



Low-Temperature Solar Rankine Cycle System for Reverse Osmosis Desalination

Project coordinator

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Cooperative Research project

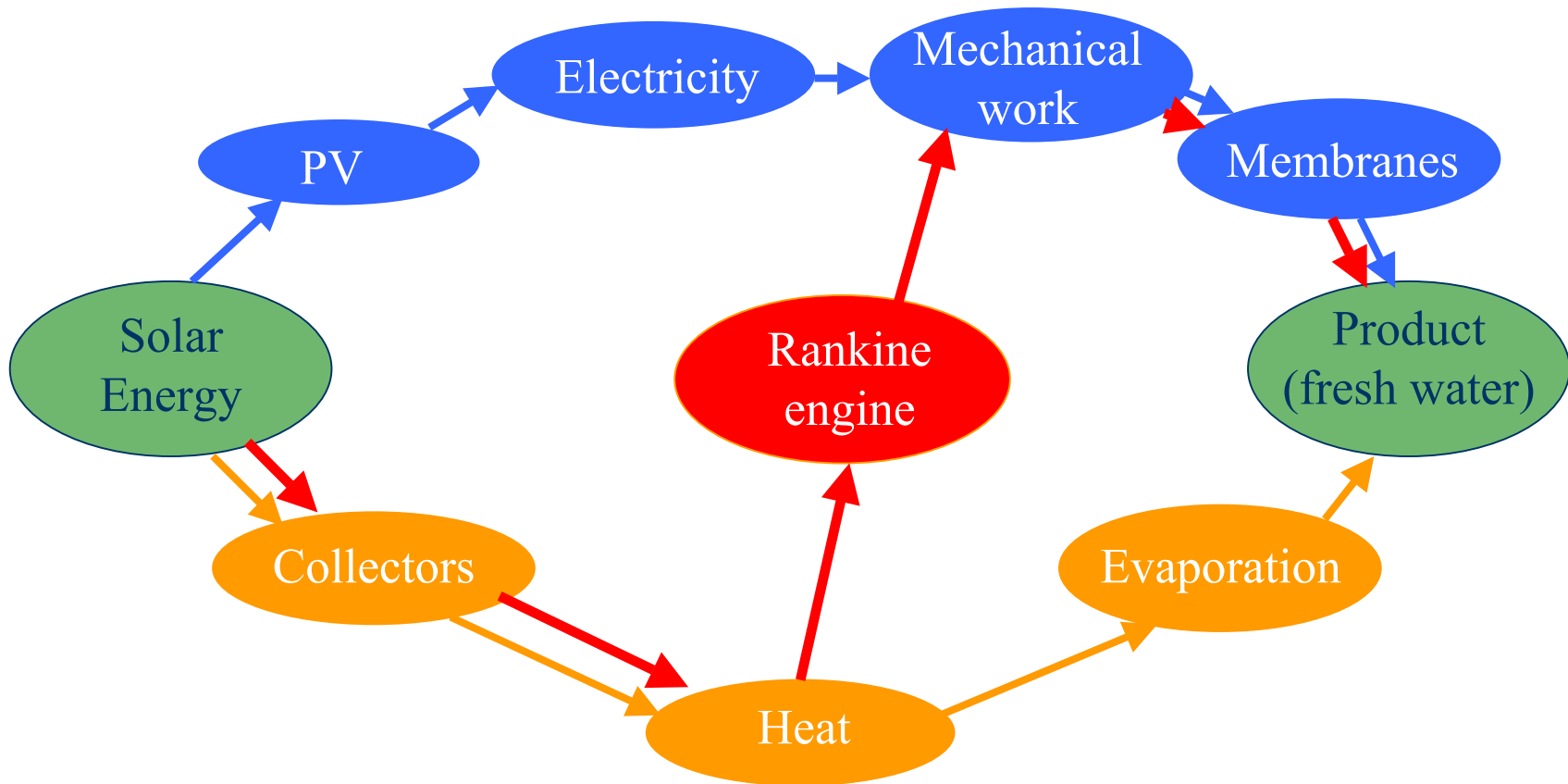
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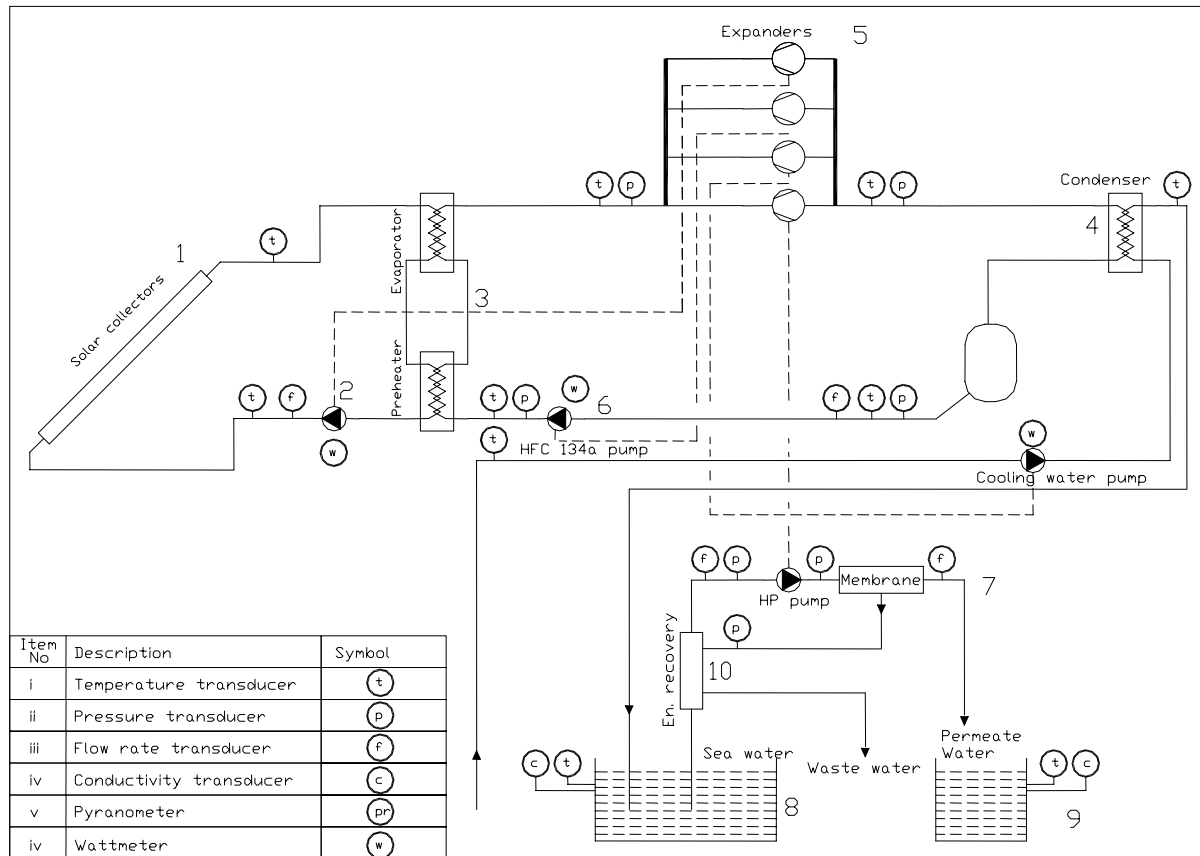




