# Solar PV
Cookstove

**DEP702 -** Project II

# Designing a supplementary cooking solution using solar PV


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# Introduction

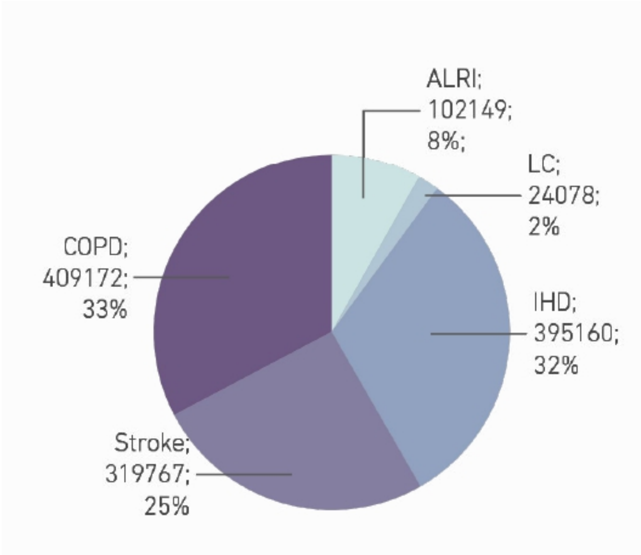


Figure 01 : Health impact of biomass-based cooking

**COPD** - Chronic obstructive pulmonary disease
**LC**- Lung Cancer
**ALRI** - Acute lower respiratory infection
**IHD** - Ischaemic heart disease
**Stroke**

The project started as an inspiration from the thesis project of Mr. Prasad Kulkarni, from the Department of Energy science and engineering, IIT Bombay. The project topic was to design and develop the solar photovoltaic equivalent of the box type solar cooker and resistive cookstove. Mr. Kulkarni's project showed the immense potential to be taken forward into the field with appropriate design considerations for a final consumer product. With the initial inspiration, I have researched the background and started looking at the broader topic of solar energy for cooking in general.

According to WHO's report on "Opportunities for the transition to clean household energy report." 2018, more than 1.3 Million Indians lost their lives in 2016-17 due to HAP (Household air pollution) generated from the burning of wood, fossil, and other solid fuels [1]. Burning biomass-based cooking practices generate harmful pollutants like $CO_2$, CO, $PM_{10}$, $PM_{2.5}$ [2].

Figure 01 shows the impact of the pollutant on the user's health in the pie chart of the death attributed to the condition that occurred due to HAP.

# Introduction

According to India's 2011 census, 67.4% of the total energy mix in cooking purposes is from firewood, crop residue, cow dung cake, lignite, and charcoal. Out of which 86.7 % of users are from rural parts of the country, 26.1 % are from the Urban [1]. Women and children of these households are most affected due to HAP from biomass based fuel [2].

The government and NGOs have taken several initiatives regarding the same. As per the Performance Audit report of PMUY (Pradhan Mantri Ujjwala Yojana), Since the inception, the distribution of subsidized and free new connections has increased the LPG coverage in the country from 61.9 percent (May 2016) to 94.3 percent (March 2019). However, the consumption pattern showed a downward trend of average annual refill consumption [3]. Many of the users don't refill these cylinders and still uses their traditional biomass-based cooking fuel as primary due to recurring costs of refilling, lack of adequate distributor in the locality, and other documentation issues, etc [3].




Figure 02 : Access to fuel sources for cooking in india, Census 2011

**PMUY beneficiery who had completed one year or more as on 31 December 2018,( Launched May 2016)**

| | |
|---|---|
| **17.61 %** | **Never came back for 2nd refill** |
| **33.02 %** | **Consumed 1-3 refill only** |

Figure 03 : Data showing the percentage of the beneficiary not utilizing the PMUY benefits optimally

# Introduction

### The Cause



**Cost**

Clean source of energy available are **Expensive and has a recurring cost**.

**Health**

**Household air pollution** generated from burning solid fuels causes health issues.

**Sustainability**

Conventional cooking is from **Non renewable** source of energy.

Figure 04 : The list of cause / rationale for the project

There is a need to transit from traditional to clean ways of cooking. There are many alternatives available such as Liquified petroleum gas (LPG), electrical cookstoves (Resistive and Induction), Thermal solar cooker, and solar PV (Photovoltaic) cooker. However, the non-affordability of these due to high initial investment, monthly recurring cost, limitation in cooking types, and usability issues are the primary barrier to clean energy cooking.

LPG, which is widely promoted, is a non-renewable source of energy extracted from fossil fuels. It has low carbon emissions as a fuel but has a higher carbon footprint due to regular transportation, storage, and distribution. There is a high cost entailed for the development of the market for LPG.

One way to move forward is to use Direct Solar PV energy with a resistive coil, as showcased in Mr. Kulkarni's project. With insulated vessels and configured system to reduce the initial investment of the solar panel.

The cause is prominent in the rural and semi-urban households. However, due to the present situation of pandemic and travel restriction, the context is kept limited to semi-urban households.

# 02
# Objective

# Design objective

Designing a **Solar PV cookstove** using **contemporary technology available** to create an efficient alternative cooking solution for **semi urban household**.

The project is envisioned as a **supplementary** cooking solution to **reduce the dependence** over the **conventional cooking method**, as a step towards the sustainable cooking practices.

# 03
# Secondary research

## Solar for cooking

Solar energy is one of the cleanest renewable sources of energy available in abundance around us. For centuries solar energy is used for cooking but not until recently, in the last twenty-thirty years, that we have seen more significant pace and developments occur in this field. Apart from the apparent advantages of time and money saved, solar cooking produces no smoke and pollution as It does not release greenhouse gases like the burning of other types of fuel.

A solar cooker or oven is a device that uses the energy from direct sunlight to cook, heat, and pasteurized foods. Many solar cookers currently available are relatively inexpensive and low-tech. However, there are some powerful, expensive, and advanced ones as conventional stoves. There are even large-scale solar cookers that can cook for hundreds of people at a time. As there is no fuel and operating cost involved, many nonprofit organizations promote their use worldwide to reduce cooking expenses, decrease air pollution, and slow down the deforestation caused by cutting firewood for cooking.

# Types of solar cooker

## Box type solar cooker

Box type solar cooker is the simplest type of solar cooker. It consists of a box with a transparent glass top, inside which food is placed for heating. A reflecting mirror reflects the sun rays onto the food. The glass prevents light rays (or heat) from escaping the apparatus and allows the food to be cooked. It is suitable for making small meals, which is limited by the box's size. However, to cook food in a box-type solar cooker, you need to keep the apparatus outside, under direct sunlight [4].

Figure 05 & 06 : Box type solar cooker

## Parabolic solar cooker

Solar cooker with parabolic reflectors concentrates the sun rays at a focal point directly on the cooking vessel. Usually, a large metal frame is used to hold The parabolic dish towards the sun's direction. Concentrated radiation thus has more efficiency than the traditional box-type solar cooker. Though it has a similar limitation as to the box type, concentrated energy helps cook faster and cooks more food dishes [5][6].

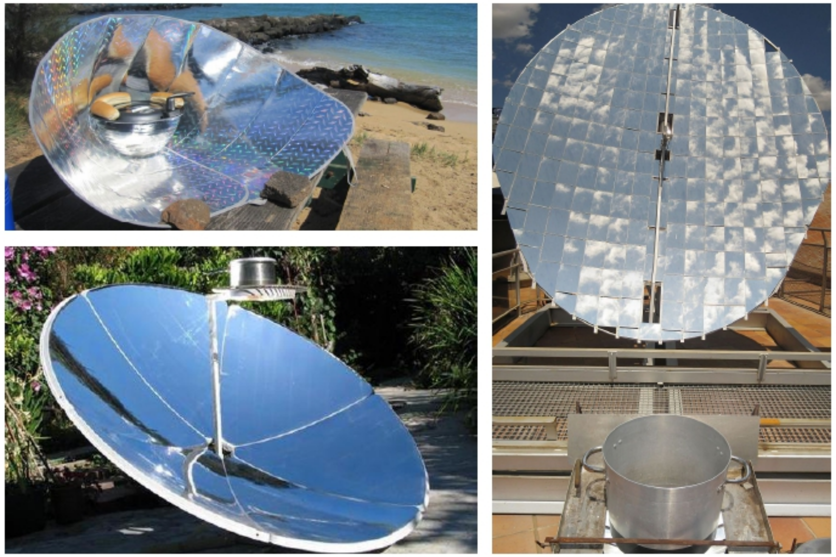

Figure 07, 08 & 09 : Parabolic solar cooker

# Types of solar cooking

### Window mounted solar cooker/oven

The window mount solar oven is designed to be mounted in a south-facing window opening, allowing the cooker to get direct sunlight. It technically works on the same principle as box type but has been developed for urban settlements that lack open outdoor spaces. Its usage is also limited to size, location of the window, and specific kinds of cooking [7] .

Figure 10 & 11 : Window mounted solar cooker/ Oven

### Evacuated tube

In cooking, significant heat loss happens through conduction and convection. Evacuated tube cooker uses a vacuum between layers of glass to create a layer of insulation for retaining heat. The inner glass has a coating of the absorption layer on the outer surface and a reflective layer on the inside surface to increase the absorption and trap heat. Therefore the cooker can reach a very high temperature and can be used for barbecue but is very limited due to the chamber's size. It also has a limitation of using outdoor and needs direct sunlight.

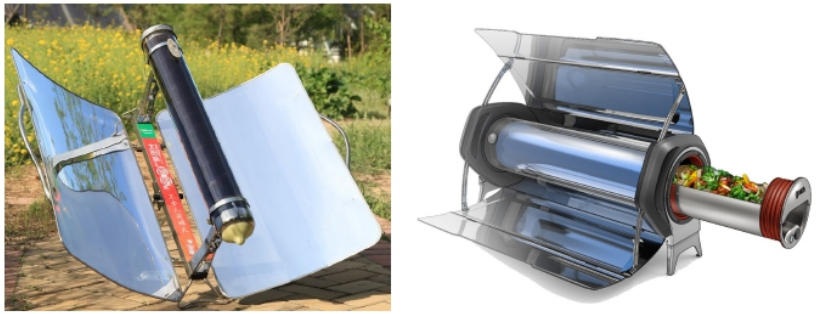

Figure 12 & 13 : Vacuum tube solar cooker

# Types of solar cooking

### Indirect Solar PV

Solar PV (Photovoltaic) converts solar energy into electrical energy and store it in batteries. The induction cook stove uses stored electricity to cook food indoors at any time of the day and for most dishes. Indirect solar PV is efficient because of induction, as there is no heat loss and have better power control for comfortable cooking [8].

The system needs a battery for storage & constant voltage and inverter to convert the direct current (DC) to alternate current (AC) for the induction coil to work. Therefore, Making the system expensive. The battery has a recurring cost of replacement as it has a 3-5 yrs life span. The battery contains toxic material and is hazardous to the environment.

A few projects use induction cook stoves directly on DC without an inverter. However, they still need a constant voltage from the battery and have a complex system, making it expensive and hard to repair if needed.

**Solar ( DC power ) - Battery - Inverter ( AC power ) - Induction coil ( Heat )**

Figure 14 : Setup for Indirect Solar PV

# Types of solar cooking

### Direct Solar PV

Direct solar PV intends to cut the extra cost of battery and inverter by directly connecting solar panels to a resistive coil for heating. The resistive coil can work with a Direct current (DC) and doesn't need a constant voltage to work. The system's cost comes down drastically by removing the battery and inverter but bringing back issues like not cooking at night or low solar irradiance. Also, cooking on a resistive coil is less efficient than induction as there is heat loss during the transfer of heat from the coil to the cooking vessel.

In the thesis project 'Design and Development of solar PV equivalent of the box type solar cooker, and resistive cookstove,' Prasad Kulkarni explores direct solar PV's potential for providing a clean and cost-effective indoor cooking solution. Solar photovoltaic panels' cost is optimized by energy-efficient cooking vessels to reduce the energy/power demand. Reducing heat losses in the cooking process is a way of improving thermal efficiency.

**Solar ( DC power ) - Resistive coil ( Heat )**

Figure 15 : Setup for Direct Solar PV

# Literature Study

**'Design and Development of solar Photovoltaic equivalent of the box type solar cooker, and resistive cookstove'** By Prasad Kulkarni, IIT Bombay (Year 2020)

The precise scope of Mr. Kulkarni's project was to provide an alternative to the box type of solar cooker by eliminating its major limitation of performing indoor cooking. As the Box type of solar cooker can cook all food items with gelatinization temperatures up to 100˚C, Mr. Kulkarni's project' was limited to cook all the food varieties with gelatinization temperatures of 100˚C. To make the solution cheaper and more accessible, Mr. Kulkarni explored ways to increase direct solar PV efficiency to make it work with relatively low (100W) and inexpensive solar panels. As proposed, there are two ways to achieve that.

**Insulated Vessel** - The use of insulated vessels significantly reduces the energy losses involved in the cooking process. Experimentation and thermal simulation results showed that insulated vessels consume less energy as it takes less time to reach the temperature of 100°C than a non-insulated cooker.


Figure 16 : Schematic of proposed cooking solution from Mr.Kulkarni's report.

# Literature Study

The experiment demonstrated that insulated vessels need 26 % less time than of non insulated vessels to heat the water to 100°C. After switching off the power supply, the insulated vessels retain the food above 80°C for 50 minutes, whereas non-insulated vessels retain only for 21 minutes. Thus, in insulated vessels, we do not need to supply the heat to food for maintaining it above 80°C.

In the experiment, Mr. Kulkarni tested three insulation types, and the insulated vessel with air insulation was more energy-efficient than a vessel with polyurethane jackets and fixed polyurethane insulation. In an interview with him, he informed that an air column as the insulation is most effective when followed a thumb rule, i.e., The column thickness should be no more than 10% of the vessel's radius, if larger than convection of heat reduces the efficiency of the insulation.

Figure 17 : Vessel with polyurethane insulation jacket

Figure 18 : Double walled cookstove with trapped air acting as an insulation

## Literature Study

**Improving Power delivery** - Improving the performance of the solar panel by maximizing the energy conversion from panel to the coil.

The Solar panels' specification is rated at STC (Standard Testing Conditions.). However, it isn't easy to maintain the STC in a real-life working scenario. Solar irradiance varies every day of the year, and also, there is a variation in solar irradiance throughout the day. Mr.Kulkarni experimented at a different time of the day to study the impact of solar radiation variation on power output from the solar panel. He found that the Nichrome coil's resistance should be higher than the panel's internal resistance at MPP ( Maximum power point ) if operated at STC.

As the current-carrying conductors resistance changes with an increase in its temperature, an increase in the temperature during usage increases the nichrome coil's resistance. To operate the system at MPP (Max. power point), the resistance of the Nichrome coil at room temperature should be 10% less than the internal resistance of the solar panel at the MPP.

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As both factors are counterintuitive, Mr. Kulkarni experimented further which concluded for the most effective energy conversion, the resistance of the coil must be the same as the total internal resistance of the solar panels.

Solar PV Cookstove with insulation and appropriate coil resistance can improve the system's efficiency and use less power output, i.e., fewer panels. Therefore reduces the initial cost. This system can be ideal as an add-on cooking method alongside LPG to minimize dependence on LPG/ other, reducing recurring costs

But the limitation of cooking to only boiling type of foods and being dependent on solar irradiance reduces the system's scope of usage, which led to the paper by P.Schwartz from California polytechnic state university addressing this issue by using a phase change material as heat storage.

# Literature Study

**'Insulated Solar Electric Cooking- Tomorrow's healthy affordable stoves? (2016).**

**Phase change material as thermal storage (2018) .**

By P.Schwartz and more, California polytechnic state university- Physics

Mr. Schwarz's paper addresses the concerns/ limitations of insulated solar electric cooker, a system similar to that of Mr. Kulkarni's project. Using Phase change material (Erythritol) as a heat storage medium, Mr. Schwarz's and the team used the same configurations as the latter,.i.e., 100W relatively low power photovoltaic panel and used it for frying. The PCM medium melted at 120 °C during exposure of the panel to the sun during the day and was hot enough to cook a meal reasonably quickly without the sun or stored battery in the evening till 3-4 hrs after the sunset.

In Ghana, Mr.Schwartz and his team successfully executed their project in a small village without electricity and introduced them to this new cooking method.

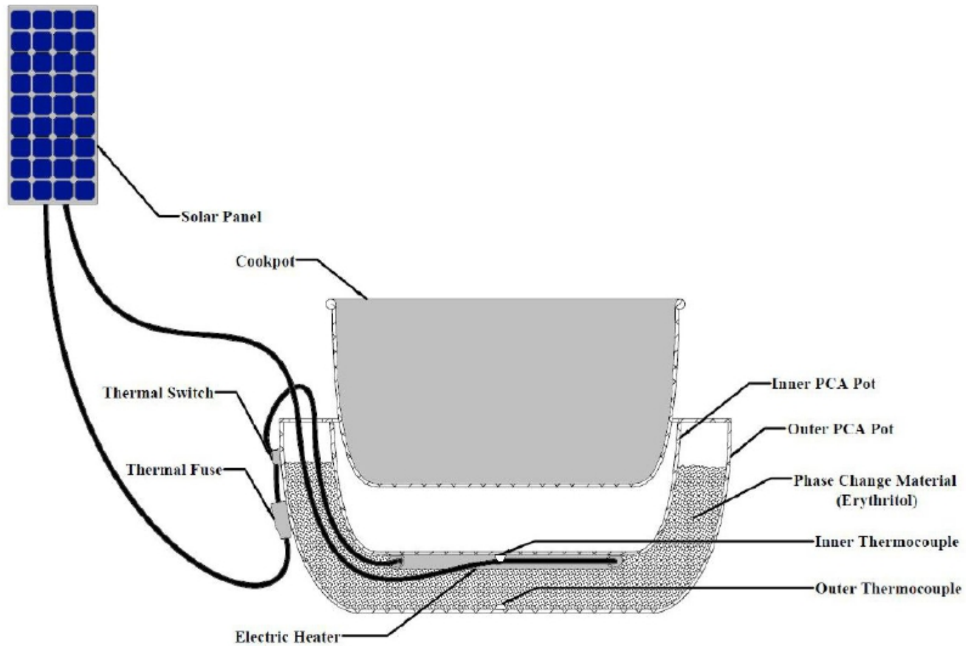



Figure 19 : Schematic diagram of the proposed system with PCM by P.Schwartz

# Literature Study

## Conclusion

Solar PV Cooker/stove with **insulation is more efficient** and can use **less power output panels** for cooking, therefore **reducing the initial cost** exponentially.

Solar PV Cooker/stove with **PCM as heat storage** can improve **usability with more cooking** options like frying, etc.

**Direct Solar PV** for cooking is **economical and environmental friendly** as a supplementary solution for household cooking.

# 04
## Design Brief

# Project Brief

To design a solar cookstove using **Direct PV with a resistive coil** as a heating element, **PCM** ( phase change material) as heat storage, and **Insulated vessel** for **an efficient and low-cost system** for a **supplementary cooking solution** for semi-urban households.



### Solar panel - 400 W

Directly connected to heating element without Battery and inverter. Customise panel for more efficient power conversion from panel to coil.



### Resistive heating - Nichrome coil

Nichrome resistive element works on DC current produced by the panel. Resistance to be matched with internal resistance of the panel for efficiency.



### Heat storage - Erythritol (PCM)

Organic Erythritol used as heat storage. The energy absorbed for phase changing is discharged faster enabling frying. (Melting point - 150˚C & Boiling point - 250˚C )



### Insulation - Air column

Most effective method of insulation need to be < 10% of radius of vessel.

Figure 20 : Technology for the project based on the cumulation of two reports from the literature study.

# 05
## Primary research

# Kitchen Study

Kitchen environment is studies to understand the issues with the present cooking method if and to have a holistic view of the needs of the users in Indian context.

### Kitchen Anthropometry

**Improper height** of the cooking surface may cause **fatigue and stress on shoulder, arms and back muscles** of the users.

The Cooking surface needs to be ideally at **4-5" below the elbow of the user.** Accordingly, as per the average elbow height for females in India, which is **956mm** ( Indian Anthropometric dimensions by Debkumar chakrabarti ), the cooking surface height should be at 830 mm from ground, which is the typical counter height of indian kitchen followed by architects.

