CONSOLFOOD 2018 Advances in Solar Thermal Food Processing

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PHOTOVOLTAIC SOLAR COOKING WITH THERMAL ENERGY STORAGE (TES)

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Energy for cooking

- In our countries we can cook with the sun, but this is only anecdotic, as the energy expenses for cooking are negligible in front of other uses.
- Electrical Cooking (e. g.) includes some “solar” Cooking.
- But …
  - 1/3 of human kind lacks Access to modern forms of energy.
  - This obliges to cook with biomass (firewood, dung and agricultural residues).
  - This brings many problems, like:
    - Pollution.
    - Deforestation.
    - Delay in development because of the time required to collect biomass.

Indoor (and outdoor) pollution because of fumes

- Bad combustion and low efficiency cookstoves, no chimney.
- Long term breathing polluted air causes illnesses: heart, stroke, pulmonary, cancer, ...

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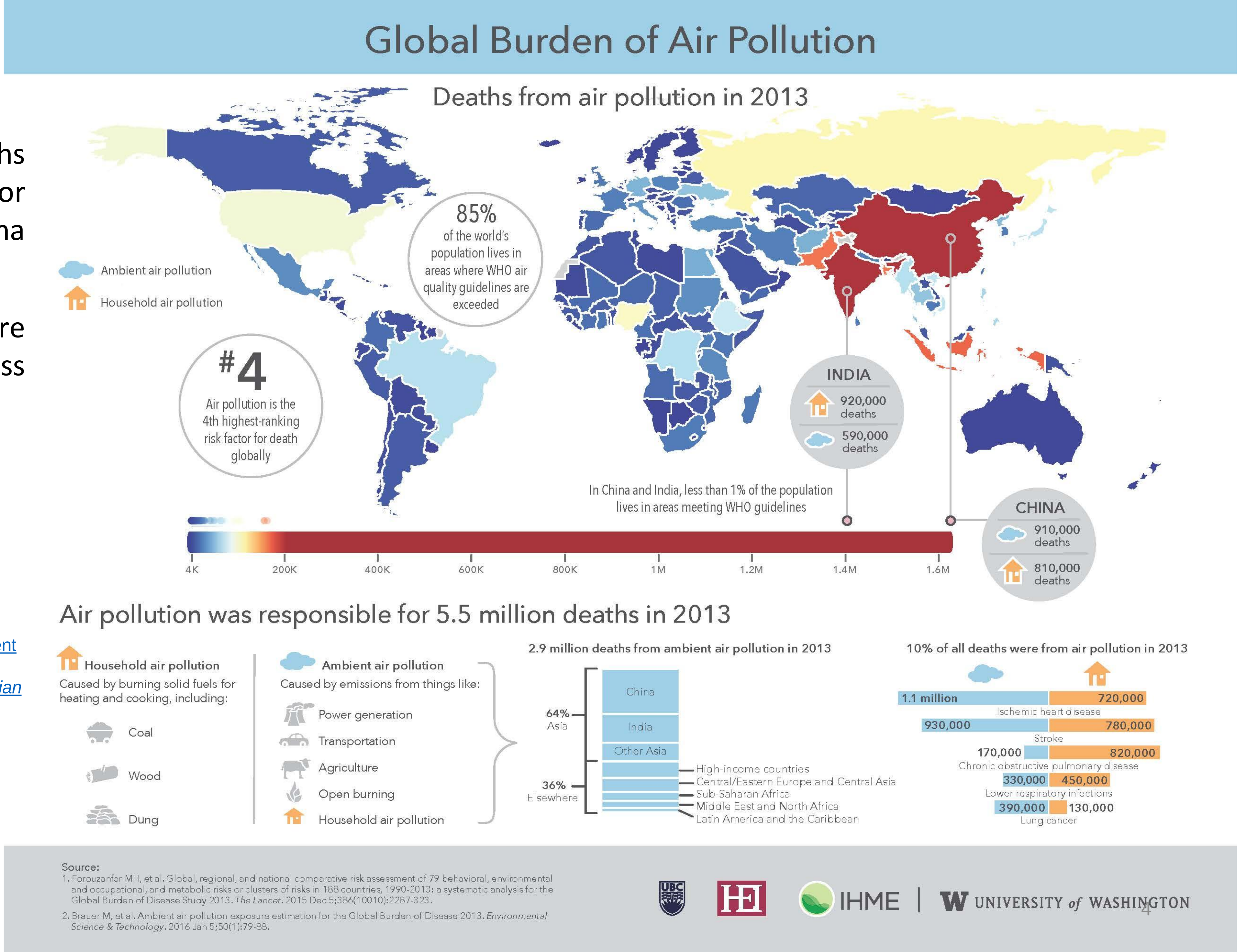
- 5.5 annual premature deaths from indoor and outdoor pollution, Asia and China especially.
- From them, 2.9 million are caused by burning biomass indoors.
- Data from WHO.
- More data:
  - Global Health Observatory
  - Boman, B., Forsberg, A., & Järvholm, B. (2003). Adverse health effects from ambient air pollution in relation to residential wood combustion in modern society. *Scandinavian Journal of Work, Environment & Health, 29*(4), 251-260.



More problems from cooking with biomass

Painful firewood collection. Excessive time consumption. Risks, accidents.

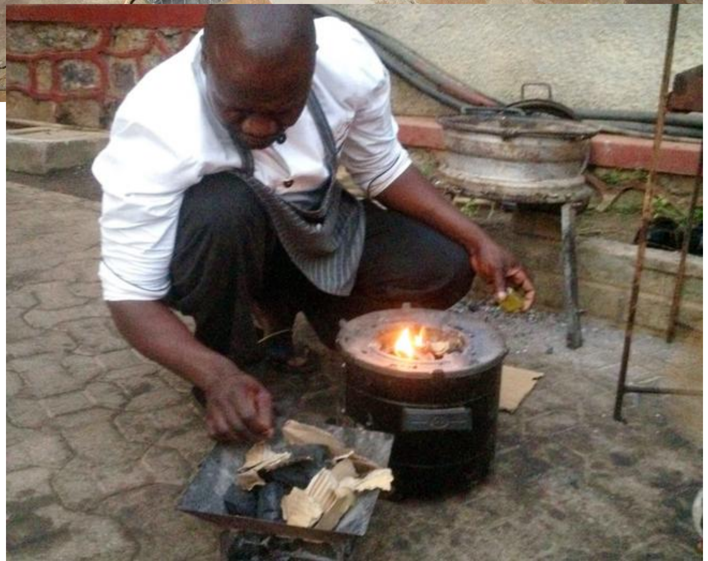
More problems from cooking with biomass

- Charcoal production is even worse

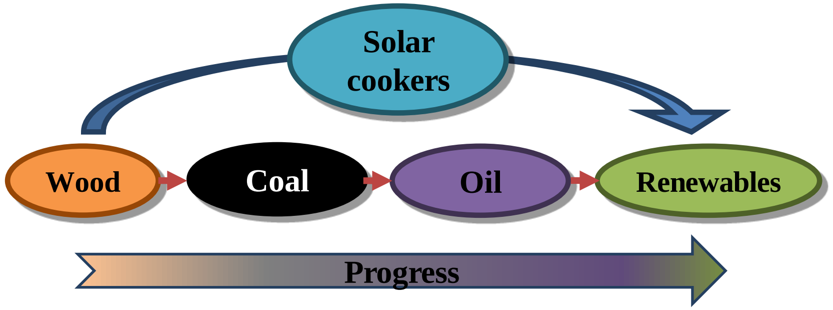
- Deforestation

Alleviating the problems

- Improved cookstoves are being proposed



- Solar thermal cookers are well known



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Limitations of solar thermal cookers

- Cooking outdoors and only during sunny periods of the day.
- Cooking dinner and breakfast is not possible.

Excepting by the use of heat insulating “Hay baskets”

Limitations of solar thermal cookers

- Dinner and breakfast cannot be cooked, because of the absence of sun.
- Cooking outdoors causes contamination, social problems and animal threats, thefts.
- Wind can spoil the cooked meal and the solar cooker.
- Incompatibility with traditional cooking practices and reluctance to change.
- Difficult to handle, too bulky.
- Risk of failure in cloudy weather.
- Continuous care for tracking the sun. Too slow.
- Non available in the local market.
- High procurement cost. No funding.
- Tendency to return to "traditional cooking"
- Difficult or impossible in peri-urban areas, no sunny space.

Why PV solar cookers?

- There is an expanding market of electronics and telecommunications.
- The price of PV panels has fallen dramatically, now .
- Nano-power and nano-technology offer promises of innovations and growth.

There are now actions to introduce nano-PV systems to fight energy poverty, e. g.:

M-KOPA 5 Control Unit with Lithium Battery
8W Solar Panel
4 Bright, 1.2W LED Bulbs
Rechargeable Torch
Rechargeable FM/USB Radio
5-in-1 Phone Charge Cable
Custom Charge Cable
Source: http://www.m-kopa.com/products/

Pay-As-You-Go (PAYG) program in Africa. Business model, a company essentially rents consumers a solar home system that comes with a battery, a charge controller, a solar panel, LED bulbs and a mobile charger.
Photo by Russell Watkins/DFID.

