



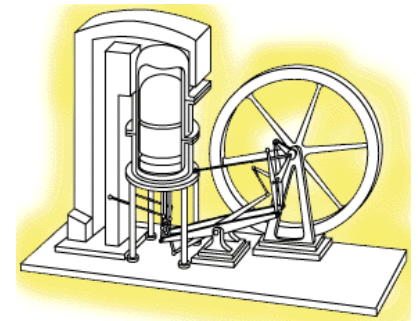
Chap 5

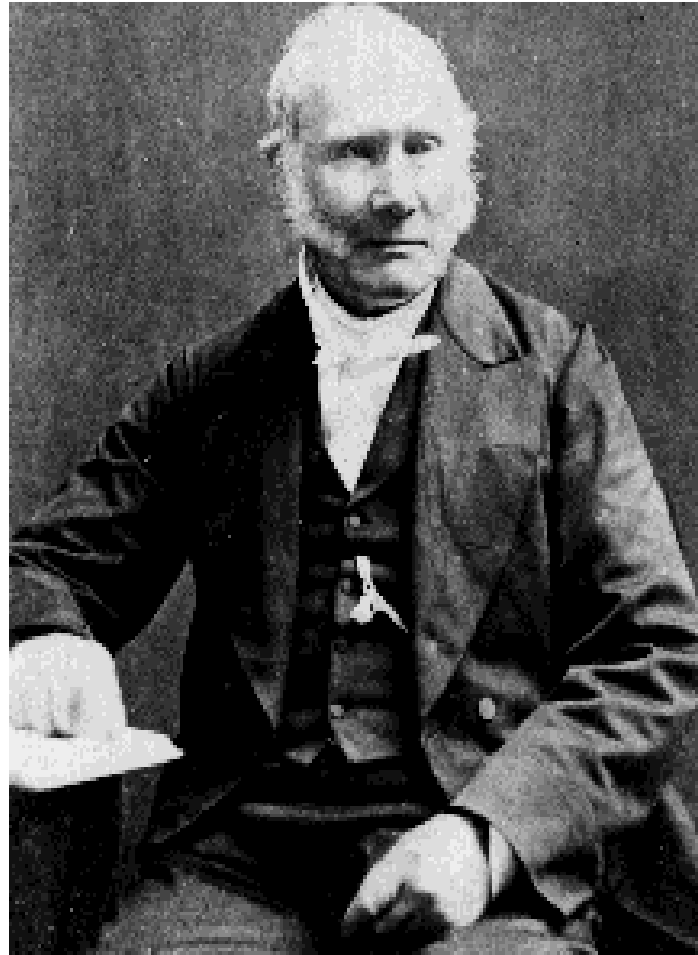
Theory of Stirling Engines



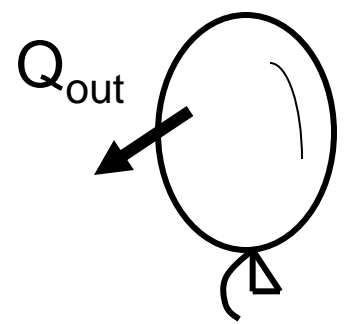
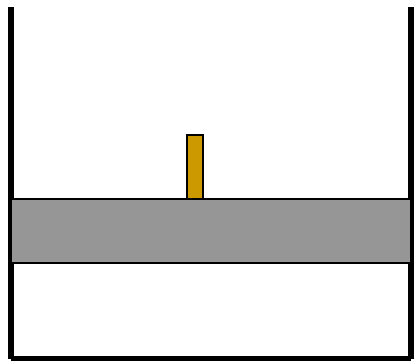
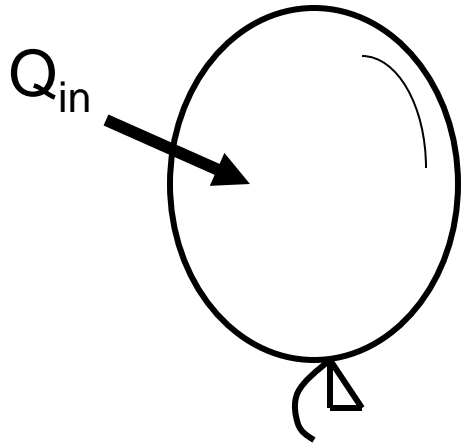
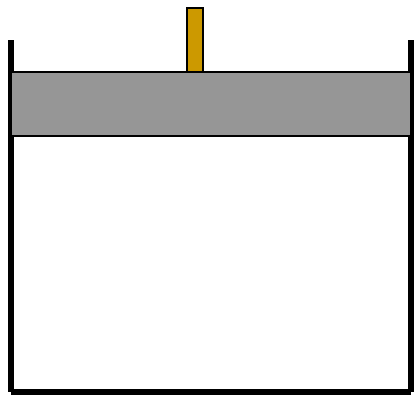
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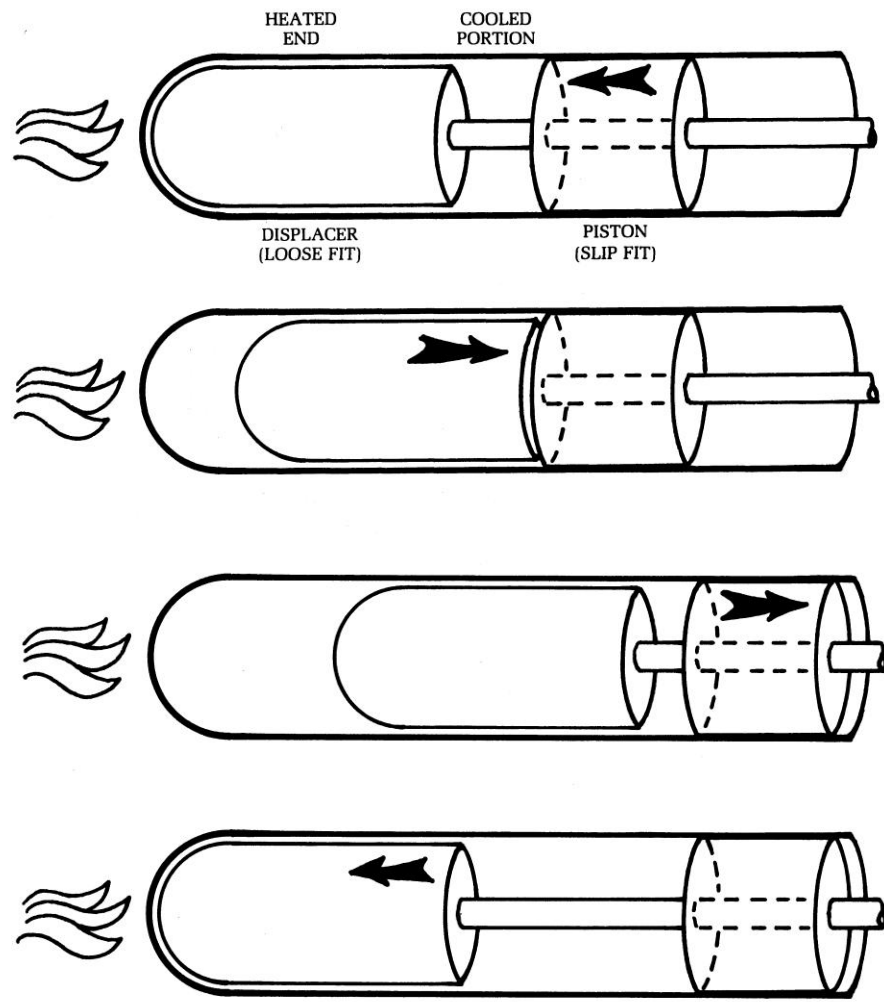
- Introduction
- Stirling Engines in History
- Modern Stirling Engines
- Industrial Projects
- Potential Technologies
- Concluding Remarks

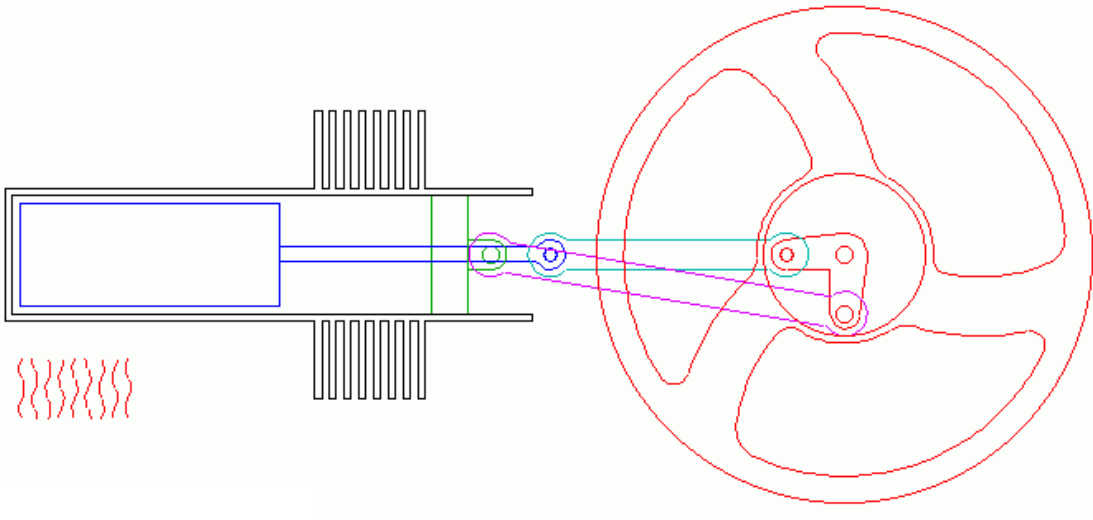




Reverend Dr. Robert Stirling (1790-1878)







Source: www.keveney.com

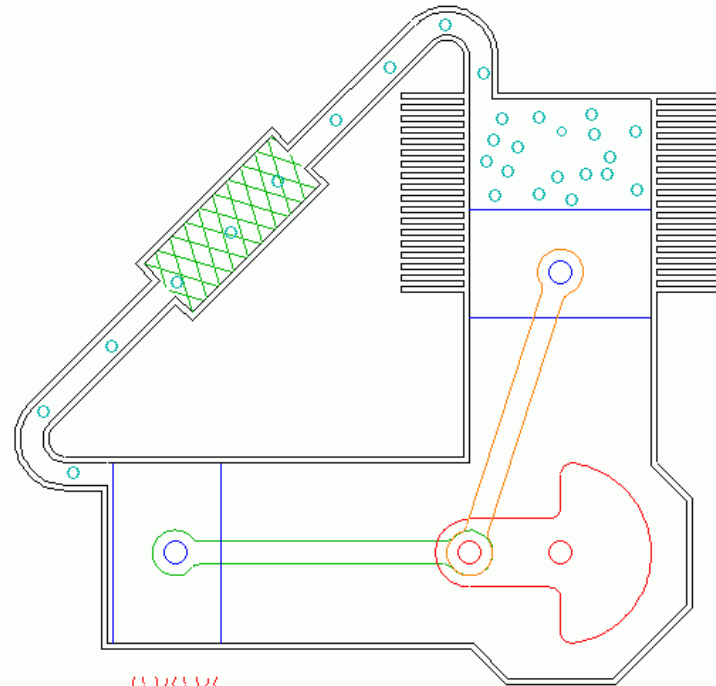


Classification of Stirling Engines

- **α configuration**—This type of configuration features two pistons, each in its own cylinder.
- **β configuration**—This type of configuration has a piston and a displacer in the same cylinder.
- **γ configuration**—This type of configuration has a piston and a displacer, each in its own cylinder.



