WG
WORM GENERATION

WORMING OUR WAY OUT OF PLASTIC WASTE

Co-funded by the Erasmus+ Programme of the European Union

BUILD'S building urban intelligent living design solutions

RCE Vienna Regional Centre of Expertise on Education for Sustainable Development

Iaac ADVANCED ARCHITECTURE GROUP

WU WIRTSCHAFTS UNIVERSITÄT WIEN VIENNA UNIVERSITY OF ECONOMICS AND BUSINESS

UNIVERSITÉ DE LORRAINE


14
Million
tons

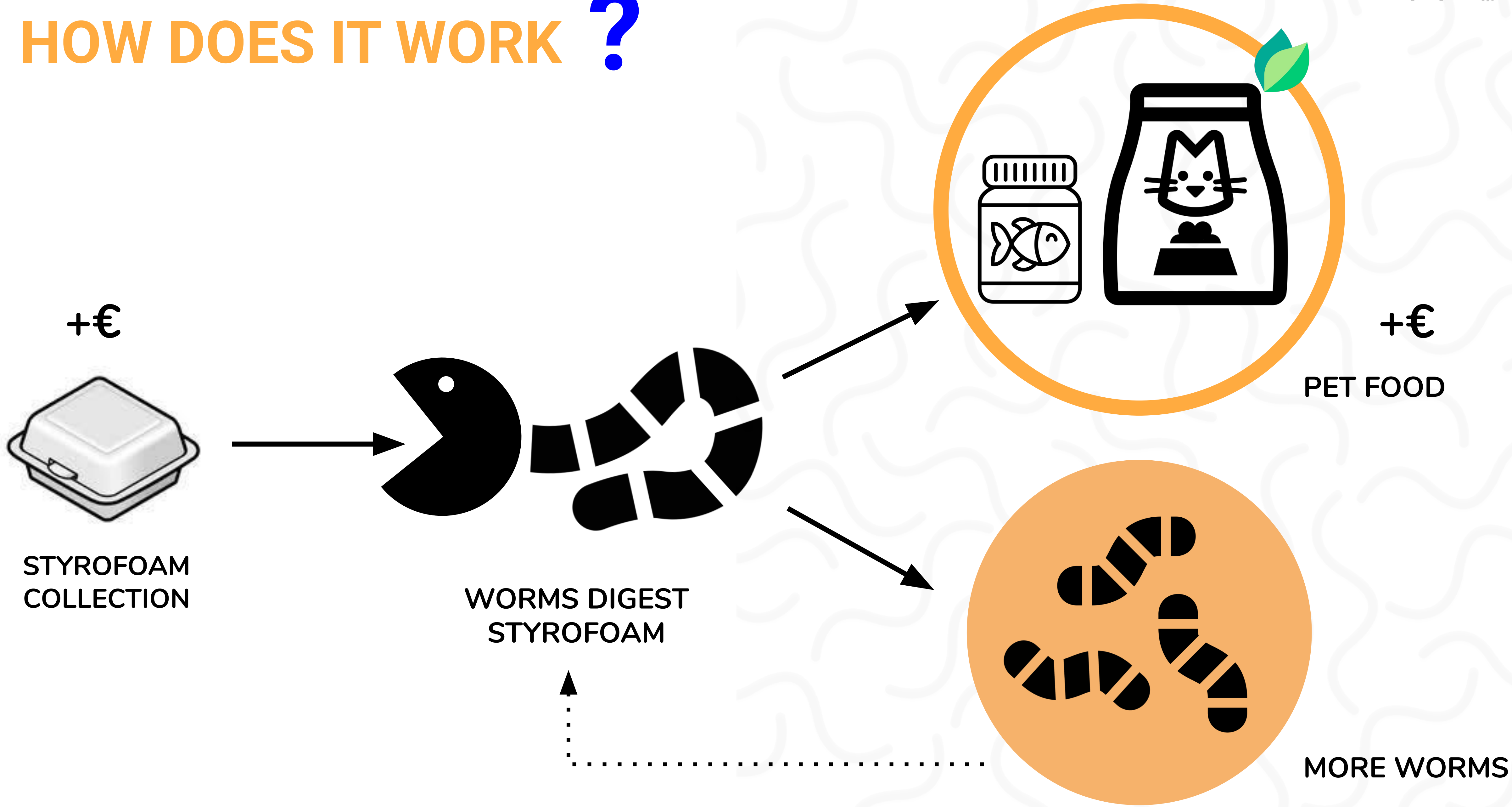
PROBLEM?


10%
WHAT ABOUT RECYCLING...

SOLUTION

WHY NOT USE NATURE?

HOW DOES IT WORK ?



WHO OWNS THE PROBLEM?

&

BUT, DOES IT WORK ? YES WE TESTED IT!

Supervised by
Pr Auclerc, A

LABORATOIRE SOLS & ENVIRONNEMENT

600 SQM

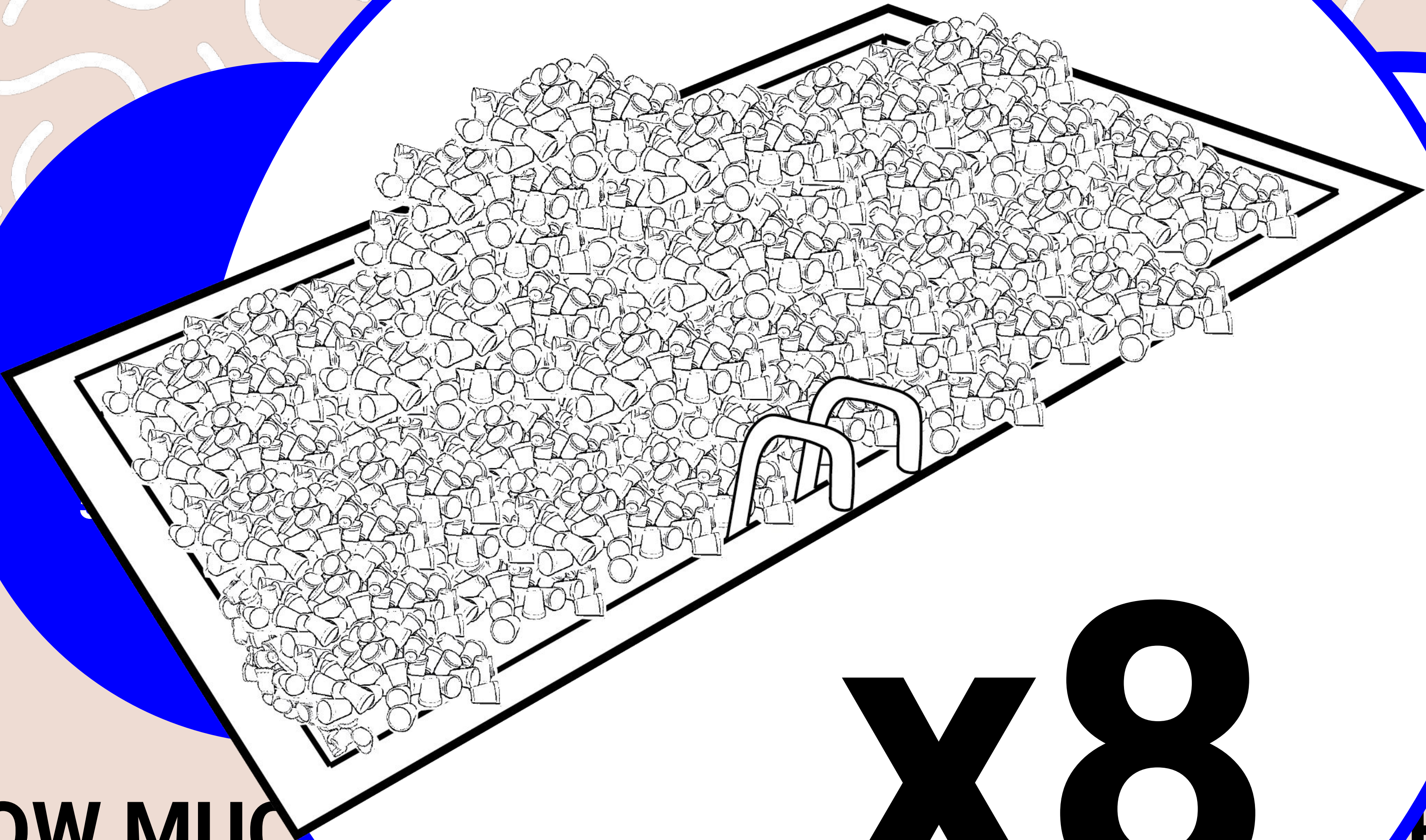
500,000 MEALWORMS
PER 1 SQM

=

1 TON
PER MONTH

HOW MUCH SPACE?

