



**CRP F23036**

# Recycling of polymer waste for structural and non-structural materials by using ionizing radiation

from ideas to execution

**Bin Jeremiah D. Barba**  
Science Research Specialist  
Philippine Nuclear Research Institute  
Chief Scientific Investigator, CRP F23035-24423



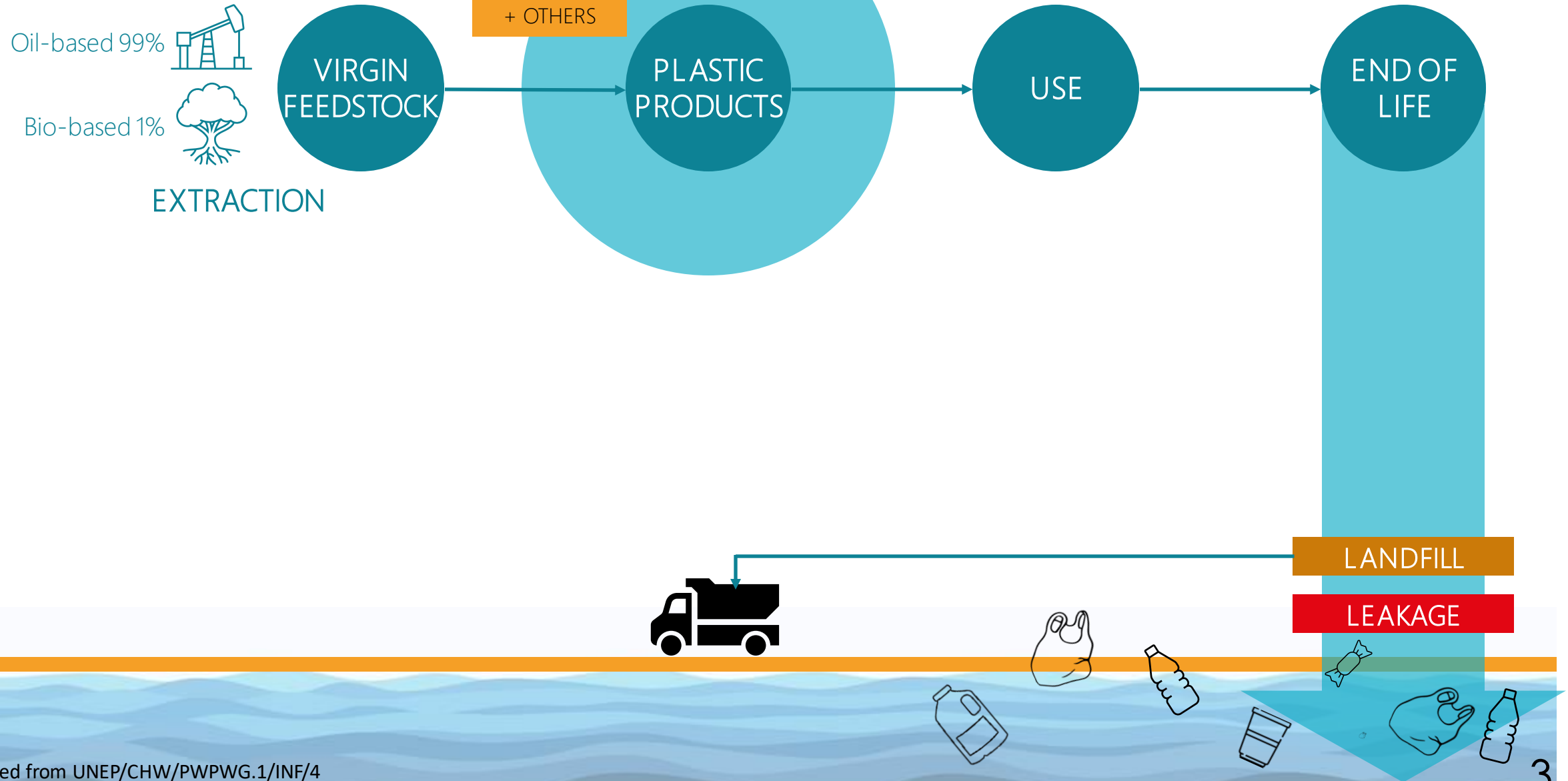
# The Plastic Problem

Polymers are one of the most versatile materials that comprise the majority of commodity and industry products

➔ Steadily increasing proportion of plastic waste ends up in landfills and leaks into oceans