α configuration: two pistons, each in its own cylinder

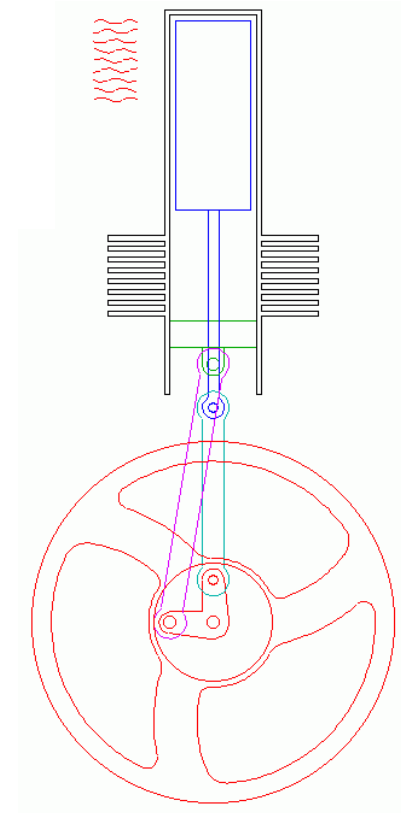
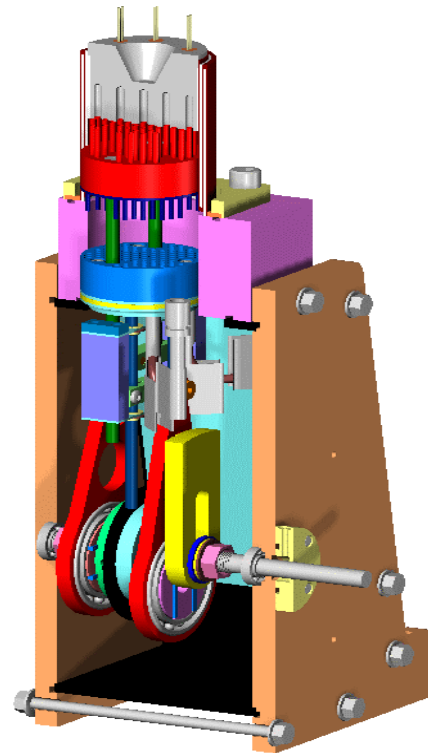


Copyright 2000, Keveney.com

Source: www.keveney.com



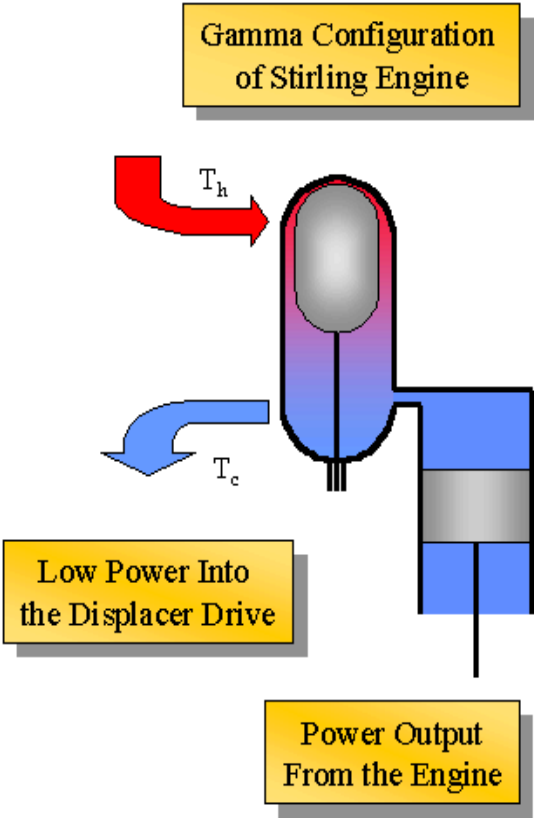
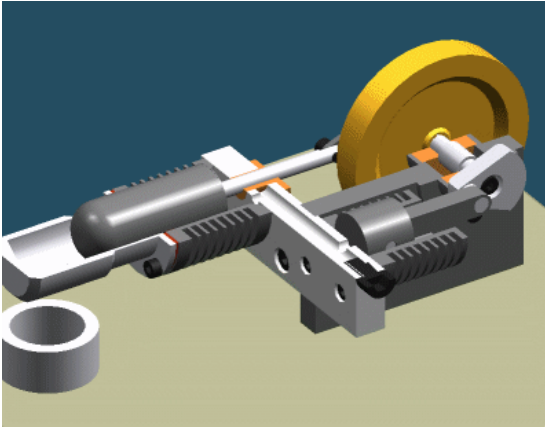
β configuration: a piston and a displacer in the same cylinder



Source: www.keveney.com



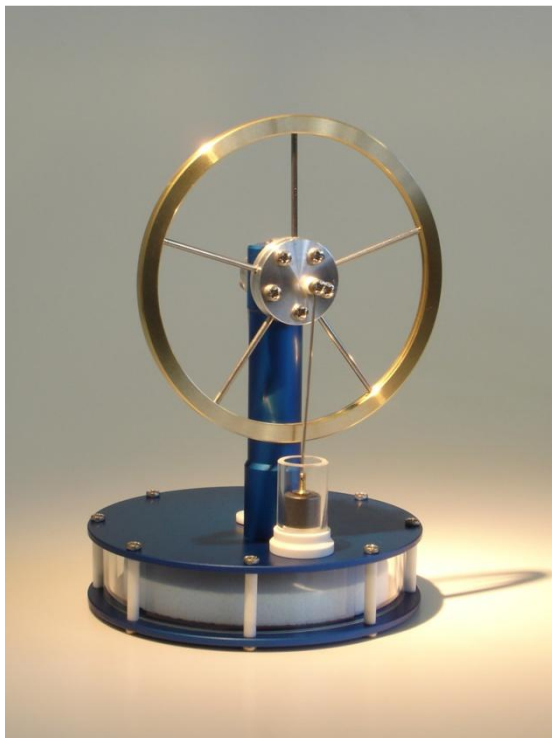
γ configuration: a piston and a displacer, each in its own cylinder.



Source: www.grc.nasa.gov

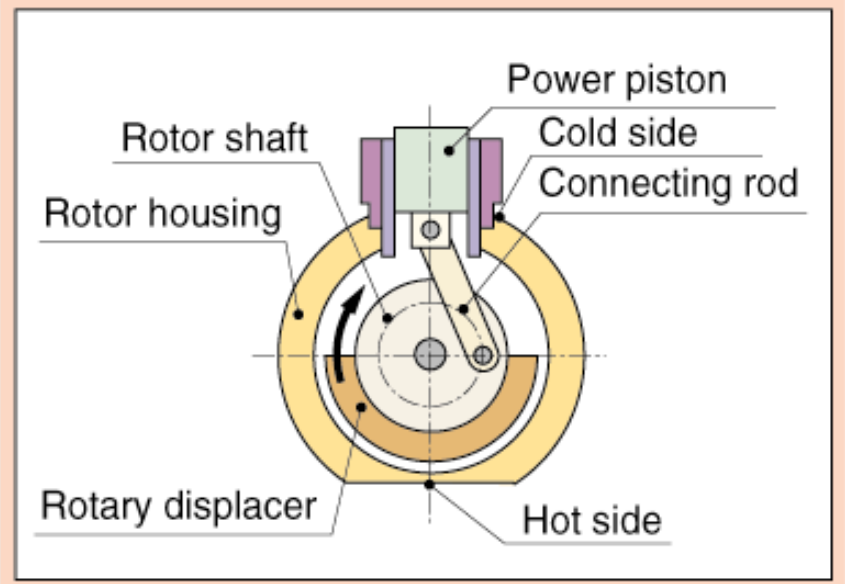
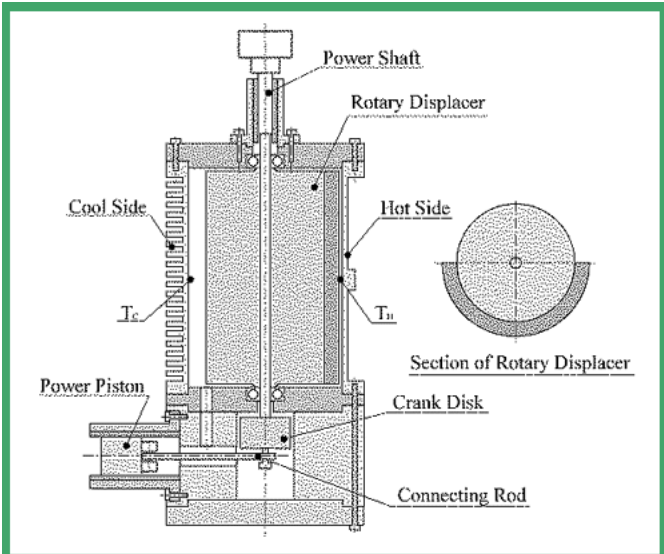


γ type (1)



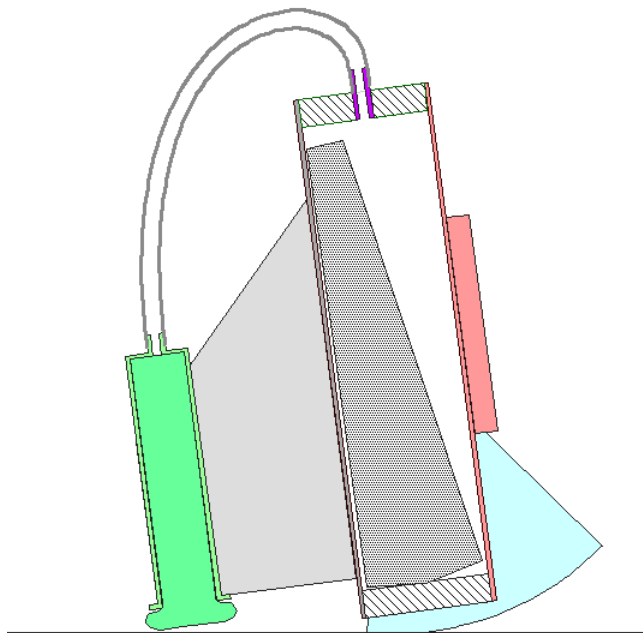


γ type (2)



