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ENERGY INNOVATIONS for a SUSTAINABLE WORLD

PRO-TEM Special Session on Power Generation and Polygeneration Systems

Free-CHP:
Free-Piston Reciprocating Joule Cycle Engine

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Research Councils UK Energy For a Low Carbon Future

PRO-TEM Network
Process Industry Thermal Energy Management Network

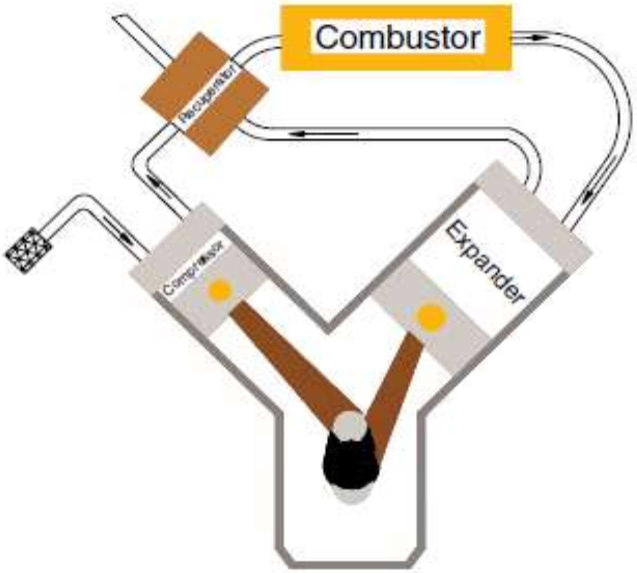
Background: micro-CHP

- Huge market worldwide, plus governmental incentives
  - E.g. replacing all floor standing boilers in the UK with micro-CHP units would produce half of UK's electricity consumption (Moss et al., 2005)
- Electrical efficiency critical for economic viability

Currently available systems:

- Stirling engines (e.g. Whispergen)
  - Reliable, proven technology
  - Low electrical efficiency (~12% @ 1 kW_{el})
  - Silent, low emissions
- IC engines (e.g. Senertec Dachs)
  - Emissions
  - Fuel requirements
  - Noise

Background: RJC engine



- Reciprocating Joule cycle engine: gas turbine cycle with reciprocating compressor and expander.
- GT cycle in itself efficient, but turbines inefficient at small size (<20 kW).
- RJC engine suitable for scaling down to small sizes without major penalties.
- (If penalty in power-to-weight ratio is acceptable.)

- RW Allen, PhD thesis, Plymouth 2008: 33% electrical and 79% total efficiency possible.
- RW Moss et al., Applied Energy 2005: 33% electrical at 5 kW_{el} output and 72% mechanical efficiency.
- MA Bell & T Partridge, IMechE, 2003: Theoretical 50% electrical efficiency with exotic materials (1300K), adiabatic operation and low-friction design.

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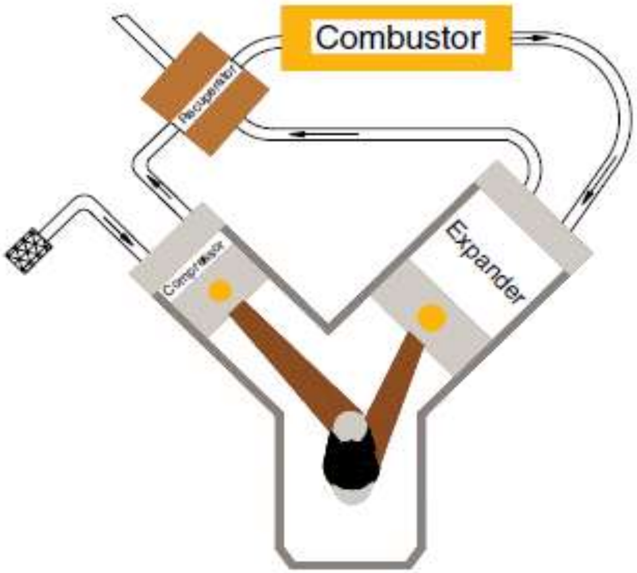
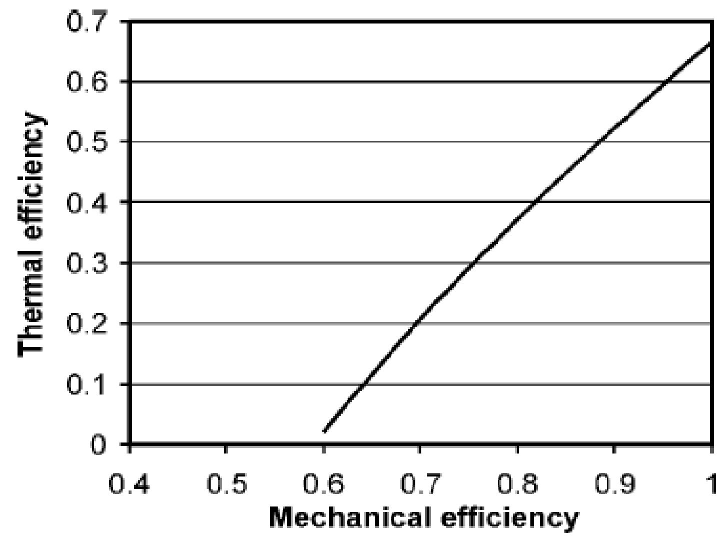
Background: RJC engine



