

Fossil-Fuel-Free Irrigation in NE Syria

Development Strategy for Sand Battery / Stirling Engine System

Summer 2025 (v2)



Agenda

- Requirements
- Overview of Solution
- Discussion
 - Key Features of the Solution
 - Why does this Solution Stand Out?
 - Potential Challenges and Risks of the Solution
 - Unproven Aspects of the Solution
 - ChatGPT validation of underlying physics
- Testing/Development Strategy

Basic Requirements

1. Project is led by Climate Resilience Team at the Airbel Impact Lab, a department of the International Rescue Committee (“IRC”).
2. System objective is to provide adequate electric power to allow farmers in NE Syria to irrigate their wheat fields.
 - Power a submersible pump for up to 6 hours per day. Example pump is stage 37 of Empower DSP4RFF08 (Multi-Stage Centrifugal Borehole Pump) at <https://www.benaxsolar.co.ke/products-and-solutions/product/27-dsp4rff08>.
 - Pump needs to be able to output 10 m³/hour when pumping from 100 meters depth in a 4” pipe. This should support 5 sprinklers on a relatively level property.
 - Requires 5.5 kW at 415 V.
3. Run this pump without fossil fuel.
 - Replace existing diesel generators with a non-fossil-fuel solution to free farmers from cost of fuel and oil and difficulty in obtaining both.

Detailed Requirements

1. Pump needs to pull water out of ground & drive sprinkler heads to get water to fields.
2. Wheat cultivation happens from December – June (see “Insolation” line to right)
3. The time of highest irrigation is March and April
4. There are typically 84 days per season where irrigation is done (out of ~180 days of the season)
5. There is a need to irrigate when cloudy.
6. There is a need to irrigate at dawn.
7. The current farmer expense for diesel fuel and lubricating oil for the diesel engine is US\$1,500 per year.
8. A farmer will not consider an alternative to the current technology if it requires more than a 5 year payback (this limits our cost to US\$7,500).

<https://www.gaisma.com/en/location/al-hasakah.html>

al-Hasakah, [Syria](#) - Solar energy and surface meteorology

Variable	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Insolation, kWh/m ² /day	2.20	3.10	4.33	5.39	6.50	7.67	7.63	6.75	5.62	3.78	2.52	1.96
Clearness, 0 - 1	0.46	0.50	0.54	0.55	0.59	0.67	0.68	0.66	0.64	0.55	0.48	0.44
Temperature, °C	5.01	6.13	10.72	17.19	23.11	28.53	32.43	31.73	27.14	20.94	12.92	6.89
Wind speed, m/s	4.43	4.87	5.30	5.46	5.29	5.89	6.62	6.46	5.46	4.73	4.14	4.29
Precipitation, mm	59	49	50	53	21	1	0	0	2	19	28	50
Wet days, d	10.9	10.0	10.6	9.9	6.0	4.7	7.2	7.7	5.3	5.1	7.3	10.2

These data were obtained from the NASA Langley Research Center Atmospheric Science Data Center; New et al. 2002

Notes: [Help](#). Change [preferences](#).

[Gaisma Planet](#) - Interactive Climate and Environment Imagery Viewer

Solution Overview

Strategy: The system is composed of:

