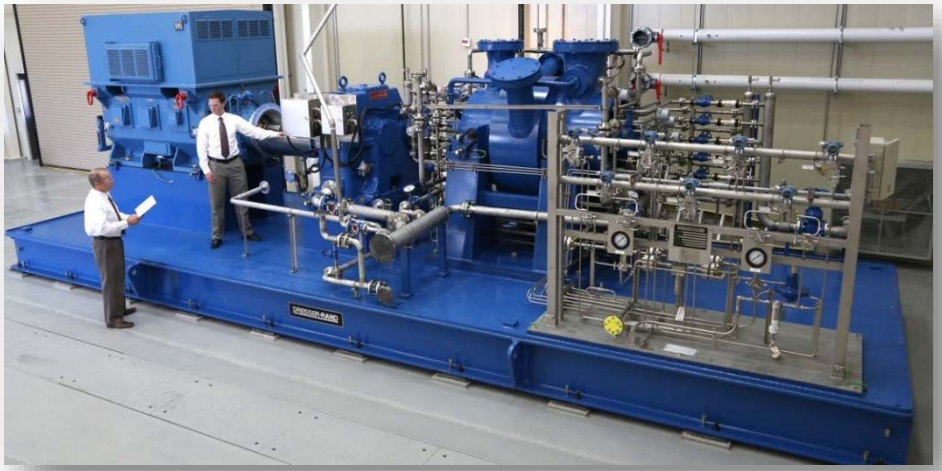
CFD Analysis for Centrifugal and Axial Compressors and Expanders





Single Stage Test Rig for Measuring Aerodynamic Performance

Isothermal CO_2 Compression



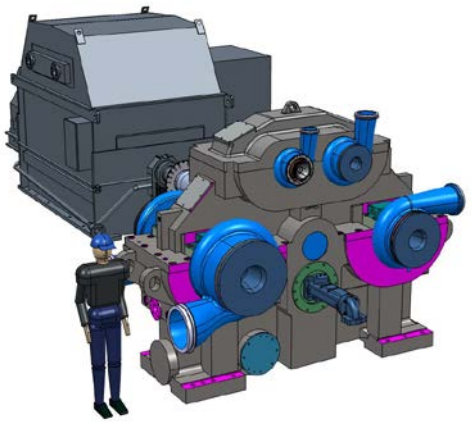
DoE-Sponsored CO_2 Compressor

CO_2 Liquefaction Loop

- DoE-sponsored pilot-scale internally cooled isothermal compressor and liquefaction/CO_2 pump
- Enabling thermodynamic analysis of CO_2 separation, compression, and transport
- CO_2 liquefaction loop for proof of concept demonstration

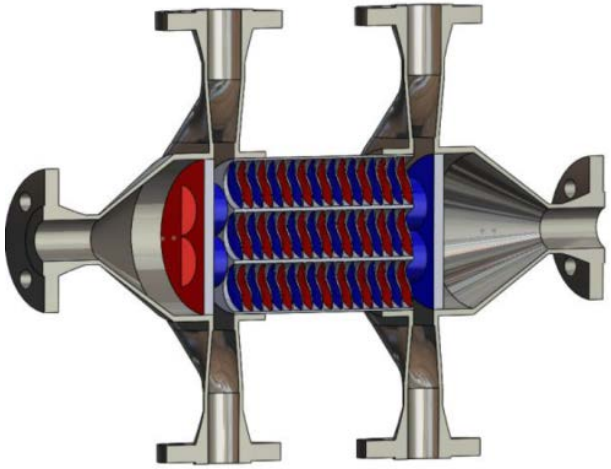
Ultra High Efficiency Integrally-Geared sCO_2 Compander