- Challenge 1: frictional losses highly influential.
  - Crankshaft engine not best suited for this due to high relative losses at low cycle mean effective pressures.



(Bell & Partridge, 2003)

- Challenge 2: pulsating flow.
- Challenge 3: valve system directly downstream of combustor (expansion cylinder inlet).

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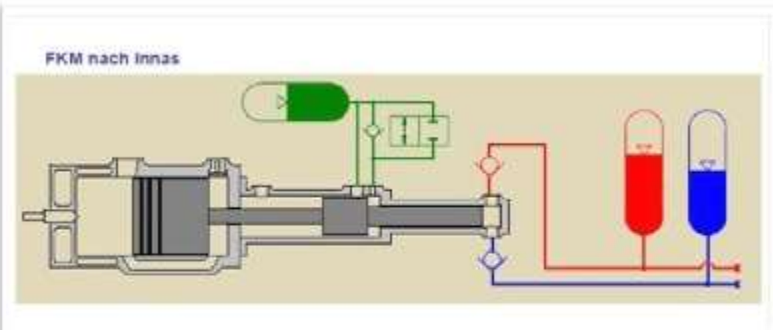
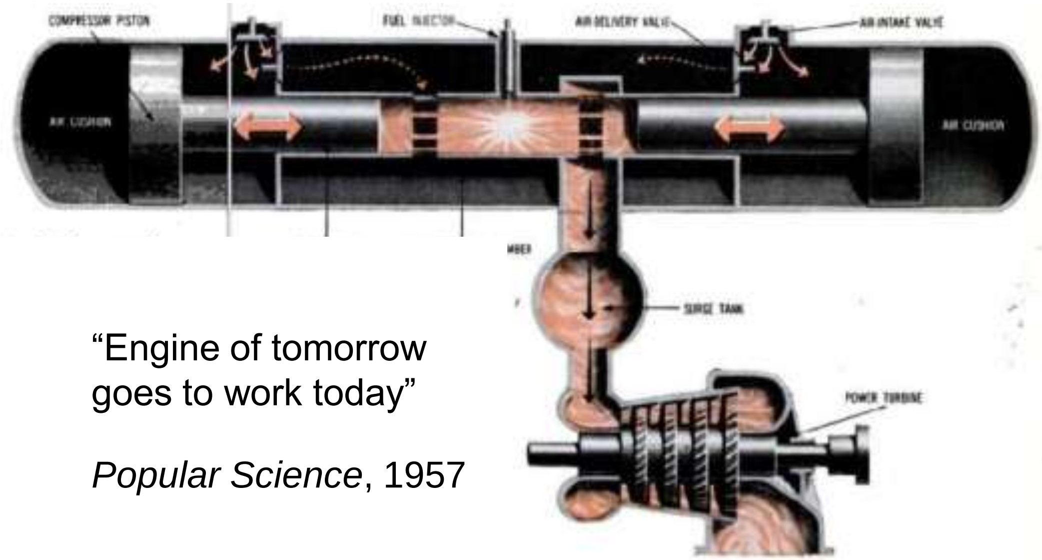
Free-piston engines