Solar Energy and Desalination



System Layout

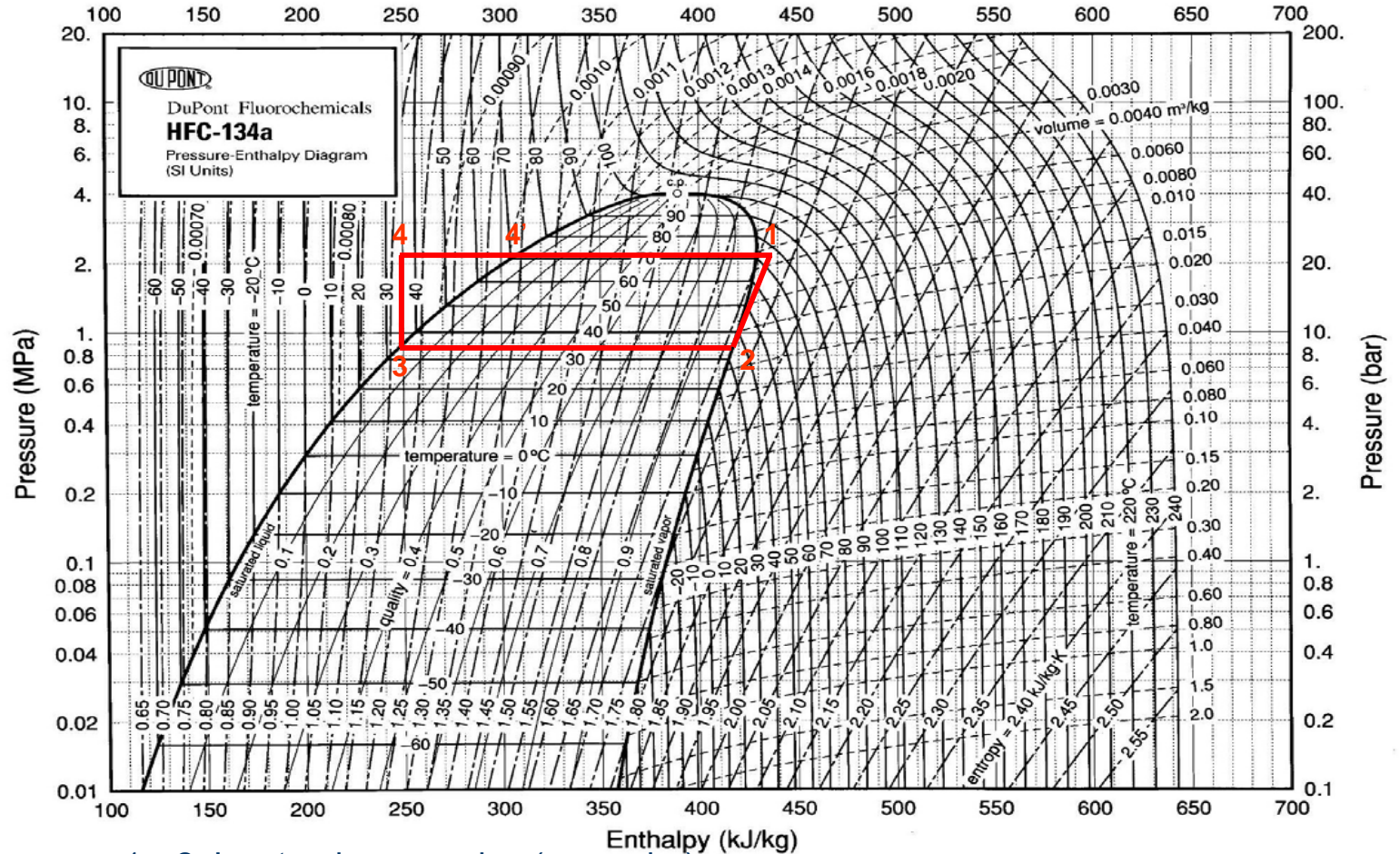


1. High efficiency vacuum tube solar collectors' array
2. Circulator
3. Preheater-Evaporator
4. Condenser
5. Expanders
6. HFC-134a pump
7. RO unit
8. Insulated seawater reservoir
9. Fresh water reservoir
10. RO energy recovery system





The Rankine cycle



- 1→2: Isentropic expansion (expander)
- 2→3: Isobaric heat rejection (condenser)
- 3→4: Isentropic compression (HFC-134a pump)
- 4→1: Isobaric heat supply (evaporator)





Thermodynamic states

State	T (°C)	P (kPa)	H (kJ/kg)	S (kJ/kg°K)
S1 Super-heated vapour, evaporator outlet, expander inlet	75.8	2200	435.7	1.7138
S2 Saturated vapour, expander outlet condenser inlet	35	887.91	417.5	1.7138
S3 Saturated liquid, condenser outlet	35	887.91	249.2	1.1676
S4 Sub-cooled liquid, pre-heater inlet	≈35	2200	248.0	1.1676
S4' Saturated liquid, evaporator inlet	71.7	2200	307.8	1.3433





Why this System? (1)

- Use of **market available components** (heating and cooling industry, at **low cost**)
- **Ideal exploitation of low temperature energy sources**
- Mechanical work is driven **directly** to RO pumps → direct **efficiency gain**
- It can be **easily standardised**
- **Rankine cycle approaches the efficiency of Carnot cycle**
- Continuous and **safe operation** at low temperatures.
- The working fluid (**HFC-134a**) is **not corrosive** and is **environmentally** friendly.
- **Low maintenance cost**

Continued...