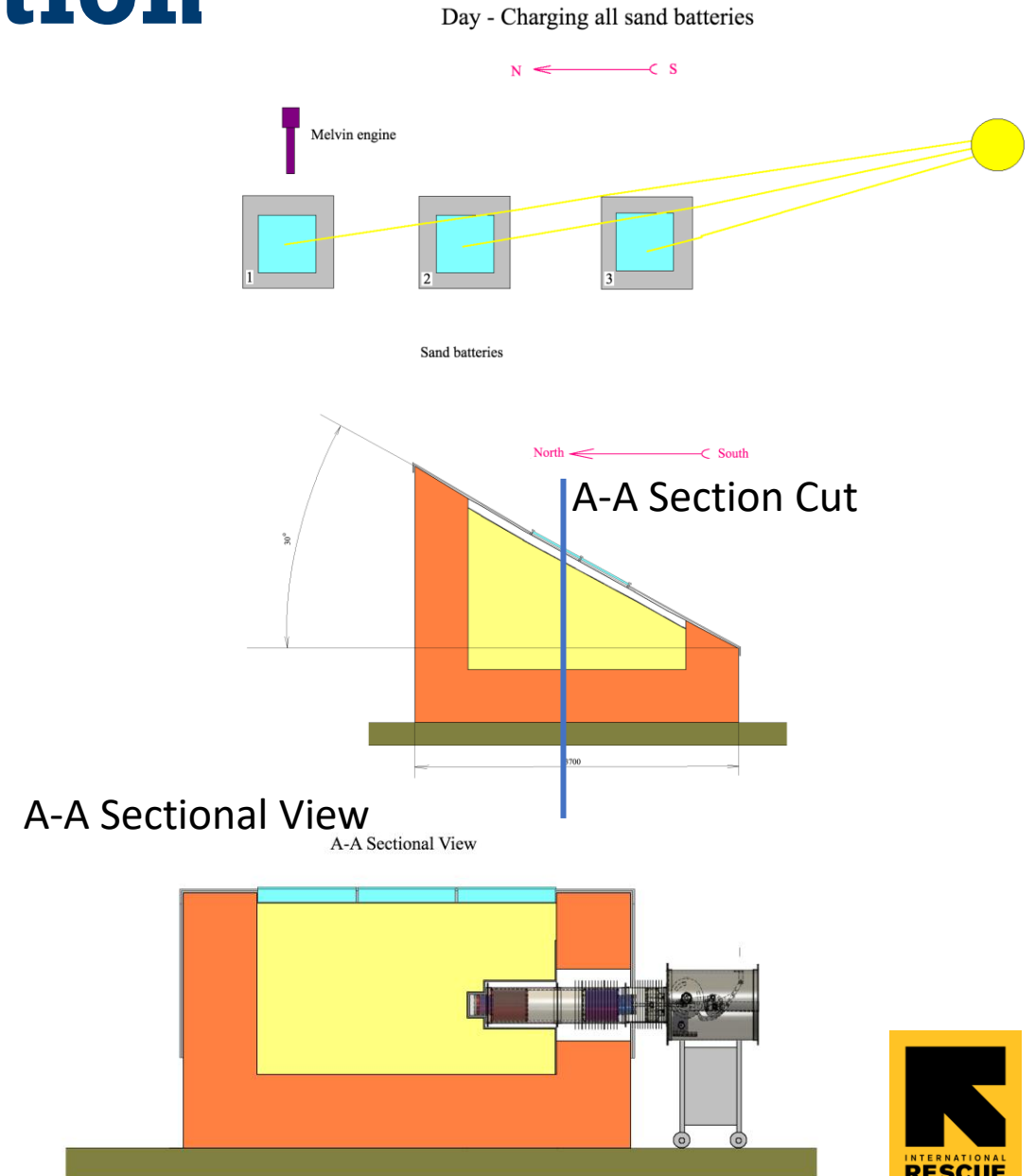
1. 3 identical and separate 7.2 m³ sand/loam batteries (12.9 metric tons) that store heat that is created by 3 identical and separate 8.3 sq-mt Fresnel-lens solar concentrators.
2. 1 5-kW Stirling engine. It is the Melvin engine designed by Sefton Motors. This engine permits local manufacture in Syria with license fee of US\$250/machine.
3. Electrical equipment to convert the output of the Melvin engine to be suitable to run the submersible pump.

Key Design Details:

1. The Fresnel cover will be oriented to the south and at a 30° angle to the ground in each battery
 - Allows you to set the most optimal position relative to the sun in December and January. In other months, it helps to avoid overheating due to indirect rays, thereby maintaining a constant average power of the installation during the operating period.
2. The Fresnel cover will use Fresnel lenses arrays (efficient, large surface area)
 - We plan to use advanced Fresnel lenses sold in an array and which are specially adapted for solar heating and allow efficient use of the surface. These allow collecting and accumulating solar energy with minimal losses.
3. The sand battery will be insulated with 600 mm of thermal insulation on the bottom and sides
 - The thickness of the thermal insulation allows it to reduce losses in the cold winter time, provide longer storage of stored thermal energy, create a reliable energy reserve, and provide the maximum temperature regime for Melvin engines.
4. The sand battery will be laced with steel rebar from different parts of the sand and pointing at the 'hot' end of the Stirling
 - Sand is a poor conductor of heat so the rebar is intended to increase its effective thermal conductivity
5. The sand battery will have a sleeve to allow easy install/removal of Stirling engine
6. The 'cold' end of the Stirling engine will be cooled with irrigation water to ~ 10 °C
 - The temperature difference between hot and cold end should be > 340°C (676 °F) to support effective power generation
7. The Melvin engine operates at an internal pressure of ~40 psi and includes a misting feature to leverage the water->steam phase change