HOW MUCH EATEN?



x8

HOW MUC H EATEN?

THE TEAM

MYRIAM
#biology

MADHAVI
#architecture

MALTE
#business

VINCENT
#biology

EVE
#architecture

KAROLINA
#business

WE NEED CONTACTS TO:

- Municipalities
- Waste Management Companies

office@wormgeneration.com

Worm Generation

www.wormgeneration.com

malte.paschen@outlook.com

https://www.linkedin.com/company/worm-generation/

WG

STATUS QUO?

MARKETING

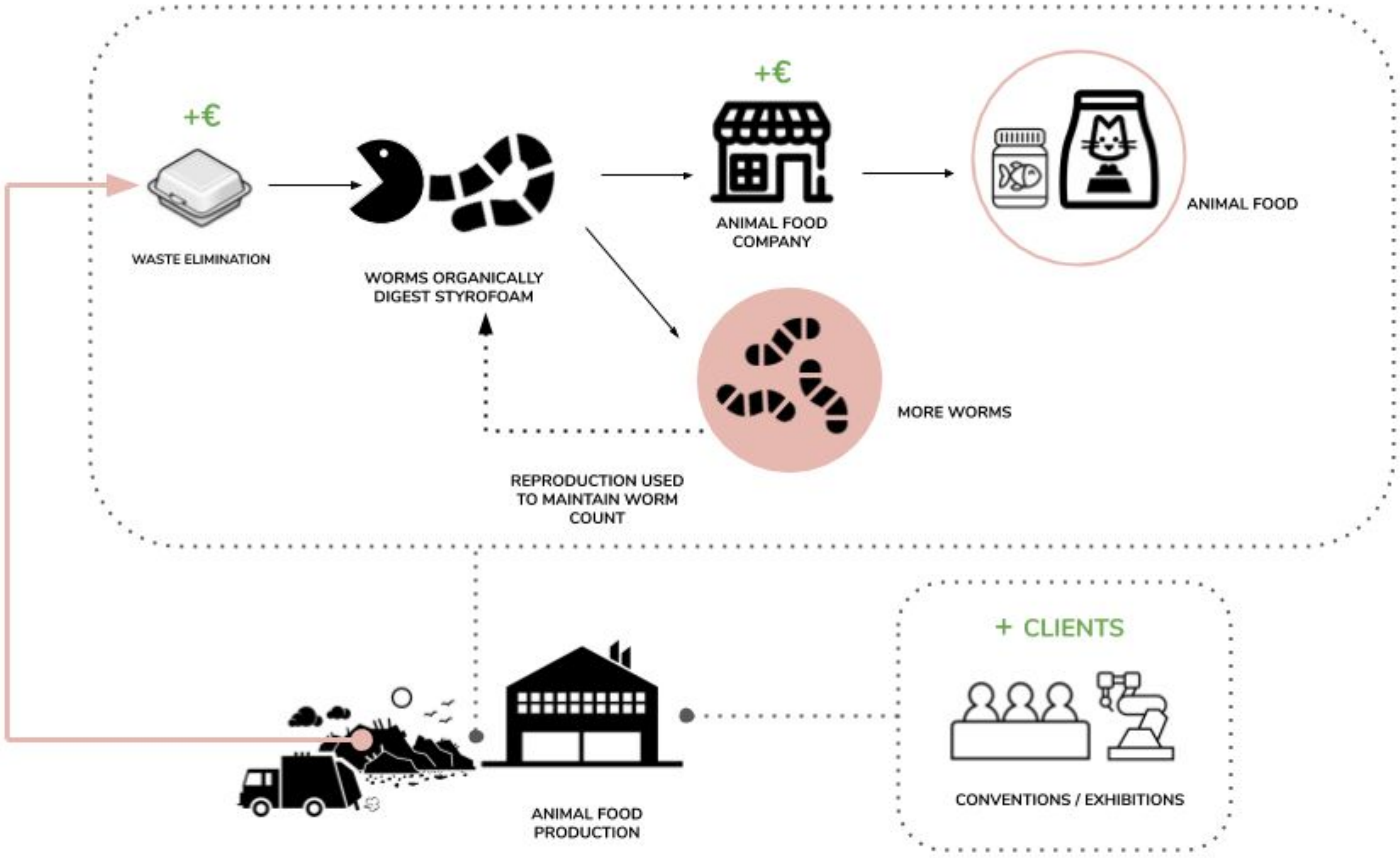
BUSINESS DEVELOPMENT

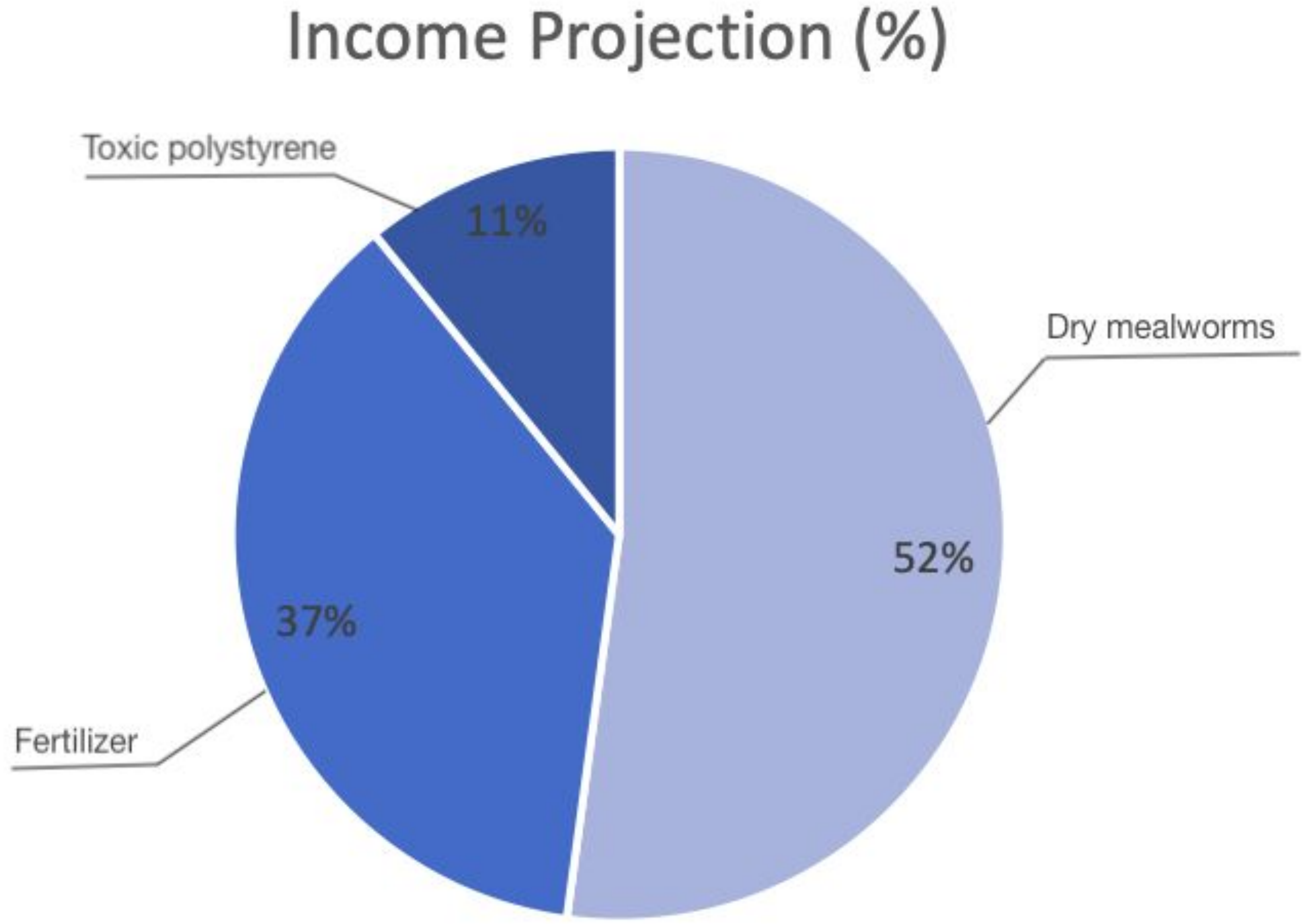
RESEARCH

FINANCIAL PROJECTION

BUSINESS MODEL

Mapping the major components of the business




Income Projection (%)
Toxic polystyrene
11%
Dry mealworms
52%
37%
Fertilizer

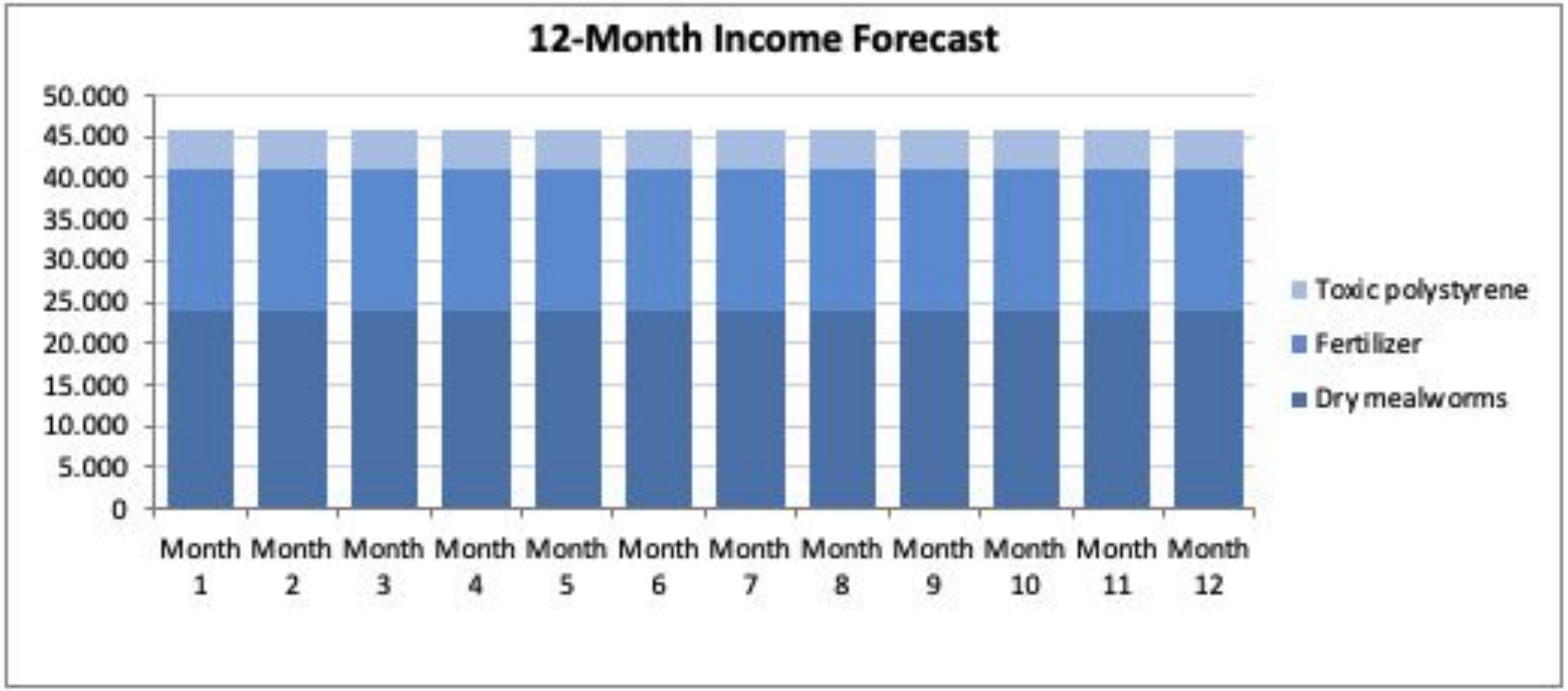
Profit & Loss 600m2

INCOME	2021	% of OI	2022	% of OI	2023	% of OI
Operating Income						
Dry mealworms	205.824,00 €	71,0%	207.539,20 €	60,3%	209.254,40 €	52,5%
Fertilizer	50.463,00 €	17,4%	50.463,00 €	14,7%	50.463,00 €	12,7%
Toxic polystyrene	33.480,00 €	11,6%	86.220,00 €	25,0%	138.960,00 €	34,9%
Total Operating Income (OI)	**289.767,00 €**		**344.222,20 €**		**398.677,40 €**	
Total INCOME	**289.767,00 €**	100,0%	**344.222,20 €**	100,0%	**398.677,40 €**	100,0%
EXPENSES						
Operating Expenses						
Accounting and Legal	2.500,00 €	0,9%	2.500,00 €	0,7%	2.500,00 €	0,6%
Utilities	6.736,51 €	2,3%	6.736,51 €	2,0%	6.736,51 €	1,7%