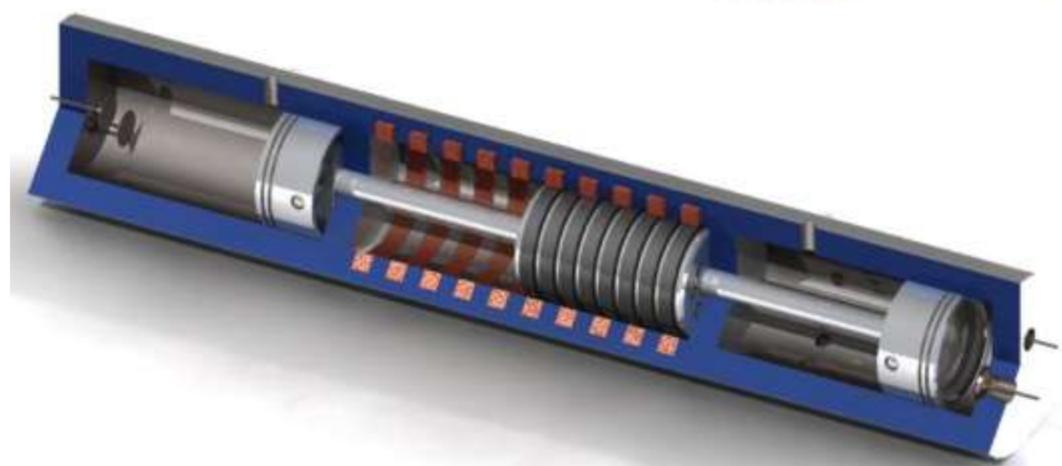
- Old concept: invented in 1920’s (Pescara); used in air compressors and as gas generators for power generation plants in 1930-1960.





“Engine of tomorrow goes to work today”

Popular Science, 1957



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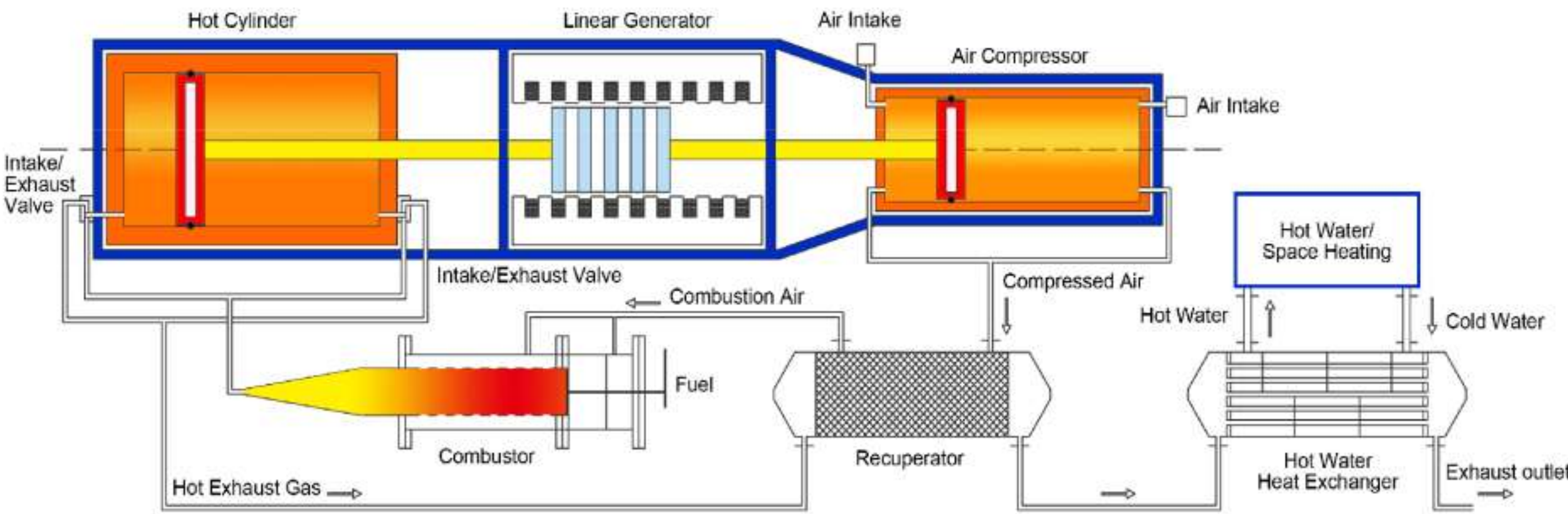
Free-CHP concept overview

Crankshaft energy converter replaced by free-piston unit with linear electric generator.