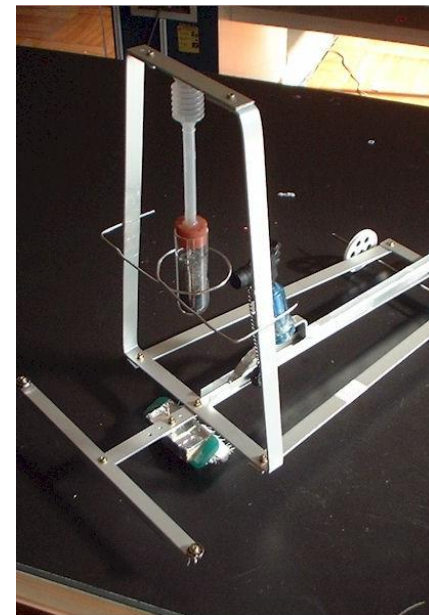
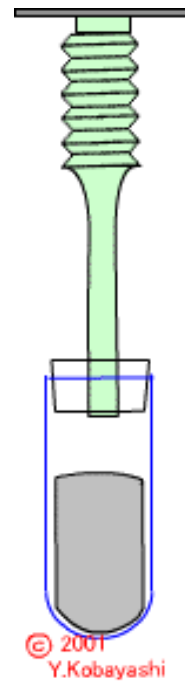


γ type (3)



© 2002 Y.Kobayashi

γ type (4)





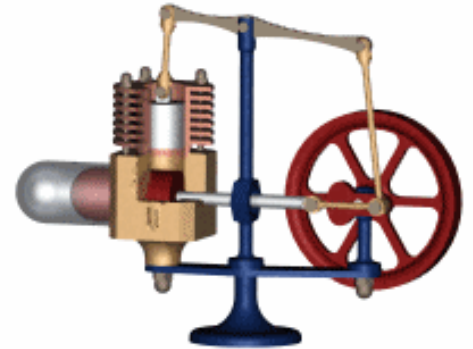
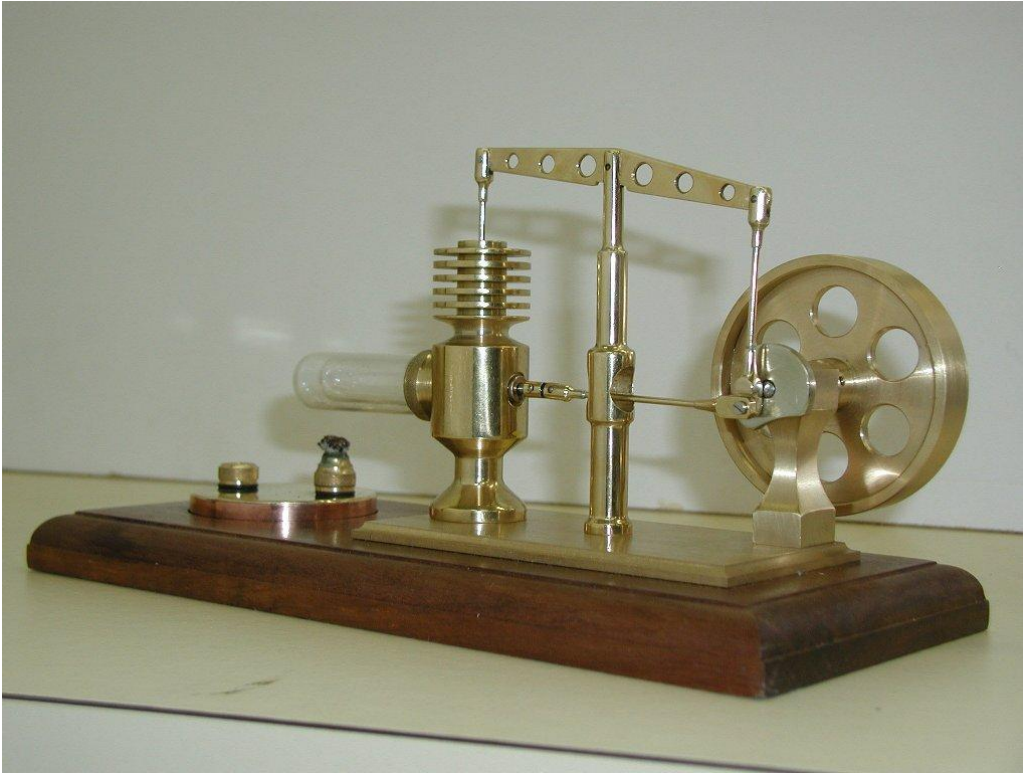
γ type (5)





T-swing arm

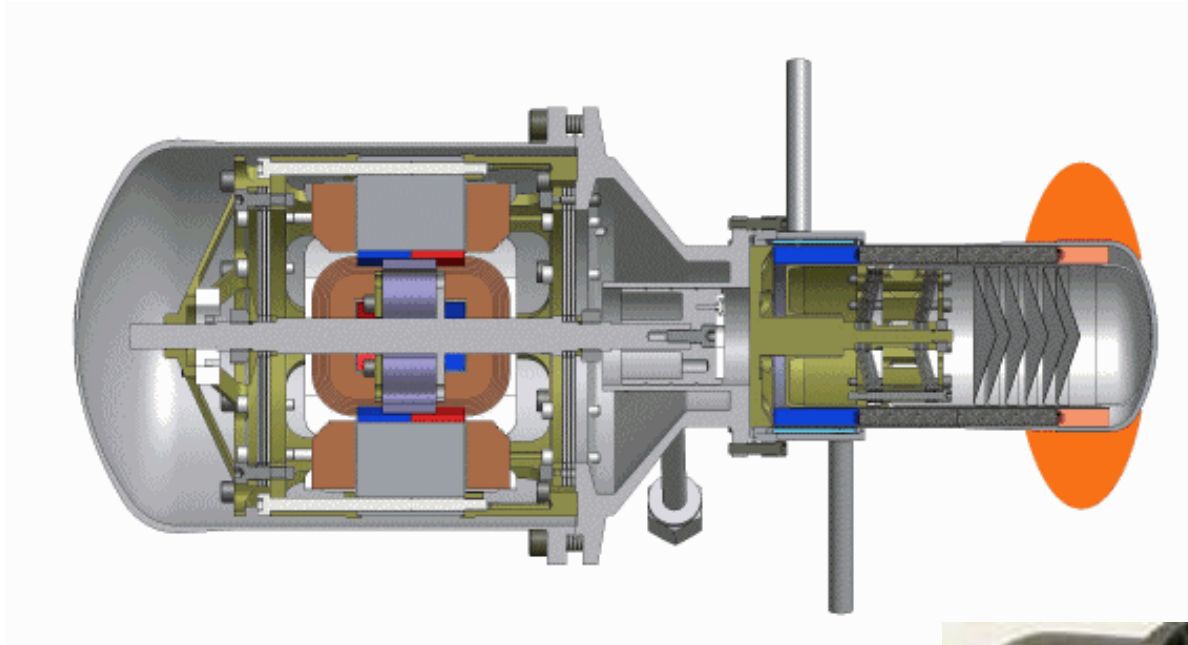
γ type (6)