Feed costs	5.739,17 €	2,0%	5.739,17 €	1,7%	5.739,17 €	1,4%
Research and Development	19.250,00 €	6,6%	19.250,00 €	5,6%	19.250,00 €	4,8%
Salaries and Wages	72.000,00 €	24,8%	72.000,00 €	20,9%	72.000,00 €	18,1%
Depreciation and amortization	21.104,69 €	7,3%	21.104,69 €	6,1%	21.104,69 €	5,3%
Web Hosting and Domains	50,00 €	0,0%	50,00 €	0,0%	50,00 €	0,0%
Total Operating Expenses	**127.380,36 €**	44,0%	**127.380,36 €**	37,0%	**127.380,36 €**	32,0%
Total EXPENSES	**127.380,36 €**	44,0%	**127.380,36 €**	37,0%	**127.380,36 €**	32,0%
NET INCOME	**162.386,64 €**		**216.841,84 €**		**271.297,04 €**	

NET INCOME for 20 facilities	**3.247.732,79 €**	**4.336.836,79 €**	**5.425.940,79 €**

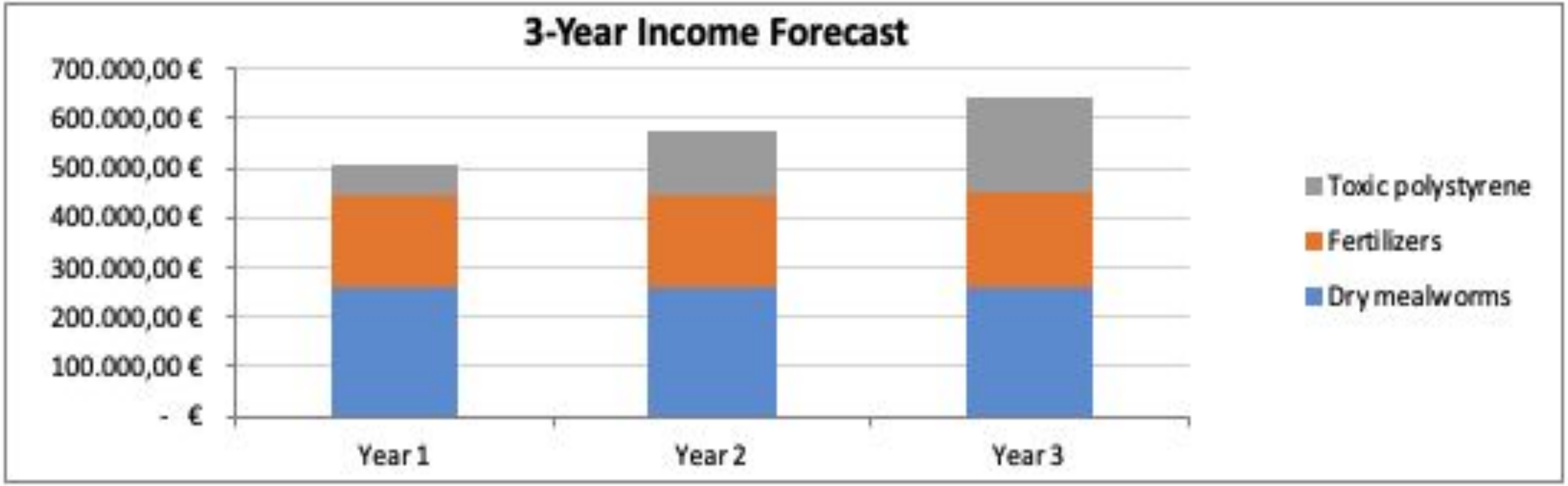
Income Forecast 12m

600m2



Income Forecast 3yrs

600m2



ROI 600 m2

RETURN ON INVESTMENT	2020	2021	2022	2023
Farm initial investment	428.020,85 €			
Net Income		162.386,64 €	216.841,84 €	271.297,04 €
ROI		-6,2%	-1,0%	5,4%

ROI 300 m2

RETURN ON INVESTMENT	2020	2021	2022	2023
Farm initial investment	241.425,51€			
Net Income		47.804,26 €	47.804,26 €	47.804,26 €
ROI		-8,0%	-6,0%	-4,1%

ROI 1200 m2

RETURN ON INVESTMENT	2020	2021	2022	2023
Farm initial investment	705.603,05 €			
Net Income		408.961,51 €	408.961,51 €	408.961,51 €
ROI		-4,2%	1,6%	7,4%

MARKETING

ASSEMBLY

The styrofoam is to be etched in the laser cutter using the file containing the curves to be etched.