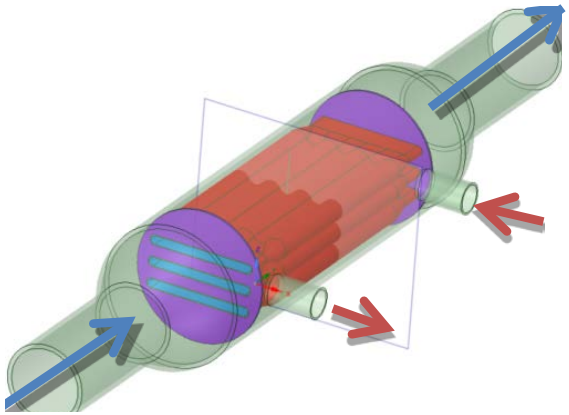
- Integrally Geared (sCO_2) Compander (IGC)
  - Combines compression and expansion stages into a single integrally geared housing connected to a low speed motor/generator
- Provides:
  - Reduced footprint
  - Potential cost reduction up to 35%
  - Design or test component efficiency over a wide range of operating conditions
  - Improved cycle controllability
  - Improved reliability and reduced maintenance



Compact 47MWth High Temperature Recuperator for sCO_2 Power Cycles

- DOE 10MWe STEP Facility
  - Low cost
  - 96% Thermal effectiveness
  - Scalable from 10-1,000 MWe cycles





- Phase 1
  - Concept development
  - Selection and testing
  - Preliminary design

DOE FE, Thar Energy, Oak Ridge National Labs, Georgia Tech

U.S. DEPARTMENT OF ENERGY | NETL

ADVANCED SCIENCE. APPLIED TECHNOLOGY.

SwRI

Advanced Reciprocating Compressor Technology (ARCT)

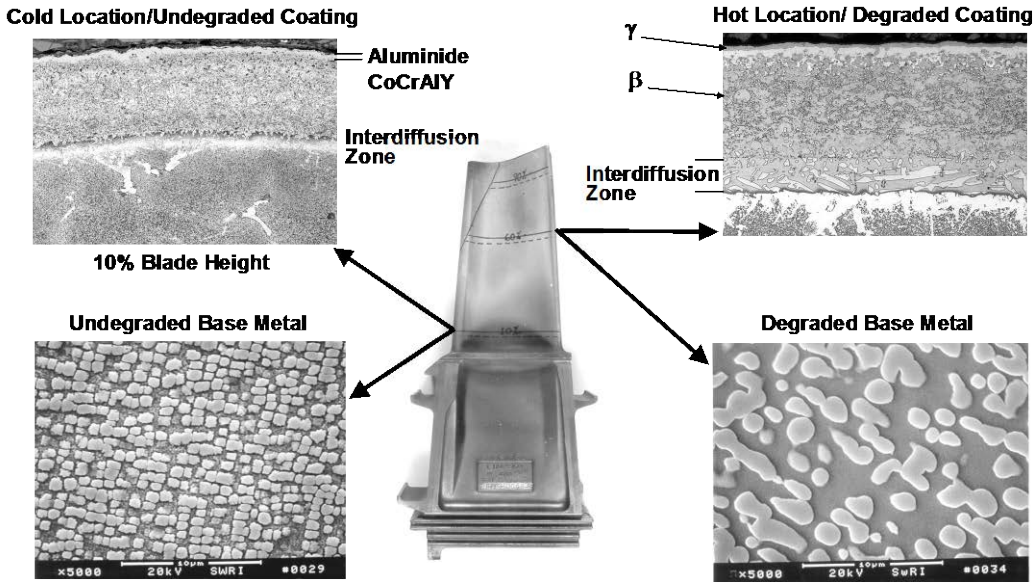
- Addressing the complex challenges of advanced reciprocating compression technology
- Testbed for technologies to enhance reliable, efficient, and affordable compression choices for the natural gas industry
  - Pulsation design and analysis

5-year DOE/GMRC Program

Materials Analysis Capabilities

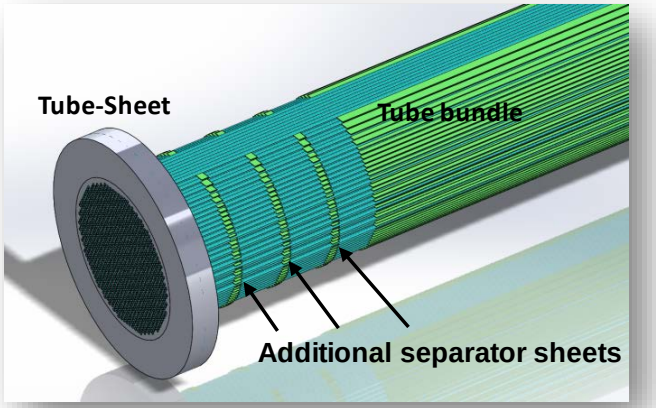
- Superalloy & coating metallurgy
- Mechanical behavior
- Condition/durability assessment
- Component life prediction, extension, and management
- Hot-Section parts refurbishment

