Toward the Development of a Thermodynamic Fuel Cell

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Hydrogen, Fuel Cells & Infrastructure Technologies Program
Merit Review and Peer Evaluation
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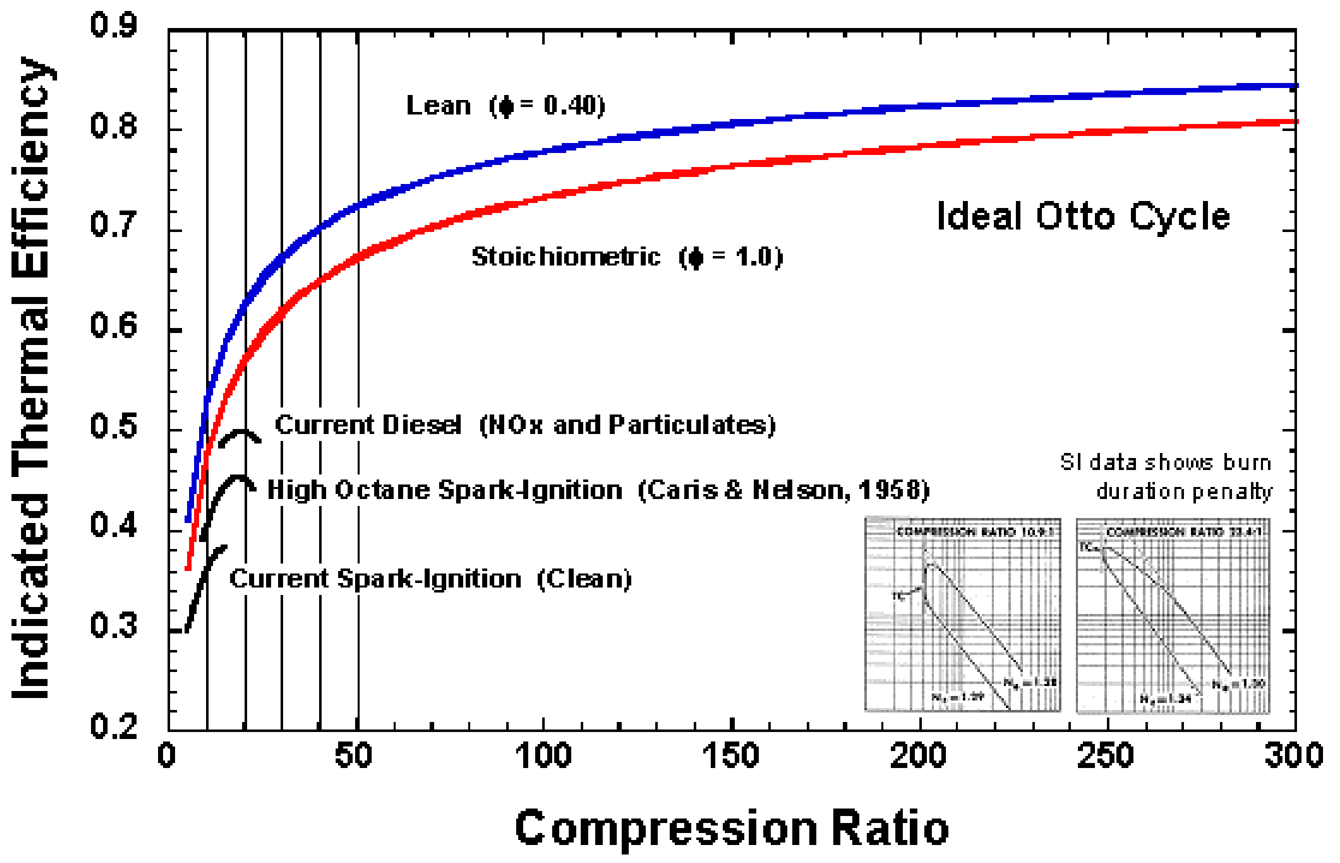
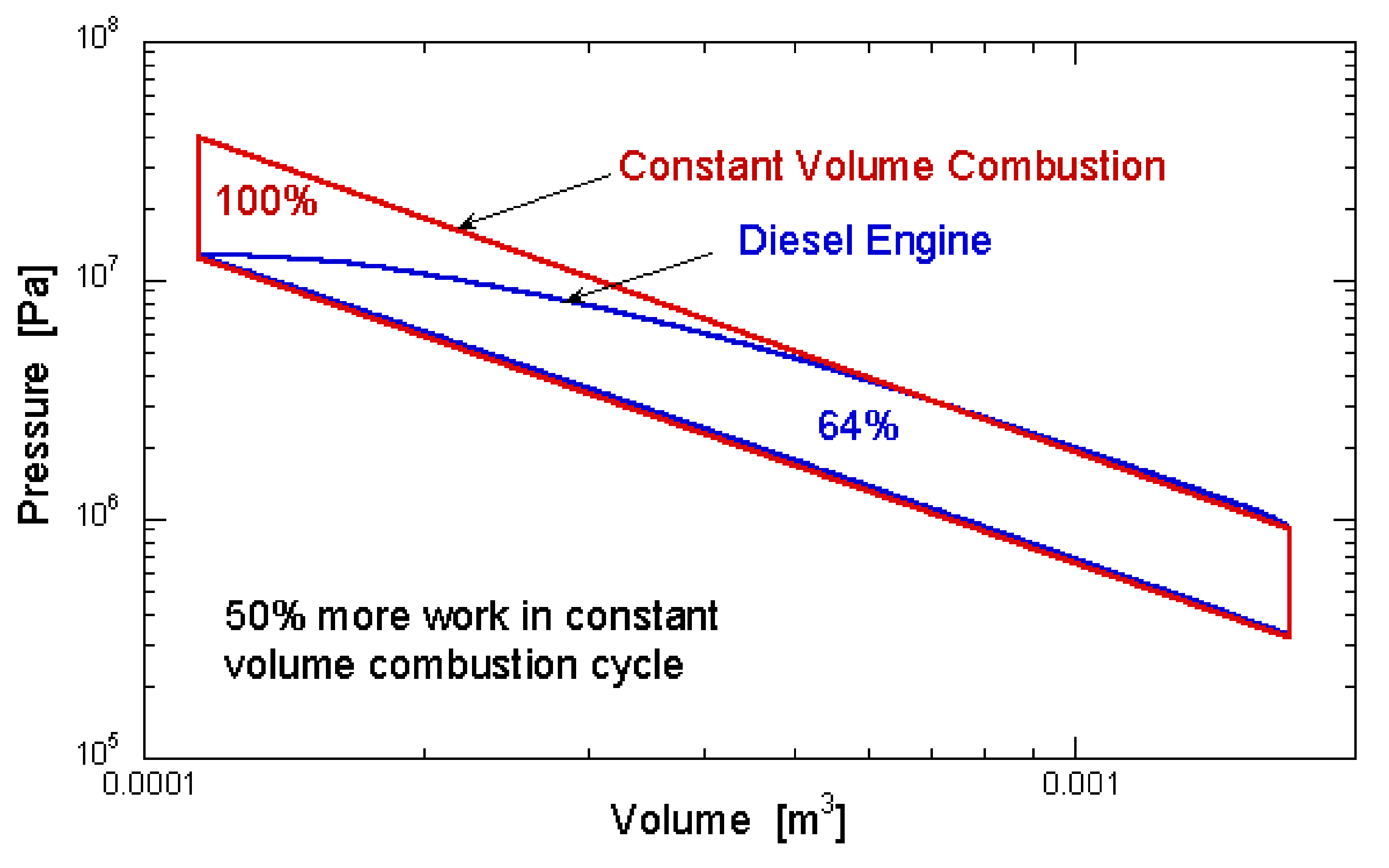
Goal