The styrofoam is then to be placed into the assembled acrylic case.

Once the barriers are placed on the styrofoam surrounding the eating pattern, the juice points can be inserted into the pattern.

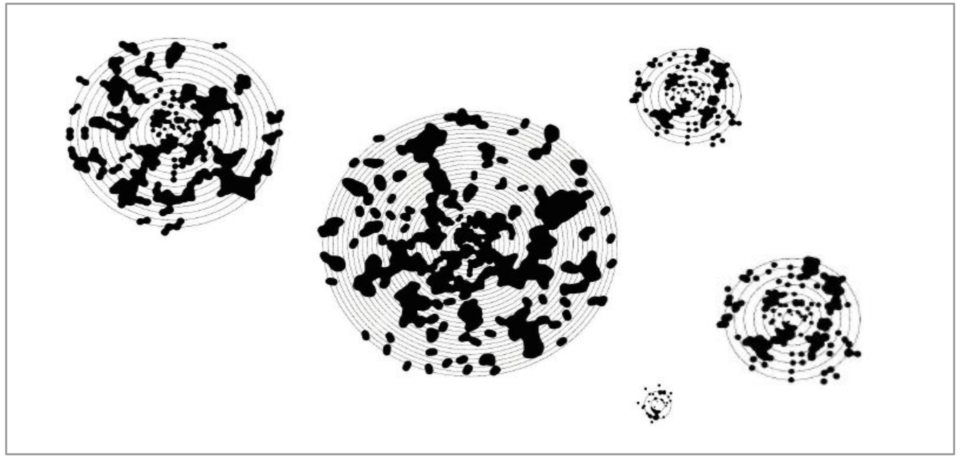
The mealworms will then be placed into the barriers.

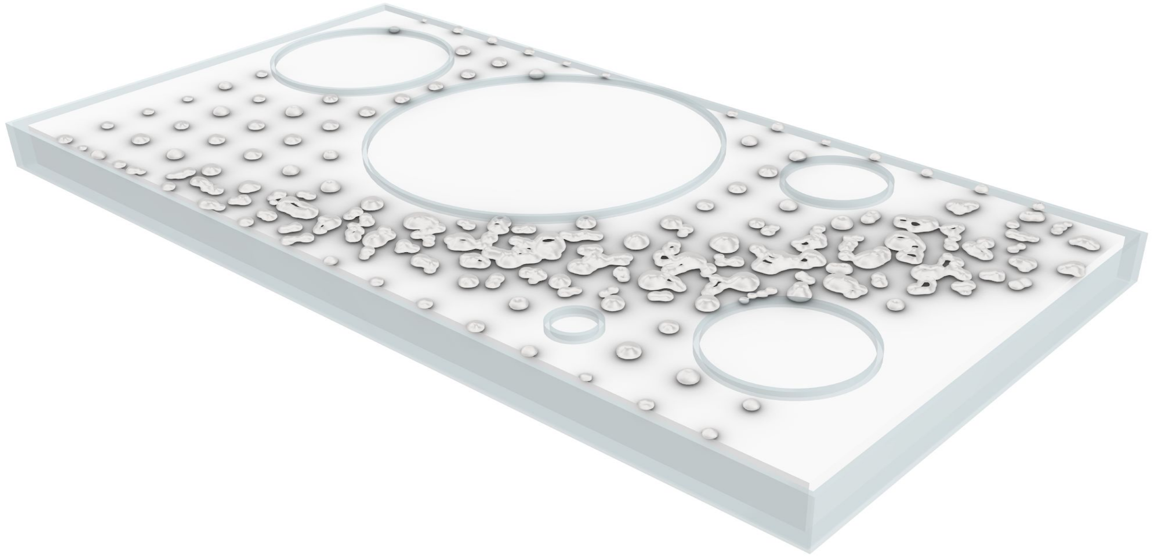
After this set up, the robotic arm can start the process of printing the clay and waste mixture.