Free-Piston Stirling Engines

β type

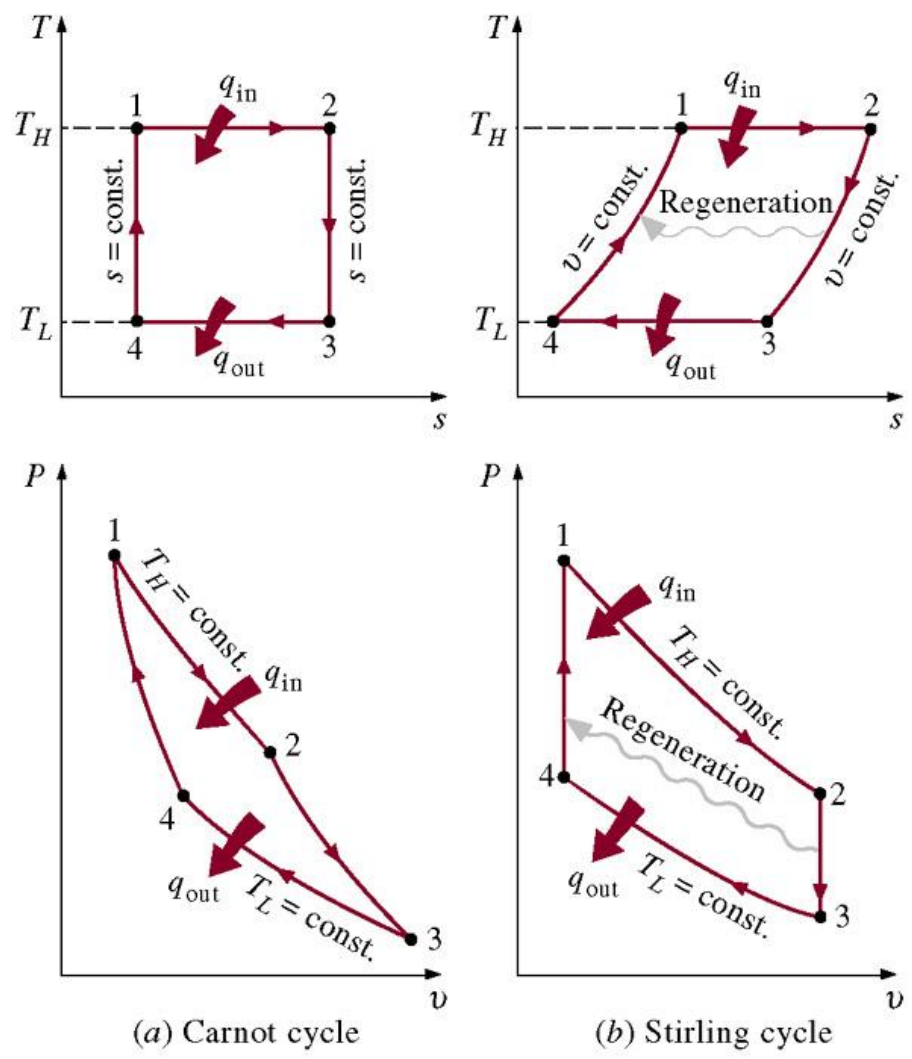


Source: www.grc.nasa.gov



Advantages of Stirling Machines

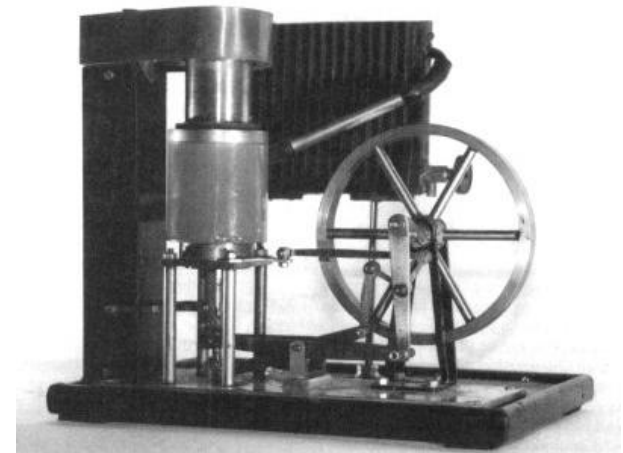
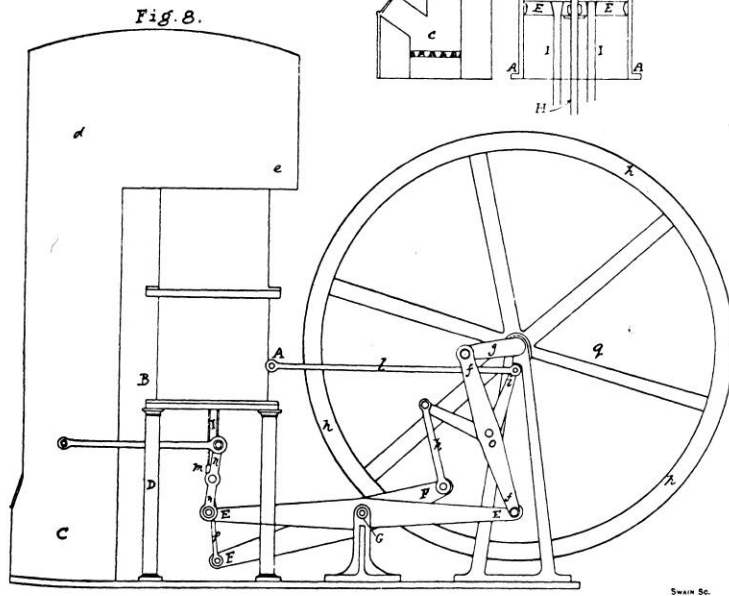
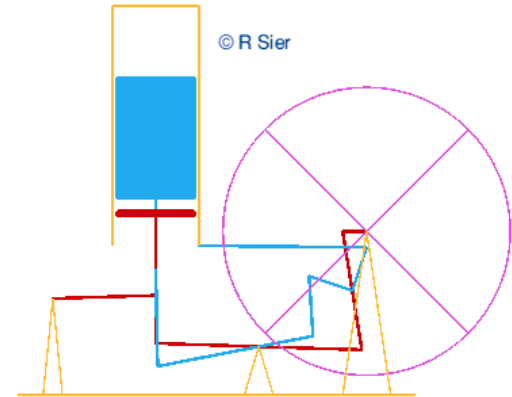
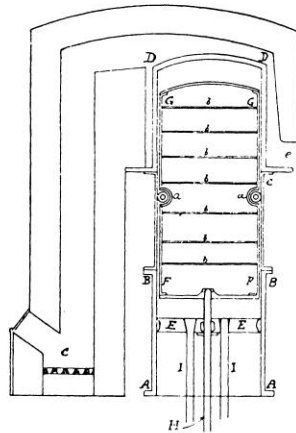
- High thermal efficiency
 - A variety of external heat sources
 - Low in emissions
 - Quiet
-



Source: Y.A. Cengel & M.A. Boles, *Thermodynamics-An Engineering Approach*, 4th Ed.

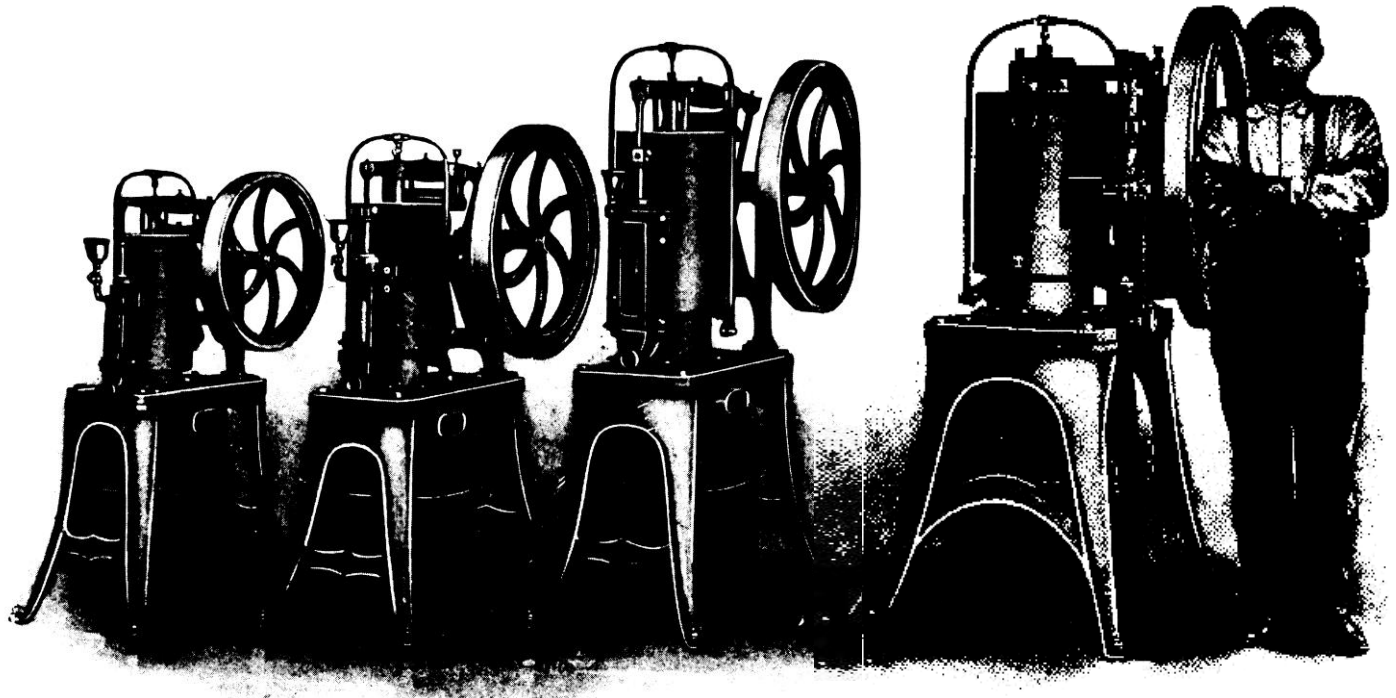
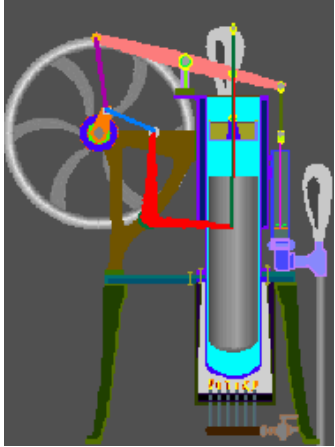


Hot-Air Engine (Robert Stirling, 1816)





Ericsson and His Pumping Engines (5-, 6-, 8-, and 10-inch, during 1870-1905)





THE FOLLOWING letters were written by our customers after having used the engines for the time mentioned in their letters. These were taken at random from thousands of similar letters:

BALDWIN LOCOMOTIVE WORKS

George Burnham Samuel M. Vauclain
William L. Austin John H. Converse
William P. Henszey Alba B. Johnson
George Burnham, Jr.

PHILADELPHIA, PA., July 3, 1889

Ericsson GENTLEMEN: I have used for six or seven years, both for my own house and for other houses built by me, the Ericsson Hot-air Pumping-engines of your build. They have given me entire satisfaction, and I take pleasure in recommending them as the most convenient, serviceable, and economical pumping-engines for domestic use.

Very truly yours,
JOHN H. CONVERSE.

**The Same Engine After a Service of
Twenty Years**

PHILADELPHIA, PA., Feb. 11, 1904.

GENTLEMEN: I have used the Ericsson Hot-air Pumping-engines in several of my houses and have one in use at this time for supplying water to my own residence at Rosemont. The engine has always given satisfaction, and after an experience of twenty years I am able to commend it as effective and reliable.

ed anything like so much water with as little expense or with as much satisfaction to owner and operator. An ordinarily intelligent man can use it, and there is no possible danger from it. I most heartily recommend the Rider as the most satisfactory engine and motor I know of.

Yours truly,
W. W. COCKS.

SAUGATUCK, CONN., March 24, 1883.

**6-inch
Rider** In reply to your inquiry as to my Rider Engine, I can say it has been in use four years, and the cost of repair in that time has been about \$10. So far as I can judge, it is very economical of fuel and very easily handled, my coachman always operating it.

Yours truly,
S. M. BURNHAM.

LATER

SAUGATUCK, CONN., February 10, 1904.

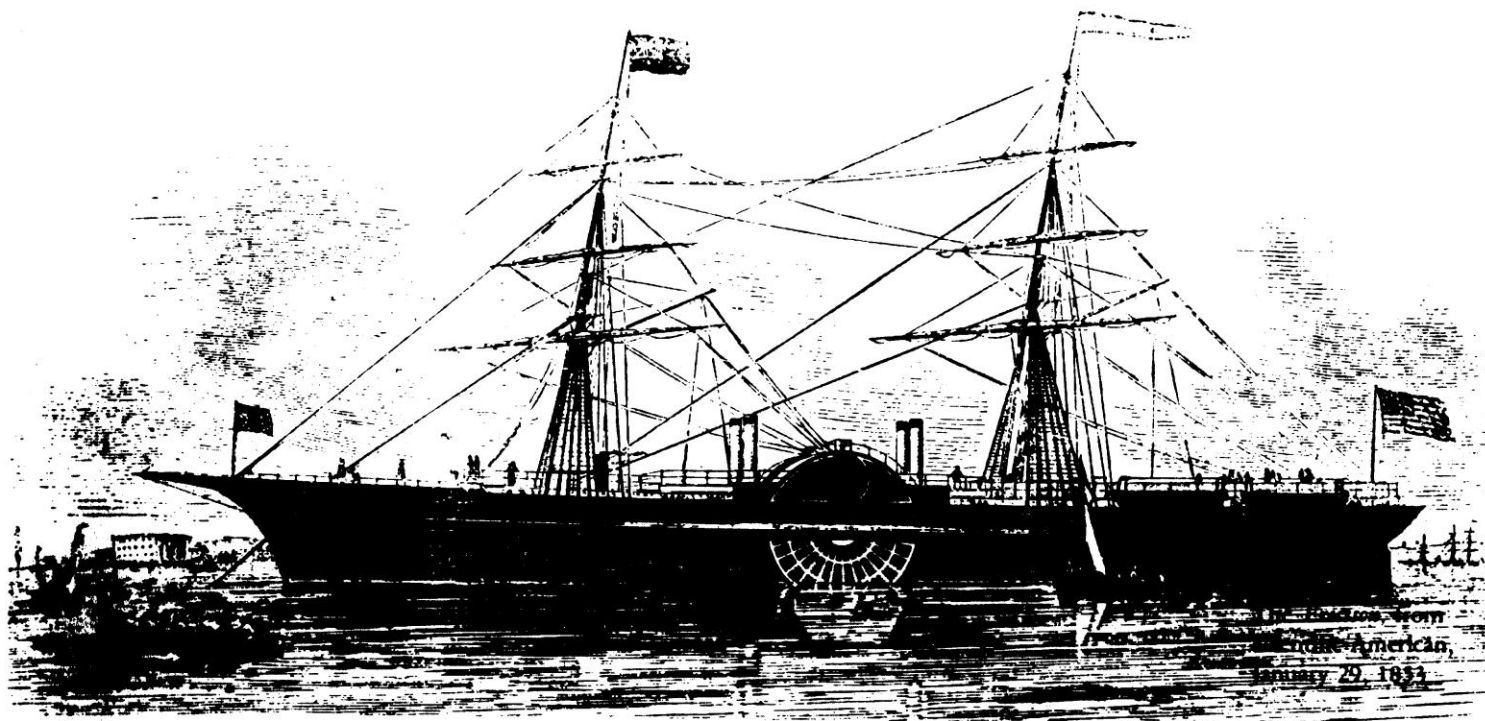
GENTLEMEN: Your engine is admirable, although in use almost twenty-five years. I am glad to commend so good a servant.