Why PV solar cookers?

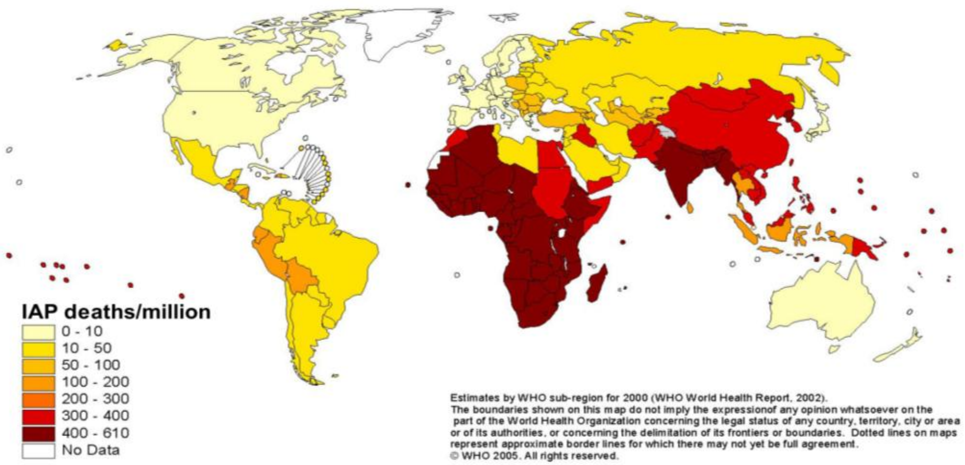
- Is PV solar cooking possible for a family?

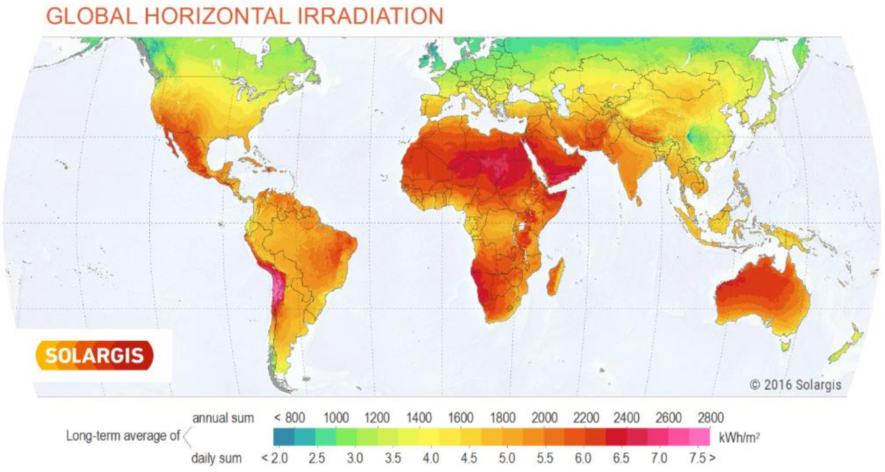
PV panel of yields in 1 average day an energy in kWh, considering 18% total system losses, no tracking:

Madrid	Argelia	Sudan	Central India	Central China	Average kWh
1.5	1.6	1.5	1.3-1.7	0.8-1.7	1.5

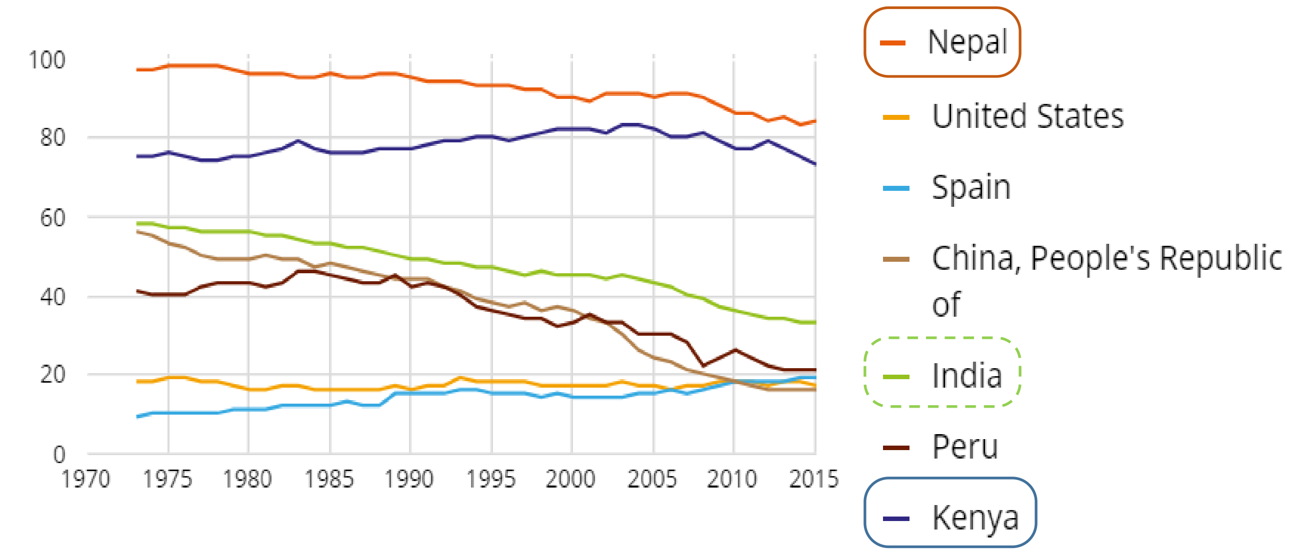
Heating 2 kg of water from 15 ºC up to 100 ºC consumes 0.2 kWh.

From another point of view solar thermal cookers have about 1.2 m^2 of aperture and an efficiency . PV has





Will the impact of renewable residential energy be large?



IEA Statistics: Energy Atlas", International Energy Agency. http://energyatlas.iea.org/#!/tellmap/-1002896040/4

According to "*Medios, Noticias: Una dendroenergía más ecológica es clave para mitigar el cambio climático y mejorar los medios de vida rurales*", FAO, 21-03-2017 http://www.fao.org/news/story/es/item/853537/icode/ :

-- 7% of the anthropogenic World emissions of greenhouse effect gases are caused by the combustion of firewood and charcoal --

Decentralized rural electrification, why?

- Combustion based, Hydroelectric and more widely available: solar.
- Lighting and mobile charging is quite simple, cooking and refrigerating needs more power.
- Levels:

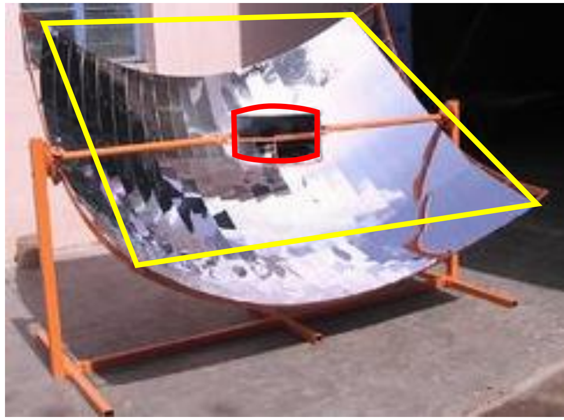
	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Power capability	very low	low	medium	high	very high
Hours of electricity available each day	4 hours	4 hours	8 hours	16 hours	23 hours

- Contribute to 8 of the 17 the "Sustainable Development Goals" , *ODS de la Agenda 2013*.

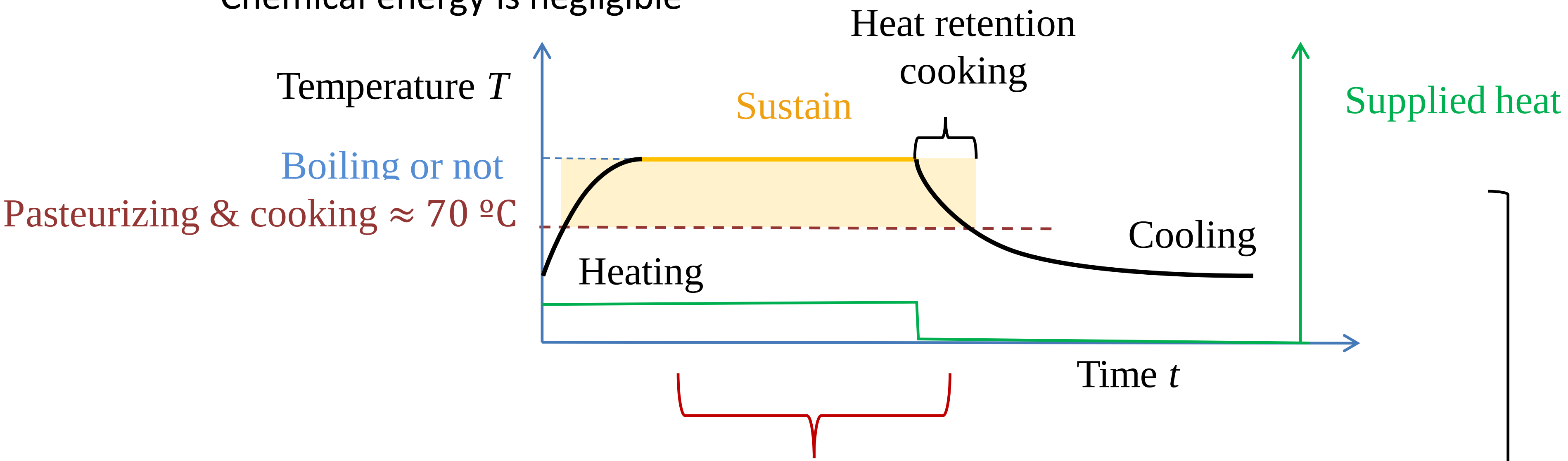
1. NO POVERTY2.	ZERO HUNGER	3. GOOD HEALTH & WELL-BEING	4. QUALITY EDUCATION	7. AFFORDABLE & CLEAN ENERGY	8. DECENT WORK & ECONOMIC GROWTH	10. REDUCED INEQUALITIES	13. CLIMATE ACTION

- From: *2017. UN Climate Change Conference in Bonn, Germany, Sustainable Energy for All (SEforALL) and Power for All. Why Wait?*
- It costs less than grid access in remote areas.
- It prepares for full electrification.

