Ramgen Supersonic Shock Wave Compression and Engine Technology

2012 NETL CO₂ Capture Technology Meeting
Sheraton Station Square, Pittsburgh, PA

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Kirk Lupkes
Ramgen Power Systems
Company

• Privately-held R&D company founded in 1992
• Focused on unique applications of proven supersonic aircraft technology
• Primary technology innovations
  – Supersonic air & gas compressors
  – High velocity vortex combustor
  – Supersonic expander
• Product embodiments
  – Two-stage 100:1 Pr CO₂ Compressor
  – 20:1 High Efficiency ISC Engine
Project Overview
Funding and Objectives

- **Funding**
  - $50M Total Compressor and Engine DOE Funding
  - $29.7M Private funding including Dresser-Rand contribution

- **Overall Project Performance Dates**
  - Start: August 1, 2009
  - End: June 30, 2014

- **Project Participants**
  - Dresser-Rand: Engineering support and host to Olean CO2 test facility

- **Overall Project Objectives:**
  - Compressor Project: High-efficiency, low-cost CO2 compression using supersonic shock wave technology to significantly reduce capital and operating costs associated with carbon capture and storage
  - Engine Project: High power density engine with lower capital and operating costs and cogen efficiencies to 80+. The heat:power ratio would approach 1:1
Dresser-Rand Investment in Ramgen

• **Dresser-Rand invests in Ramgen’s “game-changing technology”**
  – Support on-going CO2 compressor development
  – Satisfy DOE matching funds requirement
  – Consistent with strategy to be technology leader
  – Extend served market into Electric Utility industry
  – Investment to:
    ▪ Fund development & demonstration
    ▪ Obtain an option to purchase assets

• **Dresser-Rand is consistently ranked among top three manufacturers in its served markets**
  – Turbomachinery
  – Reciprocating compressors
  – Steam turbines

• **Leading supplier of CO2 compressors**

• **Global sales & service presence**
Ramgen Technology Fundamentals

Compressor
Shock Waves and Supersonic Inlets

- Initial External Shock System Followed by Internal Shock System
- Throat Bleed Slot For Inlet Starting
- Side Window For Schlieren Photography

2-D Mixed Compression Inlet Model
F-15 2-D Planar Supersonic Inlet

\[ M_{rel} = \sim 2 \]

Inlet Cross Section

Engine Face

M < 1
Rampressor Rotor Development

\[ M_{\text{rel}} = \sim 2 \]

Supersonic F-15 Inlet

\[ M = \sim 0.3 - 0.5 \]

Rampressor Rotor

\[ M = \sim 0.5 \]

Stationary Case

Normal Shock

Planar Shocks

Rotor Rim

Compressed Fluid

Rotation Direction
Typical Rotating Supersonic Flow Path

- **Rotor Flow Path:**
  - Three Supersonic Compression Inlet Flow Paths On Disk Rim
  - High Efficiency, Compact Compression
  - Flow Path Geometry Similar For Different Pressure Ratios

- **Combination of Supersonic Flight Inlet & Conventional Axial Flow Compressor Aerodynamics:**
  - Rotor Rim Radius Change Produces Compression
  - 3 “Blades” (Strakes) Do Minimal Flow Work
  - Axial Inflow/Outflow for the rotor shown
HP Stage Utilizes Back-to-Back Configuration

Key fluid flow features

- Suction (inflow)
- Discharge (outflow)
- Starting/bleed recycle
- Rotor
The “State-of-the-Art” is Expensive

- 10-stage 6000 hp
  - $8.0 million ⇒ $1350/hp
  - Pr 200:1 ⇒ 1.70 per stage

- 8-stage 20,000 hp
  - $15.0 million ⇒ $750/hp
  - $23.0 million installed ⇒ $1150/hp
  - Pr 143:1 ⇒ 1.86 per stage
Reduce CC(C)&S COE Penalty

**MAN Turbo CO\textsubscript{2} Compressor**

- **10-stage 6000 hp**
  - $8.0 million $\Rightarrow$ $1350$/hp
  - Pr 200:1 $\Rightarrow$ 1.70 per stage

- **8-stage 20,000 hp**
  - $15.0 million $\Rightarrow$ $750$/hp
  - $23.0 million installed $\Rightarrow$ $1150$/hp
  - Pr 143:1 $\Rightarrow$ 1.86 per stage

**Ramgen CO\textsubscript{2} Compressor**

- Pr 10+:1 per stage
- 1/10\textsuperscript{th} the physical size
- 40-50\% of the installed capital cost
- ~Same shaft input power requirements
- Recover of ~80\% of the input Btu at 500°F
  - Improve CCS efficiency
  - Reduce power plant de-rate
Ramgen Technology Fundamentals