Key advantages over 'conventional' RJC engine:

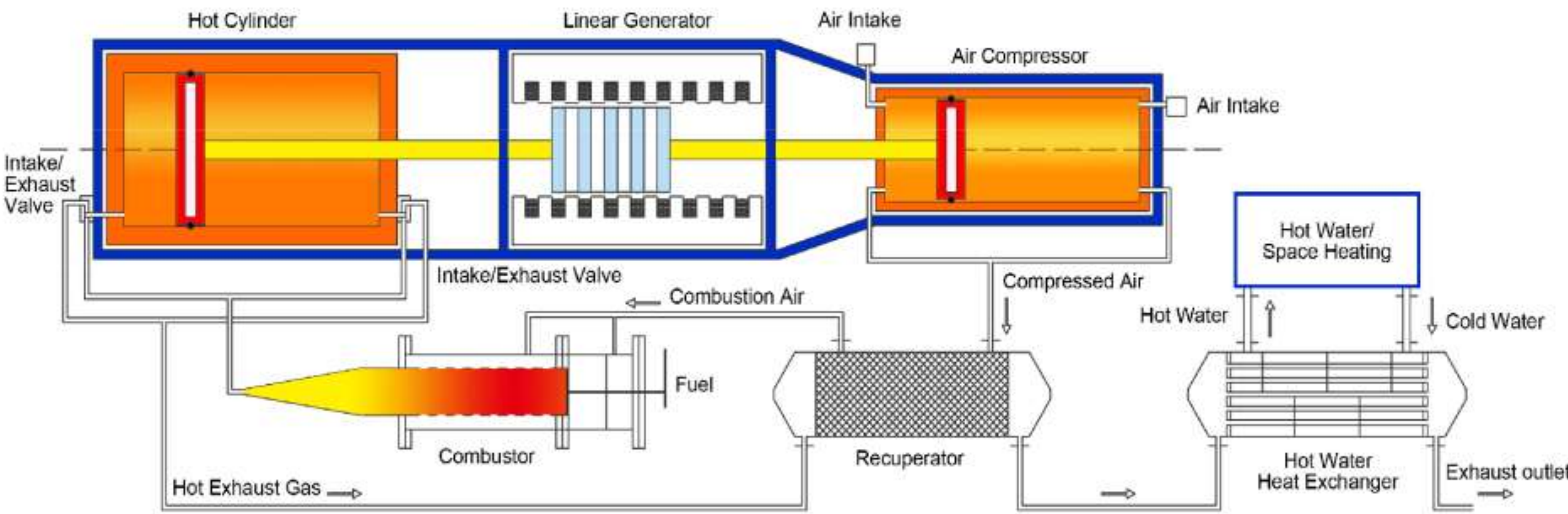
- Elimination of the complete crank system reduces friction.
  - Notably: no load-carrying bearings.
- Double-acting units reduces problem with pulsating flow.
- (Effect of leakage limited: relaxes sealing requirements.)



Free-CHP performance predictions

Challenges:

- Complex interaction between fluid dynamics, mechanics and thermodynamics throughout the system.
- Key aspect: piston motion is not pre-determined as in a conventional engine, but depends at any point on the prevailing operating conditions.
  - Stroke length must be controlled (avoid collision + low clearance at ‘TDC’)
  - Speed not a free variable (spring-mass analogy).
- High number of operational and optimisation variables



Free-CHP performance predictions

Full-cycle (1D, multi-domain) simulation model developed (AMESIM) to:

- Understand system behaviour, particularly gas flows / piston dynamics.
- Estimate performance (electrical efficiency).

Engine base design (semi-optimised):

Variable	Value
Combustion temperature	800 degree C
Target stroke length	116 mm
Piston assembly mass	1 kg
Compression cylinder diameter	66 mm
Expansion cylinder diameter	80 mm
Cylinder length	120 mm

Performance predictions:

Variable	Value
Combustor power	13.90 kW
Mechanical power out	4.47 kW
Power lost over air inlet and exhaust	8.46 kW
Additional power loss	0.97 kW
Compression cylinder output pressure	5.9 bar
Frequency	36.4 Hz
Efficiency	32.2 %

- Efficiency predicted corresponds well with previous reports on reciprocating Joule cycle engines.
- Some improvement potential through more detailed optimisation.