Overview of the Solution

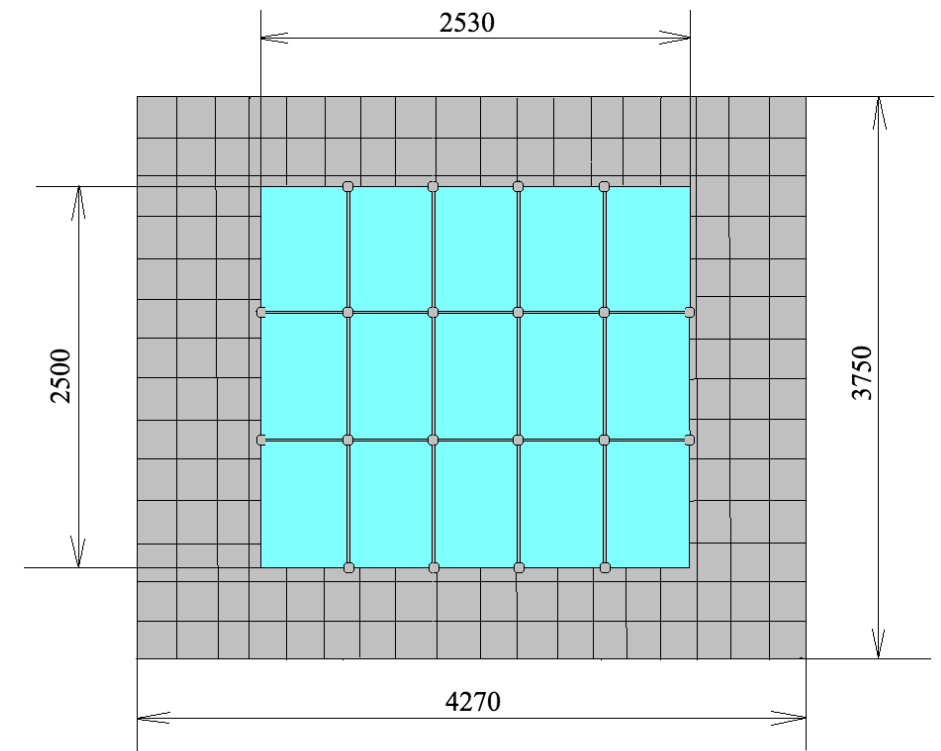
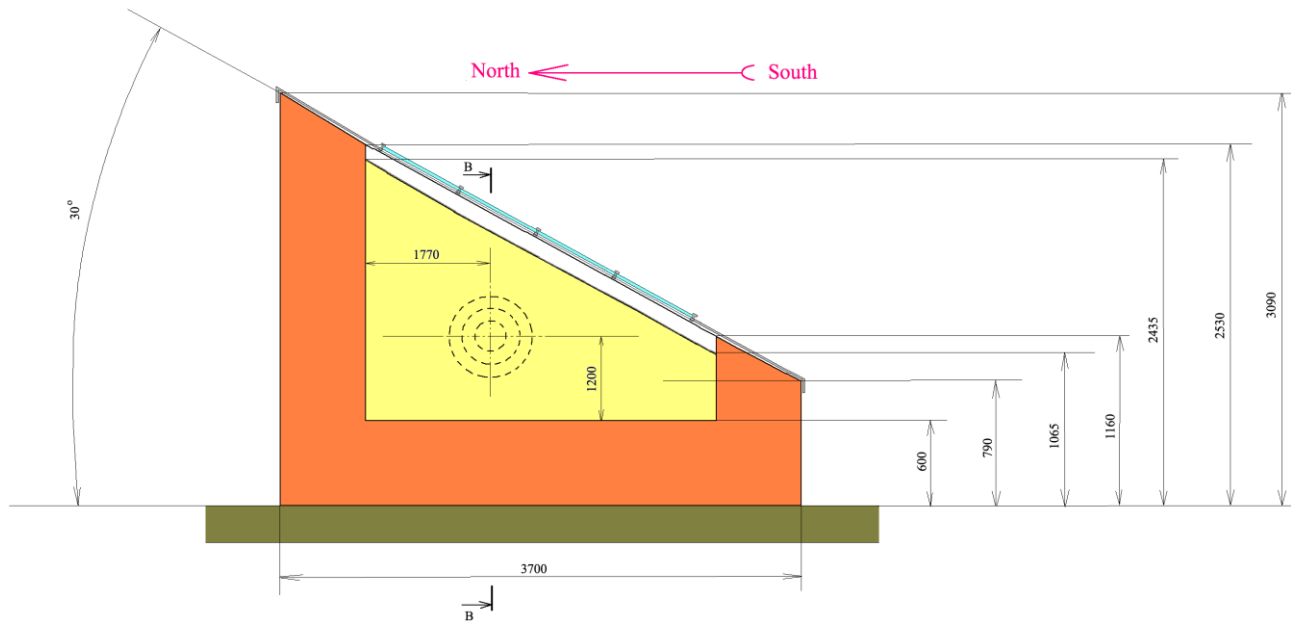
- 2 key ideas
 - All-Season sand battery
 - High-kW Stirling engine
- Intended to work with electric submersible pump of 5.5kW/7.5HP.
- No fossil fuel needed
- Capital costs:
 - BOM – US\$4,881
 - Labor – US\$1,700
 - **TOTAL - US\$6,581**
 - Plus freight allowance of US\$500
 - **GRAND TOTAL – US\$7,081**



