Design of solar pesticide sprayer for agricultural use

Project III

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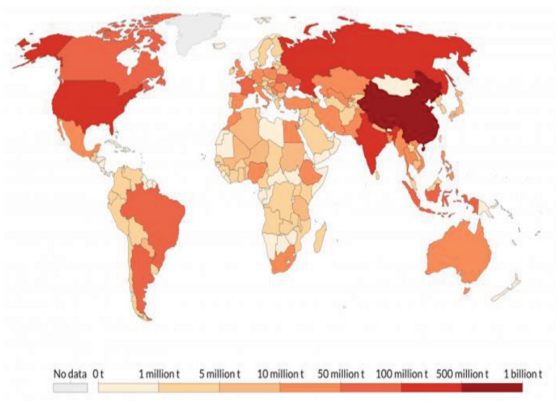
1. INTRODUCTION

1.1. Agriculture in India

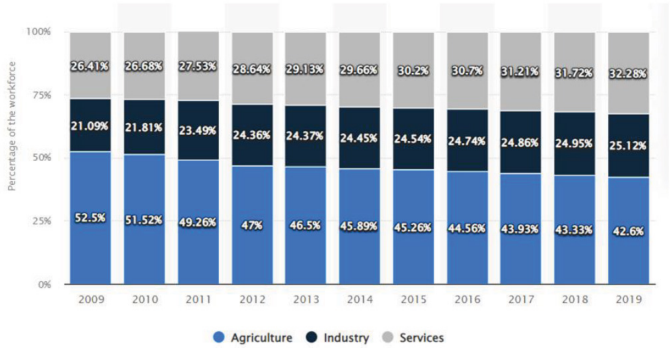
Agriculture is India's largest economic sector in terms of population. According to a 2018 poll, India ranks second in the world for farm outputs and first in the world for net cultivated area, followed by the United States and China. Agriculture employed approximately 45 percent of India's workforce and provided 15-18% of the country's GDP.

Farming is an important element of agriculture in India, and it entails cultivating the soil for crop growth as well as raising animals for food, wool, and other items. Farming, on the other hand, is the activity or business of raising crops and cattle. Fort this study the number of farmer taken is 100 million considering the beneficiary of PM-Kisan yojana.



https://ourworldindata.org/agricultural-production

Fig 1.1:Worldwide agricultural production



https://www.statista.com/statistics/271320/distribution-of-the-workforce-across-economic-sectors-in-india/

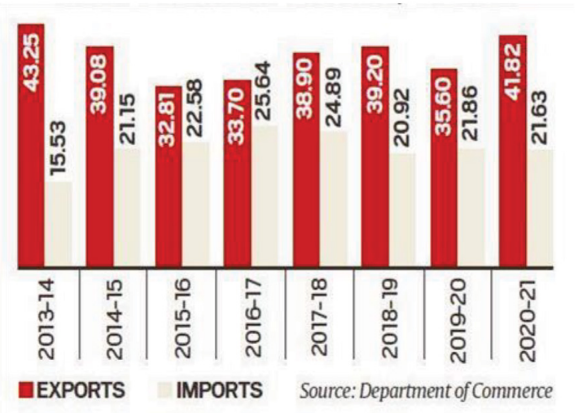
Fig 1.2: Workforce across sectors in India

India exports agricultural and processed goods to about 120 nations, particularly the United Arab Emirates, the United States, Southeast Asia, SAARC countries, and the European Union.

COUNTRY	EXPORTS VALUE IN (US $ BILLION) - <APR20-JAN21>
Saudi Arabia	1.09
USA	0.91
United Arab Emts	0.90
Bangladesh	0.87
Hong Kong	0.82
Nepal	0.77
Iraq	0.66
Malaysia	0.66
Vietnam	0.57
Indonesia	0.57

https://www.cogoport.com/blogs/indias-agricultural-exports-waiting-for-a-bumper-harvest

Fig 1.3: Top 10 destination for Indian agri exports 2020-2021



https://indianexpress.com/article/india/agricultural-exports-rose-17-5-in-20-21-but-rural-surge-cloud-over-repeat-7312851/

Fig 1.4: India's farm exports in billion dollar

PRODUCTS	EXPORTS VALUE IN (US $ Billion) Apr20 - Jan21	KEY DESTINATIONS
Cereals	7.63	Nepal, Djibouti, Saudi Arab, Iran, Iraq, Kuwait, USA, UK, Germany, Sri Lanka, United Arab
Animal products	3.01	Vietnam, Egypt, Iraq, Saudi Arab, Hong Kong, Myanmar, Philippines, Indonesia, United Arab
Other processed foods	2.80	USA, Russia, Norway, Germany, UK, Netherland, China, Malaysia, Nepal, Saudi Arab
Processed fruits & vegetables	1.26	USA, UK, Germany, Thailand, Russia, Saudi Arab, United Arab, Nepal, Malaysia
Fresh fruits & Vegetables	0.91	Bangladesh, Nepal, Saudi Arab, Singapore, UK, United Arab, Oman, Kuwait, Germany
Floriculture & Seeds	0.15	Netherlands, USA, Bangladesh, Thailand, Japan, Iran, Korea, France, Malaysia

https://www.cogoport.com/blogs/indias-agricultural-exports-waiting-for-a-bumper-harvest

Fig 1.5: India's top agri exports 2020-2021

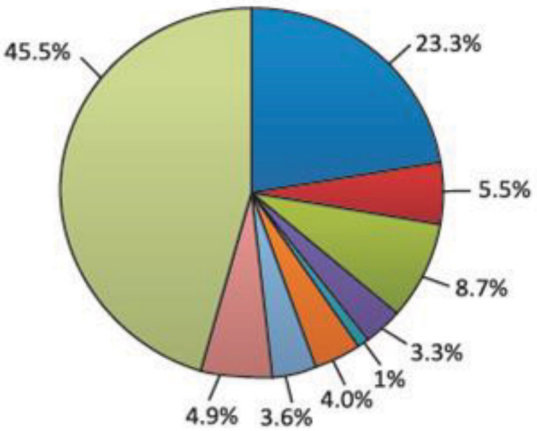
1.2. Agricultural land holding pattern in India

India has a total geographical area of around 329 million hectares, of which 160 million hectares (45 percent) are arable land. Groundwater wells can irrigate about 39 million hectares, while irrigation canals can irrigate another 22 million hectares. Monsoons are responsible for about two-thirds of India's agricultural area. Around 70% of India's population lives in rural areas, with agriculture serving as one of the country's primary sources of income. Landholdings, on the other hand, are modest and unequally distributed. The average size of an agricultural landholding has shrunk from 1.15 hectares in 2010–11 to 1.08 hectares in 2015–16, indicating that most smallholder farmers perform subsistence agriculture and are trapped in a low-income trap.

Category	Size class (Hectare)	Size class (Acre)
Marginal	Below 1.00 hectare	Below 2.47 Acre
Small	1.00 to 2.00 hectare	2.470 to 4.94 Acre
Semi medium	2.00 to 4.00 hectare	2.94 to 9.88 Acre
Medium	4.00 to 10.00 hectare	9.88 to 24.71 Acre
Large	10.00 hectare & above	24.71 Acres & above

https://pib.gov.in/newsite/PrintRelease.aspx?relid=188051

Table 1: Land holding by farmer category

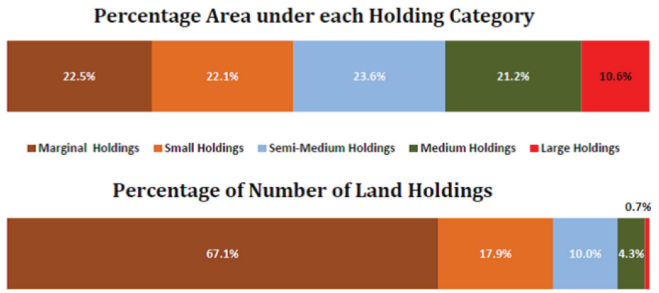


1 Hectare = 2.47 Acre

https://lotusarise.com/changes-in-pattern-of-land-use-in-india-upsc/

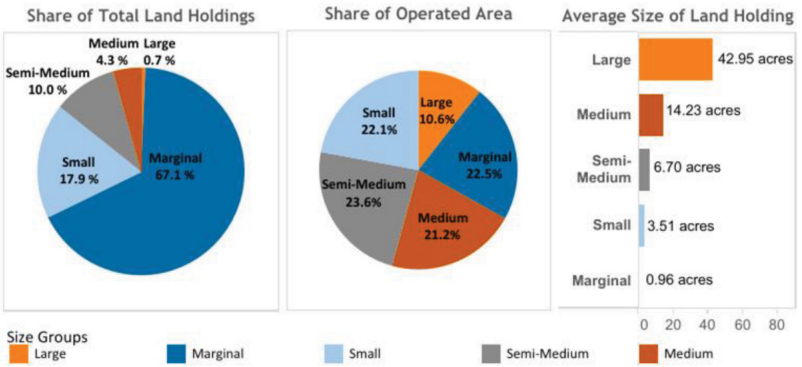
Fig 1.6:Land utilization pattern - 2015

In comparison to marginal & smallholding farmers, Semi-medium and medium land holding farmers owning between 2-10 hectares of land account for 13.2% of all farmers, but own 43.6% of crop area. 200,000 households across rural India owned more than 10 hectares of land in 2018-19, a recent report of the National Sample Survey (NSS) has estimated. 13% farmers in India own 43.6% crop area & they own 2-10 hectares of land per household



https://factly.in/agricultural-land-holdings-statistics-india-account-for-close-to-a-third-of-the-total-agricultural-land/

Fig 1.7: Percentage of land holding



https://www.indiaspend.com/land-reforms-fail-5-of-indias-farmers-control-32-land-31897#:~:text=No%20more%20than%204.9%25%20of,households%20own%20no%20agricultural%20land.

Fig 1.8: Landholding statistics

1.3. Major crops grown in India

Agricultural activities employ two-thirds of India's population. It's a primary activity that provides food grains and industrial raw materials. Because India is such a large country, it has a diverse range of food and non-food crops that are grown during the three primary agricultural seasons of rabi, kharif, and zaid. Major crops can be classified into food crops, cash crops, horticulture crops, plantation crops, fibre crops.

Types of crops	Meaning	Major crops
Food grains	Crops that are used for human consumption	Rice, Wheat, Maize, Millets, Pulses and Oilseeds
Commercial Crops	Crops which are grown for sale either in raw form or in semi-processed form	Sugarcane, Tobacco and Oilseeds
Plantation Crops	Crops which are grown on Plantations covering large estates	Tea, Coffee, Coconut and Rubber
Horticulture	Sections of agriculture in which Fruits and Vegetables are grown	Fruits and Vegetables
Fibre crops	Plants that are deliberately grown for the production of fiber for textile cordage,, and filling.	Cotton, jute

https://www.insightsonindia.com/agriculture/major-crops-and-cropping-patterns-in-various-parts-of-the-country/major-crops-grown-in-india/

Table 2 Types of crops in India

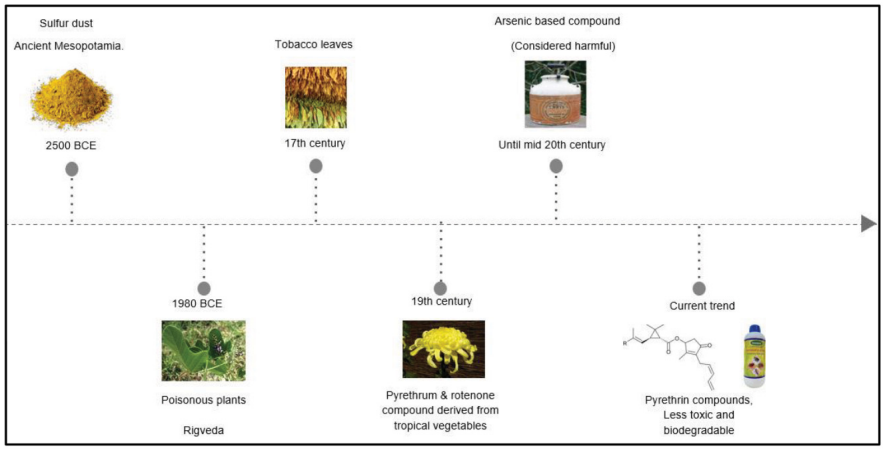
Cropping season	Time period	Crops	States
Rabi	Sown: October-December Harvested: April-June	Wheat, barley, peas, gram, mustard etc.	Punjab, Haryana, Himachal Pradesh, Jammu and Kashmir, Uttarakhand and Uttar Pradesh
Kharif	Sown: June-July Harvested: September-October	Rice, maize, jowar, bajra, tur, moong, urad, cotton, jute, groundnut, soybean etc.	Assam, West Bengal, coastal regions of Odisha, Andhra Pradesh, Telangana, Tamil Nadu, Kerala and Maharashtra
Zaid	Sown and harvested: March-July (between Rabi and Kharif)	Seasonal fruits, vegetables, fodder crops etc.	Most of the northern and north-western states

https://www.insightsonindia.com/agriculture/major-crops-and-cropping-patterns-in-various-parts-of-the-country/major-crops-grown-in-india/

Table 3 Cropping season in India

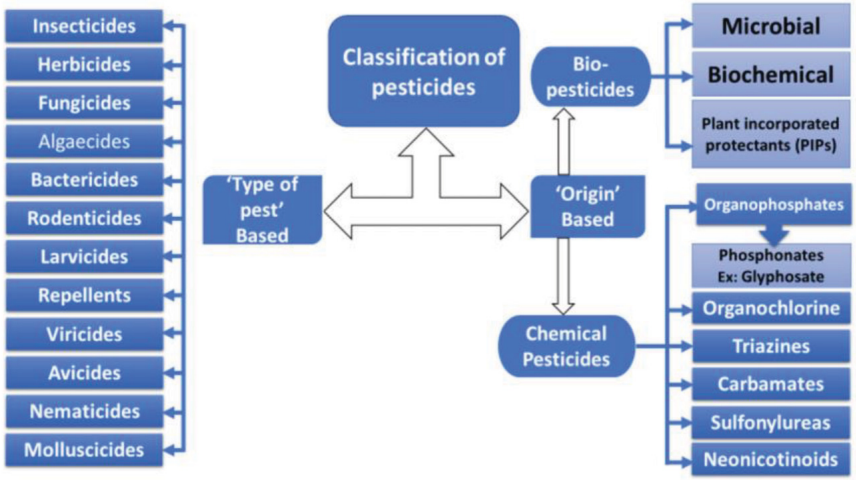
1.4. Pesticides in farming

Pesticides are chemicals that are used to keep pests at bay. Herbicides, insecticides, nematicides, molluscicides, piscicides, avicides, rodenticides, bactericides, insect repellents, animal repellents, antimicrobials, fungicides, and lampricides are all pesticides. A pesticide is a chemical or biological substance (such as a virus, bacterium, or fungus) that prevents pests from reproducing. Pesticides are classed based on the creature they target, their chemical structure, and their physical state.



Source: Author

Fig 1.9:History of pesticides



https://www.researchgate.net/figure/Fig-1-The-classification-of-pesticides-A-higher-resolution-colour-version-of-this_fig1_340045595

Fig 1.10:Classification of pesticides

1.5. Types of pesticide sprayer

In agriculture, a sprayer is a device that sprays liquids such as water, insecticides, and pesticides. In agriculture, they're also used to spray herbicides and fertilisers on crops. Spray nozzles, liquid tanks, sprayer pumps, pressure regulators, valves, and fluid pipes are all included in agricultural sprayers, and some even feature spray guns. Agriculture sprayers are available in a variety of sizes, designs, and performance levels. Sprayers range in size from small to very large, and are used to cover small to vast areas of land. Sprayers are available for a variety of spraying applications, including gardening, crops, trees, fruit, animal needs, and weed control.

Various types of sprayers suitable for small to large lands, viz.

- Knapsack Sprayer
- Portable Power Sprayer
- Knapsack Power Sprayer
- Mist Dust Sprayer
- HTP Sprayers
- Orchard Sprayers

Knapsack sprayer

Knapsack Sprayers are a common and widely utilised piece of equipment all over the world. They're perfect for spraying insecticides, pesticides, fungicides, herbicides, and other pesticides in field regions to protect crops from pests. Sprayers are frequently employed in agriculture, horticulture, sericulture, plantations, forestry, and gardens, among other applications.

Capacity	16 liters
Tank Material	HDPE
Lance Material	Stainless Steel
Size	36x18x51.3 cm
Net Weight	3 kg, 15kg with solution
Nozzle	8 Hole Nozzle
Price	Rs: 3000

https://www.indiamart.com/proddetail/hariyali-08-neptune-manual-backpack-sprayers-22269910188.html

Fig 1.11:Knapsack sprayer

Portable power sprayer

Portable power sprayer with a forced air cooled 4 stroke petrol engine and a brass metal pump, it is capable of very high pressure.

Engine Type	4-Stroke
Displacement	26 cc
Speed	7500 rpm
Fuel Used	Petrol
Suction Volume	7-9 Ltr/Min.
Area Covered	25 Feet
Fuel Tank Capacity	600 ml
Frequency Hz	50
Weight Kg	16
Fuel Consumption	500 ml/hr
Price	Rs:12000

https://www.amazon.in/Neptune-Sprayers-Portable-Pressure-Sprayer/dp/B0767FGL7J?th=1

Fig 1.12: Portable power sprayer

Knapsacks power sprayer

It is a spraying device that is frequently used to protect crops from insects, pests, and illnesses in various farms and fields. It saves time and effort, making it cost-effective. a bigger region is covered Stores easily, is light, and is simple to use.

https://www.youtube.com/watch?v=b2kxsUQKoxk

Fig 1.13 Knapsack power Sprayers, Capacity: 20 litters

Tank Capacity(litre)	20 Liter
Fuel Type	Petrol
Stroke Type	4 Stroke
Model Number	Honda ASR -25708
Tank Material	HDPE Tank
Price	Rs: 18000
Weight	20kg with solution

https://www.indiamart.com/asr-agriexports/knapsack-power-sprayer.html

Fig 1.14:Knapsack power sprayer

Mist dust sprayer

The mist dust sprayer is a type of backpack power sprayer that is used to mist liquid chemicals and granulate urea. This sprayer can be used for tall trees such as rubber, arecanut, palm, and coconut trees in addition to typical crops.

Chemical tank	20L
Displacement	82.4cc
Engine Type	2 Stroke
RPM	7000
Net Weight	24kg with solution
Fuel Consumption	500ml/hour
Price	Rs:10000

https://www.indiamart.com/kisankraftmachine-tools/mist-dust-sprayer.html

Fig 1.15: Mist dust Sprayers, Capacity: 20 litres

HTP (Horizontal triplex power) sprayer

HTP Sprayers are the most common and widely used equipment in the world. They're perfect for spraying insecticides, pesticides, fungicides, herbicides, and other pesticides in field regions to protect crops from pests. Sprayers are frequently employed in agriculture, horticulture, sericulture, plantations, forestry, and gardens, among other applications.

Weight	7.5 kg
Engine Speed	800-1200 rpm
Output (Ltr/min)	14-22 Ltr/min
Pressure (kg/cm2)	20-45 kg/cm2
Dimensions	340x280x320 mm
Price	Rs: 9000

https://www.neptunesprayers.in/htp-sprayer.html

Fig 1.16: HTP (Horizontal triplex power) sprayer

Orchard sprayer

Orchard sprayers do the same job as pest controllers, but orchard sprayers are more efficient in terms of target areas, time, and manpower. They use liquids to apply nutrients, herbicides, crop production ingredients, and insect control agents in enormous amounts of air. We can adapt to a wide range of orchard circumstances by adjusting the fluid and air delivery systems in this sprayer. Sprayer parts, such as the spray gun and spray nozzle, are used to apply the liquid.

- Power: 11 kW(15 hp)
- Chemical Tank: 600 L
- Spray Range: 10 m
- Nozzles: 10
- Pump Flow Rate: 54 L/min
- Working Pressure: 0-4 MPa
- Ventilation Fan Dia: 600 mm
- Hand Wash Tank: 10 L
- Net Weight: 300 kg
- Price: Rs 80000

https://www.munckhof.org/en/machine/trailed-orchard-sprayer/

https://www.kisankraft.com/about-orchard-sprayer/

Fig 1.17:Orchard sprayer

battery & solar sprayer, 3 in 1 sprayer

Tank made from high-quality HDPE. Simple design for easy repairs and operation. Solar Battery operated Knapsack Sprayer 3 in 1 is fitted with Solar Panel as well as Handle-Lever which helps the farmer to charge the battery with solar panel while using the product.

- Product Type: Battery Sprayer
- Capacity: 16 Liters
- Output: 4 L/min
- Maximum Pressure: 100 PSI
- Battery : 12V/ 8 AH
- Tank Material: Plastic
- Weight: 18Kg with solution
- Price: Rs 6000

https://www.indiamart.com/proddetail/solar-sprayer-14696484233.html

https://www.toolsvilla.com/solar-sprayer-3-in-1

Fig 1.18: Solar & battery knapsack sprayer

1.6. Observations

Most of the farmers use manual and battery powered knapsack spray for the farming which they need to carry on a back throughout the large field to spray the pesticides.

Problems in current pesticide sprayer are:

1) Majority of the marginal, small & semi medium farmers who own around 1 to 10 acres of land prefer knapsack sprayer.

2) This knapsack sprayer is difficult to use for long period of time as it is heavy with 16 to 18 liters solution & needs to be carried on the back over a large fields which results into back, neck, shoulder and arm pain.

3) Difficult to load and unload for a single person due to very heavy weight.

4) There are vibrations & heat problem while using petrol power sprayer.

5) Uneven spray of pesticides due to the hand pump mechanism.

6) Farmer exposed to harmful pesticides while spraying.

7) In solar sprayer, solar panels are prone to damage with rough use.

2. INITIAL DESIGN BRIEF

Design a solar pesticide sprayer for agricultural use in India

Objective of the product:

1. Affordable for most of the farmers.
2. Easy to carry through large fields.
3. Comparatively Less or properly distributed load for the user while carrying the sprayer.
4. Safe for farmers to use to avoid chemical spray hit on face.
5. Automatic spray without hand pump to reduce the human effort.
6. Solar powered solution to tackle the electricity issue.
7. Suitable for variety of Indian crops.
8. Easy to manufacture & maintain at local level.
9. Quick & easy to refill, clean & store.

3. FIELD VISIT 1

Locations: Shirwal, Satara

Purpose of field visit:

- To understand geographical and social conditions of the farmer.
- To collect first hand information of how different crops are protected (from pests, fungus etc.) in farming.
- To get direct experience of the activities that are carried around for effectively applying pesticides over a crops.
- To interact with local people & discuss problems they faced during entire process of pesticide use.

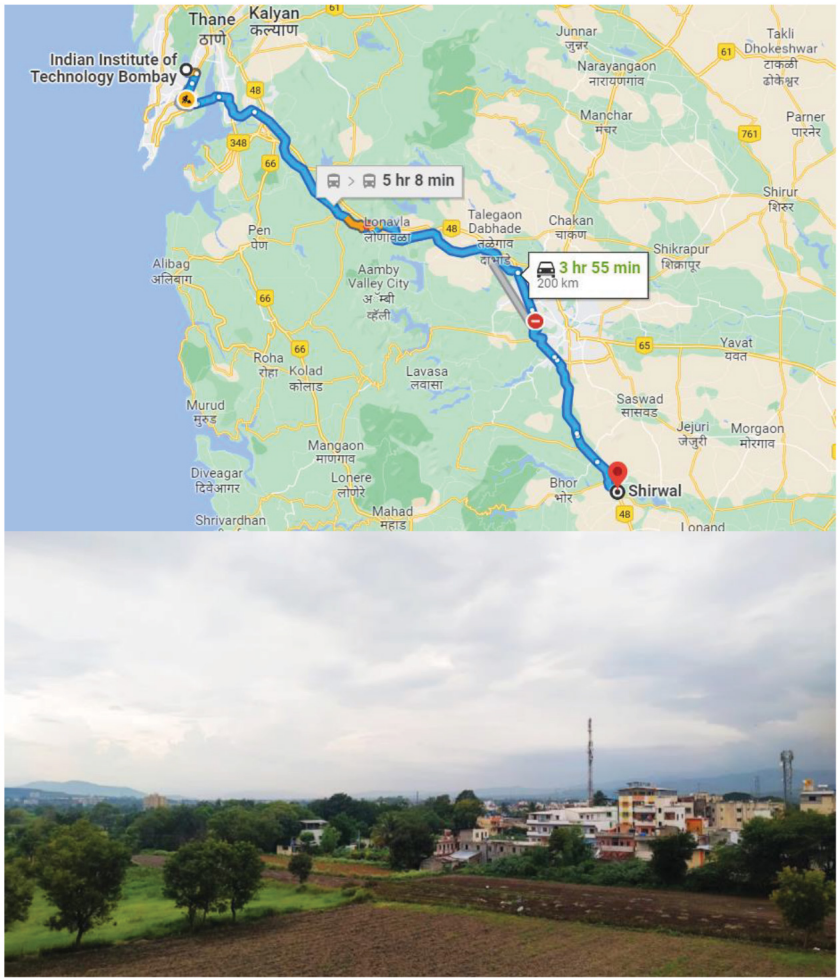


Fig 3.1 Source: Google images

Interviews recruit

- Name : Girish Govindrao Jadhav
- Age: 44 years
- Status: Married
- Location: Shirwal, Satara
- Land owned: 5 Acre
- Farming experience: 20-25 years
- Education: 12th
- Annual income: RS: 2-3 lacks.
- Family : 4 (Wife & 2 children)

Fig 3.2 Girish Jadhav, Interview recruit

Questionnaire was divide into 4 parts as follows

1) Demographic data
2) Farming related questions
3) Questions related to pesticide use in farming
4) Question related to equipment's used for pesticide spray

Meeting with the farmers

Fig 3.3 Meeting with farmers

Fig 3.4 Discussion over product

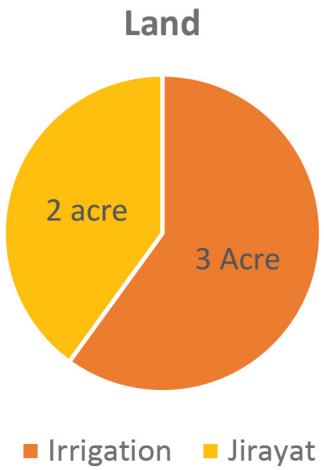


Fig 3.5 land owned

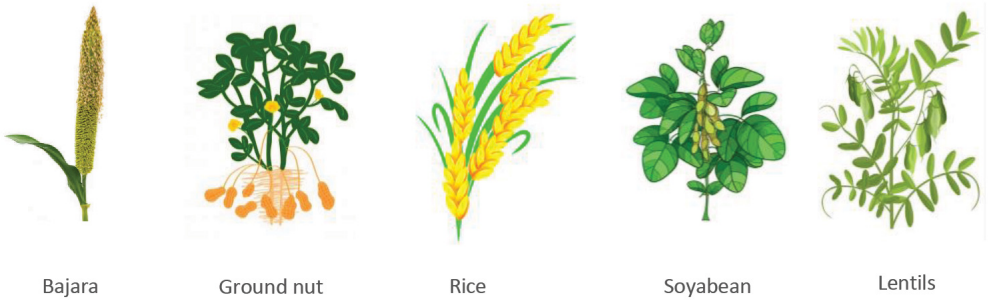


Fig 3.6 Kharif crops

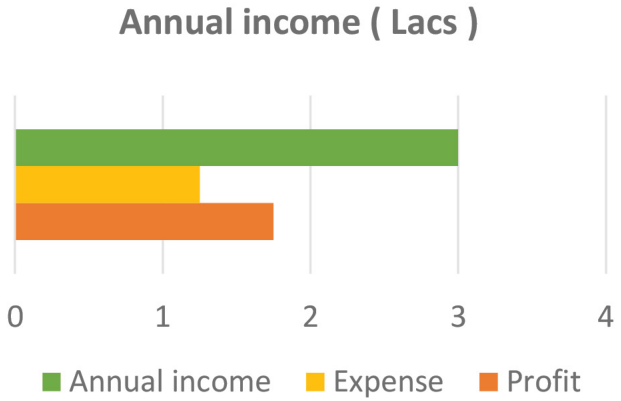


Fig 3.7 Annual income

Fig 3.8 Rabi crops

Farmers interviewed in this field visit generally tends to avoid the use of pesticides as being aware of adverse effect of chemical to the quality of crops and health of human. But if they notice that crop is being attacked or harmed by any pesticides then they have to spray the required pesticides. As shown in fig:3.9 and 3.10 following are the some symptoms and diseases which harms the crops:

- leaf starts to turn yellow & black
- leaf starts to falls down.
- top gets dried up etc.