Cooking process



- Chemical energy is negligible



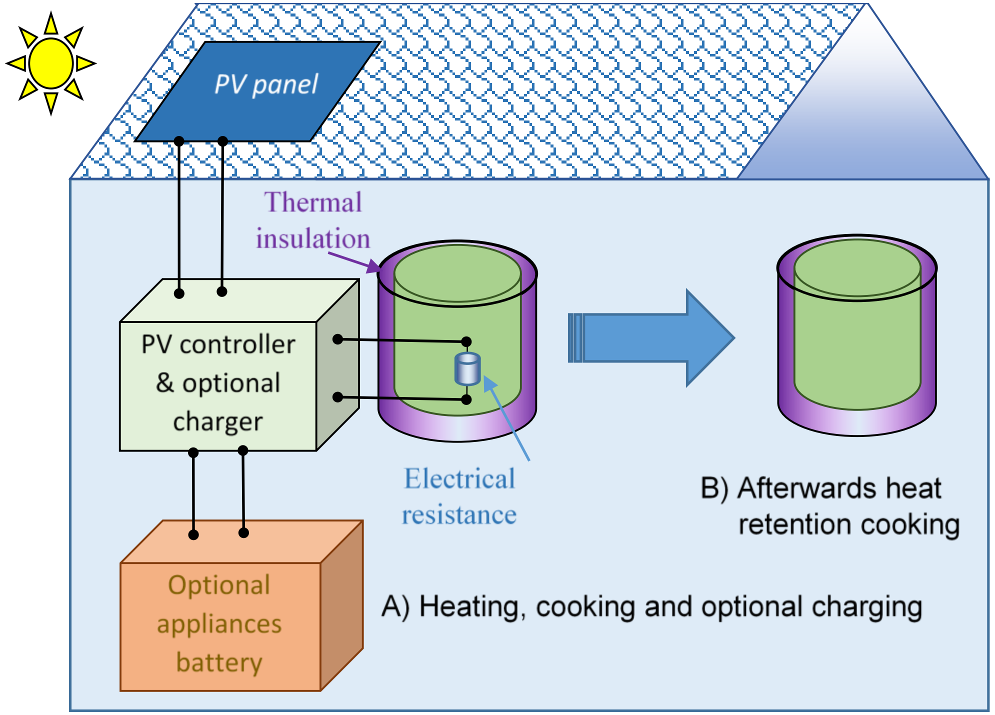
Only steady-state heat losses:

- Sensible:
- Latent (boiling):
- Latent (non boiling):

- Water evaporation and heat transfer to ambient should be minimized. Boiling is not needed! → slow cooking.

Family size PV solar cooking proposal

- Large batteries are too expensive, polluting and too heavy. Instead thermal storage.
- DC/AC converters (inverters) are not needed → Direct 24 V DC coupling with a resistance for heating.
- In addition, a 300 W_p panel allows charging lighting, mobiles and other small appliances batteries.



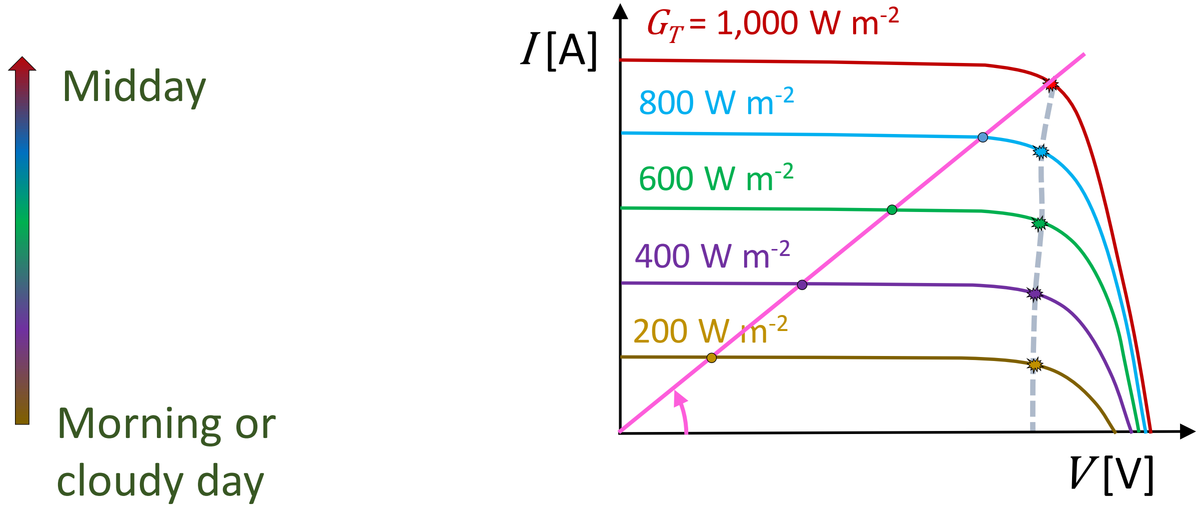
Cost breakdown Item	Off the shelf cost (€)
PV panel	150-300
Installation & training	30
Controller	10
Cables & plugs	10
Electronic pot*	30
DC resistance	10
TOTAL AVERAGE	330

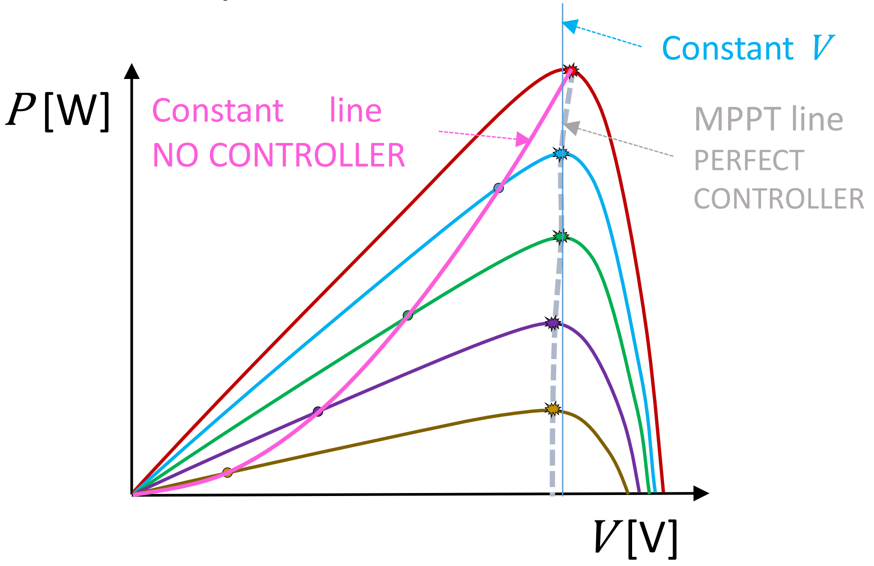
With a factor 2.0 for financing & maintenance: ( ) in a per day use – COMPETITIVE

Family size PV solar cooking proposal. Control.