**Insight**

The **Height of the cooking surface** should be at the **counter level** ideally or atleast closest to the average height of the existing gas stove. (i.e. 100mm from counter )

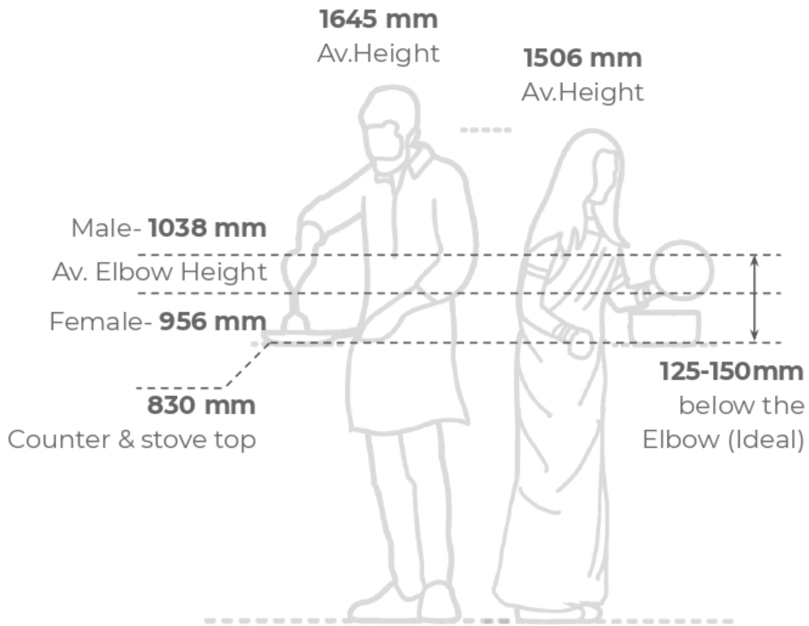



Figure 21 : Diagram showing average total height and elbow height of Indian Men and Women [12].

# Kitchen Study

## Cooking study

5 day study for understanding the type of cooking behaviour of user in a semi urban household.

| S. no | Date | Cooking Dish | Time Placed | Time Pemoved | Duration in h:m:s | Utensil Used |
|---|---|---|---|---|---|---|
| 1 | 29-09-2020 | Milk Boiling | 9:15 am | 9:30 am | 0:15:00 | |
| 2 | 29-09-2020 | Tea | 9:30 am | 9:45 am | 0:15:00 | |
| 3 | 29-09-2020 | Fried rice (Leftover) | 9:30 am | 9:45 am | 0:15:00 | |
| 4 | 29-09-2020 | Rice | 11:00 am | 11:25 am | 0:25:00 | |
| 5 | 29-09-2020 | Ocra fry | 11:00 am | 11:30 am | 0:30:00 | |
| 6 | 29-09-2020 | Tea | 11:30 am | 11:35 am | 0:05:00 | |
| 7 | 29-09-2020 | Curd fry | 11:30 am | 11:35 am | 0:05:00 | |
| 8 | 29-09-2020 | Tea | 9:30 am | 9:45 am | 0:15:00 | |
| 9 | 29-09-2020 | Chutney fry | 8:30 pm | 8:35 pm | 0:05:00 | |
| 10 | 29-09-2020 | Tadka | 8:35 pm | 8:40 pm | 0:05:00 | |
| 11 | 29-09-2020 | Roti | 8:50 pm | 9:15 pm | 0:25:00 | |
| | | | | | | |
| 12 | 01-10-2020 | Milk boiling | 8:30 am | 8:45 am | 0:15:00 | |
| 13 | 01-10-2020 | Tea | 8:45 am | 8:55 am | 0:10:00 | |
| 14 | 01-10-2020 | Boiling Soya chunks | 11:00 am | 11:05 am | 0:05:00 | |
| 15 | 01-10-2020 | Sabzi | 11:05 am | 11:35 am | 0:30:00 | |
| 16 | 01-10-2020 | Rice | 11:35 am | 11:55 am | 0:20:00 | |
| 17 | 01-10-2020 | Roti | 12:00 pm | 12:25 pm | 0:25:00 | |
| 18 | 01-10-2020 | Tea | 5:00 pm | 5:10 pm | 0:10:00 | |
| 19 | 01-10-2020 | Rice | 8:00 pm | 8:20 pm | 0:20:00 | |
| 20 | 01-10-2020 | Roti | 8:30 pm | 8:55 pm | 0:25:00 | |
| 21 | 01-10-2020 | Omlette | 9:00 pm | 9:10 pm | 0:10:00 | |
| 22 | 02-10-2020 | Milk boiling | 8:30 am | 8:45 am | 0:15:00 | |
| 23 | 02-10-2020 | Breakfast - Puffed rice | 8:45 am | 9:00 am | 0:15:00 | |
| 24 | 02-10-2020 | Tea | 8:45 am | 8:55 am | 0:10:00 | |
| 25 | 02-10-2020 | Aloo boiling | 11:00 am | 11:15 am | 0:15:00 | |
| 26 | 02-10-2020 | Aloo sabzi | 11:30 am | 11:45 am | 0:15:00 | |
| 27 | 02-10-2020 | Paratha | 12:00 pm | 12:45 pm | 0:45:00 | |
| 28 | 02-10-2020 | Tea | 5:00 pm | 5:10 pm | 0:10:00 | |
| 29 | 02-10-2020 | Veg biryani | 8:00 pm | 8:30 pm | 0:30:00 | |
| | | | | | | |
| 30 | 03-10-2020 | Milk boiling | 8:30 am | 8:45 am | 0:15:00 | |
| 31 | 03-10-2020 | Tea | 8:45 am | 8:55 am | 0:10:00 | |
| 32 | 03-10-2020 | Oats | 8:45 am | 9:00 am | 0:15:00 | |
| 33 | 03-10-2020 | Rice | 11:00 am | 11:20 am | 0:20:00 | |
| 34 | 03-10-2020 | Aloo boil | 11:20 am | 11:30 am | 0:10:00 | |
| 35 | 03-10-2020 | Curry | 11:30 am | 12:00 pm | 0:30:00 | |
| 36 | 03-10-2020 | Tea | 4:30 pm | 4:40 pm | 0:10:00 | |
| 37 | 03-10-2020 | Rice | 8:10 pm | 8:30 pm | 0:20:00 | |
| 38 | 03-10-2020 | Egg Bhujji | 8:30 pm | 8:55 pm | 0:25:00 | |
| 39 | 03-10-2020 | Roti | 8:55 pm | 9:20 pm | 0:25:00 | |
| | | | | | | |
| 40 | 04-10-2020 | Milk boiling | 8:00 am | 8:15 am | 0:15:00 | |
| 41 | 04-10-2020 | Tea | 8:30 am | 8:40 am | 0:10:00 | |
| 42 | 04-10-2020 | Rice | 11:00 am | 11:20 am | 0:20:00 | |
| 43 | 04-10-2020 | Chicken | 12:00 pm | 12:35 pm | 0:35:00 | |
| 44 | 04-10-2020 | Chicken Fry | 12:35 pm | 12:55 pm | 0:20:00 | |
| 45 | 04-10-2020 | Tea | 4:30 pm | 4:40 pm | 0:10:00 | |
| 46 | 04-10-2020 | Rice | 8:00 pm | 8:20 pm | 0:20:00 | |
| 47 | 04-10-2020 | Roti | 8:30 pm | 8:55 pm | 0:25:00 | |

Table 01 : Cooking type and time study

# Kitchen Study

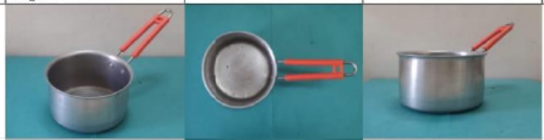
| Cookware List | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| S.no. | Type | Image | | | Internal dia. | Rim size | Height | Handle length | Material | Purpose |
| 1 | Pan |  | | | 17 cm | 0.5 cm | 9.5 cm | 17.5 cm | Aluminium | Boiling milk / water Making tea |
| 2 | Pan |  | | | 14.5 cm | 0.7 cm | 8 cm | 14 cm | Stainless Steel | Boiling milk / water Making tea |
| 3 | Pan |  | | | 15.5 cm | 1.25 cm | 10 cm | - | Stainless Steel | Boiling milk / water Making tea |
| 4 | Pot |  | | | 19.5 cm | 1.5 cm | 11 cm | - | Aluminium | Rice |
| 5 | Pot |  | | | 17 cm | 1.5 cm | 8.3 cm | - | Aluminium | Rice |
| 6 | Kadai / Wok |  | | | 27 cm | .4 cm thi | 9.3 cm | 6 cm | Wrought Aluminium | Frying |
| 7 | Tawa / Frying pan |  | | | 25 cm | .4 cm thi | - | 18 cm | Wrought Aluminium | Roti / Dosa |
| 8 | Pressure Cooker |  | | | 18 cm | - 1.25 cr | 12 cm | 16 cm | Wrought Aluminium | |

Table 02 : Utensil study

## Utensil study

Study of Utensils used regularly in cooking, type of cooking and the size.

| Total time | Utensil Used | Times used |
|---|---|---|
| 3:30:00 | | 38.3% |
| 3:00:00 | | 19.1% |
| 3:25:00 | | 21.3% |
| 3:20:00 | | 17.0% |
| 0:25:00 | | 4.3% |

Table 03 : Utensil and Time study

## Observations

1. The total time the cooking done on different kind of utensils are almost same except of cooker.
2. Pressure cooker is used least,i.e., 25 min in a week.
3. Yellow denoted utensil is only used for milk (boiling and making tea). So this utensil can be merged with orange denoted utensils as the sizes are almost same.

# Kitchen Study

**Limitation**

Study was done on the family whose staple food is rice and hence Orange denoted vessels is used predominantly but this would differ based on the geographical area the user belong.

**Insights**

The total time the cooking done on different kind of utensils are almost same except of cooker. Therefore the proposal needs to be
-**Versatile and for different types of cooking.**

Type of cooking can be categorized in to 2 types - **Boiling and Frying**

Type of vessel used in to 3 types
- **Pot, Wok and Pan.**

Note : Size of the vessel should be **1.6-2 liter.** ( An estimate as per the projected values provided by NSSO -National sample survey office, 2010 ).

**Pot**

Size: Dia-17cm

H-95mm

**Pan**

Size: Dia-25mm

**Wok**

Size: Dia-27mm

H-80mm

Figure 22, 23 & 24 : Common household utensil.

# User persona

**Situation**

'We use around a cylinder in 2 months, the nearest LPG station is 8 km away, and they don't deliver it in our village. We have to book an autorickshaw every time we have to refill the cylinder, which cost us 200 rs. It's an extra expense we have to take care of everywhere we get transferred. Mr. Tripathi always needs help for carrying cylinder because of his age and health'.

The personas were created to represent the different aspirations, frustrations and issues faced by the users as identified from the user study

**Persona 01**

Name - **Mr & Mrs Tripathi** (Travelling couple)
Age - **50 & 46 yr**
Occupation - Panchayat Secretary & Housewife
Location- Phulera village , UP

Mr. Tripathi's generally gets transferred in every three years, and the locations are at the outskirts of the city. They live alone as their children stay in Lucknow because of their education and job. Mr. Tripathi also has a back problem, so he doesn't ride a motorcycle.

| Pain Point | Needs |
|---|---|
| Hassle of booking. | Less frequent booking and pickup of LPG cylinder |
| Picking up the cylinder. | Unnecessary extra cost |
| Extra cost of delivery and service. | |

# User persona

**Situation**

'We don't have LPG connection so we buy cylinder in black which cost a lot. To compensate the amount i cook half of the dishes on Kerosene stove. Smell and smoke of kerosene gives me headache but we have no other way, we don't have enough money. '

**Persona 02**

Name - **Priyanka jha** (Struggling migrant)
Age - **34 yr**
Occupation - Housewife, husband ( security guard )
Location- Aya Nagar Village, New Delhi.

Priyanka lives with her daughter and Husband. In a single room flat. Her husband works as a security guard at an ATM near the Main market. They have come from a small village in Bihar for better livelihood and schooling of her daughter.

| Pain Point | Needs |
|---|---|
| Expensive LPG (Unsubsidized) | Alternative to kerosene stove |
| Recurring cost | Low recurring cost |
| Kerosene stove- smell / HAP has effect on health. | |

# User persona

**Situation**

'I am concerned about the environmental impact we humans are causing to this world. We are on the verge of an environmental crisis, and all of us have to do our part. I try my best to reduce my carbon footprint. I mostly use public transport and ride a bicycle to the office, segregate my waste and prefer buying products which can be recycled. '

**Persona 01**

Name - **Varun Mathews** (Environmental Enthusiast)
Age - **26 yr**
Occupation - IT Engineer.
Location- Trivandrum City, Kerala.

Varun lives alone in a flat 10 km away from his office. He is independent and takes care of his living requirement without any help. He loves to cook food and avoid eating outside as he is diet conscious.

| Pain Point | Needs |
|---|---|
| To reduce dependence on non renewable source of energy | Alternative Renewable source of cooking stove |
| To reduce his carbon footprint | Low/ No environmental impact from the product |

# The Comprehension

The list of comprehension is derived from previous study as a guideline for developing the concepts.

**Usability**

Ease of use based on various indian cooking style.

**Familiar**

Unknown new technology, need to have familiar element and a simple interface to adapt quickly.

**Flexible**

Easy to switch to convention in case of necessity.

**Blends**

Merges with the existing kitchen ecosystem in terms of form, shape and size.

**Manufacturing**

Manufacturing at the local level with small scale industries.

**Serviceable**

Easy to disassemble and repair. Availability of spare parts.

# 06
# Working Rig

# Working rig

A working rig is developed from the technology derived from literature research to validate the practical significance and to get a deeper understanding of the usability issues which may arise with it..

On Series of discussion with R&D team of **Sirius Solar Design** a **customised specification of panel** is derived for most **effective energy conversion** for resistive coil heating.

**400 W** Panel configuration achieved by **2 Panels** of **200W** with **Vm 49** and **Am 4** connected in the series. Therefore Resistance of coil needed is **24.5** ohms.

Note - Unable to procure solar panel on time due to COVID pandemic. I have used a makeshift alternative for testing the rig, which gave a conclusive result.

Figure 25 : Rig with a cardboard body on kitchen platform.

**Stove size**
Height - 180 mm
LxB - 270 - 360 mm

**Utensil size**
Height - 90 mm
Diameter - 170 mm

**Volume**
2L

**PCM body size**
Height - 110 mm
Diameter - 190 mm

**PCM Volume**
600 ml

**Insulation body size**
Height - 150 mm
Diameter - 215 mm

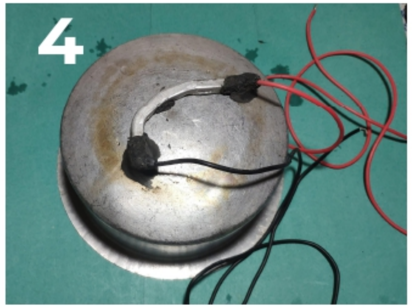
# Working rig / Mockup

Steps to the construction of rig.


Filament is taken from an old Electric iron and cut into a desired length for 22 ohms. ( As per the panel configuration) Ends of the filament is sealed to protect MgO2 to fall off and to to liquid seal the filament.


Filament is submerged in water to check if its sealed properly and do not conduct any current.


Filament is connected to a Ac to DC adapter of 65 W. On direct connecting to 220V outlet the filament melted down. ( The resistance was too low for the voltage.)




Filament is then fixed to the base of the inner pot.


Gaps are filled with aluminium foil for better conduction to the vessel.


600 gm of Erythritol is used as PCM ( Phase change material ).


Erythritol is melted on a gas burner.


After the Erythritol is completely melted the Vessel is kept aside.

# Working rig / Mockup


Inner pot with Filament is placed inside the vessel with PCM.

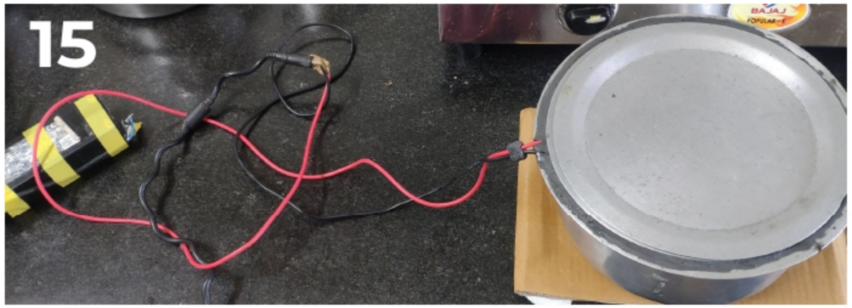

Weight are put on the inner pot to counter the buoyancy from the PCM and left until PCM solidifies.


Inner pot retains the position after the PCM solidifies.
All gaps are sealed so that PCM does leaks out.


To create air column insulation, another pot of larger dimension


Pot with air gap around will act as an insulator


Epoxy compound is used to join the insulation pot.and to seal all gaps to avoid heat leak by convection.




System is tested to see if all components are working properly

## Working rig / Mockup

Figure 26 : Testing the rig - Preheating the vessel

Rig was tested for different condition to validate the claims of the technology used .

Due to unavailability of the solar panel, a available laptop adapter is used to test the system.

**Power** - Adapter of 65 W with V 19.5 and A 3.33
**Resistance** - 22 ohms

**Water** - 300ml

**Power Generated** - P = V2/ R = ( 19.5)2/ 22 = **17.3 W**

**Test 01 - Vessel Without Insulation**
Preheated PCM for 2.5hr

**Observations**

2.5 hr for water to reach a temperature around 48° C

Even after 3 hrs the water didn't start boiling. Not visibly water droplets on lid.

**Test 02 - Vessel With Air Insulation**
Preheated PCM for 2.5hr

**Observations**

35 min for water to reach a temperature around 48° C

After 1 hr visible water droplets on the lid.

After 3 hrs, No visible boiling but water has evaporated.

**Test 03 - With Air Insulation and no preheating**

**Observations**

2 hrs for water to reach a temperature around 48° C

After 3 hr visible water droplets on the lid.

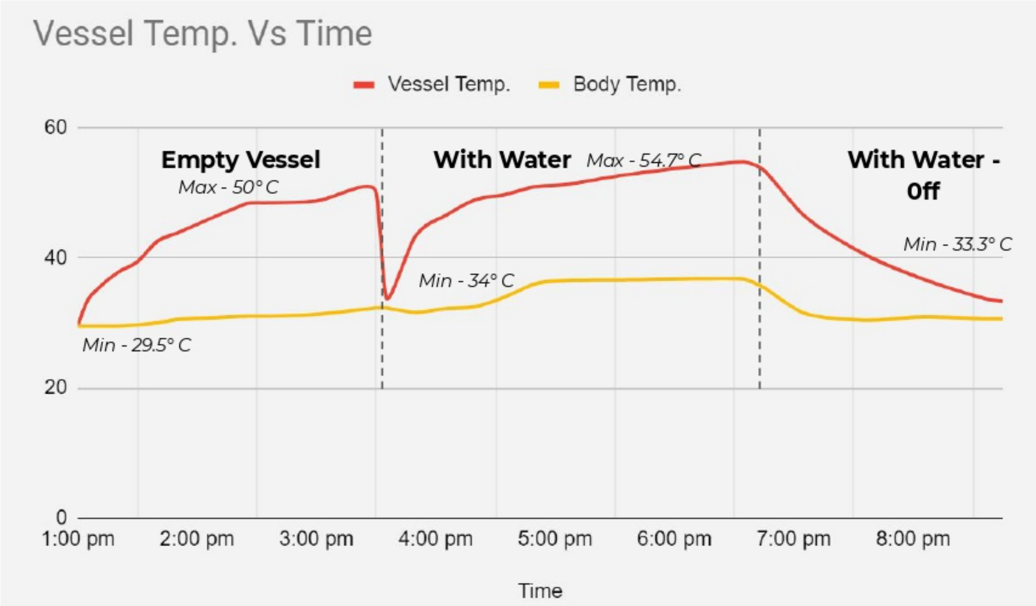



Chart 01 : Temperature vs time when the vessel is preheated and then added water; after reaching a constant temperature, the power is disconnected.

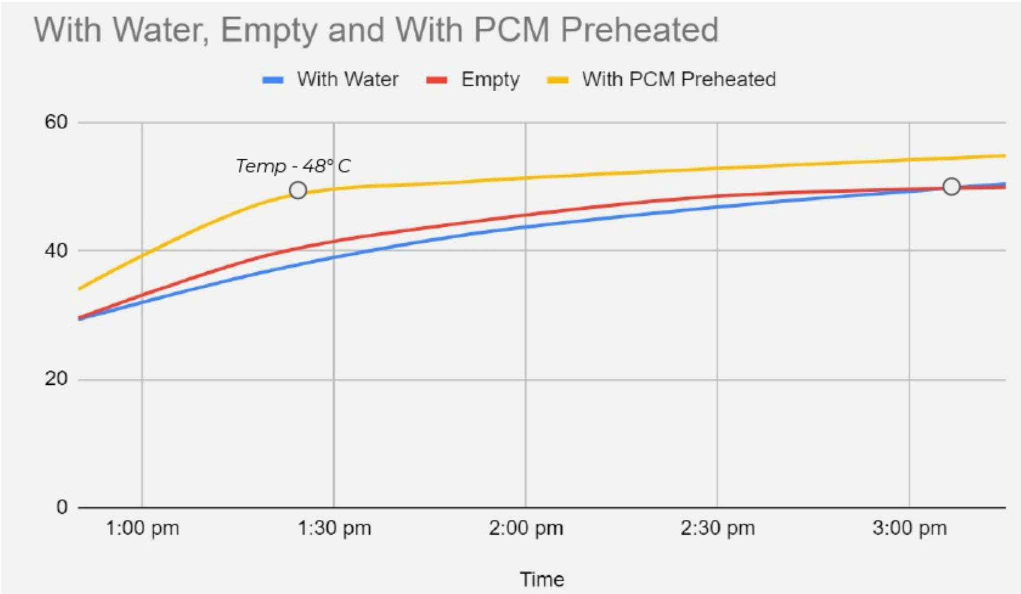



Chart 02 : Temperature gain when vessel is empty vs with water not preheated vs with water PCM preheated

# Working rig / Mockup

**Observations**

| | |
|---|---|
| Time taken to preheat an empty Vessel till 48° C | - **1hr 20 min** |
| Time taken to water reach 48° C In a preheated vessel | - **35 min** |
| Time taken to water reach 48° C Without preheating | - **1hr 40 min** |
| Time taken to water reach Min After switching off the power | - **2hr 15 min** |

Only takes **35 min** for water to reach **48° C** in taken in preheated vessel

Vessel with water takes a little more time than the empty vessel to reach same temperatures.