Details of the Solution – Single Sand Battery

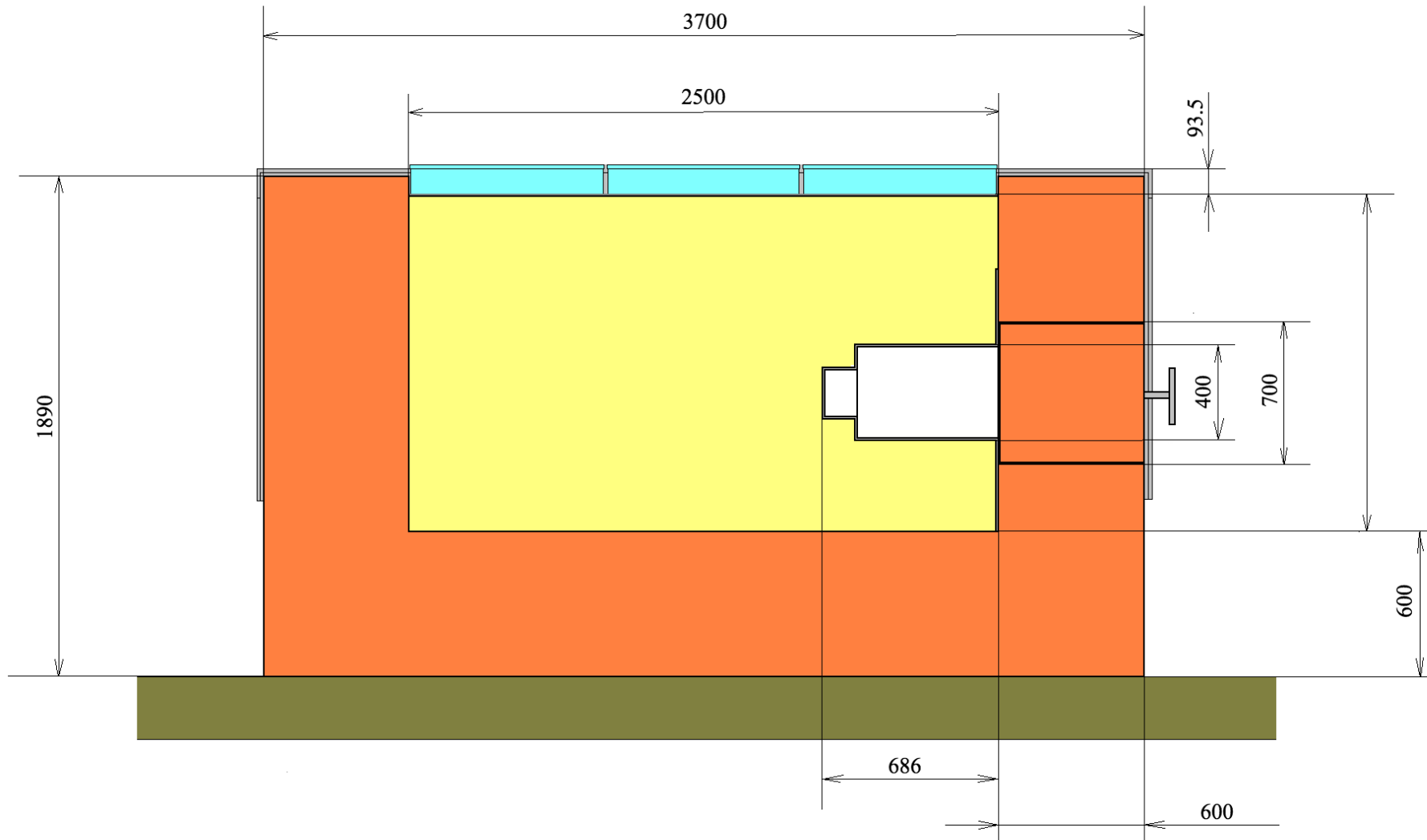
- 3 Separate Sand Heat Sinks – Accumulates heat to drive Stirling Engine