Yours truly,
S. M. BURNHAM.

2101 Chestnut Street
PHILADELPHIA, PA., April 7, 1903

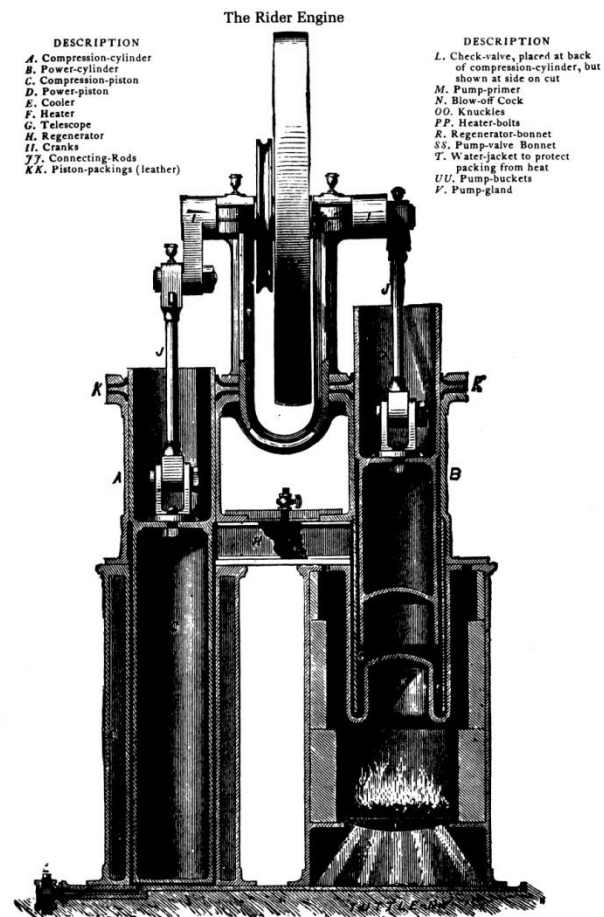


The Ericsson (2200 ton, 4 hot-air engines, 14 ft piston diameter)





Rider Water-Pumping Engine (A.K. Rider, 1876)





Watering the Herds

WITH the fencing of the ranges has come the need for an artificial water supply upon the great stock farms of the West. That cattle may thrive and fatten for the market, it is absolutely essential that this supply be both *constant* and *abundant*. The picture shows a typical scene upon many of the largest ranches, where the **HOT AIR PUMP** is delivering its supply into the storage tank, whence it is drawn off daily as required, in any volume up to 100,000 gallons. No driving of the herds to some distant river is required, thus much expense is saved and the cattle drink quietly, as nature dictates, at an *ever ready* and *abundant* supply. Descriptive Catalogue C5 sent free on application.

Rider-Ericsson Engine Co..

Remember, the Hot Air Pump is Automatic, requires no skilled attention, and is the cheapest form of constant water supply now known.

35 Warren St., New York.
40 Dearborn St., Chicago.
40 N. 7th St., Philadelphia.
239 Franklin St., Boston.
602 Craig St., Montreal, P. O.
22 Pitt St., Sydney, N. S. W.
Teniente-Rey 71, Havana, Cuba.





Stirling Fan (Lake Breeze Motor, 1918)



Courtesy Andy Ross Historical Collecti



Runs on Kerosene Alcohol or Gas Anywhere

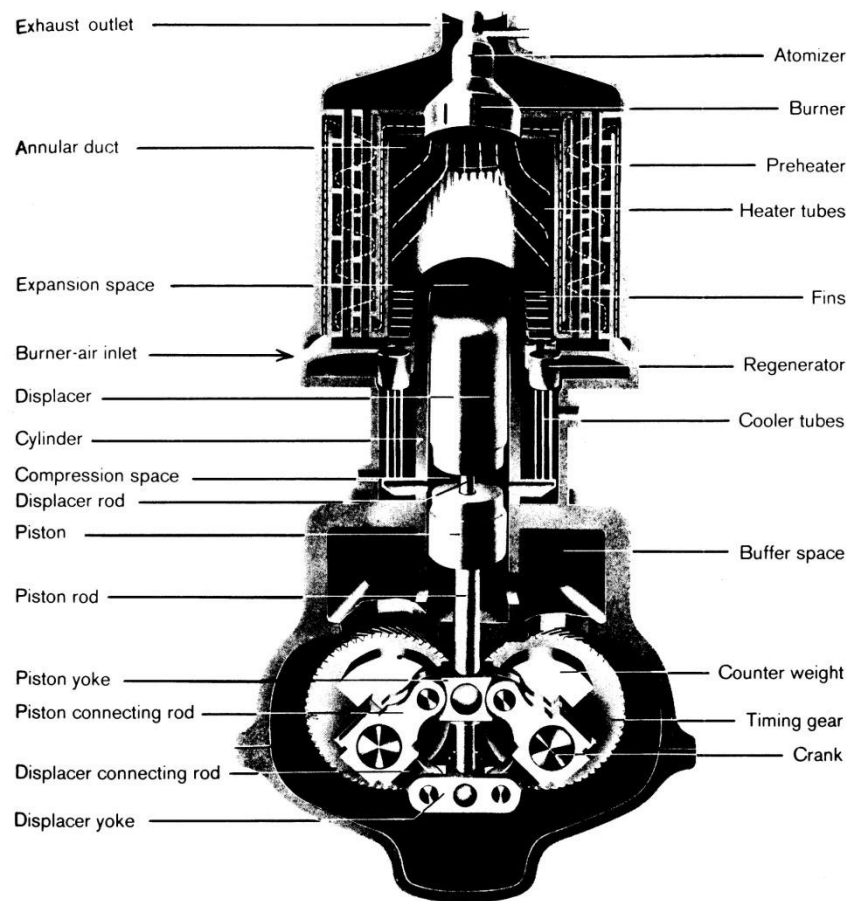
A most remarkable invention. No electricity, wires or springs. 1918 Improved patented Models. Runs 8 hours for a cent on kerosene. Quiet - Convenient. Brings genuine comfort and satisfaction. Ideal for the sick. A proved success. 4th season. Increase your efficiency. Every home and office should have one. The Wonder Fan. Two Models. Three Sizes. **BE WELL. KEEP COOL.** Address

Lake Breeze Motor, 566 W. Monroe St., Chicago



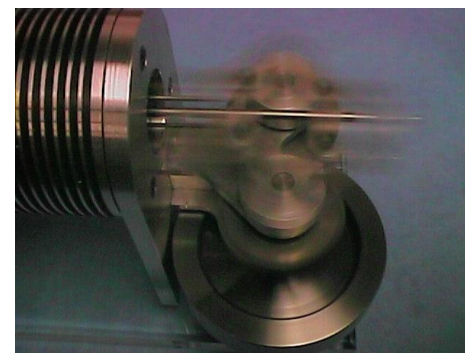
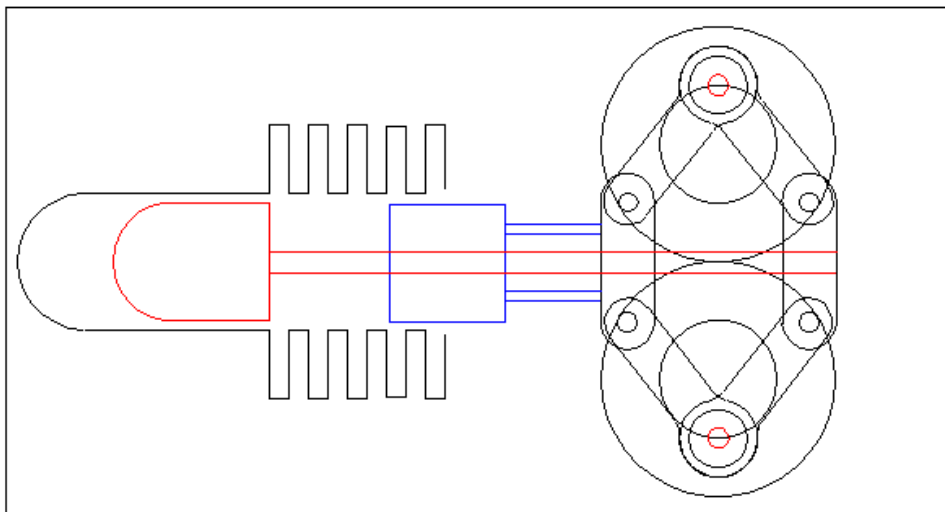


Philips Stirling Engine (1950-) with Rhombic Drive





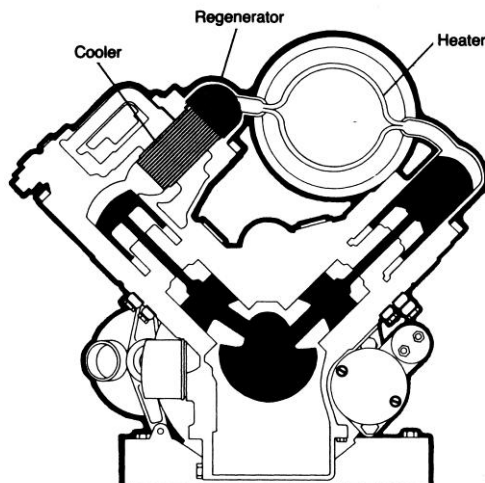
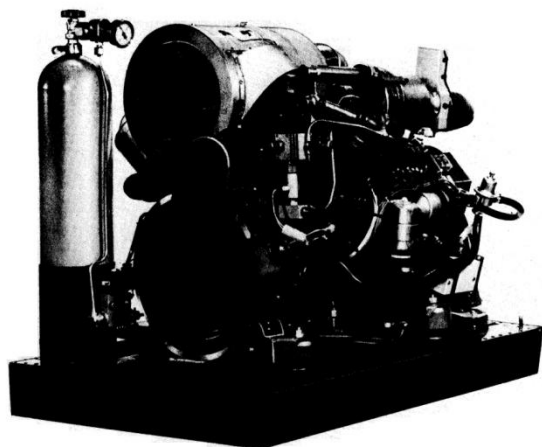
Rhombic Drive



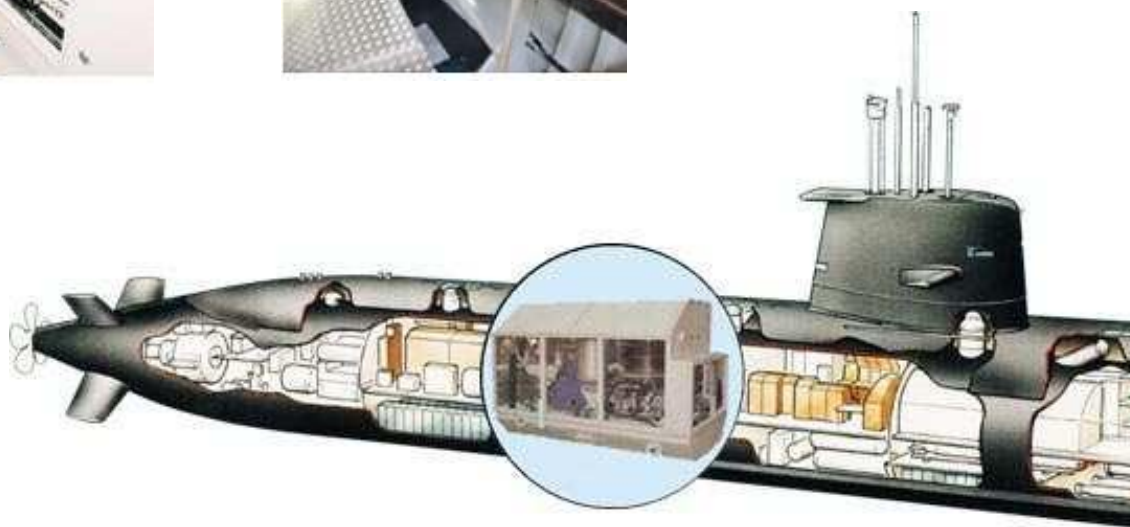
Source: www.stirlingsouth.com



V-2 Stirling Engine (Stirling Power System Co., 1981)