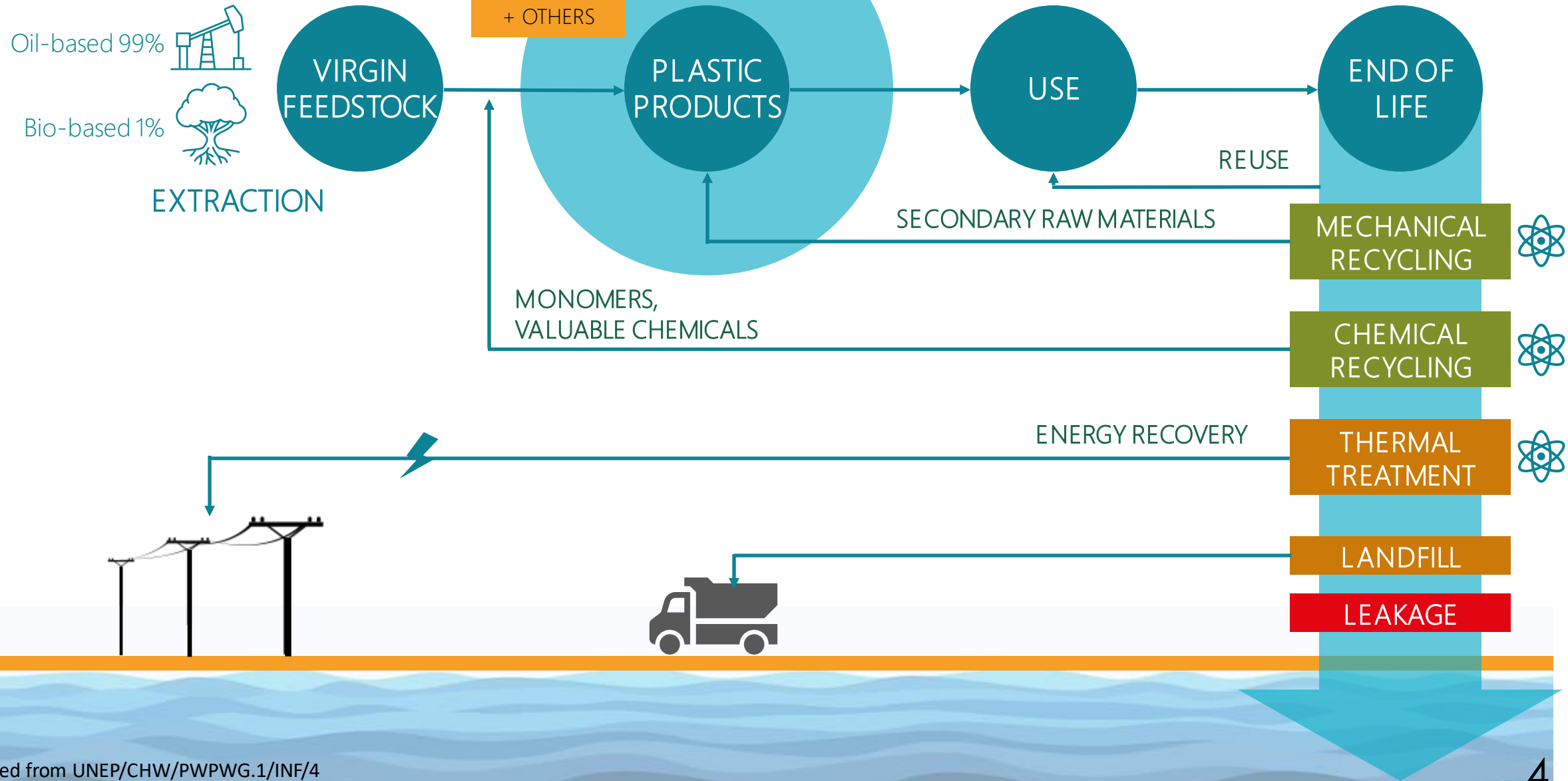


# The Plastic Problem



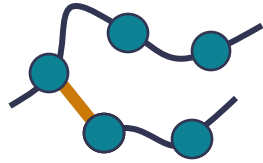
<sup>1</sup>Adapted from UNEP/CHW/PWPWG.1/INF/4

# The Plastic Problem



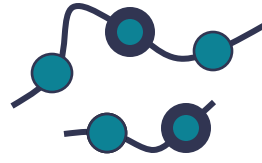
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# Nuclear Technology



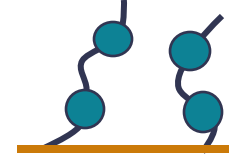
## Crosslinking/Branching

Enhancing thermo-mechanical properties



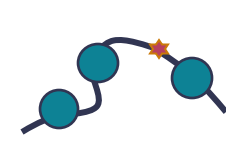
## Oxidation

Improving miscibility, forming reactive points



## Grafting

Imparting compatibility or functionalities



## Scission

Improving processability, forming LMW products

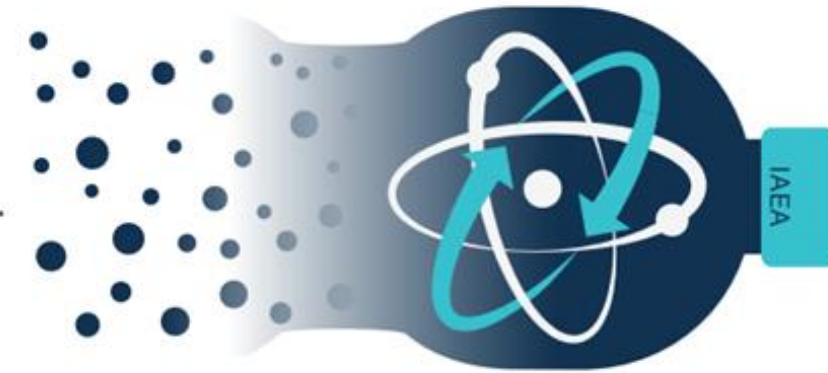
# Radiation Processing

Ionizing radiation has the capability of altering the structure and properties of bulk materials in various forms and states, with little to no additional chemical reactants and at moderate conditions



# Nuclear TECHNOLOGY for Controlling Plastic Pollution (NUTEC Plastics)

builds on the IAEA's efforts to deal with plastic pollution through recycling using radiation technology and marine monitoring using isotopic tracing techniques. It provides science-based evidence to characterize and assess marine microplastic pollution, while also demonstrating the use of ionizing radiation in plastic recycling, transforming plastic waste into reusable resources.