Fig: 3.9:White pests on leaf

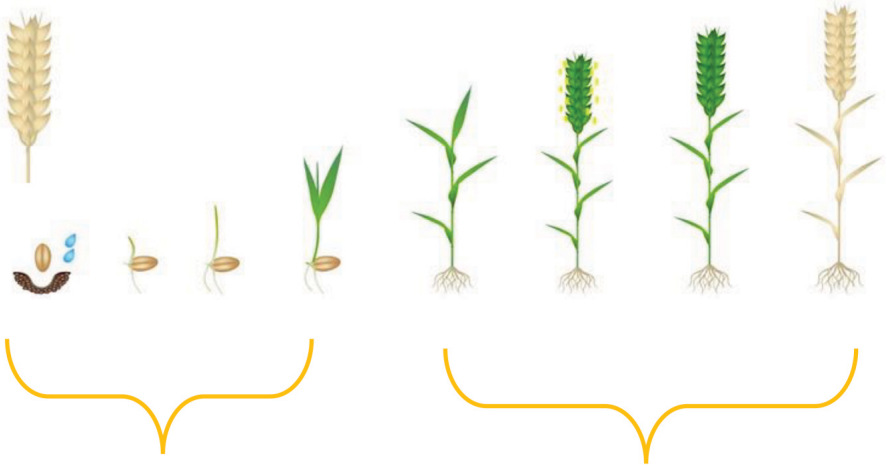


Fig: 3.10:Fungus at the top of crop

For spraying 1 acre land it take 2 person's entire day starting from 11 am to 6 pm. Around 4 km distance is needs to be covered carrying 20kg tank on back, even if 4 grooves are covered in one straight walk. 1 person sprays the solution while other person helps to fill up the water. It takes around 8- 10 times tank refuelling with solution to cover 1 acre of land

Considering 4 km of walking per acre farmer needs walk 20 km for 5 acre. With current product spraying all this land in a single day is not possible as charging only lasts for up to 8 to 10 pumps which covers only about acre.

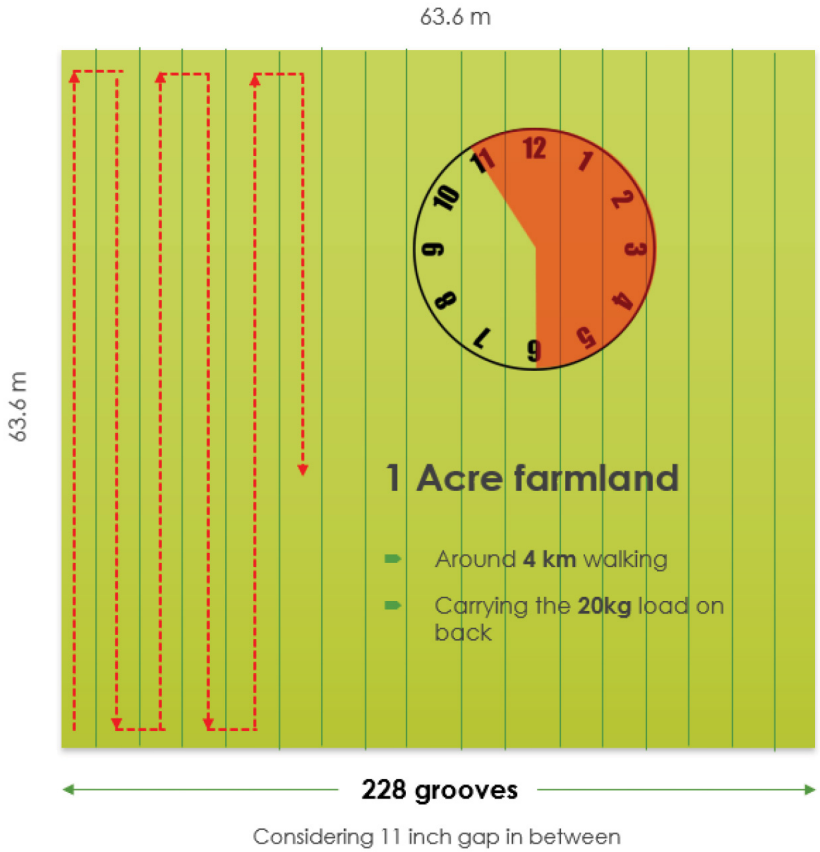


Fig 3.11: Operations in 1 acre farmland

Fig 3.12: Groove pattern in farm

3 types of sprayer were used by people in village. Very Large field owners were using HTP sprayer which is costly (Rs 10000)to buy & operate (Fuel & manpower). 80% of the farmers in village were using manual + battery knapsack sprayer.

https://www.neptunesprayers.in/htp-sprayer.html

Fig 3.13: HTP sprayer

https://www.youtube.com/watch?v=DjYyxSvShD8

Fig 3.14: Manual + battery knapsack

https://www.youtube.com/watch?v=DjYyxSvShD8

Fig 3.15: Battery knapsack

Farmers use variety of fertilizers and pesticides for farming depending upon the crops they grow as shown in the fig 3.16 and fig 3.17. The famers that was interview in this visit use to store this pesticides and fertilizers in the pesticides tank itself to keep them away from the reach of small children and cattle in his house. While using any particular pesticides, herbicides or weedicides farmers needs to be very careful as this chemicals are very plant specific and can be harmful for not recommended plants and might damage them if sprayed.

Fig 3.16: Fertilizers used by farmers

Fig 3.17: Pesticides, fungicides & Herbicides used by farmers

Fig 3.18: Storage of pesticides in tank

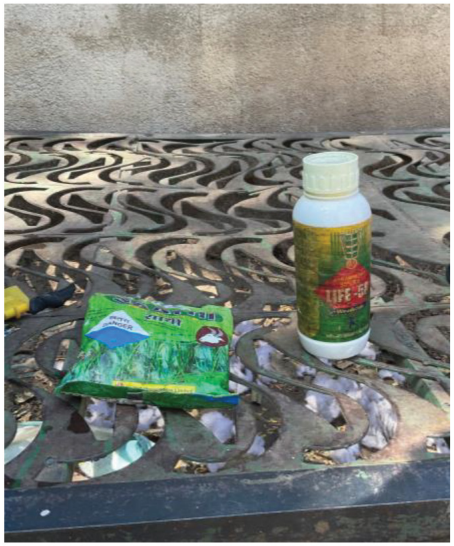


Fig 3.20: Pesticides used by farmers

Existing Product study

Girish switched from 18 litre to 16 litre just because of weight. It was observed that battery of one of the sprayer was drained because less frequent use. Manual handpump was almost discarded by everyone because of extra Manuel efforts and complex mechanism which frequently use to get damaged.

Fig 3.21: Products currently used by farmers

Fig 3.22: Manual + battery knapsack sprayer

Cost: Rs 3700
Capacity : 18 litre
Weight: 22 kg

Refill: 6-7 times for 1 acre

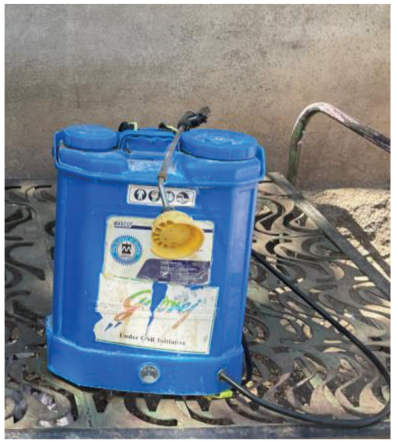


Fig 3.23: Battery knapsack sprayer

Cost: Rs 2100
Capacity : 16 litre
Weight: 19 kg

Refill: 8-10 times for 1 acre

Study of components

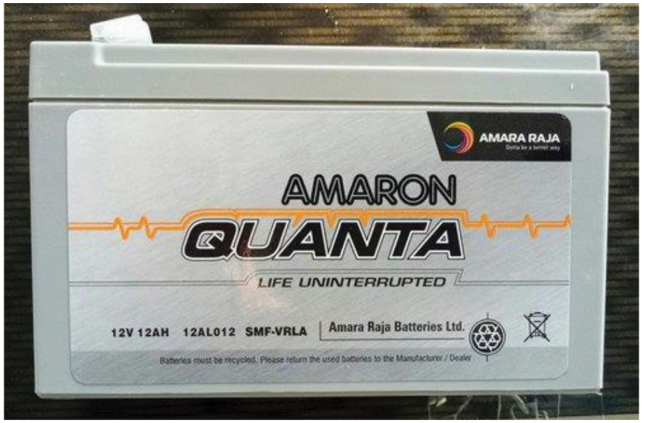
Fig 3.24 : Components of existing knapsack sprayer

Components of existing sprayer

Fig 3.25: Components of existing knapsack sprayer

https://www.indiamart.com/proddetail/battery-knapsack-sprayer-14046676888.html

Fig 3.26: Ventilated back support



https://www.indiamart.com/proddetail/amaron-battery-for-agriculture-sprayer-pump-22293070548.html

Fig 3.27: Battery

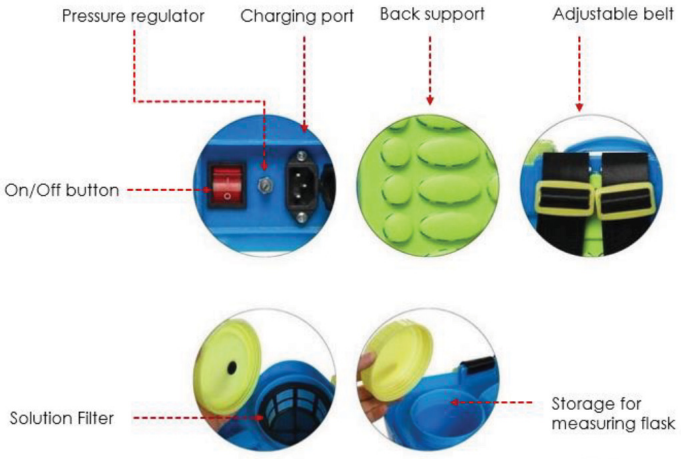


Fig 3.28: Components

Capacity	12V – 12AH
Battery type	Flat plate battery
Price	980/-
Charging time	6-8 Hrs
Weight	500g

Table 3.1:: Battery specifications

https://www.indiamart.com/proddetail/battery-knapsack-sprayer-14046676888.html

Fig 3.29: Nozzle spray variations

Fig 3.30: Box packaging

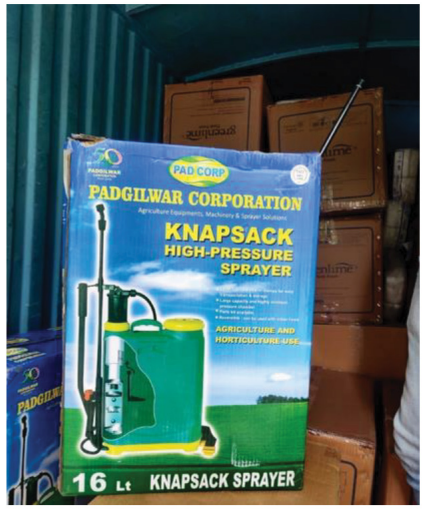


Fig 3.31: Transportation

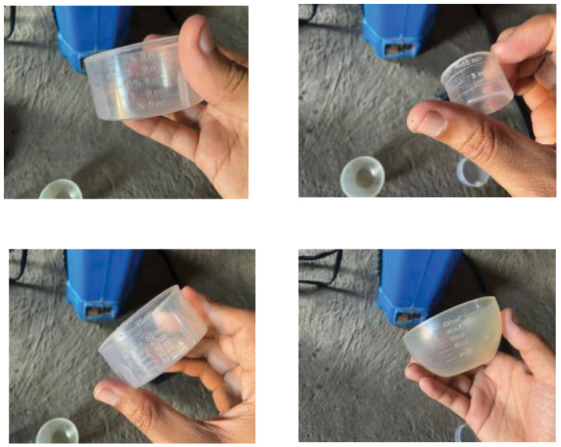


Fig 3.32: Measuring flasks

Fig 3.33: All parts placed in tank to assemble

Demonstration

Fig 3.34: Step 1

- Locate the sprayer which is generally is kept on a store room.
- In this case the pesticides were stored inside the tank only to keep it away from children and animals.
- Empty the tank.

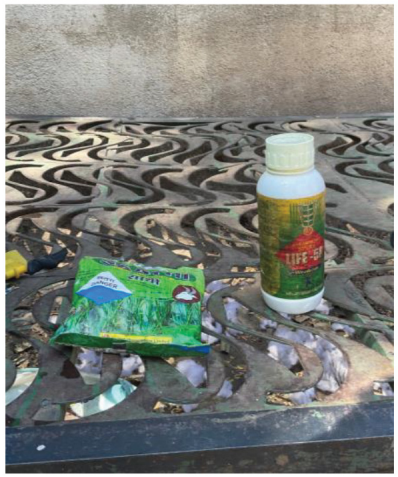


Fig 3.35: Step 2

- Select desired pesticides according to the plants
- Being poisonous needs to be handled very carefully.
- Carry sprayer and pesticides to the farm

Fig 3.36: Step 3

- Measure the mentioned quantity using the flask.
- Pour it into the tank.

Demonstration

Fig 3.37: Step 4

- Fil the tank with water using a nearby water source with vessel through given filter to avoid foreign particle from damaging the pump.

Fig 3.38: Step 5

- Shake the tank well or spray the solution into the tank itself using the nozzle until it gets mixed properly.

Fig 3.39: Step 6

- Load the tank on your body, ask for help if available while loading

Fig 3.40: Step 7

- Spray the solution uniquely on plants by walking all-over the field

Generally farmers prefer to spray the pesticides when there is a less wind to avoid coming in contact with chemicals. Due to the chemicals, they face coughing, sneezing, headache, skin issues etc.

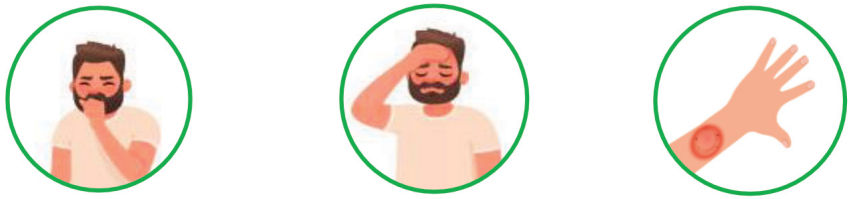


Fig 3.41: Flow bending due to the wind

Role play was done to from start to end where each step was studied in detail. Very first thing that was noticed in this roleplay was that once the tank is filled completely it is quite heavy to operate for a single person and might hurt self while doing so. It was also noticed that the strap of the device gets worn out with time and become very uncomfortable to use as shown in fig: 3.42.

Fig 3.42: Role play

4. FIELD VISIT 2

Purpose of field visit

To visit a family who was heavily involved into the gardening & farming at some extent and also to discuss spraying techniques they use. Discuss the pesticide prevention methods that use for their plants and gain some good insights for a practical product design solution. To study solar product developed by farming enthusiast to spray the pesticide for their gardening use.

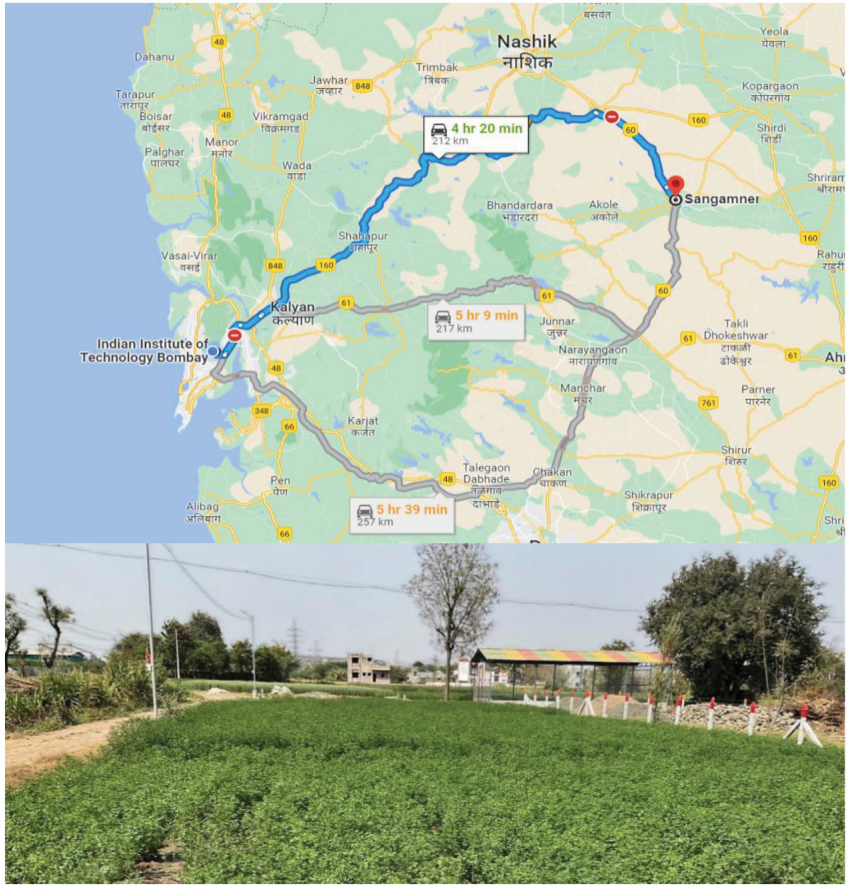


Fig 4.1: Source: Google images

Disease of the plant due to pests & fungus

Fig 4.2: Disease on the plant

Pesticides and fertilizers in use

Fig 4.3: Pesticides and fertilizers for plants

Devices for pesticides spraying

As mostly they were performing the gardening in their backyard, so they had variety of pesticides sprayer at their disposable as seen in the images. They were using two small single hand operation pesticide sprayer with the capacity ranging from 1 litre to 3 litre. They were also using the solar powered knapsack pesticide sprayer with the capacity of 16 litre.

Fig 4.4: Devices used for pesticide spraying

5. INSIGHTS OF FIELD STUDY

Affordability

Affordability plays a very important role while designing the agricultural product considering the majority of lower income group of farmers. This suggest that proposed product solution needs to fall into similar or lower price bracket than the existing one to make it affordable to majority of farmers. *The average annual income per farm household from all sources is Rs: 1,22,616 according to 2018-19 data – Hindustan times.* As shown in the figure.

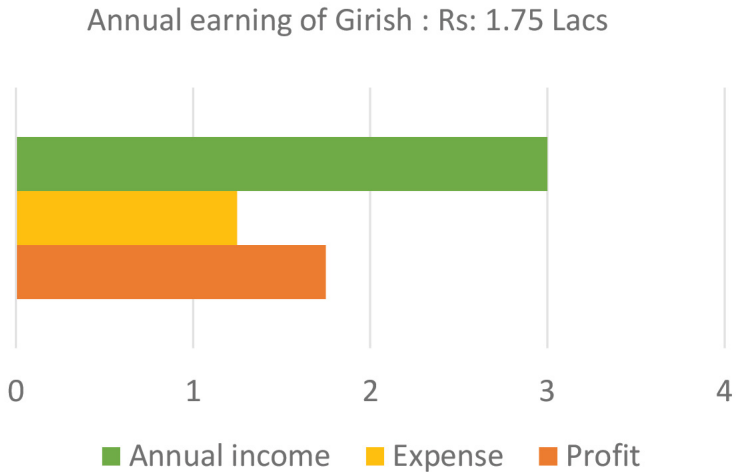
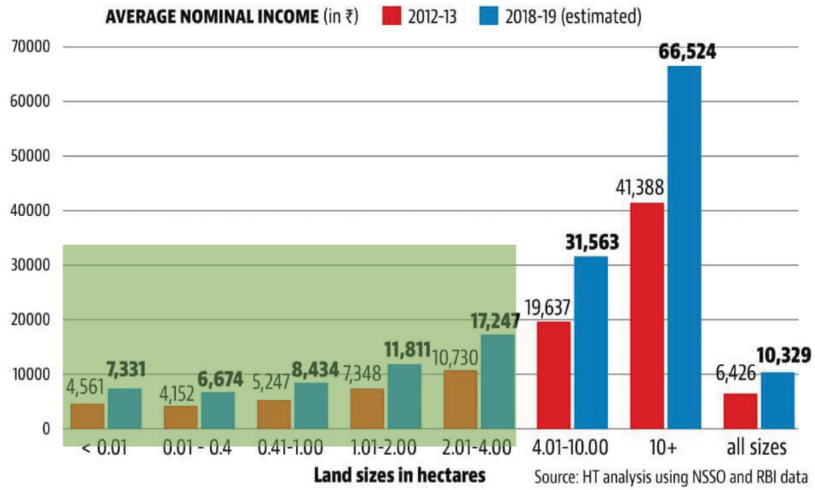


Fig 5.1: Annual earning of Girish



https://www.hindustantimes.com/india-news/rs-6-000-is-6-of-a-small-farmer-s-annual-income-according-to-nsso-data/story-rddMw0hk6cSbxjo7E1GyKK.html

Fig 5.2: Average nominal income as per land sizes

Physical strength

Person with only certain physical strength is able to perform the task of spraying efficiently as it requires walking of 4 km distance with a weight of around 20 kg for more than 4 hours for a 1 acre land. Women, younger, older or weak person would not be an ideal candidate to perform such tasks.

Fig 5.3: Physical strength required

Even loading full tank of 20 kg is difficult for a one person and often requires assistance from other, otherwise person might suffer from back or shoulder injury.

Fig 5.4: Difficulties while loading the sprayer single handed

Ergonomic issues

Spraying the pesticide using the knapsack sprayer for Long term is difficult & causes pain in both shoulders, back & arm. Shoulder discomfort : Belt strap of the machine gets very uncomfortable to shoulder once worn out. Holding a metal pipe of around 400g for a long duration causes pain in the wrist, fingers & forearms.

Fig 5.5: Discomfort in arm, shoulder & back

Fig 5.6: Discomfort due to worn out belt

Movement in uneven terrain

Spraying activity cannot be performed while the wind is flowing as chance of user inhaling poisonous pesticides is more. Spraying the pesticides in a very sunny weather is not advisable by pesticide producer as droplets of solutions get evaporated thus reducing the overall effect of pesticides.

Fig 5.7: Uneven terrain in farm

Alley size of crop

Alley size of the crops in India is different for different crops in India. In this visit of village in Maharashtra the gap in between the crop grooves is observed between 9 inch to 11 inch as shown in the figure.

Fig 5.8: Alley size of crops

No wind or harsh sunlight

Spraying activity cannot be performed while the wind is flowing as chance of user inhaling poisonous pesticides is more. Spraying the pesticides in a very sunny weather is not advisable by pesticide producer as droplets of solutions get evaporated thus reducing the overall effect of pesticides.

https://www.motherjones.com/food/2015/05/monsanto-syngenta-merger-45-billion-pesticides/

Fig 5.9: Uncontrolled spray direction due to wind

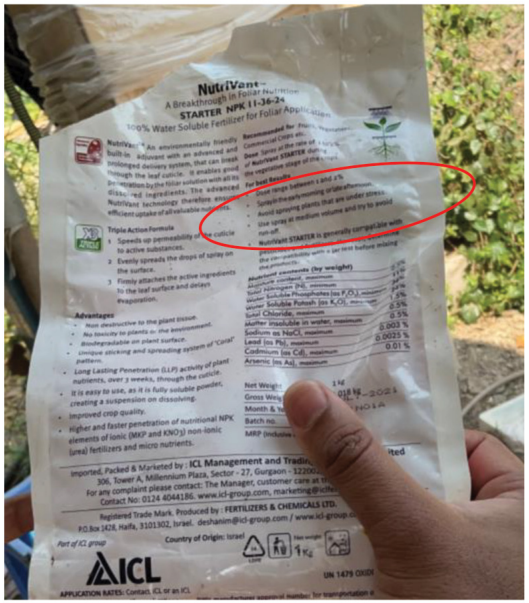


Fig 5.10: Instructions to avoid sunny weather

Poor interface

All the controls & interface on the machine are on backside, which are quite hard to access while device is in use & keeps the user uninformed about the settings.

Fig 5.11: New user struggling to access on/off button

Battery drain issue

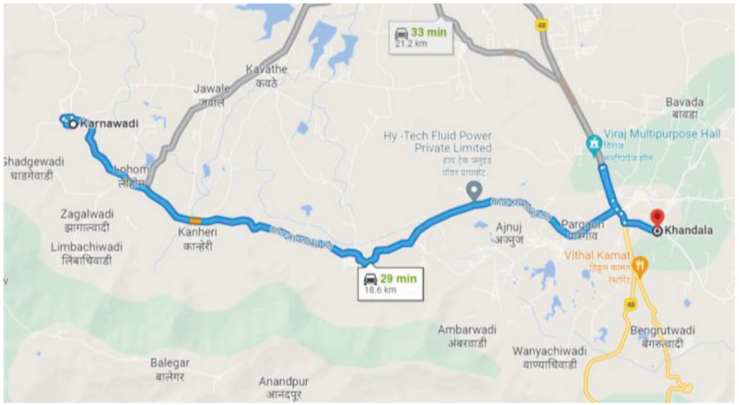
Existing product tends to get damaged due to the inconsistent use (e.g. battery drain) as the machine don't gets used consistently due to the sole function of pesticide spraying.

Cleaning issue

There is no reminder or affordance to wash the tank after using the poisonous solution which are very crop specific & might damage if applied on other crops. (e.g. herbicides)

No local maintenance solution

In case of repairing of the sprayer farmer needs to travel to other places (taluka place) where all the resources are available. There is no local repair facility in village. In Girish's case they needed to travel 18 km to taluka places to get it repaired or replace any components.



Source: Google images

Fig 5.12: 18 km travel to repair the device

6. REVISED DESIGN BRIEF

Design a solar pesticide sprayer for agricultural use in India:

Objective of the product

- Affordable to the majority of small & semi medium farmers.
- Easy to maneuver between crop alleys sizes.
- Comparatively effortless & comfortable to use than the existing knapsack sprayer.
- Solar powered automatic spray to reduce human efforts.
- Feasible to tackles the electricity & battery drain issue thus reducing the labor waiting period for charging the battery.
- Multifunctional with additional product value for farmers to increase the frequent use of the device.
- Able to manufacture, maintain & repairs locally.

7. DESIGN DIRECTIONS

- Two design directions were selected for the design of this sprayer considering the easiest way to carry the liquid throughout the farms.
- First design direction that was selected is shifting all the weight from back and putting it on single frame of wheel to push forward with the help of arms.
- The second design direction finalised is that farmer will lead the way while spraying on crops & tank will follow him on the wheel & find more effective way to carry weight on back & shoulder which will reduce human efforts.