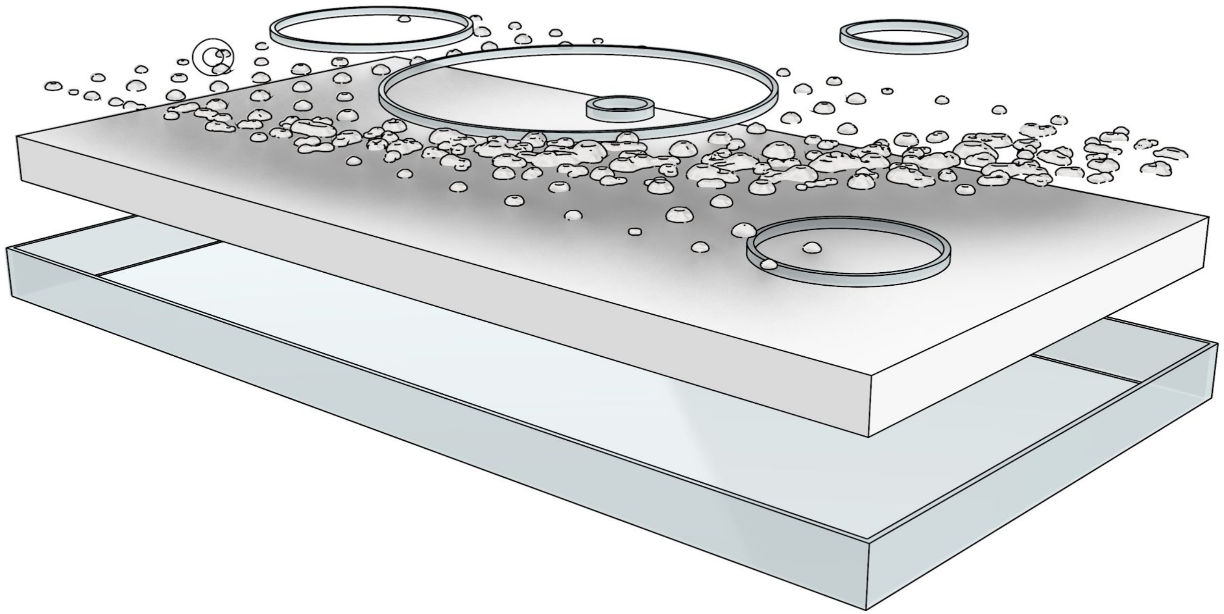
Width: 50cm

Length: 100cm

Width: 5cm



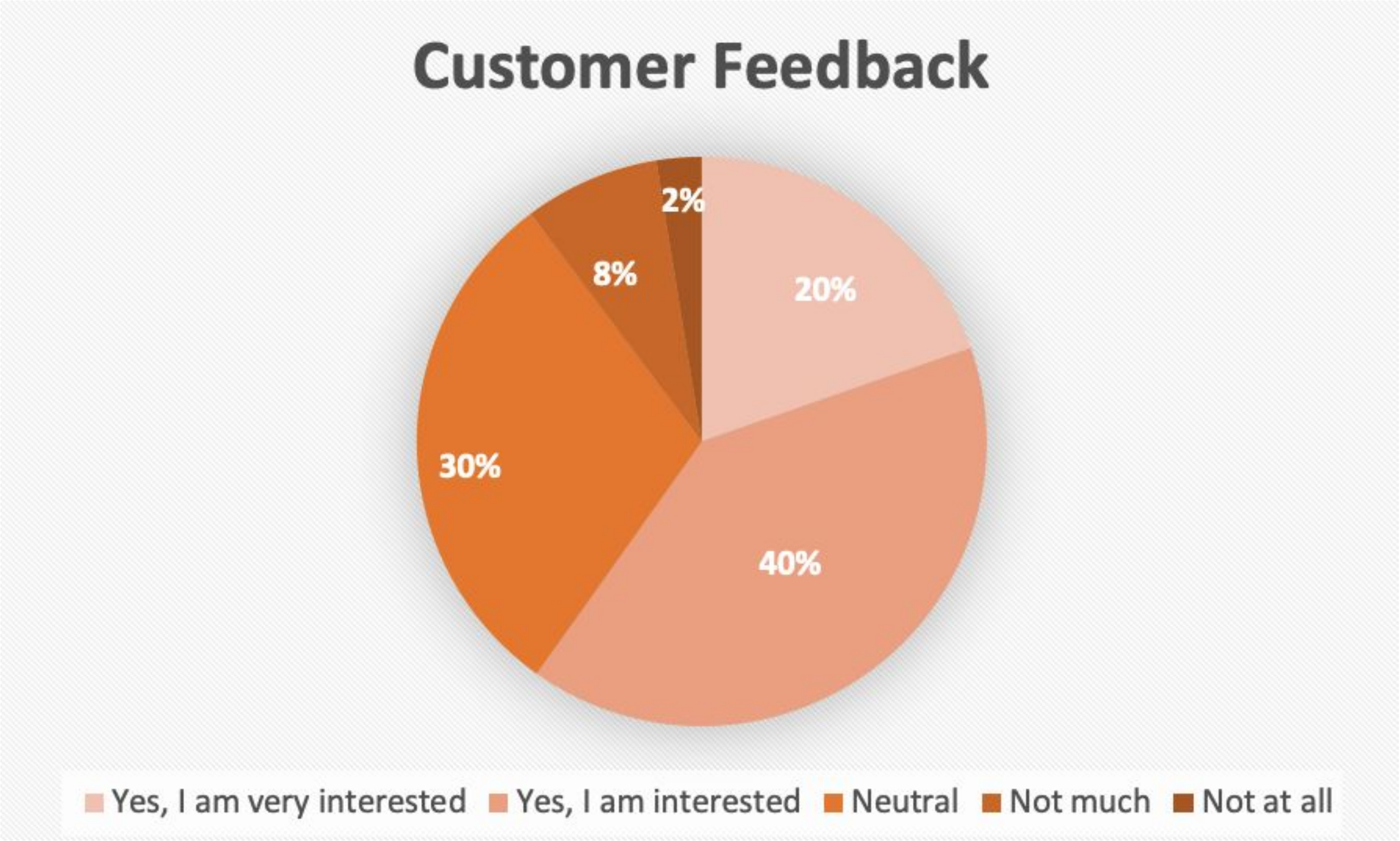




INSTALLATION RENDER

Would you be interested in buying our pet food?

117 answers



ENVIRONMENTAL IMPACT

Environmental impact

14 mln tons of polystyrene

600 m2

Number of facilities (600m2)	1	20	250
Surface in total (ha)	0,06	1,2	15
Years	1.167	58	5

1200 m2

Number of facilities (1200m2)	1	20	250
Surface in total (ha)	0,12	2,4	30,0
Years	467	23	2

11 SUSTAINABLE CITIES AND COMMUNITIES

13 CLIMATE ACTION

14 LIFE BELOW WATER

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

MARKET ANALYSIS

MARKET SIZE/ VOLUME AND MARKET POTENTIAL/ GROWTH

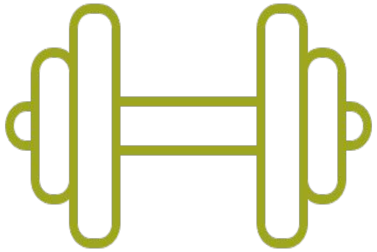
- Germany: whole trash being burned in 2011: 19,7 mio tons, in 2014 it was 44% of all plastics being burned
- Austria: 900.000 tons of plastic waste each year (71% burned, 28% recycled, 1% landilled) – forecast 2021: over 1 million tons already!
- Worldwide plastic waste: only 9% being recycled, therefore 90% either burned (12%) or landfilled (60%)
- Special waste burning waste facilities: min. 1100 degree
- Revenue potential
- Expected growth because of landfill bans (e.g. planned EU-wide)

https://plastik.greenpeace.at/assets/uploads/assets/uploads/Factsheet-Plastikluegen_A4.pdf

https://plastik.greenpeace.at/10-plastikmythen/?_ga=2.31820028.39002407.1591535286-1031374392.1591535286

MARKET SIZE/ VOLUME AND MARKET POTENTIAL/ GROWTH

EPS + XPS: Polystyrene: **market is growth at a CAGR of 4.7%** during the forecast period



Market Size: of ~ **280.000.000€** just in three countries HBCD-contaminated polystyrene in Germany: every year more than 40.000 tons

= market size **Germany 144.000.000€/ year**

France: ~ 117.000.000€ / year

Austria ~ 15.000.000€ / year

https://www.sabprofil.de/assets/user/Duits/HBCD_document.pdf

https://www.duh.de/projekte/hbcd-daemmstoffe/

https://www.mordorintelligence.com/industry-reports/polystyrene-market

MARKET SIZE/ VOLUME AND MARKET POTENTIAL/ GROWTH

- 1,1 mrd tons of waste daily burned outside of controlled structured/ 40% of global waste being burned uncontrolled in open fire (v. a. in developing countries) -> Higher consumption -> Higher amount of waste

Combustion: this releases large quantities of toxic gases and dirt particles into the air. These are pollutants that do not appear in any official statistics and can cause enormous damage to the climate and health.

 Waste incineration responsible for five percent of total man-made greenhouse gas emissions

- The exact number and variety of pollutants produced by and released from waste incineration is not known.
- The danger lies in the fact that a great many different substances are present when waste is incinerated. Due to the large number of substances, it is hardly possible to determine the danger of individual compounds that only occur in trace amounts.
- Alternative: Avoiding producing waste

COMPLETED RESEARCH

EXPERIMENT : SET 2

porosity

SET 2B : POROSITY

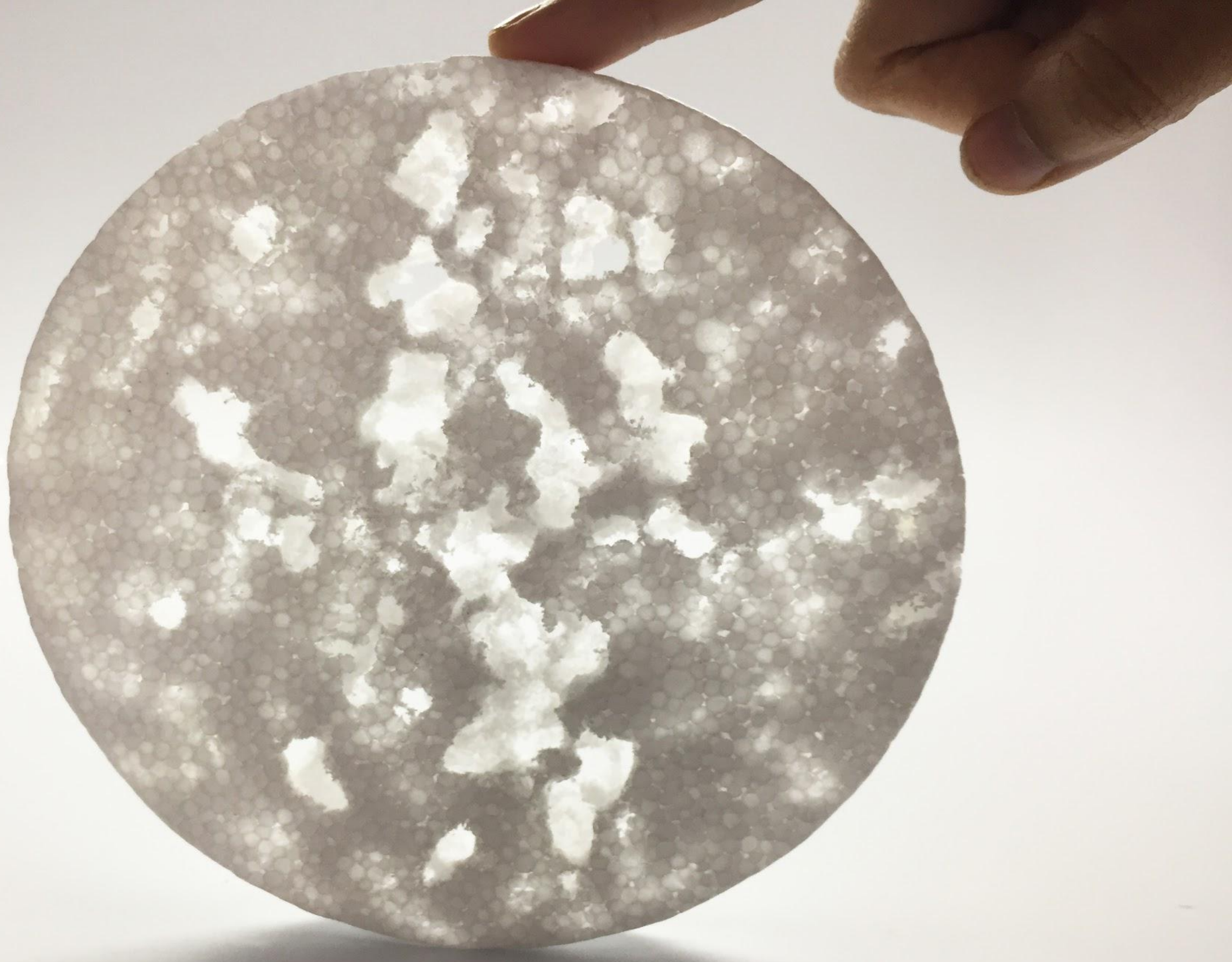
A 4mm thick piece of styrofoam was injected with apple juice in random locations and placed into the container of worms

SET 2C : POROSITY

A 5 gram piece of styrofoam was injected with apple juice in random locations and placed into the container of worms.