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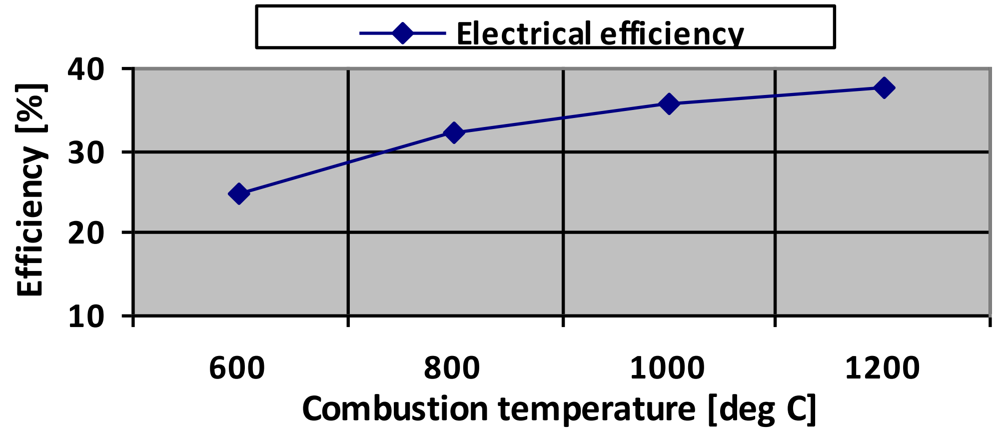
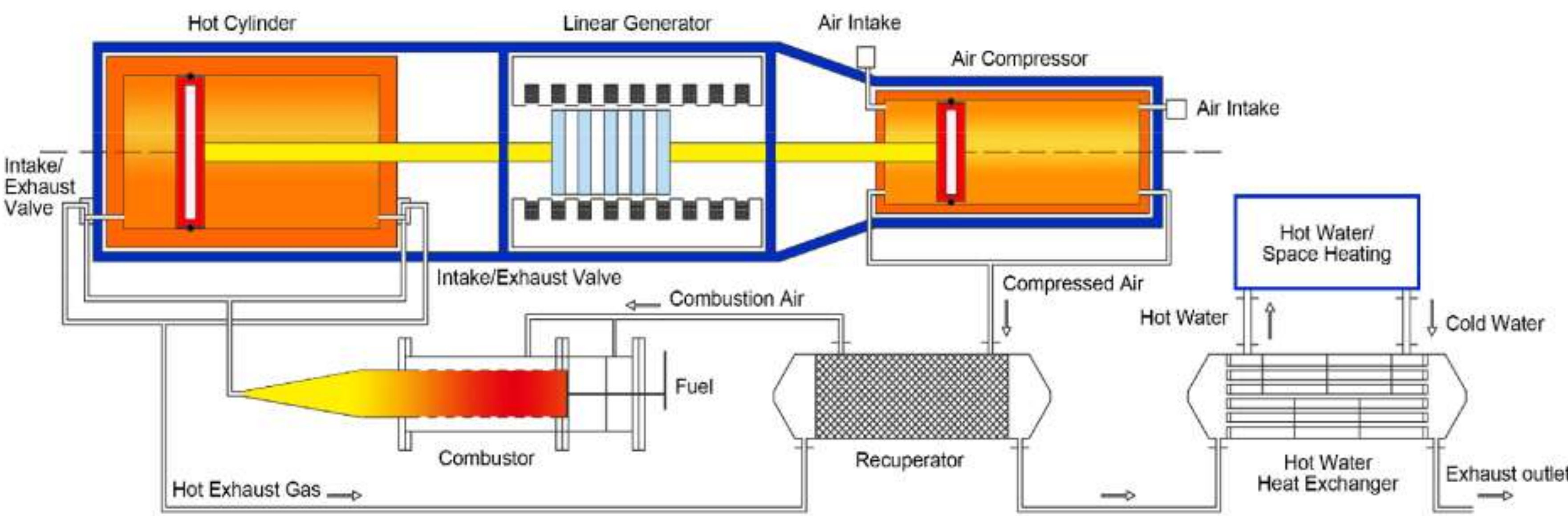
Free-CHP performance predictions

Influence of **peak cycle temperature**:

- Efficiency drops below 800°C; optimum not reached <1200°C
- System nearly adiabatic → HT losses less influential.
- Demonstrates potential benefits of using high-temp. materials.

