Thermal Energy Storage system level

AAE- E3080/81 Thermal Energy Storage Systems

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Learning outcome of this session

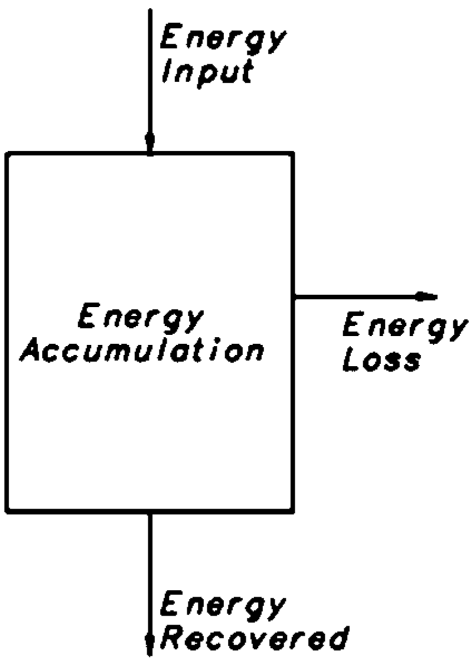
Perform energy conversion and energy balance analysis on sensible heat electric thermal energy storage systems

Able to determine different technologies to convert heat into electricity

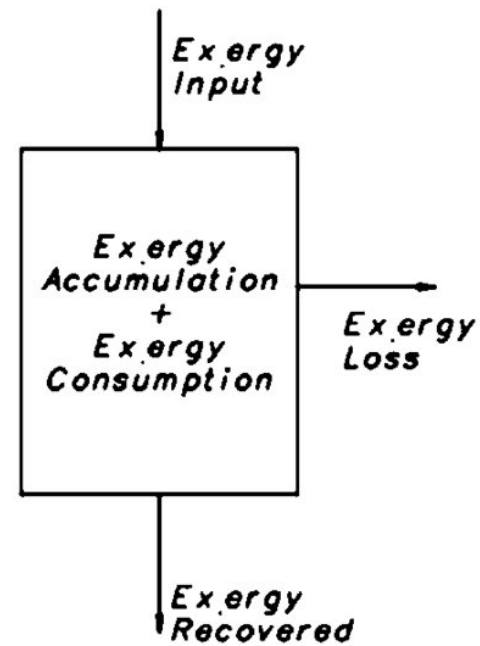
TES systems

Energy & Exergy Balance of TES Systems

- **Energy Balance**



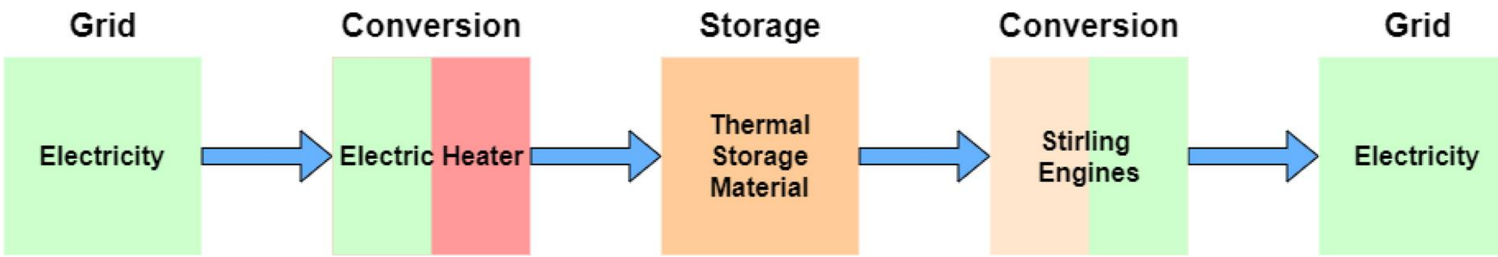
- **Exergy Balance**



A. Sowale et al., “Thermodynamic analysis of a gamma type Stirling engine in an energy recovery system,” Jun. 2018, doi: 10.1016/j.enconman.2018.03.085.

Energy Conversion in TES-electricity to electricity

Heat losses to
the environment.



No losses when using an
Electric resistance heater.

Energy losses due to
work done.

