ASME INTERNATIONAL GAS TURBINE INSTITUTE

ORC13 2ND INTERNATIONAL SEMINAR ON ORC POWER SYSTEMS

Keynote Lecture

Rotterdam, October 7, 2013

Short Review of the Long History of ORC Power Systems

Lucien Y. Bronicki

AMATITLAN GEOTHERMAL POWER PLANT, GUATEMALA

Carnot Teachings

The economy of the combustible is only one of the conditions to be fulfilled in heat engines. In many cases it is only secondary. It should often give precedence to safety, to strength, to the durability o… to the small space which it must occupy, … cost of installation, etc. To know how to appreciate in each case, at their true value, the consideration of convenience and economy which may present themselves; to know how to discern the more important of those which are only accessories to balance them properly against each other, in order to attain the best results by the simplest means: such should be the leading characteristics of the man called to direct, to co-operate towards one useful end, of whatsoever sort it may be.

RÉFLEXIONS

SUR LA

PUISSANC…

DU FEU

PAR S. C…

ANCIEN ÉLÈVE DE…

A PARIS,

CHEZ BACHEL…

QUAI DES AUGUST…

**

1824

"On ne doit pas se flatter de mettre à profit, dans la pratique, toute la puissance motrice des combustibles. Les tentatives que l'on ferait pour … plus

… tel doit être le principal talent de l'homme appelé à diriger, à coordonner entre eux les travaux de ses semblables, à les faire concourir vers un but utile de quelque genre qu'il soit."

"The economy of the combustible is only one of the conditions to be fulfilled in heat engines. In many cases it is only secondary."

"It should often give precedence to safety, to strength, to the durability of the engine, to the small space which it must occupy, to small cost of installation, etc."

"…in order to attain the best results by the simplest means:"

The Long History

1823
Sir Humphrey Davy suggest the ORC as an alternative to steam

1824
Carnot Teachings

1853
Du Trembley applies the ORC to ship propulsion (ether as motive fluid)

1883
Gantt, Maury, Wood studies of working fluids

1888
Yarrow develops the “Zephyr” for small boats, commercially not successful

Rapid improvements in the steam engine design and construction curtail the development of non-aqueous Rankine cycle systems.