Develop an ideal, thermodynamic cycle based electrical generator.



→ **Otto cycle is fundamentally capable of high (>80%) conversion efficiency.**

Illustration of burn duration penalty



→ **Modern 4 stroke Diesel is extreme case, pressure limitations control design.**

Ideal, thermodynamic (Otto) cycle is constant-volume combustion

Possible approaches

Spark-Ignition /Diesel

Homogeneous Charge Compression Ignition (HCCI)

Piston stops and waits for combustion to finish.

Combustion is so fast that piston is stationary during burn.

Details

→ Mechanically complex.
→ Greater heat loss.
→ Compression ratio limited by knock (SI).

→ Loss of timing control.

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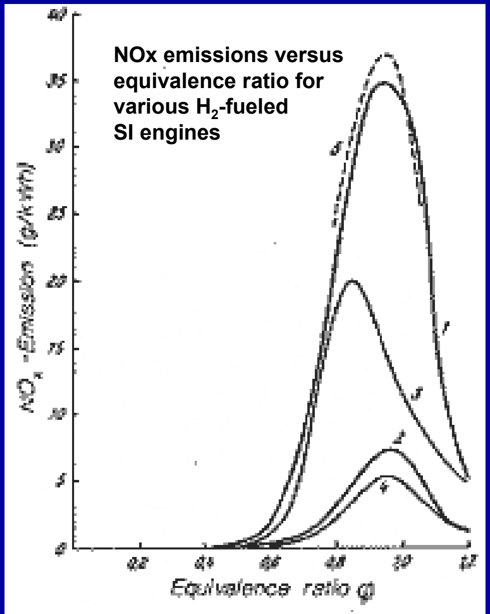
Homogeneous Charge Compression Ignition

- Fuel / air premixed.
- Charge combusts due to compression heating.
  - – No flame propagation / diffusion mixing required
  - – Chemical kinetics dominate (VERY FAST!)
- Can achieve constant-volume combustion.
- Multi-fuel capable → no flammability limits.
- NOx control by dilution.
  - → limits combustion temperatures



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Device utilizing HCCI to its full potential will:

- Compress the fuel / air mixture rapidly to reach high compression ratio at ignition.
- Electronically control compression ratio.
- Be capable of surviving high peak, short duration pressure pulse.
- Have mechanical simplicity for high reliability / low cost potential.