Sensible Heat Storage

$$\triangle Q = m * \int_{T_1}^{T_2} C_p(T) * dT$$

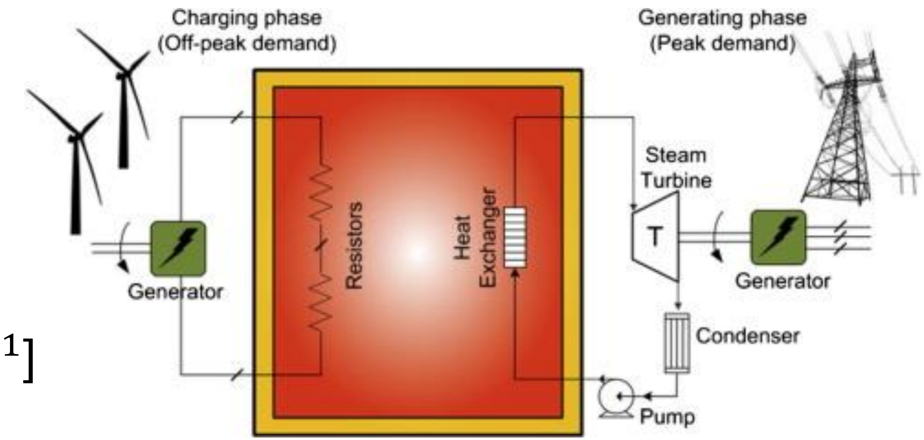
Where

$\triangle Q$ is the energy stored [J]

m is the mass of storage medium [kg]

C_p is the specific heat capacity $[\mathrm{J.kg^{-1}.K^{-1}}]$

dT is the temperature difference [K]



Question

What is the energy stored in sand when the temperature is raised from 37 °C to 250 °C?

Take the mass and specific heat capacity as 1538 kg and 1130 $\mathrm{J.\,k}g^{-1}.\mathrm{K}^{-1}$ repectively

$$\triangle \boldsymbol{Q} = \boldsymbol{m} * \int_{T_1}^{T_2} \boldsymbol{C_p(T)} * \boldsymbol{dT}$$

Answer

$$\boldsymbol{Q} = m.cp.(T_2 - T_1)$$

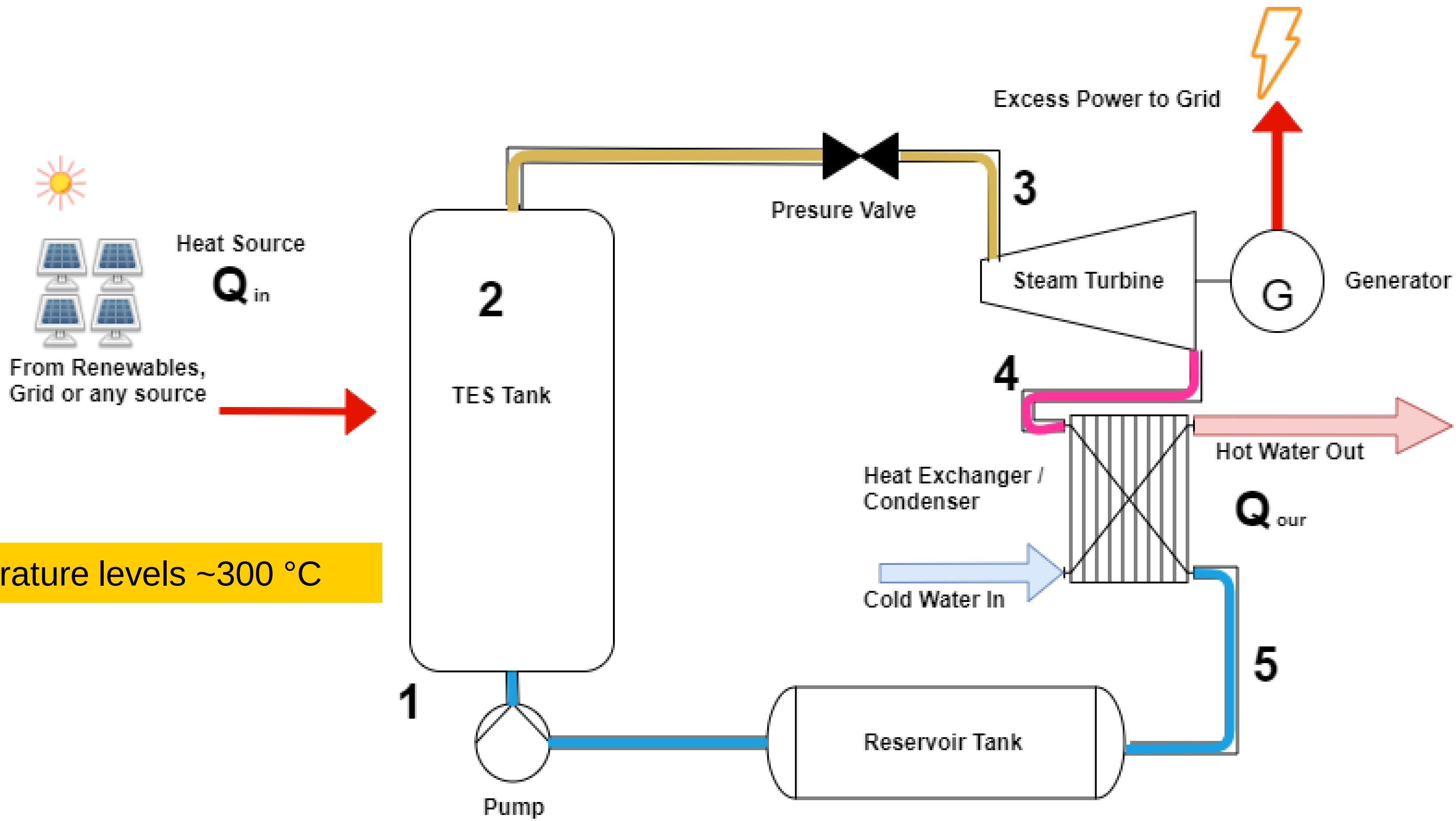
$$\boldsymbol{Q} = 1538\text{kg} * 1130\text{J}.\text{k}g^{-1}.\text{K}^{-1} * (250 - 37)\text{K}$$