# Working rig / Mockup

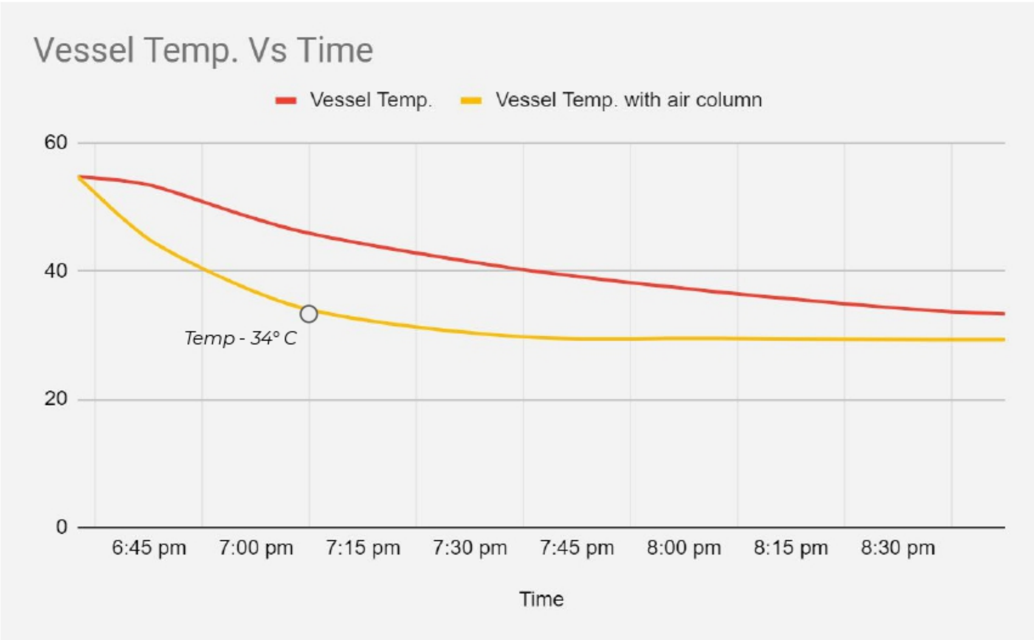



Chart 03 : Temperature drop in vessel without insulation vs with air insulation

### Observations

Vessel without PCM and insulation takes **30 min** to drop from **54° C** to temp. of **34° C.**
(A vessel of same dimension with water is heated till it reaches 54° C and then kept aside to check temperature drop)

Vessel with PCM and air column takes **1 hr 45 min** to drop from **54° C** to temp. of **34° C.**

### Conclusion

The test conducted was with very low power, i.e, 17.5 W with respect to the proposed solution of 400 W. The test still showed a very conclusive result.

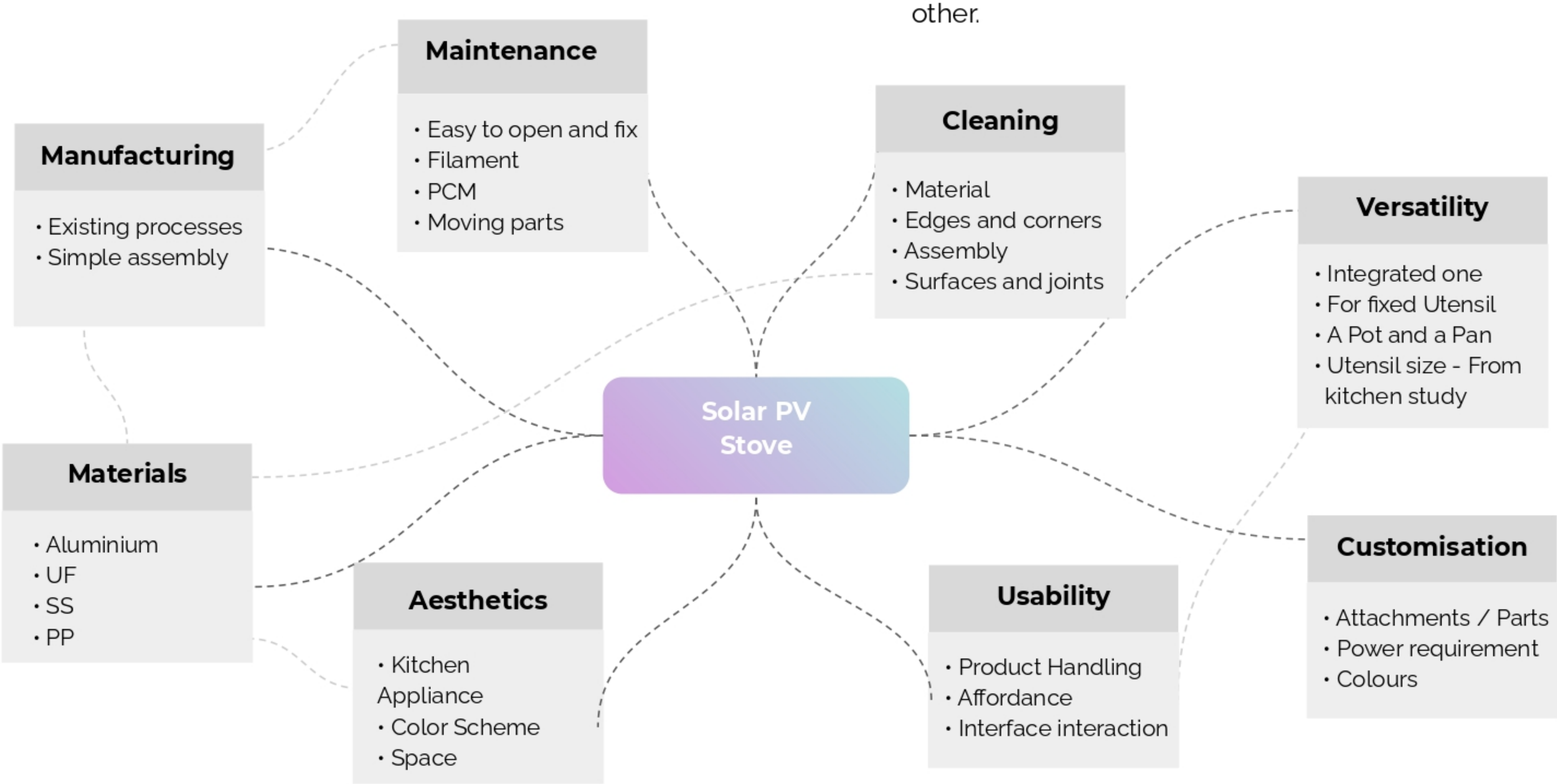
PCM as heat storage assist in fast cooking and extended the usage period after disconnecting power.

Air column helps in retaining the heat inside the vessel, hence increases the efficiency in total.

# 07
# Ideation

# Mind mapping

Mind mapping to list down all possible directions from comprehension and their relations to each other.



# Concepts

### Concept 01

**An Integrated solution** inspired by the assembly of a rice cooker.

PCM, Insulation, and the cooking vessel are integrated into a **single body.**

Single type vessel is used for all type of cooking. (200mm dia & ht 85mm with 10° draft angle) 2L capacity with larger fillet angle for using it for frying.

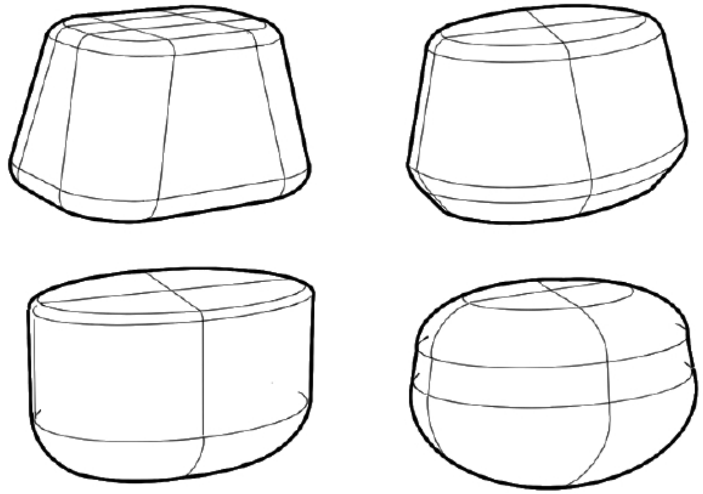


Figure 25 : Form exploration for concept 01

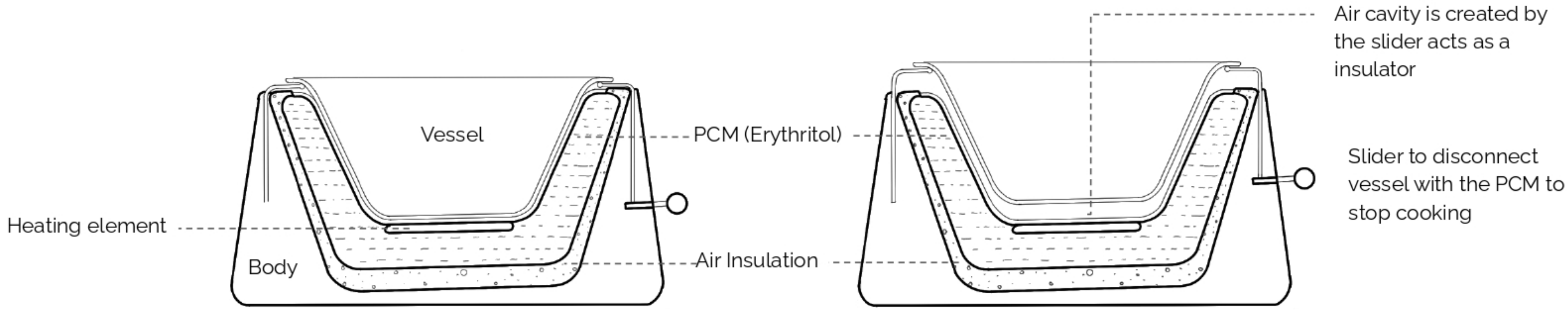



Figure 27 : Section of concept 01 with assembly details

### Concept 01

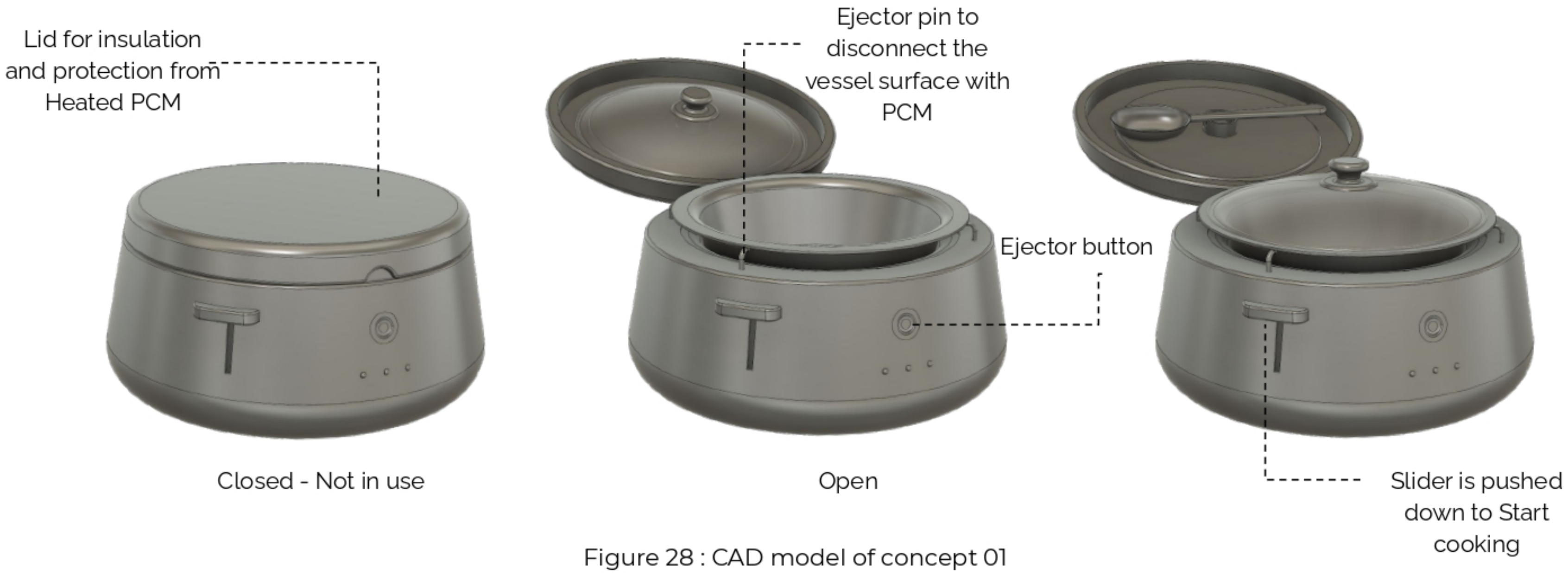



Figure 28 : CAD model of concept 01

**Pros**

- Integrated solution
- Compact.
- Familiar form factor.
- Similar manufacturing processes for most parts. Can be retrofit into existing industry.

**Cons**

- Less versatile due to fixed size of vessel.
- Low heat storage capacity
- Slider can be little confusing.
- User needs instruction.

# Concepts

### Concept 02

**Removable vessel insulation** inspired by the assembly of mixer grinder.

PCM and heating applied only from below and insulation as a separate attachment.

Insulation can be attached like the containers in the mixer grinder body - Can have multiple insulations for different pots and pans.

Comfortable for different cooking types - As more vessel types can be used with varying attachments of insulation.

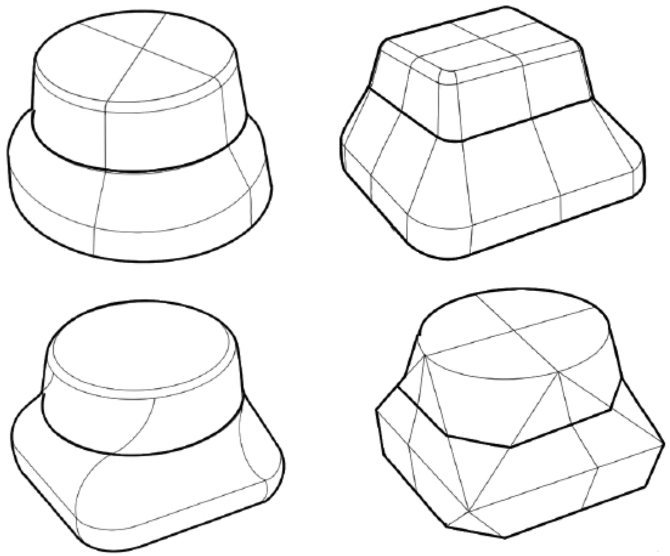


Figure 27 : Form exploration for concept 02

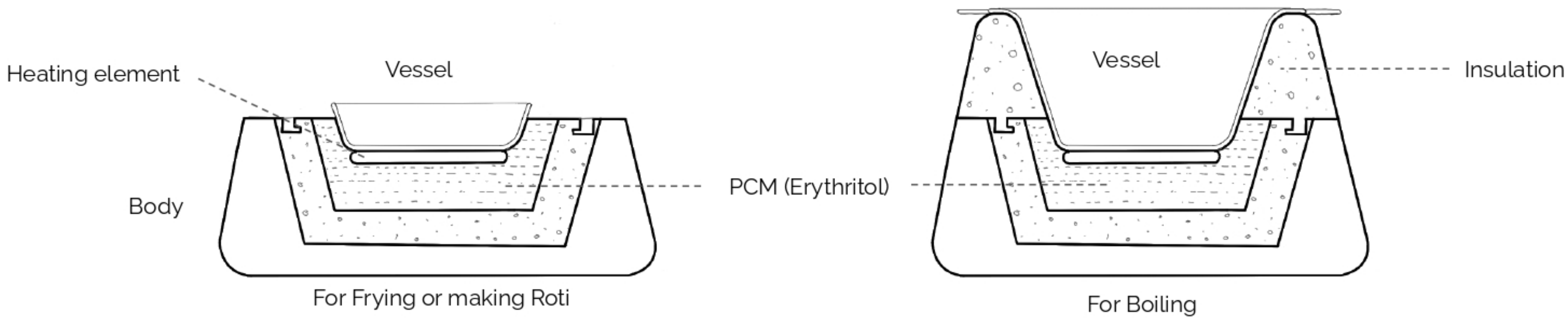



Figure 29 : Section of concept 02 with assembly details

## Concept 02

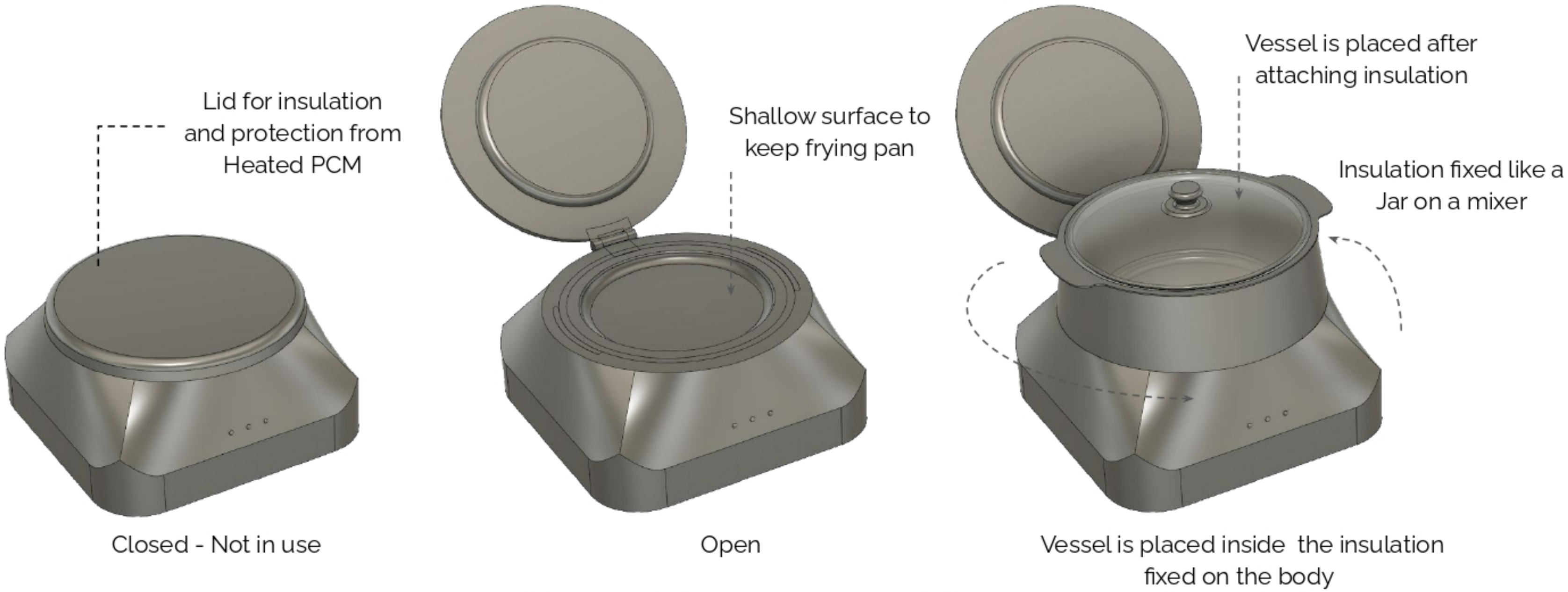



Figure 30 : CAD model of concept 02

**Pros**

- Versatile - Flat pan and pot can be used
- Customised insulations for different size vessels
- Familiar form factor - Attachment kept similar to jar attachment of mixer grinder.

**Cons**

- Many components
- Keeping / Storage of these components (insulation body) as it's used regularly.
- Heating from base - Less efficient.

# Concepts

## Concept 03

A countersunk variant of concept 02, envisioned as a Pre-installed component in a modular kitchen same as a sink or inbuilt oven.