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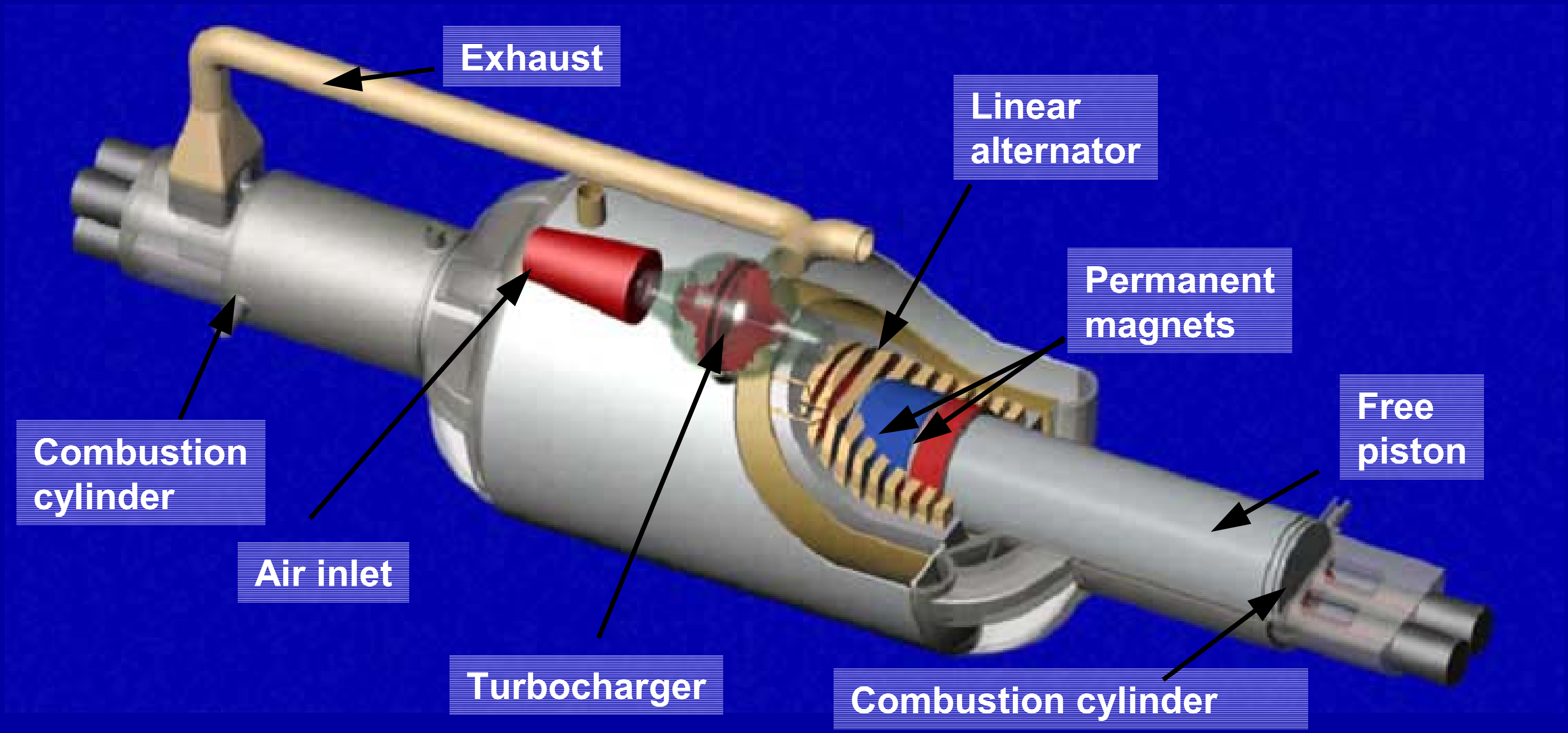
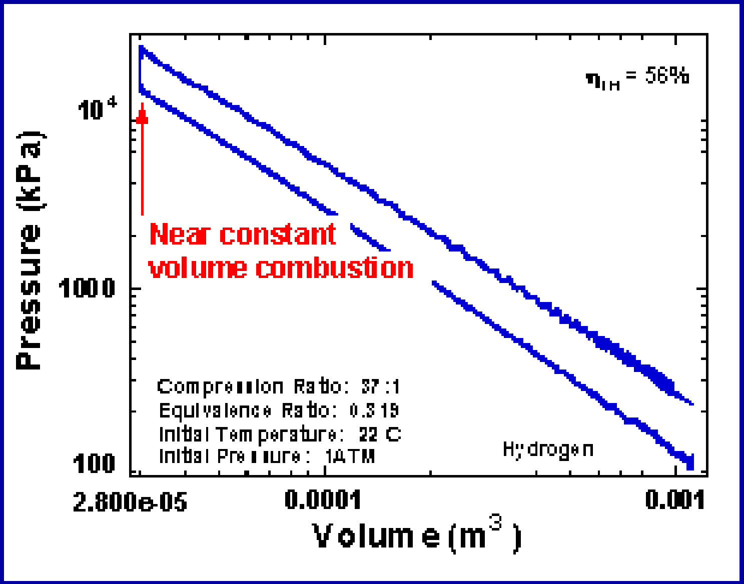
Thermodynamic Fuel Cell



- Free piston → rapid compression
- HCCI combustion driven
- Direct electrical output

Characteristics of Thermodynamic Fuel Cell

- Optimizes thermodynamic cycle with free piston, rapid compression.
- Combustion experiments show high compression ratio and high efficiency, with near 0 NOx emissions.
- Utilizes linear alternator for compression ratio control and mechanical simplicity.