$$\boldsymbol{Q} = \mathbf{370}\ \boldsymbol{MJ}$$

Heat to Electricity Conversion

TES Rankine Cycle

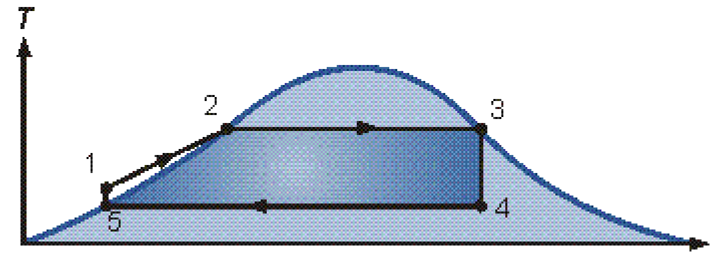
Old way heat to electricity

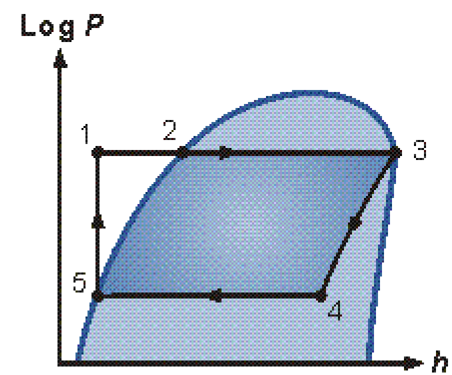


Temperature levels ~300 °C

A?

Rankine Cycle Process





1-2-3: Isobaric Heat Transfer

3-4: Isentropic Expansion

4-5: Isothermal Heat Rejection

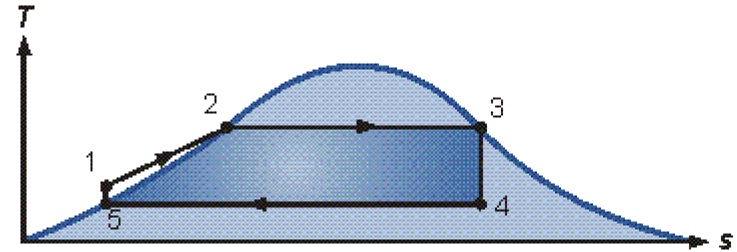
5-1: Isentropic Compression

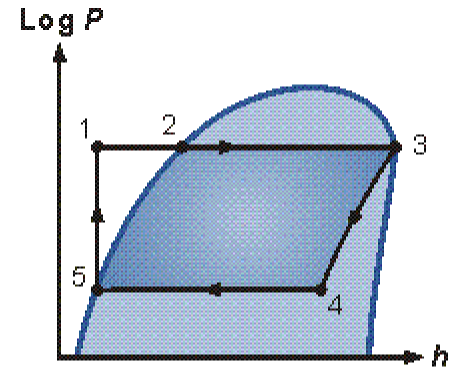
R.C Equations

$$Q\ in = m(h3 - h1)$$
$$W\ out = m(h3 - h4)$$
$$Q\ out = m(h4 - h5)$$
$$W\ in = m(h1 - h5)$$