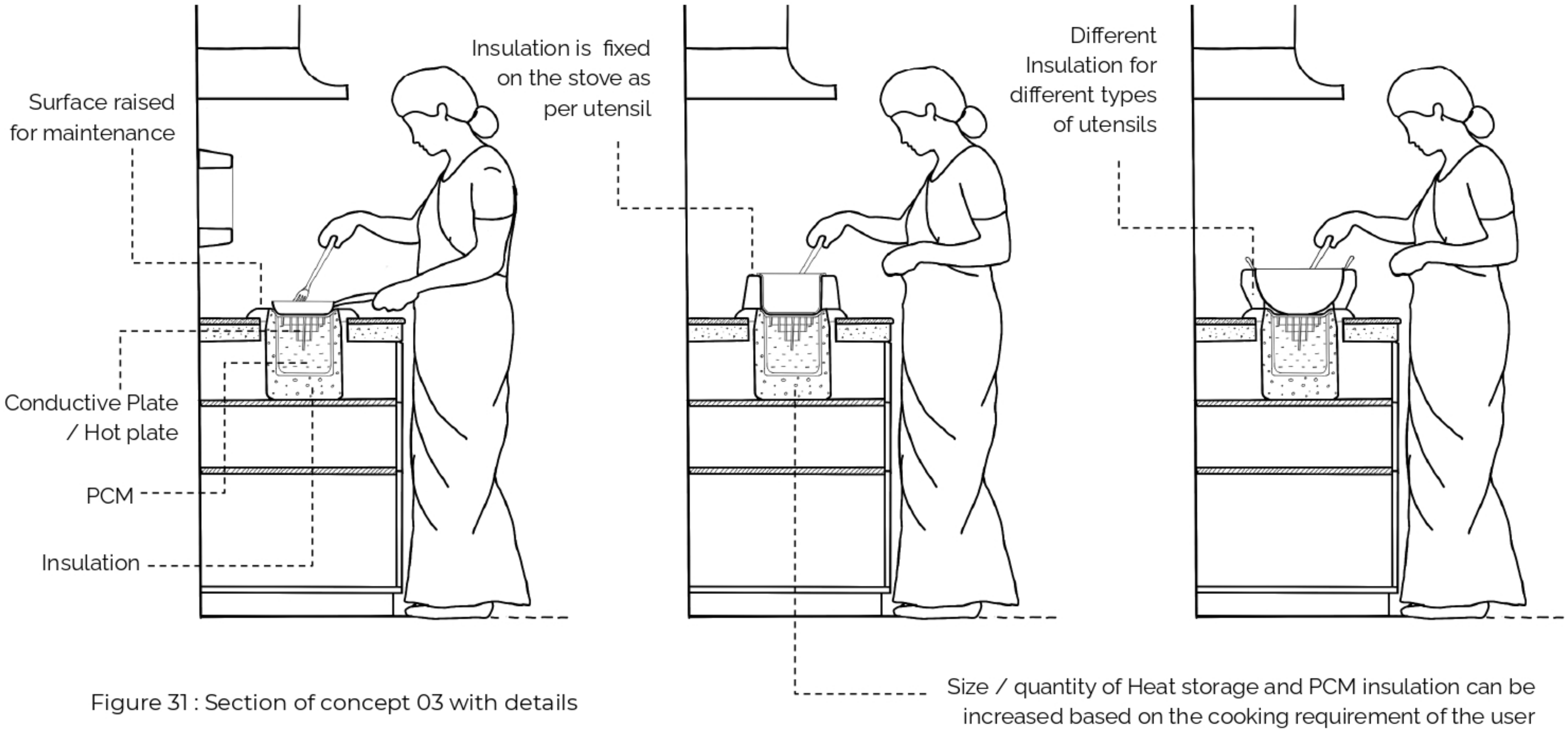



Figure 31 : Section of concept 03 with details

## Concept 03

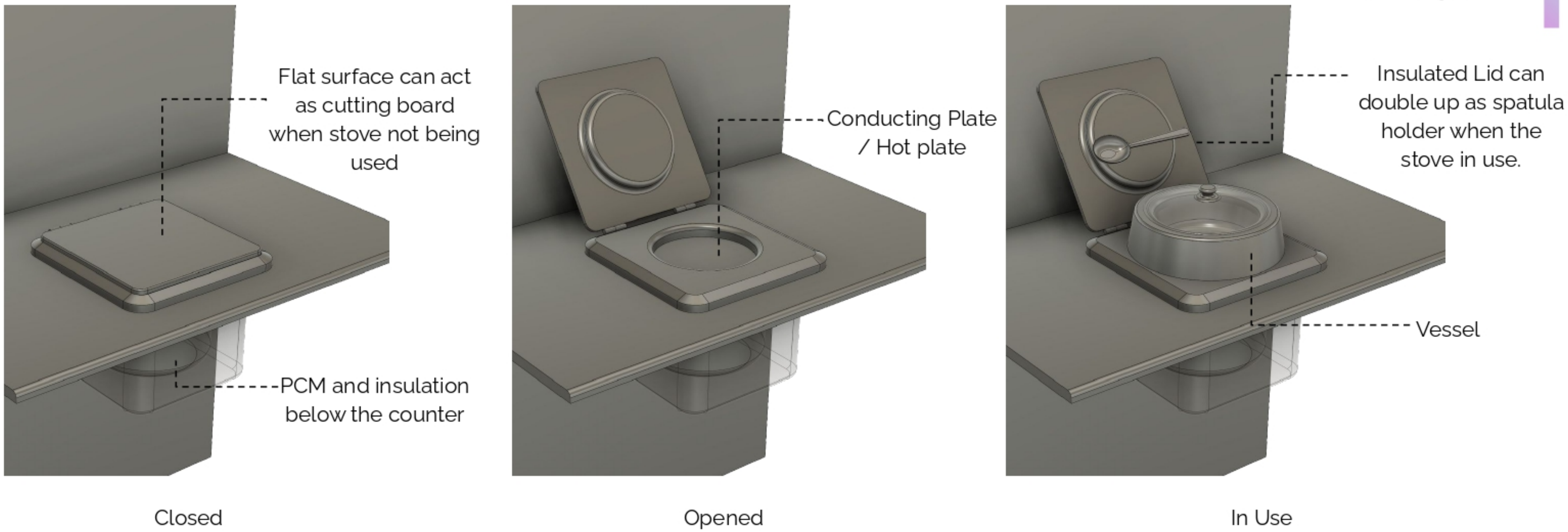



Figure 32 : CAD model of concept 03

**Pros**

- Versatile - Flat pan, pot and wok can be used
- Customised insulations for different size vessels.
- Larger PCM and insulation therefore more efficient in cooking.

**Cons**

- Installation- Needs expert
- Installation cost
- Many components.
- Needs expert to repair.

# Concepts

**Concept 04**

**Adjustable insulation and shape of the heating component**

PCM is enclosed in a circular tubing to take the shape of the utensils.

The concept can be used with Most types of Utensil.

Adjustable PCM and Insulation gives versatility to the product.

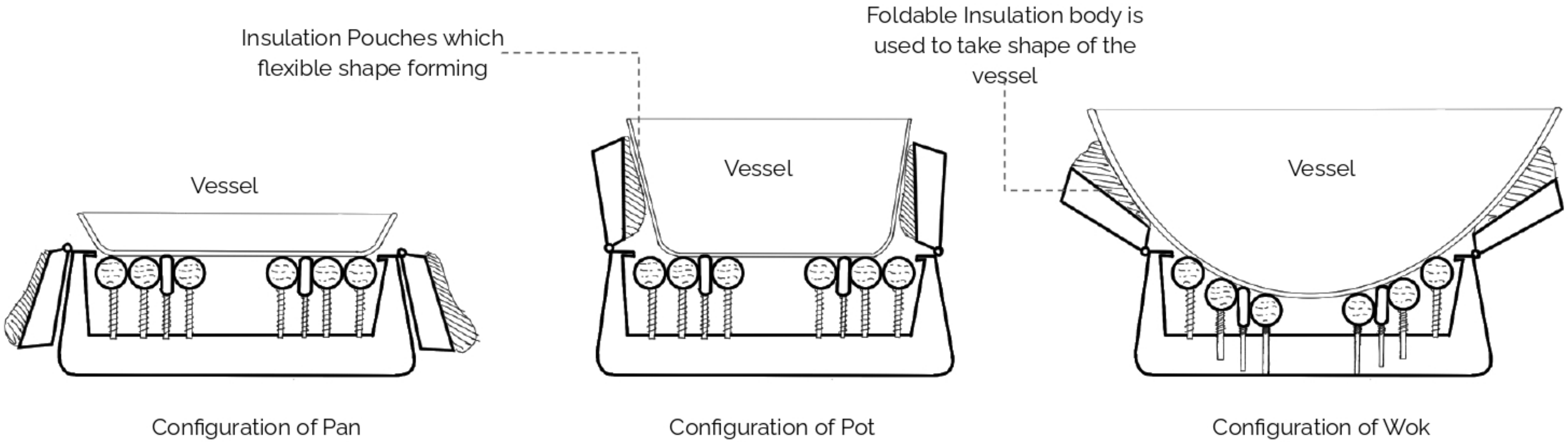



Figure 33 : Section of concept 04 with assembly details

# Concepts

## Concept 04

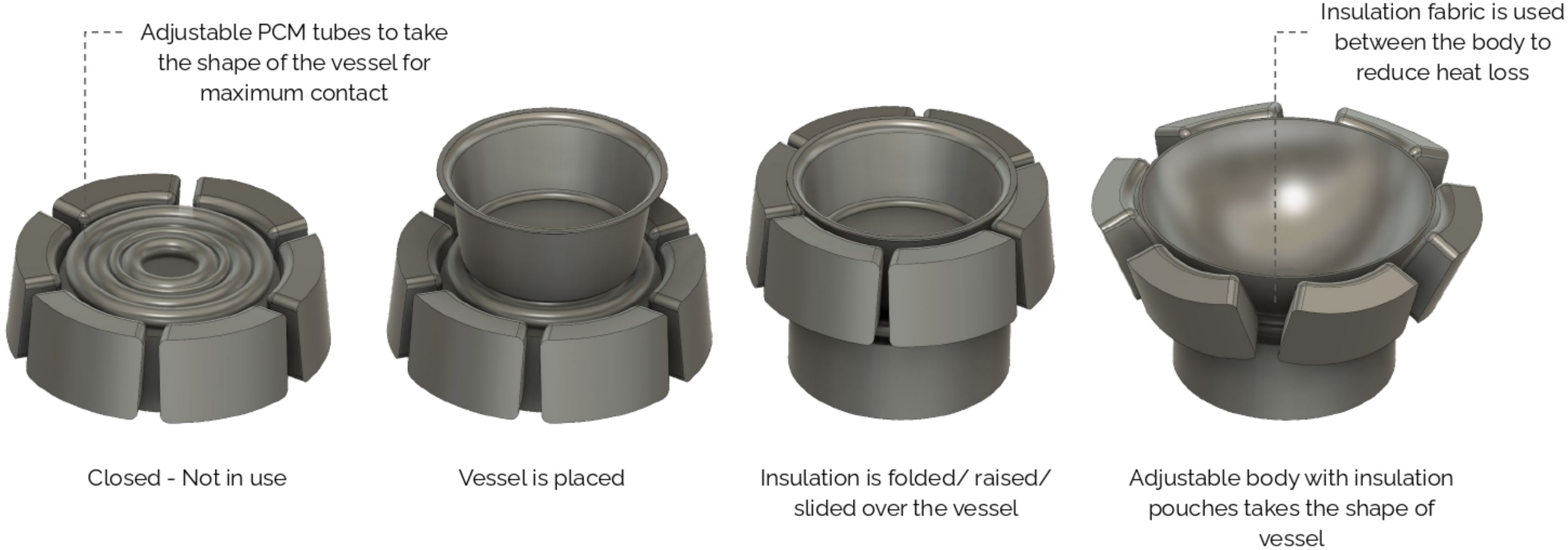



Figure 34 : CAD model of concept 04

**Pros**

- Versatile - For all vessels
- Cost of new vessel is reduced
- Integrated insulation.

**Cons**

- Moving parts
- Unfamiliar form
- Less efficient in insulation and heat Transfer from PCM.
- Needs maintenance and expert to repair

# Concepts

### Concept evaluation

The first step was to list down the criteria user might consider while buying a new type of cookstove.

A survey on google forms is floated to ask the users the criteria they preferred while buying a new cookstove and their priorities.

The outcomes from the survey to used as criteria to evaluate the concepts developed.

12 users were interviewed for the evaluation, all users cooks regularly at their homes .

7 Working individuals (4M 3F)
3 Students (2M 1F)
2 Homemaker (2F)

As technology is the same, the cooking time is similar in all concepts; safety and attentiveness aspects need to incorporate in all irrespective of a particular concept. Therefore they are excluded in evaluating the concepts developed.

**Evaluating criteria**

The following are the number rated by the user out of 5 for the given criteria.

| | |
|---|---|
| **Usability** | **4** |
| **Cleaning** | **5** |
| **Versatility** | **4** |
| **Maintenance** | **3.5** |
| Safety / attentiveness | 3.5 |
| Time of cooking | 3.5 |
| Easy repairability | 2 |
| Visual appeal | 3 |
| **Total cost** | **4** |
| **Space needed** | **3.5** |

**Preference**

Out of those the top 5 criteria preferred by them buying while buying a new cookstove

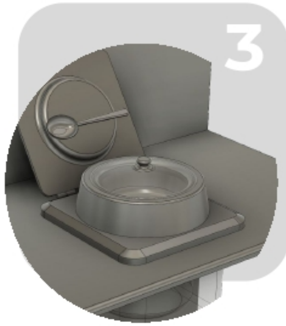
**Usability > Cleaning > Versatility > Total cost > Space needed > Maintenance** ( Most to least )

# Concepts

## Concept evaluation

Shortlisted criteria are used to rate the concept proposed and finalise the design direction..






| Evaluation criteria | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| **Usability** | 3/5 | 2/5 | 2/5 | 1/5 |
| **Cleaning** | 3/5 | 3/5 | 2/5 | 1/5 |
| **Versatility** | 2/5 | 3/5 | 3/5 | 4/5 |
| **Total cost** | 3/5 | 3/5 | 1/5 | 2/5 |
| **Space needed** | 4/5 | 3/5 | 2/5 | 3/5 |
| **Maintenance** | 2/5 | 3/5 | 2/5 | 1/5 |
| | **17** | **17** | **12** | **12** |

Table 04 : Concept evaluation

# Concepts

### Feedback

Concept 01 and concept 02 rated highest among all but a meeting and discussion was conducted with all the users to get a better insight into their decision and get additional feedback

**Insights**

**Integrated solution without moving / additional parts.**

Adjusting to new technology takes time, and adding more steps, complicate things and unpreferable for users..

**One type of cooking or All type of cooking**

One type of cooking is too less for encouraging users to buy the product. And all types are unnecessary as the product is only for supplementary cooking.

**Functional timing.**

During low solar irradiance (Certain seasons, cloudy sky, late evening and night) stove will not be used. and most probably kept aside for more space on the counter.

**Solutions**

**Integrated cookstove with simple interface and operation.**

**For two types of vessels/ cooking styles. Pot for boiling like for making rice and Pan for basic frying or making roti.**
( Staple foods )

**Adding additional functionality by connecting it to the electric grid, it can be used when there is no substantial sunlight for cooking**.

## The Check

After user feedback, the decision to incorporate the grid power into the solar power stove is taken to make it more practical and for the market.

**Primary Source of power**
Electric power generated from Solar Panels directly without battery and inverter.

**Secondary Source of power**
Electric from the grid to assist during the unfavorable solar conditions. Like during clouded sky and nights.

1. Integrated Product / Compact in size.
2. Option of connecting to Grid power and automatic switchability for most efficient usage.
3. Easy to clean and maintain materials / finishes.
4. Used with a Pot and a Pan.
5. Simple interface and usage mechanism.
6. Easy manufacturing and serviceability.

# 08
# Final Design

# Final Concept

Final Concept is the culmination of concepts 01 and 02 based on the evaluation and incorporating the insights derived from user feedback.

The core consist of PCM and  two filaments of different resistance, one for solar and other for grid as both works on different principles. A simpler slidable / collapsible insulation is created for  an integrated solution.

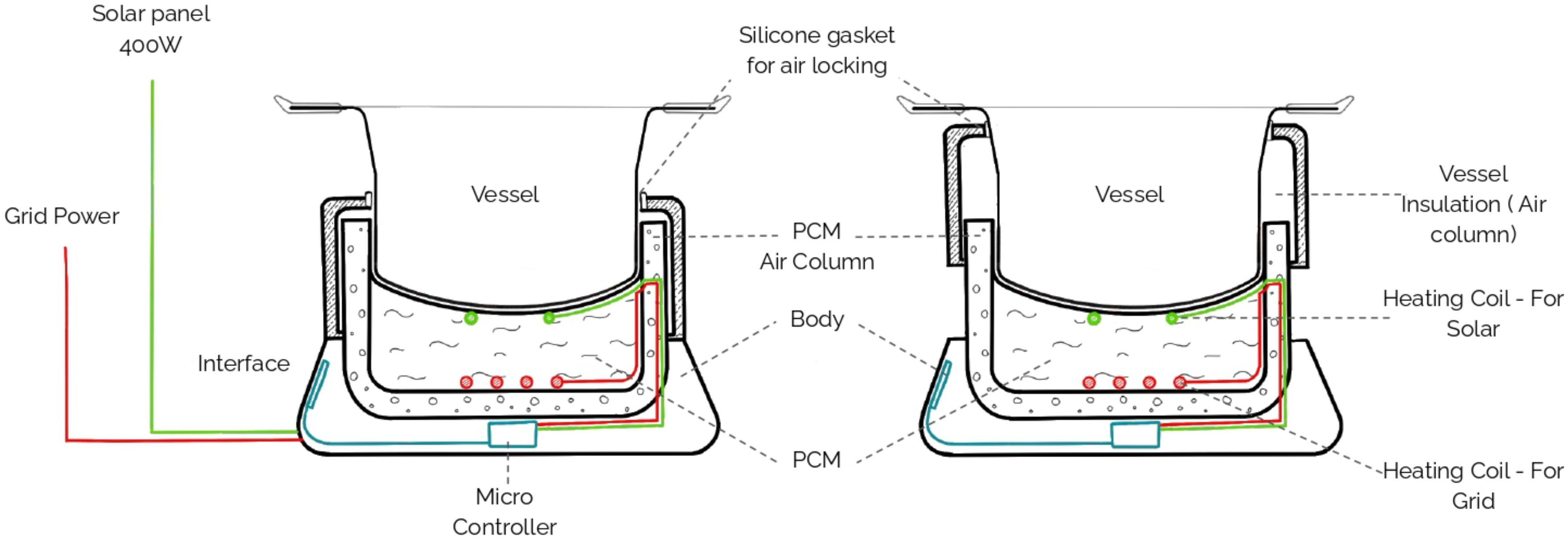



Figure 35 : Section of final concept  with internal details.

# Final Concept

## The System

With two different power source integrated, a system is devised for comfortable usage by the user. As the primary motive is to use solar PV energy, power from the grid will only be used when there is a need for extra juice.