- Cover – 15 Fresnel lenses arrays concentrate solar radiation to produce 350°C sand



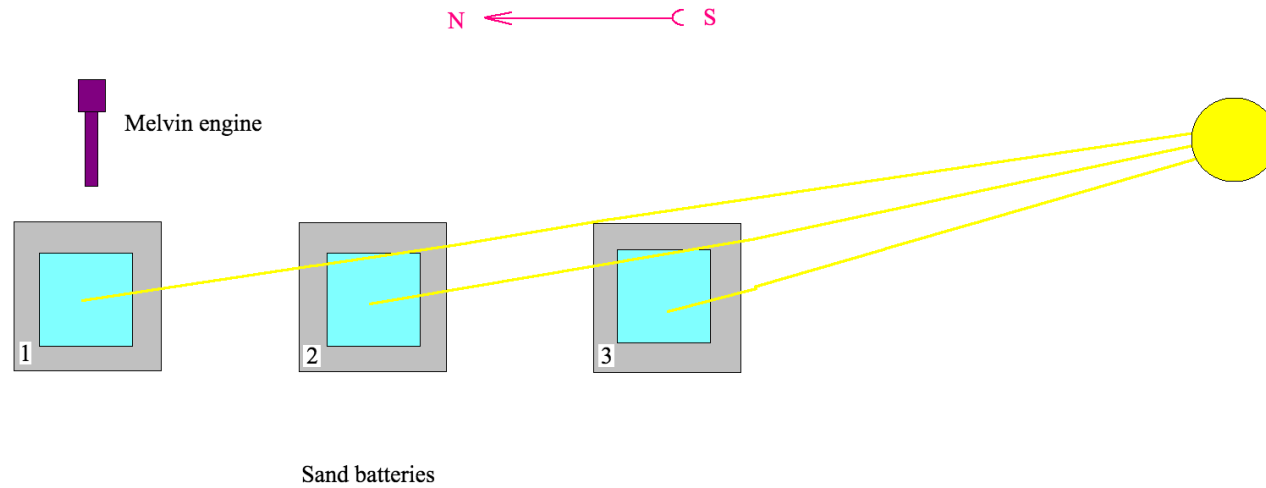
Details of the Solution – Single Sand Battery