Typical pressure – volume data from a free piston, Rapid Compression Expansion Machine

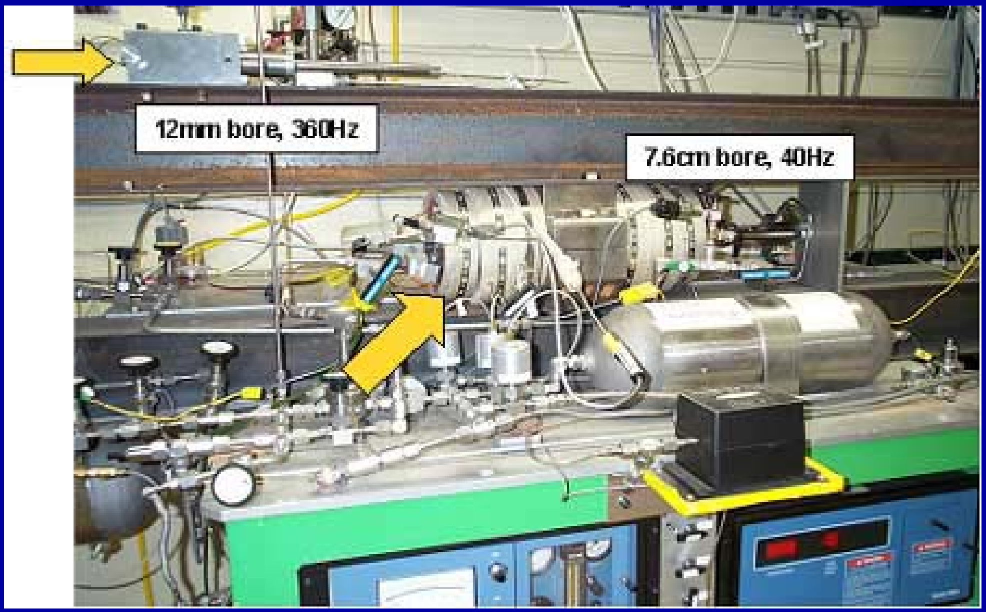
- Compression is developed inertially – no heavy support components required.
- Linear alternator is electromagnetic equivalent of brushless, direct-current permanent magnet generator, +96% efficient.

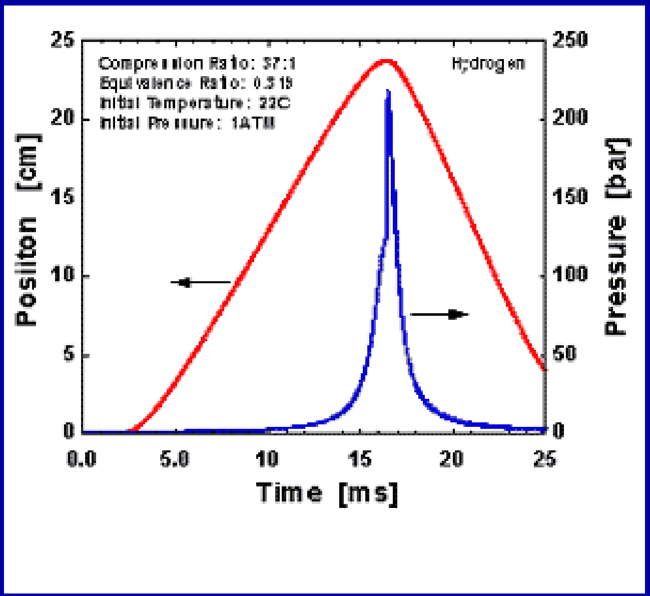
Approach to Development

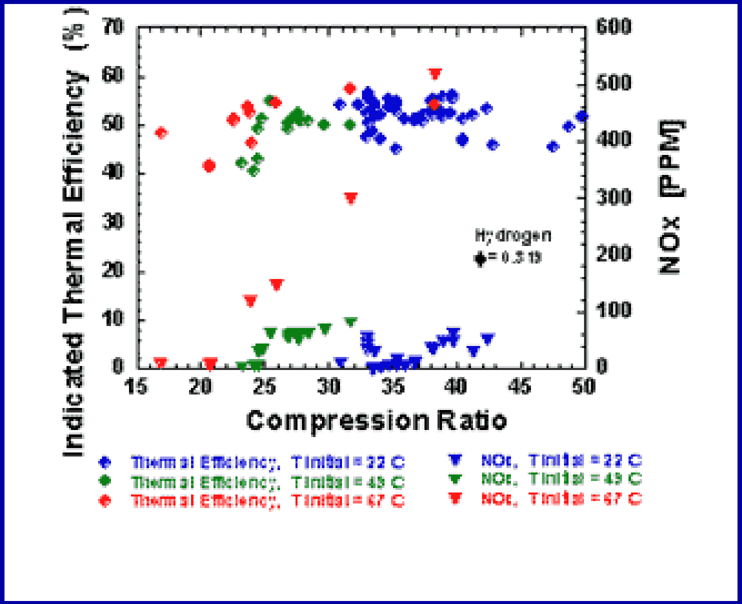
- Demonstrate HCCI combustion potential.
- Develop linear alternator.
- Develop inlet / exhaust process.