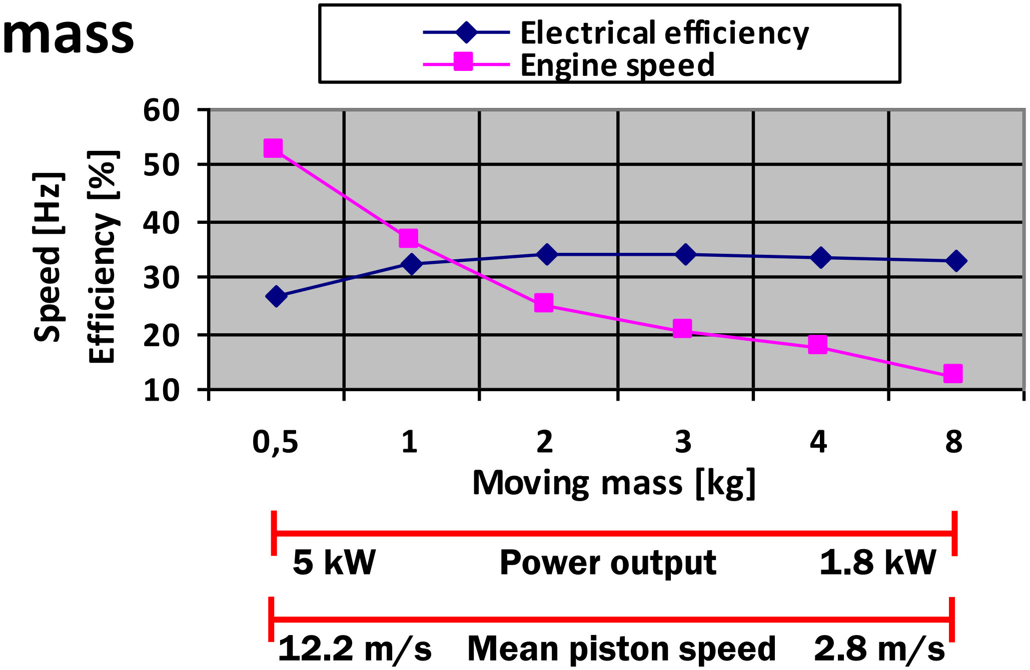


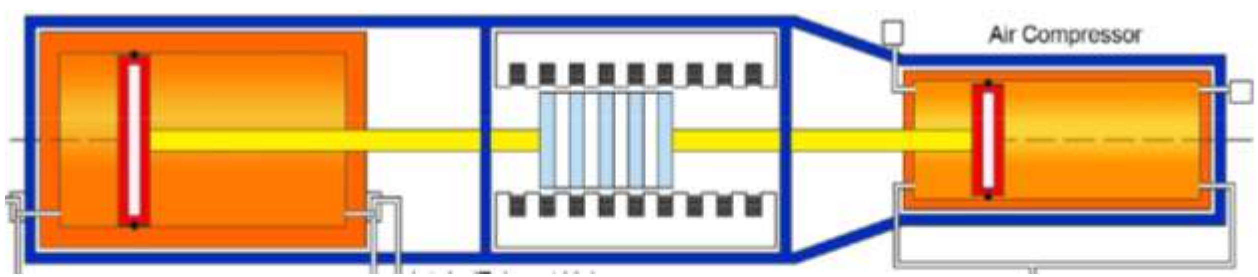


Free-CHP performance predictions

Influence of **piston assembly mass**

- Effect of changes in moving mass well-known in free-piston engines: large influence on speed and thereby power density.
- Optimum point for efficiency: trade-off between gas flow losses and heat transfer loss, leakage, etc.
- Speeds within reasonable range: OK for valved operation without excessive pumping losses.