Spirit of American Motors
Corp., 1979



The Kockums Stirling AIP system - proven in operational service



Whisper Tech Ltd. <www.whispertech.co.nz>

The DC(AC) WhisperGen 750W





Tamin Enterprises <www.tamin.com>

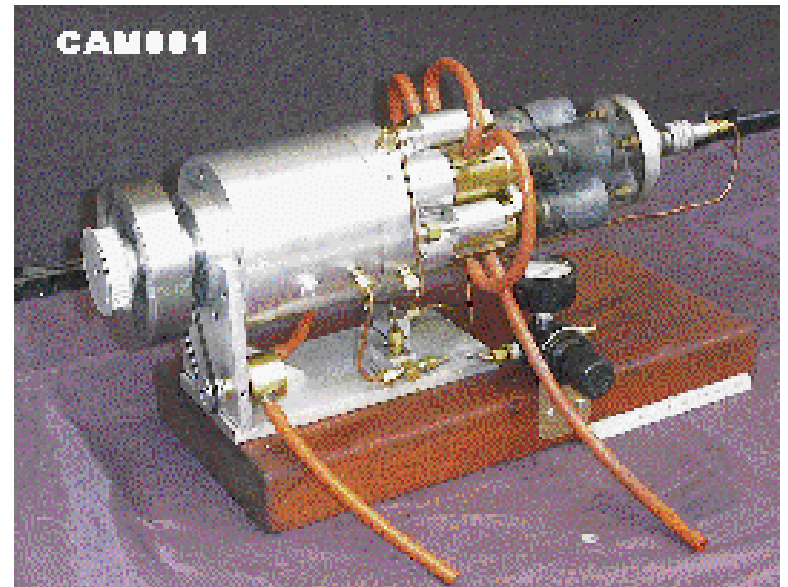
TESE002

Single-cylinder rhombic-drive



CAM001

Four-cylinder cam-drive





Stirling Technology Company <www.stirlingtech.com>

MODEL	<u>RG-55</u>	<u>RG-350</u>	<u>RG-450</u>	<u>RG-1000</u>	<u>RG-3000</u>
Electrical Output	60-80 W	350 W	450W@50Hz 550W@60Hz	1000W@50Hz 1250W@60Hz	3000 W
System Efficiency	29%	23%	30%	23%	39%
Duty Cycle	Continuous	Continuous	Continuous	Continuous	Continuo us
Minimum Lifetime	50,000 hr	50,000 hr	50,000 hr	50,000 hr	50,000 hr
Dimensions	13.8 in. x 5 in. dia	23 in. x 8 in. dia	24 in. x 7.5 in. dia	28 in. x 9 in. dia	34 in. x 10in. dia
Weight	3.5 kg	80 lbs.	100 lbs.	130 lbs.	160 lbs.
Maintenance	None	None	None	None	None



Stirling Technology Company <www.stirlingtech.com>



RG55



RG350



RG450

RG1000



RG3000





Sunpower, Inc. <www.sunpower.com>



M87 cryocooler
mass 2.7 kg
length 280 mm
diameter 83 mm

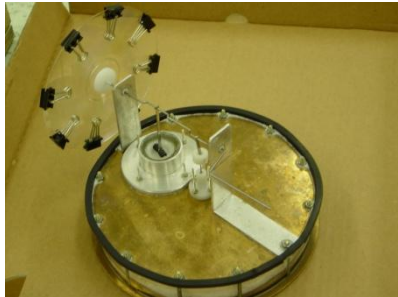
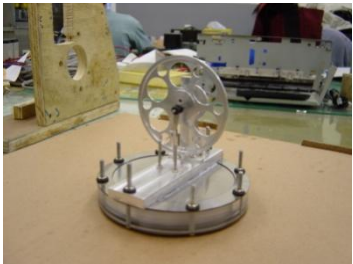
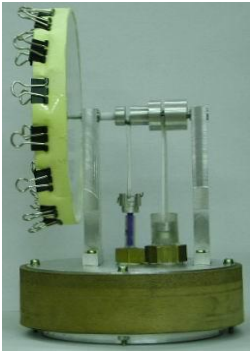


Model B-10B
Beale Free-Piston 1 W
height 250 mm
base diameter 100 mm
cylinder diameter 60 mm





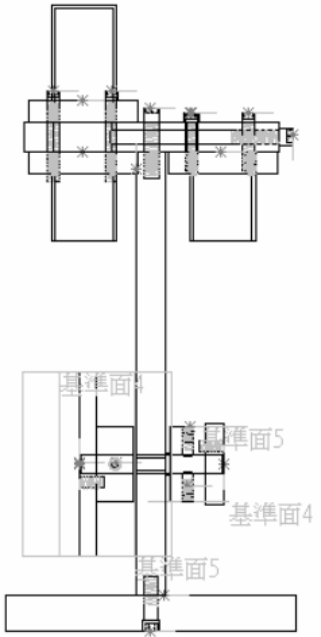
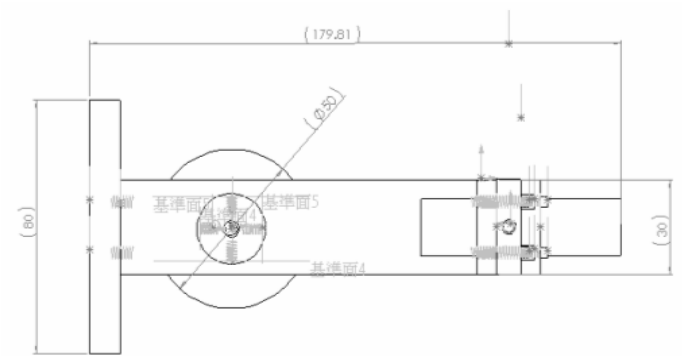
Miniature Engines (PEACE Lab., NCKU)