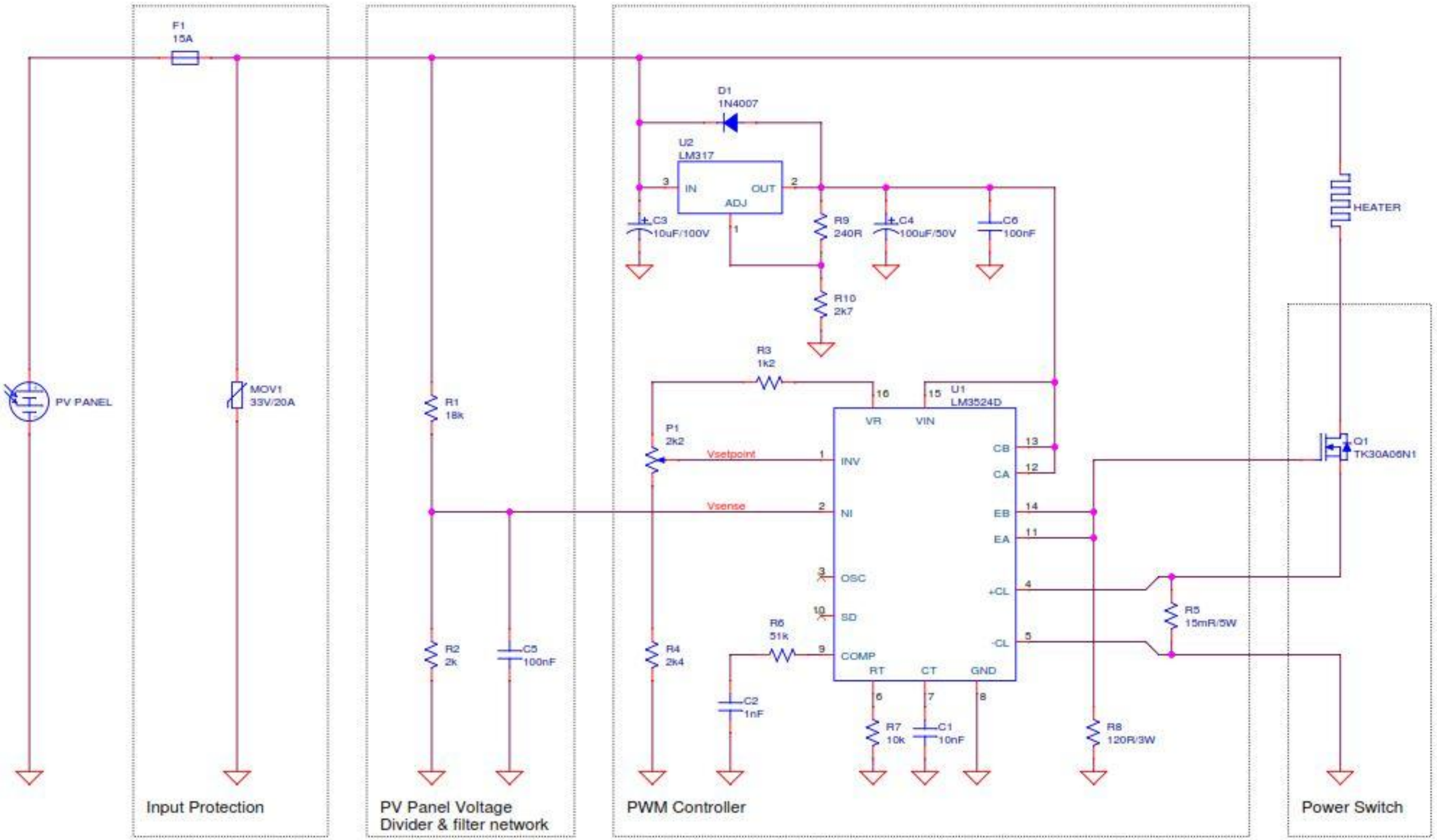
- PV panels require a “controller” circuit owing to the generating characteristics of PV cells and the variable solar irradiance .
- Conventional PV controllers use the battery as an intensity sink with relatively constant voltage.
- There is need of an “appropriate technology” PV controller:
  - Low cost.
  - *In situ* constructed, maintained and repaired.

PRINCIPLES: Under standard testing conditions, 25 ºC, no aging, no silt the performances are:





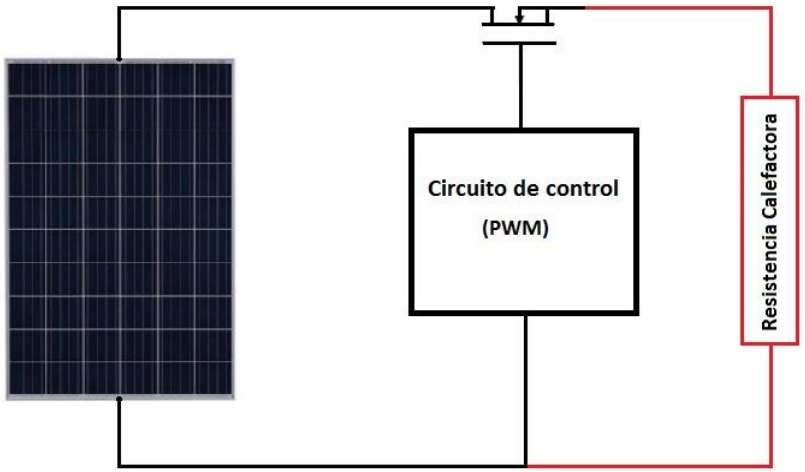
Very simple PV controller circuit

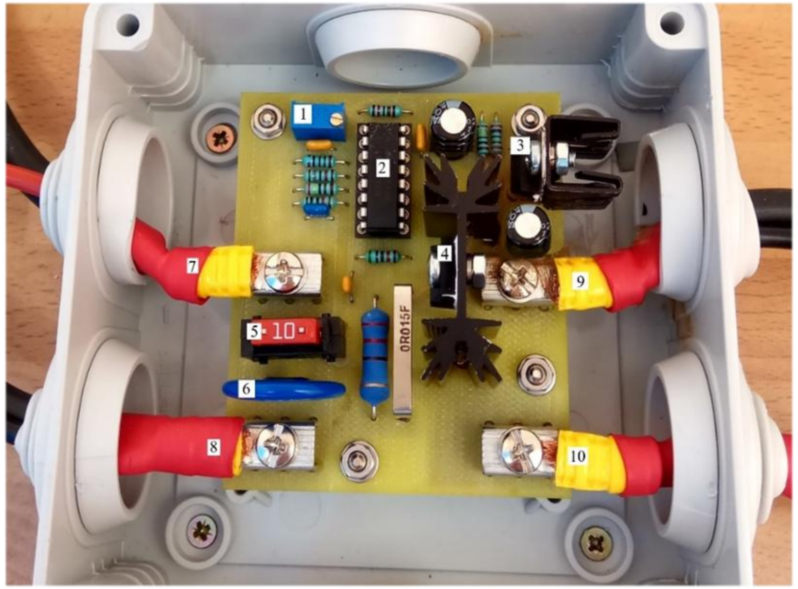


- The concept of the proximity of the constant voltage to the MPP tracking makes possible an on/off circuit that approximately maintains the **average input voltage**.
- The price to pay is a power loss. In our case 3 W are lost from a nominal of 300 W_p.
- 7×6 cm PCB using through-hole components costing ~ 5 €.

Detail of the circuit prototype implementation

Requires a minimum of 8 V nominal of PV supply (actually starts working with 8 V). It consumes 1-10 W, being worthwhile for — — with an MPP matching resistance at .





1. Potenciómetro de 2,2 kΩ
2. Generador de pulsos (PWM) LM3524D
3. Transistor de potencia MOSFET TK30A06N1
4. Regulador de tensión LM317
5. Fusible protector del circuito de 15 A tipo automoción
6. Varistor 33 V/20 A
7. Terminal positivo de entrada
8. Terminal negativo de entrada
9. Terminal negativo de salida
10. Terminal positivo de salida

Images by Carlos Serrano-Hernández, Master Thesis 2018 “CIRCUITO DE CONTROL DE PANEL SOLAR FOTOVOLTAICO SIN BATERÍA”

.

Modified commercial cooking pot for TES

Original electronic boiler/fryer
110-230 V 900 W. 5 liters capacity.
Walls are insulated.
Pressure cooking is possible.
Removable inner pot.

DC resistance added to the inner hot plate.
230 V AC operation is kept.

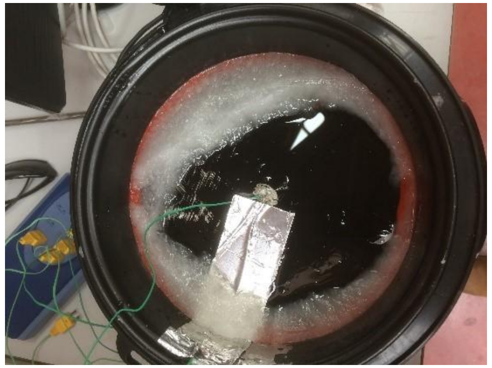
When there is need of using the grid electricity, the pot is still valid.

Inner pot with thermocouple.

Bottom of inner pot filled by a composite of PCM erythritol and aluminum tubes.

Bottom of inner pot covered and with thermocouple

Expansion problems →



PV solar cooker testing platform

PV testing platform. Comparing using batteries is possible.

Especificaciones	
Modelo	RED310-72M
Potencia máxima (Pmax)	310W
Tensión de potencia máx. (Vmp)	37,52V
Tensión de corriente máx. (Imp)	8,27A
Tensión de circuito abierto (Voc)	46,46V
Corriente de cortocircuito (Isc)	8,7A
Eficiencia de célula (%)	18.40%
Máxima tensión del sistema (V)	1000VDC
Coef. de temp Isc (%)/ºC	0,037%/ºC
Coef. de temp Voc (%)/ºC	-0,34%/ºC
Coef. de temp Pmax (%)/ºC	-0,48%/ºC
Temperatura nominal de funcionamiento de célula	45±2ºC
Tolerancia	±3%
Tipo de célula (mm)	Policristalino
Nº de células	156x156mm
Tipo de conectores	72 células
Peso (kg)	23kg
Dimensiones (mm)	1956x992x50mm

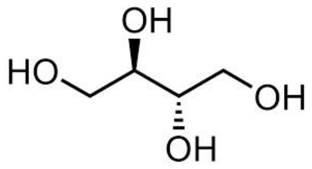
Ficha técnica testeada según STC, STC:AM 1.5,1000W/m2, 25ºC.