$$Thermal\ Efficiency = \left[\frac{(work\ out\ - work\ in)}{heat\ in}\right]$$

$$R.C\ Efficiency = \left[\frac{m(h3 - h4) - m(h1 - h5)}{m(h3 - h1)}\right]$$

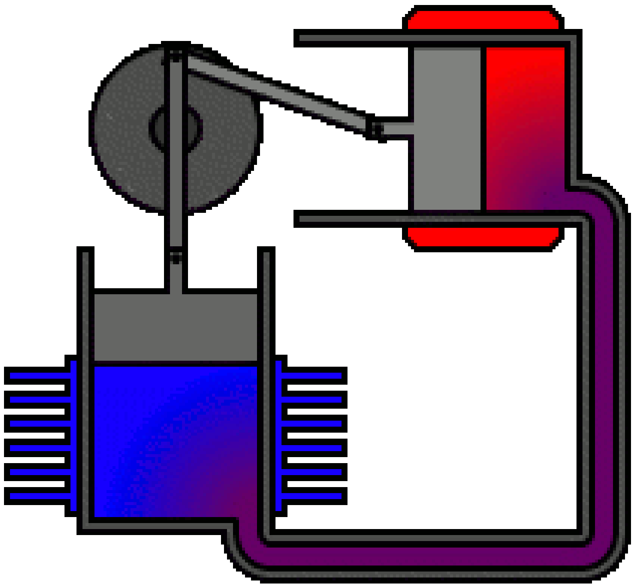




Thermal Efficiency is 33%

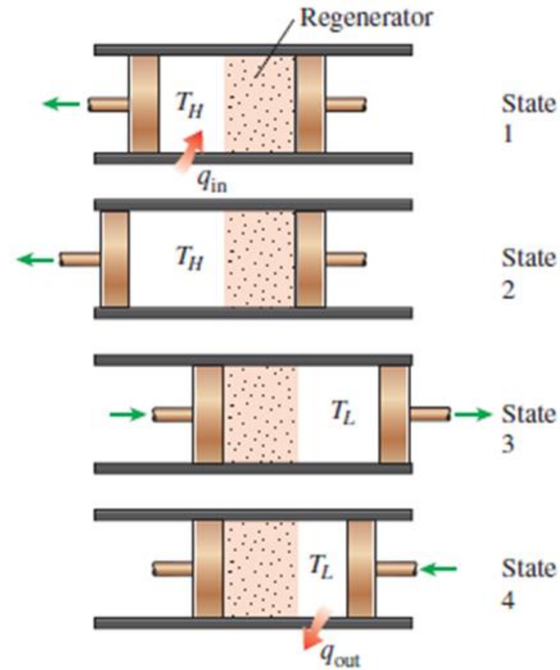
What is Stirling Engine?

- Converts heat energy to mechanical power
- Compresses and expands working fluid (air, He, H)
- Some employs regeneration mechanism