Cross-section at B-B from prior slide

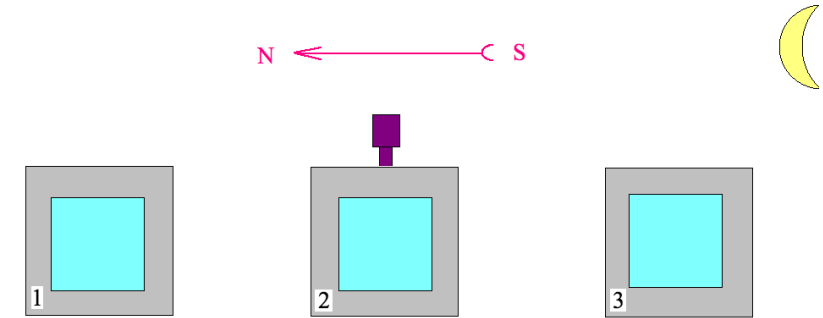


January Irrigation Strategy – 3 Batteries

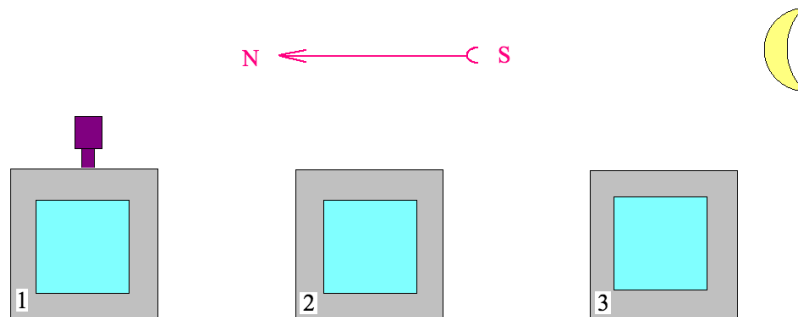
Day - Charging all sand batteries



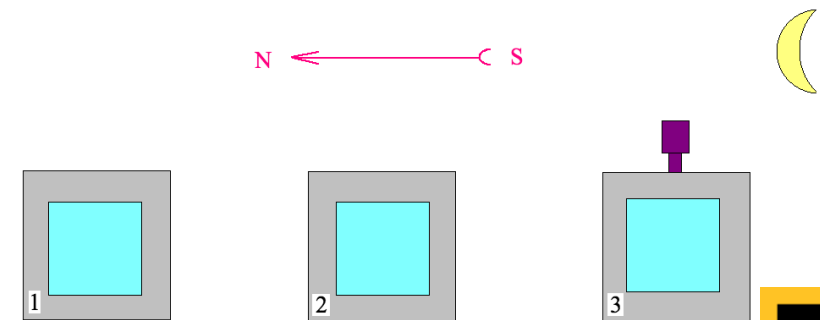
Night # 2 - Using sand battery # 2



Night # 1 - Using sand battery # 1



Night # 3 - Using sand battery # 3



Details of the Solution – Stirling Engine

- Small company (www.seftonmotors.com) in Michigan, USA.
- Still doing R&D to improve electric output and maintenance. Currently requires 2 units to generate 6kW. Introducing increased pressure inside engine and water-mist-to-steam-phase-change as innovations to increase power.
- Willing to license design to IRC for Syria manufacture.
- Youtube channel for the company at <https://www.youtube.com/@seftonmotors>.
 - a. Details of how the engine works and company update (15:30) - <https://youtu.be/dTiHu7VfFfA>.
 - b. Details of the electric output process for the engine (10:35) <https://www.youtube.com/watch?v=oTMZGBXJmMM>



The Melvin-Base Engine

\$ 1,800.00

Quantity

1

 Add to Cart

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Description

Introducing the Melvin. The heart of becoming a resilient. The Melvin Engine runs off of heat. The Generator" (tm), you can use any form of



Details of the Solution – Costs

Subsystem	Components	BOM Cost	Labor Cost	Total Cost	Sub-system Cost
Sand Battery					
	Fresnel Lenses (45 arrays, tempered glass)	\$ 2,250	\$ 400	\$ 2,650	
	Insulation & Cover	\$ 569		\$ 569	
	Sleeve	\$ 150		\$ 150	
	Sand or Clay (15 tons) and other heat-capture materials	\$ 97		\$ 97	
	Sensors, fasteners, misc	\$ 40		\$ 40	
	SUBTOTAL				\$ 3,505
Stirling Engine					
	Melvin Base Engine (1.5kW)	\$ 1,100	\$ 1,100	\$ 2,200	
	Enhancements to increase power output to 5kW	\$ 300		\$ 300	
	Cart & Support System	\$ 100		\$ 100	
	SUBTOTAL				\$ 2,600
Electrical					
	Charge Controller (12-48V)	\$ 96		\$ 96	
	Inverter (12V)	\$ 135		\$ 135	
	Battery (12V)	\$ 29		\$ 29	
	Wires/Cabling	\$ 15		\$ 15	
	On-site labor		\$ 200	\$ 200	
	SUBTOTAL				\$ 475
TOTALS		\$ 4,881	\$ 1,700	\$ 6,581	
	Allowance for Freight, Tax, etc.			\$ 500	
	GRAND TOTAL ESTIMATE			\$ 7,081	

Why Does Solution Stand Out?