EXPERIMENT : SET 2C

porosity



Initial weight: 5 grams
Final weight: 2 grams

Mass eaten: 3 grams
Duration: 3 days

EXPERIMENT : SET 3A

controlling porosity

CONTROLS

Juice was inserted into the central area of the styrofoam. The worms were then placed on and around the piece of styrofoam.

OBSERVATIONS

The worms have infiltrated largely the central area where the driver was placed, proving that thai are able to eat in a designed region.

EXPERIMENT : SET 3A

controlling porosity

FRONT

Initial weight: 4.7 grams
Final weight: 3.5 grams

Mass eaten: 1.2 grams
Duration: 10 days

EXPERIMENT : SET 3B

controlling porosity

FRONT

The same experiment was carried out with the superworms.

BACK

The underside showed the same results at an elevated scale.

ASSESSMENT

styrofoam remnants

1 week

2 weeks

Mealworms were left in the remnants of the styrofoam from an eating test. Samples were taken to understand if the remnants were be eaten and if new organic matter was being produced.

Main interrogations before starting the experiments:

- Do mealworms actually eat polystyrene?
- How much do they eat and therefore how quickly do they degrade the polystyrene?
- How to optimally breed mealworms (temperature, humidity, brightness)?
- What is the life cycle of the mealworm (lifespan, age of maturity, reproduction rate, mortality rate)?

EXPERIMENTS

3 repetitions of each: (PS = polystyrene)

- ➢ Control (normal quantity of food + without PS)
- ➢ Normal quantity of food + block of PS
- ➢ Few food + block of PS

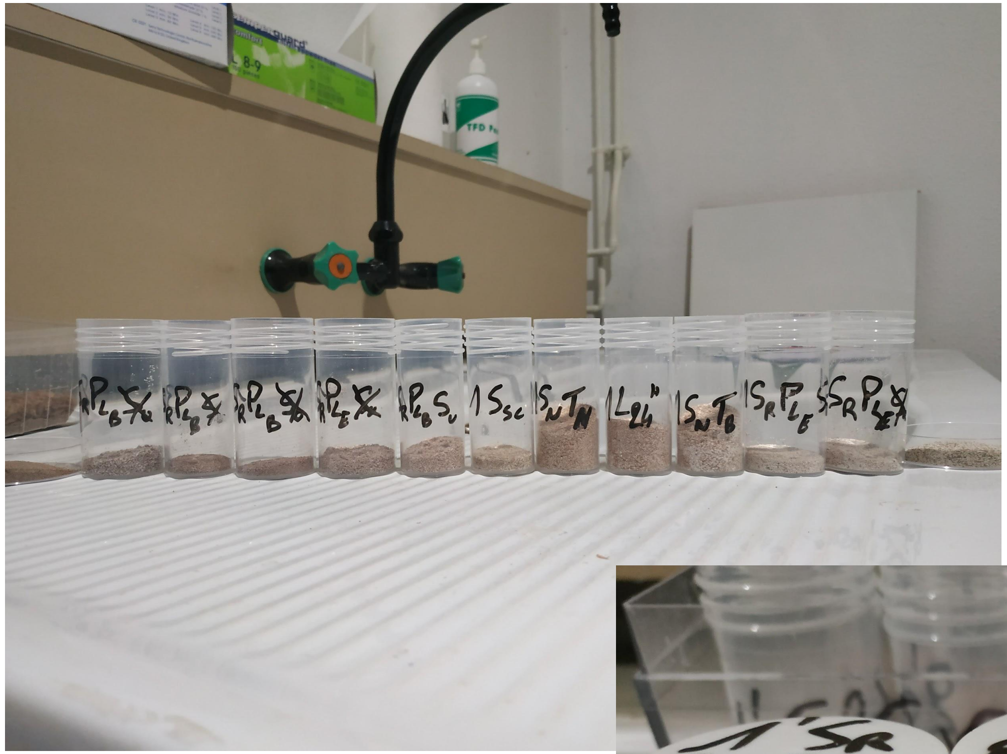
Without food:

- ➢ Block of PS:
  - ○ PS injected with sugar
  - ○ Normal PS
- ➢ Crumbled PS:
  - ○ PS injected with sugar
  - ○ Normal PS
- ➢ Wood chips + block of polystyrene

Material and method

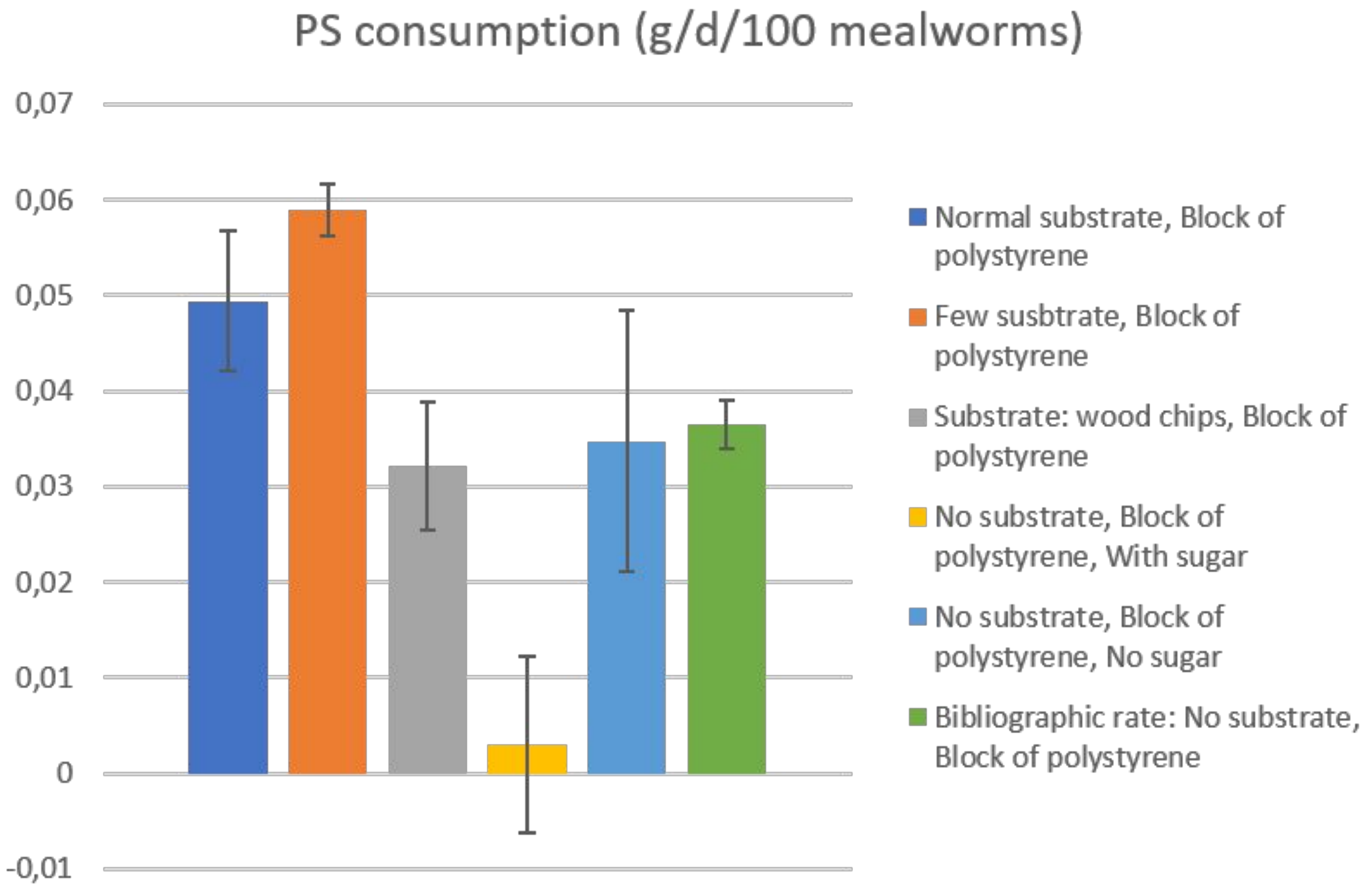
Weighing to prepare rearing boxes

Sorting of mealworms boxes before measurement of results



Excrement samples

Dead mealworms samples



PS consumption (g/d/100 mealworms)
0,07
0,06
0,05
0,04
0,03
0,02
0,01
0
-0,01
Normal substrate, Block of polystyrene
Few susbtrate, Block of polystyrene
Substrate: wood chips, Block of polystyrene
No substrate, Block of polystyrene, With sugar
No substrate, Block of polystyrene, No sugar
Bibliographic rate: No substrate, Block of polystyrene