Spalled TBC Coating



High Efficiency Hot Gas Turbo-expander and Low Cost Heat Exchangers

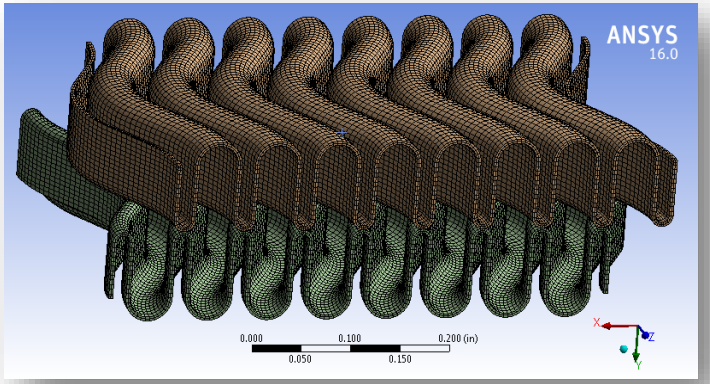
- SwRI Test Facility
  - Will provide sCO_2 flow necessary for validating expander and recuperator performance



- All components are in the final stages of fabrication and assembly

Thin Film Primary Surface Heat Exchanger for Advanced Power Cycles

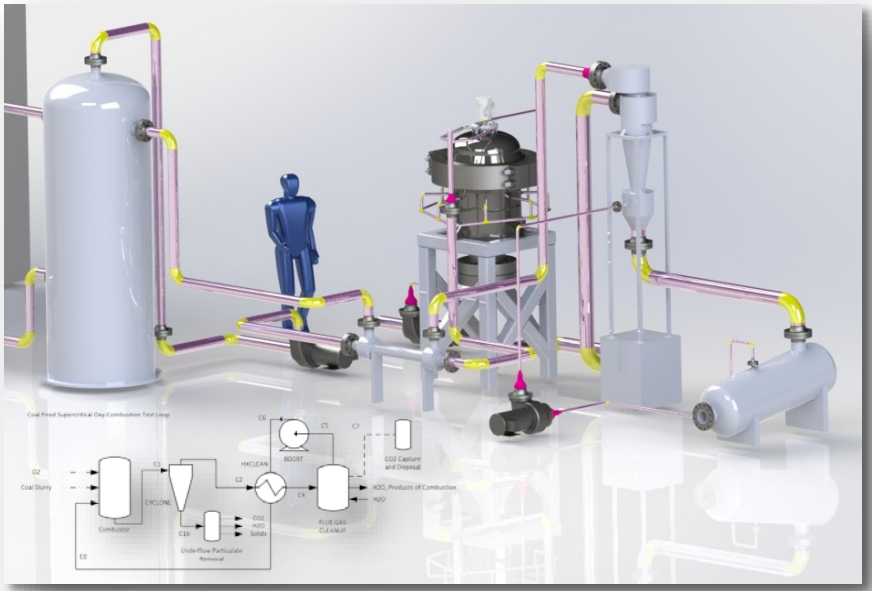
- Heat exchanger for CO_2 at 821°C (1,510°F), ΔP of 130 psi (9 bar)
  - Possible 18% increase in cycle efficiency relative to existing air Brayton cycle
  - Estimated 30% increase in power density
- 8 high-temperature alloys and two coatings tested at 820°C:
  - Niobium & Tantalum coatings may improve corrosion resistance
  - Favorable weight gain in some alloys



sCO_2 Oxy-combustion Power Cycle

with 99% Carbon Capture

- Coupling coal-fired oxy-combustor with sCO_2 power cycle
  - 40% efficiency at low firing temperature (650°C)
  - Limited by TRL of critical components
- Cost of Electricity: $121/MWe
  - 49% more than sH_2O without carbon capture ($81/MWe), exceeding the 35% target
  - 12% less than sH_2O with 90% carbon capture ($137/MWe)