PV testing platform. Very simple PV controller circuit, pot and data logger.

Evaporative losses experiment.
Open pot on lower platform.

Thermal storage using a Phase Change Material (PCM)

- Phase change allow to store more heat, but melting temperature must be high enough.
- Must be non-corrosive, non-toxic, low cost.
- Erythritol edible non-caloric four-carbon polyol is a good candidate.



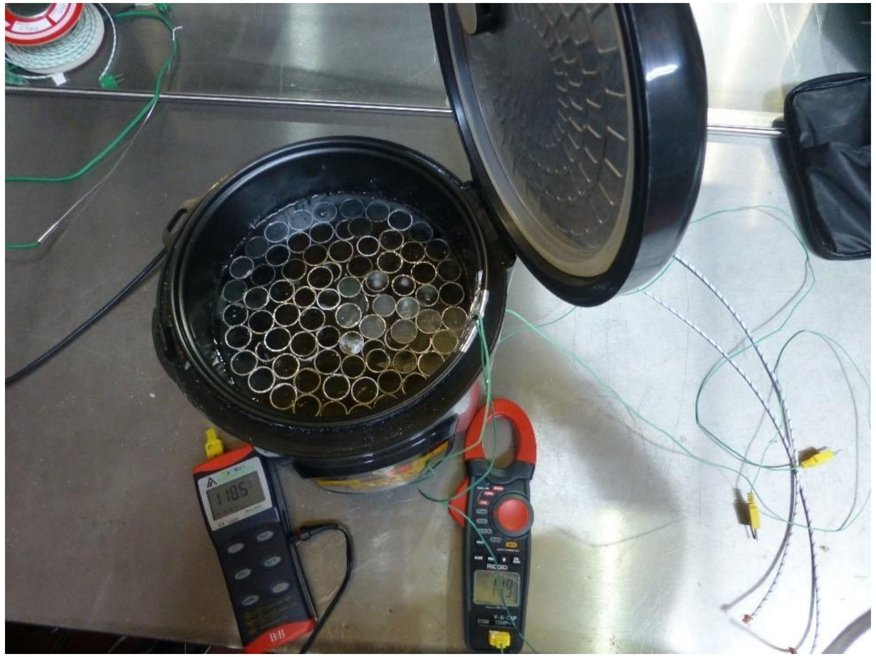
	Heat conductivity solid/liquid [$W\ m^{-1}\ K^{-1}$]	Density solid/liquid [$kg\ m^{-3}$]	Melting heat @ T [$J\ g^{-1}$] @ [ºC]	Specific heat solid/liquid [$kJ\ kg^{-1}\ K^{-1}$]
Erythritol	0.733/0.326	1,480@25ºC/1,300@120ºC	340 @ 118 ºC	1.38/2.76

Similar to ice

Too low, but enhancement is possible …

Pot modification and preliminary experiments with erythritol

Boiling experiment, no storage with DC resistance.

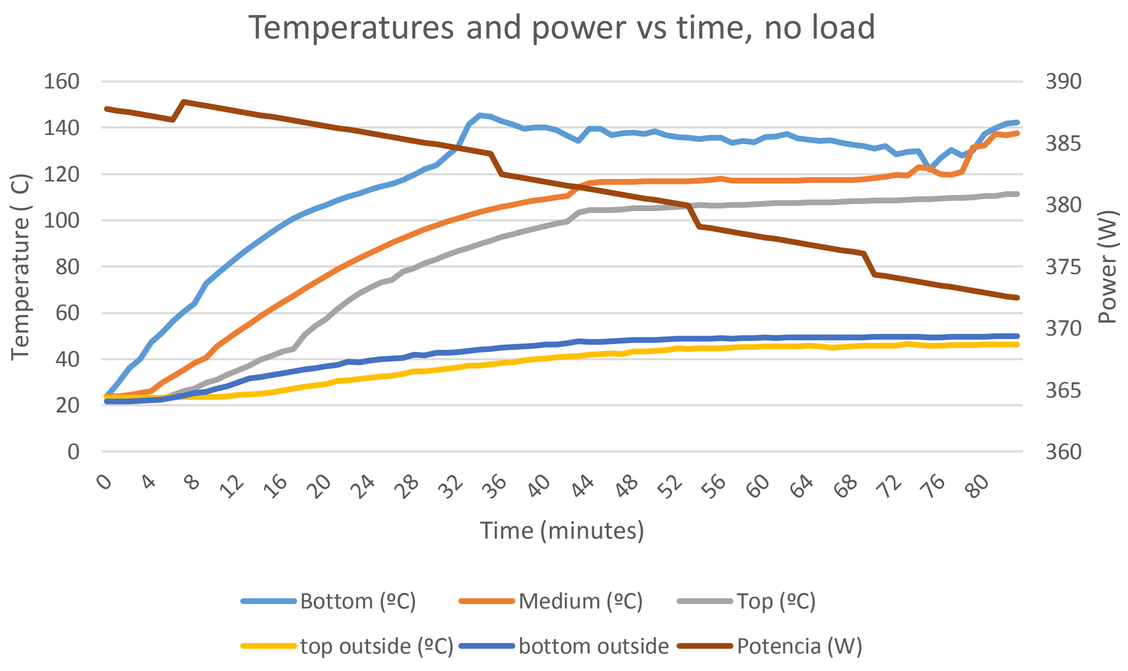


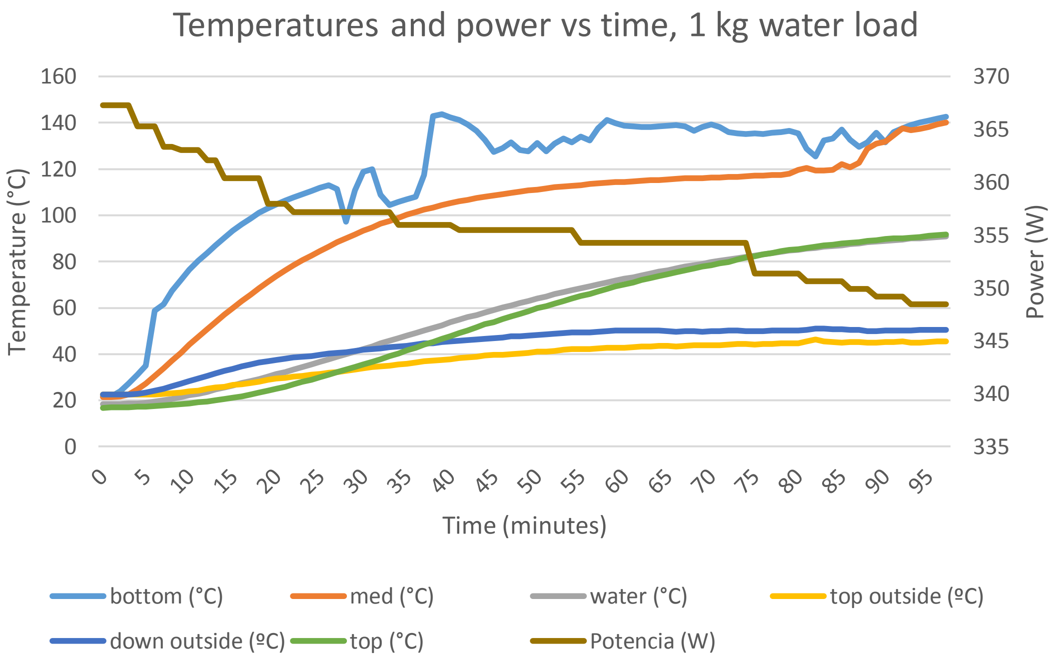
PCM composite Thermal Energy Storage (TES). Aluminum tubes directionally enhance heat conductivity. Melting before closing.

TES Closed

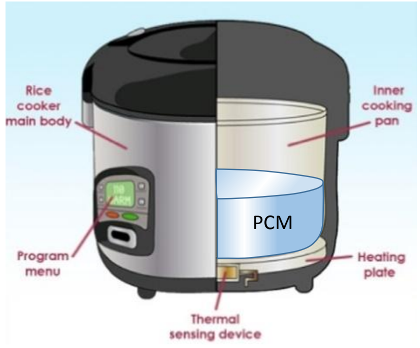
PCM retraction when solidifying.