Pushing the tank

Make tank follow user

7.1. Push type ideations

Initial ideations

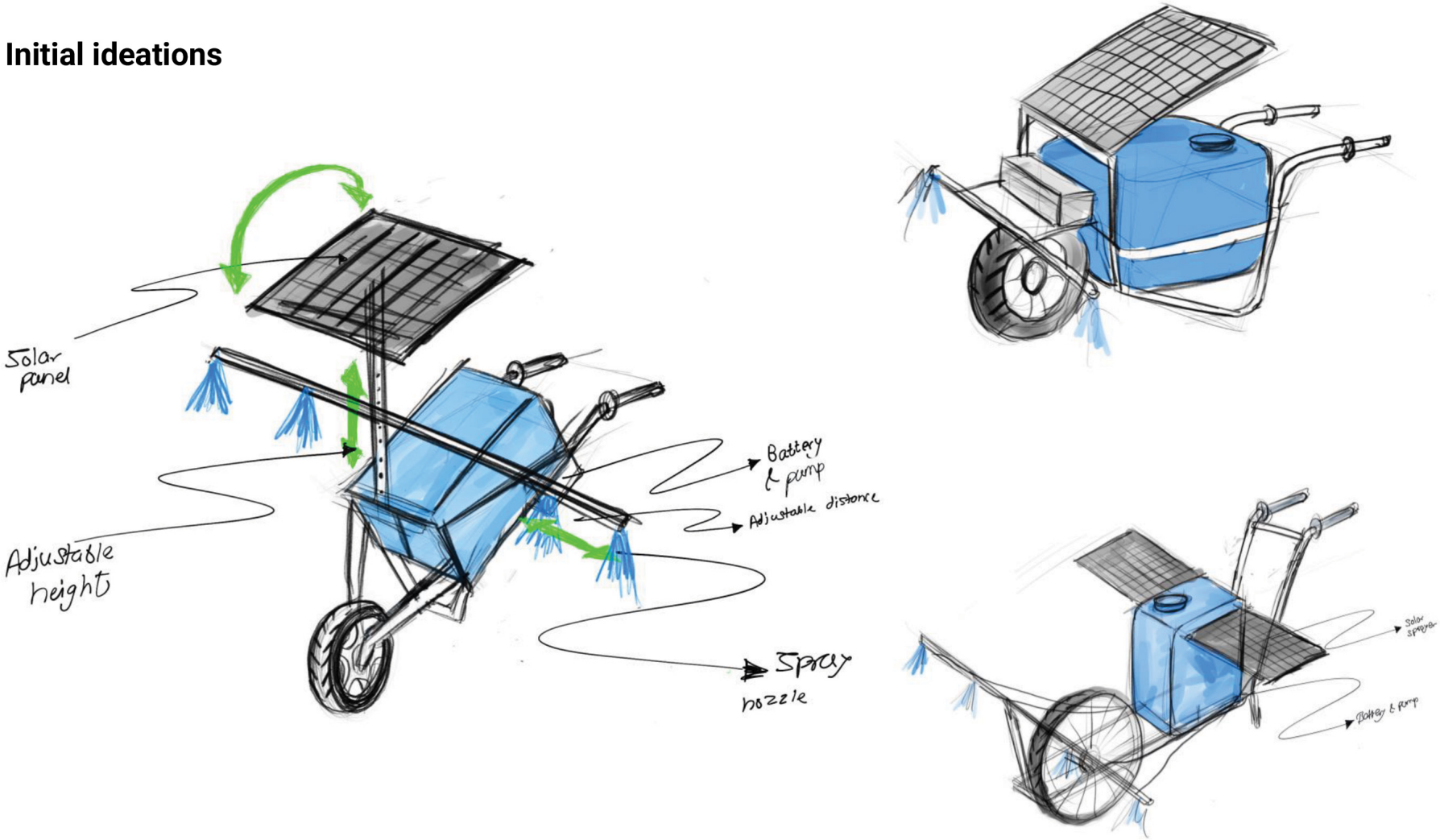
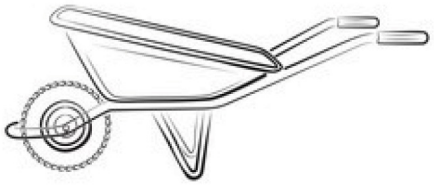


Fig: 7.1:Initial ideations

Initial ideations



Inspiration

Modular components

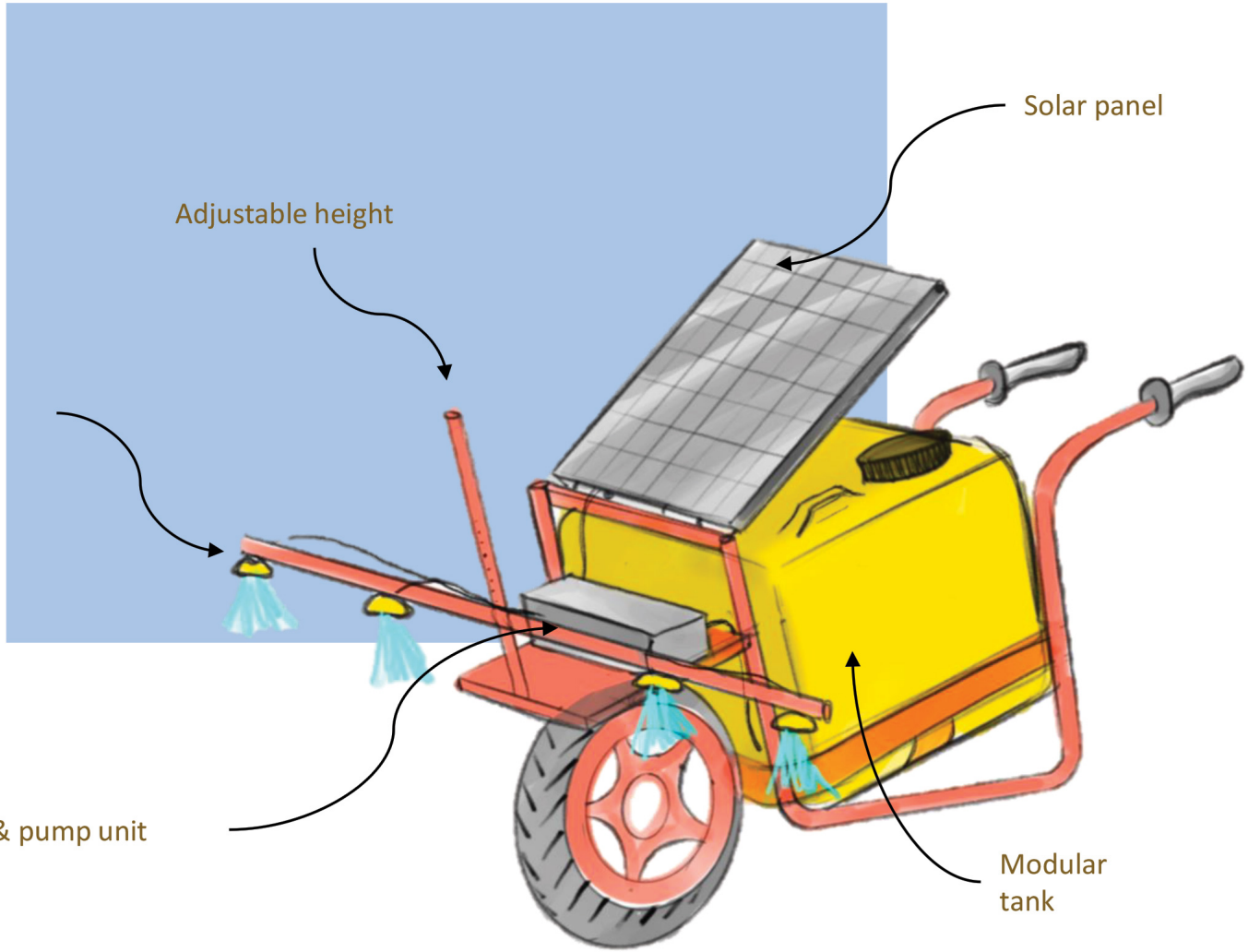


Fig 7.2: Initial ideations

Initial ideations

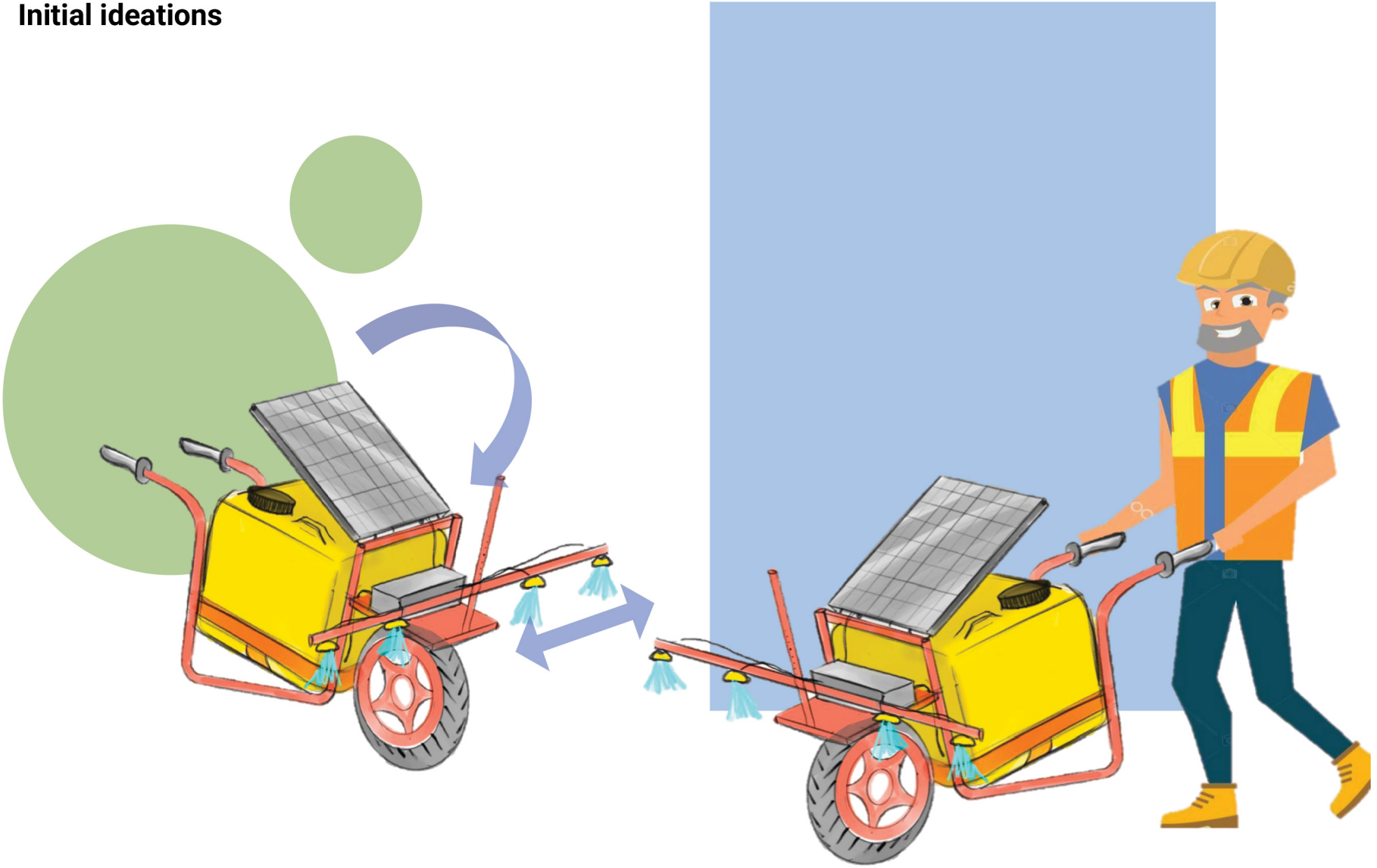


Fig: 7.3:Initial ideations

Initial ideations

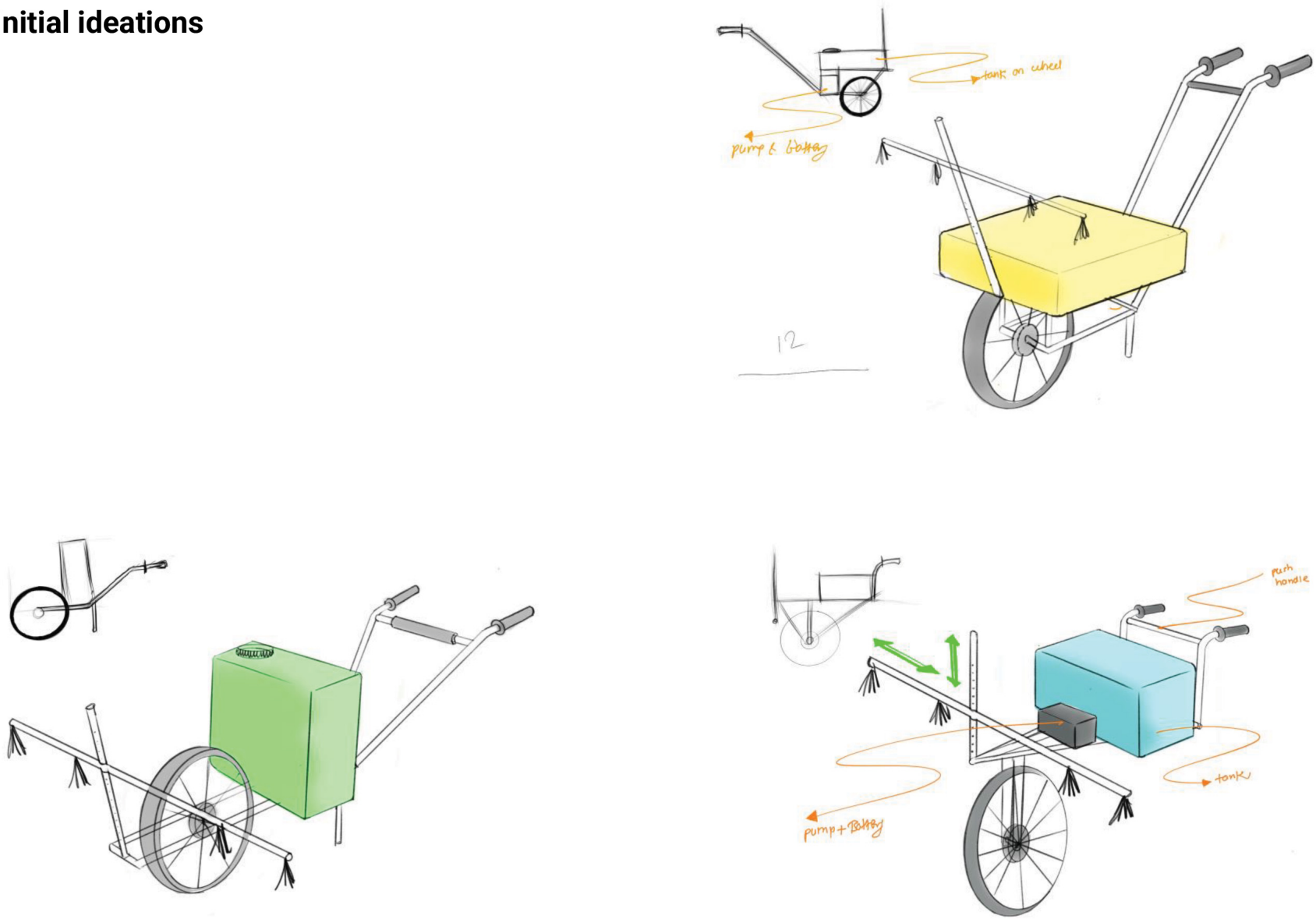


Fig 7.4: Initial ideations

7.2. Pull type ideations

Inspiration

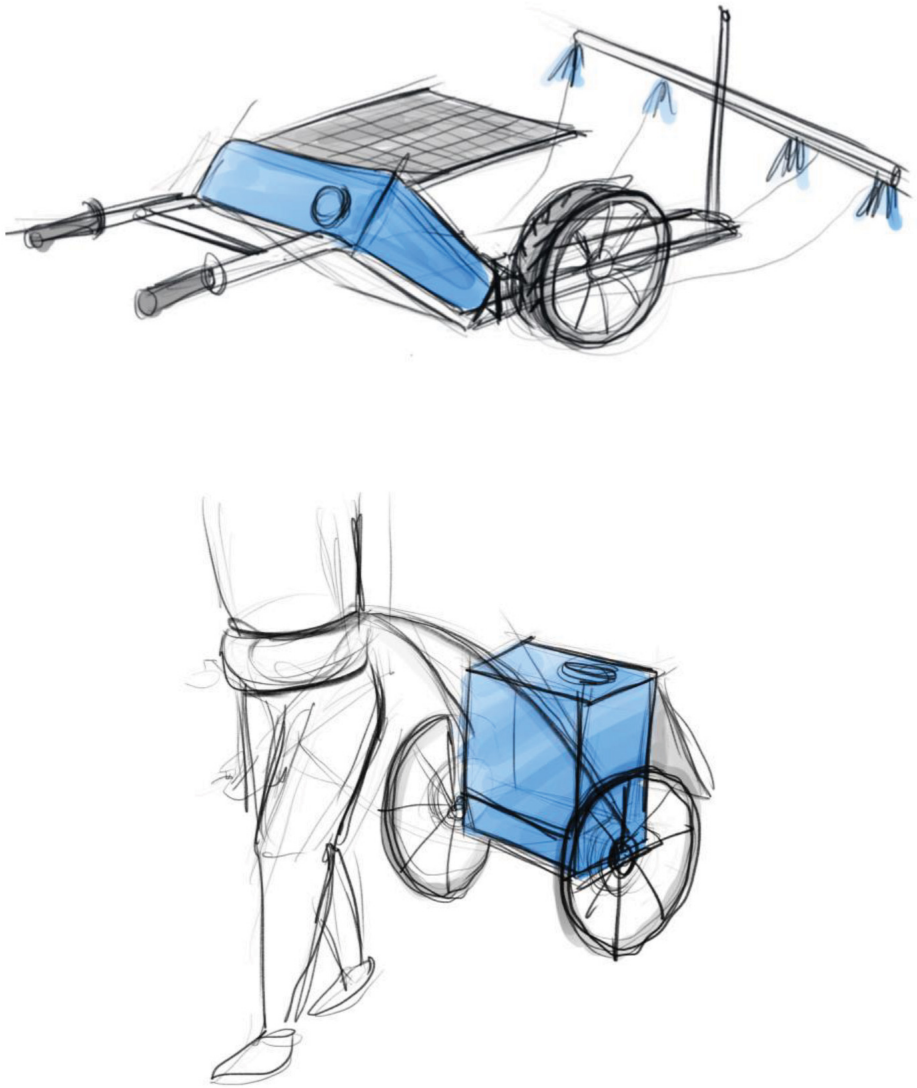


Fig 7.5: Initial ideations

Initial ideations

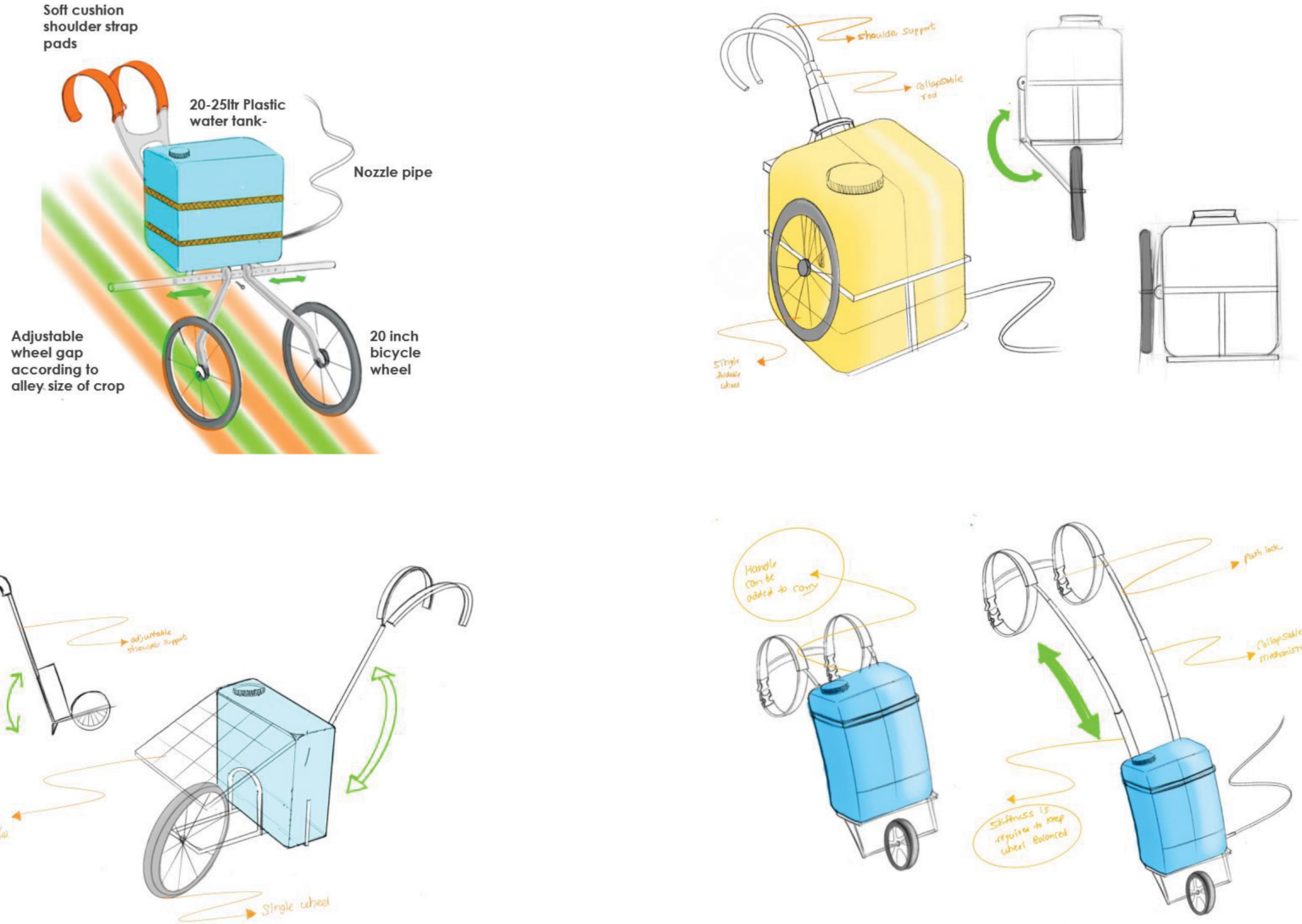


Fig 7.6: Initial ideations

8. SHORTLISTED CONCEPTS

Concept 1

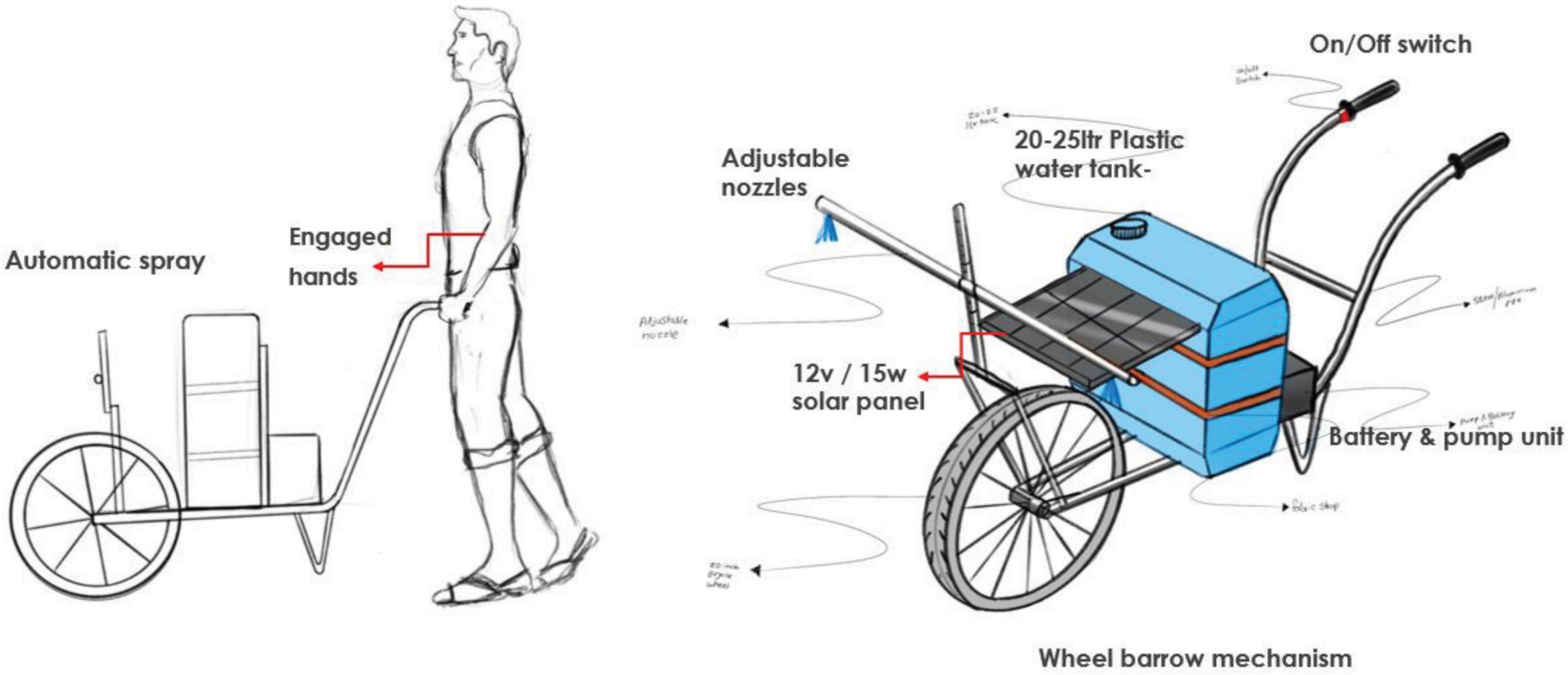


Fig 8.1: Selected concept 2

Concept 2

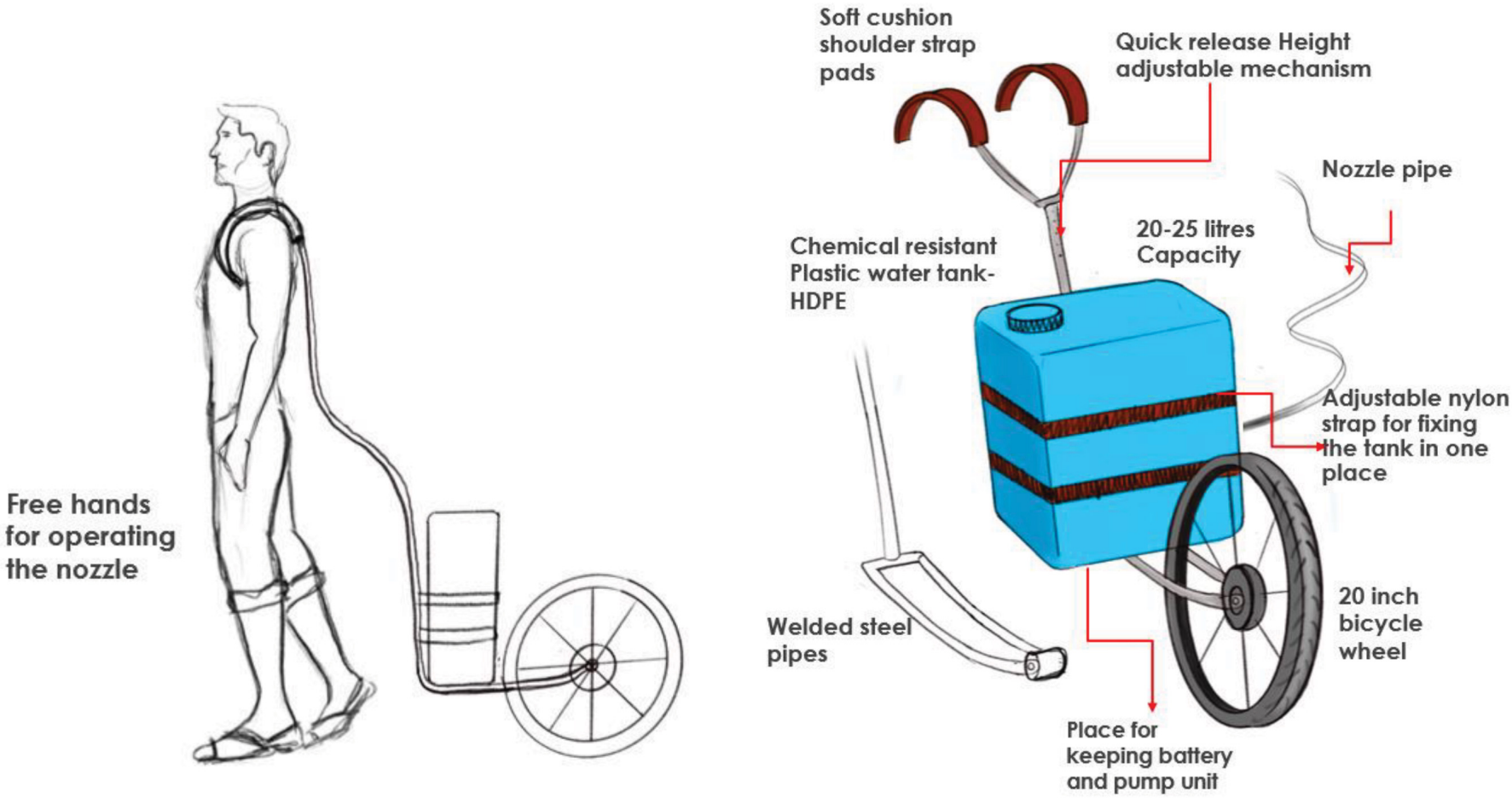


Fig 8.2: Selected concept 1

Concept 3

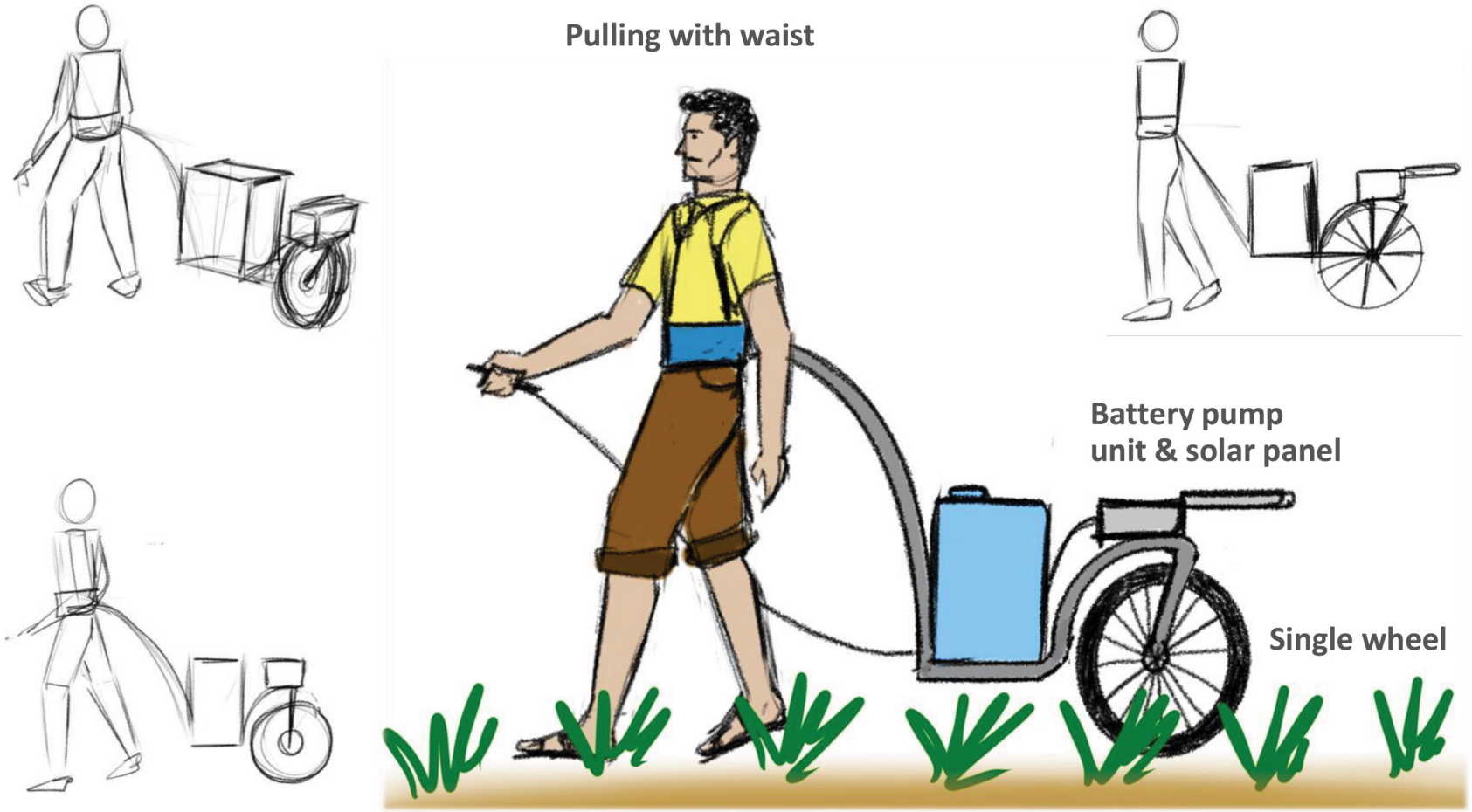


Fig 8.2: Selected concept 3

9. MOCK-UP 1 DEVELEOPMENT : PUSH TYPE

After all the ideations, 3 concepts were finalized based on the design brief and practicality. Manufacturing if all three full scale mock-up started in order to understand which concept is more feasible solution for the current problem statement. Initially I created a 3d model of the mock-up 1 considering the human factors. 1 inch diameter pipe of steel with 2mm thickness is used for manufacturing after failure of 1mm thickness pipe while bending. Purpose of all this mock-ups to find out the new way to distribute the load.