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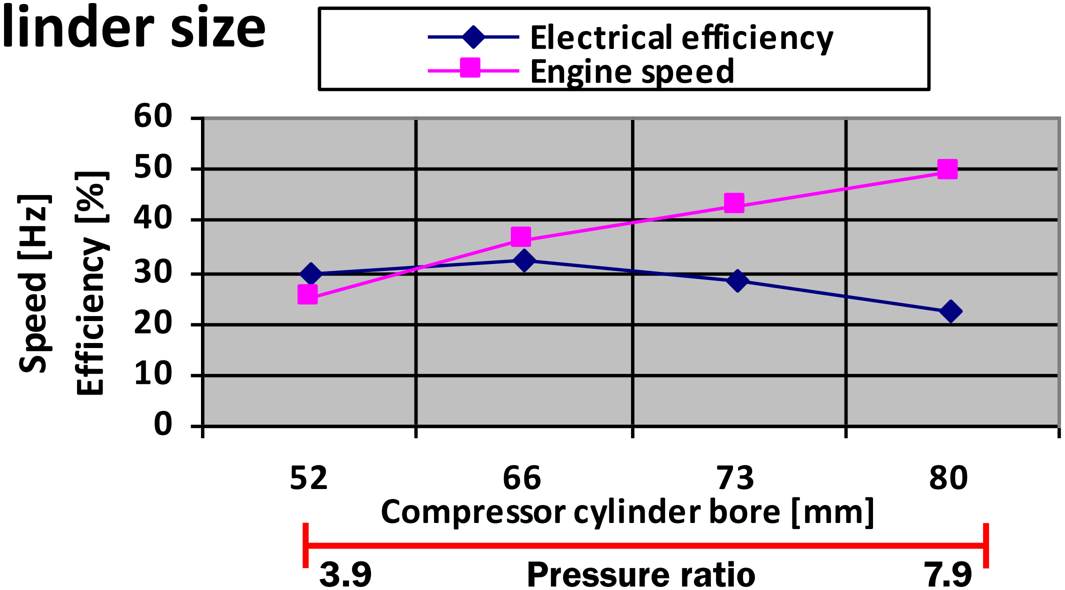
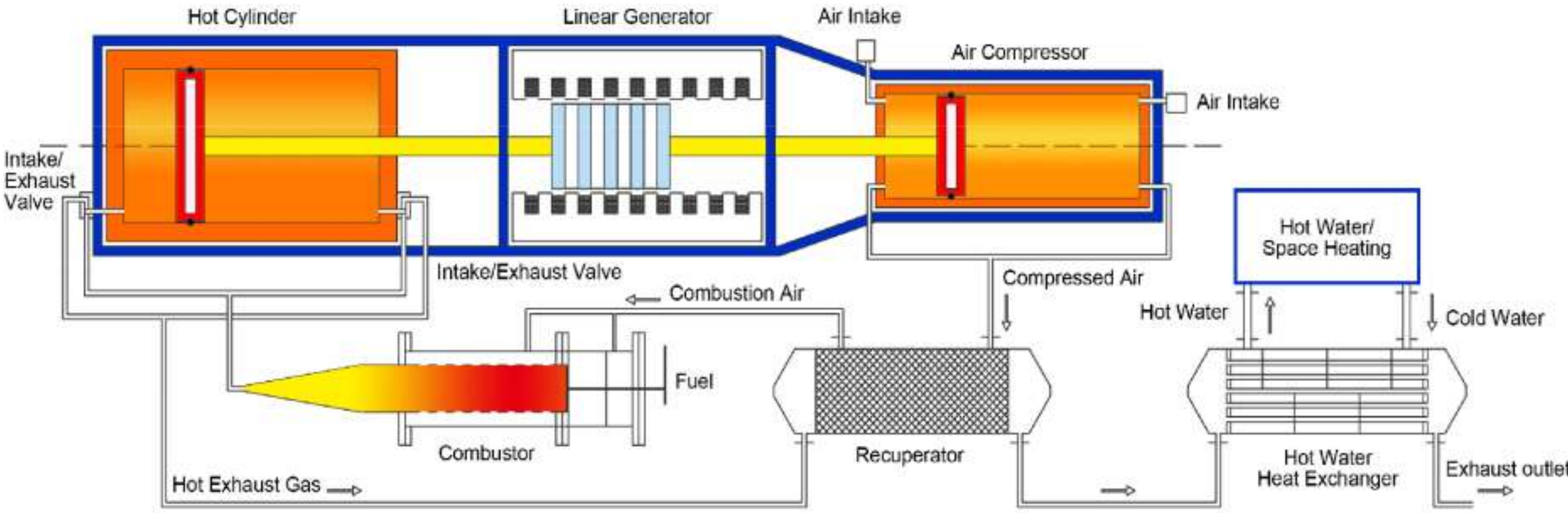
Free-CHP performance predictions

Influence of **compression cylinder size**

- Ratio of compression cylinder to expansion cylinder bore determines cycle pressure ratio and influences efficiency.
- Also: secondary effects on operating speed and other operational variables.
- Power not heavily influenced.