The Long History

1930’s

Luigi D’Amelio experiments with ethyl chloride at the University of Naples

1935

Small solar pump based on D’Amelio’s work

1940’s

-1 MW geothermal plant in Citara, Ischia Island using Ethylene

-Gasperini and Grassi develop SOMOR solar pump using a refrigerant

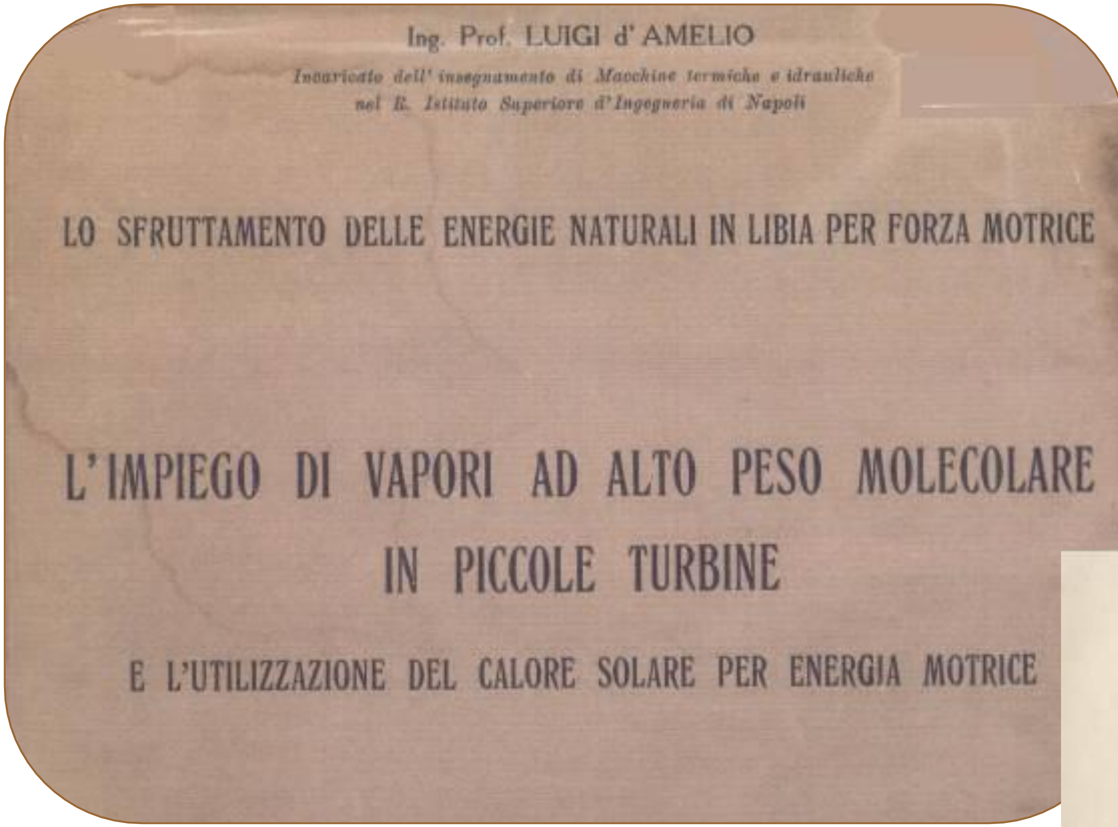
1958 to 1961

Tabor and Bronicki establish criteria for the selection of suitable fluids to optimize efficiency at the National Physical Laboratory in Jerusalem, Israel

1961

A new ORC cycle was developed with a 3kW prototype and presented at the UN conference in Rome. This work led to the establishment of Ormat in 1965.

D’Amelio’s first ORC turbine



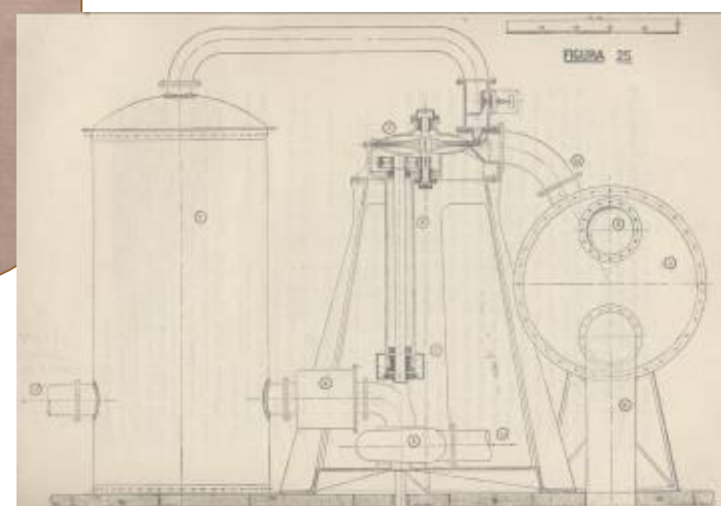
Ing. Prof. LUIGI d’ AMELIO

Incaricato dell’ insegnamento di Macchine termiche e idrauliche
nel R. Istituto Superiore d’Ingegneria di Napoli