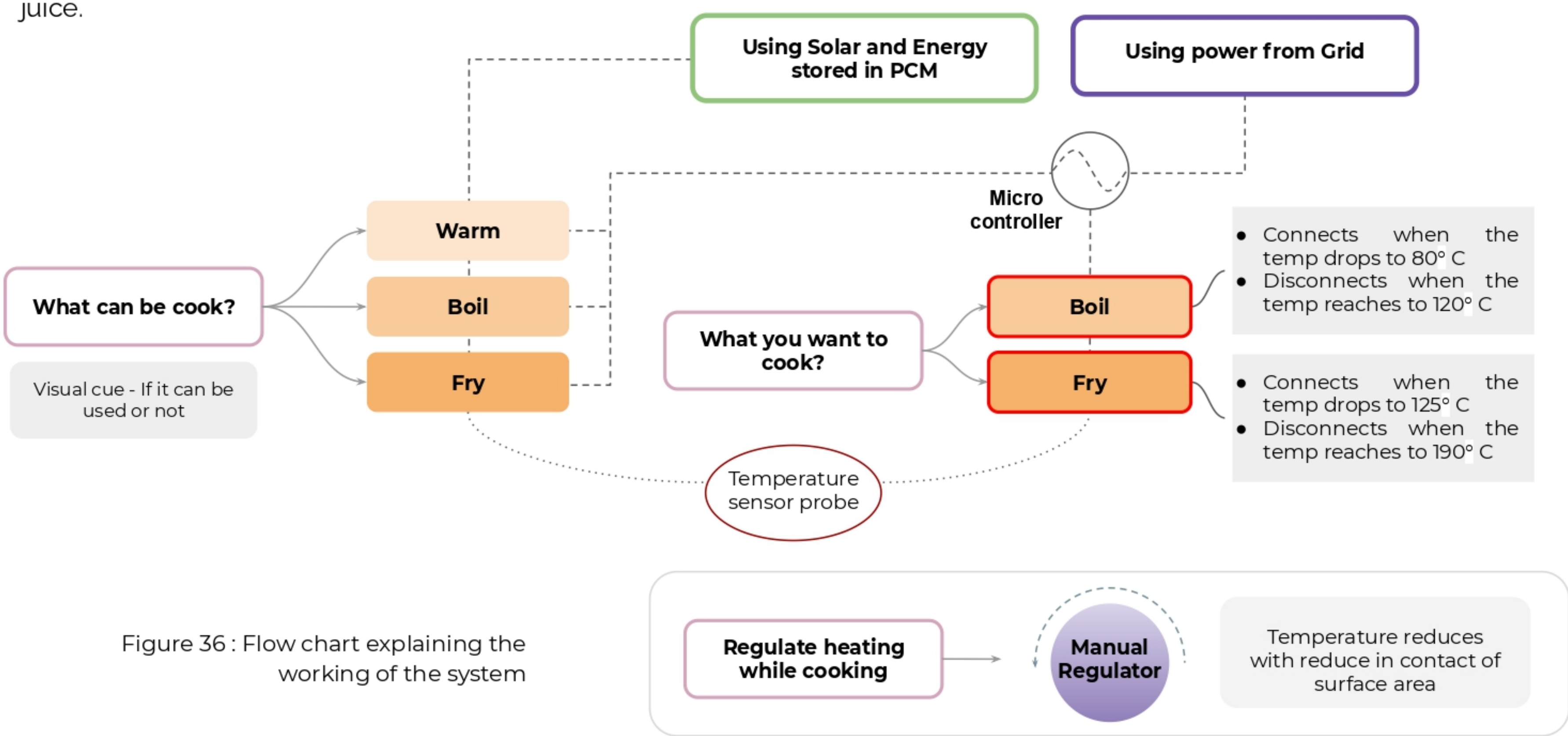



Figure 36 : Flow chart explaining the working of the system

# Final Concept

## The System

The system works based on the temperature of the core. As categorized into three types of cooking, when a user needs to, for example, fry food and the core temperature is insufficient, The power from the grid is taken to raise the core's temperature to the required and then disconnect. A microcontroller with a probe, programmed with the temperature ranges, will automate this process. Frying the temperature range would be 125° C - 190° C, as 120° C is the erythritol melting point. If the core temperature drops to 125° C, the grid power gets connected until the core temperature reaches 125° C.

Due to the limitation of the technology, a typical regulator cannot be provided as the rate of heat transfer from PCM can not be regulated; a mechanism is developed to assist in quick reduction of heat transfer to avoid burning or overcooking.

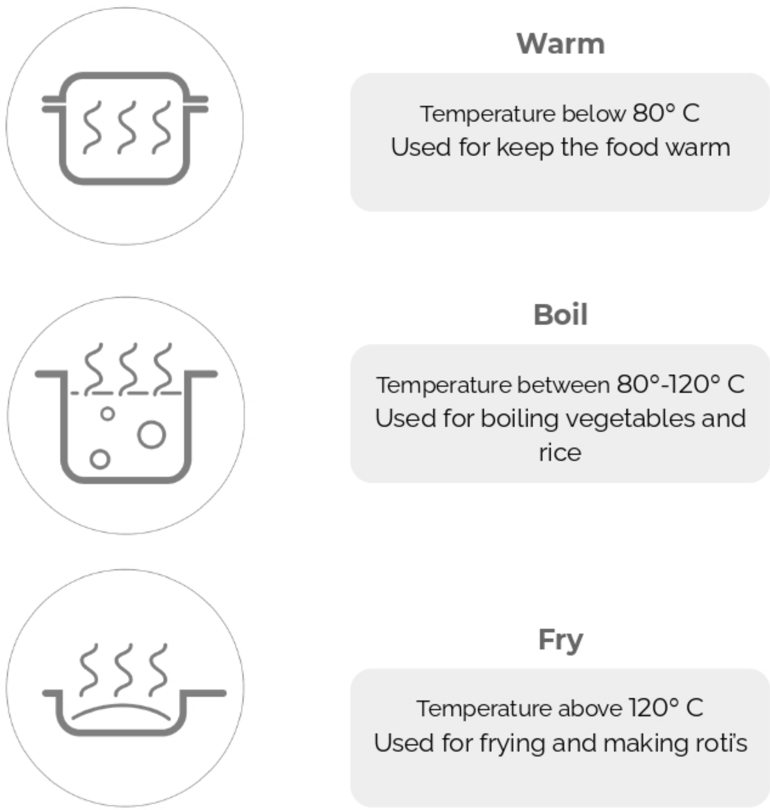



Figure 37 : Three modes of cooking provided in the system.

# Final Concept

### The interface / controls

The technical part of the concept is hard to grasp for the user, and the new cooking solution needs little time to adjust; a simple and straightforward interface is proposed. The core function and least required information are shown, so the user does not get overwhelmed.

The interface will have three buttons for three modes/types of cooking styles with multiple visual cues for additional information. The button with color lights indicates the core temperature is enough or not for cooking a particular mode/type. When pressed, a different color light glows, showing the selected mode. If the core temperature is enough for the mode, no change in the power chain happens, and if it is not enough, the power from the grid is taken. While cooking, the core temperature may drop as the energy is being used for cooking; these buttons help maintain the temperature for consistency in cooking.

Extra visual cues are provided for the user to know the source of power, As it is the supplementary solution, users can either connect to the grid or not.

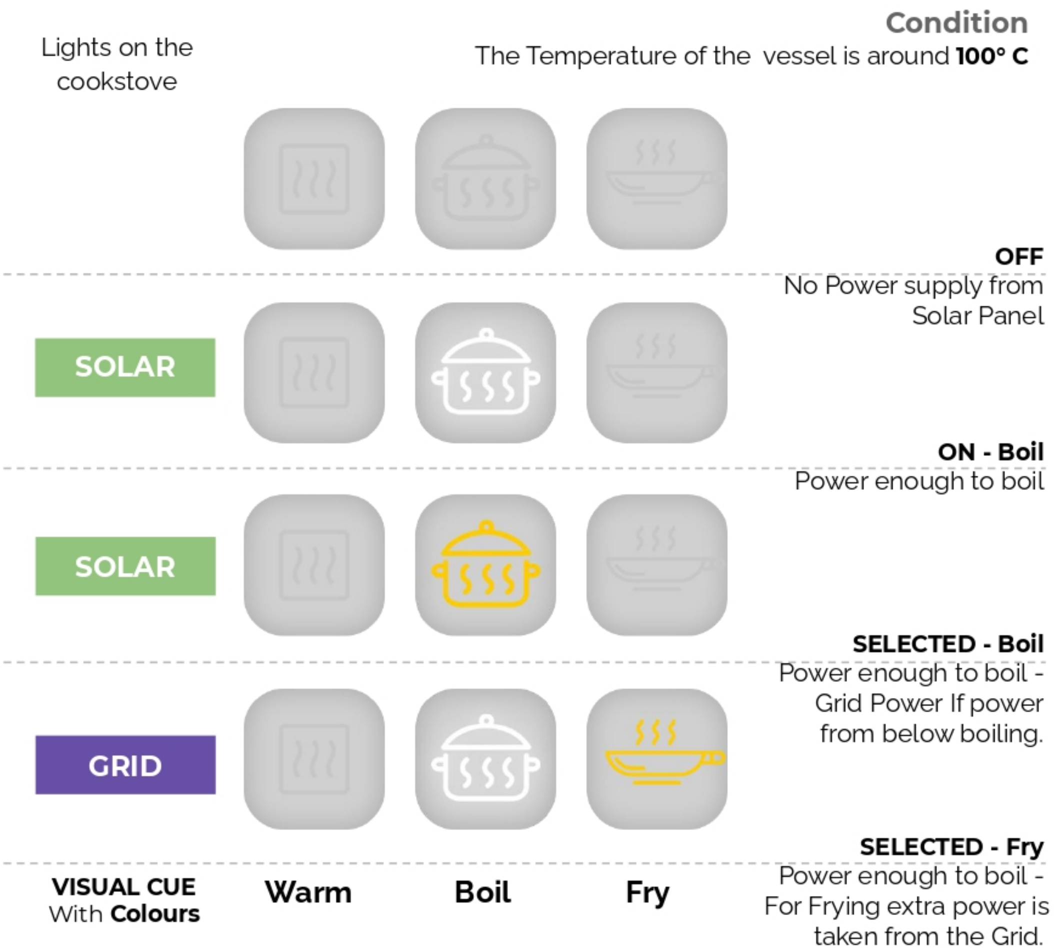



Figure 38 : Working of the interface / controls.

# Final Concept

### The regulator

The heat transfer from conduction is directly proportional to the surface of contact. The regulator exploits this property to control the heat transfer while cooking, as the convention method cannot be applied here. The regulator controls the heat transfer by changing the core's surface area in contact with the cooking vessel.

The user needs to get habituated to the rate of control from the regulator.

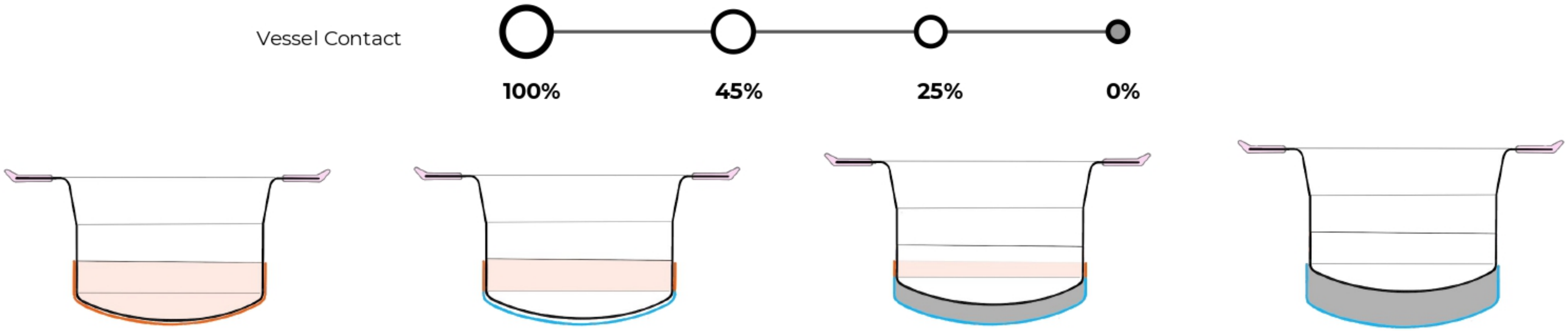



Figure 39 : Working of the regulator.

# Final Concept

### The cooking vessel

The stove needs a vessel with sizes specific for the stove for good conduction and to avoid heat loss. The vessel size is derived from the kitchen study done in the previous section.

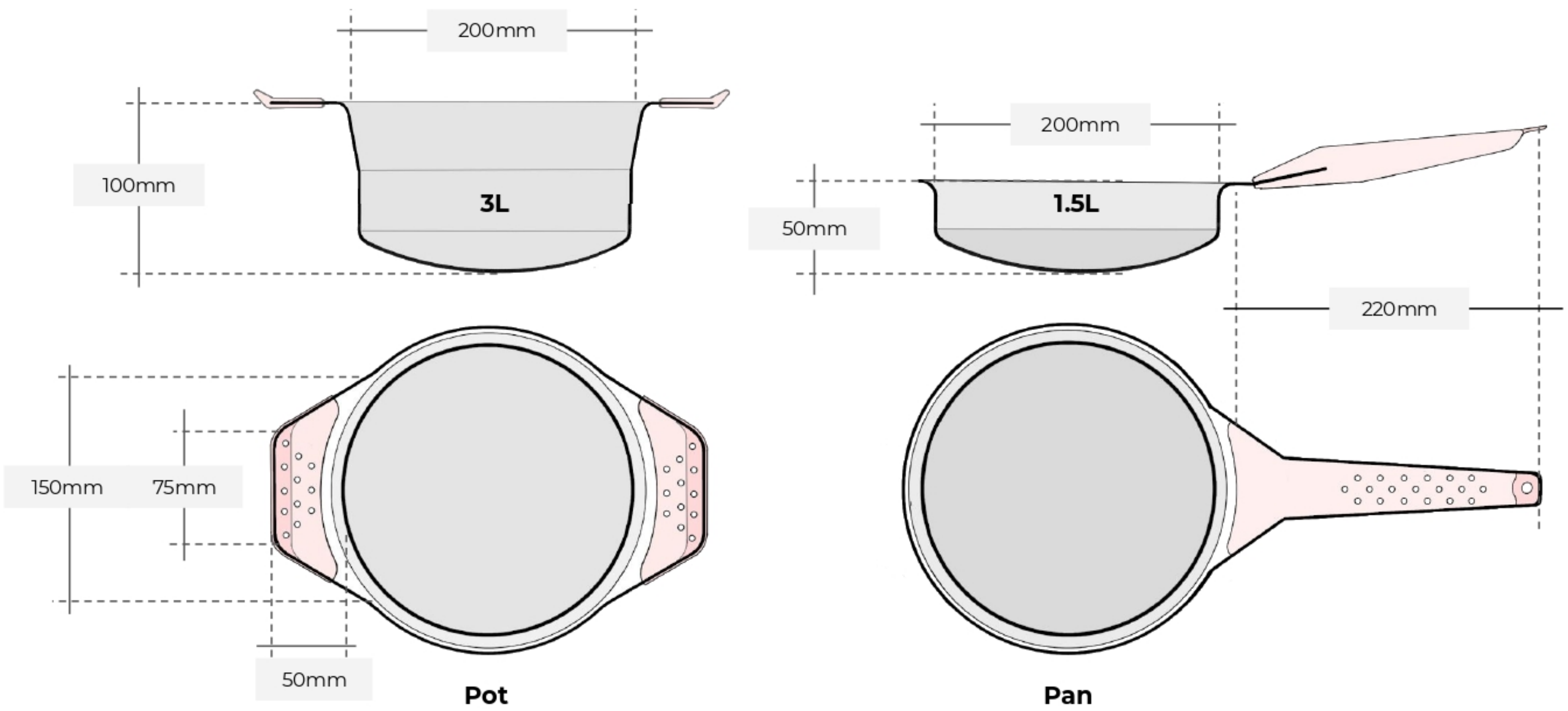



Figure 40 : Two types of vessels for the product, one for boiling and the other for frying

# Final Concept

### Explorations 01

The interface is on the slidable vessel insulation and protrudes out to act as a grip to lift insulation over the cooking vessel.


Figure 41 , 42 & 43 : Renders showing working mechanism of exploration 01; 1 is default position, 2 vessel kept on stove and 3 insulation slided over the vessel.

## Explorations 02

Here, the interface is at the bottom of the stove fixed with slidable insulation separated by a folding silicone used for air sealing any possible gaps during the sliding mechanism.

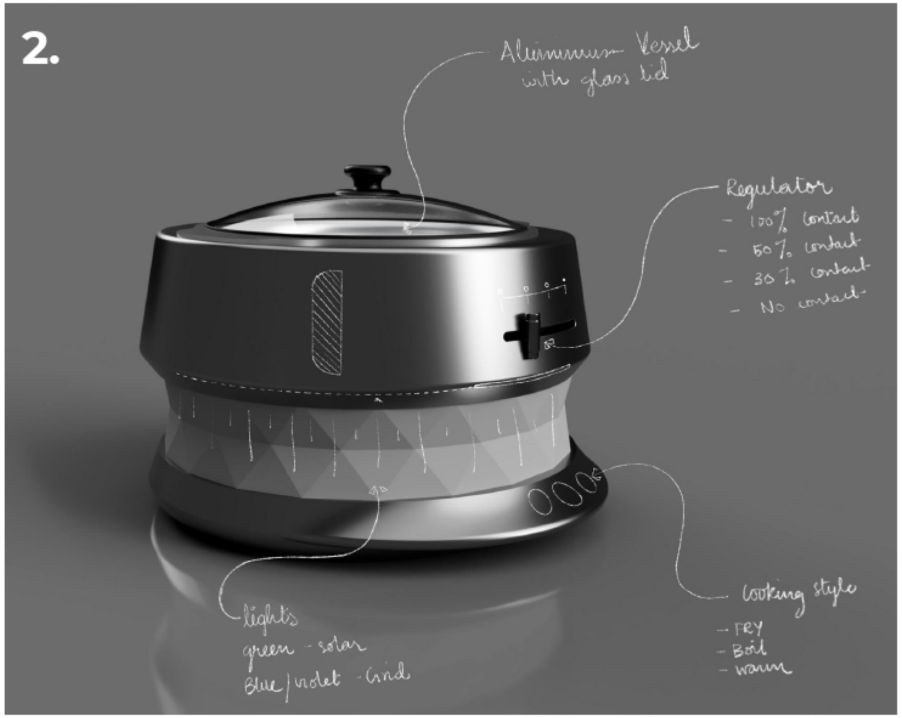




Figure 44 & 45 : Renders showing working mechanism of exploration 02 ; 1 is default position, 2 vessel kept on stove with insulation slided over the vessel.

# Final Concept

### Explorations 03

It's the same as Exploration 02 in terms of the configuration of parts with an ergonomic form factor for easy handling of the slidable insulation.

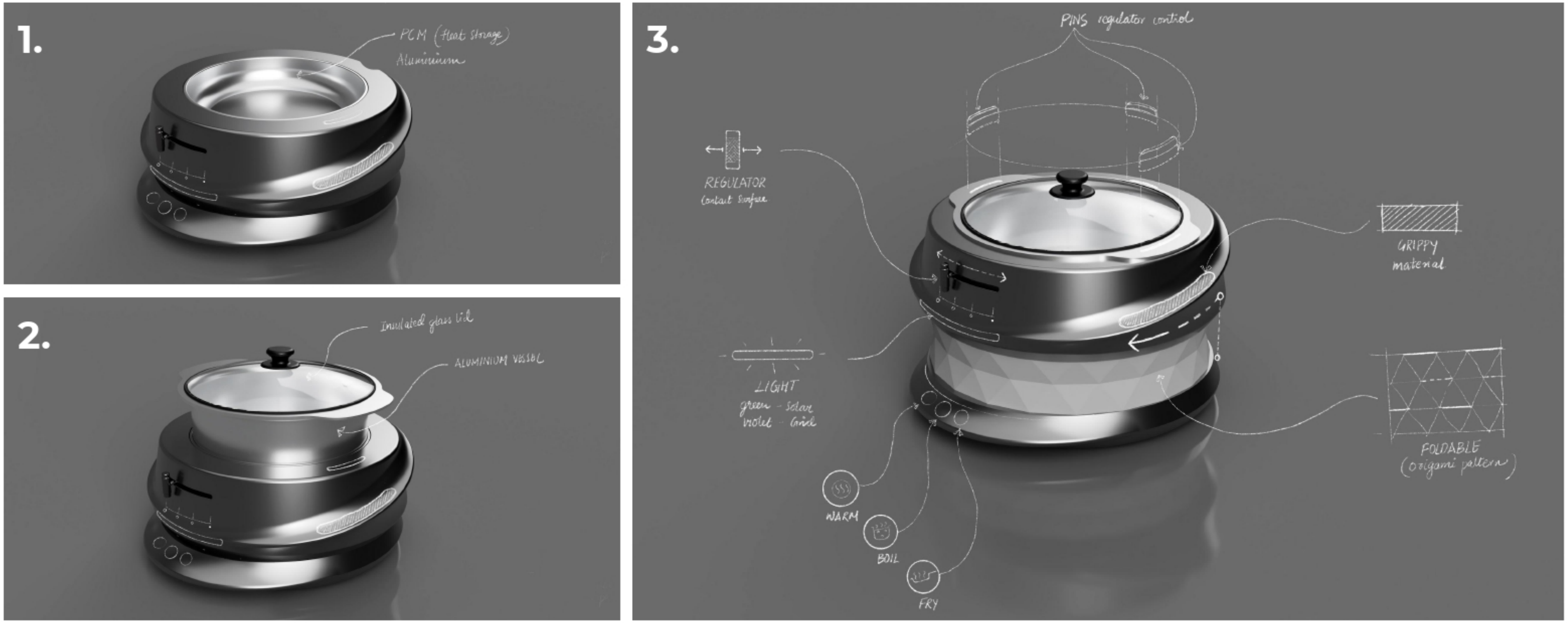



Figure 46 , 47 & 48 : Renders showing working mechanism of exploration 03 ; 1 is default position, 2 vessel kept on stove and 3 insulation slided over the vessel.

# Final Concept

## Moodboard







# Final Design

Play of curves and material was used to create a dynamic and modern look to the stove. The foldable silicon brings a new visual identity to a kitchen appliance with engaging and interactive sliding mechanism.