- ◆ Technical cooperation projects
- ◆ Coordinated research projects
- ◆ Training courses
  - Applied Radiation Technology as a Tool for Recycling of Polymer Waste
  - Technical-Economic Feasibility Studies to Implement Radiation Technology for the Recycling of Polymer Waste

<sup>3</sup><https://www.iaea.org/sites/default/files/21/05/nutec-plastics.pdf>

# CRP: Recycling of Polymer Waste for Structural and Non-Structural Materials by using Ionizing Radiation (F23036)

*The overall objective of this CRP is the applied research and development, demonstration, and scaling-up of feasibility studies to optimize the recycling of plastic waste by radiation technologies.*

- ◆ To **develop processes, techniques, protocols** for radiation recycling of plastic wastes for structural and non-structural applications
- ◆ To **investigate key factors** behind scientific challenges in radiation recycling, such as structural and functional parameters
- ◆ To **optimize the radiation process parameters** considering synergistic effects when radiation technologies are combined with other conventional treatments, to achieve efficient degradation or repurposing effects on the plastic wastes
- ◆ To endeavour in **transfer of research results to end-users**;
- ◆ To establish and develop the **network of collaboration** in the field of radiation-recycling

# CRP: Recycling of Polymer Waste for Structural and Non-Structural Materials by using Ionizing Radiation (F23036)



22 Participating Countries

Argentina  
Brazil  
Peru

Croatia  
Hungary  
Poland  
Serbia  
Turkiye

Algeria  
Egypt  
Ghana  
Tunisia

Bangladesh  
India  
Malaysia  
Thailand  
Viet Nam

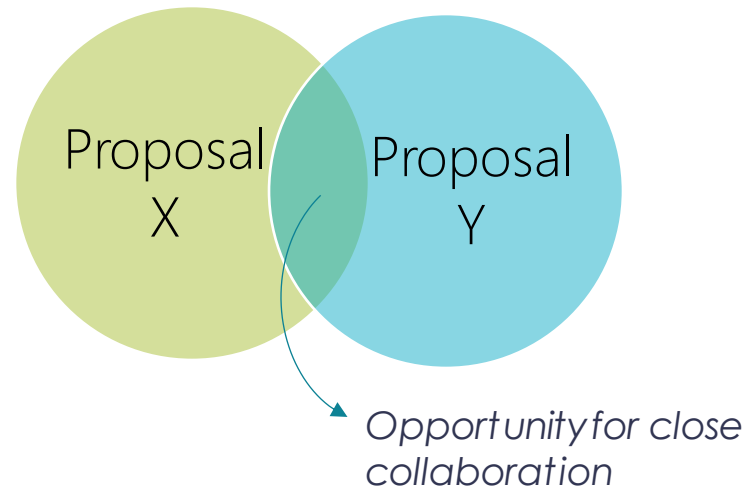
China  
Indonesia  
Philippines  
Russian Federation  
Republic of Korea



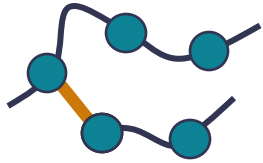
# CRP: Recycling of Polymer Waste for Structural and Non-Structural Materials by using Ionizing Radiation (F23036)

Strategic implementation of radiation-supported recycling initiatives while tailoring processes to specific country needs

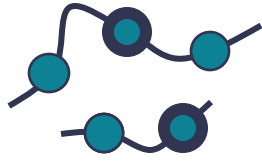
- ◆ Polymer waste type and source
- ◆ Target product / industry
- ◆ Available resources
- ◆ Technology fit



# Team Coordination



**Crosslinking/Branching**



**Oxidation**

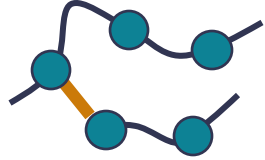


**Grafting**



**Scission**

# Team Coordination



Radiation crosslinking for reuse or repurposing into high value products



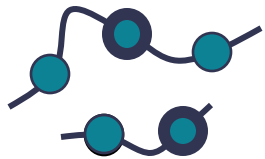
## Crosslinking/Branching



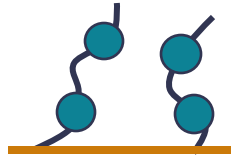
Radiation degradation for the production of value-added low molecular weight products



## Scission



## Oxidation



## Grafting

Radiation compatibilization and grafting for property improvement and special applications



# Resource Sharing

## Collaboration Table

	Algeria	Argentina	Brazil	China	Croatia	Egypt	Ghana	Hungary	Indonesia	Malaysia	Peru	Philippines	Poland	Russian Federation	Serbia	Thailand	Turkey	Vietnam
Algeria	■					■	■						■					
Argentina		■									■	■		■		■		
Brazil			■	■						■								
China				■	■							■		■				
Croatia					■							■	■	■				
Egypt	■					■	■		■					■				■
Ghana	■					■	■						■					
Hungary								■						■			■	
Indonesia						■			■									
Malaysia			■							■			■	■				
Peru	■	■	■								■							
Philippines		■		■	■							■	■	■				
Poland	■					■				■		■	■		■		■	
Russian Federation		■		■	■	■		■	■	■		■		■				
Serbia													■		■			
Thailand		■											■			■	■	
Turkey								■					■			■	■	
Vietnam						■												■

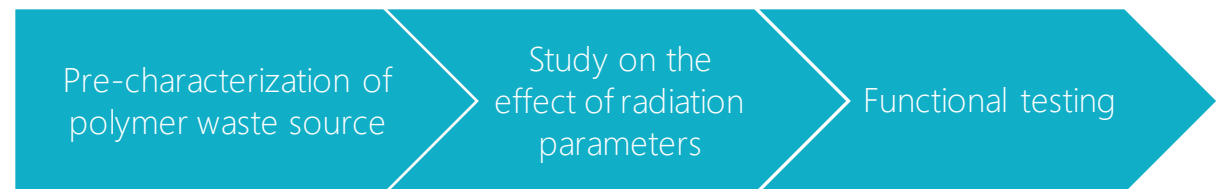
- ◆ Full contact information
- ◆ List of irradiators
- ◆ List of processing equipment
- ◆ List of analytical equipment