- Concept
 - No fossil fuel required
 - No operating costs expected
 - Not quite as easy as turning on diesel generator, but could be close, except in Dec-February when will require engine movement between batteries
- Sand Battery
 - Holds heat even on cloudy day or at night
 - No moving parts
 - Only maintenance is covering at night to reduce heat loss
 - Temperature expected to be at least 350 °C
- Stirling Engine
 - This model needs hot-cold delta $>340^{\circ}\text{C}$ to generate power.
 - Few moving parts. Easy to maintain.
 - Option to manufacture in Syria or elsewhere. Production license available.

Potential Challenges & Risks

- Concept
 - Need to work out an 'easy' way to engage & dis-engage engine from battery
- Sand Battery
 - Need to verify with IRC that physical land and sand requirement is acceptable to target farmers
 - Need to prove that the Fresnel cover can generate temps of $\sim 600^{\circ}\text{C}$ on the surface of the sand
 - Need to prove that temperature inside sand will be consistently above 350°C
 - Need to prove that the low thermal conductivity of sand does not 'starve' the Stirling engine of adequate heat.
 - Need to prove that heat loss during night and/or clouds is not too great
 - Need to prove that the unit can be made 'safe' enough for farm use
- Melvin Stirling Engine
 - Need to prove that engine can run on 'sand heat'
 - Need to prove that engine can produce 5kW per engine. Two current unknowns include the increase in internal pressure to 40 psi and the introduction of water mist to induce a water >steam phase change

Unproven Aspects of Solution

- Sand battery is unproven but we have external validation
 - Commercial sand battery heating sand to 600 °C: <https://polarnightenergy.com/sand-battery/>
 - Fresnel lens (5m x 5m) can produce temperatures of 800-1,000 °C: <https://thekidshouldseethis.com/post/solar-metal-smelter-jelle-seegers-video>
- Melvin Engine Unknowns
 - Company needs to operate unit in a pressurized mode to enhance electricity output.
 - Produces 400W at ambient pressure now. Expectation is 1.5kW with one hub motor and internal pressure of ~20psi.
 - Expected later in 2025.
 - Theoretical potential to get to 40psi internal pressure, which would generate 3kW with one hub motor.
 - Injection of small amounts of water into engine could increase output to 5-6kW from one Melvin engine
 - Can independent machine shop actually build a working unit?
- Electrical
 - Will a system based on 12V be appropriate for this application?