Fig 9.1: CAD models

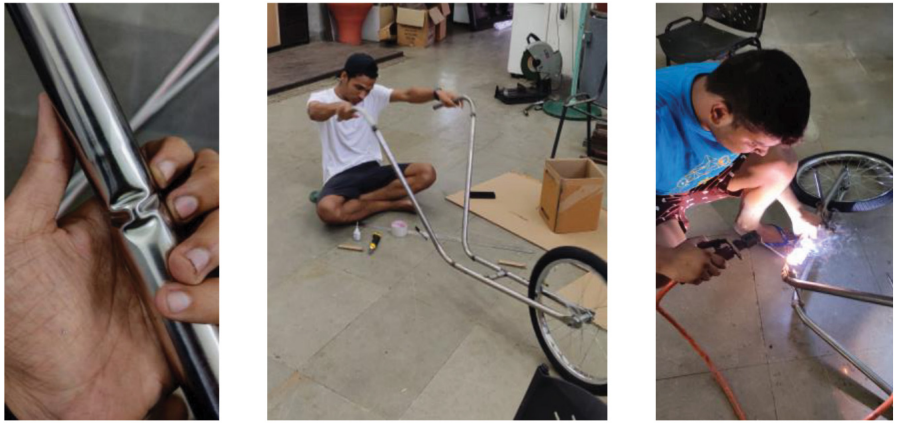


Fig 9.2: Manufacturing work in progress

9.1 Mock-up 1

This push type mock-up 1 is designed in such a way that user would pickup the ending handles with his both hands and with the help of level action user can pickup the tank easily. Inspiration behind this concept was a wheel barrow.

Fig 9.4: Mock-up 1

Fig 9.3: Mock-up 1

Fig 9.5: Mock-up 1

9.2 Mock-up 1 : study

Testing of mock-up 1 was done in order to understand the concept better. Testing was done on the garden terrain were quiet uneven/ up-down surfaces were available to get the idea of farming terrain. Role play was done with empty, full & half tank in order to understand the water behaviour with different water levels.

Observation in this mock-up was that both the hands are engaged and lots of pressure was coming on forearms and shoulder to lift the device up as shown in the figure.

Fig 9.6: Mock-up 1: study

Fig 9.7: Mock-up 1: study

Fig 9.8: Mock-up 1: study

10. MOCK-UP 2 DEVELEOPMENT : PULL TYPE

For developing mock-up 2, little preparation was needed like studying the anthropometric measurements of the Indian and human gait cycle as it was playing huge role in this concept.

10.1 Anthropometric measurements

Average Indian height

	Men	Women
India	163.4 cm (5 ft 4½ in)	151.9 cm (5 ft 0 in)
India	163.7 cm (5 ft 4½ *in)*	152 cm (5 ft 0 in)

https://en.wikipedia.org/wiki/Average_human_height_by_country

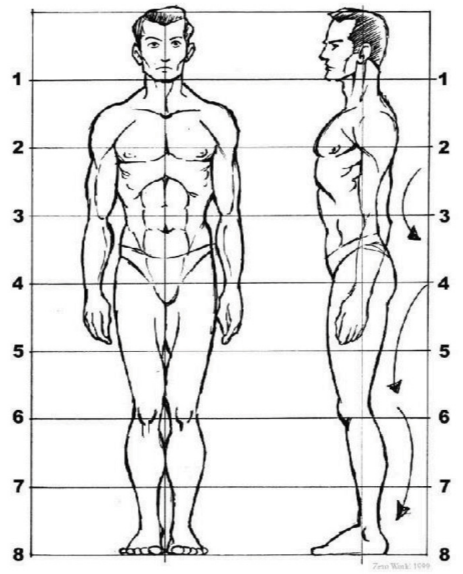
Maharashtra	96.88	166.1	152.5	0.79	0.49

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2630164/

Fig 10.1: Average Indian height

Proportions of human body

On average this ratio is between 1 to 6.5 and 1 to 8. Infants and children have relatively bigger heads, and as they grow, the body becomes considerably taller, while the head doesn't grow as much.



https://anatomymasterclass.com/anatomy-video-lessons/human-figure-proportions#:~:text=Not%20every%20adult%20person%20has,doesn't%20grow%20as%20much.

Fig 10.2 Proportions of human body

Step length

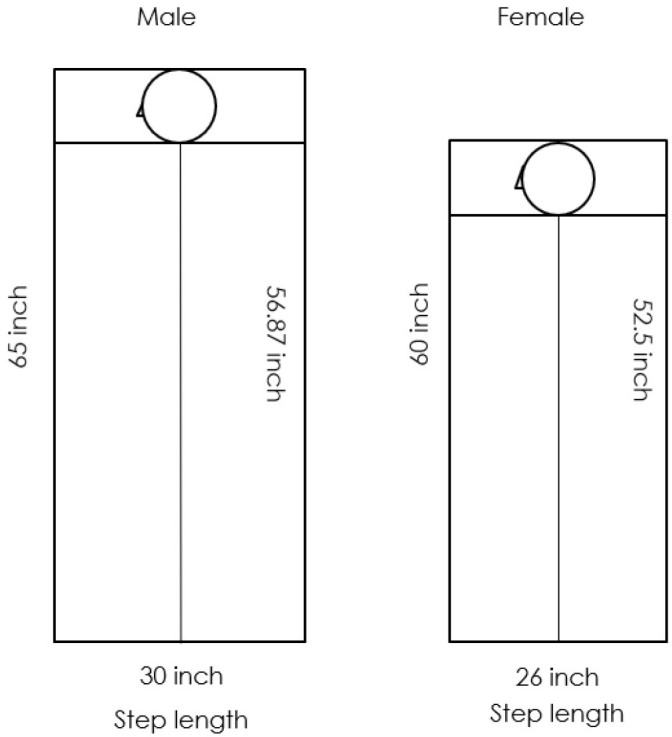


Fig 10.3 Average step length

Shoulder width

Shoulder width of people in the age bracket of 21 to 55 is considered for this study for the purpose of mock-up development. The findings were that the average shoulder width for a mock-up can be considered as 42.5 cm.

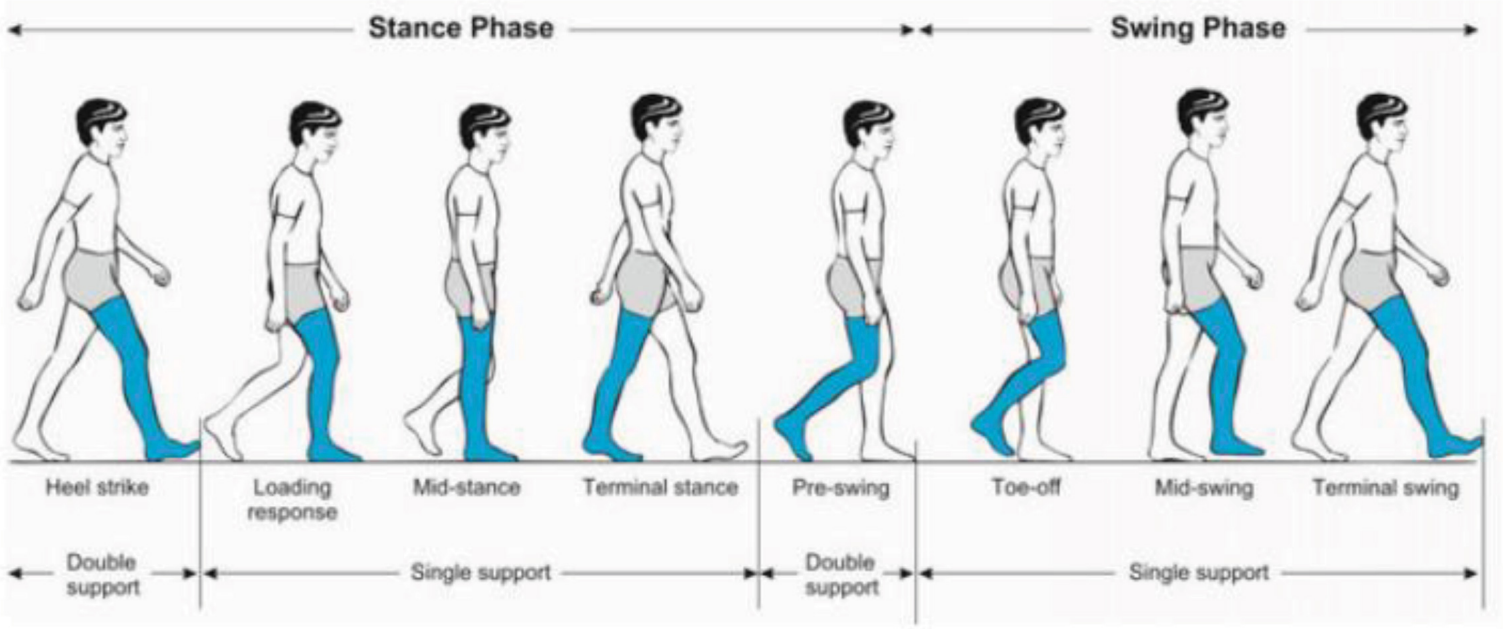
Age bracket		18-20	21-25	26-30	31-35	36-40
Height (cm)	M	169.9	170.2	170.1	169.8	169.6
	F	158.8	159.2	159.4	159.0	158.9
Weight (kg)	M	59.2	61.2	63.2	64.6	65.7
	F	51.1	51.3	53.5	54.9	56.5
Shoulder width (cm)	M	42.5	42.6	42.5	42.5	42.4
	F	39.7	39.8	39.9	39.8	39.7
Age bracket		41-45	46-50	51-55	56-60	
Height (cm)	M	168.9	167.8	167.8	167.6	
	F	158.2	157.7	157.4		
Weight (kg)	M	66.2	66.0	66.2	66.3	
	F	58.1	58.8	58.5		
Shoulder width (cm)	M	42.2	42.0	42.0	41.9	
	F	39.6	39.4	39.4		

https://www.researchgate.net/figure/Mean-values-of-indian-adults-height-weight-and-shoulder-width_tbl1_241817718

Fig 10.4 Shoulder width chart

10.2 GAIT cycle study

Study of gait cycle is done in order to get the distance of the longest phase of the cycle so that the proper mock-up can be developed in which base of the device and legs are not touching.



https://www.researchgate.net/publication/309362425_Gait_disorders_in_adults_and_the_elderly_A_clinical_guide/figures?lo=1

Fig 10.5 GAIT cycle

10.3 Wire mock-ups

Wire scaled mock-ups from 3d cad models were generated to see multiple iterations for the placement of tank, wheel, battery and pump unit. Two scales were generated that is 1:12 and 1:6. Materials used for this mock-up was steel and aluminium wires. The scaled blocks of tank and battery, pump unit were also used in this mock-ups. The arrangements such as flat and wide placement of tank was tested in this mock-ups.

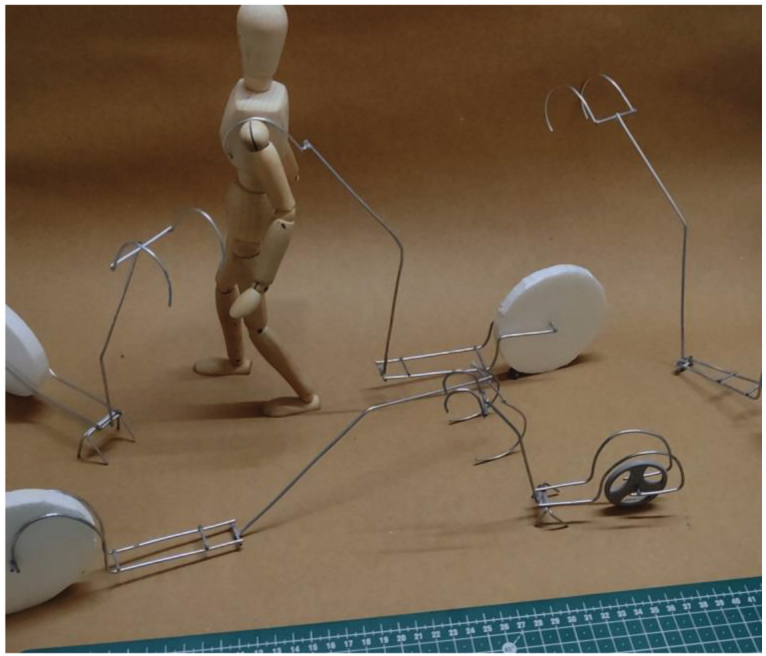


Fig 10.6 Wire mock-up

Wire mock-up 1 (scale 1:6)

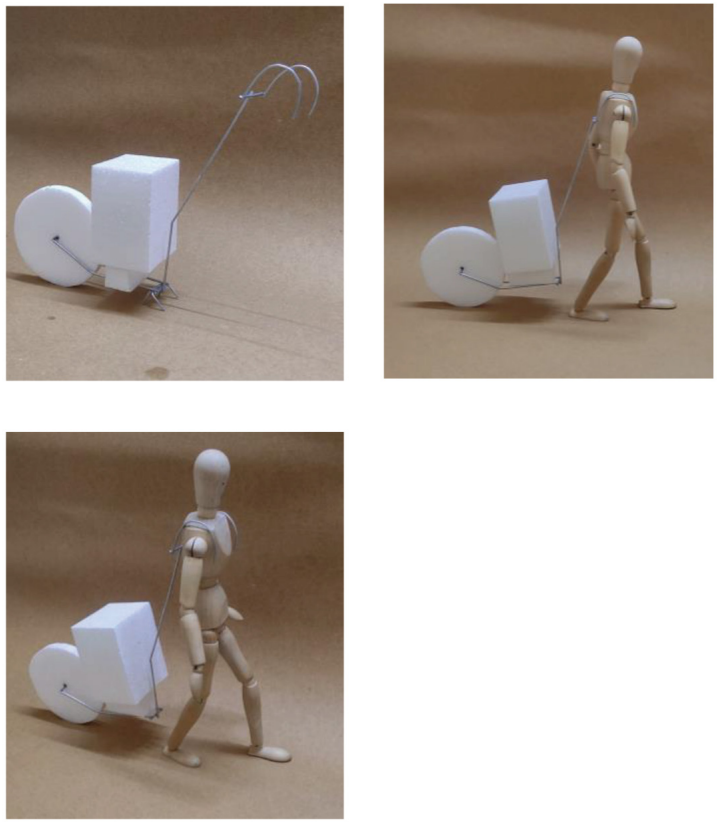


Fig 10.7 Wire mock-up : 1

Wire mock-up 2 (Scale 1:12)

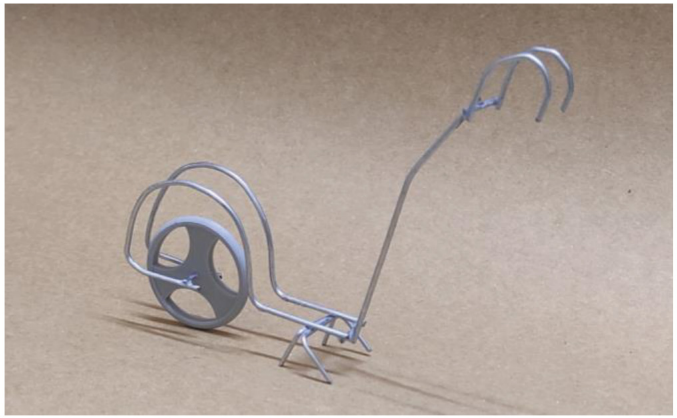
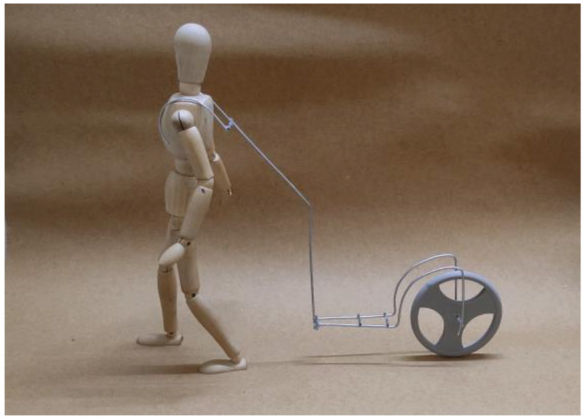


Fig 10.8 Wire mock-up : 2

Wire mock-up 3 (Scale 1:6)



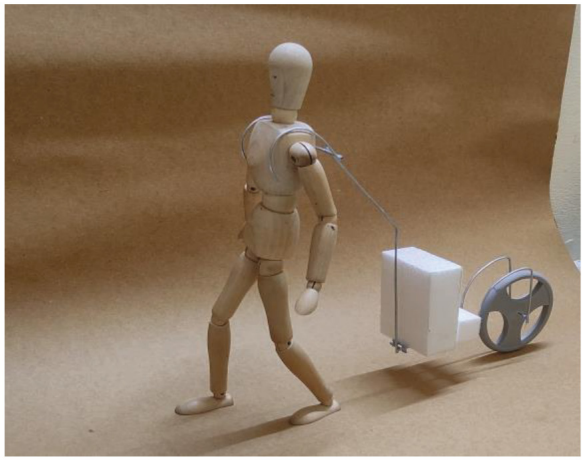


Fig 10.9 Wire mock-up : 3

Wire mock-up 4 (Scale 1:6)

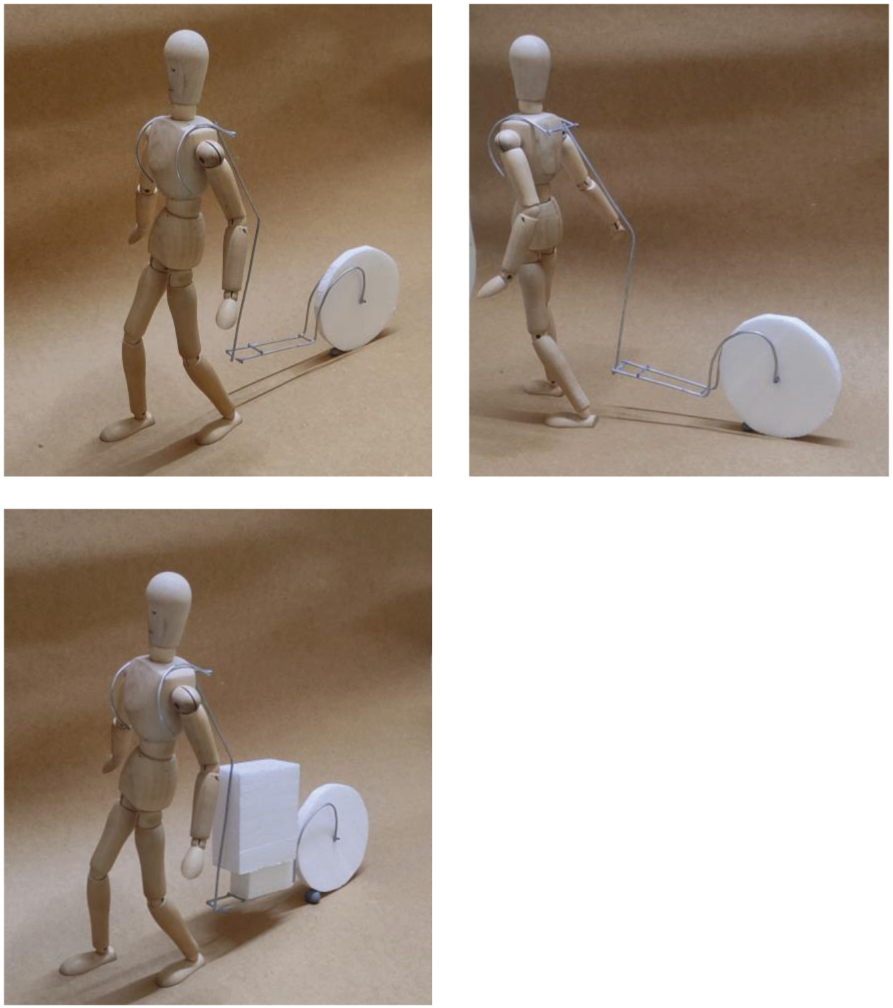


Fig 10.11 Wire mock-up : 4

Wire mock-up 5 (Scale 1:6)

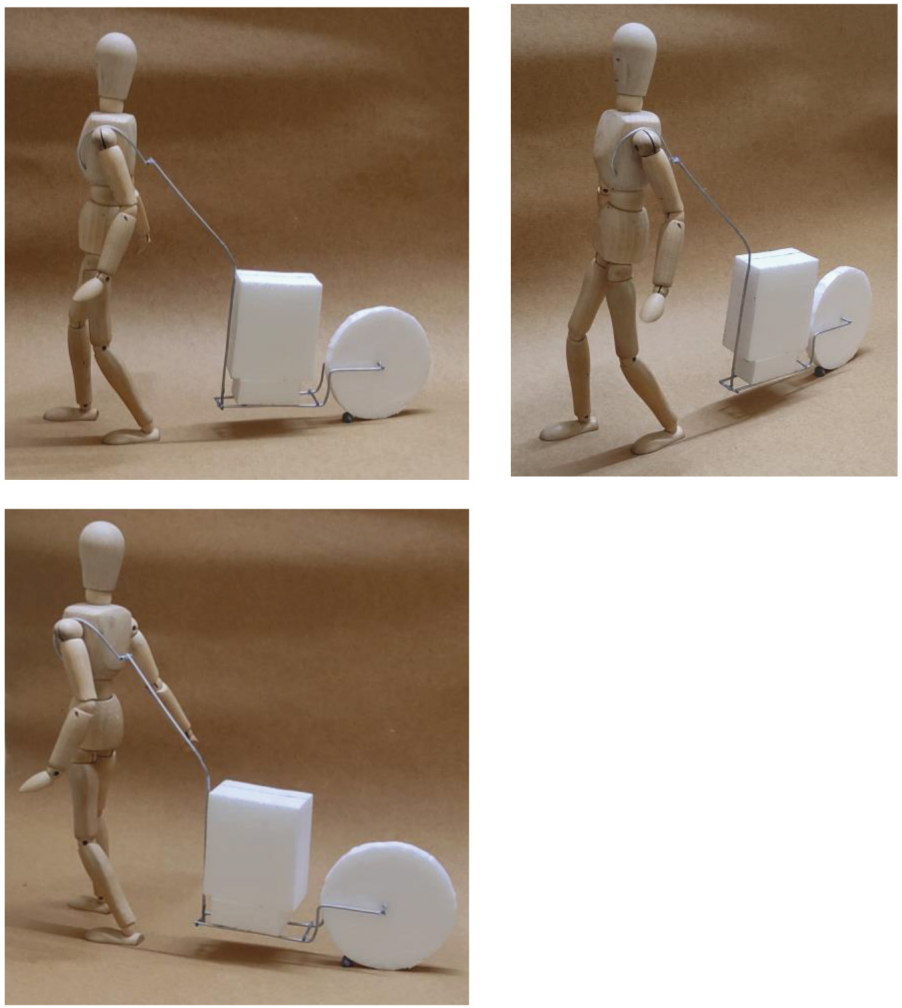


Fig 10.12 Wire mock-up : 5

10.4 Observation from mock-up study

- Thin/slimmer tank is needed for easy manoeuvrability.
- length of the cart has to be less in order to turn easily
- Minimum 20 inches distance from legs to tank base is to be maintained.
- Weight has to be near the ground to maintain the good balance.
- There is a possibility of enclosing entire package into one box which will ready to assemble.

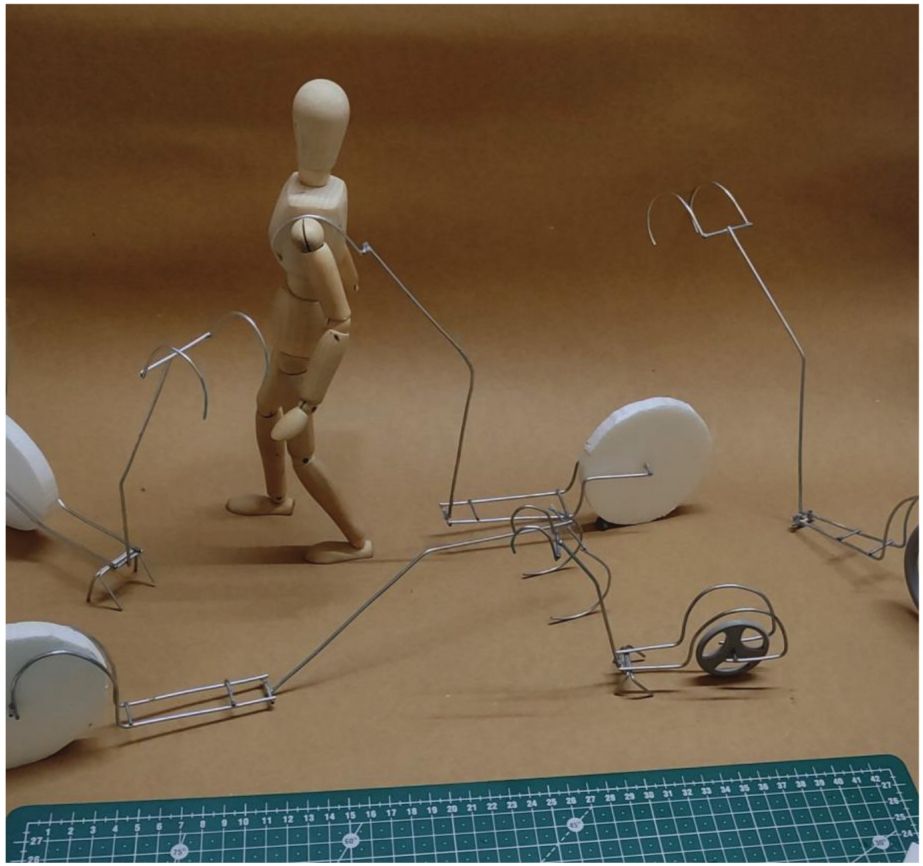


Fig 10.13 Wire mock-up

10.5 Mock-up 2

Study of gait cycle was done in order to get the distance of the longest phase of the cycle so that the proper mock-up can be developed in which base of the device and legs are not touching.