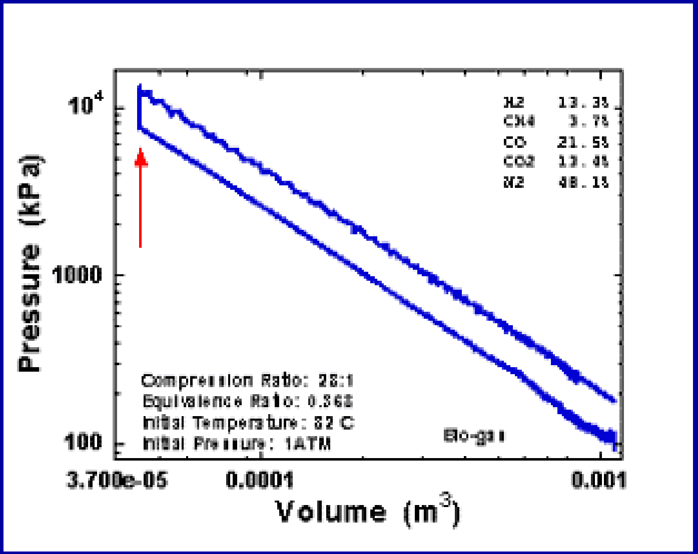
∴ Combine critical components into 30kW prototype research engine.

RCEM Combustion Experiment







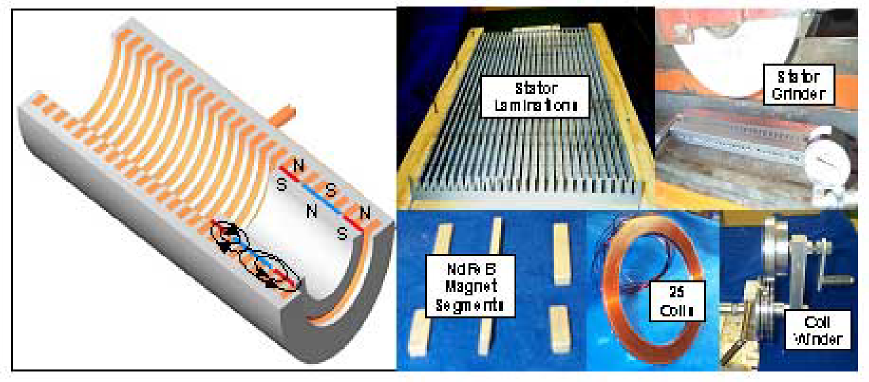


Pressure – volume data using low BTU bio-gas

Linear Alternator

Parallel development plan

- **In-house (Sandia / Magsoft)**
  - Electromagnetic modeling (FLUX2D)
    - Describe velocity profile, anisotropic materials. Calculate I^2R losses.
  - Parametric variations to focus on optimal configuration.



- **Magnequench International**
  - Design, fabricate and supply at no cost.