Experimental results: charging, descending power

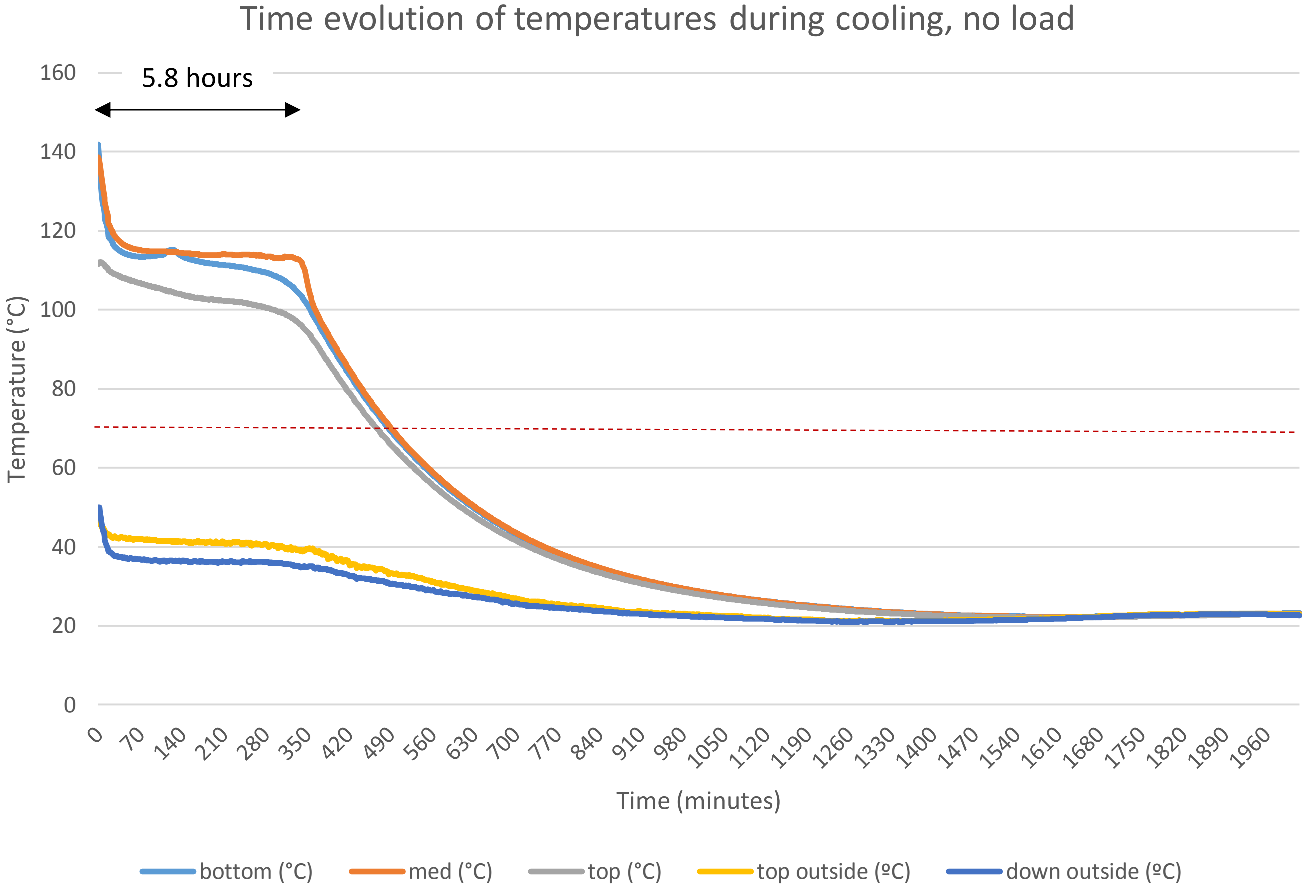


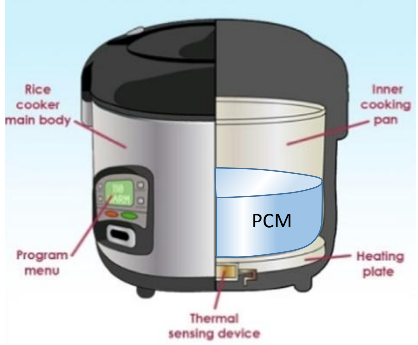


2 MJ_e added, 83 min with no load and 97 min loaded.
About 1 hour is necessary for full storage, no load.
With load, about 1.5 hour. Differences not relevant.
and 0,80 resp.



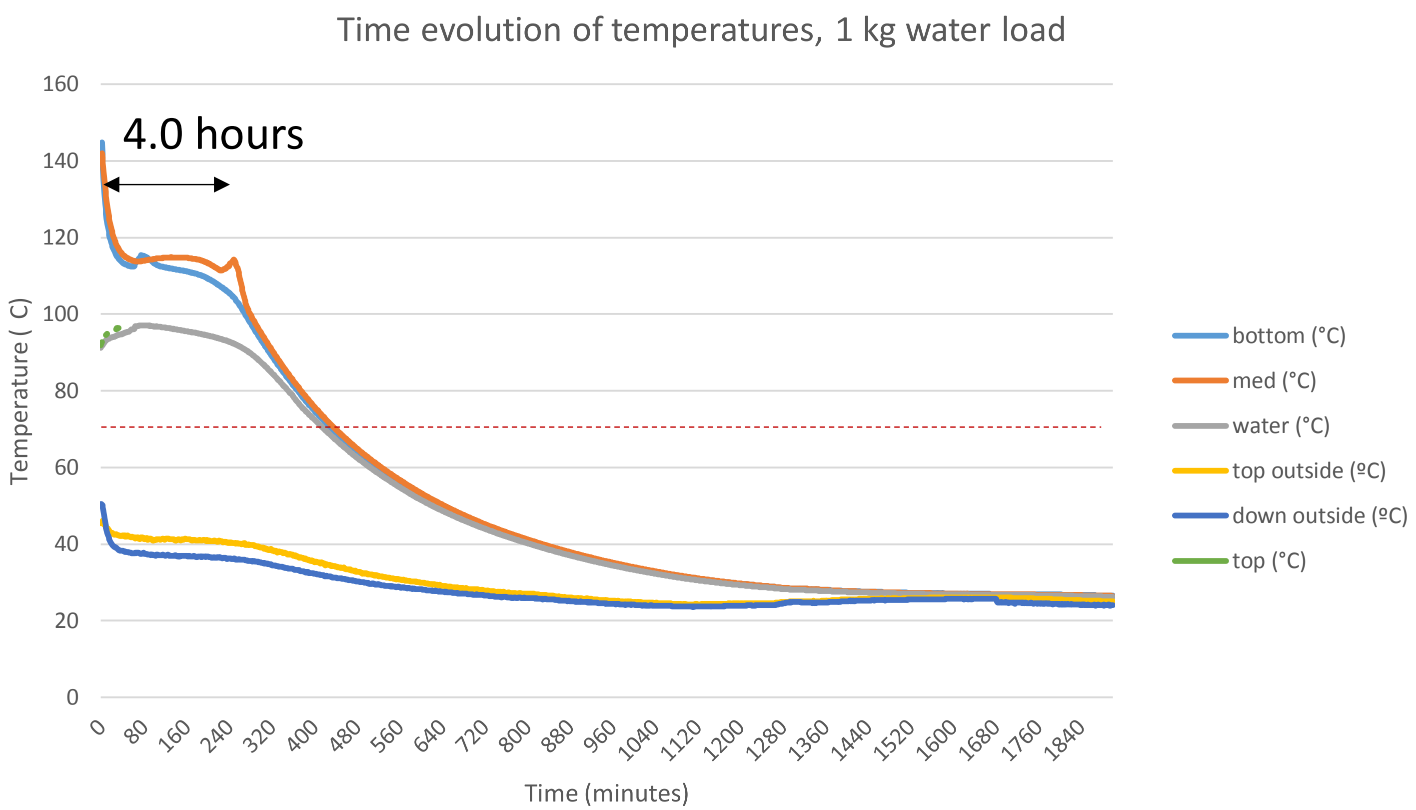
Experimental results: cooling, no load

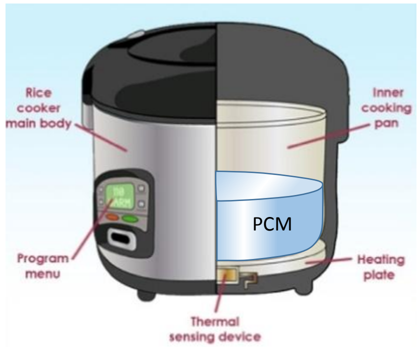




- No external insulation was added.
- About 6 hours heat is available for cooking, heating or sanitary water preparation
- Characteristic cooling time is 3.3 hours.