**Dynamic** **Modern** **Engaging** **Interactive**

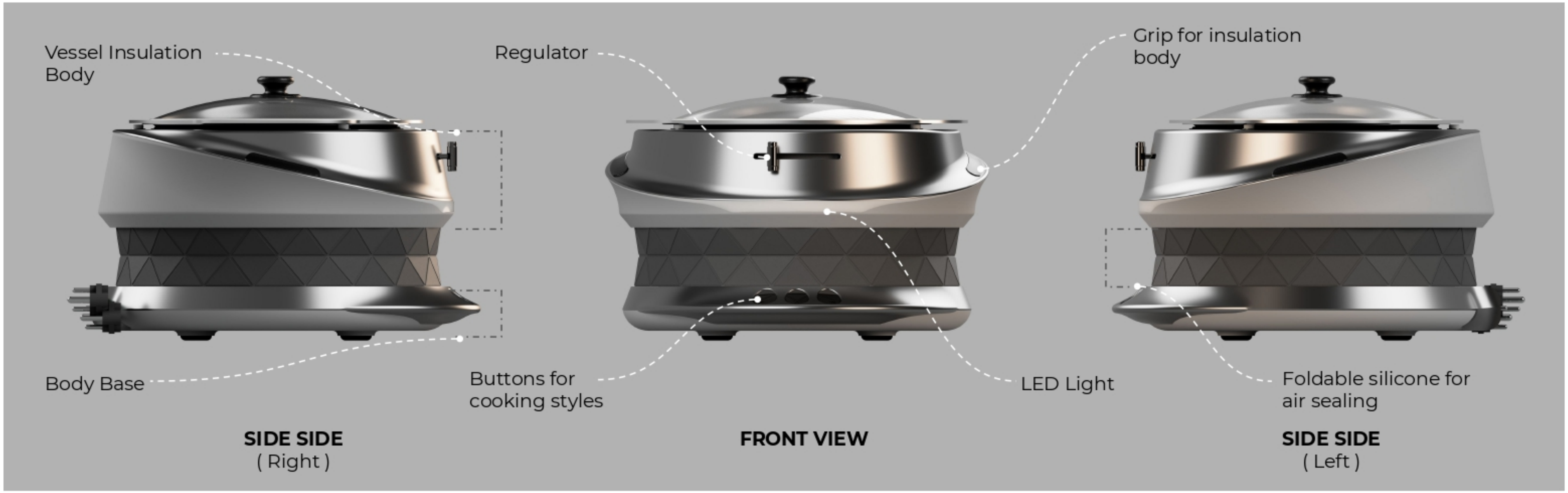



Figure 49 : Renders showing elevations of the final design

# Final Design

Internal components and the assembly details

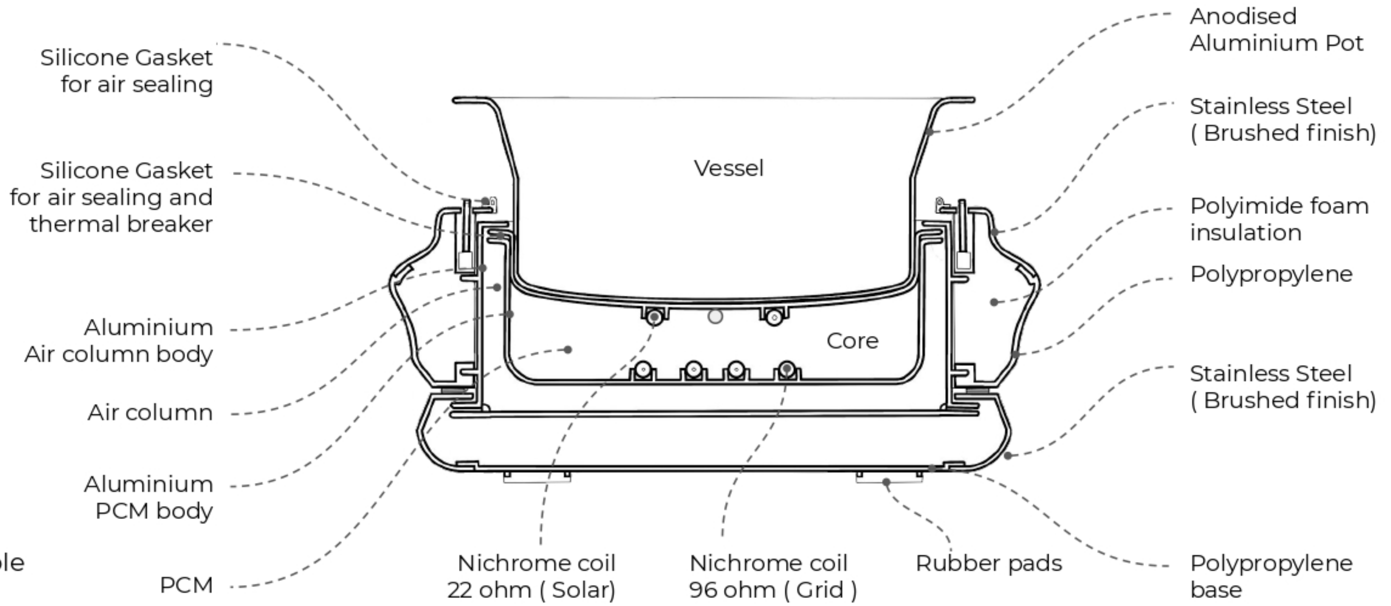



Figure 50 : Section with slidable insulation at default position.

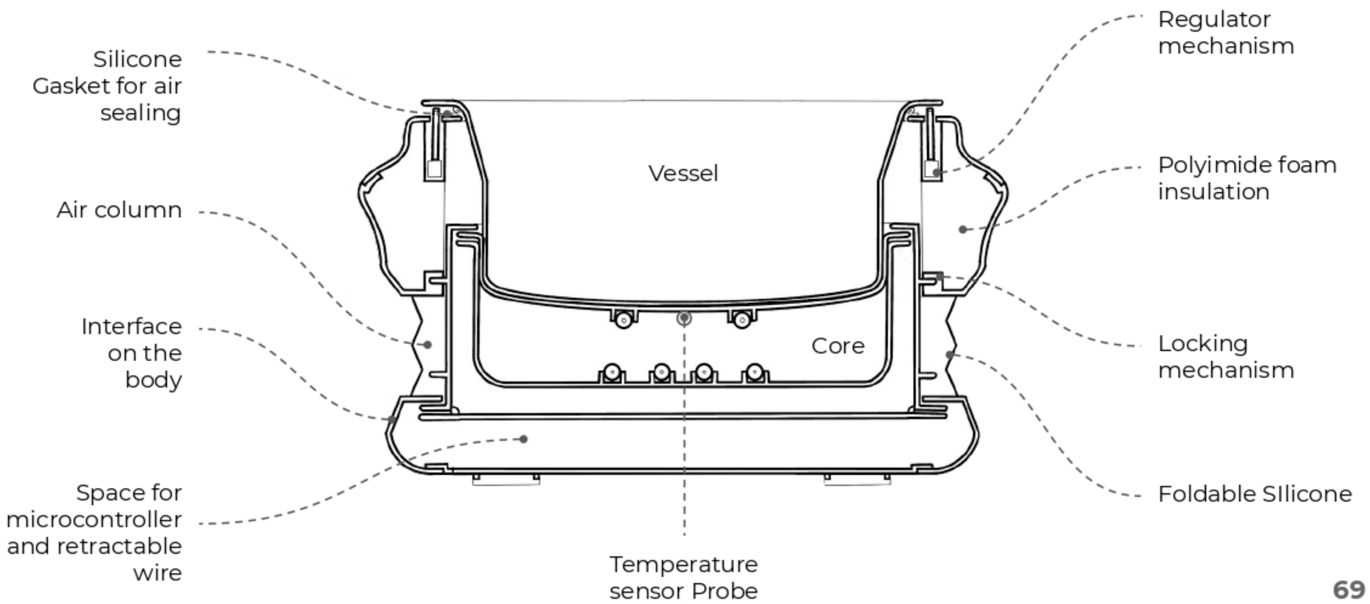



Figure 51 : Section with slidable insulation over the vessel.

# Final Design

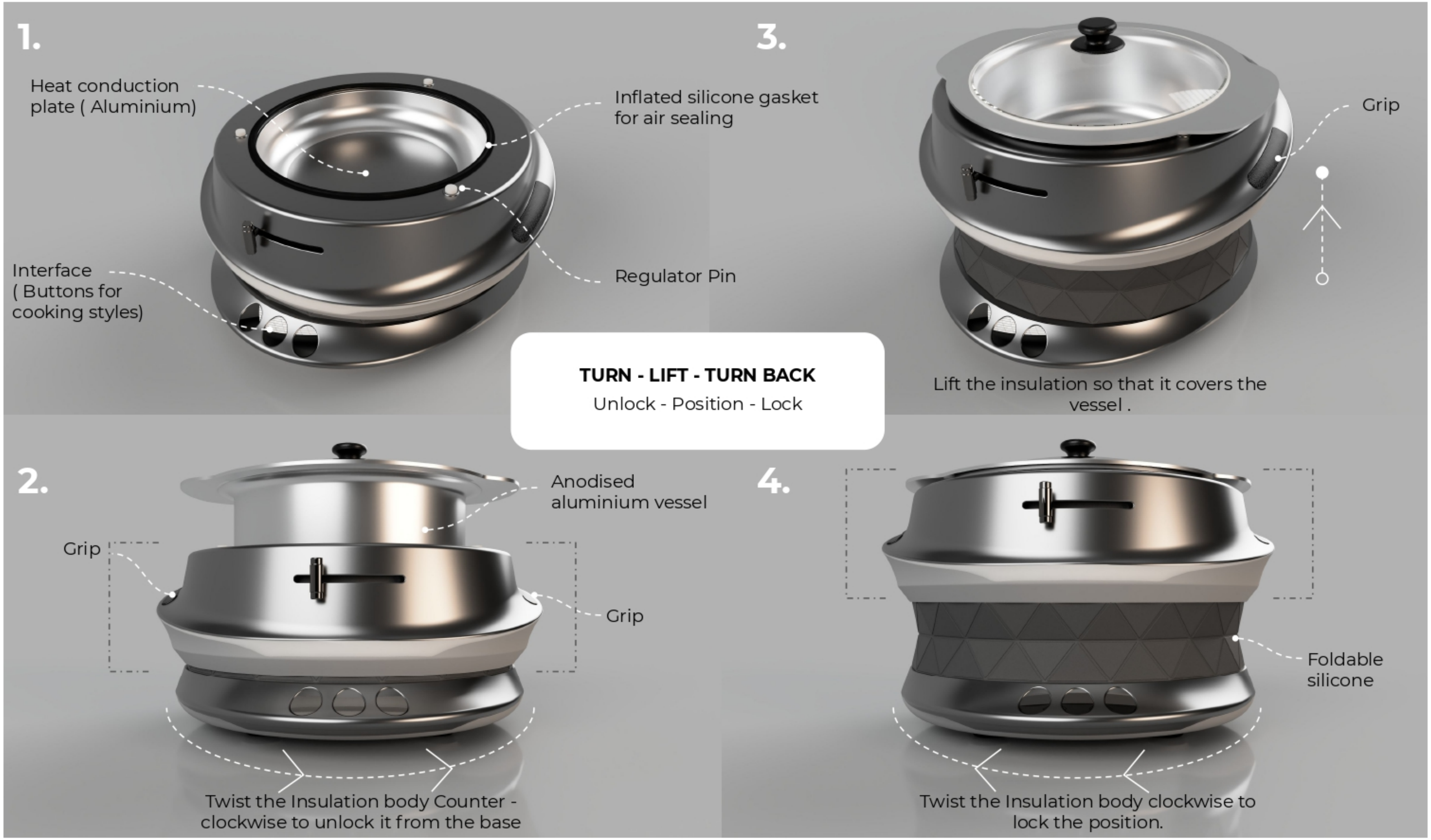



Figure 52 : Renders showing working mechanism of final design.

## Final Design

**Final dimensions of the product**

( All dimensions are in mm and measured from the outermost point )


Figure 53, 54 & 55 : Renders with final dimensions.

# Final Design

### Exploded view

The exploded view showing all the components of the product with materials used.

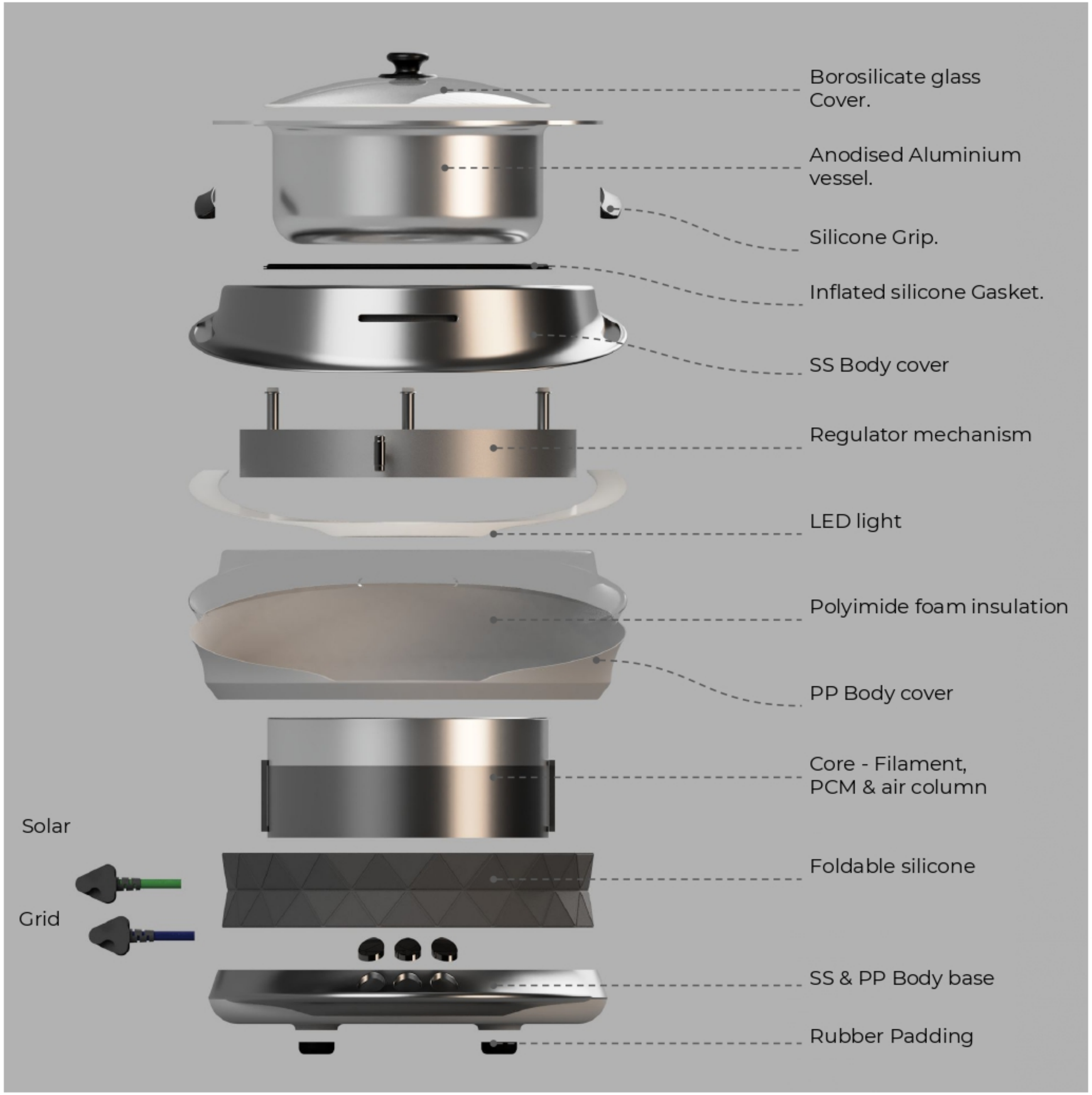



Figure 56 : Exploded view of the product.

# Final Design

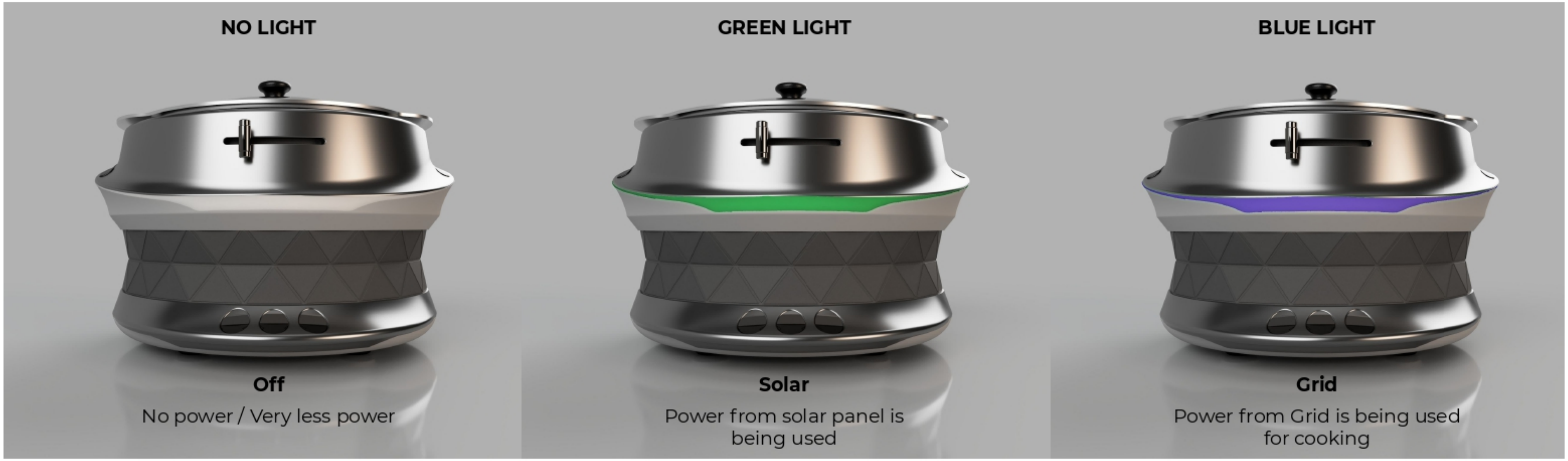
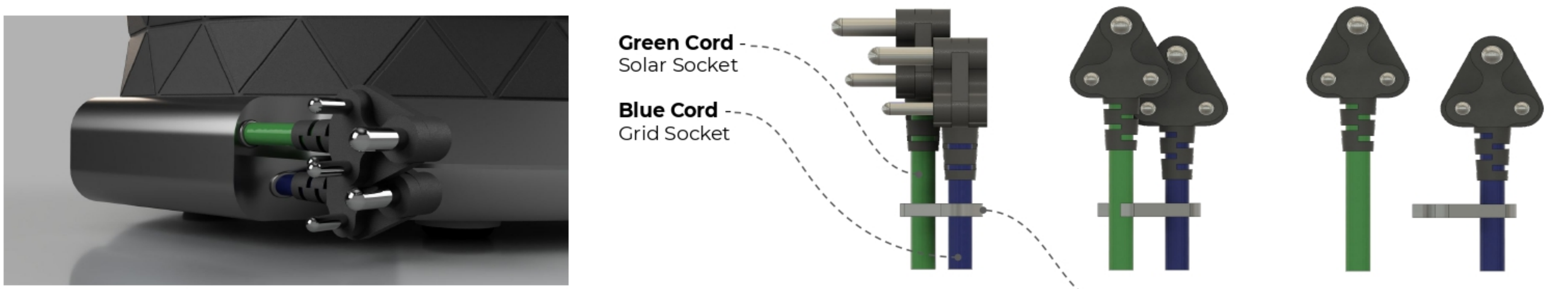



Figure 57 : Color cue for different power usage.




Base body will have winding mechanism for both cords separately at the bottom.

Interlocking plug for easy cable management.

Detachable for situation where sockets are at different location.

Figure 58 : Integrated power cable management

# Final Design

**Pre jury feedback**

Simplify usage of product

Simplify the form as per the semi urban household

To reconsider the plug detail as it could damage the product if used interchangeably.

**Way forward**

Resolving form for easy manufacturing.

Finalising CMF

Detail out the assembly as per manufacturing and local repairability.

Fixing / joining details of the components.