FUTURE DEVELOPMENTS

SHORT-TERM (TECHNICAL)

- Milestone #1: *Conditions/materials for healthy growth and best biodegradation*
  // 4-5 months, in the pilot farm
  - Testing conditions (temperature, relative humidity, photosensibility)
  - Testing farm materials
  - Testing farm rearing process

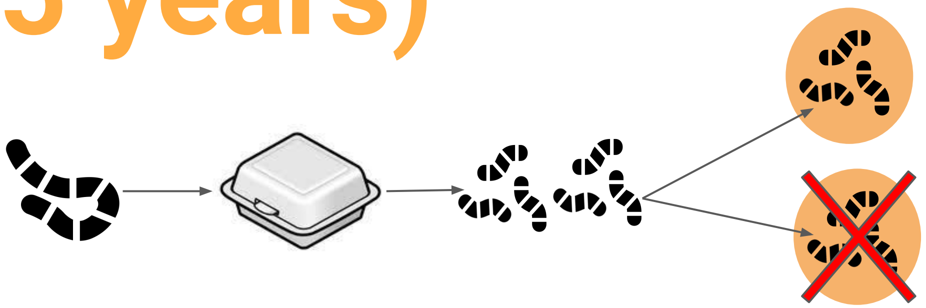
- Milestone #2: *Food/organic waste for the best biodegradation / best environmental impacts*
  // 4-5 months
  - Testing food (quantity, mix, ...)
  - Partnership with industrial food companies
  - Testing feeding with organic waste

- Milestone #3: *Plastic incorporation into mealworms and bioaccumulation*
  // 5-6 months, €€€ (chemical and biological tests)
  - Partnership with laboratories
  - Quantification of plastics incorporation
  - Testing of non-bioaccumulation

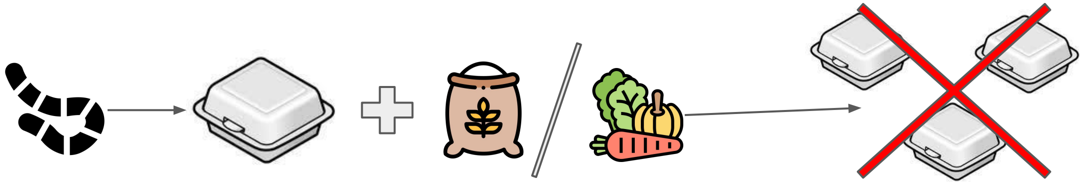
- Milestone #4: *Remnants molecules in excrements and complete biodegradation process*
  // 5-6 months, €€€ (chemical tests)
  - Partnership with chemists (Carbios)
  - Testing other organisms
  - Process of producing fertilizers

LONG-TERM (5 years)

- Selection of mealworms



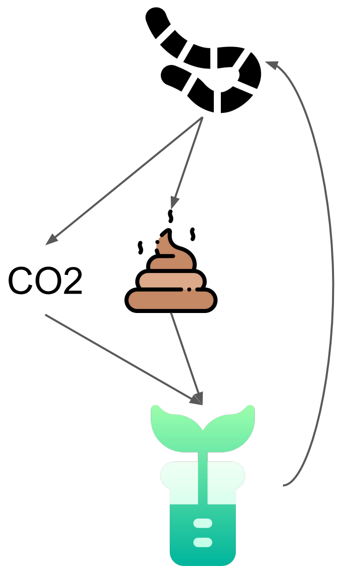
- Food used for rearing mealworms



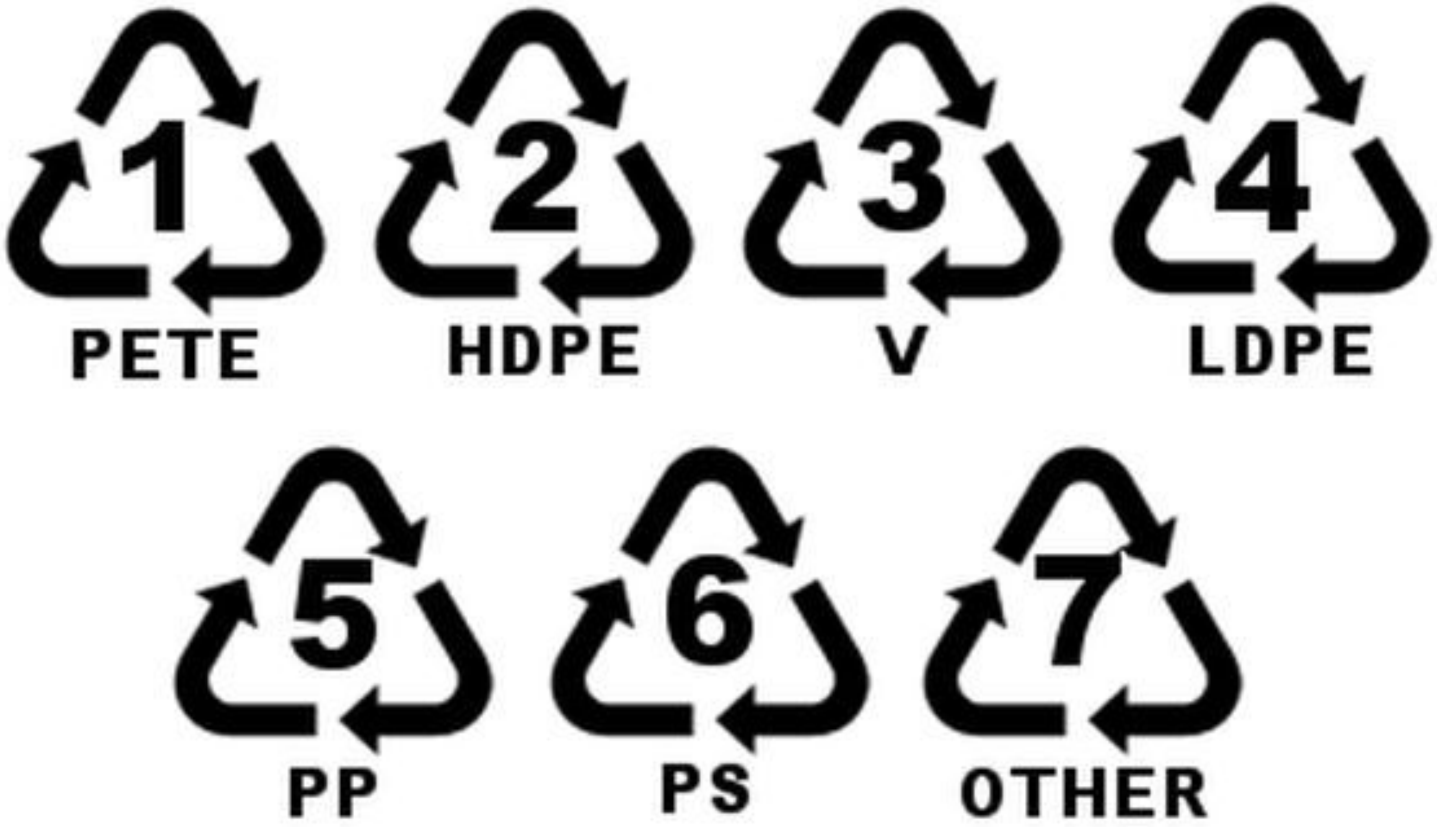
- Conditions of the environment: optimizing the factors that enable rapid eating rate

- Combination of organisms to facilitate biological process

- Association with plants to reuse CO_2 and excrement (completed circular economy)



OTHER PLASTICS



- PLA
- PUR

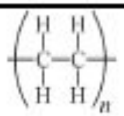
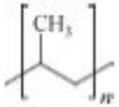
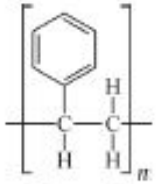
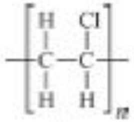
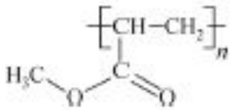
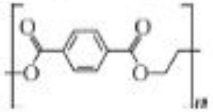
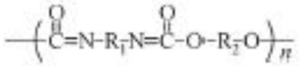
“**Ubiquity of polystyrene digestion and biodegradation within yellow mealworms, larvae of Tenebrio molitor Linnaeus (Coleoptera: Tenebrionidae)**”
https://doi.org/10.1016/j.chemosphere.2018.08.078.