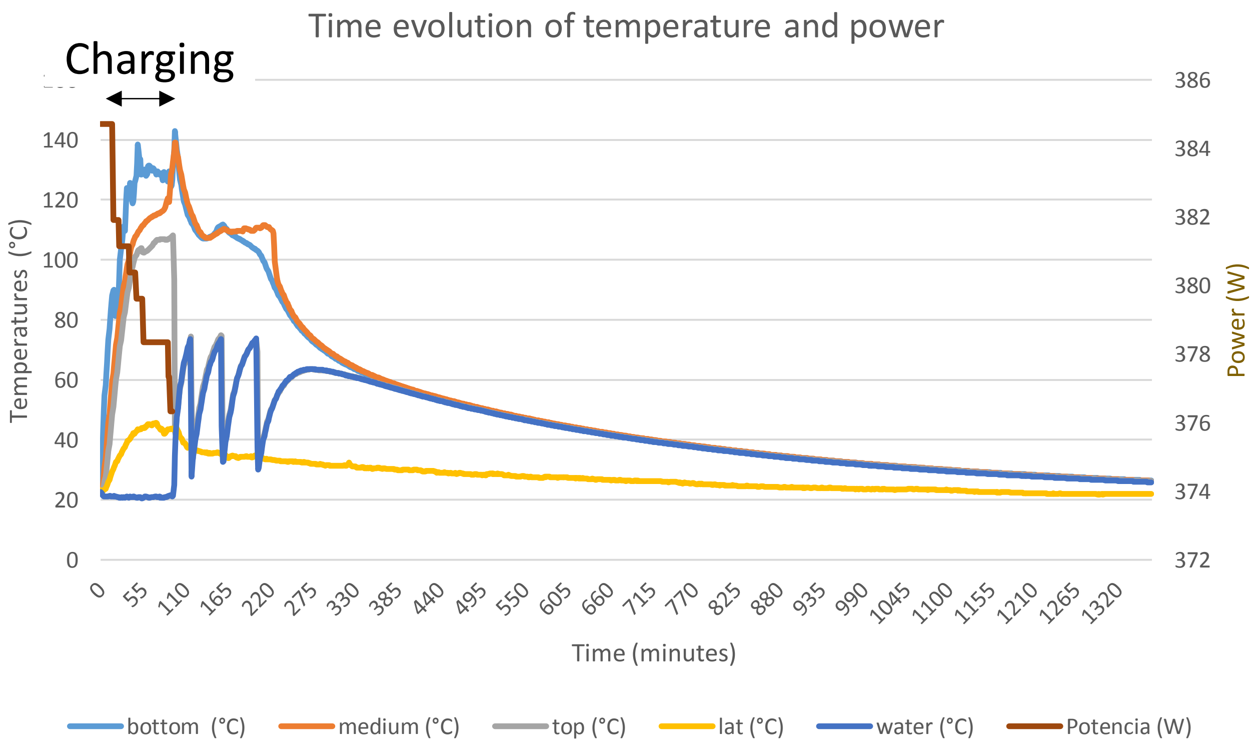
Experimental results: cooling, 1 kg water load

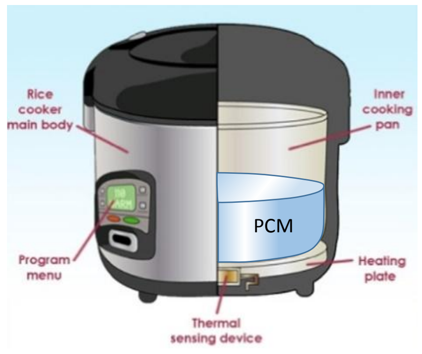




- No external insulation was added. Internally yes.
- Evaporation losses are evident in speeding of the cooling.
- About 4 hours heat is available for cooking, heating or sanitary water preparation
- Characteristic cooling time is 3.3 hours.

Experimental results: cooking capacity

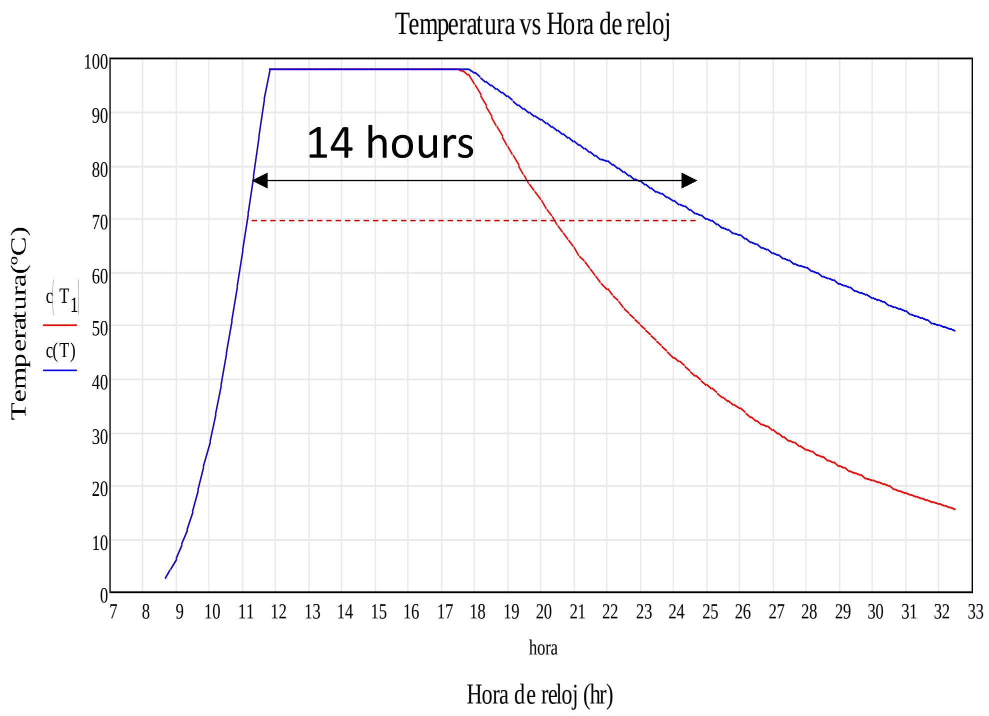




After charging with no load:

- Up to 3 loads of 1 kg can be brought up to 74 ºC in about 25 minutes average.
- 4th load heats up to 63 ºC. And keeps warm for 8 hours.

Modeling results: effect of a “hay basket”



Even with no PCM:

- The retention time can be extended overnight.

¿load?

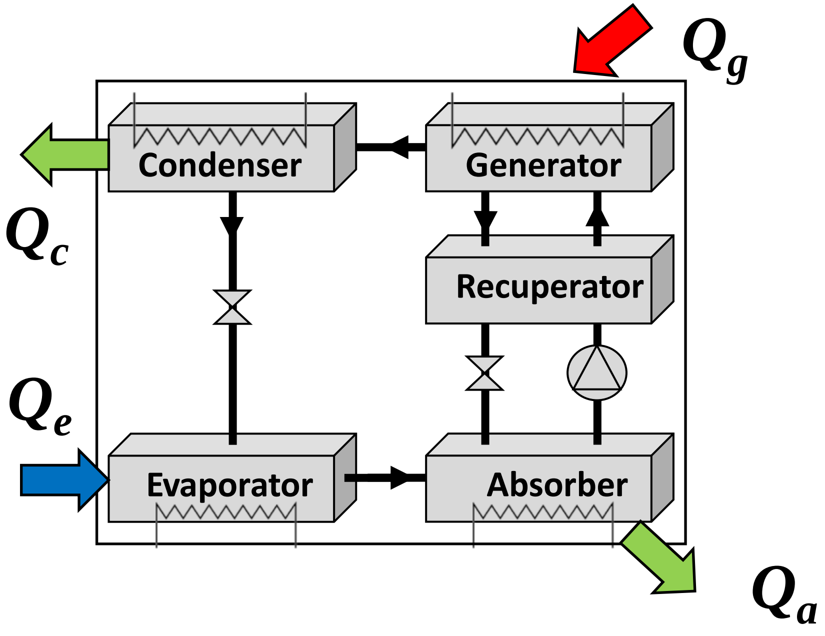
Conclusions

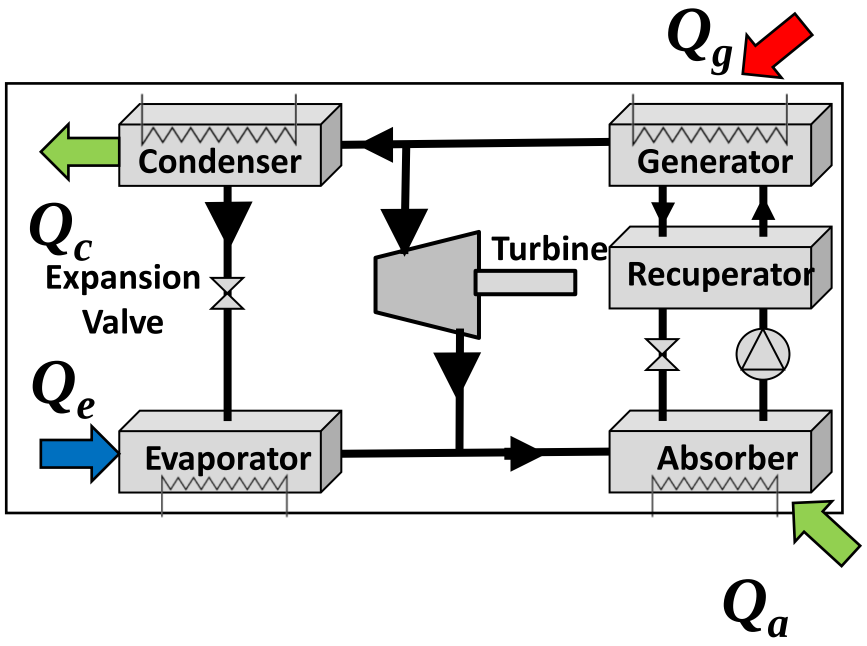
For the developing countries families, PV cooking:

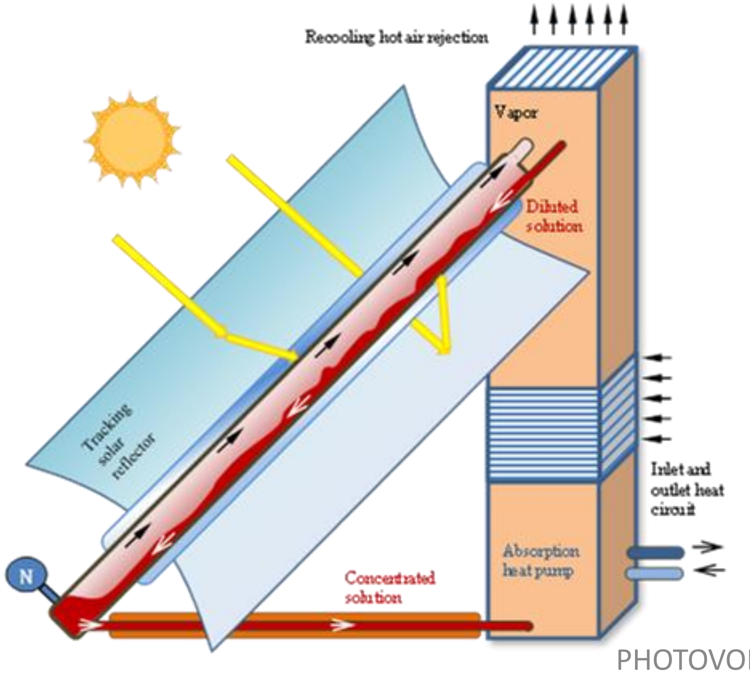
- Is possible at reasonable investments, if micro-financing tools are deployed.
- It will highly improve the living level and allows sustainable development.
- The “high” power needed for cooking ( ) will allow:
  - A quantum leap from primitive into “electric energy” world.
  - Future integration into smart grids.
- First-stage electrification for remote communities.
- The design proposed:
  - Uses low-cost commercial components and a appropriate technology circuit.
  - **Substitutes batteries by thermal storage (TES) using an edible low-cost PCM.**

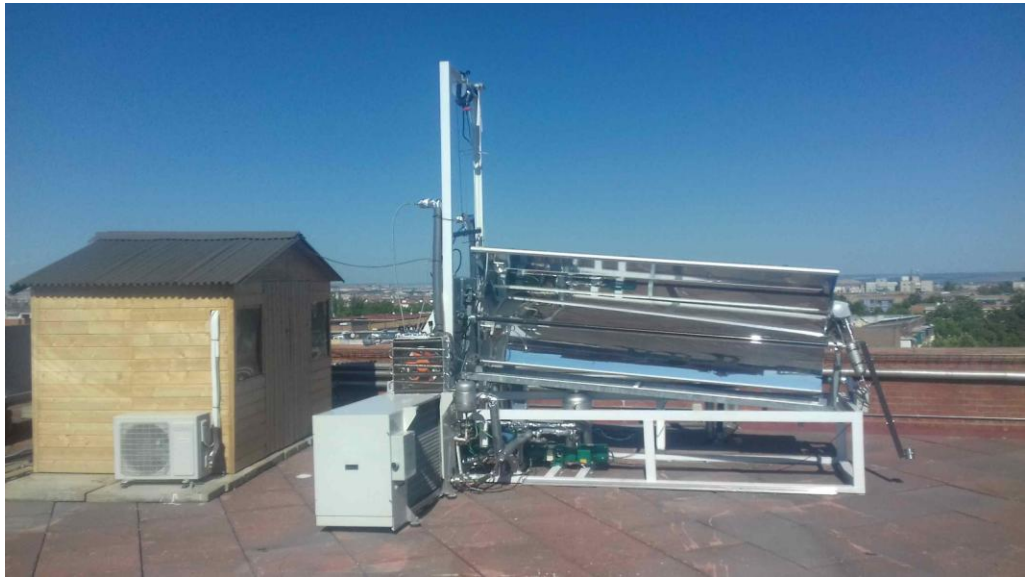
Research activity of the group “ITEA” in the field of absorption technology

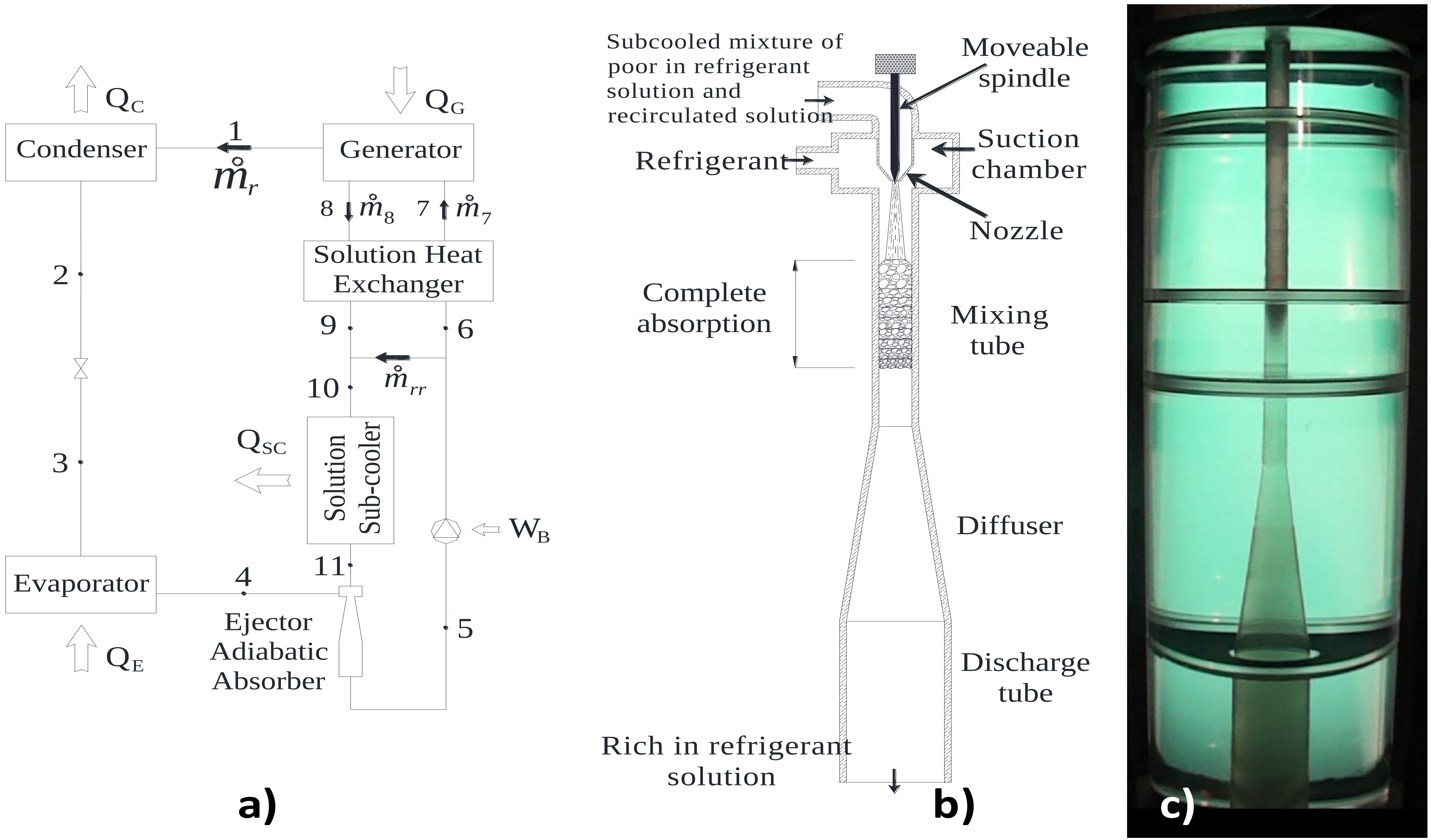
- Hybrid cycles capable of producing cold/heat/electricity.
- Combined cycles capable of consuming waste/solar heat or electricity.
- Solar energy by direct production of refrigerant inside the collector.


Condenser
Generator
Recuperator
Evaporator
Absorber
Q_g
Q_c
Q_e
Q_a


Condenser
Generator
Turbine
Recuperator
Expansion Valve
Evaporator
Absorber
Q_g
Q_c
Q_e
Q_a


Recooling hot air rejection
Vapor
Diluted solution
Tracking solar reflector
Inlet and outlet heat circuit
Absorption heat pump
Concentrated solution
N




Q$_C$
Q$_G$
Condenser
1
Generator
$\mathring{m}_r$
8 $\mathring{m}_8$
7 $\mathring{m}_7$
Solution Heat Exchanger
2
9
6
$\mathring{m}_{rr}$
10
Q$_{SC}$
Solution Sub-cooler
3
W$_B$
Evaporator
4
11
Ejector Adiabatic Absorber
5
Q$_E$
a)
Subcooled mixture of poor in refrigerant solution and recirculated solution
Moveable spindle
Refrigerant
Suction chamber
Nozzle
Complete absorption
Mixing tube
Diffuser
Discharge tube
Rich in refrigerant solution
b)
c)

Thank your very much for the attention

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- Miguel A. Sánchez-Bodas
- Miriam Cabañas

Technicians:

- Jorge Picurelli
- Manuel Santos
- David Díaz
- Israel Pina

Another proposal from our group ITEA