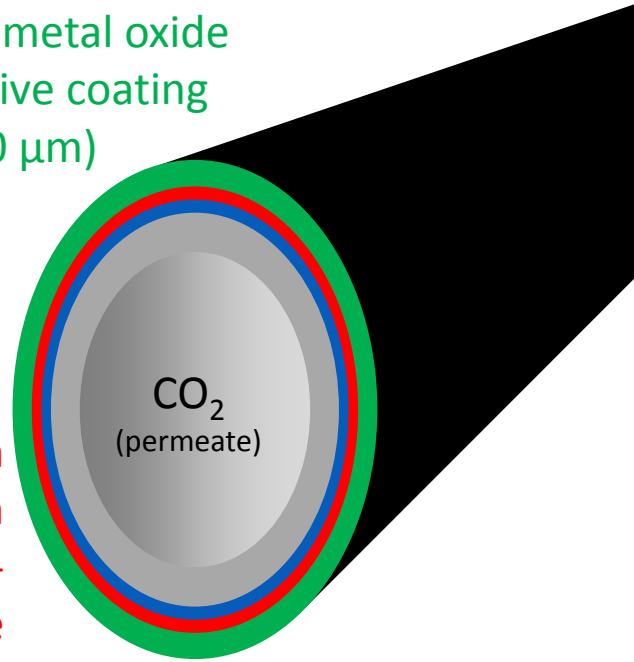


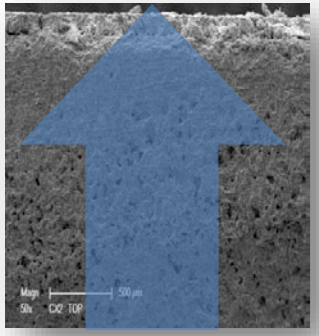
Ready to demonstrate supercritical oxy-combustor and critical low TRL technologies

Supported by DOE Project DE-FE0009395

CO_2 Separation

- High temperature, multilayer ceramic CO_2 separation membrane
- Robust
  - No regeneration required
  - Contaminant tolerant for stack gas contact
  - Continuous reaction avoids limit of equilibrium
- Unlimited configurations