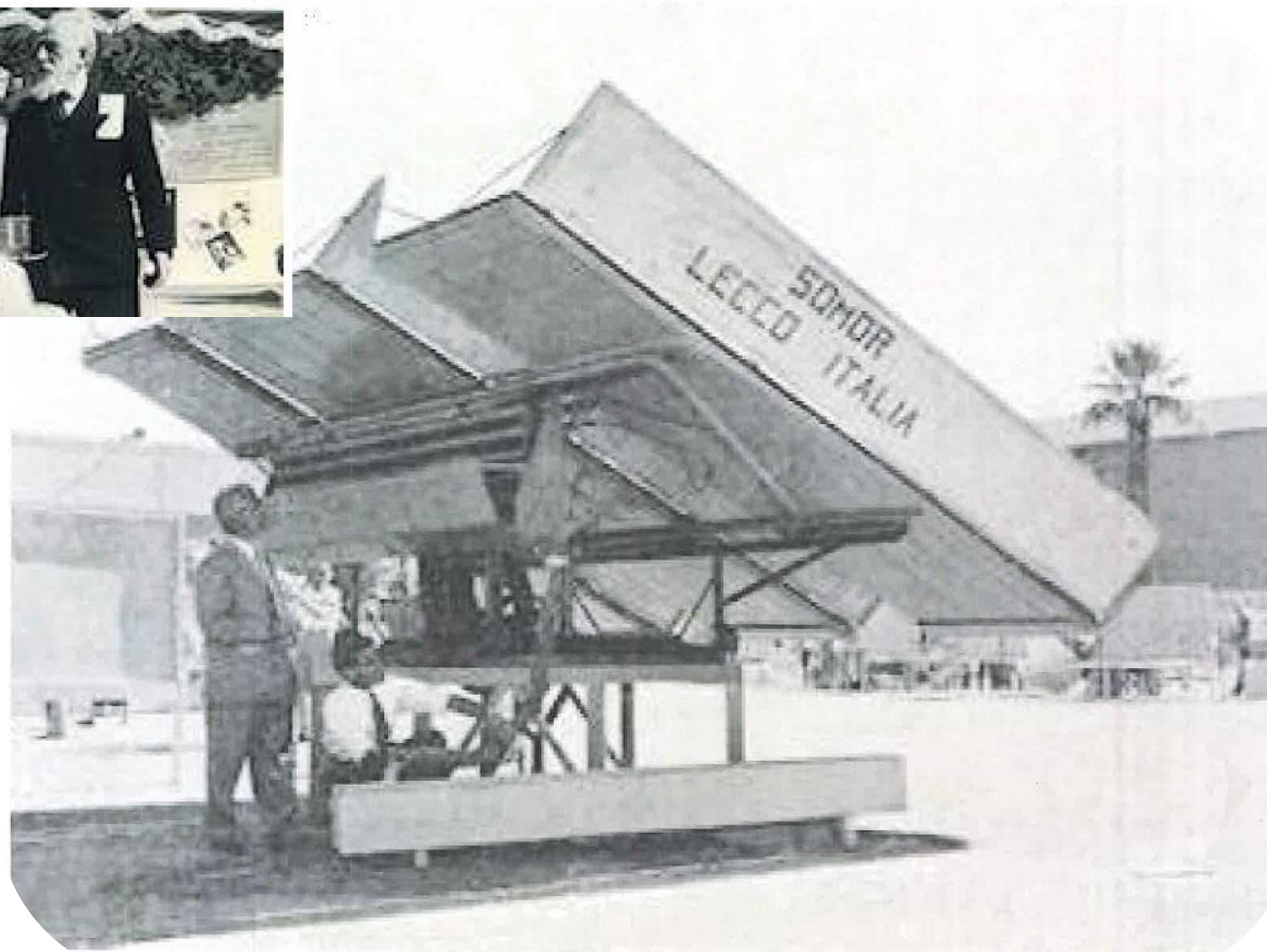
LO SFRUTTAMENTO DELLE ENERGIE NATURALI IN LIBIA PER FORZA MOTRICE

L’IMPIEGO DI VAPORI AD ALTO PESO MOLECOLARE
IN PICCOLE TURBINE

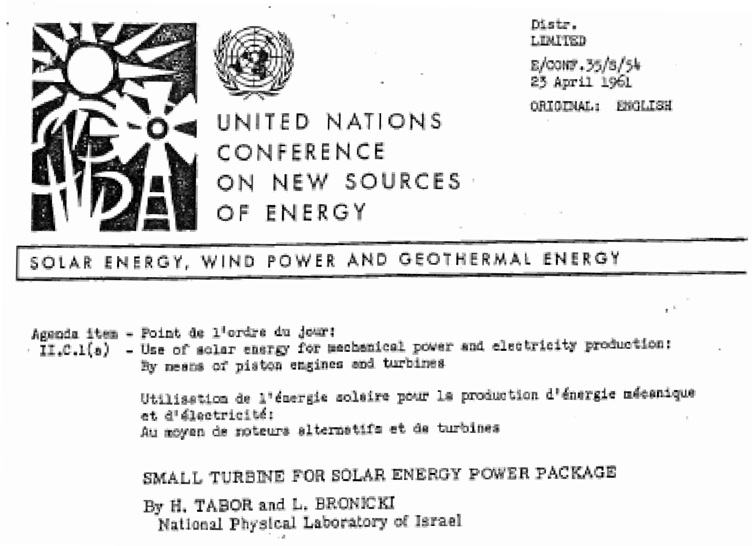
E L’UTILIZZAZIONE DEL CALORE SOLARE PER ENERGIA MOTRICE



SOMOR Commercial Solar Pump 1940's



3 kW Solar Unit Developed at NPLI in Israel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LIMITED
E/CONF.35/S/54
23 April 1961
ORIGINAL: ENGLISH