Why this System? (2)

- It fits perfectly for applications in isolated, not grid connected areas.
- Compared to PV-RO desalination system this system prevails in the following:
 - Water storage is used instead of batteries
 - It is more environmentally friendly
 - The absence of batteries implies **less maintenance**
 - The system is **safer for the end users.**
 - **No qualified staff is needed** for O&M.
 - The **fresh water cost** is expected to be **at competitive level.**
- Compared to thermal systems is characterised by a much **higher efficiency** and much **less product water cost.**
- **Variable pressure working conditions** in RO system → **higher energy availability** and **higher efficiencies** in the whole system





Components size

Collectors	
Manufacturer	Thermomax Ltd.
Type	SOLAMAX
No. of tubes/collector	30
No. of collectors	56
No. of collectors connected in series	2
Slope (°)	40
Preheater	40 kW
Evaporator	65 kW
Condenser	100 kW
RO Unit	1 m ³ /h
Expander	Scroll type
Freon pump	Piston/diaphragm 0.9 kW





Energy balance of the system

Collectors' energy gain (MWh/y)	101.3
HFC-134a pump (MWh/y)	0.89
Energy for condensation (MWh/y)	90.83
Energy for preheating (MWh/y)	35.5
Energy for evaporation (MWh/y)	65.8
Energy from expanders (MWh/y)	7.10
System efficiency (%)	7
Energy for desalination (MWh/y)	2.53
Fresh water produced (m ³ /y)	1012
Specific energy consumption (kWh/m ³)	2.5





The collectors' field





Collectors' array



Rankine engine



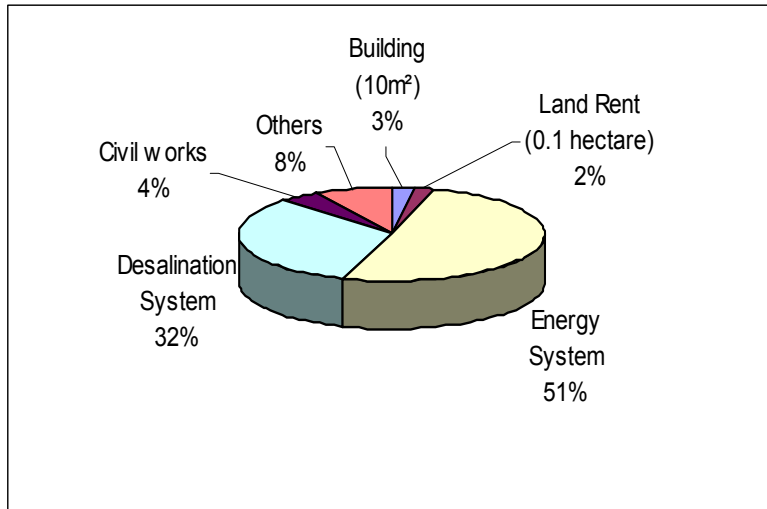


Cost analysis

	Total cost (€)	% of total			
Building (10m²)	5000	2.61%	Condenser (100kW)	5500	2.87%
Land Rent (0.1 hectare)	300	1.95%	Freon pump (0.9kW)	7600	6.40%
Energy System		50.59%	Pipes	1500	0.78%
Collectors part		35.00%	Expanders (7kW)	1236	0.64%
Solar collectors (100.1kW)	50400	23.24%	Rankine labour	4000	2.09%
Collectors Pipes and installation	25000	11.53%	Desalination System (RO unit 1m³/h)		32.37%
Collectors pump	440	0.23%	Membranes	4000	7.33%
Rankine cycle part		15.59%	All other components (Labour included)	40000	25.04%
Preheater (40kW)	2700	1.41%	Civil works	8000	4.17%
Evaporator (65kW)	2700	1.41%	Others		8.31%
			Instrumentation	5000	3.13%
			Tanks	800	0.42%