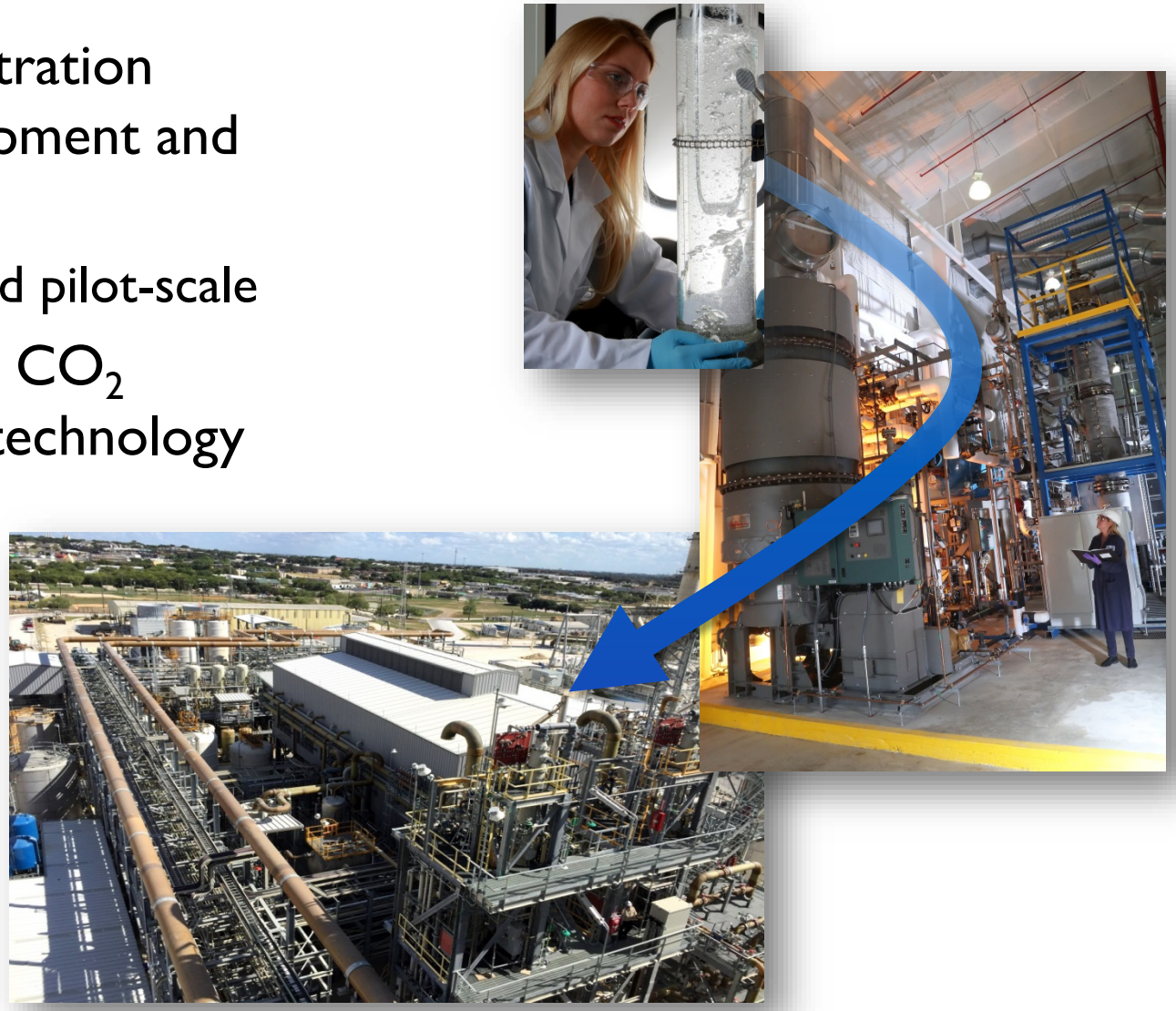




CO_2 selective at high temperature

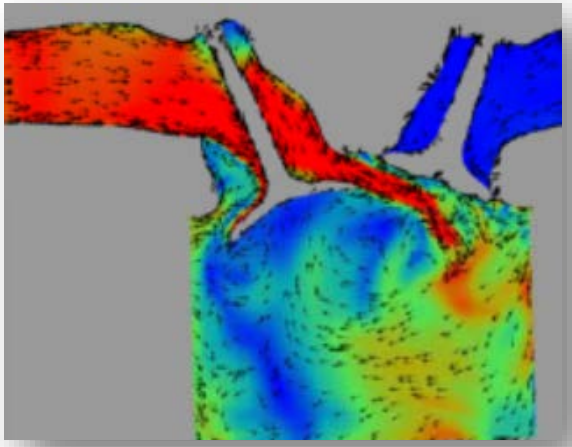
Flue Mining: CO_2 as a Product

- Carbon sequestration process development and demonstration
  - Lab-scale and pilot-scale
- *Next Generation* CO_2 mineralization technology



Dilute Spark-Ignited Combustion

- SwRI-developed Cooled EGR for gasoline engines
  - Improved thermal efficiency
  - Reduced CO_2 emissions
- SwRI's HEDGE Consortium
  - >25 members since 2005
  - Dedicated EGR (R&D 100 winner)
  - >10% CO_2 reduction
  - Road-tested technology



Cooled EGR

D-EGR

Diesel Engine Efficiency

- Joint Industry Research consortium (CHEDE-VII) is evaluating all aspects of diesel engine efficiency
- Advanced diesel combustion and alternative combustion modes
- Improvements in engine air handling and EGR systems
- New friction reduction technology
  - Advanced coatings
  - Low viscosity lubricants
  - Smart accessories

CHEDE-VII

CLEAN HIGH EFFICIENCY DIESEL ENGINES

An SwRI Consortium

Targeting 55% System Efficiency (Engine + WHR)

Thank You