UNITED NATIONS CONFERENCE ON NEW SOURCES OF ENERGY

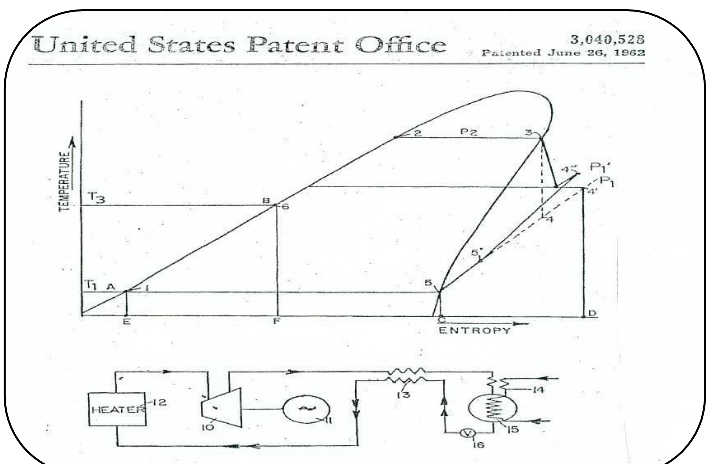
SOLAR ENERGY, WIND POWER AND GEOTHERMAL ENERGY

Agenda item - Point de l'ordre du jour:
II.C.1(a) - Use of solar energy for mechanical power and electricity production:
By means of piston engines and turbines

Utilisation de l'énergie solaire pour la production d'énergie mécanique et d'électricité:
Au moyen de moteurs alternatifs et de turbines

SMALL TURBINE FOR SOLAR ENERGY POWER PACKAGE

By H. TABOR and L. BRONICKI
National Physical Laboratory of Israel



Test were conducted with 16 different potential motive fluids to determine their reactivity to common metals and mineral oils.

The Long History

1965

Ormat commercializes its fuel powered ORCs from, 0.5 to 4kW, for remote unattended operation

1970's

Gianfranco Agelino, Ennico Macchi and Mario Gaia pursue to develop a 3KW ORC, leading to the establishment of Turboden in 1980.

1980's

Turboden manufactures units from 300kW up mainly for CHP using biomass

1990's

Ormat has substantial growth in the use of ORC in geothermal worldwide, Turboden provides numerous CHP systems in Europe

2000

A number of ORC packagers and component suppliers are available along with new technologies and research.

First Ormat hermetically sealed solar unit powering an electric water pump in Mali, Africa

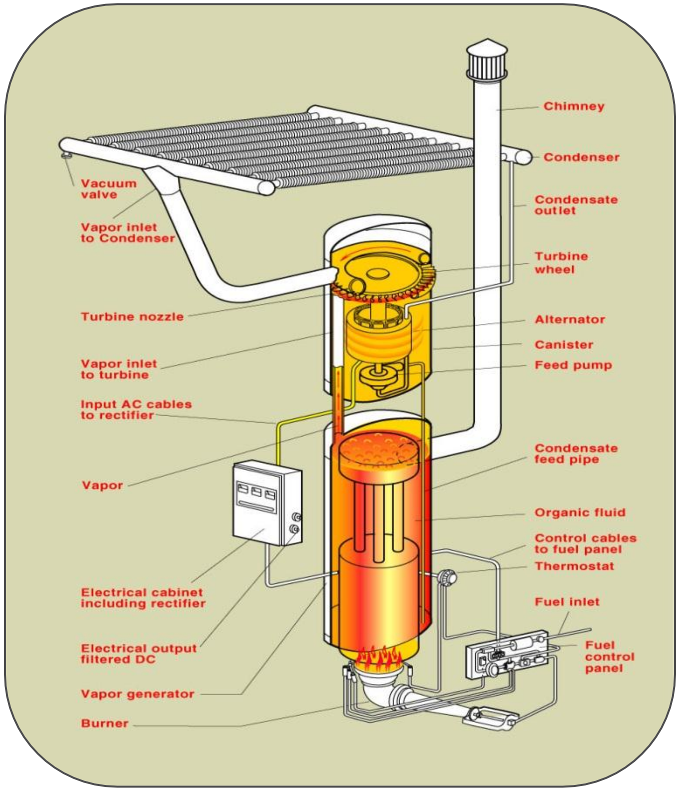
Characteristic	Value
TURBOGENERATOR	
Nominal Output	600 W
Boiler Temperature	90 – 125 °C
Max Power Output	700 W
COLLECTORS	
Total Net Collector Area	43 m^2
Auxiliary Mirror Area	16 m^2
Max Heat Output	12 kW
Average Useful Heat Output	35 kWh/day
PUMP	
Max Flow at 40m head	3 000 l/hr
Average Quantity Pumped	11 000 l/day