Fig 10.15 Mock-up 2

Fig 10.14 Mock-up 2

Fig 10.16 Mock-up 2

10.6 Mock-up 2 study

Mock-up 2 was also tested with similar terrain conditions as of mock-up 1 as shown in the figure. It was observed that the load was distributed between user's shoulder and ground, while maximum load being on the ground. It was also observed that it is easy to walk in straight line but quite challenging to take the quick U turn.

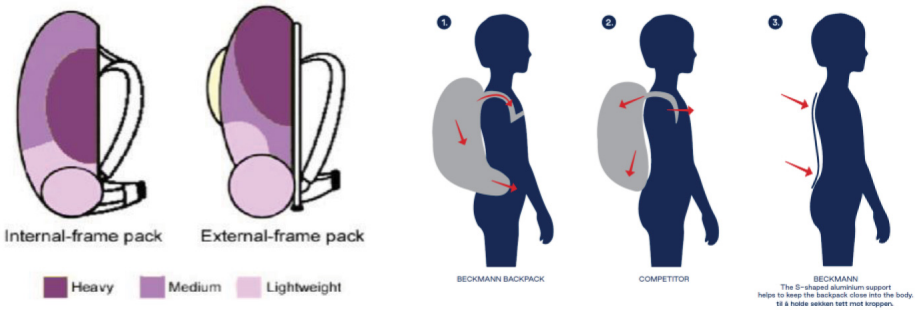
Fig 10.17 Mock-up 2 testing

Fig 10.18 Mock-up 2 testing

11. MOCK-UP 3 DEVELEOPMENT : PULL TYPE

For developing mock-up 3 which is pulling tank with waist concept, study was conducted on ergonomics of backpack & human anatomy. Post that the study of similar market product is done to understand the sturdy mechanism behind it.

11.1 Ergonomics of backpack



https://www.semanticscholar.org/paper/Designing-an-ergonomics-backpack-for-student-aged-Amiri-Dezfooli/db0c1702b69e09b8f90f8e34710cff666e4a8064

Fig 11.1: Load distribution in backpack

https://www.youtube.com/watch?v=Ji6J9B93fMA

Fig 11.2: Normal backpack

- Equally distributed load on both shoulders.
- Load on entire spine from the top.
- Downward Pull on both the shoulders.
- Stress on neck.
- Pulling on upper trapezius.

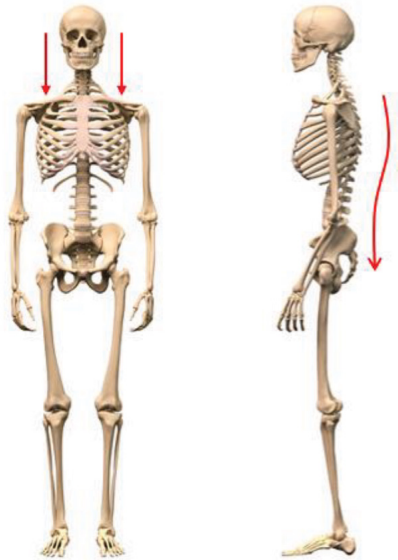


Fig 11.3: Load distribution

- Hip belt which helps to put the load of the backpack on the back pelvis, hip, knees and ankles.
- Sternum strap which helps to keep the load close to centre of gravity and keeps shoulder strap in place.
- Minimum load on the shoulder and maximum load on the big joints, bones and muscles groups.

https://www.youtube.com/watch?v=Ji6J9B93fMA

Fig 11.4: Backpack with sternum strap and hip belt

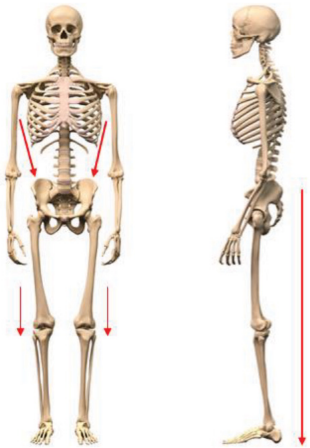


Fig 11.5: Maximum load distribution

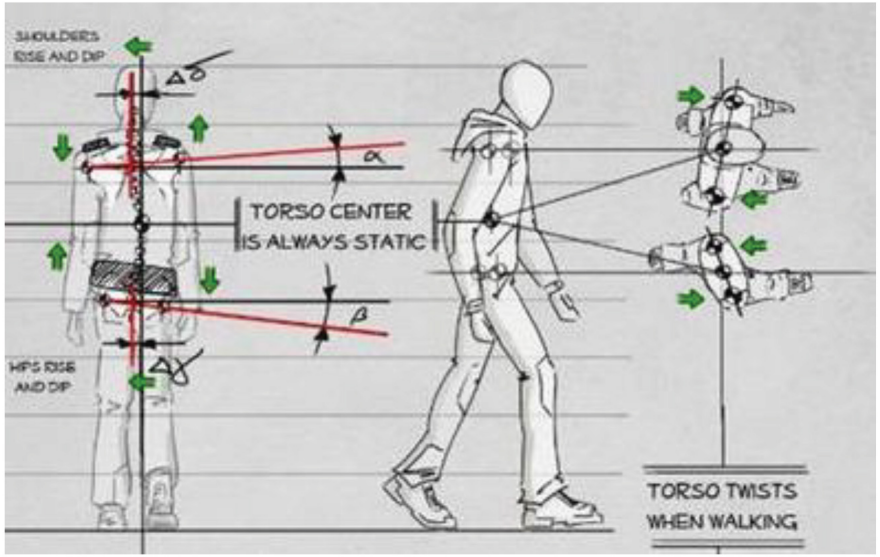


Fig 11.6: Torso movement while walking

11.2 Anthropometric measurements of Indians

Parameters	N	Mean	SD	Range	Percentile		Shapiro-Wilk	
					5	95	Statistic	Sig.
Weight (kg)	195	60.0	10.5	38-94	44.0	78.3	.988	.271
Stature	187	1647	62	1460-1861	1551	1754	.979	.034
Eye height	168	1539	60	1404-1714	1452	1643	.987	.206
Acromial height	168	1372	50	1267-1538	1293	1463	.983	.091
Iliocristale height	167	963	48	680-1104	896	1048	.920	.000
Trochanteric height	167	844	41	704-945	779	919	.983	.091
Metacarpal-III height	167	704	39	632-987	647	763	.834	.000
Knee height	167	468	30	248-544	431	510	.831	.000
Elbow height	168	1046	39	959-1149	978	1118	.990	.432
Scapula to waist back length	166	542	37	450-660	482	600	.991	.516
Waist breadth	165	275	31	187-366	233	329	.994	.788
Inter scye breadth	165	336	28	251-402	289	379	.993	.725
Chest circumference	196	886	70	715-1090	770	1006	.990	.454
Waist circumference	196	800	103	575-1100	654	1000	.986	.185
Hip circumference	181	881	71	710-1120	756	995	.989	.385
Calf circumference	196	320	32	165-440	269	375	.988	.259
Wrist circumference	188	156	9	135-185	140	173	.963	.001
Chest depth	164	223	21	164-283	192	258	.991	.476
Biceps skinfold thickness	186	4.5	2.2	2-22.2	2.4	8.5	.832	.000
Triceps skinfold thickness	186	9.1	4.2	3-20.6	3.8	18.0	.938	.000
Subscapular skinfold thickness	186	12.1	4.9	4.8-27.2	5.9	22.8	.949	.000
Supra iliac skinfold thickness	186	8.6	4.7	2.8-28.8	3.4	18.6	.876	.000
Abdominal skinfold thickness	194	12.6	6.5	3.2-28.4	4.2	24.9	.952	.000
Chest skinfold thickness	193	9.4	4.5	3-26.5	3.8	17.4	.955	.000
Midaxillary skinfold thickness	193	9.2	4.8	2-30	4.0	19.1	.882	.000
Thigh skinfold thickness	193	12.6	5.3	3.6-26.4	5.1	22.3	.971	.005
Calf skinfold thickness	192	12.0	5.8	2.6-29	4.3	23.1	.967	.002

https://www.researchgate.net/figure/Descriptive-statistics-for-measured-anthropometric-dimensions-in-the-study_tbl1_267337032

Fig 11.6: Anthropometric measurements of Indian male

Body dimensions	Anthropometric measurements					Correlation coefficient between body weight, stature and different anthropometric measurements significant at 0.1% level		Fractional relationships (f) between different body dimensions (D) and stature (H) of Indian women significant at 0.1% level ($D=f\times H$)
	Mean	SD	CV	Percentile values				
				5th	95th			
1. Weight	55.1	9.7	17.7	39.5	70.9	1.000	—	0.349
2. Stature	153.2	5.7	3.7	143.5	162.6	0.449	1.000	—
Heights								
3. Nasal root	143.6	5.4	3.8	133.2	152.6	0.442	0.860	0.937
4. Eye level	142.1	5.3	3.7	133.1	150.9	0.447	0.872	0.928
5. Supra sternal	125.4	5.0	4.0	116.5	125.0	0.474	0.877	0.818
6. Bust/nipple	111.6	4.7	4.2	104.2	119.4	0.397	0.808	0.728
7. Acromion	127.9	5.1	4.0	119.6	136.7	0.496	0.884	0.835
8. Anterior waist level	92.5	4.0	4.4	85.4	99.7	—	0.663	0.603
9. Trochanteric	80.8	4.0	4.8	74.4	86.7	—	0.567	0.527
10. Cervicale	131.0	5.3	4.1	121.5	131.0	0.526	0.873	0.855
11. Buttock	80.5	3.7	4.6	74.2	86.5	0.435	0.760	0.525
12. Gluteal furrow	71.3	3.8	5.4	64.8	77.6	0.352	0.663	0.464
13. Elbow	96.1	3.9	4.0	89.4	102.8	0.474	0.786	0.627
14. Wrist	75.1	3.3	4.4	70.0	80.7	—	—	0.490
15. Knuckle	68.1	3.1	4.6	62.6	73.6	—	—	0.444
16. Tibeal	43.9	4.7	10.7	38.3	50.4	—	—	—
17. Ankle	11.0	1.0	8.8	9.4	13.1	—	—	—
18. Lateral malleolus	6.6	0.7	10.0	5.7	7.8	—	—	—
Grasps and reaches								
19. Max. arm reach	79.2	4.2	5.3	72.5	86.8	0.424	0.603	0.515
20. Functional arm reach	71.9	4.1	5.7	65.1	79.2	0.376	0.534	0.468
21. Overhead grasp	188.9	8.3	4.4	174.1	201.6	0.417	0.790	1.232
22. Total arm span	156.5	7.6	4.9	144.3	169.3	0.403	0.781	1.020

https://www.jstage.jst.go.jp/article/jhe1972/19/1/19_1_31/_pdf

Fig 11.7: Anthropometric measurements of Indian female

Men height

- 95 percentile height is 175.4 cm
- 5 percentile height is 155.1cm

Female height

- 95 percentile height is 162.6 cm
- 5 percentile height is 143.5 cm

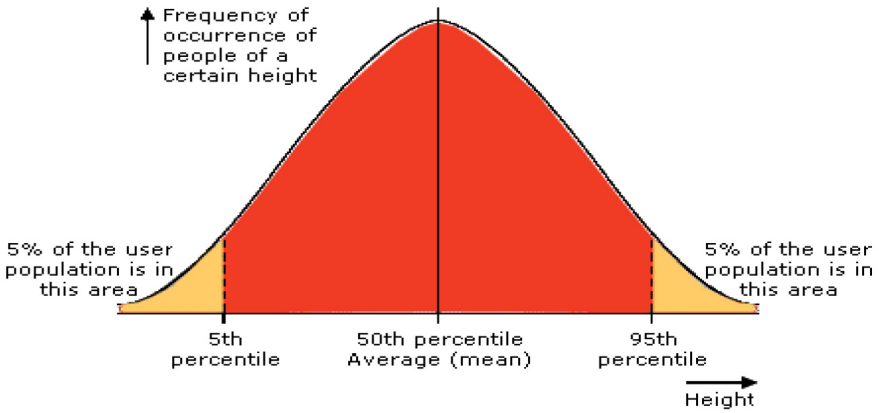


Fig 11.8: 95 percentile graph

Height	Women's Stride (inches)	Men's Stride (inches)
5 ft. 0 in.	25	25
5 ft. 1 in.	25	25
5 ft. 2 in.	26	26
5 ft. 3 in.	26	26
5 ft. 5 in.	26	27
5 ft. 5 in.	27	27
5 ft. 6 in.	27	27
5 ft. 7 in.	28	28
5 ft. 8 in.	28	28
5 ft. 9 in.	28	29
5 ft. 10 in.	29	29
5 ft. 11 in.	29	29
6 ft. 0 in.	30	30
6 ft. 1 in.	30	30
6 ft. 2 in.	31	31
6 ft. 3 in.	31	31

Fig 11.9: Height to stride length relation

Required data from the different anthropometric studies study were extracted and will be considered for the further use. The height is considered of both the 95 percentile male and 5 percentile female. Waist circumference and waist breadth will be considered for waist belt design which will be universal and can be fastened as per the requirement. Step length in this mock-up will be considered of the 95 percentile male as same can be feasible for the shorter user with small step length as shown in the figure. As shown in the figure shows how same product can be used by users with different heights and body dimensions.

	5th percentile (F)	95 percentile (M)
Height	143.5 cm	175.4 cm
Waist circumference	64 cm	100 cm
Waist breadth	23.3 cm	32.9 cm
Step length	44.45	51 cm

Table 11.1: Measurements needed for mock-up development

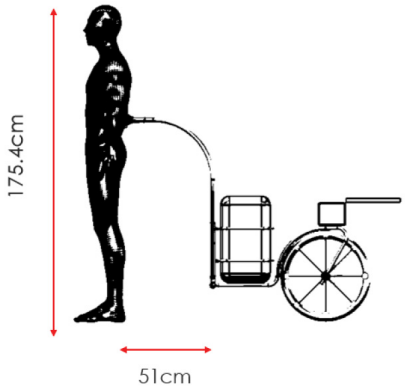


Fig 11.10: 95 percentile male

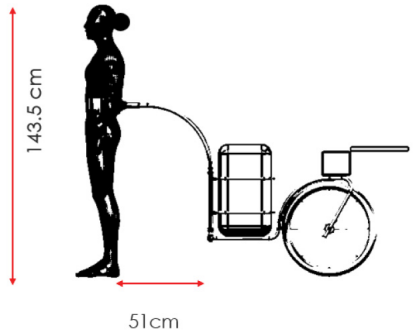


Fig 11.11: 5 percentile female

11.3 Market study of similar products

https://littlegreentracs.typepad.com/my_weblog/2011/05/long-distance-hikers-trolleys.html

Fig 11.12: Carrix trolley

http://www.hamadryad.be/offroad-hiking-cart.html

Fig 11.13: Hamadryad hiking cart

https://kidrunners.com/

Fig 11.14: Kid runner

https://www.interempresas.net/Puericultura/Articulos/384713-Cybex-Zeno-Bike-Descubriendo-el-mundo-sobre-ruedas.html

Fig 11.15: Cybex Zeno stroller running kit

11.4 Market study of belts

Fig 11.16: Gym belt: Nylon

Fig 11.17: Gym belt: Leather

After the market study of similar existing products and belts, two belts were shortlisted and procured for further development of mock-up 3. The belt design was considered on the basis of sturdiness, stiffness and comfort for the users. The Nivia gym belt which has thick and flexible plastic plate inside it which is covered with the help of nylon cloth was considered as a first choice for mock-up belt.

Fig 11.18: Weightlifting belt

Fig 11.19: Lumbar support belt

Fig 11.21: Selected belts for mock-up development

Fig 11.20: Posture correction belt

11.5 Belt design

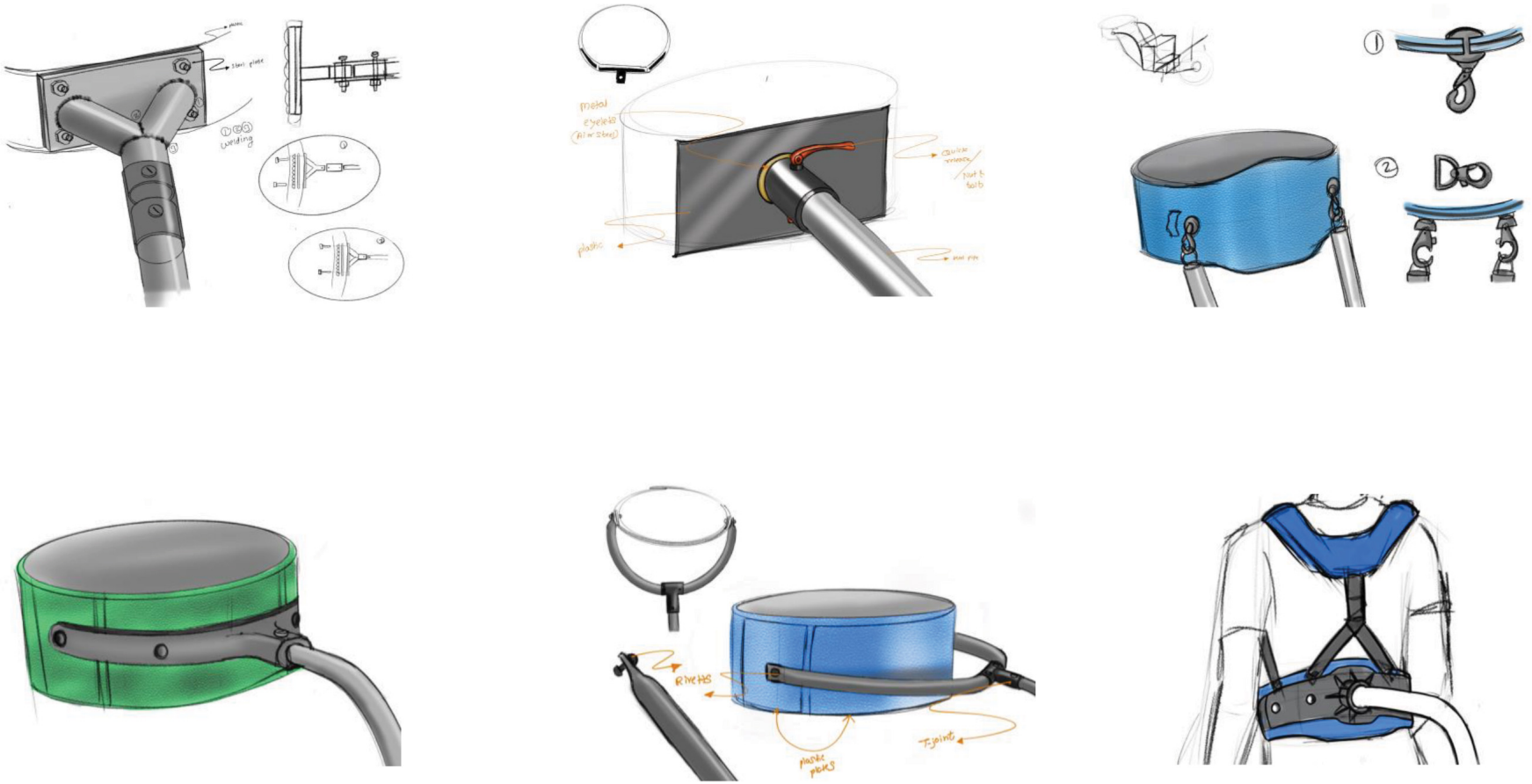


Fig 11.22: Belt design iterations

Shortlisted concept

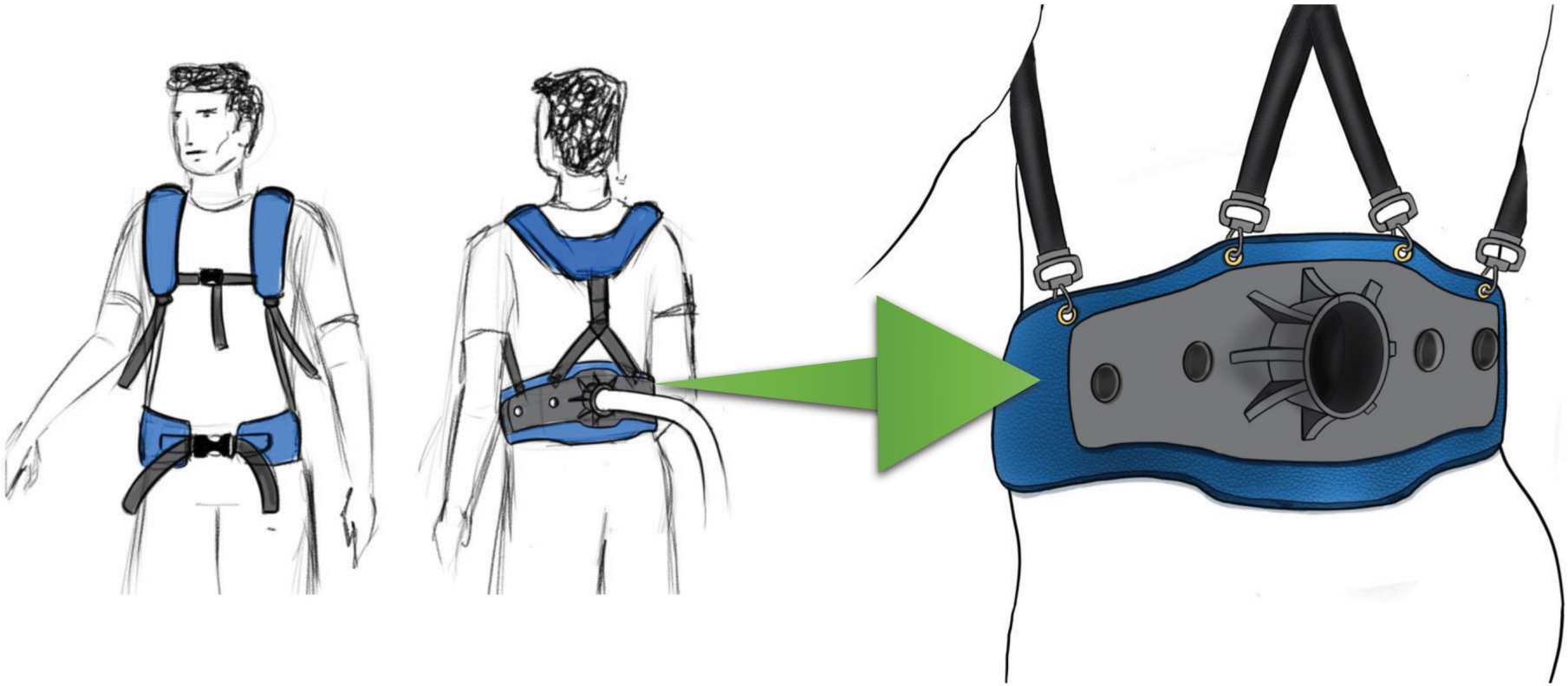


Fig 11.23: Shortlisted belt design

Belt concept was designed in such a way that the single steel pipe can be attached to the end of the belt. Outer layer of the belt will have curved plastic plate with the hole supported by ribs to insert a pipe and locking will be done with the help of nut and bolt.

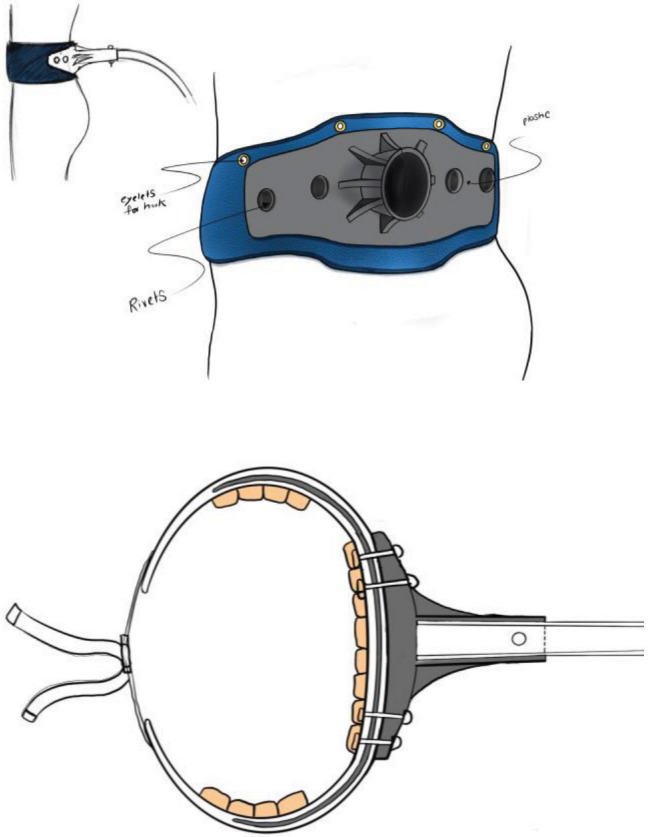


Fig 11.24: Cross section of belt

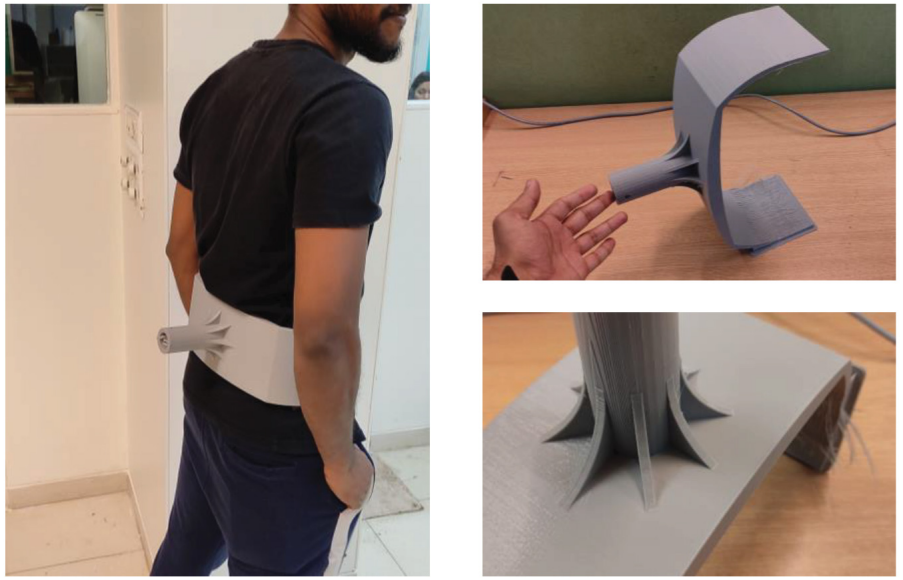


Fig 11.25: 3D printed back attachment

11.6 Wire mock-ups

Wire scaled mock-ups from 3d cad models were generated to see multiple iterations for the placement of tank, wheel, battery and pump unit. Three scaled mock-ups were generated with the scale of 1:6. Materials used for this mock-up was steel and aluminium wires.

Fig 11.26: Wire mock-up

Wire mock-up 1 (scale 1:12)

Fig 11.27: Wire mock-up : 1

Wire mock-up : 2 (scale 1:12)

Fig 11.28: Wire mock-up : 2

Wire mock-up : 2 (scale 1:12)

Fig 11.29: Wire mock-up : 3

11.7 Mock-up 3

After considering the above research, anthropometric measurements and design consideration, mock-up 3 was developed. For the belt attachment two steel plates were placed outside the back side of the belt and were tightened with the help of small nut and bolt such a way that it does not causes discomfort to the user. Then two small steel pipe pieces were welded together symmetrically with the outer plate of the belt as shown in the figure.