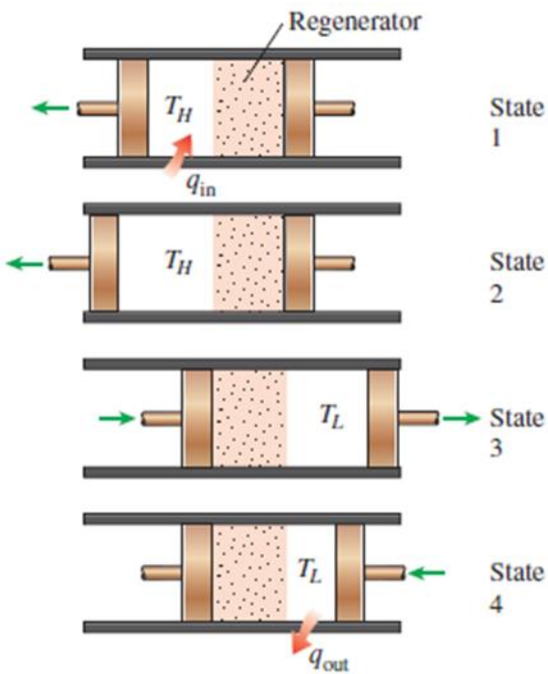


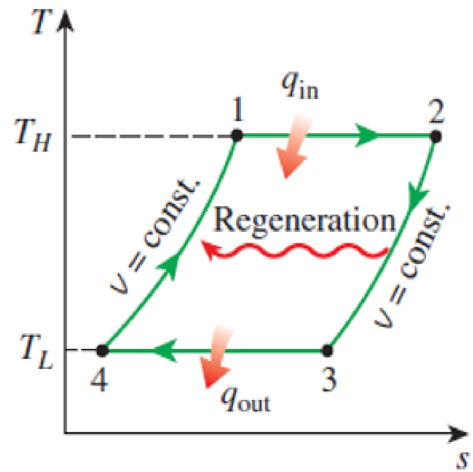
Operating Principle

1. **Constant heating on one cylinder and the other cylinder is constantly cooled**
2. **Air expands in the hot cylinder and push a piston.**
3. **The cold cylinder contracts the air and pulls the piston.**
4. **The alternating expansion and contraction makes the engine run.**

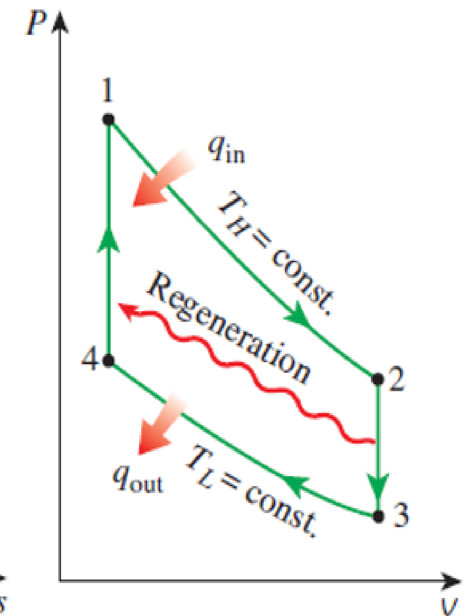


Operating Principle





T-s Diagram of Stirling Cycle



P-v Diagram of Stirling Cycle

Fundamental Equations

First Law of Thermodynamics

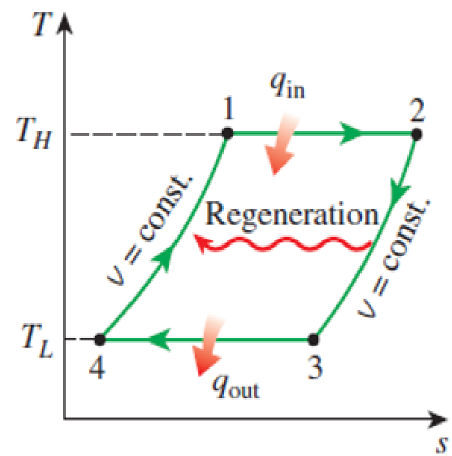
$$W_{net} = W_{1-2} + W_{3-4} = q_{in} - q_{out}$$

Thus thermal efficiency

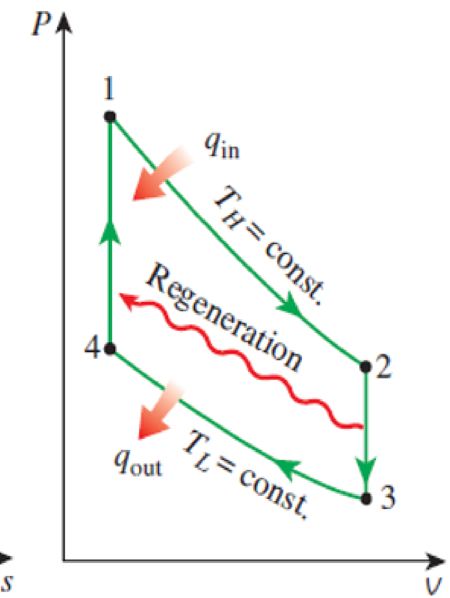
$$\eta_{th} = \frac{W_{net}}{q_{in}} = \left(1 - \frac{q_{out}}{q_{in}}\right)$$

Carnot efficiency

$$\eta_{th} = \left(1 - \frac{T_L}{T_H}\right)$$



T-s Diagram of Stirling Cycle



P-v Diagram of Stirling Cycle

Question?