# Harmonized research approach

## TECHNOLOGY READINESS LEVEL (TRL)

RESEARCH DEVELOPMENT DEPLOYMENT	9	ACTUAL SYSTEM PROVEN IN OPERATIONAL ENVIRONMENT
	8	SYSTEM COMPLETE AND QUALIFIED
	7	SYSTEM PROTOTYPE DEMONSTRATION IN OPERATIONAL ENVIRONMENT
	6	TECHNOLOGY DEMONSTRATED IN RELEVANT ENVIRONMENT
	5	TECHNOLOGY VALIDATED IN RELEVANT ENVIRONMENT
	4	TECHNOLOGY VALIDATED IN LAB
	3	EXPERIMENTAL PROOF OF CONCEPT
	2	TECHNOLOGY CONCEPT FORMULATED
	1	BASIC PRINCIPLES OBSERVED



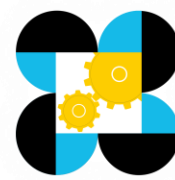
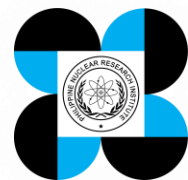


Contract No. 24423

# Radiation Processing Intervention in the Recycling of Post-Consumer Plastics for the Development of High-Performance Products

Chief Scientific Investigator: Bin Jeremiah D. Barba  
Implementing Agency: DOST-Philippine Nuclear Research Institute  
Collaborating Agencies: DOST-Industrial Technology Development Institute  
Envirotech Waste Recycling Inc.  
National Institutes for Quantum Science and Technology (QST)

Duration (Current): July 2021 – 2025



**Envirotech**  
Envirotech Waste Recycling Inc.



# The Philippine Context

## PROBLEM

low collected-for-recycling (CFR) rates

**1.1 MT** plastic waste  **28 %** recycled 

Source: World Bank Group (2021)

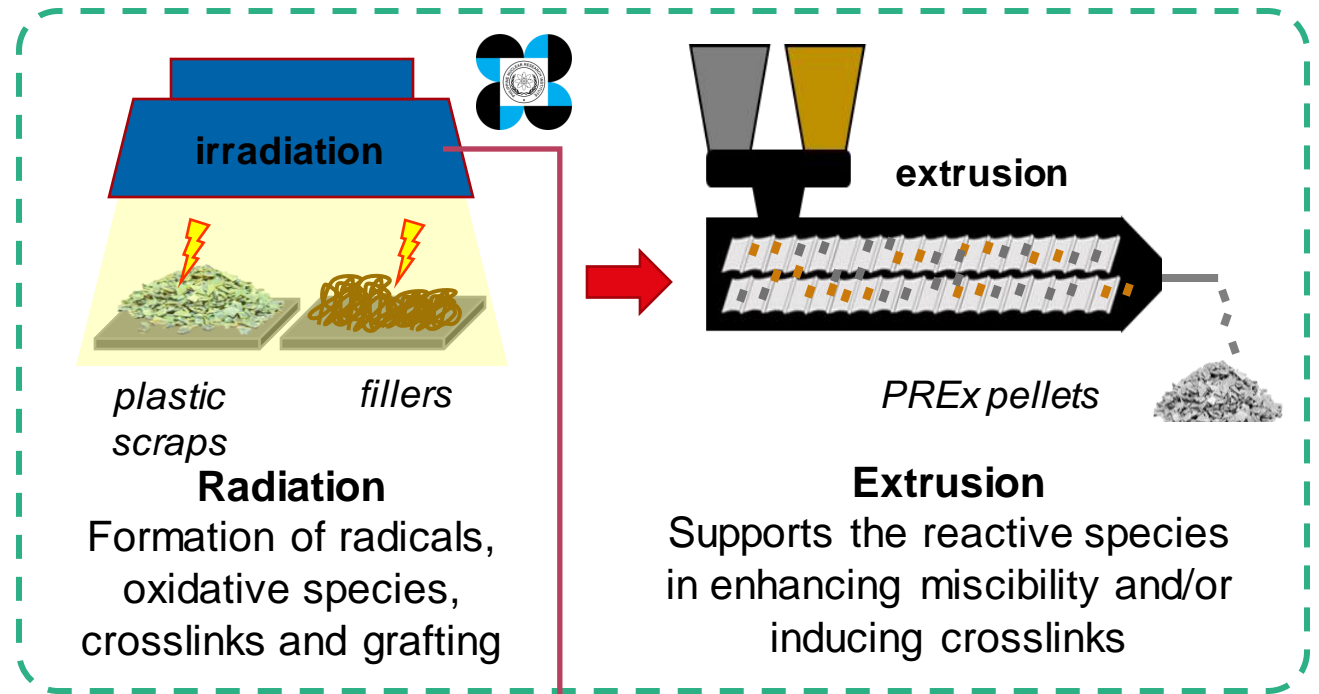
**No sustainable and economic product = no demand for recycling**