Fig 11.30: Mock-up : 3

Fig 11.31: Mock-up 3 development

Fig 11.32: Mock-up 3 details

11.8 Mock-up 3 study

During the testing of mock-up 3 it was observed that nylon strap used for holding the tank in one place was not enough and tank was slipping from its original position so the metal cage was added into the later modification of the mock-up. Ground clearance of the mock-up was observed to be very low which was 5 inches. Water sloshing effect was also observed when the tank is half empty. It was seen that for this concept to work belt was needed to be exactly in the centred position where minimum torso movements is noticed.

Fig 11.33: Mock-up study

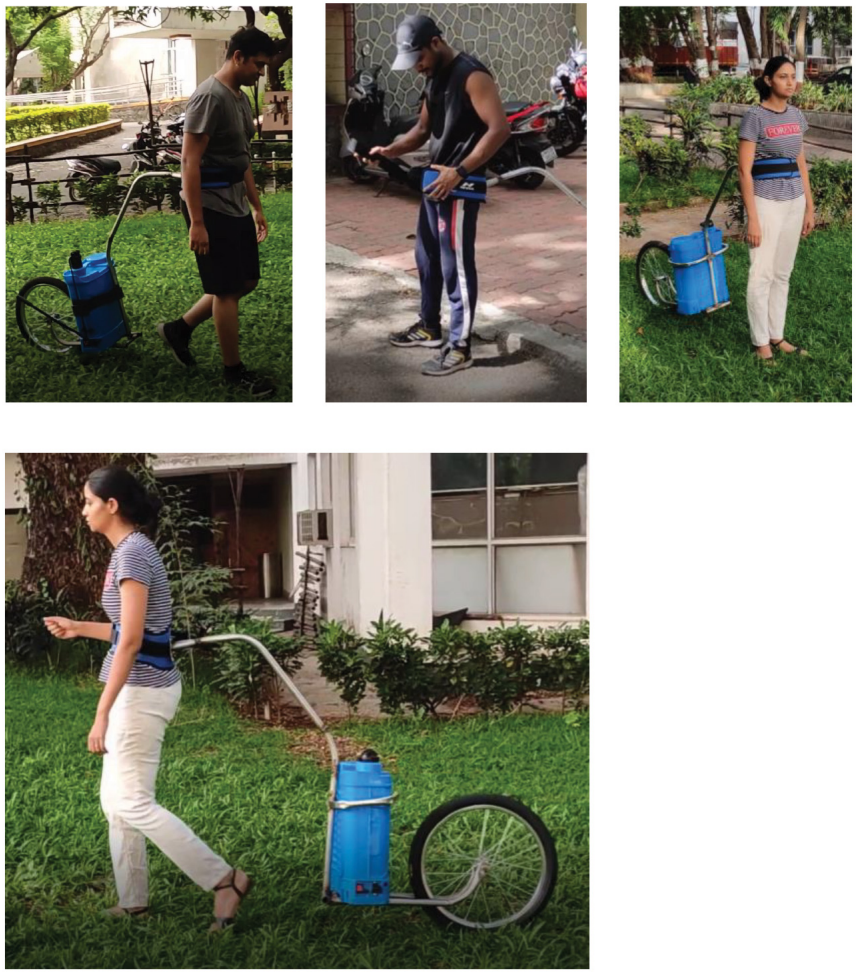


Fig 11.34: User testing

11.9 Mock-up details

Fig 11.35: Cad model

Fig 11.36: Back attachment

Fig 11.37: Height adjusting mechanism

Fig 11.38: Cage for tank

Detachable solar panel and battery unit

Detachable battery & solar power unit which will act as a external power source while frequent power cut in village.

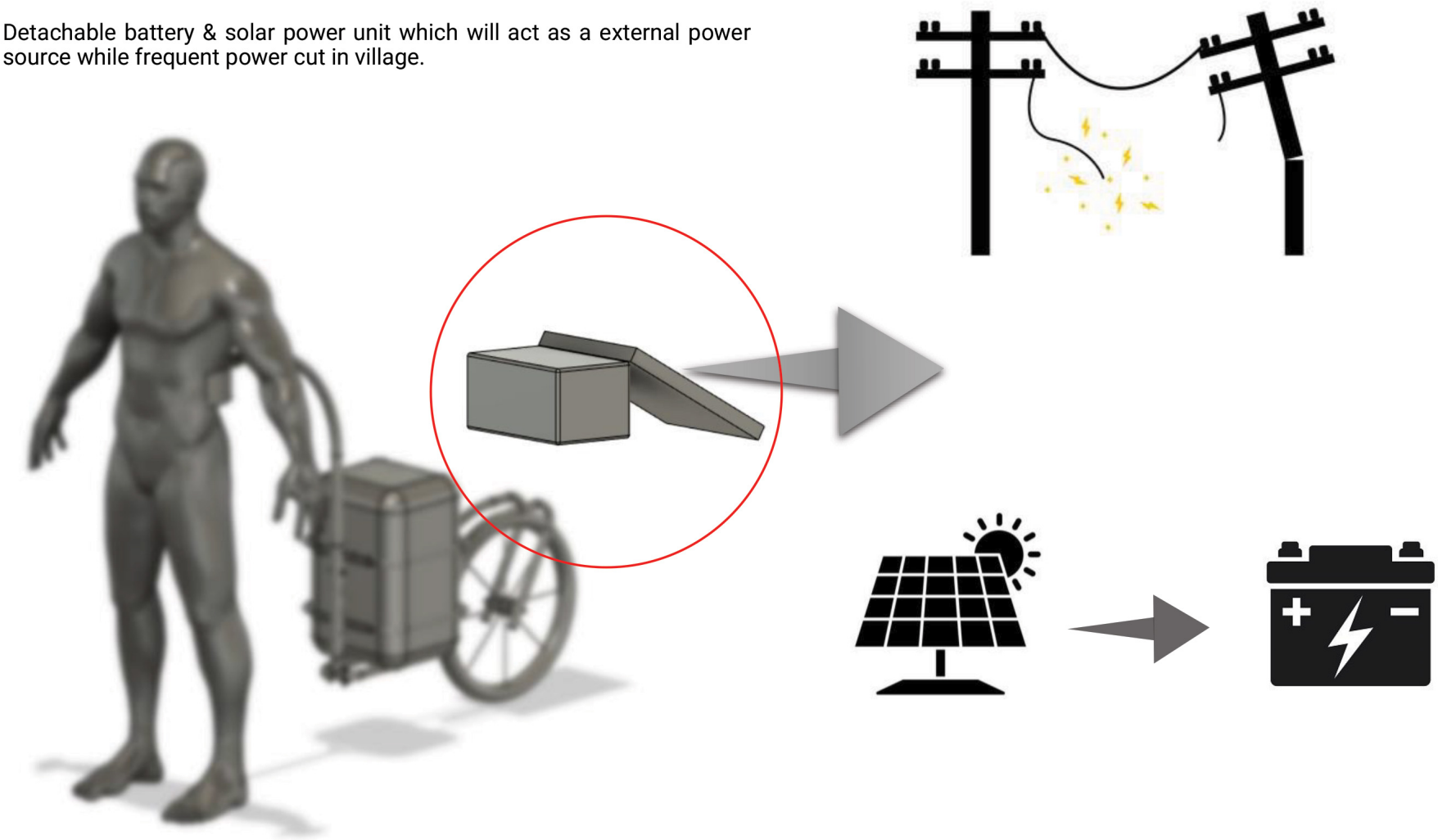


Fig 11.39: detachable solar panel & battery unit

12. CONCEPTS EVALUATION

Concept	Overall comfort in walking	Loading & unloading	Load carrying capacity	Manoeuvrability	Simplicity	Compactness	Cost	Protection against chemicals
	2	2	2	4	3	4	3	2
	3	4	4	3	3	2	2	2
	3	3	4	2	2	2	2	3
	4	4	4	3	3	2	2	3

Table: 12.1: Evaluation chart - Scale 1 to 5

(5 being the highest)

Evaluation result

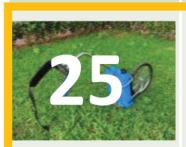
Concept	Overall comfort in walking	Loading & unloading	Load carrying capacity	Manoeuvrability	Simplicity	Compactness	Cost	Protection against chemicals
	2	2	2	4	3	4	3	2
	3	4	4	3	3	2	2	2
	3	3	4	2	2	2	2	3
	4	4	4	3	3	2	2	3

Table: 12.2: Evaluation chart: Scale 1 to 5

(5 being the highest)

13. MOCKUP 3 USER TESTING

The third mock-up being the winner in mock-up evaluation was tested again with multiple users of different height, strength, build etc. to gain more insight about the usability of the product. After rigorous user testing there were issued noticed with the proposed design as shown in the Table 13.1.Due to the severity mapping of the problems caused in the mock-up 3, rectification of the problems became much more easier in further mock-up and designs..

Fig 13.1: User testing 1

Fig 13.2: User testing 2

Fig 13.3: User testing 3

13.1 Mock-up 3 : Issues noticed

Problem noticed	Problem intensity	Potential solution
Nylon cloth Strap was not sufficient to hold the tank stable while turning.	★ ★ ★ ★	Cage frame
Ground clearance of the cart was very low and cart was touching the ground.	★ ★ ★	increase the GC to 8 inch from 5 inch
Water sloshing when the tank was half empty.	★ ★	Baffle balls / compartment
Belt position is needs to be exactly correct and at the centre.	★ ★	Shoulder strap
tyre twisting while taking the turn.	★ ★	Shoulder strap

Table: 13.1: Issues noticed in mock-up 3

14. REVISED CONCEPT POST FEEBACK

All the shortcomings of the previous mock-ups were considered while designing the revised concept for pesticide sprayer. A Metal cage was considered for tank to hold it in a proper position. Ground clearance was increased from 5 inch to 10 inch in order to avoid the obstacles in uneven terrain of the field. As single 20L tank was causing a water sloshing effect, two 10L tank was considered as they were comparatively easy to handle and sloshing effect was reducing by nearly 50%. Due to addition of two wheels with the gap of 8 inch in between the overall stability of the cart increased a lot which also helped in a effective load distribution. Thus twisting of the belt while turning also can be eliminated.

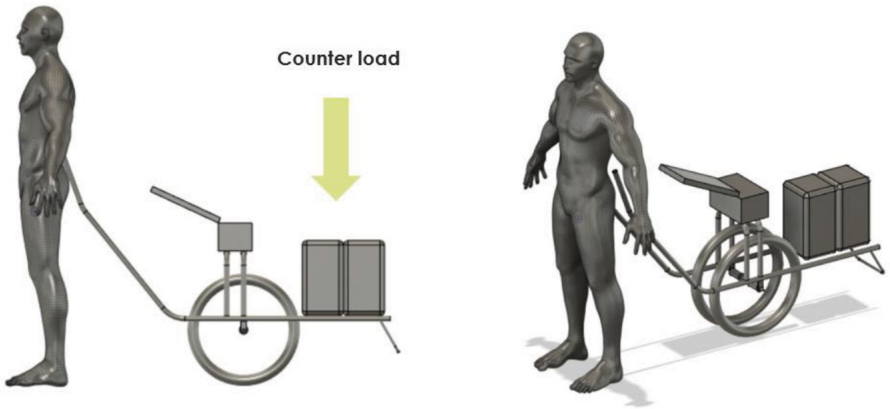


Fig 14.1 Revised concept CAD models

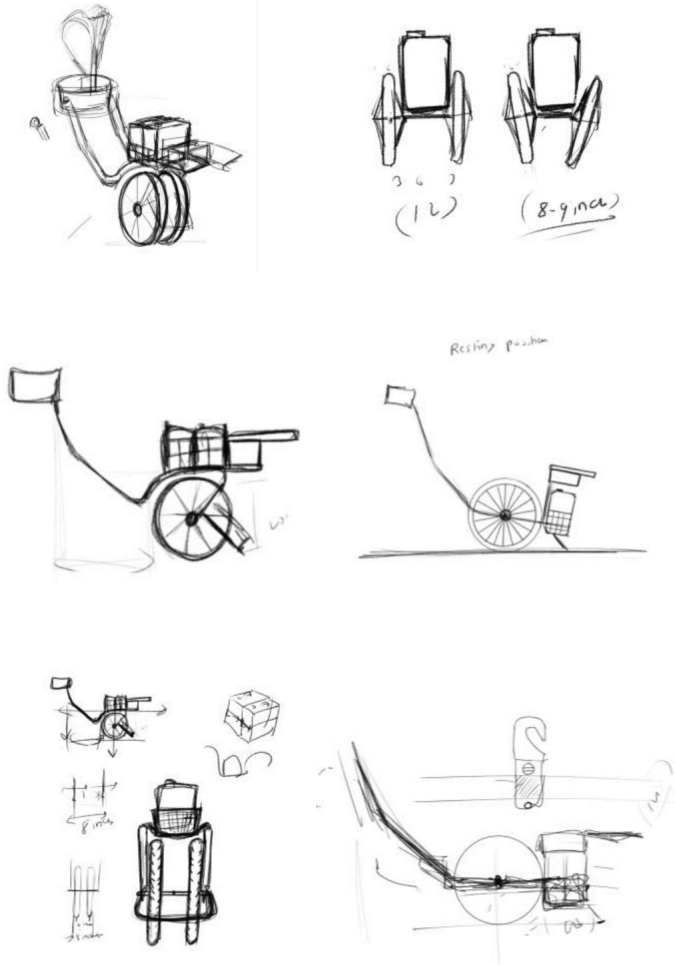


Fig 14.2 Revised concept ideations

15. MOCKUP 4 DEVELOPMENT

Mock-up 4 was built using SS pipe of 25mm diameter with 1.6mm thickness. Considering the rough conditions of the farm SS was selected as it has more strength and durability. Pipe to belt joining mechanism was considered as the hook mechanism is not very stiff but at the same time it can handle the shocks that caused due to the obstacles in the farm tertian.

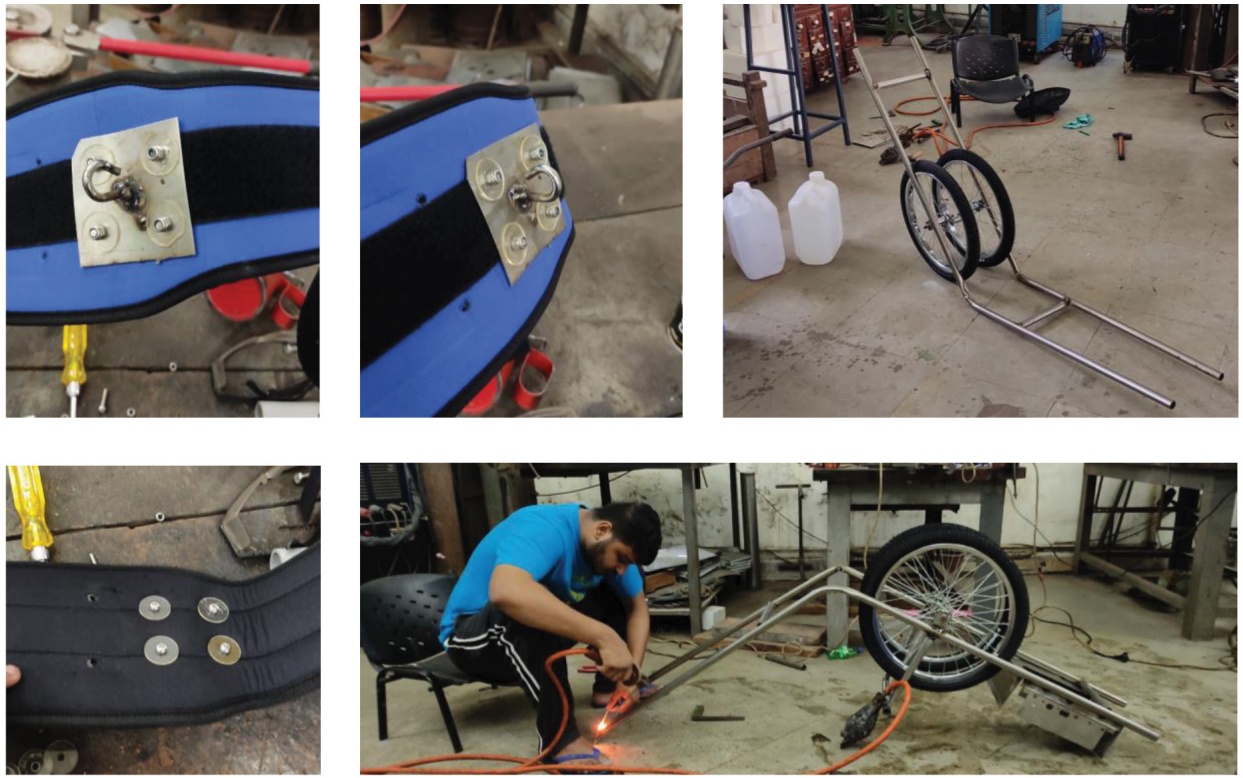


Fig 15.1 Mock-up 4 development

15.1 Mock-up 4

Inspiration behind the design of mock-up 4 was the backpacking trolley which was used by professional hikers to carry the load. Two rods, two wheels, two tanks, two hooks with single waist belt attachment was the highlight of this iteration which helped this design to be more stable and easy to carry.

Fig 15.2 Mock-up 4

15.2 Mock-up 4 study

Design of mock-up 4 was again tested in the uneven terrain to find out the shortcoming of this recent iterations. Overall it was observed that all the previously mentioned and implemented changes in this design were working together to create a one sturdy cart to carry the load of around 20L tank. Due to the addition of 2 wheels cart very much stable and easy to manuvour between the farms. Twisting of belt was also reduced in this new much stable design.

Fig 15.3 Mock-up 4 testing

15.3 Insights

- Overall stability increased due to 2 wheels.
- Less turning radius required as compared to mock-up 3.
- Very less water sloshing due to small tank width.
- Easy to operate/ lift tank.
- Very less load experienced due to counter load.

Fig 15.4 Mock-up 4 testing

15.4 Issue noticed in mock-up 4

- **Belt started lifting up above belly button level due to the counter load.**

Fig 15.5 Belt lifting issue

15.5 Insights from mock-up 3 & mock-up 4

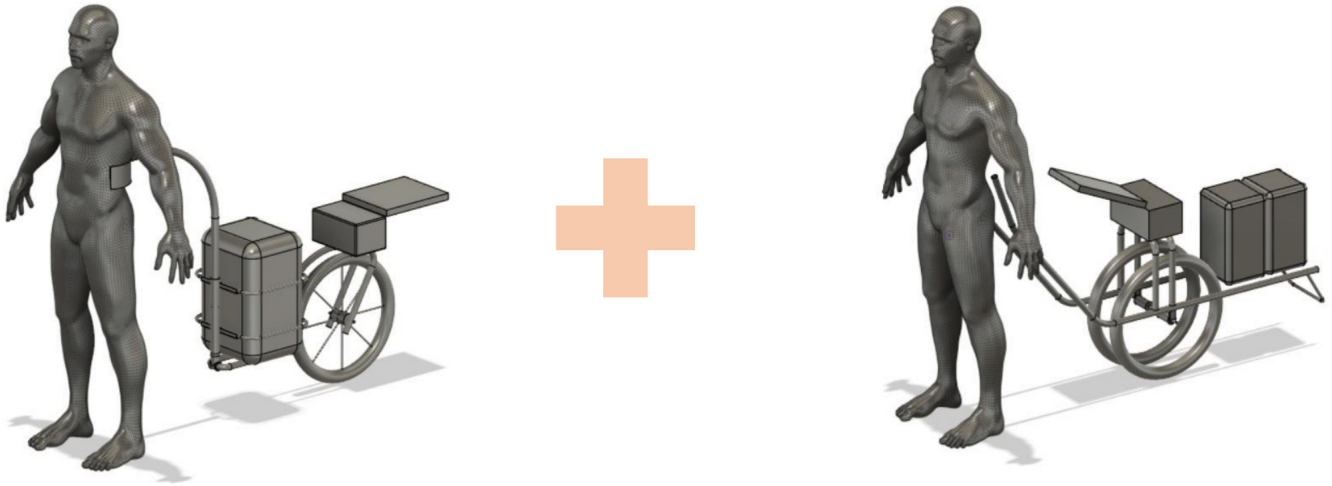


Fig 15.6 Combination of mock-up3 and mock-up 4

- Distributed load among waist and ground.
- Tank near body

- Two wheels for better stability.
- Two connecting pipe rods.
- Reduced water sloshing.
- Lighter tanks.

16. REVISED DESIGN

Amalgamation of Insights from mock-up 3 and mock-up 4 were done in order to come up with the revised final design of the solar pesticide sprayer. Distribution of load amongst waist and ground while keeping the tank near the body of the user helps in maintaining the good balance of the cart, While two wheels and two tanks provides the better stability and usability respectively.

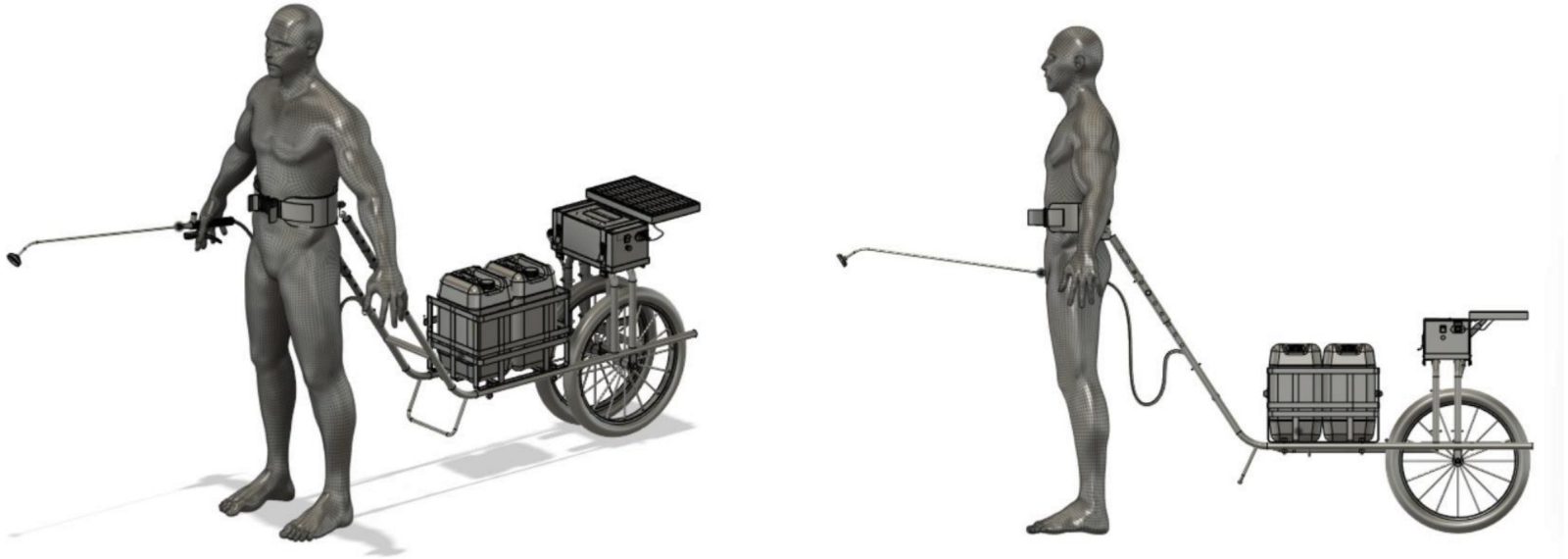


Fig 16.1 Revised design: Mock-up 4

16.1 Load distribution in revised design

Below image fig:16.2 demonstrated the load distribution between the waist and ground. Bigger muscle and bone group are now responsible to carry the load unlike shoulder in traditional knapsack sprayer. The waist belt sits on pelvis muscle and creates a natural lock mechanism due to the weight of the tank.