A Stirling Engine has a rated power of 2.5 kW when the hot side cylinder is 500°C and the cold side is kept at 25°C constant temperature. Calculate the Carnot efficiency.

$$\eta_{th} = \left(1 - \frac{T_L}{T_H}\right)$$

Answer

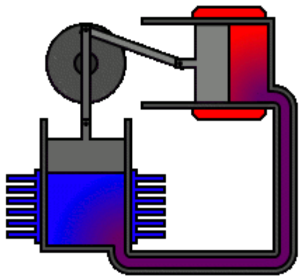
$$\eta_{th} = \left(1 - \frac{T_L}{T_H}\right)$$

$$\eta_{th} = \left(1 - \frac{25 + 273K}{500 + 273k}\right)$$

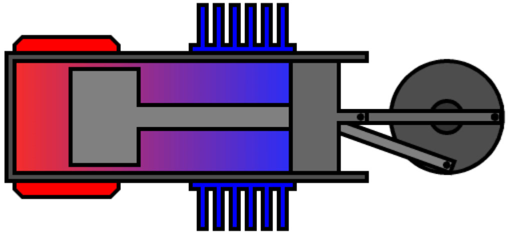
$$\eta_{th} = \mathbf{61\%}$$

3 major types of Stirling Engines

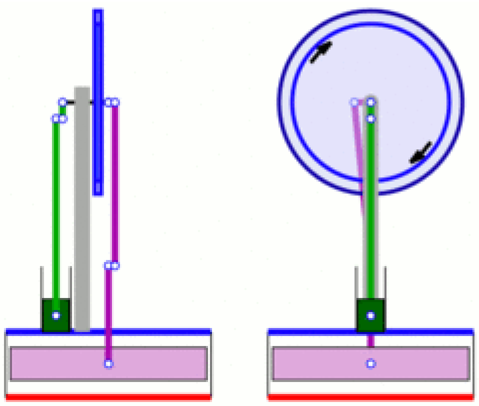
Alpha Stirling Engine



Beta Stirling Engine



Gama Stirling Engine



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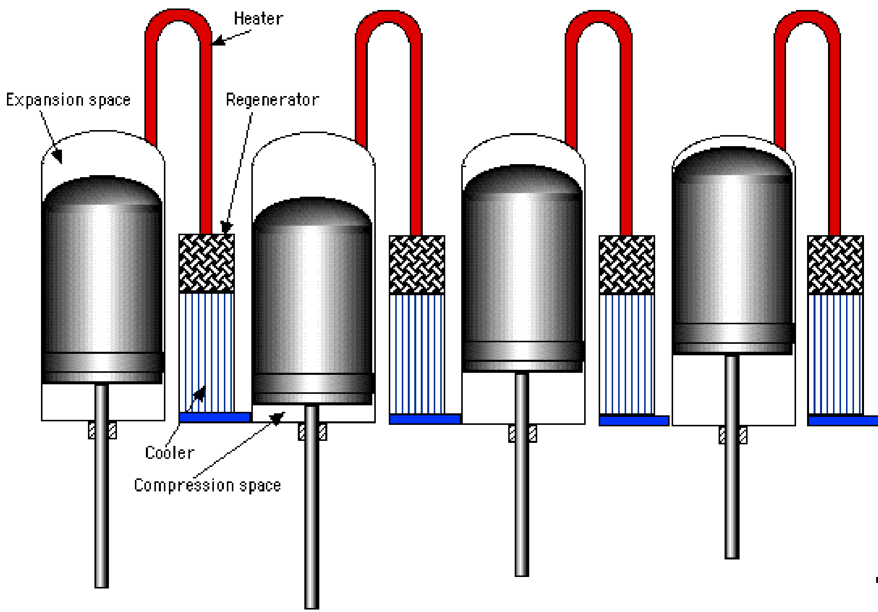
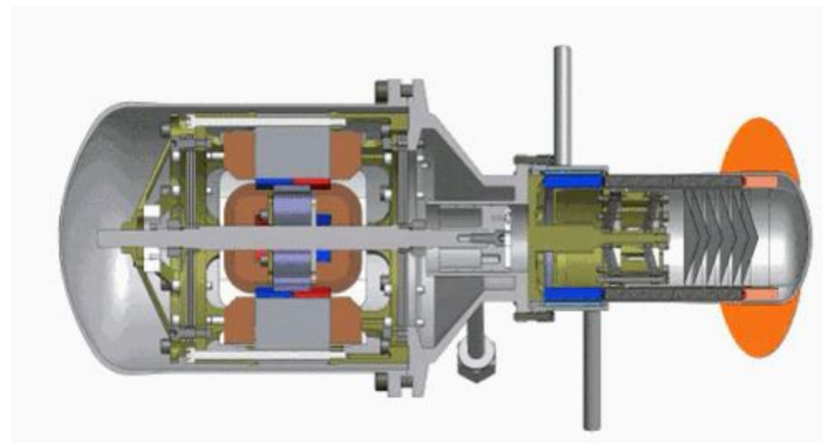
Advanced Stirling Engines