1966

Fuel operated Hermetically Sealed ORC Units

3000+ build for Remote Unattended Sites

120 Remote ORC Units
Providing Power and Heat to
62 Remote Gate Valve Stations
along the TransAlaska Pipeline
-most still in operation since 1976



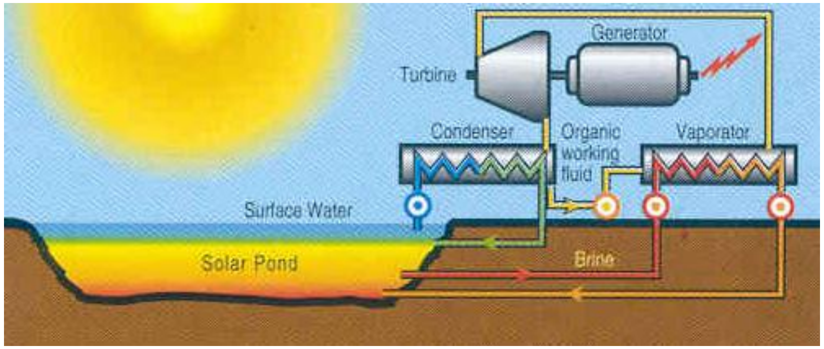
Boiler temp 130 °C ; ambient temperature +35 to -60 °C
Propane consumption at 600 W : 1.2 kg/hr ; operating hours: 26 Million

Dual Fluid Radioisotopically Heated ORC

Characteristic	Value
ORC	
- First Stage:	
Boiler Temperature	195°C
Condensing Temperature	112°C
- Second Stage:	
Boiler Temperature	100°C
- Condensing Temperature	45°C
- Electrical Output	680 W
Heat source Cobalt 60 Isotope	
Life span: 2 years	
Thermal Output	4.8kW

5 MW Solar Pond Power Plant 1982 at Dead Sea, Israel

Characteristic	Value
Ormat Energy Converter	
Brine Inlet Temp.	85 °C
Brine Flow Rate	10M l/hr.
Cooling Water Inlet Temp.	27°C
Cooling Water Flow Rate	10M l/hr.
Turbine Stage Efficiency	83%
Generator Output	5070 kW
Net Output	4000 kW

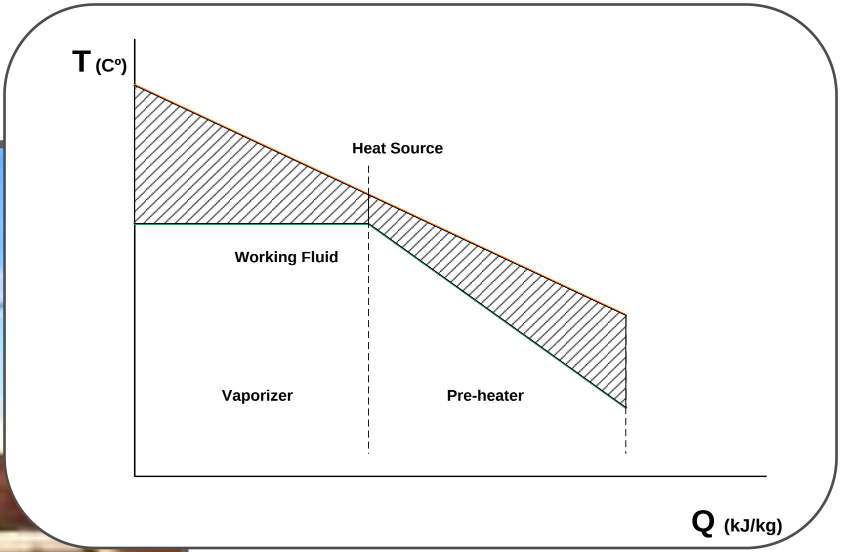


A number of prototypes (most are decommissioned)

- Mutnovsky geothermal plant in Kamtchatka
- I.K. Smith, City University of London, triangular cycle, screw expander
- MTI
- Sundstrand
- EDF Ammonia bottoming ORC
- Thermoelectron
- BiPhase turbine
- Bertin
- Rocketdyne
- Lappeenranta University of Technology
- IHI
- Kalina
- Barber Nichols – 2 plants (still in operation)
- Ben Holt – 2 plants (still in operation, refurbished with Ormat turbines)