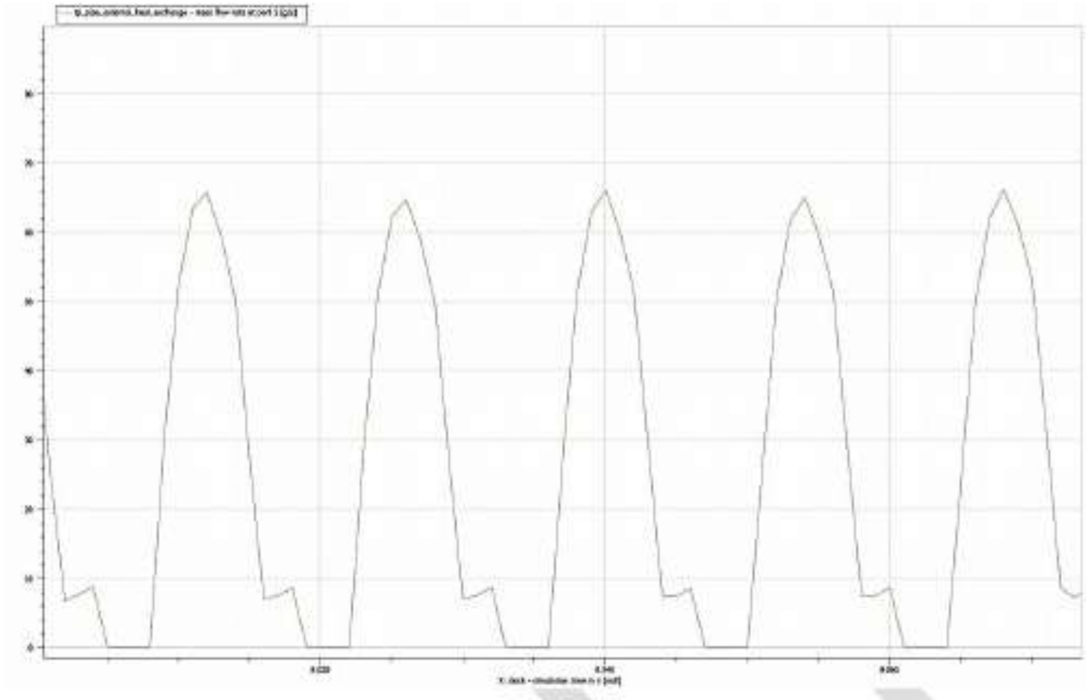




Free-CHP current work

Pulsating flow challenge must be resolved

- Modifying pipe diameters does influence flow characteristics – but cannot use throttling to solve problem!
- Also issue for H/E efficiency, but not critical.
- Pulsating fuel injection may be required.
- Catalyst to stabilise combustion?



Prototype system under construction at Newcastle.

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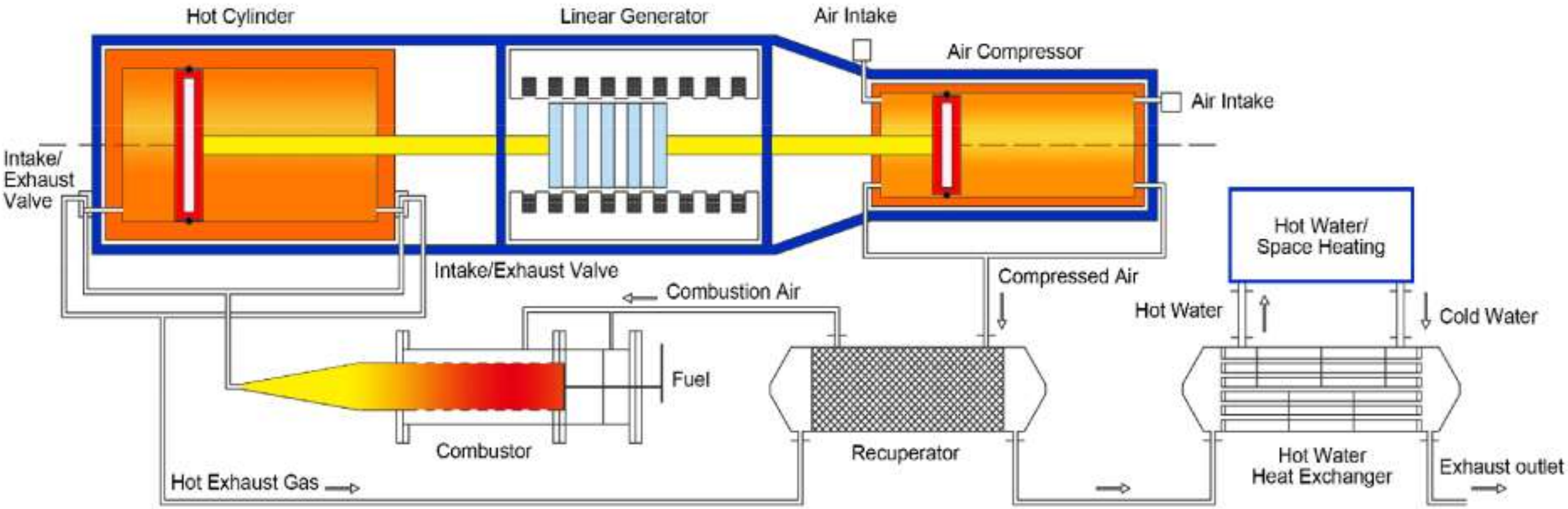
Thank you



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