Double - Acting Stirling Engine

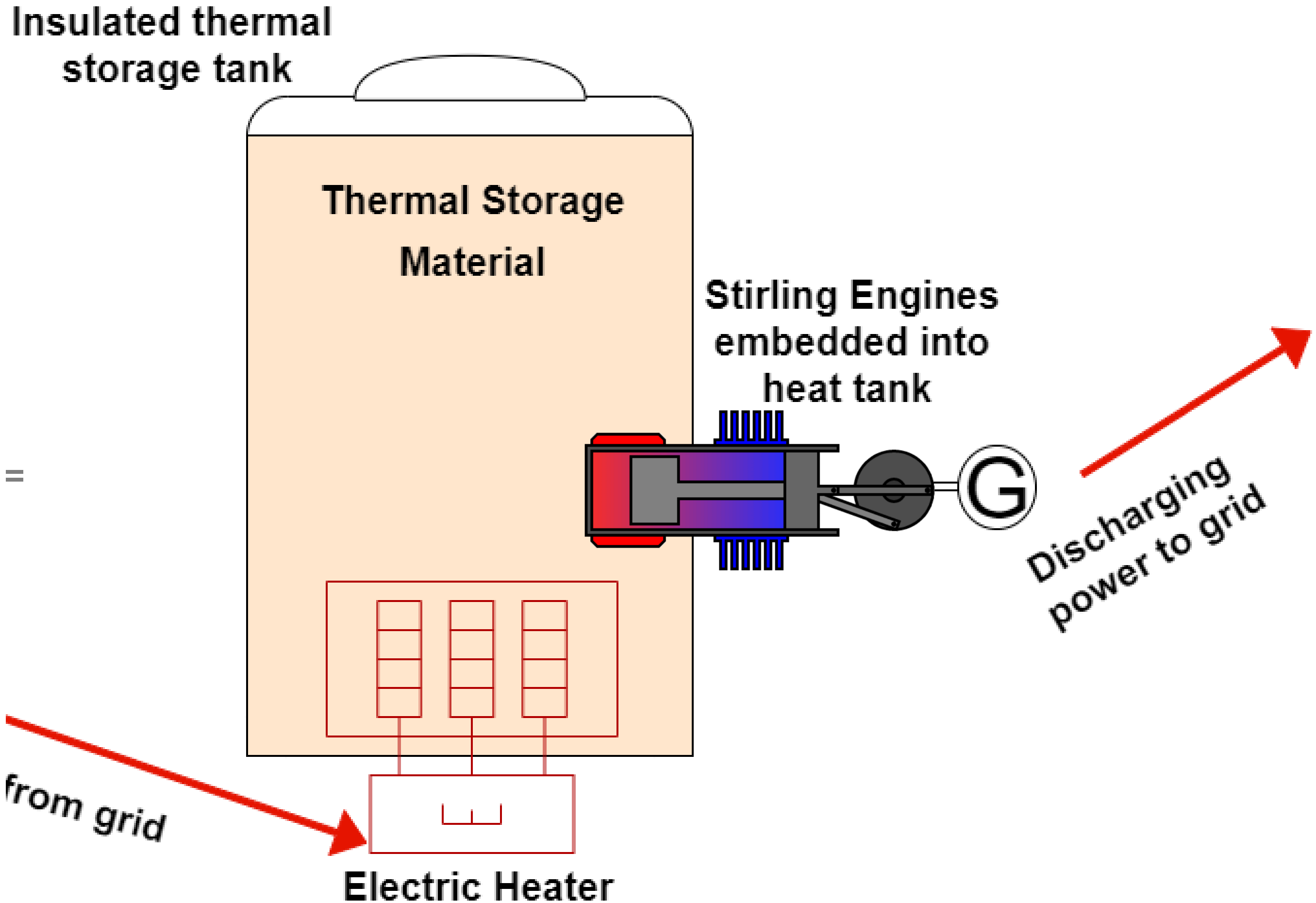


Free - Piston Stirling Engine



Thermal Efficiency is 40% and more

Stirling Engine in TES



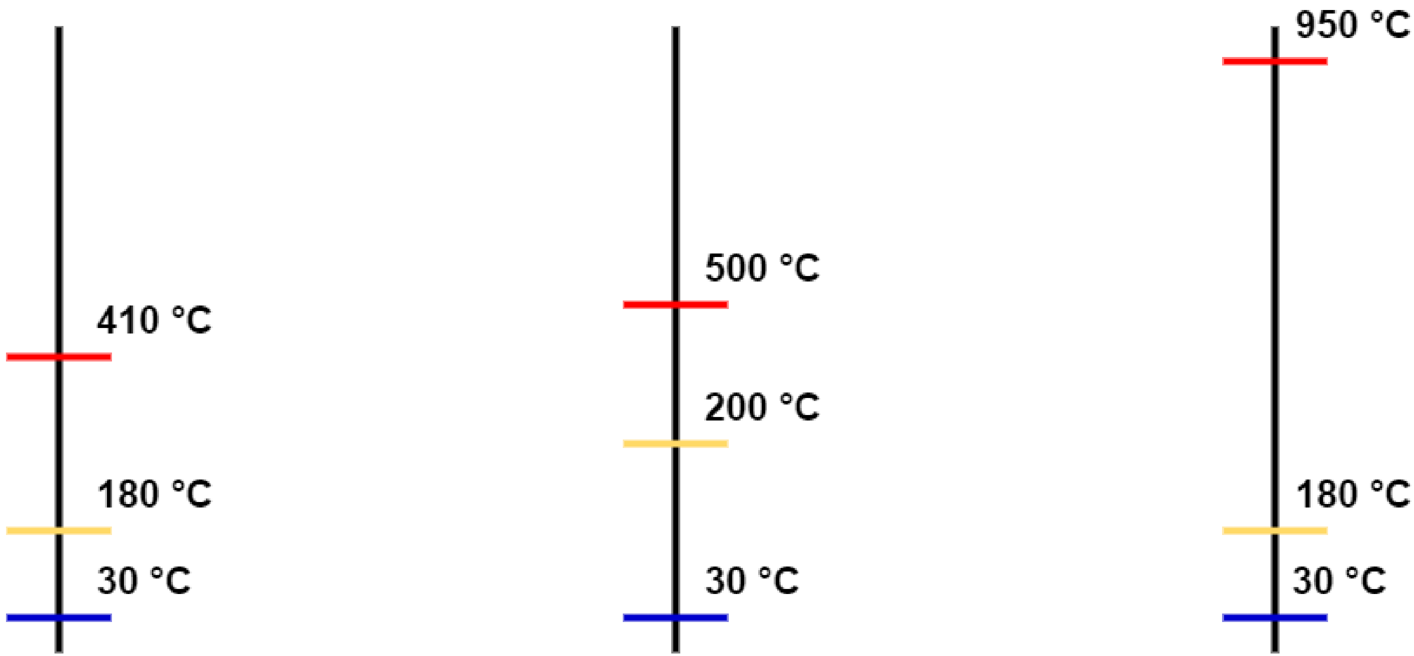
S. Tetteh et al. (2021) The Journal of Energy Storage 41(6):102829
DOI: 10.1016/j.est.2021.102829

TES Material Options

Thermal Oils
Storage Efficiency 35%

Molten Salts
Storage Efficiency 39%

Sands
Storage Efficiency 48%



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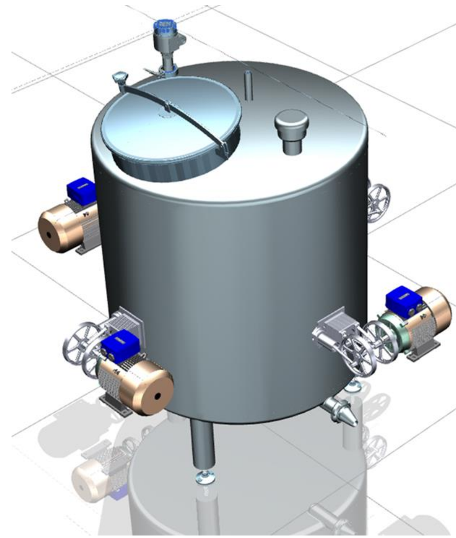
ETES with thermal Energy Storage Materials



Lithium-ion Battery	Thermal Oil	Molten Salt	Sand
565 €/kWh	137 €/kWh	64 €/kWh	17 €/kWh

↓ 33 X cheaper

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Take a home message

TES provides low cost of electric storage and low dependence on critical materials

Heat pumps - Online lecture at MyCourses