OTHER ORGANISMS

Only for polystyrene:

- **Worms (4 species minimum)**
  - Tenebrio molitor (mealworms)
  - Zophobas atratus (superworms)
  - Tenebrio obscurus
  - ...
- **Bacteria (10 species minimum)**
  - Exiguobacterium
  - Rhodococcus ruber
  - Actinomycete sp
  - ...
- **Fungi (5 species minimum)**
  - P. chrysosporium
  - Trametes versicolor
  - ...

Table 1 Major microplastics found marine environment in literatures

Polymer type	Short	Chemical formula	Density ($g \cdot cm^{-3}$)	Biodegradation	Molecular structure	Recycle ID code
High density polyethylene	HDPE	$(C_2H_4)_n$	0.917–0.965	Not reported		02 PE-HD
Low density polyethylene	LDPE			Bacteria, fungi, waxworms, mealworms		04 PE-LD
Linear low density Polyethylene	LLDPE					
Polypropylene	PP	$(C_3H_6)_n$	0.90–0.91	Not reported		05 PP
Polystyrene	PS	$(C_8H_8)_n$	1.04–1.1	Bacteria, mealworms		06 PS
Polyvinylchloride	PVC	$(C_2H_3Cl)_n$	1.16–1.58	Fungi		03 PVC
Polymethylacrylate	PMA	$(C_4H_6O_2)_n$	1.17–1.2	Cyanobacteria		07 O
Polyethylene terephthalate	PET	$(C_{10}H_8O_4)_n$	1.37–1.45	Bacteria		01 PET
Polyurethane	PUR	$(R-(N=C=O)_n$	1.20	Fungi		07 O
Polyester	PET, Nylon, Acrylic	PET or various	1.24–2.3	Bacteria	Similar to PET or various	07 O

TECHNICAL ANSWERS

Effect of polystyrene on mealworms (source)

1) **“Biodegradation and Mineralization of Polystyrene by Plastic-Eating Mealworms: Part 1. Chemical and Physical Characterization and Isotopic Tests”**

Yu Yang, Jun Yang, Wei-Min Wu, Jiao Zhao, Yiling Song, Longcheng Gao, Ruifu Yang, and Lei Jiang

Environmental Science & Technology **2015** *49* (20), 12080-12086
DOI: 10.1021/acs.est.5b02661

> Styrofoam was efficiently degraded in the larval gut within a retention time of less than 24 h. Fed with Styrofoam as the sole diet, the larvae lived as well as those fed with a normal diet (bran) over a period of 1 month. The analysis of fecula egested

8) “Effect of Styrofoam Waste Feeds on the Growth, Development and Fecundity of Mealworms (Tenebrio molitor)”

Nukmal, Nismah (2018)

OnLine Journal of Biological Sciences, *18* (1). pp. 24-28. ISSN 1608-4217

> are noted. The results showed, in comparison to the standard diet, EPS and XPS foam feeds did not give a significant effect on the mortality of the

Remaining polystyrene in mealworms (source)

1) **“Biodegradation and Mineralization of Polystyrene by Plastic-Eating Mealworms: Part 1. Chemical and Physical Characterization and Isotopic Tests”**

Yu Yang, Jun Yang, Wei-Min Wu, Jiao Zhao, Yiling Song, Longcheng Gao, Ruifu Yang, and Lei Jiang

Environmental Science & Technology **2015** *49* (20), 12080-12086

DOI: 10.1021/acs.est.5b02661

formation of depolymerized metabolites occurred in the larval gut. Within a 16 day test period, 47.7% of the ingested Styrofoam carbon was converted into CO_2 and the residue (ca. 49.2%) was egested as fecula with a limited fraction incorporated into biomass (ca. 0.5%). Tests with α ^{13}C- or β ^{13}C-labeled PS confirmed that the ^{13}C-labeled PS was mineralized to $^{13}CO_2$ and

9) “Fate of Hexabromocyclododecane (HBCD), A Common Flame Retardant, In Polystyrene-Degrading Mealworms: Elevated HBCD Levels in Egested Polymer but No Bioaccumulation”

Anja Malawi Brandon, Sahar H. El Abbadi, Uwakmfon A. Ibekwe, Yeo-Myoung Cho, Wei-Min Wu, and Craig S. Criddle

Environmental Science & Technology **2020** *54* (1), 364-371

DOI: 10.1021/acs.est.9b06501

removal) with nearly a 3-log removal after 48 h. In mealworms fed PS containing high HBCD levels, only 0.27 ± 0.10%, of the ingested HBCD remained in the mealworm body tissue. This value did not increase over the course of the experiment, indicating little or no bioaccumulation. Additionally, no evidence of higher trophic level bioaccumulation or toxicity was observed when *L. vannamei* (Pacific whiteleg shrimp) were fed mealworm biomass grown with PS containing HBCD. Differences in shrimp

Remaining polystyrene in excrements

Contacts:

- PhD F.WATTEAU: specialist in microplastic in soil, CNRS Research engineer
- P.CHENON: independent expert in fertilization approval

Studies:

- Wei-Min Wu: a senior research engineer in Stanford's Department of Civil and Environmental Engineering (who has led or co-authored most of the Stanford studies of plastic-eating mealworms)

droppings. Mealworms fed a steady diet of Styrofoam were as healthy as those eating a normal diet, Wu said, and their waste appeared to be safe to use as soil for crops.

CO_2 released

Reuse:

- Carbon Capture, Use and Storage (CCUS): a growing economy
- Microalgae: the future of the fuel
- Plants: additional production of food for mealworms + reuse of excrement
- Mushrooms: an easy and healthy human food

LEGISLATION

Contacts:

- From French Ministry of Agriculture and Food: V.PLOUHINEC
- French member of parliament: Y.KERLOGOT

Laws:

- Memorandum DGAL/SDSPA/2019-836 of the 04/12/2019
- Regulation EC N°1069/2009
- Regulation EC N°142/2011
- Regulation EC N°183/2005
- Classified Installation for Environmental Protection (ICPE)

"This work provides an answer to many people who asked us whether it is safe to feed animals with mealworms that ate Styrofoam", said Wei-Min Wu, a senior research engineer in Stanford's Department of Civil and Environmental Engineering

MORE ON SUSTAINABLE FARMS

Title	Date	From	Read by	Internet site	Where	Informations on	Informations about
Insects as food and feed: Nutrient composition and environmental impact	2015 Jan.	Dennis G.A.B. Oonincx			https://drive.google.com/drive/folders/1Bmautx6MIMK7A5SKIXOS3GQWSx-AMcha		
An Exploration on Greenhouse Gas and Ammonia Production by Insect Species Suitable for Animal or Human Consumption	2010 déc.	Dennis G.A.B. Oonincx		https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3012052/	https://drive.google.com/drive/folders/1Bmautx6MIMK7A5SKIXOS3GQWSx-AMcha		Greehouse gases
Mealworm meal for animal feed: Environmental assessment and sensitivity analysis to guide future prospects	2017 sept.	A. Thévenot et al.		https://www.sciencedirect.com/science/article/pii/S0959652617320437	https://drive.google.com/drive/folders/1Bmautx6MIMK7A5SKIXOS3GQWSx-AMcha		General / Life Cycle Assessment
Environmental Impact of the Production of Mealworms as a Protein Source for Humans – A Life Cycle Assessment	2012 déc.	Dennis G.A.B. Oonincx			https://drive.google.com/drive/folders/1Bmautx6MIMK7A5SKIXOS3GQWSx-AMcha		Life Cycle Assessment
Mealworms for Food: A Water Footprint Perspective	2015 nov.	University of Salento			https://drive.google.com/drive/folders/1Bmautx6MIMK7A5SKIXOS3GQWSx-AMcha		Water impacts

INITIAL
INVESTMENT

600 sqm FARM

R&D JV Partner

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