**790 M** annual loss 

## NEED

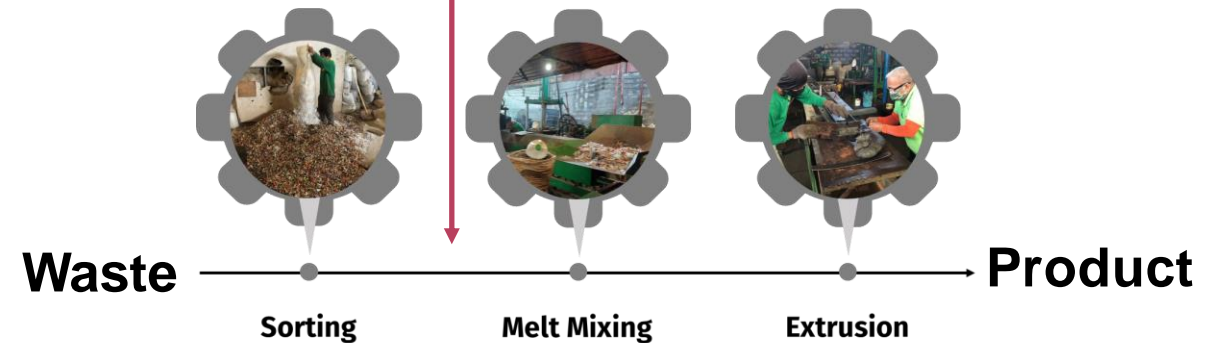
Integrable recycling technology that can improve the thermomechanical properties plastic waste to enable UPcycling into useful high value products

## PROPOSED SOLUTION



**Radiation**  
Formation of radicals, oxidative species, crosslinks and grafting

**Extrusion**  
Supports the reactive species in enhancing miscibility and/or inducing crosslinks



## CONVENTIONAL PROCESS

# Strong industry support

# Envirotech

Envirotech Waste Recycling Inc.

Philippine-based recycling company, whose mission is to minimize local plastic waste by utilizing them to generate useful commodities such as:

- School chairs and tables
- Park benches
- Pots
- Lumber
- Planks
- Pallets



<sup>6</sup><https://envirotech.com.ph/>

## Collection



## Sorting



## Extrusion



## Melt Mixing



## Molding



## Product\*





# TRL 3 – Experimental Proof of Concept

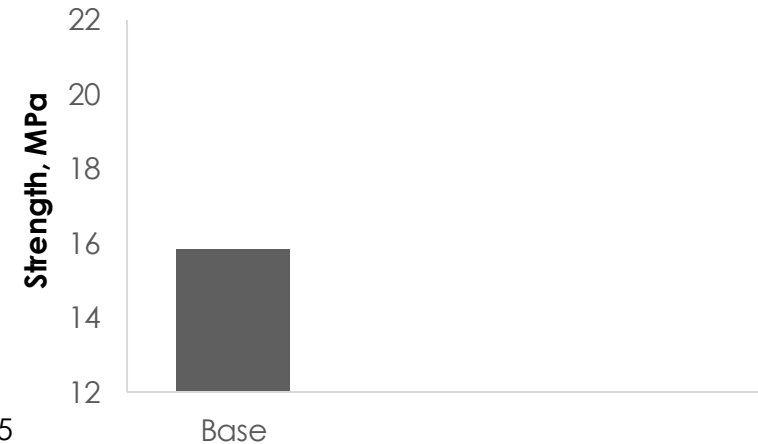
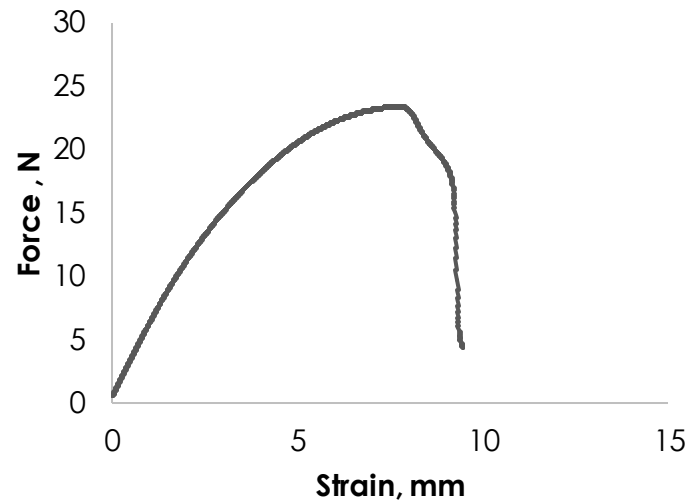