Experimental verification

Alternator Test Rig

Intake / Exhaust System

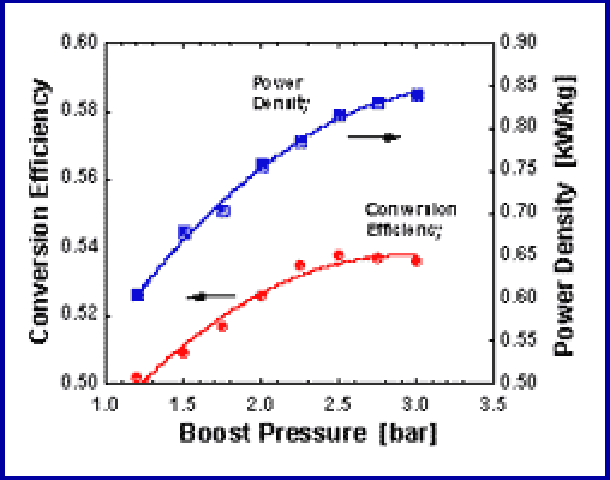
Critical for efficiency / emissions goals

- Charge preparation for HCCI combustion.
- Control of short-circuiting (fuel loss, HC emissions).
- Limit pumping power.

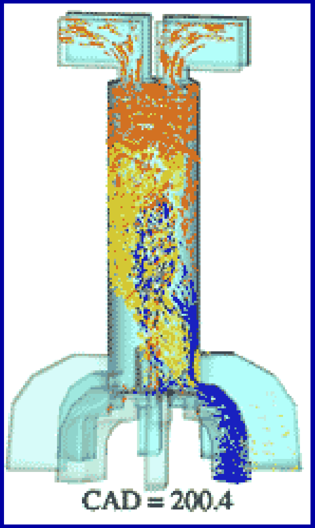
CFD modeling and visualization

- KIVA3V / Ensight.
- Parametric optimization.

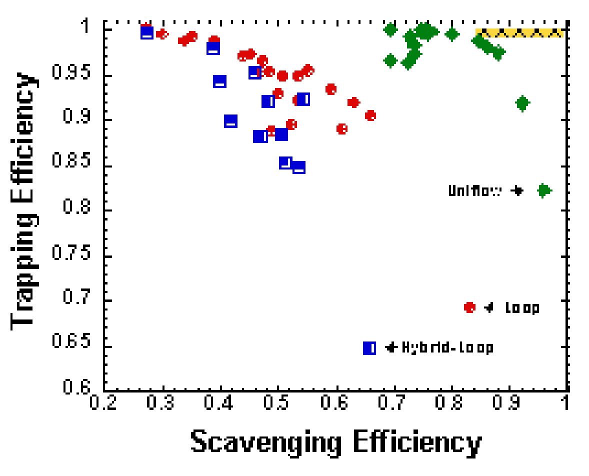
Turbocharging



Increase in fuel-to-electricity conversion efficiency, and power density with increasing boost pressures



Stratified Scavenging, uniflow design



Scavenging performance for various charge delivery methods; desired operating region illustrated

Relevance

- Thermodynamic fuel cell provides electrochemical fuel cell like performance.
- Utilizes highly developed reciprocating engine technology.
- Near term cost will be low.
- Multi-fuel capability important.
- Provides an alternative, competitive path for hydrogen conversion.
- Meets FreedomCAR 2010 goals for internal combustion systems operating on hydrogen or hydrocarbons.

	GOAL	Thermodynamic fuel cell
Efficiency	45%	50%
Cost	\$30 / kW	\$20 / kW
Emissions	Meet Standards	≈ 0

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FY 2003 Progress

- Scott Goldsborough, PhD completed.
- Investigation of turbocharging / hybrid gas turbine systems performance.
- Preliminary 4kW gas compressor design.
- Hans Aichlmayr joins group, postdoc appointee.
- Magnequench linear alternator testing.
- 5 presentations.
- 2 publications.