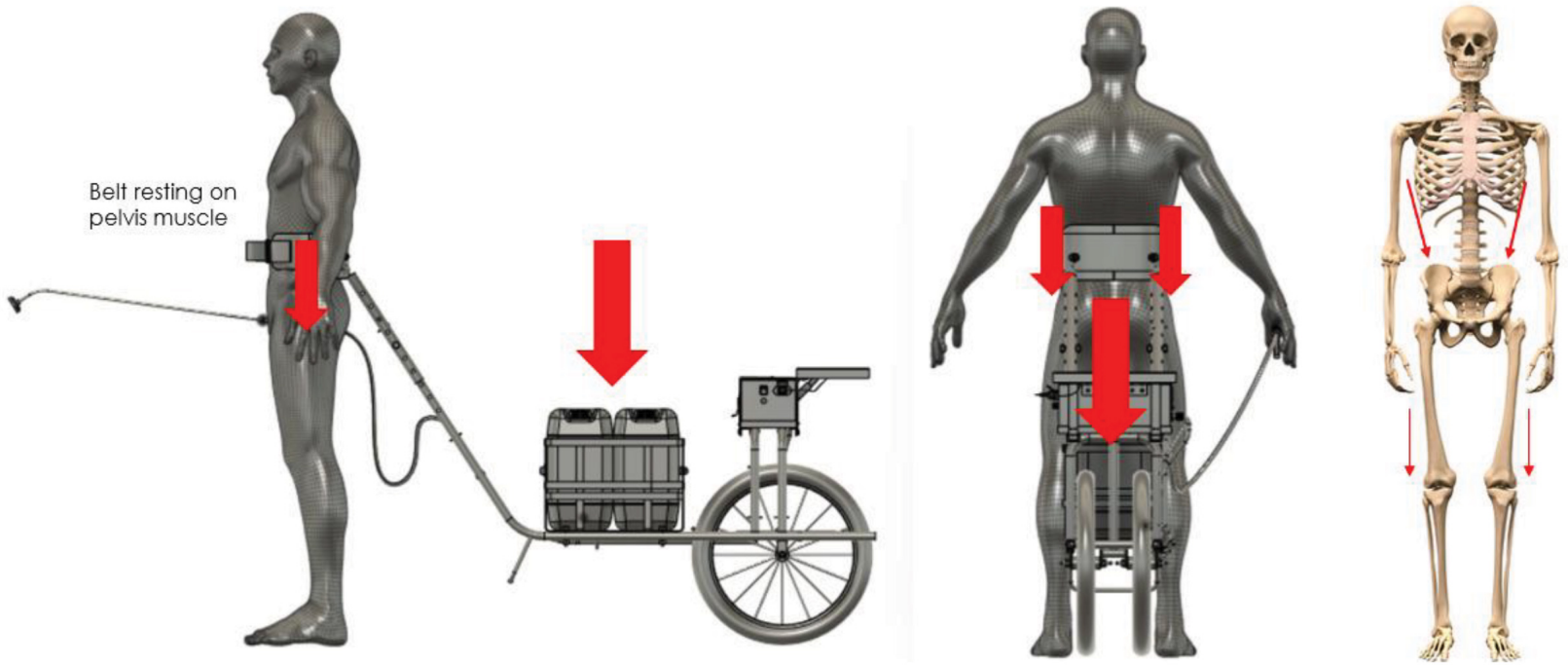


Fig: 16.2 Distributed load on ground

16.2 Final design

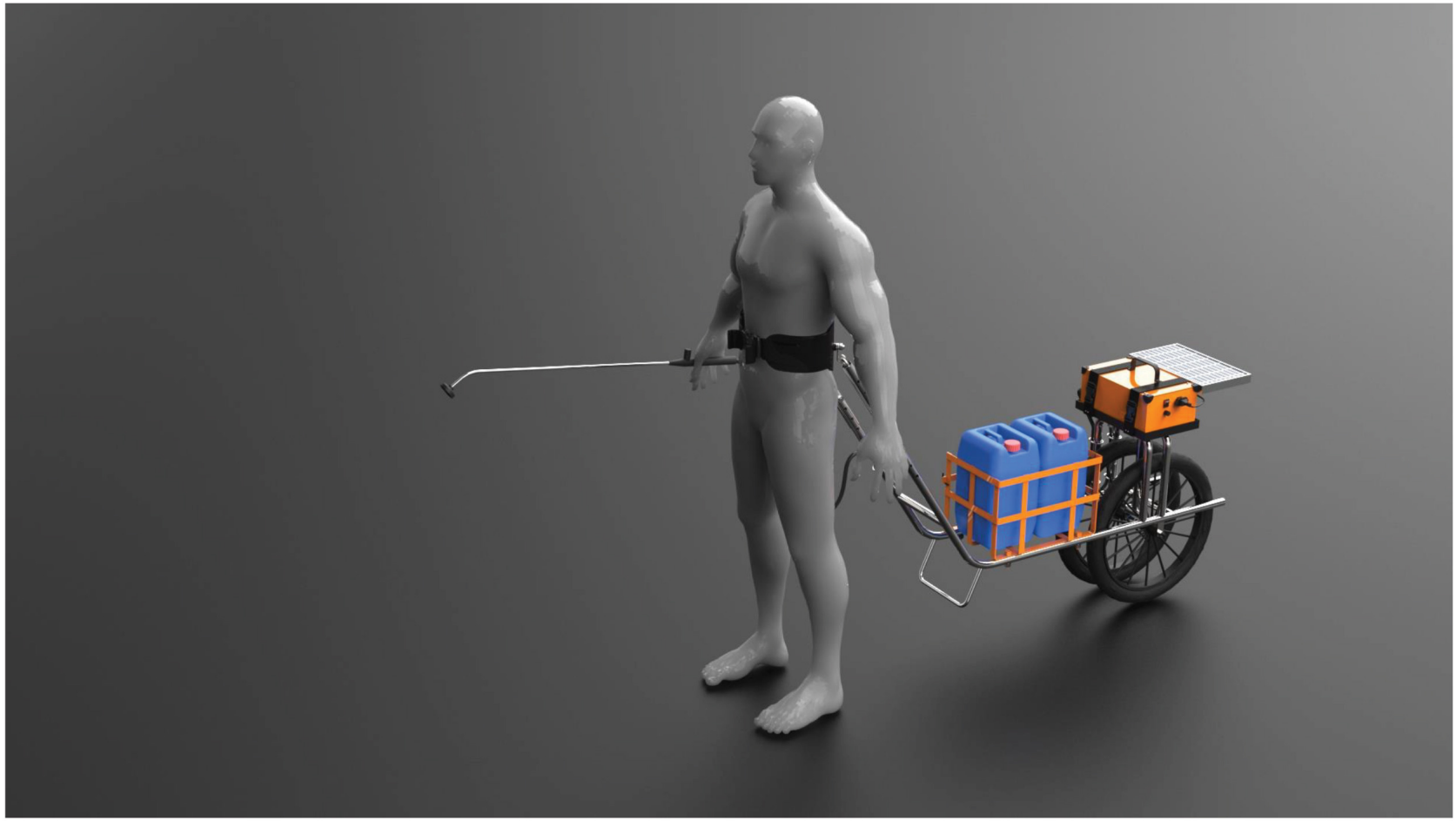
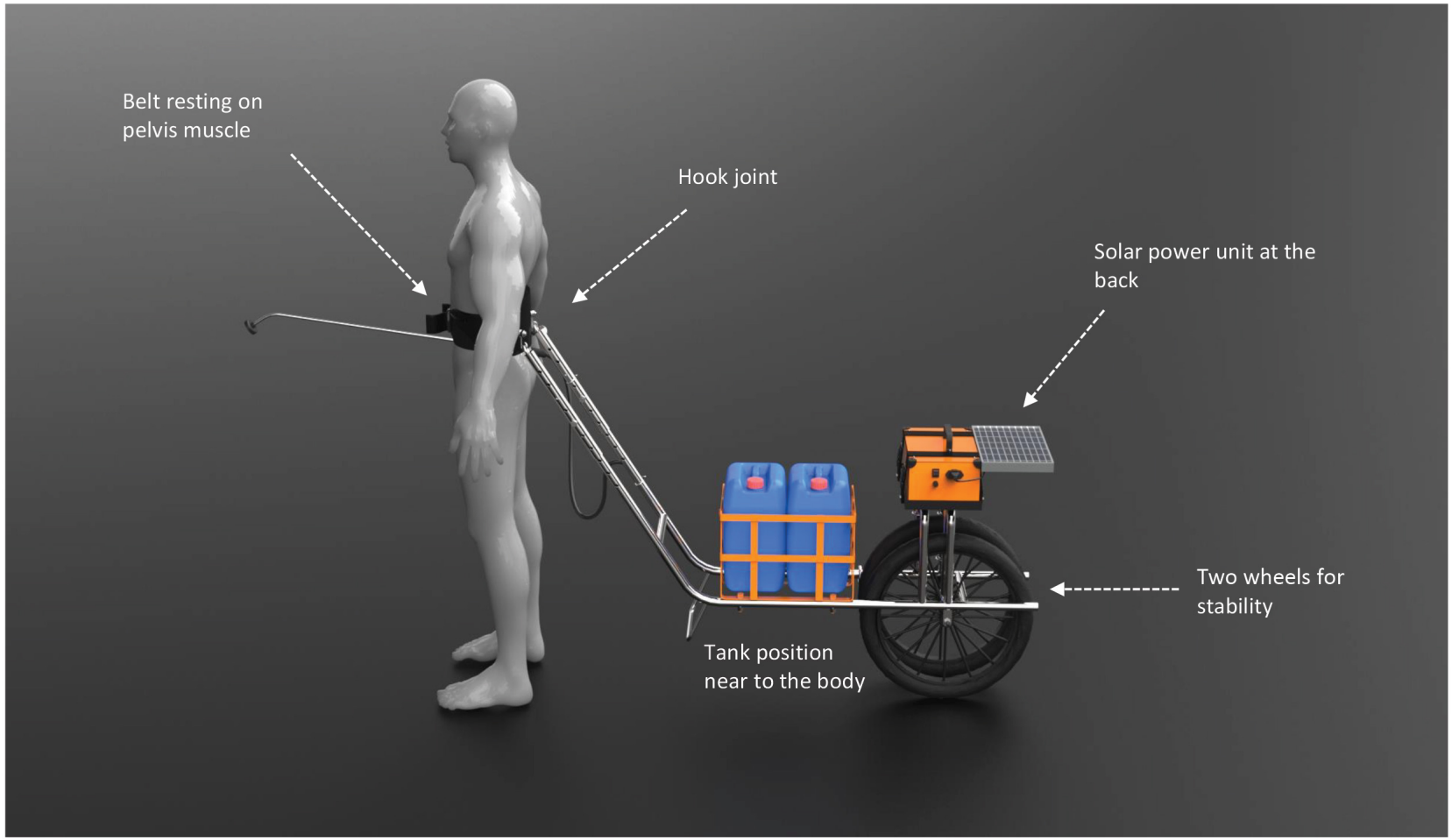