## Highlights



### mixed municipal waste

- ◆ HDPE
- ◆ PP
- ◆ L/LDPE
- ◆ MLP



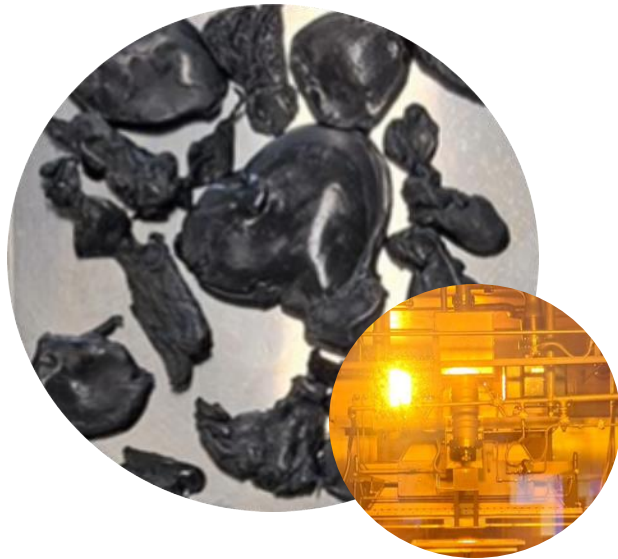
Base  
Flexural Strength

Base properties and characterization of raw materials

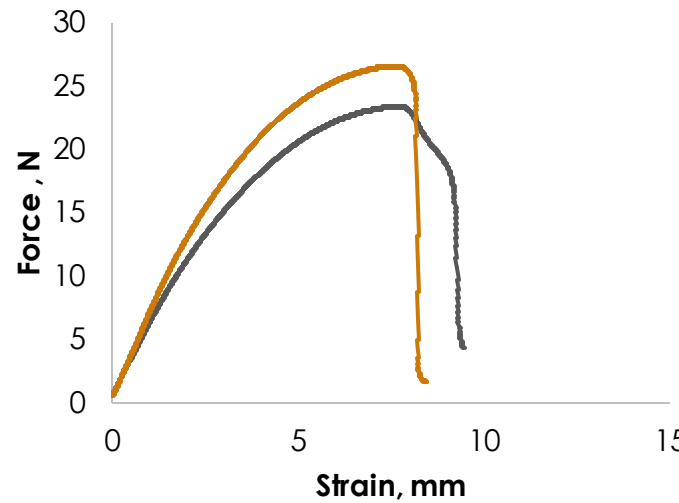
# TRL 3 – Experimental Proof of Concept



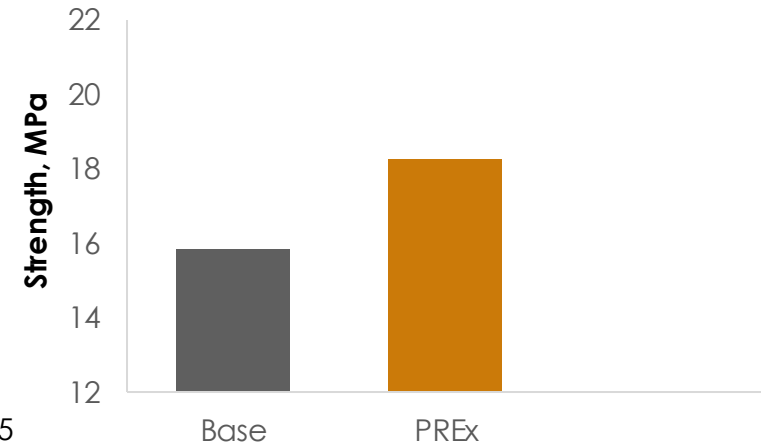
## Highlights



**PReX processed  
mixed municipal waste**



**Stronger,  
slightly more rigid**



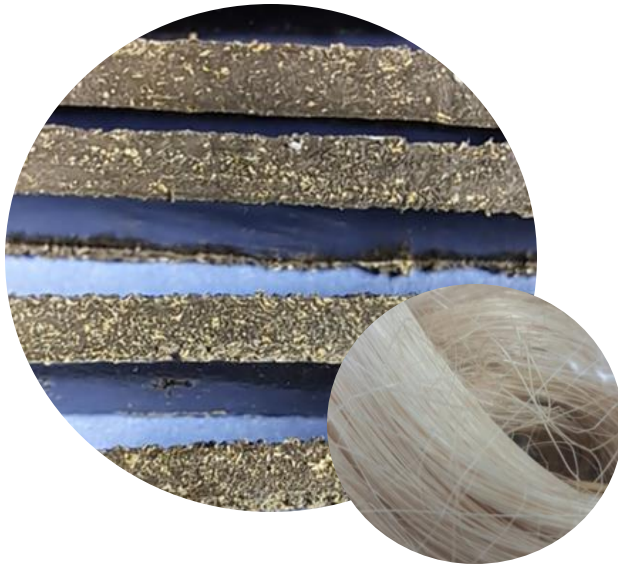
**15% increase in  
Flexural Strength**

**Optimizing dose and processing effects of PReX**

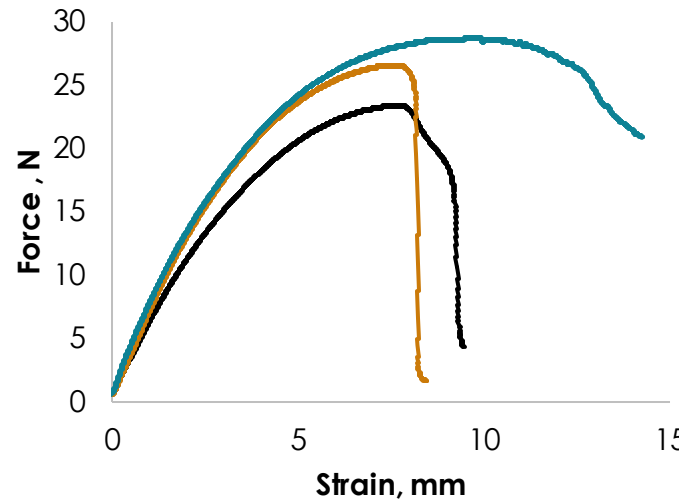
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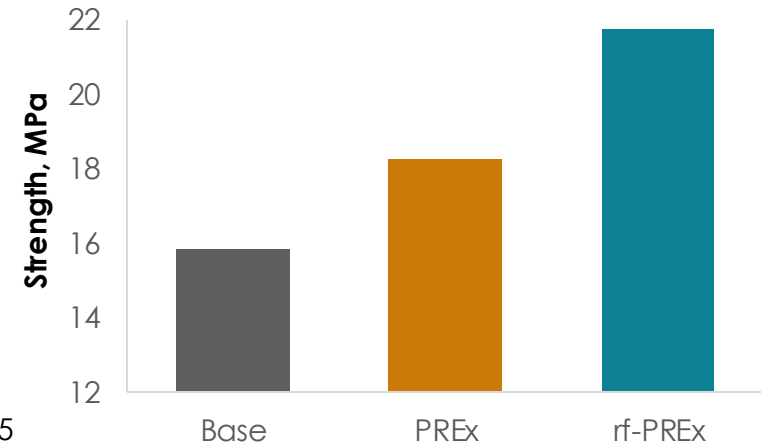
## Highlights