Interactions / Partnerships

Caterpillar – Inlet / exhaust process, free piston technology

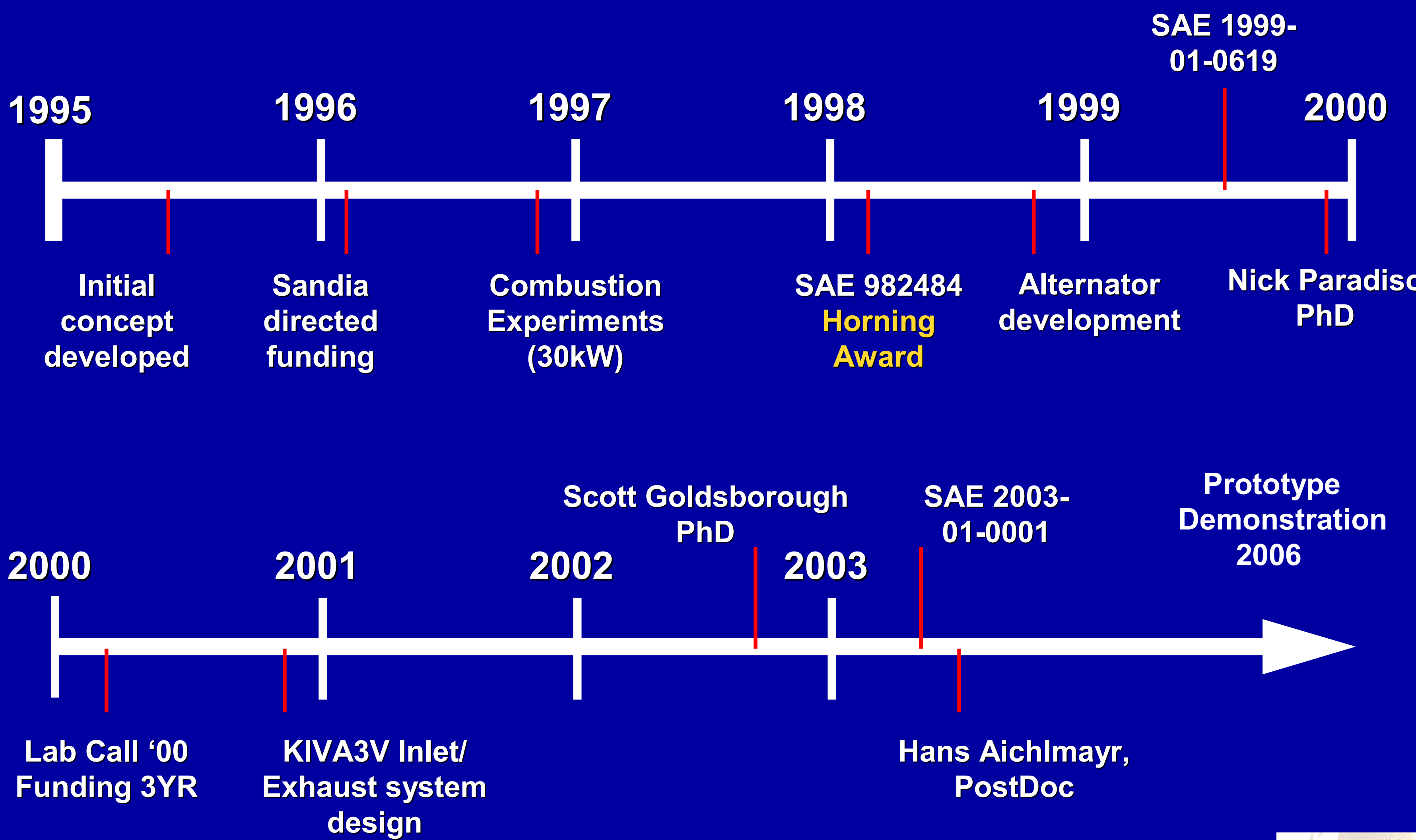
Magnequench – Permanent magnet / linear alternator

Magsoft – Alternator modeling

Lotus Engineering – Piston engine design

DOE
- Office of Distributed Energy and Electricity Reliability
  Distributed Energy Resources
- Office of FreedomCAR and Vehicle Technologies
  Engine and Emissions Control Technologies

Timeline


SAE 1999-01-0619
1995
1996
1997
1998
1999
2000
Initial concept developed
Sandia directed funding
Combustion Experiments (30kW)
SAE 982484
Horning Award
Alternator development
Nick Paradiso PhD
Scott Goldsborough PhD
SAE 2003-01-0001
Prototype Demonstration 2006
2000
2001
2002
2003
Lab Call ‘00 Funding 3YR
KIVA3V Inlet/ Exhaust system design
Hans Aichlmayr, PostDoc