Ormat's First Commercial Geothermal ORC 1984

1984 Wabuska Geothermal Power Plant, Nevada
– still in commercial operation



Simple ORC
Source at 104 °C
Sink at 25 °C
Output gross 800kW
net 720kW

The Long History

1965
Ormat commercializes its ORC from, 0.5 to 4kW, for remote unattended operation

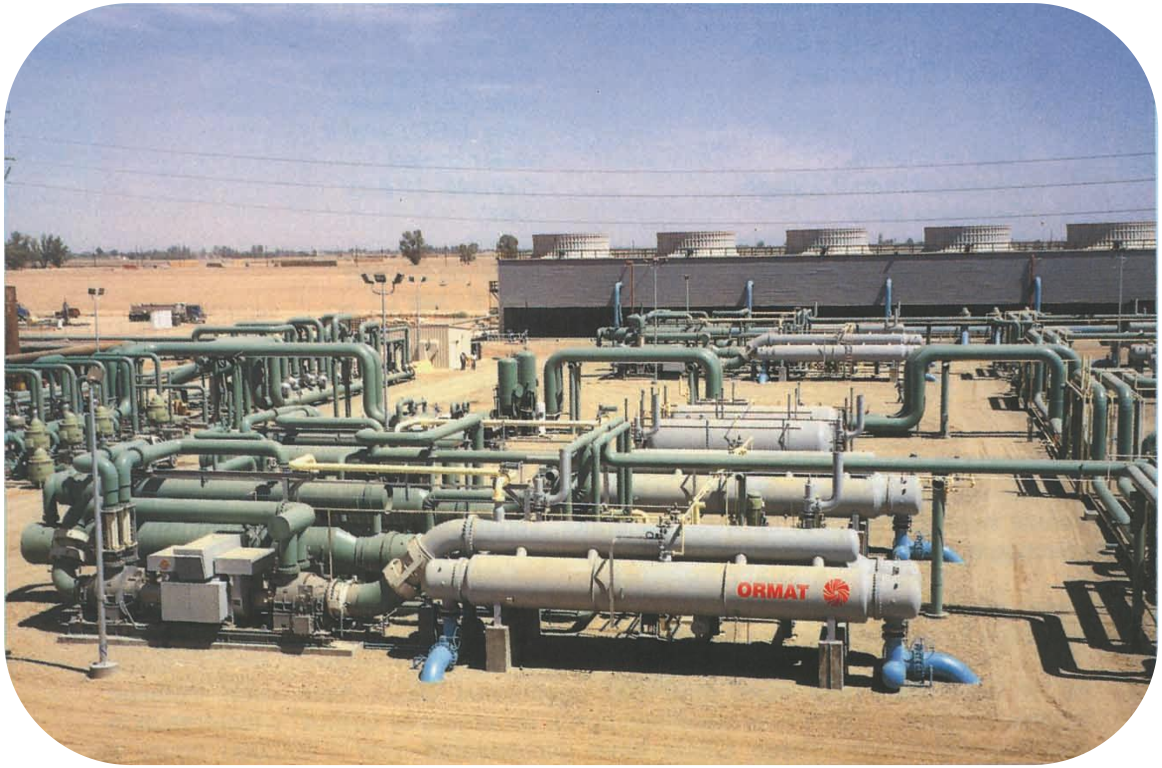
1970's
Agelino, Macchi and Gaia pursue to develop a 3KW ORC, leading to the establishment of Turboden in 1980.

1980's
Turboden manufactures units from 300kW up mainly for CHP using biomass
Ormat commissions its first geothermal ORC

1990's
Ormat has substantial growth in the use of ORC in geothermal worldwide, Turboden provides numerous CHP systems in Europe