Miniature Engines

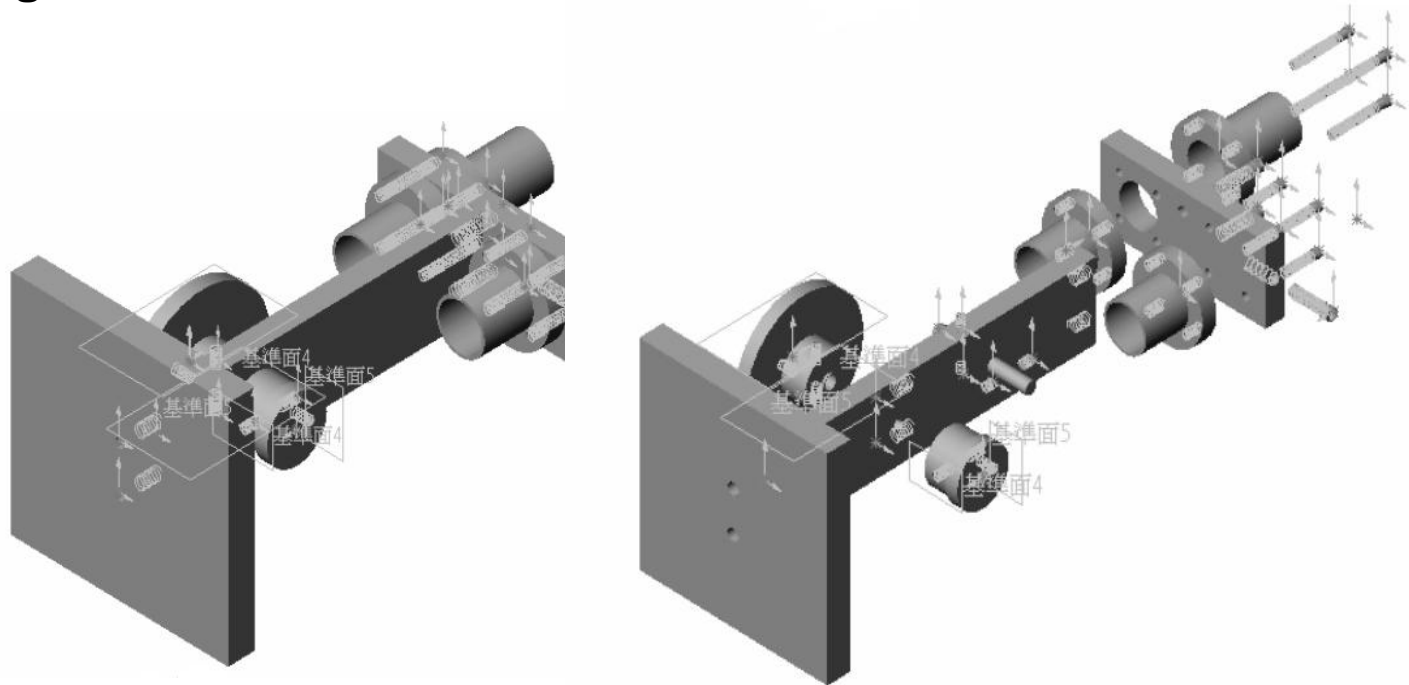
Design Phase: Two-dimensional Drawing





Miniature Engines

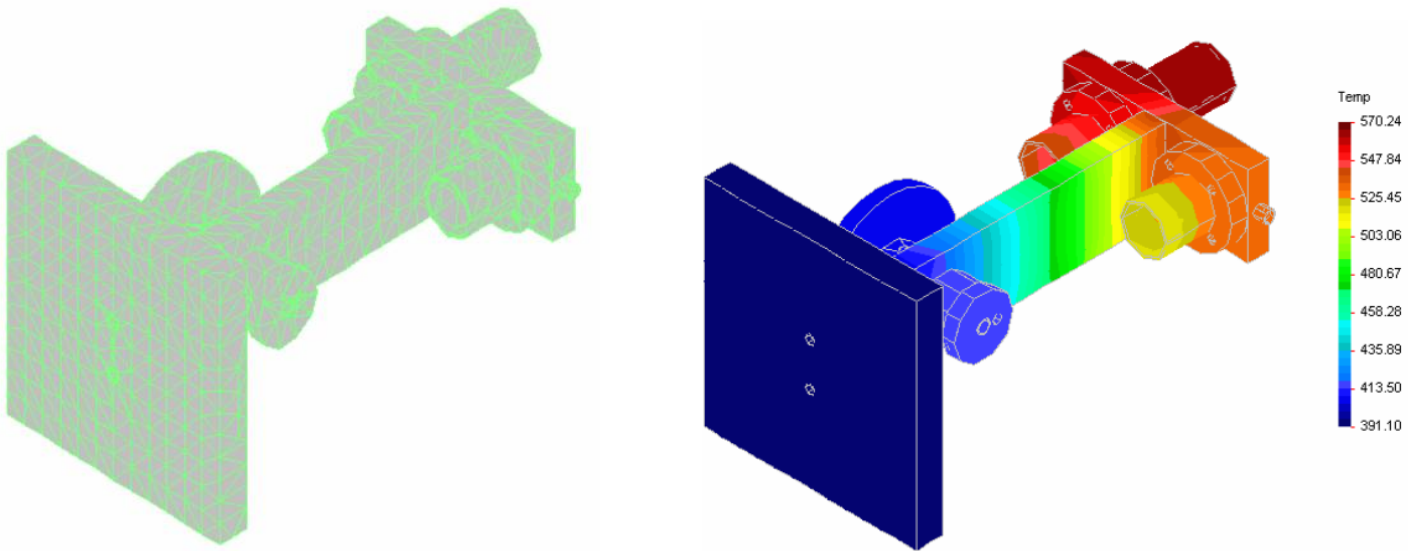
Design Phase: Three-dimensional Drawing





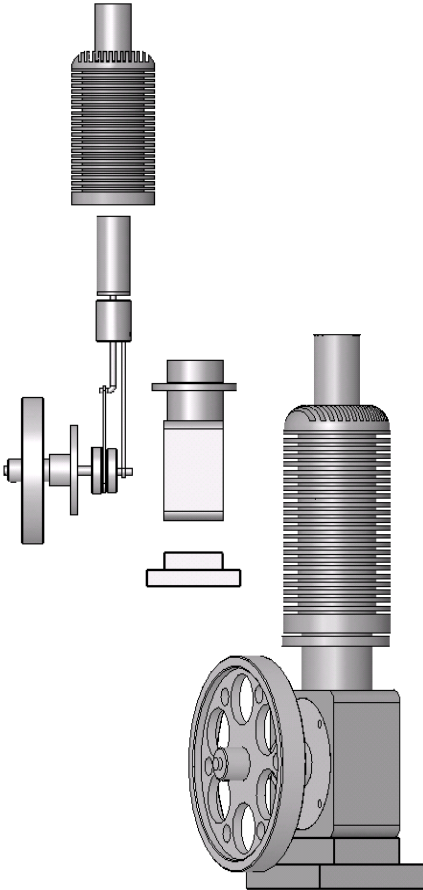
Miniature Engines

Analysis Phase: Mesh and Finite Element Analysis



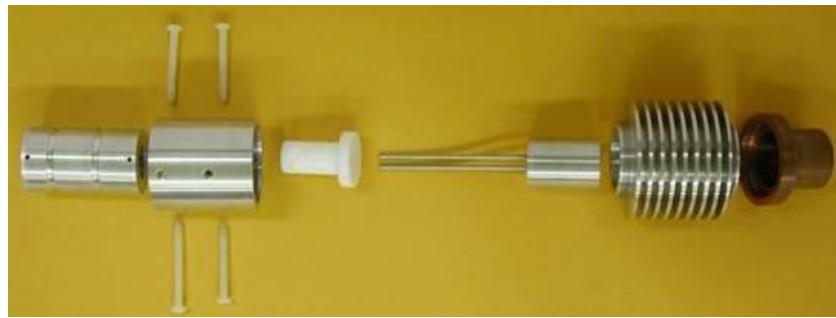
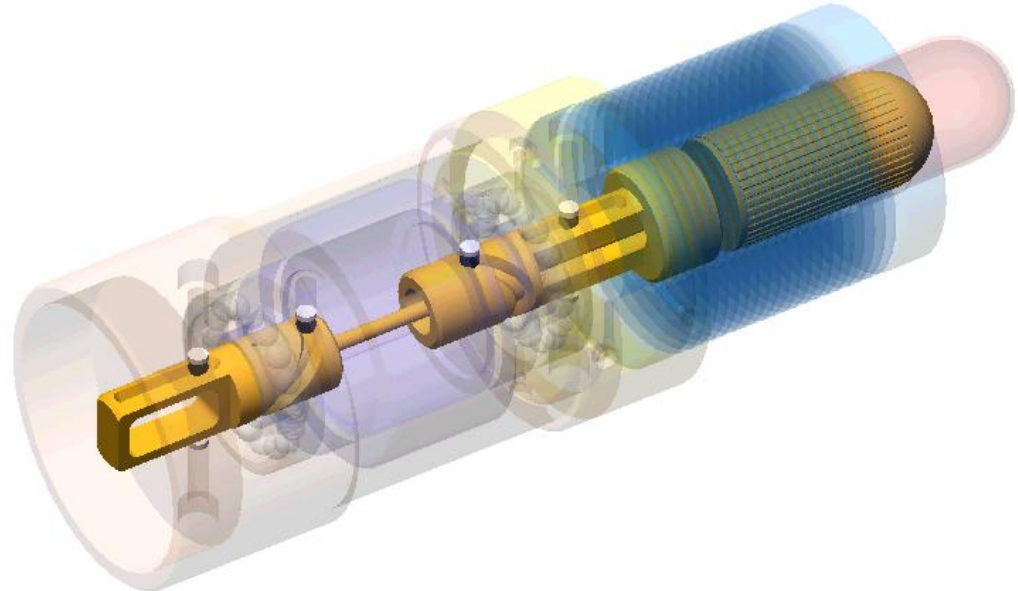
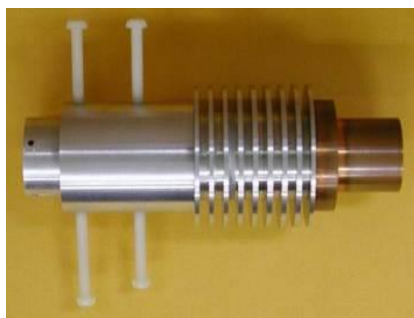


Miniature Engines (PEACE Lab., NCKU)



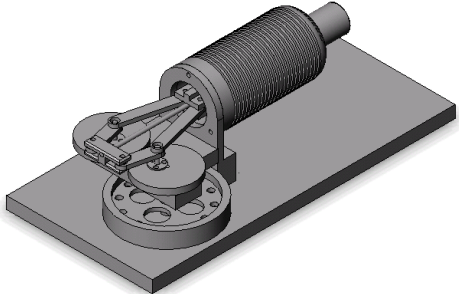


Miniature Engines (PEACE Lab., NCKU)





Miniature Engines (PEACE Lab., NCKU)





(1) Low-Temperature-Differential Stirling Engine (Logic System Technology Co.)





(2) Electronic Cooler (POLO Technology Co.)



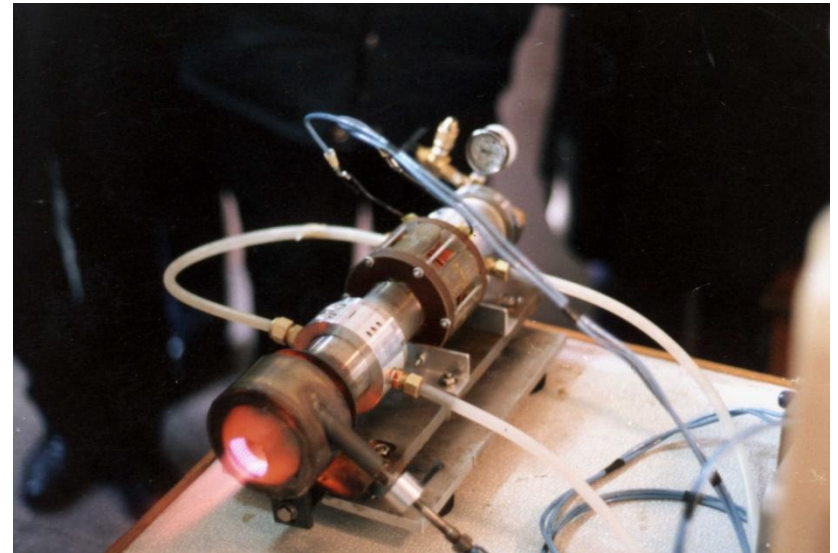
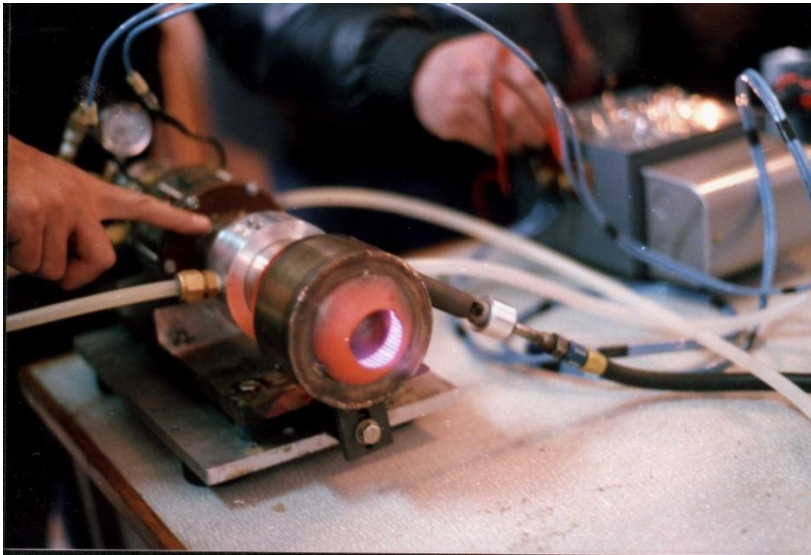