Chat-GPT5 Prompt for Validation

Test the performance of the solar heating system with the following parameters: The solar heating system will be operated in Syria, the heating material is local dry powdered compacted loam without organic residues; Loam density is 1800 kg / m^3 ; Loam heating is carried out using Fresnel lenses in rectangular sections, each of which contains 12.937 metric tons of loam insulated with mineral wool on 5 sides. The thickness of thermal insulation on all sides is 600 mm; Number of sections is 3; The upper surface is not thermally insulated, arrays of heating lenses are placed above it; For better absorption of sunlight, the surface of the compacted loam under the lenses is covered with graphite powder in a layer of 1 mm thick; Heating of each section is carried out by means of 15 arrays of rectangular Fresnel lenses, the size of each array is 830 mm by 630 mm, the array includes 192 square Fresnel lenses of 50 mm by 50 mm, the focal length of each lens in the array is 93.5 mm; The lens arrays are placed in a frame above the surface of loam covered with graphite, at a distance equal to the focal length of the lenses 93.5 mm; The lenses and the heated surface have an inclination towards the south equal to 30 degrees; In total, all three sections together contain 38.811 tons of loam; The total number of lens arrays of all three sections is 45 pieces. Each section is heated by solar heat from Fresnel lens arrays, with a temperature at the focus of each lens of 1000 degrees Celsius, solar heating of each section is carried out from February to December, while no energy is extracted, only energy is accumulated, and in December and January, solar heating of each section continues, but thermal energy is extracted from the heated loam only for two months, December and January, for the operation of the Stirling engine. DNI values for calculations: in February 109.5 kWh/m² , in March 153.2 kWh/m² , in April 165.2 kWh/m² , in May 210.9 kWh/m² , in June 257.6 kWh/m² , in July 267 kWh/m² , in August 239.7 kWh/m² , in September 214.5 kWh/m² , in October 151.7 kWh/m² , in November 121.7 kWh/m² , in December 102.6 kWh/m² , in January 98.2 kWh/m² . The loam temperature on November 30th should be 600 degrees Celsius, on December 31st the loam temperature should be 500 degrees Celsius and on January 30th the loam temperature should be 350 degrees Celsius; The thermal energy from the heated loam is used to drive one Stirling engine; The optimum operating temperature of the hot cylinder of the Stirling engine is not less than 350 degrees Celsius. During engine operation, the temperature of the hot cylinder should not fall below 350 degrees Celsius; The cold side of the Stirling engine is cooled with cold water with a temperature of 10 degrees Celsius; The temperature difference between the hot and cold sides of the Stirling engine is 330 degrees Celsius; The engine receives thermal energy for operation by connecting to sections with hot loam through side ports in which steel sleeves are installed, repeating the shape of the hot end of the Stirling engine; On the first night, the engine is connected to the first section, on the second night to the second section, on the third night to the third section, then the connection cycle is repeated; The Stirling engine is connected to a 5 kW electric generator; The Stirling engine must operate at night, producing 5 kW of electrical power; Less power is not allowed; The Stirling engine operating time at night is 6 hours every day; Operating time less than 6 hours per day is not allowed; Thermal insulation material - mineral wool, 600 mm thick, in three layers of 200 mm; No other devices and accessories, heat exchangers, protective coatings, protective glass, automation, protective systems and positioning systems and other systems are provided; Perform a system operability test taking into account all losses and the efficiency of Fresnel lenses; Perform a verification calculation taking into account all possible losses, is the energy accumulated from February to November enough to operate for two months in December and January and is there enough energy for the system to operate for 6 hours every night in December and January?

Chat-GPT5 Validation Response

Main System Parameters

- Heating Material: Dry Powdered Loam
- Loam Density: 1800 kg/m^3
- Loam Weight: 38.811 metric tons (3 sections of 12.937 metric tons)
- Thermal Insulation: Mineral Wool, 600 mm
- Fresnel Lenses: 45 arrays (15 per section)
- Focal Temperature: 1000°C
- System Efficiency: 35-45%

Thermal Energy Calculation

- Loam Thermal Capacity: $880 \text{ J/(kg } ^\circ\text{C)}$
- Total Heat:
 - In One Section: $12,937 \text{ kg} \times 880 \text{ J/(kg } ^\circ\text{C)} \times 600 ^\circ\text{C} = 6.7 \text{ GJ}$
 - In three sections: 20.1 GJ

Stirling engine power consumption

- Power: 5 kW
- Operating time: 6 hours/day
- Consumption: 30 kWh/day
- For December and January: $1800 \text{ kWh} = 6.48 \text{ GJ}$

Solar energy gain calculation

- Total lens area: $45 \times 0.83 \times 0.63 = 23.4 \text{ m}^2$
- Total DNI from February to November: 1575.5 kWh/m^2
- Total energy: 36.9 GJ
- Considering efficiency (45%): $\approx 16.6 \text{ GJ}$

Analysis of losses and efficiency

- Losses due to thermal insulation: 20-25%
- Losses during heat transfer: 15-20%
- Losses in lenses: 30-40%
- Total losses: 55-65%

Conclusion on operability

The system is operative taking into account all parameters:

- The accumulated energy is sufficient for operation in December and January
- The loam temperature ensures the operation of the engine
- The power and operating time meet the requirements

Conclusion

The system is capable of providing the required power generation, provided that regular maintenance and monitoring of operating parameters are performed. It is recommended to conduct pilot testing to clarify the actual performance indicators and adjust the control system

Testing/Development Phases

1. Prove Melvin Stirling Engine can generate 5kW of power from Fresnel-lens generated heat (summer/fall 2025 – NJ, USA)
2. Prove electrical system can output clean 110V, 220V or 440V power (fall 2025 / spring 2026)
3. Prove sand battery can heat up to 400°C and heat can move in battery at speeds adequate to power Melvin engine (TBD)

Phase I Configuration

