From Static Maps to Dynamic Flows: Designing Circular Business Models for Batteries

A System Dynamics Approach to the Battery Energy Storage System (BESS) Lifecycle

Hidde J. Huijssoon | Lucerne University of Applied Sciences and Arts

COLUMN 1: The Context & Method

1. The Problem: The Static Trap

Challenge: Industry transitioning to a circular economy, but decision-makers rely on static ecosystem maps.

The Gap: Static maps fail to capture **Time Delays, Degradation**, and **Feedback Loops.**

Research Question: How can sustainable business models be designed for material flows in BESS, aligning with the Triple Bottom Line?

2. Methodology: Design Science Research

CYCLE 1: MAPPING

Exploratory interviews & ecosystem mapping to identify actors and flows.

CYCLE 2: STRUCTURING

Causal Loop Diagrams & Stock-and-Flow diagramming to define the system.

CYCLE 3: SIMULATING

Agent-Based Modelling (ABM) in **AnyLogic** to simulate scenarios (2020–2060).

COLUMN 2: The Model & Scenarios

3. The Dynamic Ecosystem Model

OEM (Production): Introduces BESS units.

Use Phase (Degradation): Degradation based on usage profiles.

Maintenance (The Stabilizer): Slows degradation, prevents early failure.

Refurbishment (The Gatekeeper): Mid-life check; restores viable batteries (arrow back to Use Phase), sends scrap to recycling.

Recycling (The Sink): Recovers raw materials.

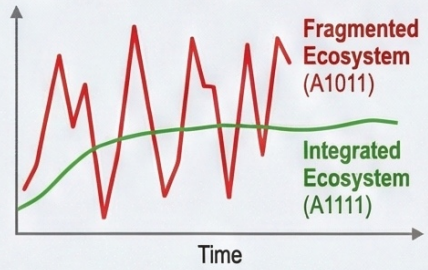
4. Scenario Analysis

Scenario	Configuration	Outcome
A1000	OEM Only	**Linear System:** 100% material loss after first life. High volatility.
A1011	OEM + Refurb + Recycle	**Unstable:** Without maintenance, inflow quality varies, causing recycling spikes.
A1111	**Full Integration**	**Circular:** Maintenance stabilizes flows + Refurbishment extends life + Recycling captures scrap.

COLUMN 3: Findings & Implications

5. Key Findings: It's About Sequencing

Fragmented vs. Integrated Ecosystem



Presence ≠ Performance: Simply having a recycler isn't enough.

The Sequencing Effect:

- **Maintenance** acts as a buffer.
- **Refurbishment** is a "quality gate".
- **Recycling** requires stable upstream flow.

The Leakage Risk: High exports undermine the domestic circular economy.

6. Managerial Implications

Design Managed Structures: Move to integrated lifecycle contracts.

Data as Infrastructure: Shared State-of-Health (SoH) data is a prerequisite.

Revenue Distribution: Cross-subsidize low-margin necessities (e.g., recycling) with high-margin services.

7. Conclusion

Effective circularity is a **coordination challenge.** Sustainable business models require an integrated sequence of **Maintenance → Refurbishment → Recycling** to convert volatile waste streams into predictable value flows.

Call to Action
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