ISC Engine
ISC Engine Technologies

Supersonic Compression Stages

Supersonic Nozzle Stages

Scale: 1 ft

Two-Stage Supersonic Compressor

Two-Stage Supersonic Expander

High Speed Direct Drive
Permanent Magnetic Motor/Generator

Supersonic Rotor Tests

Advanced Vortex Combustion

Photo Courtesy AFRL
Advanced Vortex Combustion (AVC)

- Geometric features control fluid mechanics
- Vortex shielded inside cavity providing excellent flame stability

Flame is Independent of Main Airflow Velocity
Ramgen ISC Engine

**Improves Distributed Generation efficiency**
- High net electric efficiency
- 80% cogeneration efficiency
- ~1:1 heat:power ratio

**Extracts power from Opportunity Fuels**
- Ventilation Air Methane
- Landfill gas
- Eliminates methane emissions
- Improves mine safety
- Compelling return on investment

**Enable intermittent renewable resource as a Fuel-fired Flywheel**
- “Instant-on” capability supports intermittent/unpredictable renewable resources
- Supports a variety of dual use applications
Project Status
Project Schedule – CO2 Compressor

• 10 MW Test Facility Complete - Fall 2011

• Full Speed Test Rotor Runs Complete - Winter/Spring 2012
  – 10 MW VFD, Motor, Gearbox, Couplings and Bearing Systems validated

• Compressor “Inner Bundle” Assembly currently underway

• Build 1 compressor test scheduled to begin - September 2012

• Build 1 compressor test completion - December 2012

• Build 2 compressor design currently underway
  – Oakridge National Laboratory Supercomputer utilized for CFD optimization studies
  – 18 hour / 200,000 core CFD simulation recently completed in which 800 flowpath configurations were modeled
  – This capability has a tremendous impact on the rate of technology development we are able to achieve

• Build 2 test - Spring/Summer 2013
High Pressure CO2 Compressor Facility

- Liquid CO2 tank
- Vaporizer
- Control bldg
- Vapor CO2 tank
- Vent stacks
- Vapor tank
- Water shed
- Cooling tower
High Pressure CO2 Compressor Facility
10MW HP CO$_2$ Compressor Test Stand

- Dresser-Rand Facility, Olean, NY
- 10MW Electric Variable Speed Drive
- Closed loop CO2
- P1 = 210 psia
- P2 = 2100 psia
High Pressure CO₂ Compressor Facility
Test Insertion of Inner Bundle Assembly

Rail System

Inner Bundle
Ramgen recently executed a 200,000 core simulation employing intelligently driven optimization algorithms to analyze 800 compressor configurations in 18 hours.
Project Milestone – ISC Engine

• Build 1 - 1.5MW engine design complete (Ramgen compressor retrofit to existing gas turbine engine) – September 2011

• Build 1 - 1.5MW engine assembly – May 2012

• Build 1 facility installation complete – July 2012

• Build 1 engine test start - August 2012

• Build 2 design start (1.5MW compressor/combustor/turbine) - January 2012

• Build 2 design complete – January 2013

• Build 2 testing start - April 2013
ISC Engine Build 1 Installation

1.5MW Build 1 ISC engine installation currently underway in Ramgen’s newly upgraded Redmond, WA test facility
Future Testing and Commercialization
Technology Development Roadmap

Ramgen Technology

Programs

DOE CO2 Program
HP-12
10:1 CO2

DOE ISC Engine Program
LP-12
10:1 CO2
6:1 Air

Products

CO2 Compressor
LP/HP

High Efficiency 1.5MW
GT Engine
80% CHP
Power/Heat >1:1
“Instant-on”

Derivative Products

Gas Compressor

SCO2 Engine

ORC Generator

Applications

CO2 CCS Compression
Amine-based
Chilled Ammonia
Warm Gas Clean-up
Membranes
EOR

Gas Compressor

Refrigeration Compressor

SCO2 Engine

Heat/Power Recovery

ORC Generator

Distributed Generation

“Instant-on” Renewables Support

High Efficiency
Fuel Fired Flywheel

Coal Mine Methane
Landfill Gas

Opportunity Fuel Engine

Air Compressor

SOFC Fuel Cell Hybrid
ITM Prime Mover

Fuel-fired Air compressor

Large ASU MAC (IGCC)

6:1 Air Compressor

Medium & Large Scale CAES
Industrial ITM

20:1 Air Compressor
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