(3) Stirling Fan- Heat-Driven Water Heater Ventilation



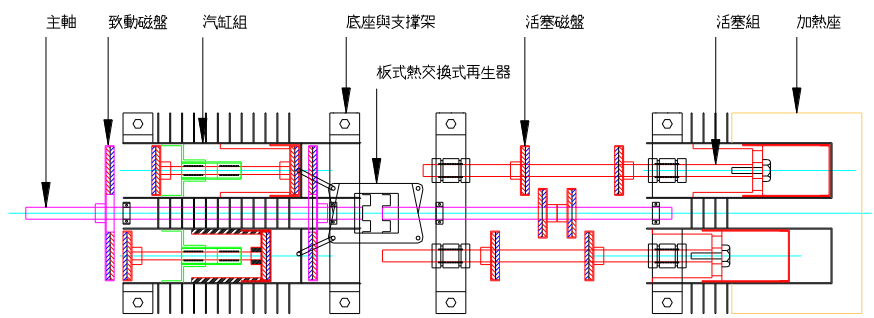
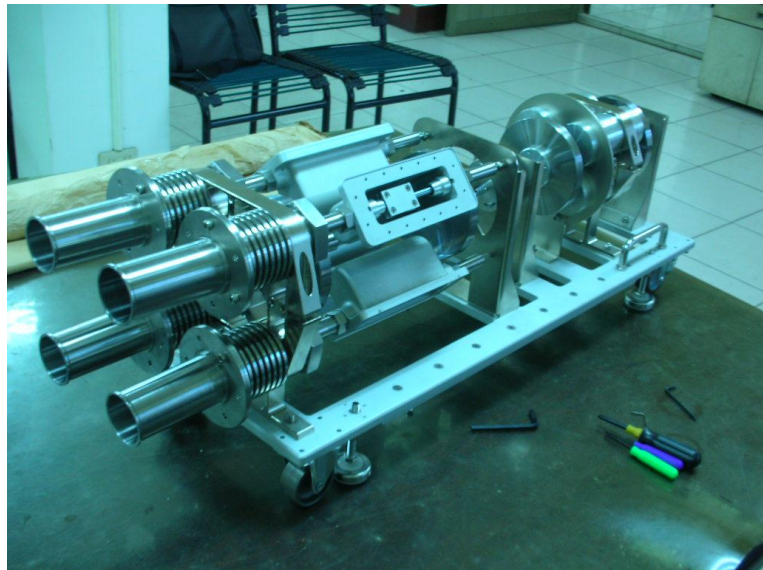
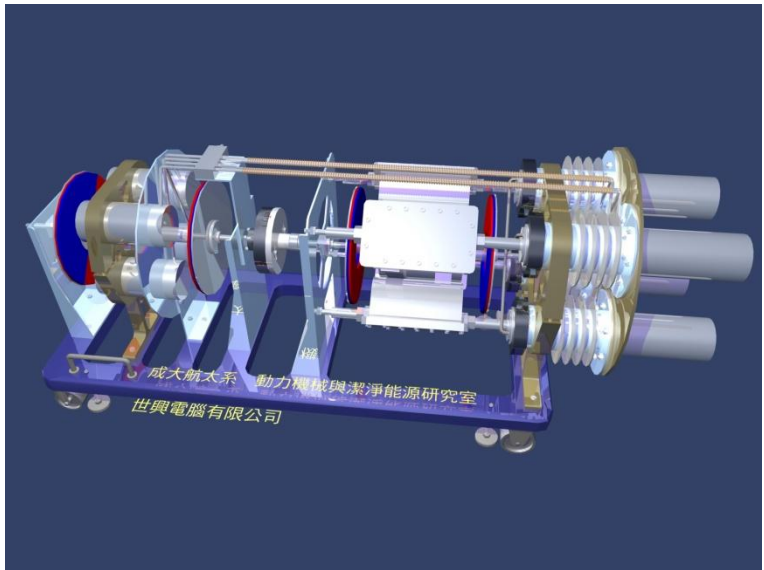


(4) 300-W Stirling Power Generator





(5) Magnetic-Enforced Stirling Engine



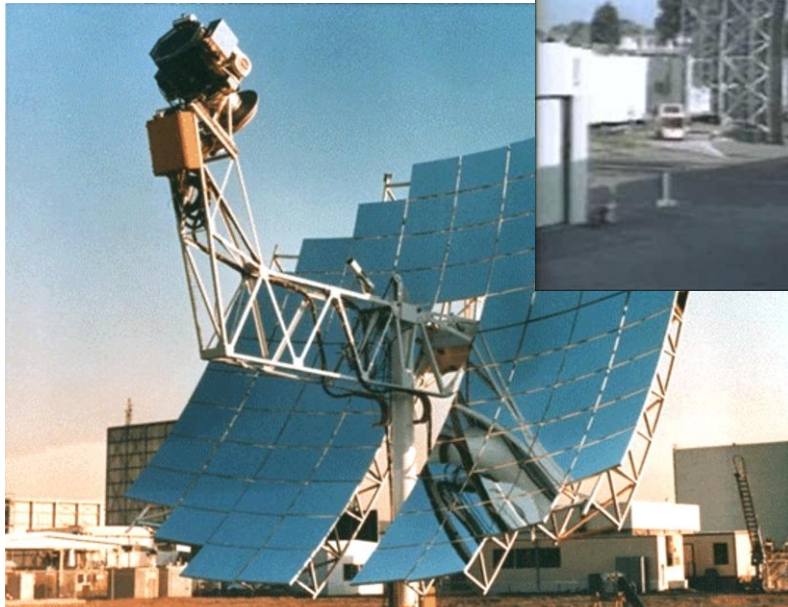


Potential Technologies

- Solar Thermal Dish/Stirling Power Systems
- Hybrid Stirling/Electric Cars
- Micro-Stirling Engines
- Energy Saving Units/Waste Heat Regeneration
- Auto-Start Electronic Cooling Devices
- Free-Piston Stirling Coolers (FPSC)
- Hydrogen Stirling Engines



Solar Thermal Dish/Stirling Power Systems



Source: Sandia National Laboratories

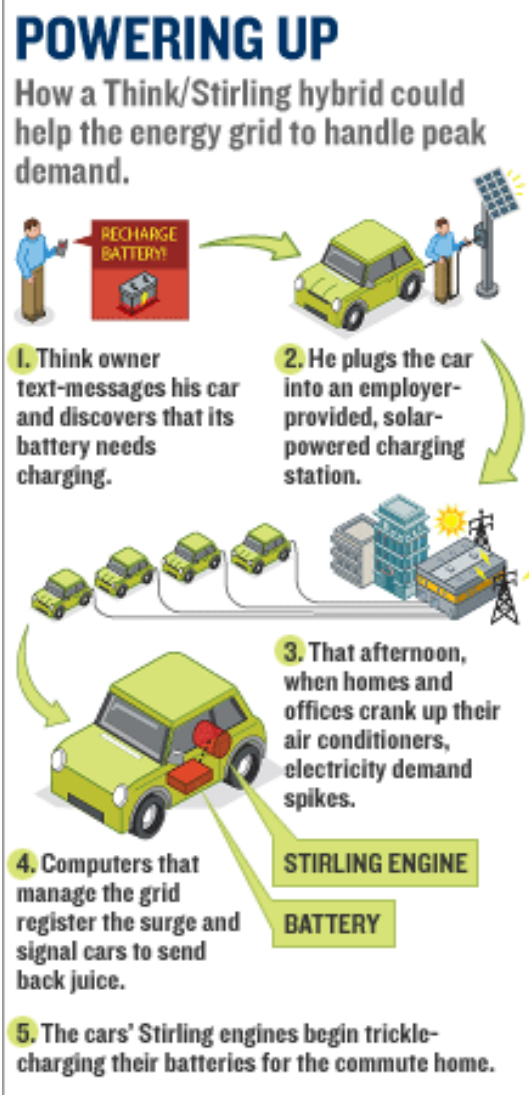


Hybrid Stirling/Electric Car



Norway's Think.
High-power lithium-ion batteries
Stirling engine
AC motor

Source: CNN money.com July 31, 2007.



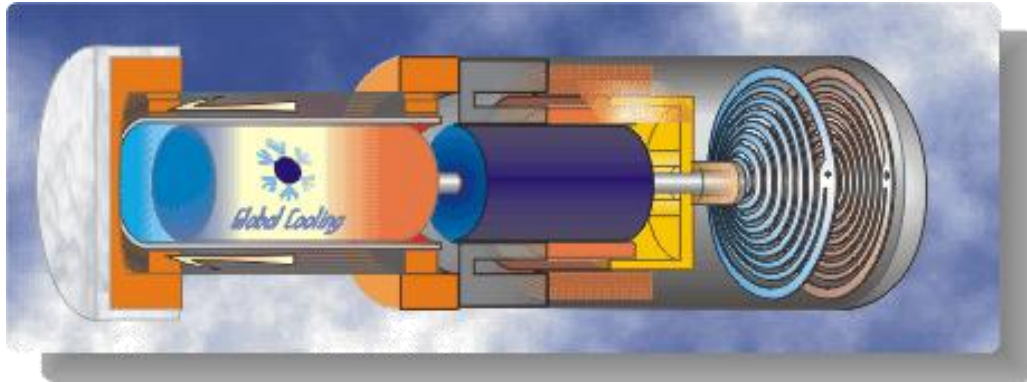


Free-Piston Stirling Cooler (FPSC)



Montreal Protocol
on substances that
deplete the Ozone
layer (CFC、HCFCs、
Halon)

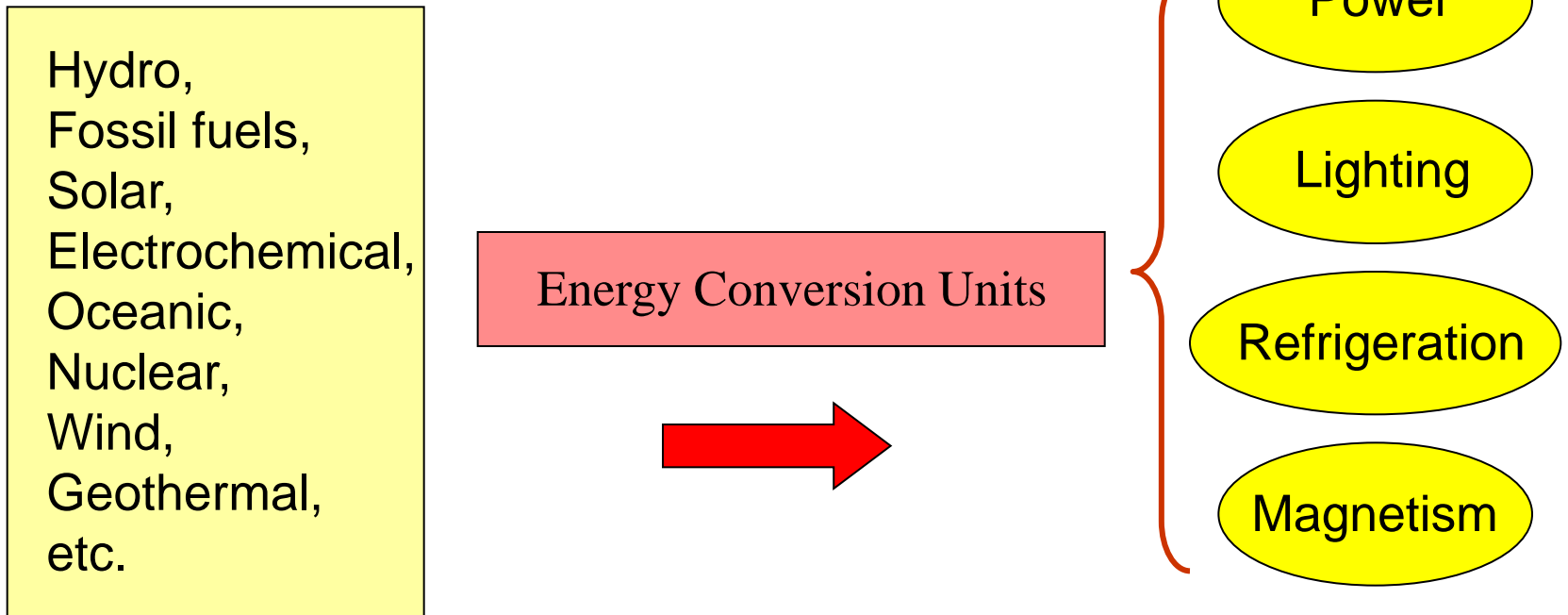
Kyoto Protocol
on greenhouse gases
(CO₂、PFCs、HFCs、
and SF₆) (GWP)



Source: www.globalcooling.nl



Summary



New Challenges = New Opportunities