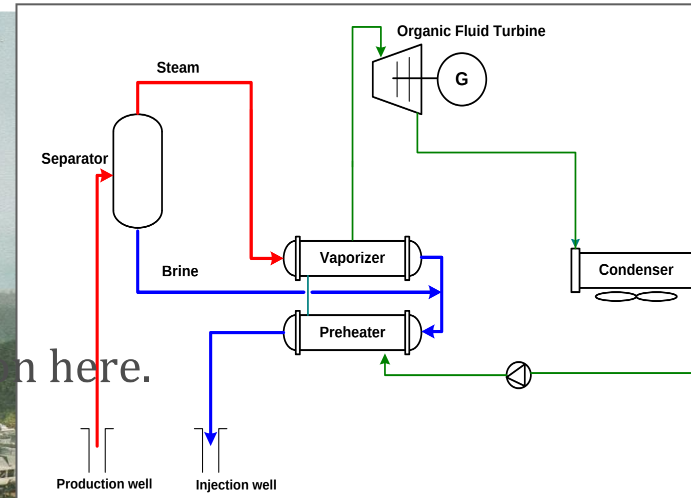
2000
A number of ORC packagers and component suppliers are available

Comparing ITLU and Supercritical Cycles



Source at 137/98 °C
Cooling water:39 °C
Output gross/net 35.4/32.9 MW

Two-Phase Geothermal Power Plant
1994 Azores Islands, Portugal



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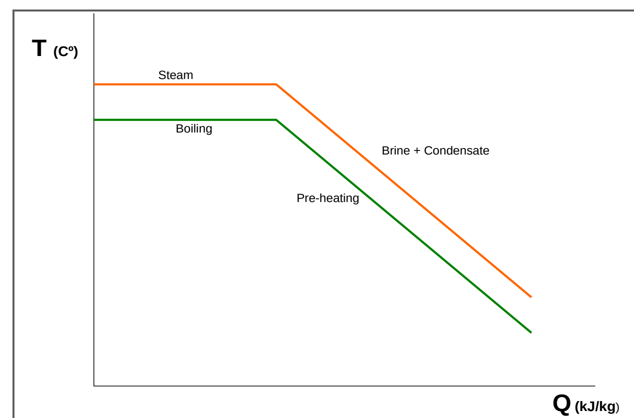
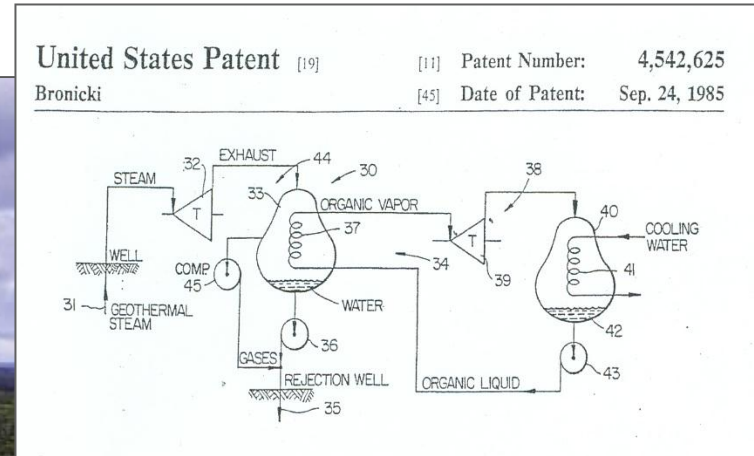


Fluid: N-pentane
Source : 158.5 °C; 2 phase flow (total): 390 ton/hr
Cooling air: 30 °C
Output gross/net; 7490/6385 kW

Ormat's 30 MW Geothermal Combined Cycle Puna, Hawaii, operating since 1992



Ormat's First Application of ORC to a Gas Compressor Station, operating since 1999

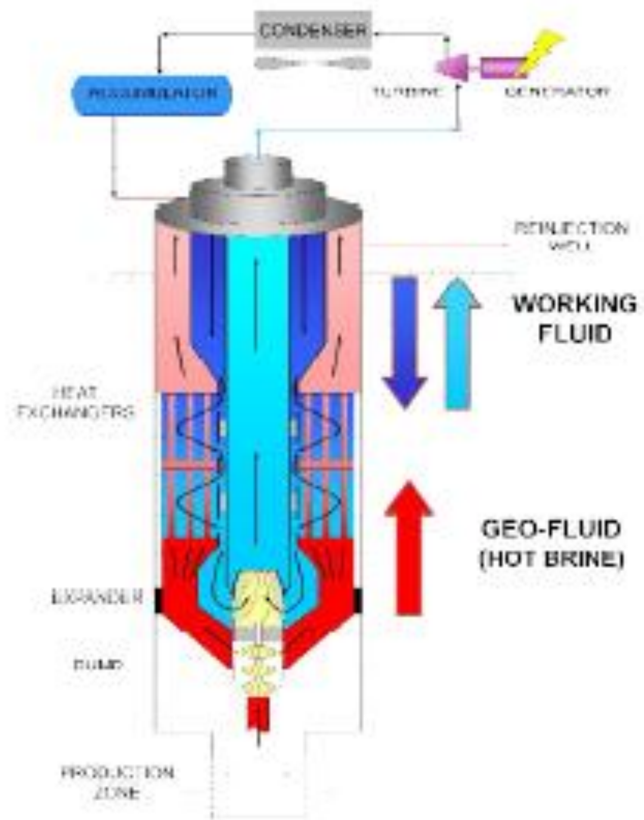
Heat source: Exhaust of RR RB211 Gas Turbine
Capacity (mechanical drive) : 25 MW
ORC capacity: Gross/Net 6.46/5.72 MW
ORC net efficiency: 17.3%
Ambient temperature: + 35 °C to -35 °C