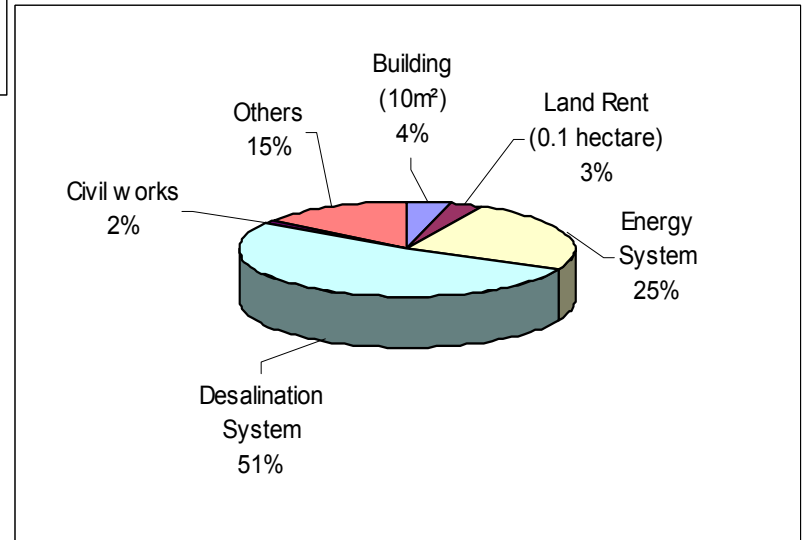


Cost sharing

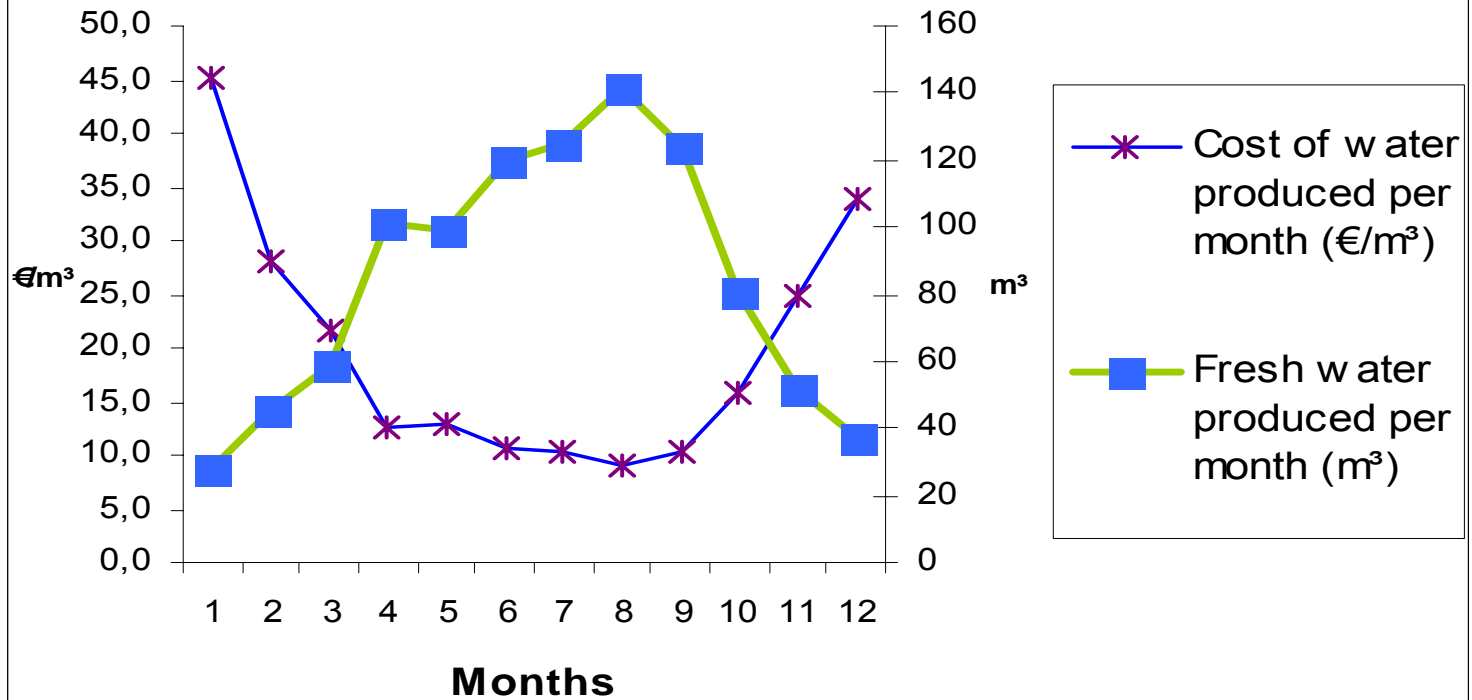


← With collectors

With other thermal source →



Cost by quantity of fresh water produced





Conclusions

- A 7% overall system efficiency is expected. It can be higher if operates at higher temperatures.
- Alternative to PV-RO systems, BUT with less O&M cost, longer life time at not much higher water price
- Ideal exploitation of low temperature energy sources like thermal wastes, geothermal energy for fresh water production.
- Average fresh water cost 15.21 EUR/m³

BUT

In case it is supplied from a steady thermal source (e.g. geothermal, co-generation plant etc.) the cost is reduced to 1.18 EUR/m³





Acknowledgements

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