**PREx processed  
mixed municipal waste  
+ abaca fibers**



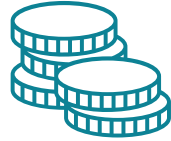
**Stronger,  
additional flexibility**



**25–37% increase in  
Flexural Strength**  
\*vs 4% increase for pristine fibers

**Optimizing radiation / grafting parameters of fiber reinforcement**

# Economic Feasibility




**IAEA**  
 International Atomic Energy Agency

**EXCEL-BASED ECONOMIC ASSESSMENT MODEL TOOL**

[Instructions](#)
[Inputs & Results](#)
[Dashboard](#)
[WP Budget](#)
[WOP Budget](#)
[Incremental Budget](#)

**E-BEAM (Excel-Based Economic Assessment Method)**

Version 1.7 - Build: 05 November 2021 - Authored by: Enrico Mazzoli

**B/C = 1.67**

## New Facility Plan

ITEMS	Cost (€)
<b>CAPEX</b>	2,111,162.00
- 2 MeV EB Accelerator	1,681,651.00
- Processing equipment	429,511.00
<b>PRODUCTION COSTS</b> (@ 60% capacity, ~4,603 TPY)	3,808,166.00
- Operation/Inputs	1,952,131.00
- Labor	174,384.00

<b>REVENUE</b> (with 40% post-processing loss) @ € 1300/ton	4,143,053.00
<b>NET INCOME (Year 1)</b> after production, labor, investment costs	(217,520.00)
<b>NET INCOME (Year 2)</b> after production, labor costs	1,833,182.00



# Potential Project Benefits



## TECHNICAL BENEFITS

A 15–40% increase in mechanical properties with one additional step to the current set-up



## ECONOMIC BENEFITS

An estimated 1.67 EUR of economic benefits could be generated per 1 EUR costs and a return of investment in 2 years<sup>7</sup>



## ECOLOGICAL BENEFITS

Diversion of plastic waste especially hard-to-recycle plastics along with the reuse of carbon-rich resources

<sup>8</sup>Based on preliminary estimates using a model process from experimental data and Envirotech inputs; not including savings from environmental costs

# Securing Local Project Funding

**Funding Agency:** DOST-PCIEERD

**Project Title:** "Post-radiation Reactive Extrusion of Plastic Waste (PREx Plastic)"



Ceremonial Signing of Memorandum of Agreement for Approved National Project and between Collaborating Agencies



# Information Dissemination

37th Philippine  
Chemistry Congress  
26-28 July 2023




**RADIATION TECHNOLOGY IN PLASTIC RECYCLING**

IAEA, Envirotech, QST

**The global scenario...**  
 14% recycled  
 40% landfilled  
 30% burned

**The Philippine context...**  
 1.1 MT plastic waste  
 28% recycled  
 USD 790 M annual material value loss

**Technical factors in low recycling rates...**  
 Variation in plastic quality/composition  
 Commingling of the different plastic types  
 Poor thermo-mechanical properties of the recycled products  
 Lack of efficient and integrable technological intervention

sort → wash → thermal process → product

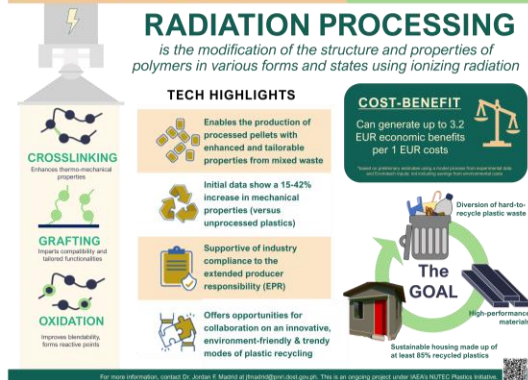


REFLECT.  
RECONNECT.  
RESET.

ADB INNOVATION FAIR 2022

5 Oct 2022 | innovationfair.adb.org

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**RADIATION PROCESSING**  
is the modification of the structure and properties of polymers in various forms and states using ionizing radiation

**TECH HIGHLIGHTS**

- CROSSLINKING**: Enhances thermo-mechanical properties
- GRAFTING**: Imparts compatibility and tailored functionalities
- OXIDATION**: Improves biodegradability, forms reactive groups

**COST-BENEFIT**  
Can generate up to 3.2 EUR economic benefits per 1 EUR costs

Enables the production of processed pellets with enhanced and tailorable properties from mixed waste

Initial data show a 15-42% increase in mechanical properties (versus unprocessed plastics)

Supportive of industry compliance to the extended producer responsibility (EPR)

Offers opportunities for collaboration on an innovative, environment-friendly & trendy modes of plastic recycling