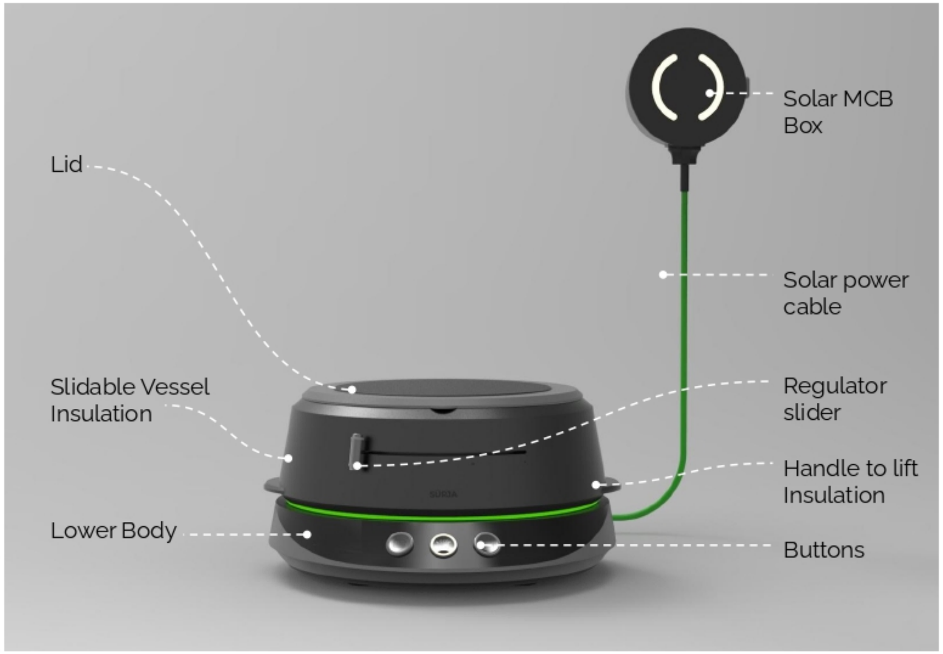
SŪRJA

Cookstove


SŪRJA

# Revised Design

The product consists of a wall box with solar MCB inside and light to indicate panel power delivery. The main body with a lid for protection from accidental contact, a regulator slider controls the heat transfer to the vessel, and slidable insulation to cover the pot type cooking vessel for retaining the heat inside. The product's base body consists of three control buttons for three modes and a foldable silicone partition between the lower body slidable insulation for air sealing.



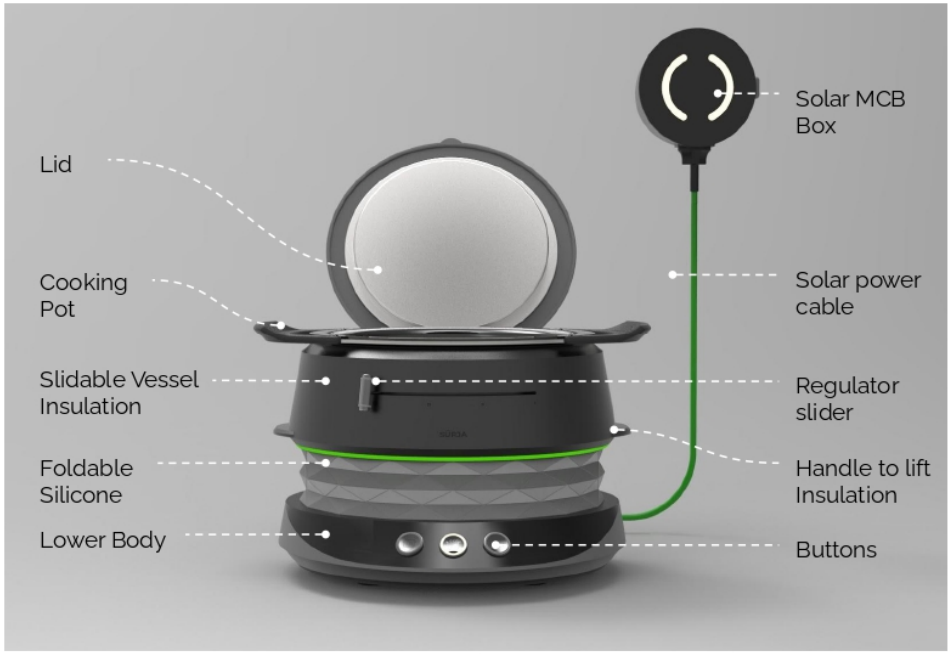




Figure 59, 60 : Parts / Components of the cookstove

# Revised Design



Figure 61, 62 : Position of cookstove as per pan or pot usage.

# Revised Design

Surja cookstove has two positions, Position 1 when the slidable insulation is a the bottom that is ideal for the pan to be placed for the frying purpose, and Position 2 when the slidable insulation is lifted above, suitable for cooking in the pot for boiling to minimize heat loss from the walls. The Slidable insulation is lifted with either pot placed first or after the lifting, and both positions 1 and 2 can be used as default as per the user's daily usage, no need to come back to a specific initial position.

**Initial Position** | **Position 1 - For Pan** | **Pot is placed inside the stove and Insulation is slided over it.** | **Position 2 - For Pot**

Figure 63-66 : Steps of usage as per pan and pot.

# Revised Design

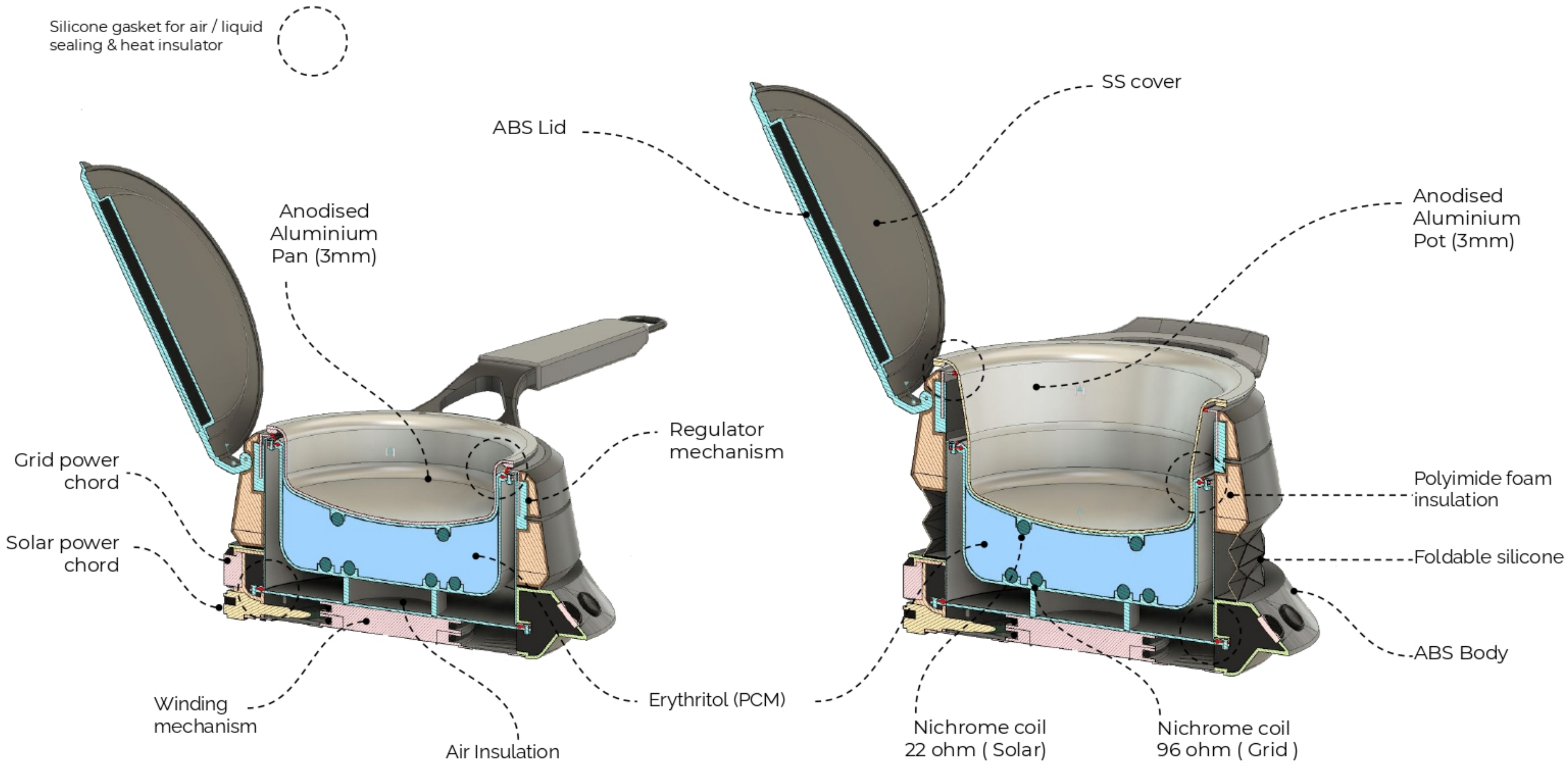



Figure 67 : 3D section of the cookstove at both positions with pan and pot.

# Revised Design

A simple turn locking method is used for slidable insulation as it doesn't require any complicated mechanical part, and most of the users are familiar with similar locking mechanisms in containers of mixer grinder. The more moving part means more air gap and requires more sealing, which was also considered for selecting this mechanism.

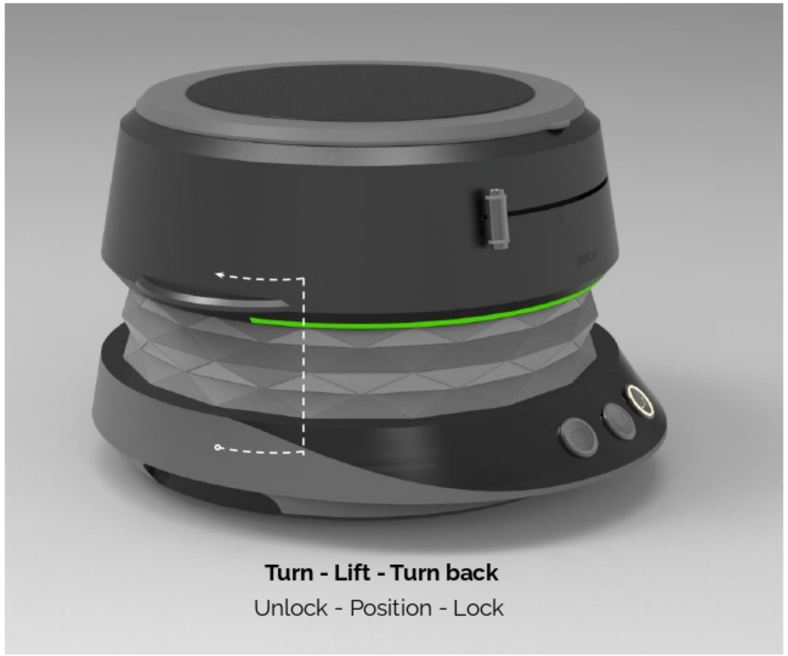



Figure 68 : Mechanism to slide / lift the insulation body.

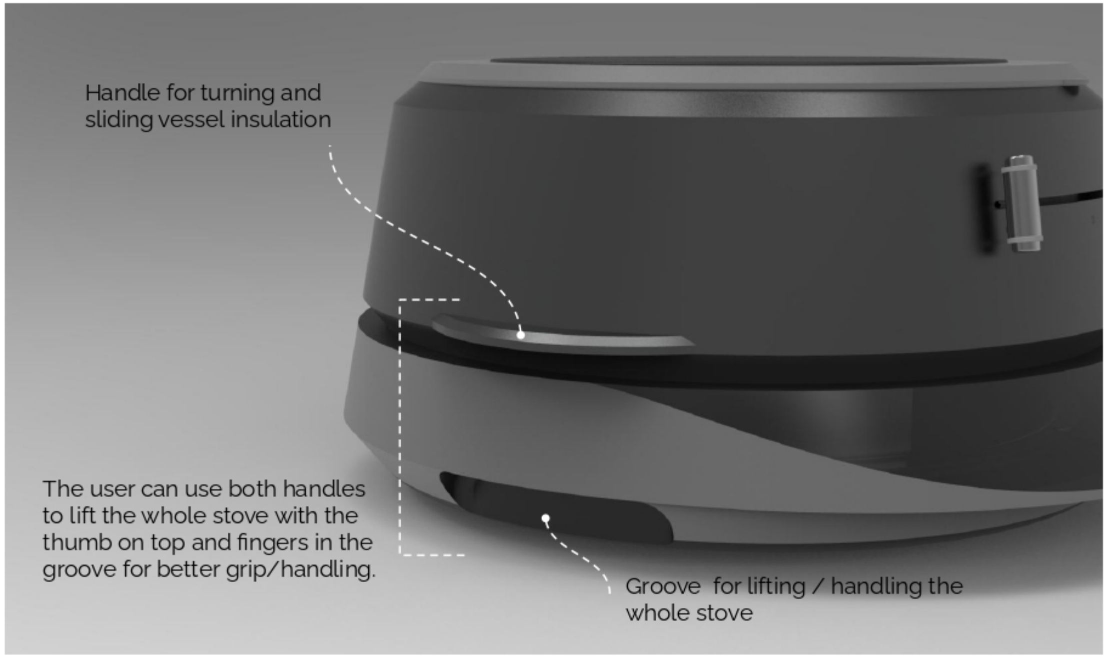



Figure 69 : Handle and groove location for handling the stove.

# Revised Design


Figure 70 : Regulator slider and ring movement direction


Figure 71 : Detail of regulator ring  with silicon gasket for air sealing and thermal breaker.

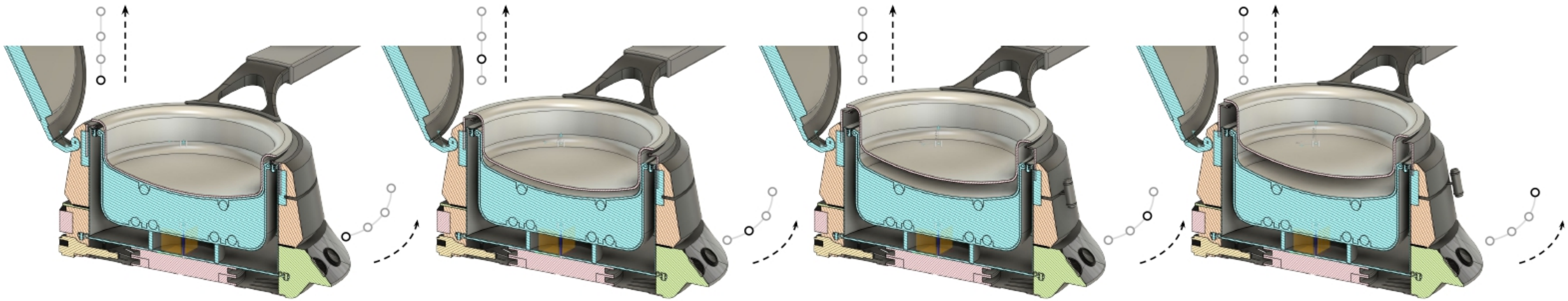


Figure 72 : Regulator mechanisms

# Revised Design


Figure 73 : Initial stage of product in daily use when the power is stated generating  from panel


Figure 74 : Subsequent stage when the constant power delivery increase the core temperature to a range good for warming food.

# Revised Design


Figure 75 : Next when temperature of the core reaches a range good for boiling food.


Figure 76 : Connected to grid and frying mode selected.

# Revised Design

Figure 77 : Interface / Controls at ideal state

Figure 78 : Interface / Controls at Temp. Boiling Range.

Figure 79 : Boiling mode is selected while Temperature of core is within Boiling Range

Figure 80 : Boiling mode is selected while temperature of core is core is dropped below Boiling Range. Power from grid is taken.

# Revised Design

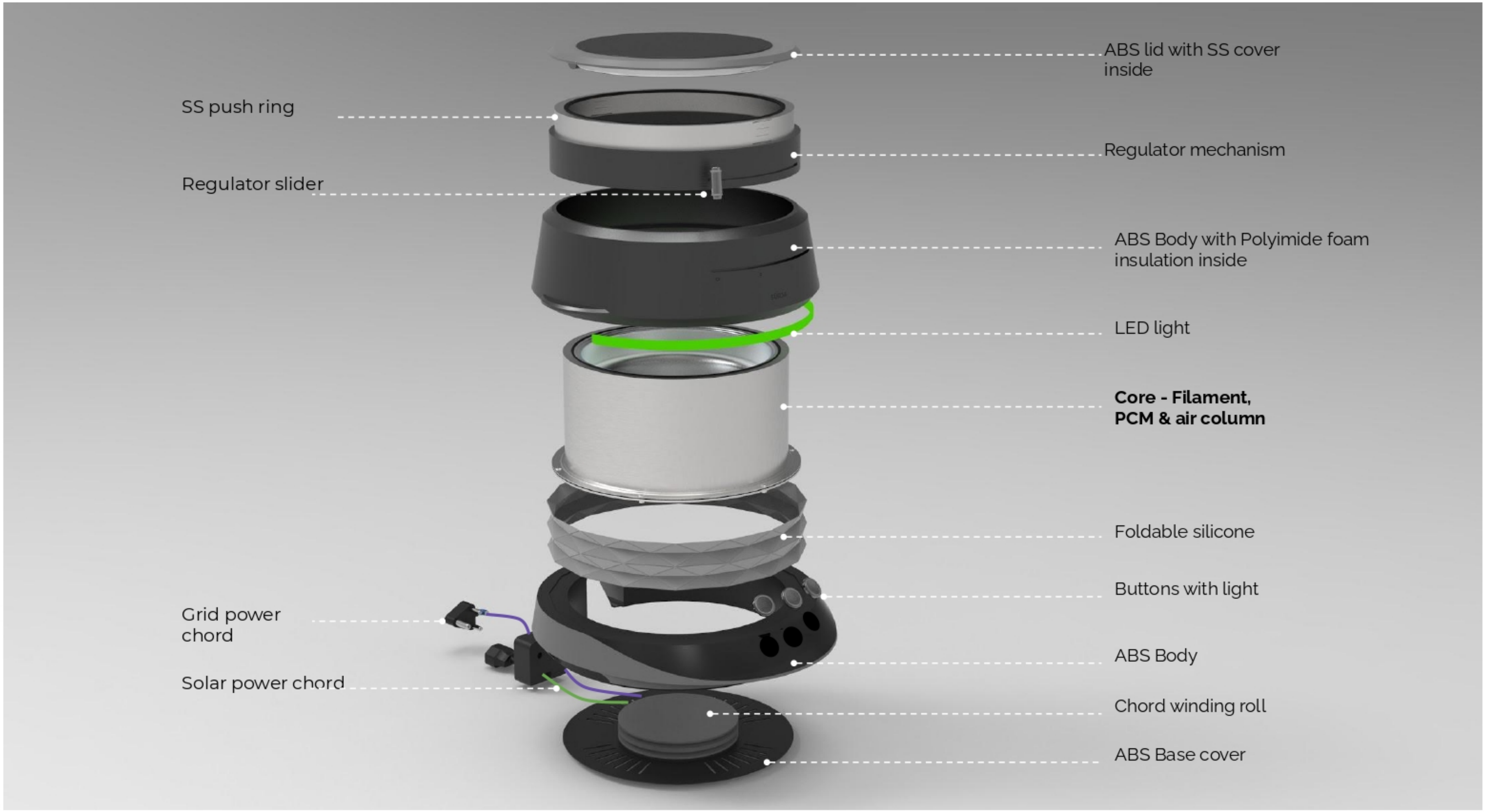



Figure 81 : Exploded view with all the components.

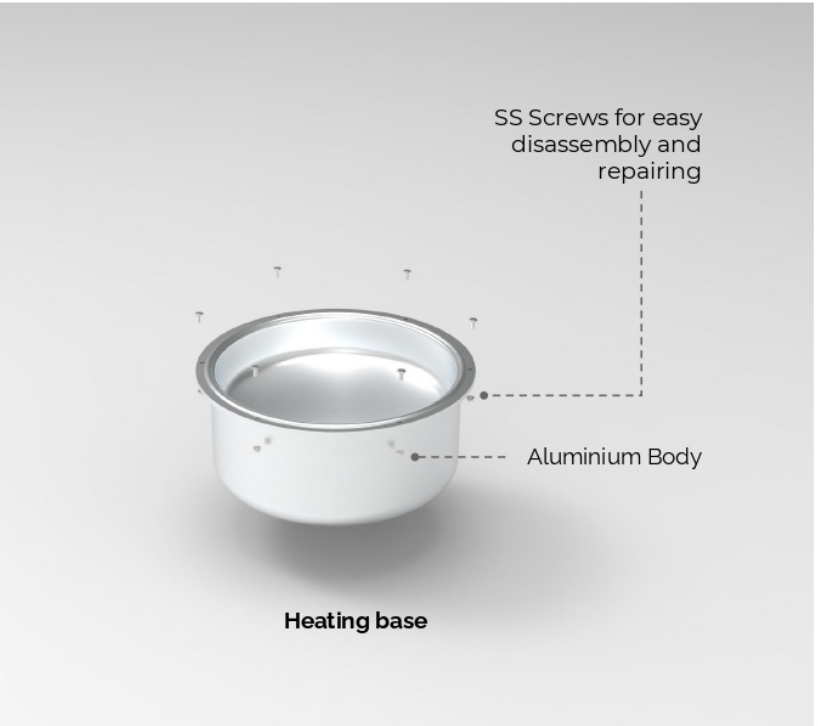
# Revised Design

As easy manufacturing and serviceability were a check for the project, I have given particular importance to the product's core, which can be easily disassembled and assemble. It provides scope for the users to repair the product locally when needed.


Figure 82, 83 & 84 : Steps to open outer body of the core for easy assembly / repairability.

# Revised Design

Easy accessibility to the core component also gives the user scope to customize the panel requirement as per his usage or increase the no. of the panel later when needed; for that, he has to change the solar resistive coil and the whole stove is good to go.