Fig: 16.3 Final deign render

Final design



Final design

Fig: 16.4 Stand and nozzle resting hooks

Final design

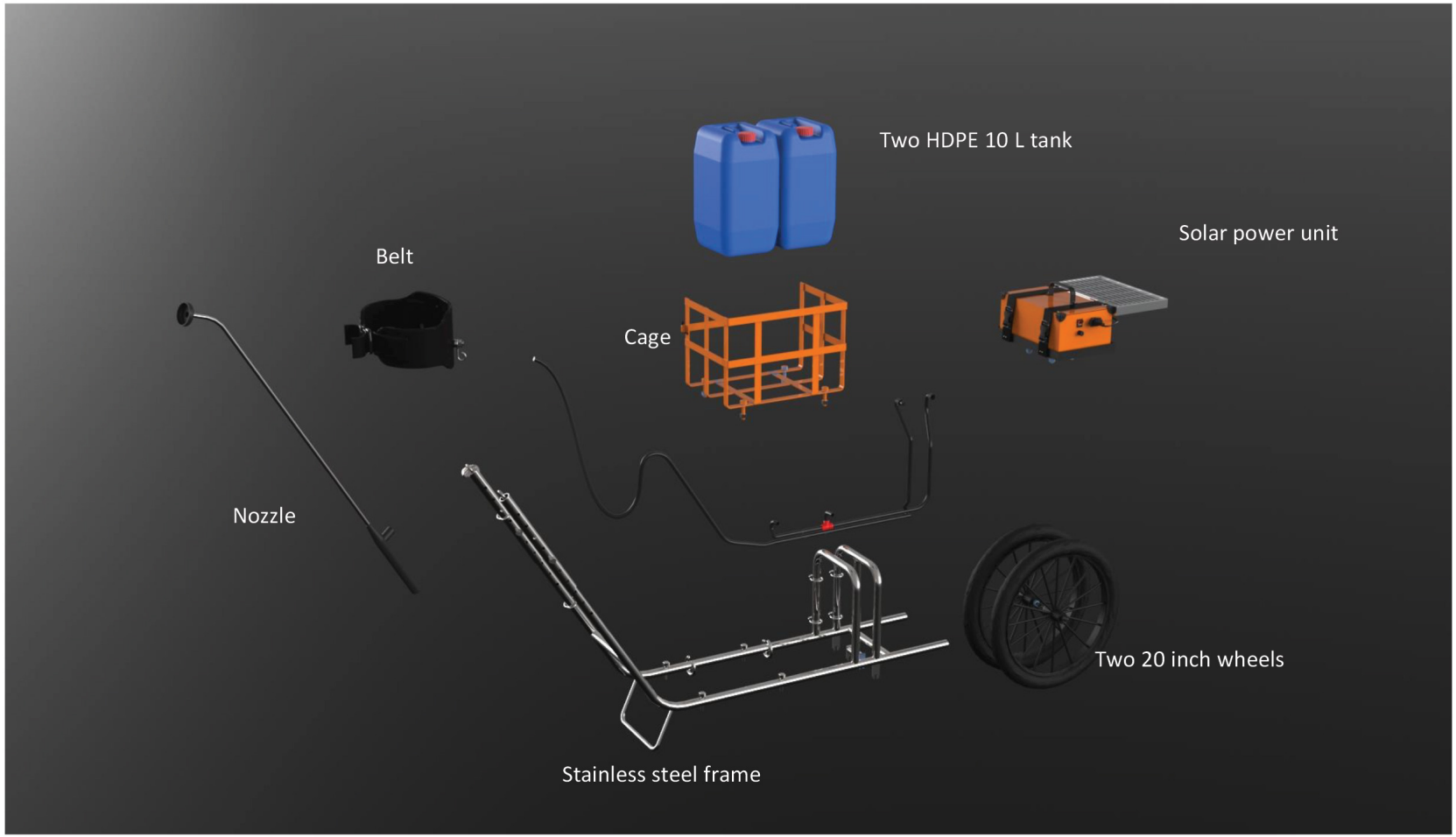


Fig: 16.5 Exploded view

Final design

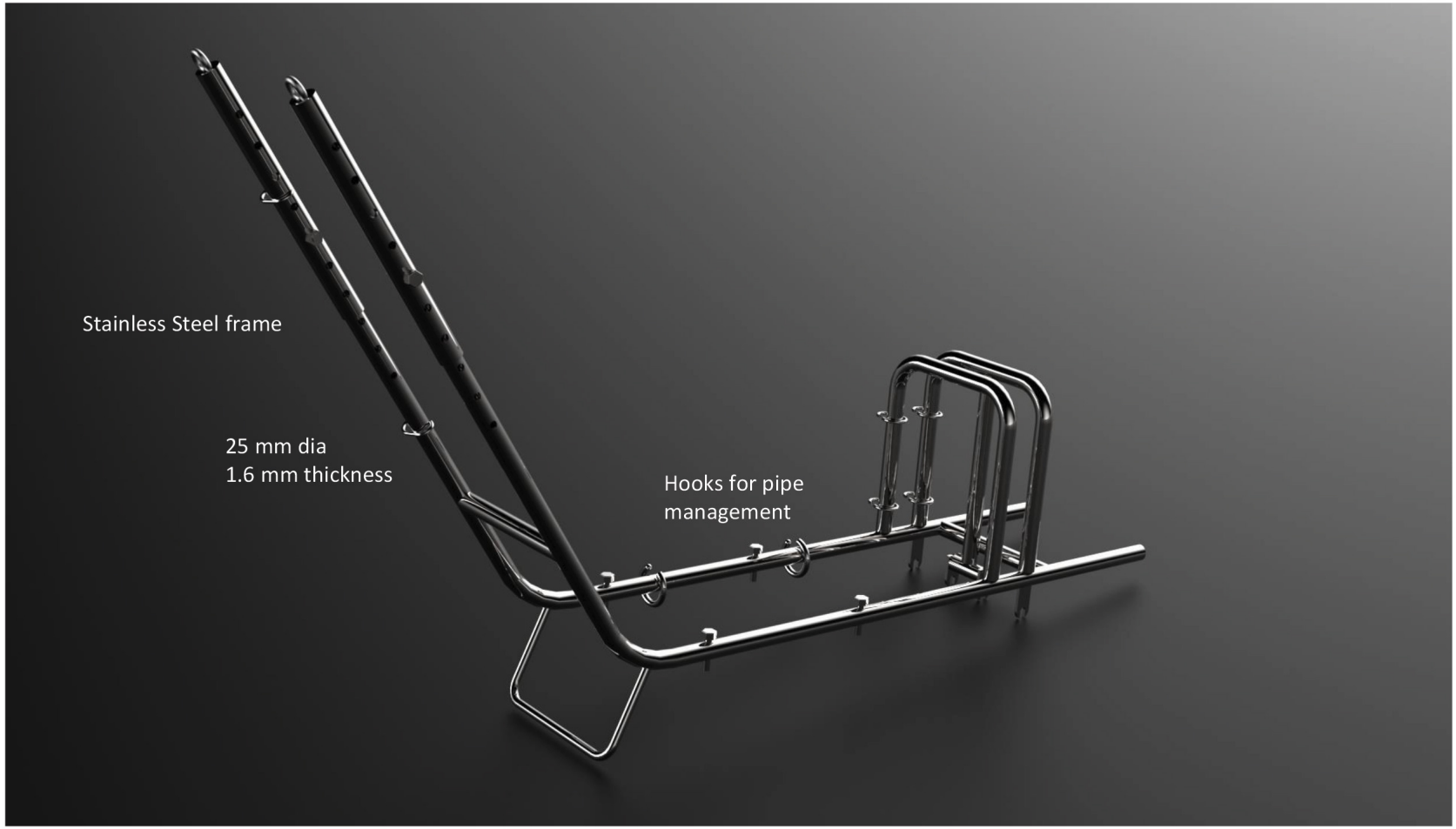


Fig: 16.6 SS welded frame

Final design

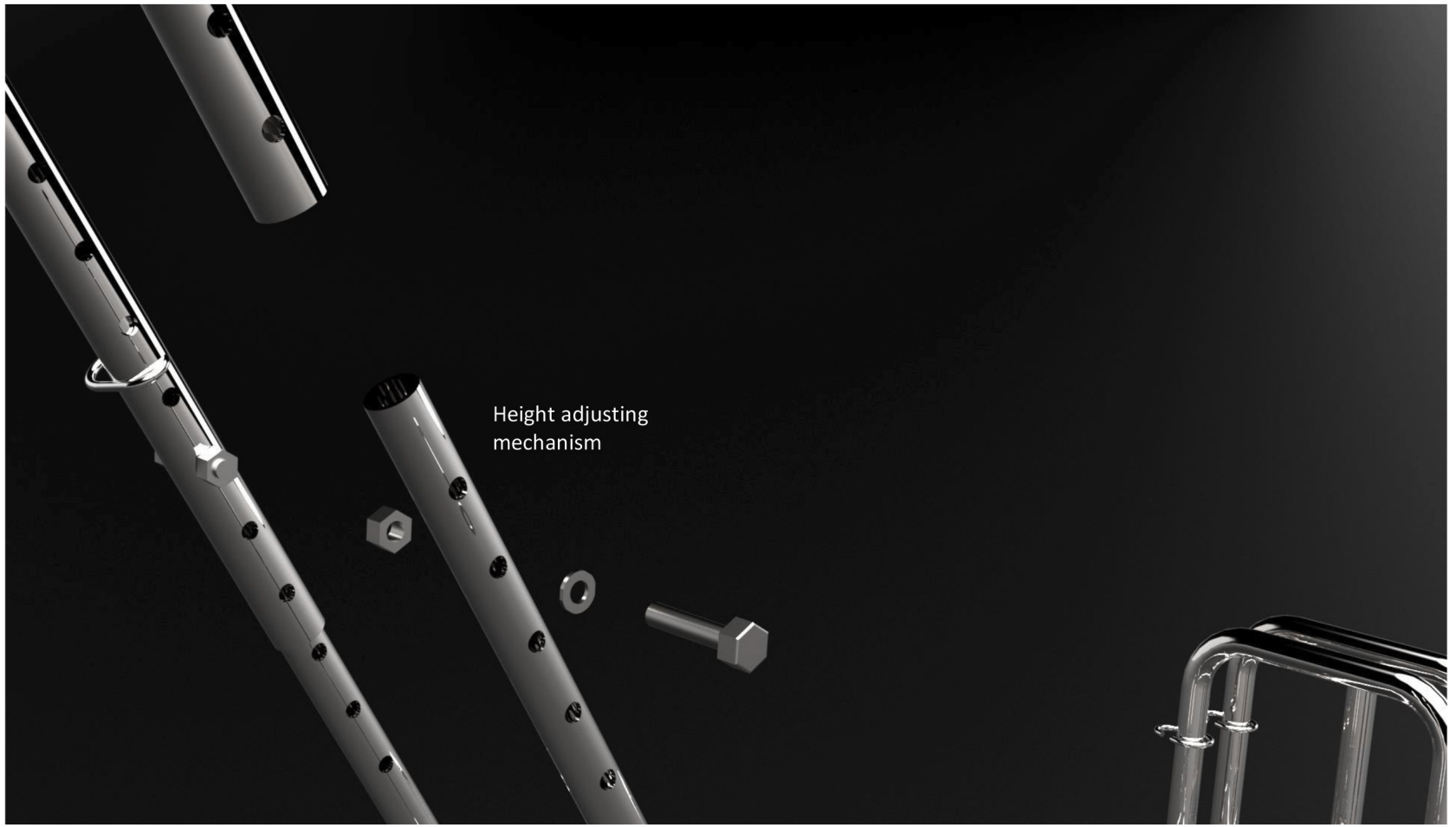


Fig: 16.7 Height adjusting mechanism

Final design

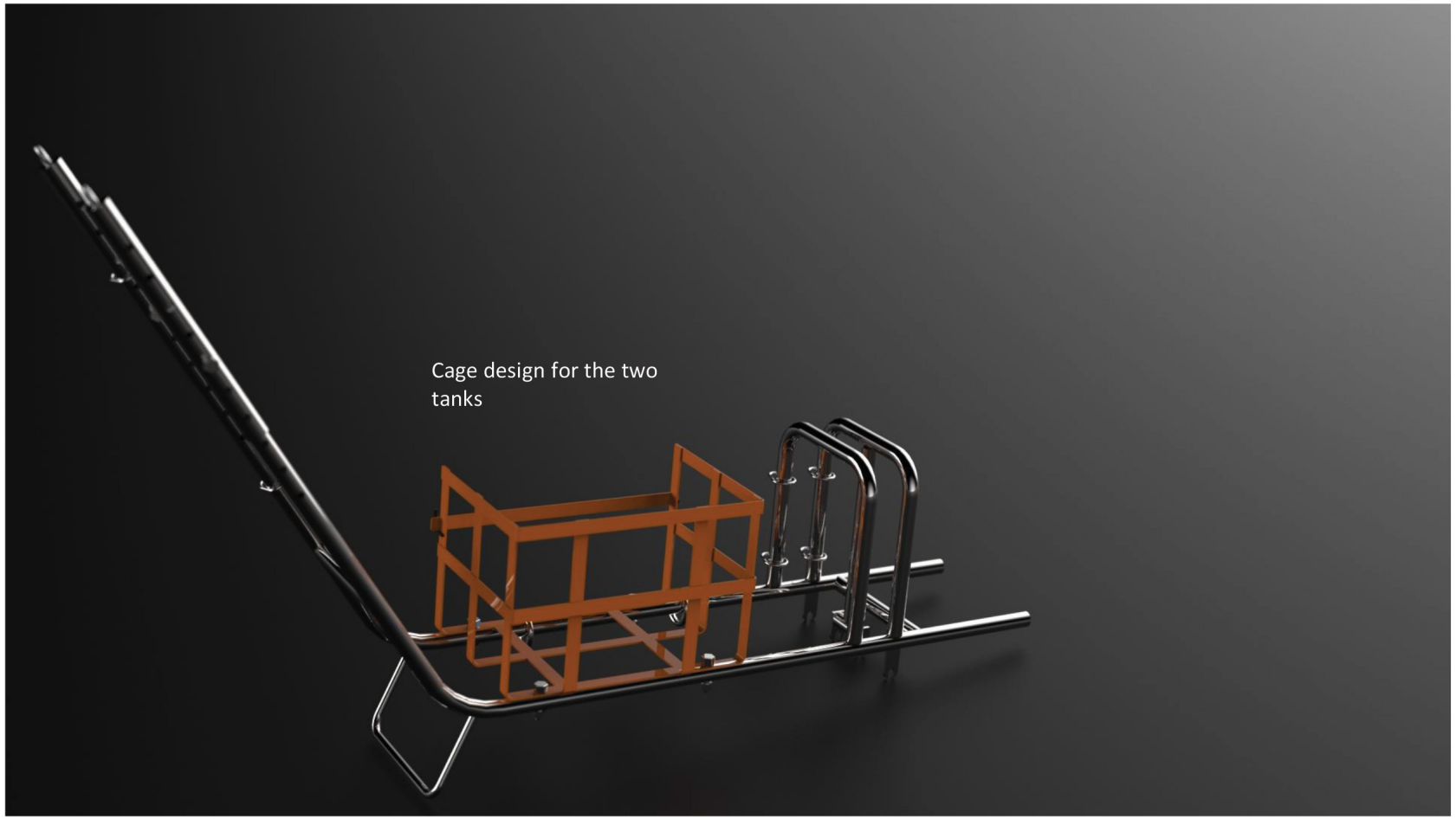


Fig: 16.8 Cage design for two 10L tanks

Final design

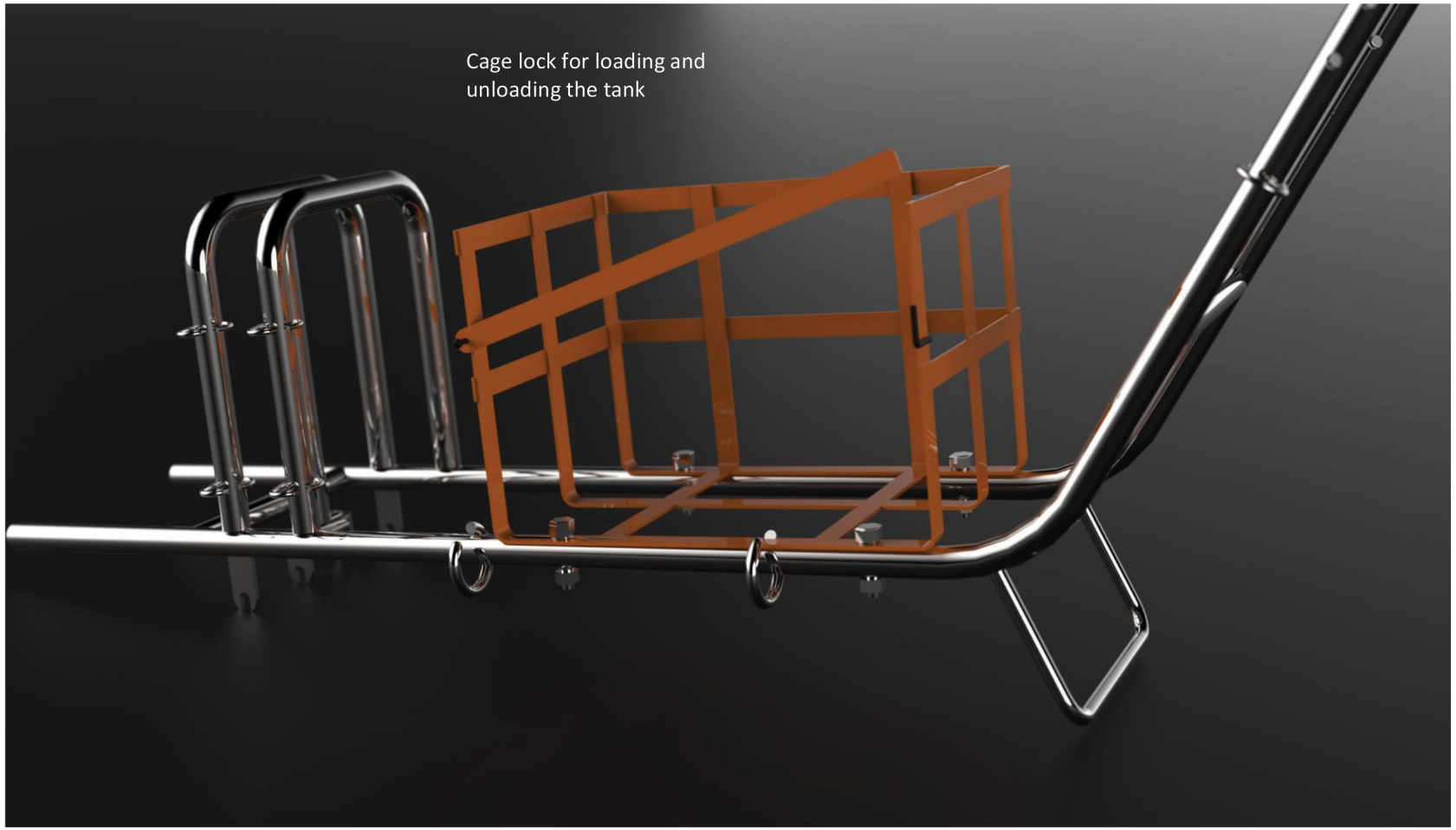


Fig: 16.9 Cage lock for securing the placement of tanks

Final design

Fig: 16.10 Side release buckle clip

Final design

Fig: 16.11 hook mechanism

Final design

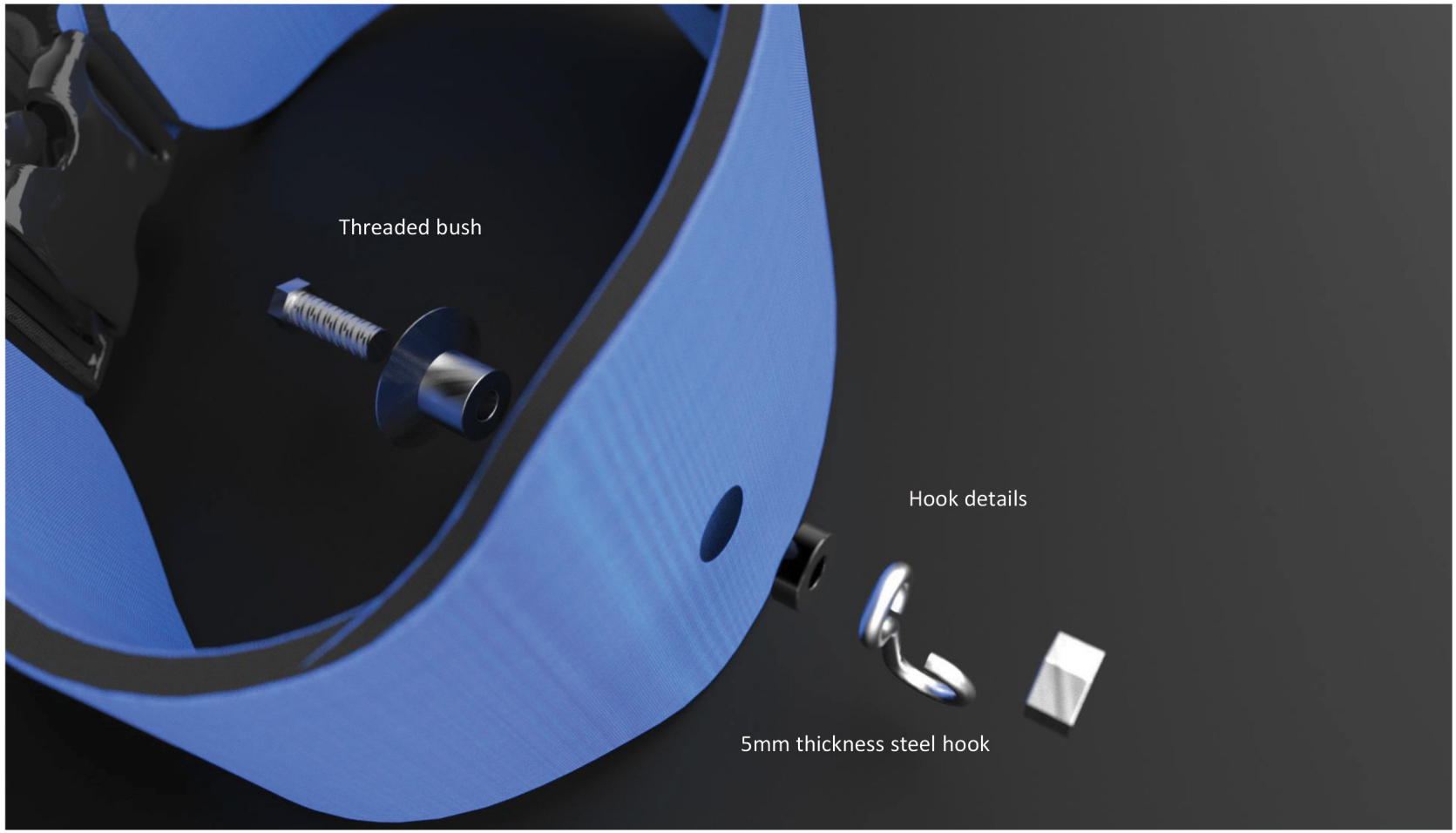


Fig: 16.12 hook mechanism details

Final design

Fig: 16.13 Pipe management

Final design

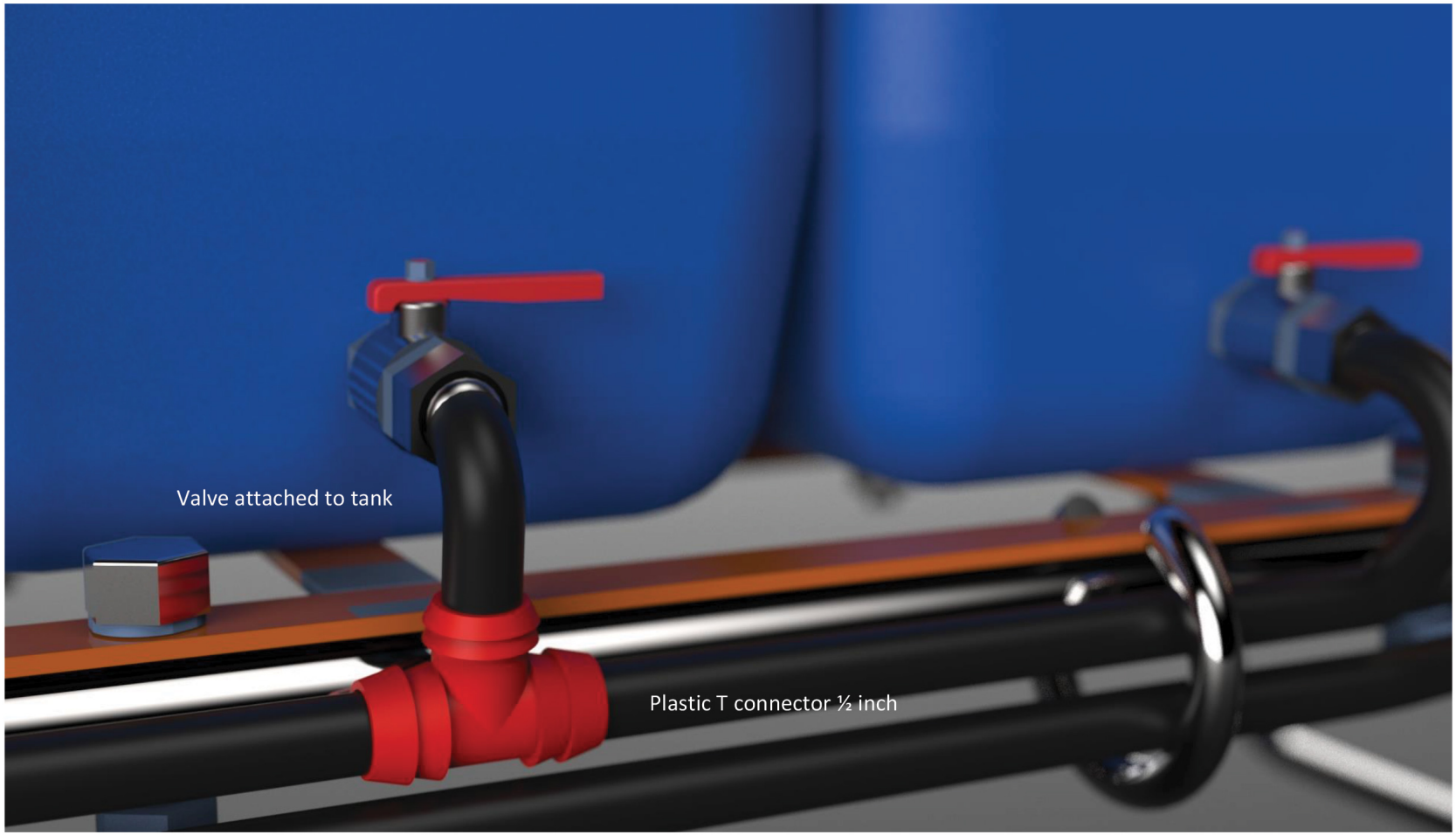


Fig: 16.14 Valve & t connector

Final design

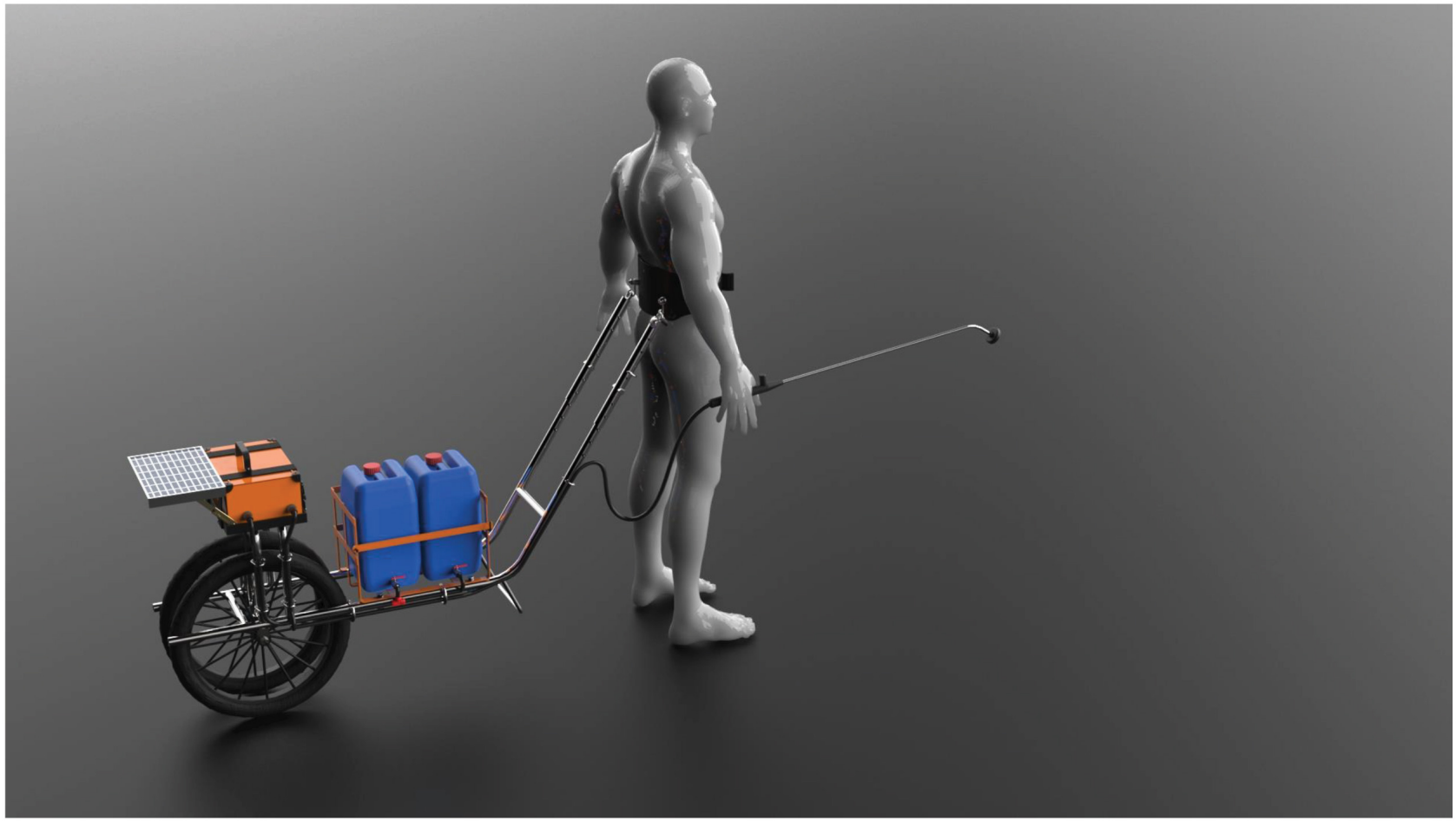


Fig: 16.15 Pipe management

Final design

Fig: 16.16 Portable solar power unit

Final design

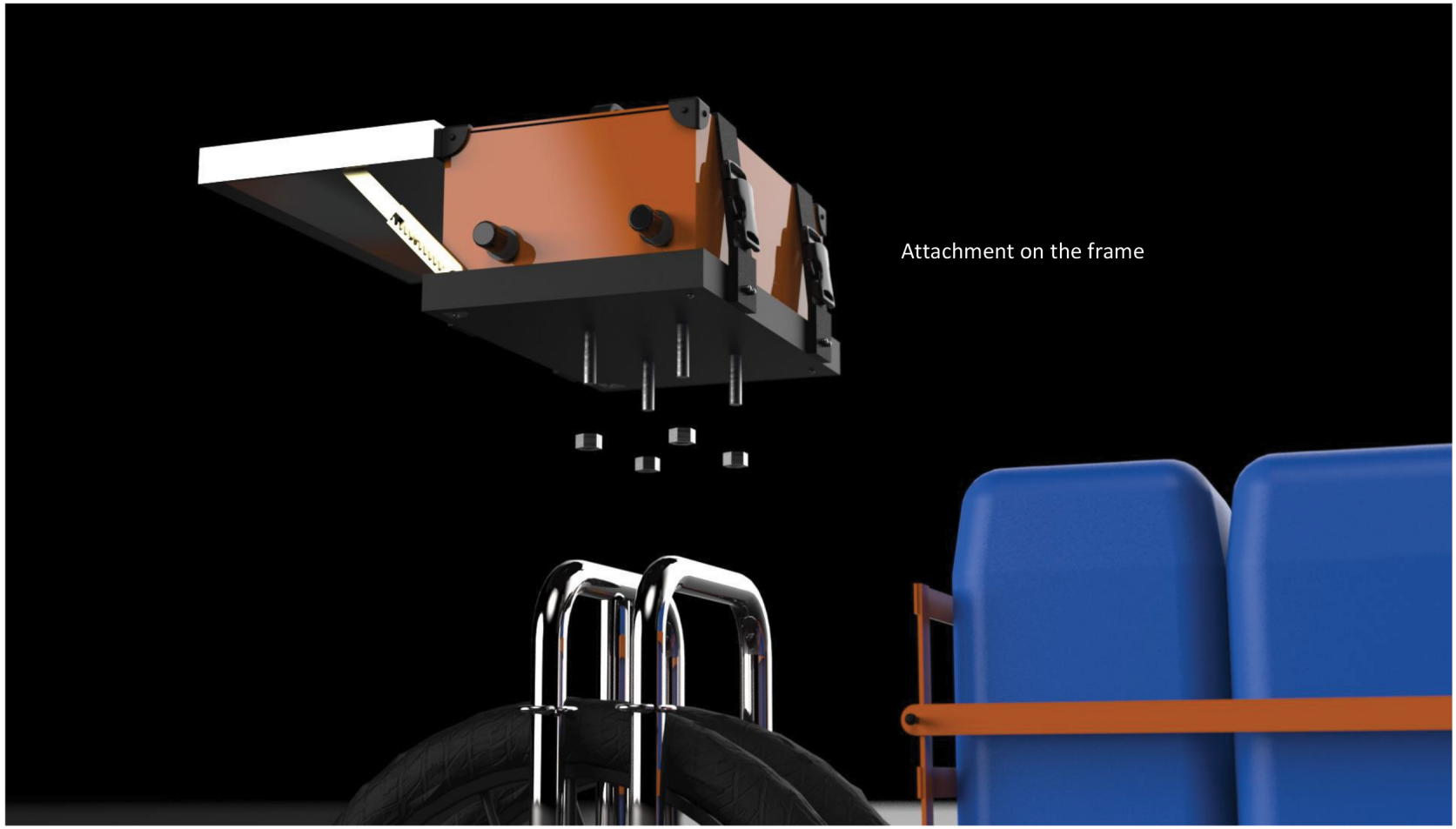


Fig: 16.17 Modular frame attachment

Final design

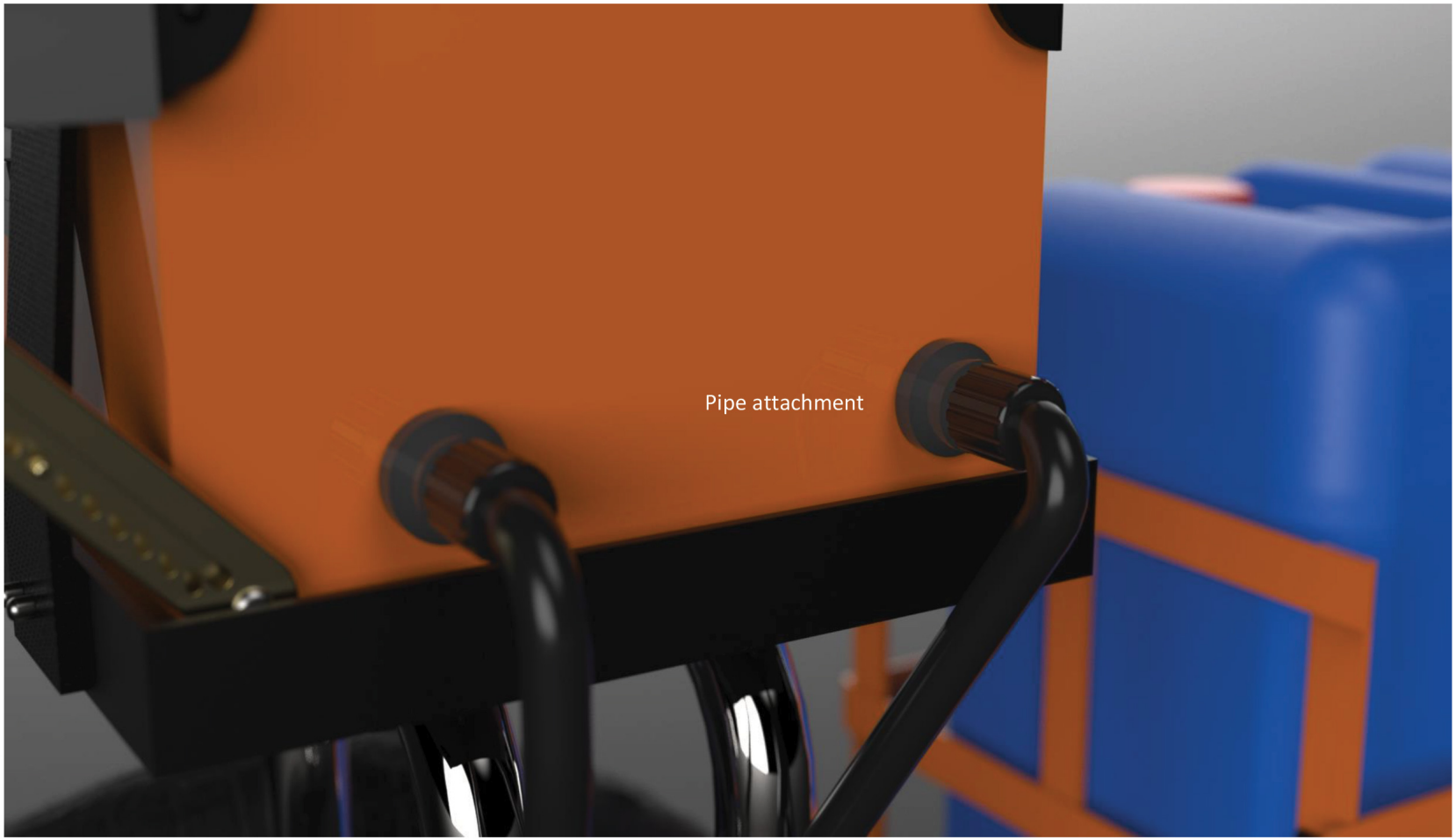


Fig: 16.18 Pipe attachment

Final design

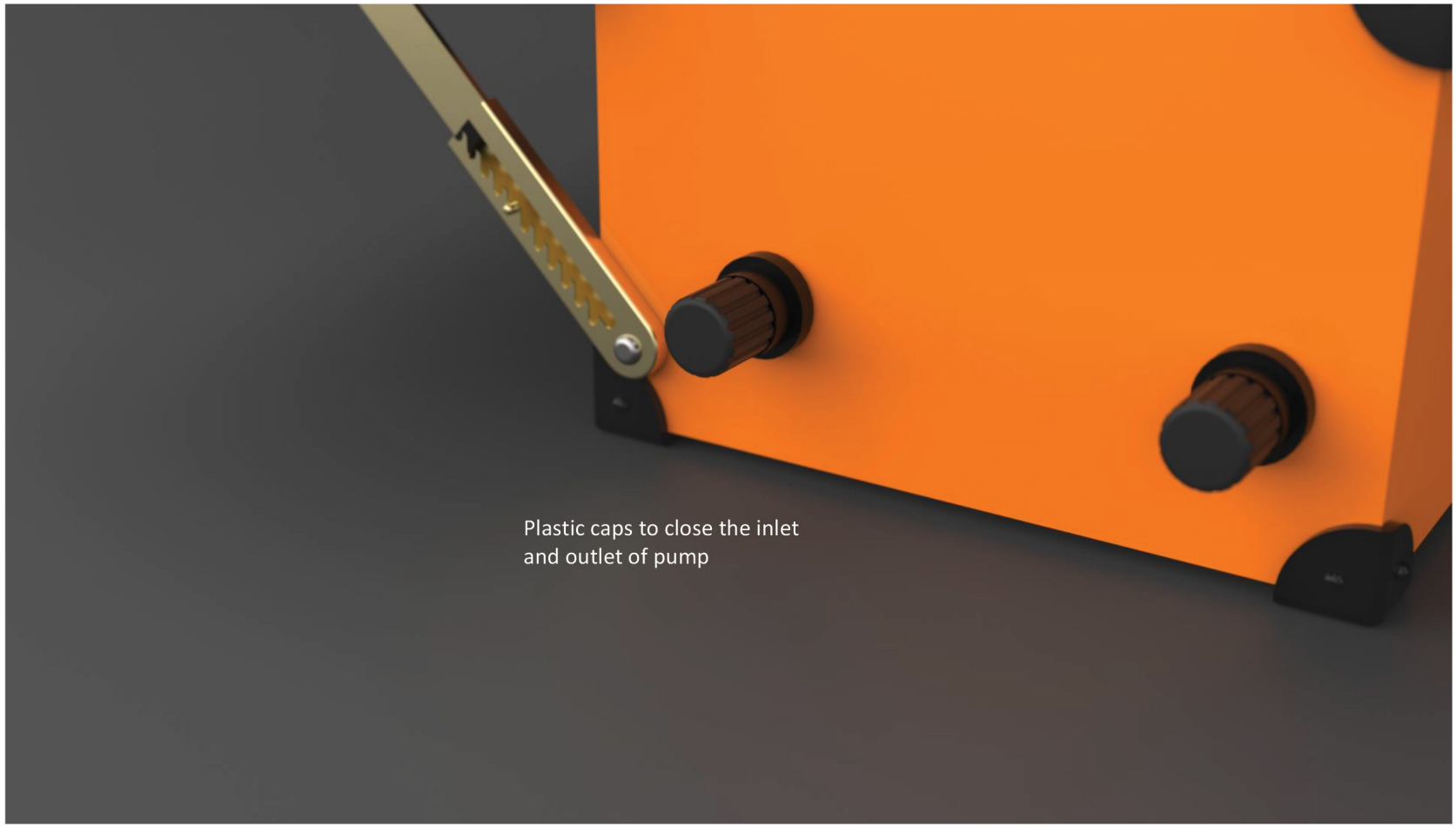


Fig: 16.19 Plastic caps

Final design

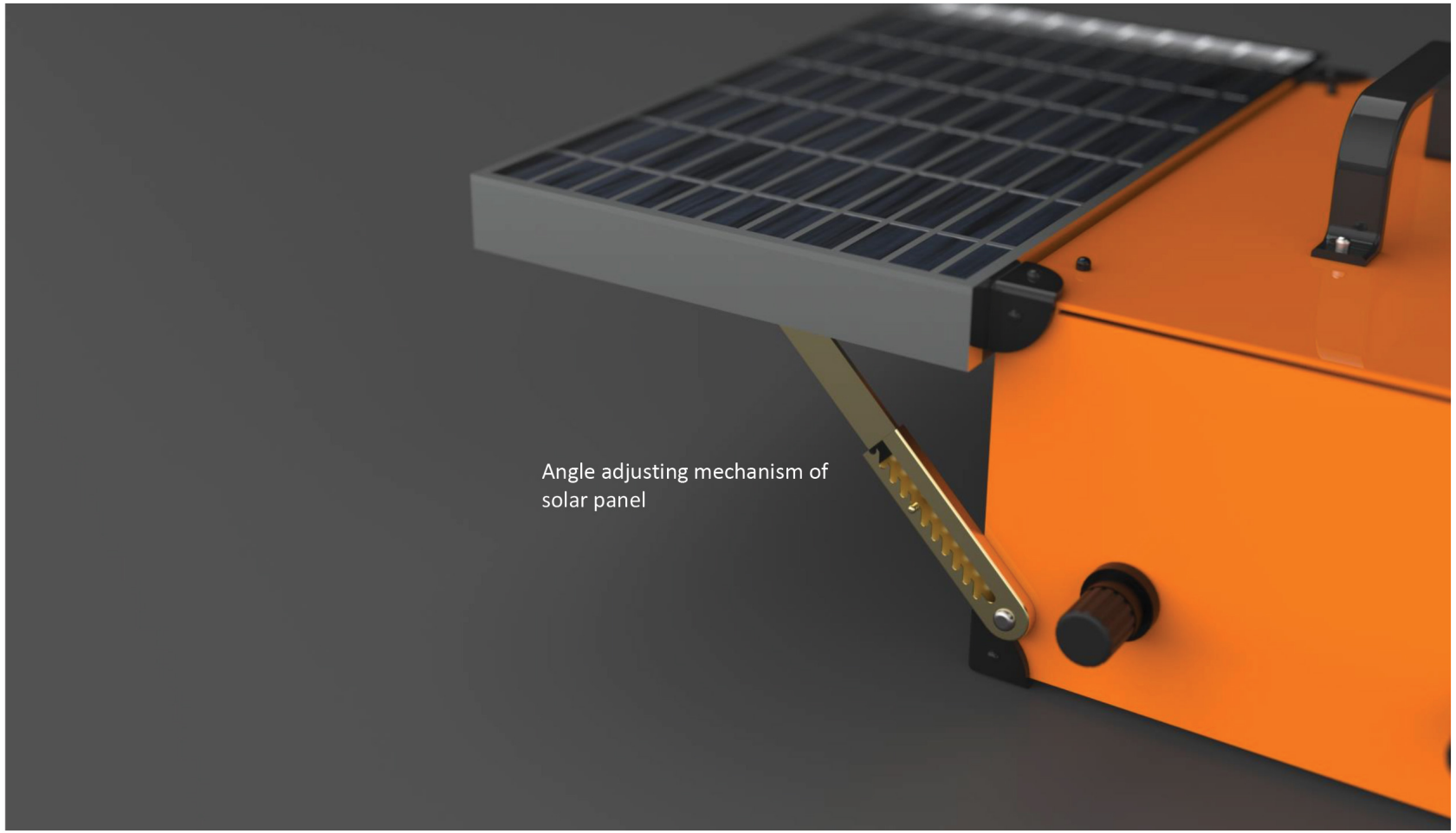


Fig: 16.20 Angle adjustor mechanism

Final design

Fig: 16.21 Switch and controller

Final design

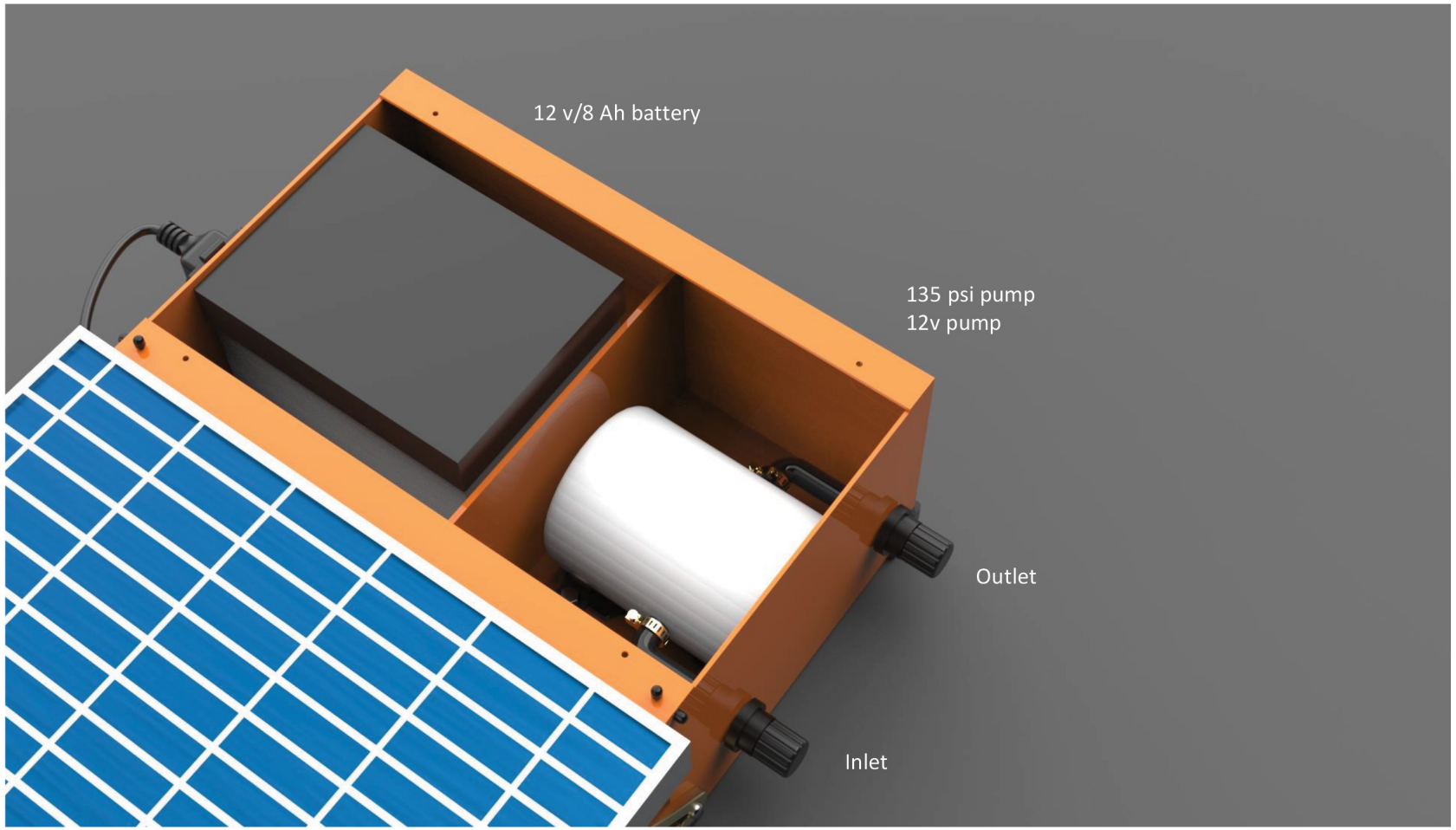


Fig: 16.22 battery and pump placement

17. Cost estimation

The overall material cost for the manufacturing the final design was is around **Rs:5000/-** but considering the system level integration & bulk manufacturing at the local level as per the requirement of the farmers can bring down the cost of total manufacturing to Rs:4000/-. This price bracket very well falls between the bandwidth of currently used knapsack sprayers by the farmers.

Material	Cost (Rs)
Tank	80/-
Stainless steel pipe	570/-
Valve	250/-
Belt	400/-
pump	400/-
Battery	800/-
Solar panel	700/-
Charger	200/-
Pipe, nozzle etc.	250/-
Tank Filter/ funnel	50/-
Wheel with rim	1200/-
Nut bolts	100/-

Table: 16.1 Cost estimation

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