**The GOAL**  
Sustainable housing made up of at least 85% recycled plastics

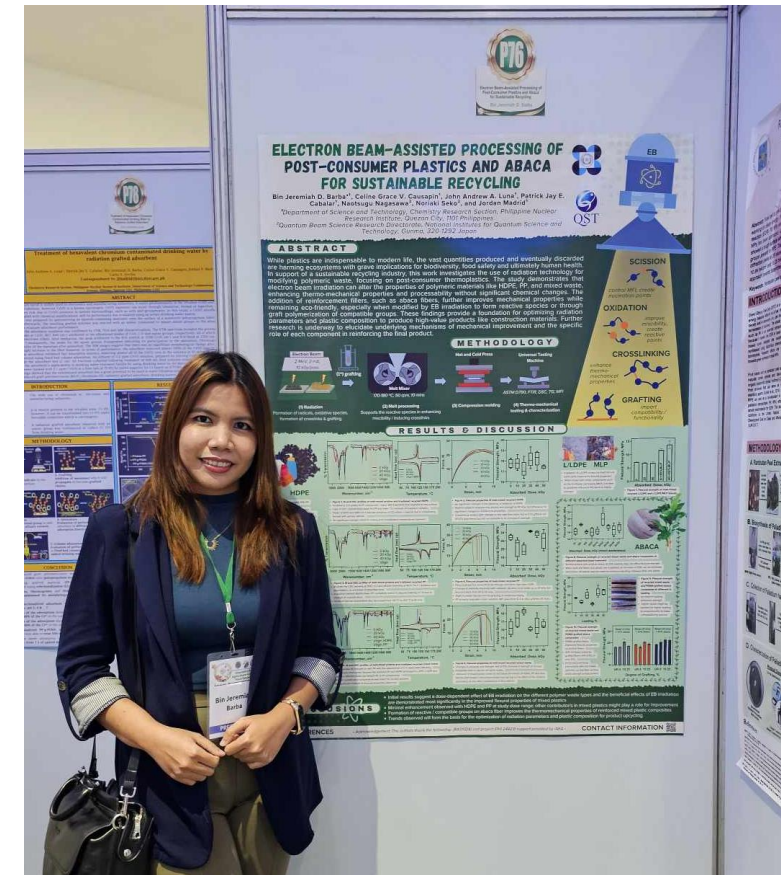
High performance materials

Division of hard-to-recycle plastic waste



IAEA, Envirotech, QST

**RADIATION TECHNOLOGY IN PLASTIC RECYCLING**  
Introducing The Philippine PReX Plastics



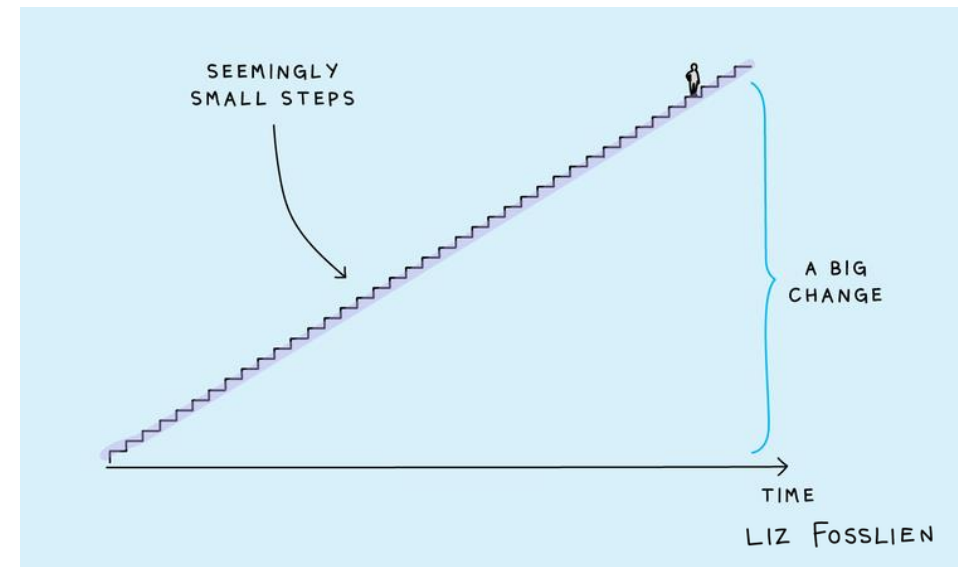
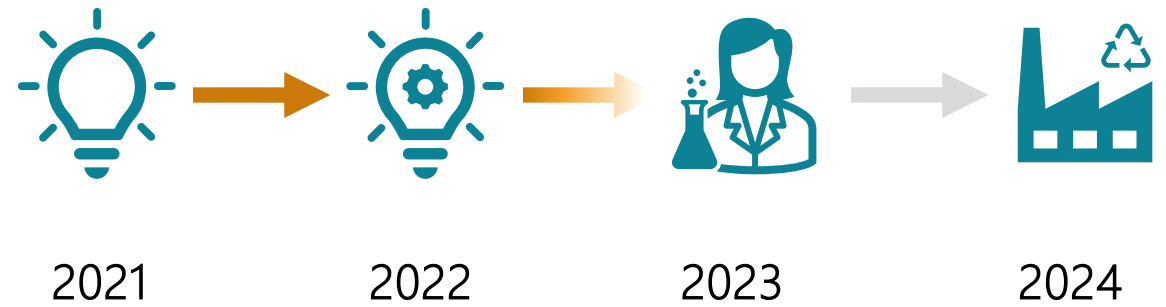
ADB Innovation Fair  
5 October 2022

# The next steps . . .

**TECHNOLOGY READINESS LEVEL (TRL)**

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8	SYSTEM COMPLETE AND QUALIFIED
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1	BASIC PRINCIPLES OBSERVED

**RESEARCH** (TRL 1-3)  
**DEVELOPMENT** (TRL 4-6)  
**DEPLOYMENT** (TRL 7-9)





**Thank You**