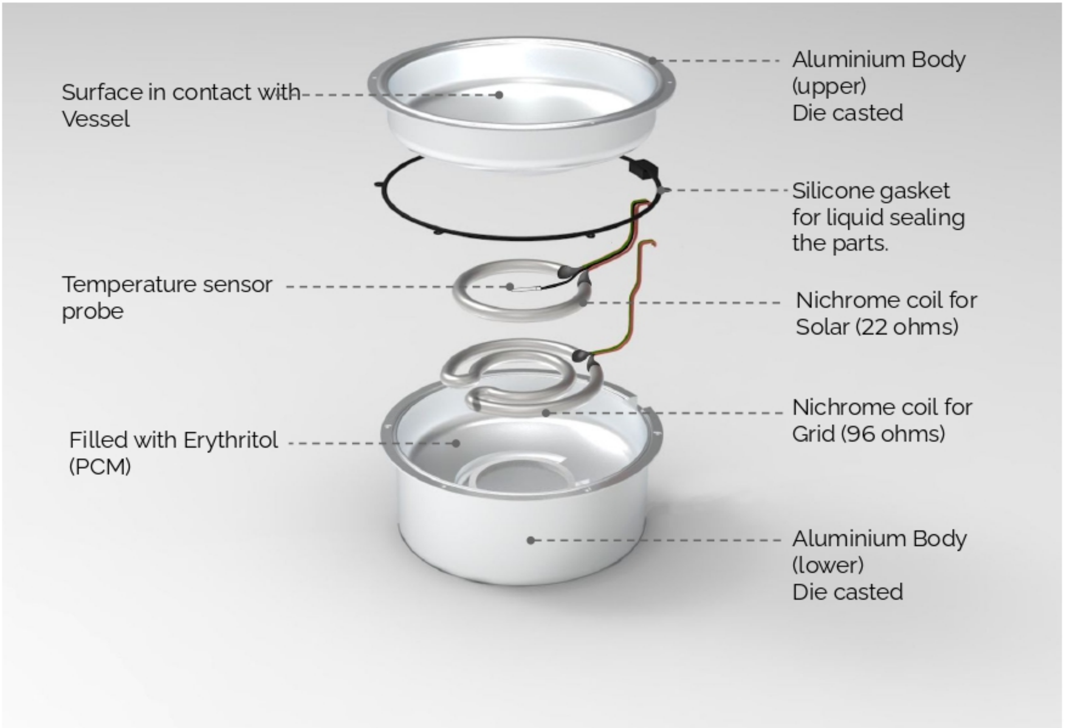




Figure 85 & 86 : Steps to open heating base of core.

# Revised Design

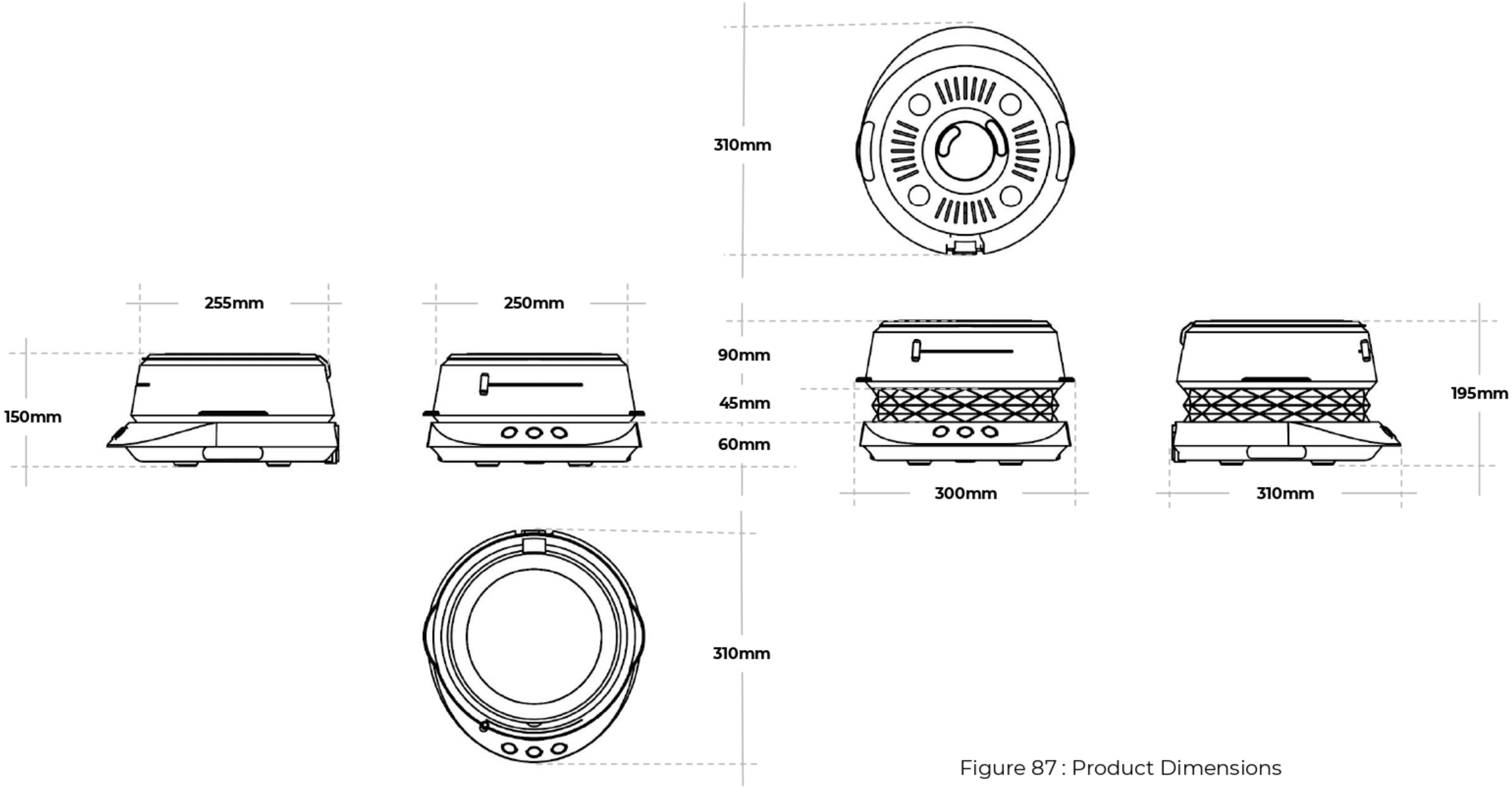



Figure 87 : Product Dimensions

# Revised Design

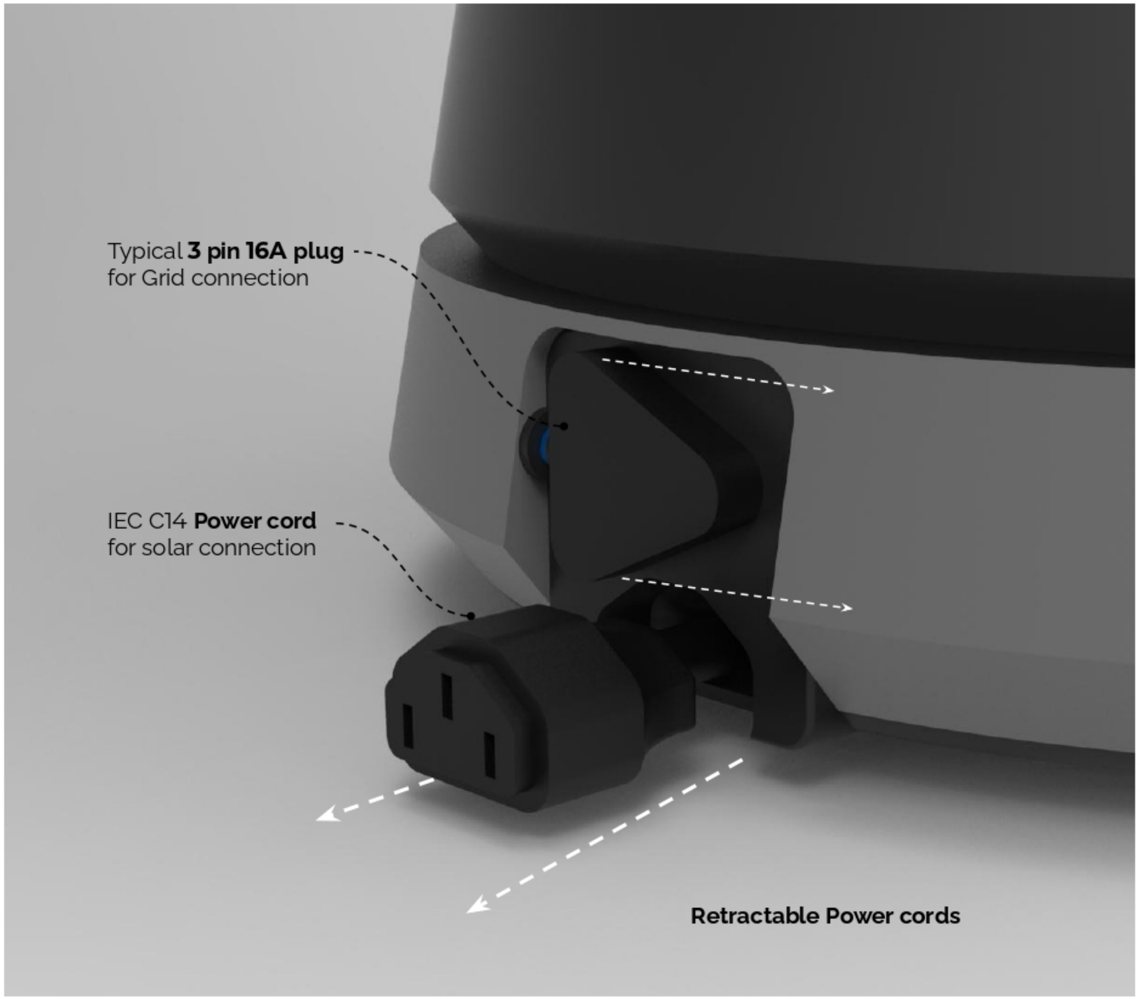



Figure 88 : Details- Retractable power cables

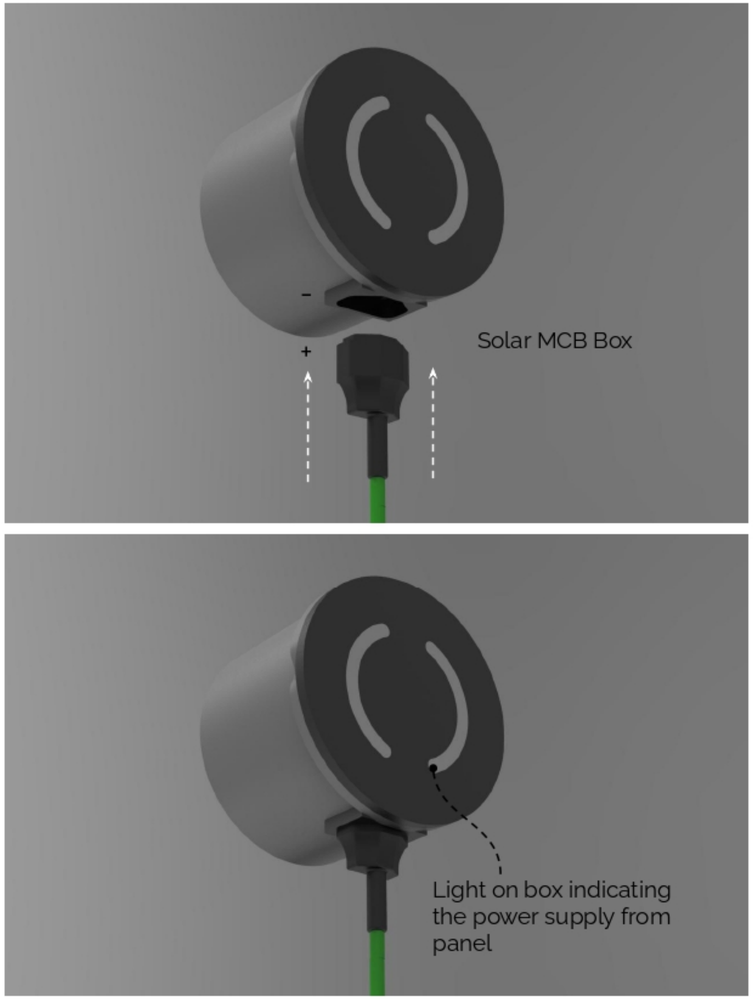



Figure 89 & 90 : Fixing details- Solar power cord to MCB

# Revised Design

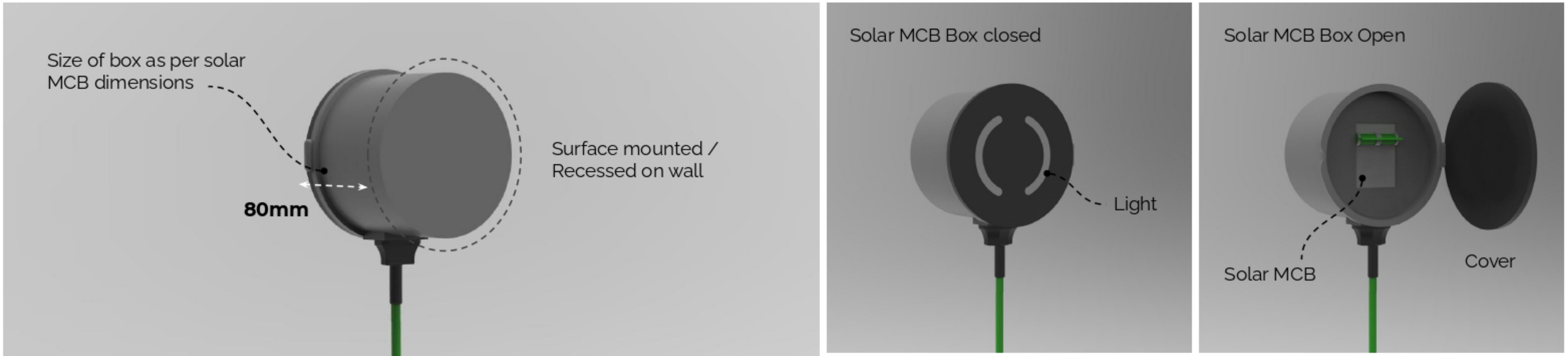



Figure 91, 92 & 93 : Details- Solar MCB box details

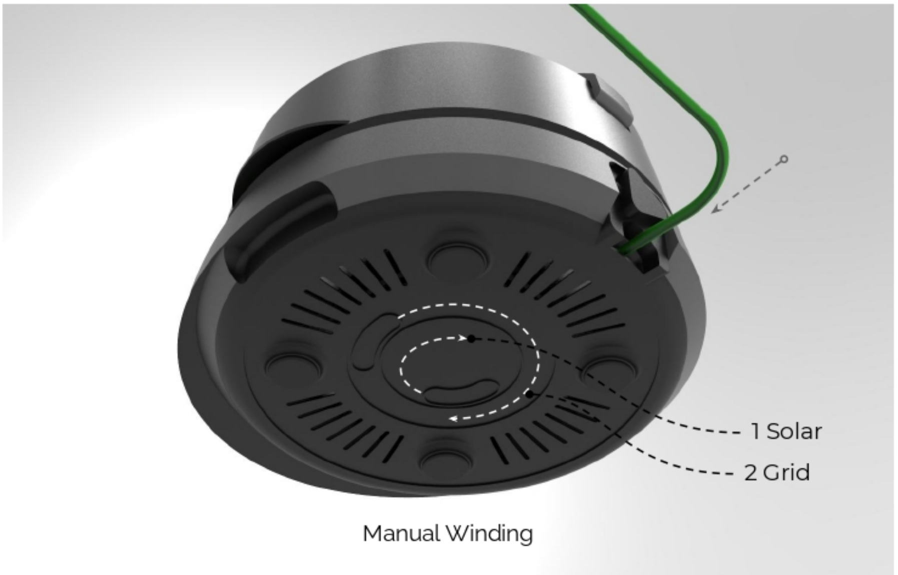



Figure 94 : Details- Cable/ Cord winding Mechanism

# Revised Design

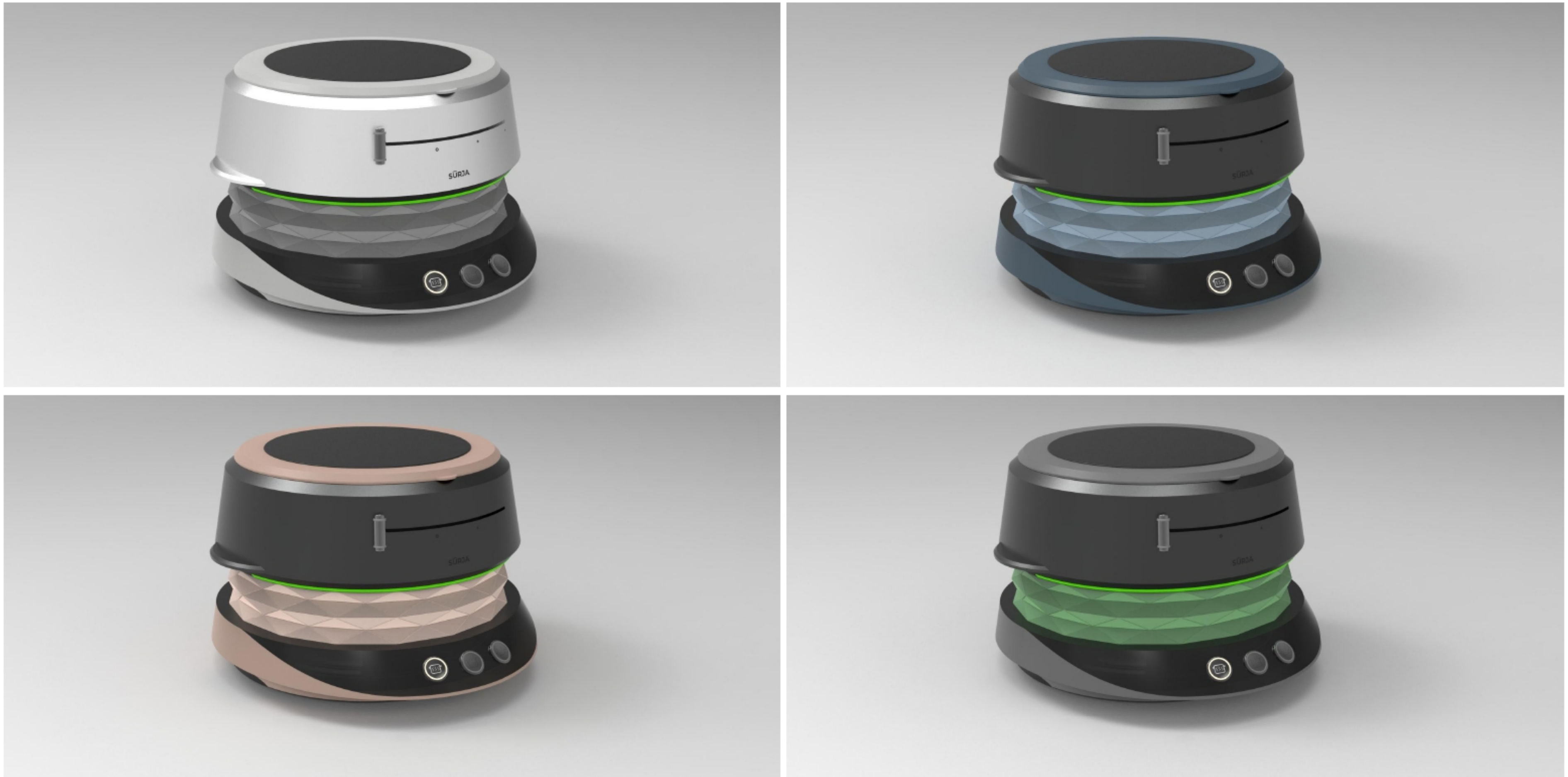


Figure 95-98 : Colour options of the product.


H
V
S

# Conclusion

The proposed design provides a clean and affordable cooking solution for users who need to reduce their dependence on conventional cooking mediums. With only the initial investment and no recurring & maintenance cost, the product will be economical in the long run.

It upturns all the existing solar solutions available with the ability to be used indoors and fry food with an extended usage period after sunset. Accommodated to Indian cooking styles and simple interface makes it readily acceptable by the user.

Particular focus on the local manufacturing and repairability aspect makes it easily adaptable by the local industries to retrofit into their existing manufacturing and localize the supply chain.

A proper strategy canvas for meeting end-to-end innovation can make low-cost clean solar cookstoves accessible to most households in the country and take a significant step towards sustainability.

**Future scope of work**

Substantial research needs to be taken forward to get a perfect configuration of the technology in the system to bring out maximum efficiency.

Incorporating upcoming technologies into the product, such as more effective PCM solutions and electronic heat conduction control, which are being researched around the world, will increase product usability.

Reimagine the product for a rural context as it has immense potential and need in that direction.

On-field trials for further developing the design.

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Figure 13- GoSun solar cooker
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Thank you.