Present ORC Manufacturers, Integrators, Suppliers

- Ormat
- Turboden
- TAS
- Atlas Copco
- United Technologies Pure Cycle – discontinued
- General Electric
  - Clean Cycle – small, some installations
  - ORegen – first pilot under construction
- Exergy
- SME:
  - Electratherm
  - GMK
  - Tri-O-Gen
  - Energent

GeoTek Energy LLC

- Integration of Pumping and Power Production in ORC

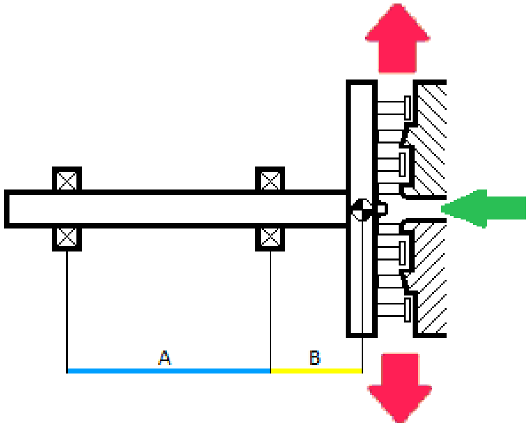


EXERGY RADIAL OUTFLOW TURBINE

In the radial outflow turbine, the flow enters axially into the center and flows radially outwads through the various stages.

Main features:

- Cross section increases across the expansion stages, together with the increment of volumetric flow, allowing for a high volumetric ratio
- Multiple stages and pressures on a single disk
- Low vibrations, due to distance 'B' being fixed no matter how many stages
- Straight blades
- Overhung configuration
- Available on a wide range of power output



Hurdles and Challenges for Geothermal

Geothermal Plants: Integration of Upstream and Downstream

- Similarities with oil and gas
  - "Fuel" supply similar to oil and gas – exploring, drilling
  - Power conversion similar to thermal power plants
- Differences
  - Link of upstream and downstream
  - Value of one barrel produced
    - **Oil: $30 ?**
    - **Water at 150°C: 30 Cents**
- The challenge
  - Explore, drill, produce for the same cost per barrel as oil BUT for 1/100 of the revenue, at availabilities of Base Load Power Plants

Hurdles and Challenges for ORC Heat Recovery

Waste Heat Recovery: Always Secondary

- Will not be “off the shelf” for industrial processs
  - Each application requires substantial engineering
  - Space and process constraints are unique to the site
  - Little tolerance for being offline
- Industrial processes became more efficient, reducing quality and quantity of waste heat
- Utilization of exhaust heat from combustion engines is better, but engines are becoming more efficient

Ormat:35 Years of ORC Pioneering and Commercialization

From 2kW power units at a hot spring of 120°F (48.9°C) in Alaska (1979)

To a 95 MW power plant at a high enthalpy resource of 382°F (194.4°C) in New Zealand (2013)

Smallest Geothermal Plant

World's Largest Binary Power Plant!

- Over four decades of experience
- Established renewable pure-play
- Technology leader with over 82 U.S. patents
- Over 1600 MW of constructed capacity
- Owns and operates 595 MW of installed capacity in 17 complexes and power plants

NYSE	ORA
Share Price:	$26.67
52wk Range:	$16.67 - $26.73
Avg. Vol. (3m):	95,217 shares
Market Cap:	$1,210 RM
FY12 Rev.:	$501M

THANK YOU!

84 MW Ormat plants in Reno, NV: supplies electricity to all households in Reno