Circular Economy of Materials and Global Supply Chains

Fazleena Badurdeen, PhD

Professor of Mechanical Engineering

Director of Graduate Studies for Manufacturing Systems Engineering,

Institute for Sustainable Manufacturing,

University of Kentucky

University of Kentucky College of Engineering

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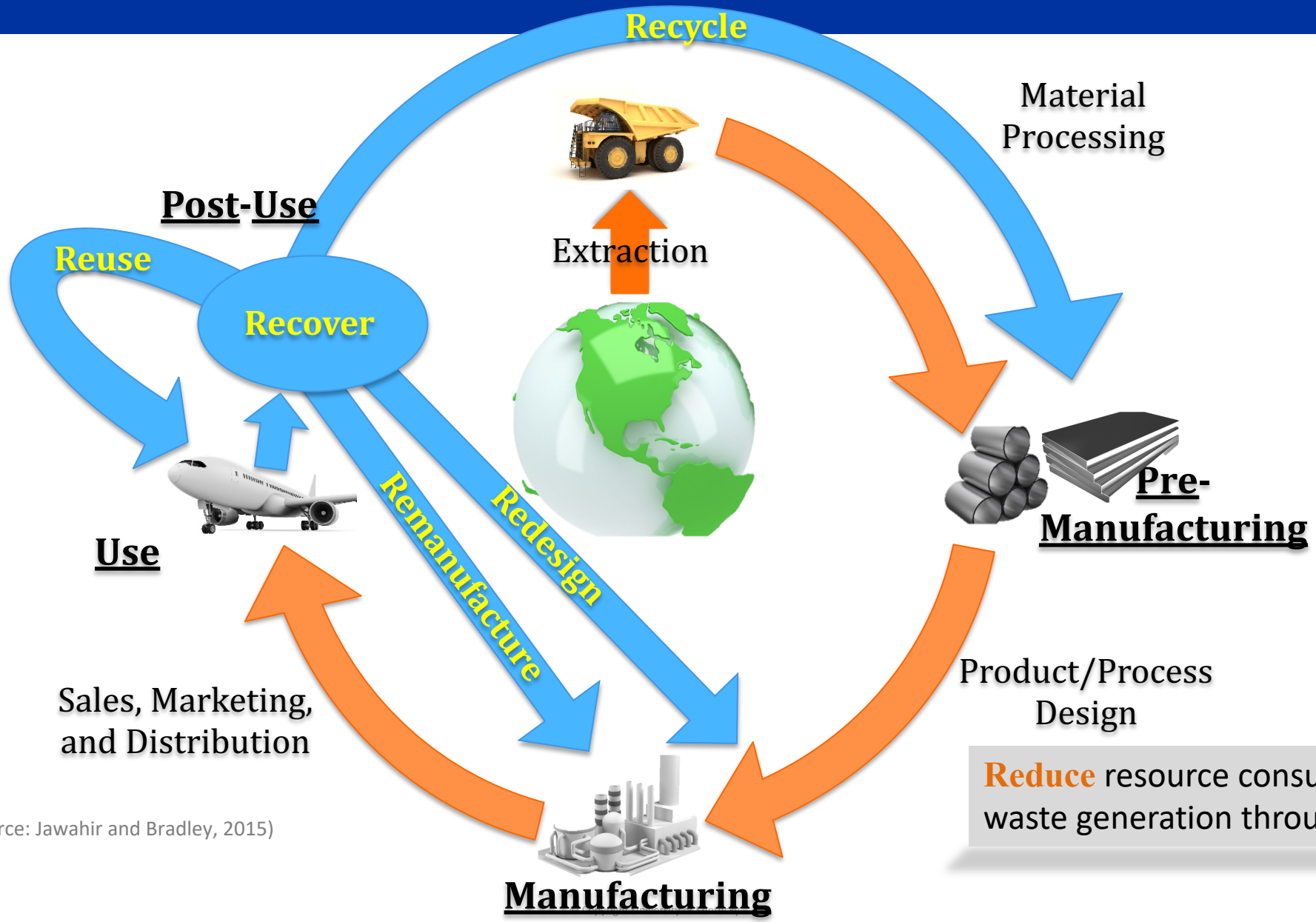
Circular Material Flow: The 6R Approach



(Source: Jawahir and Bradley, 2015)

Reduce resource consumption and waste generation throughout lifecycle…

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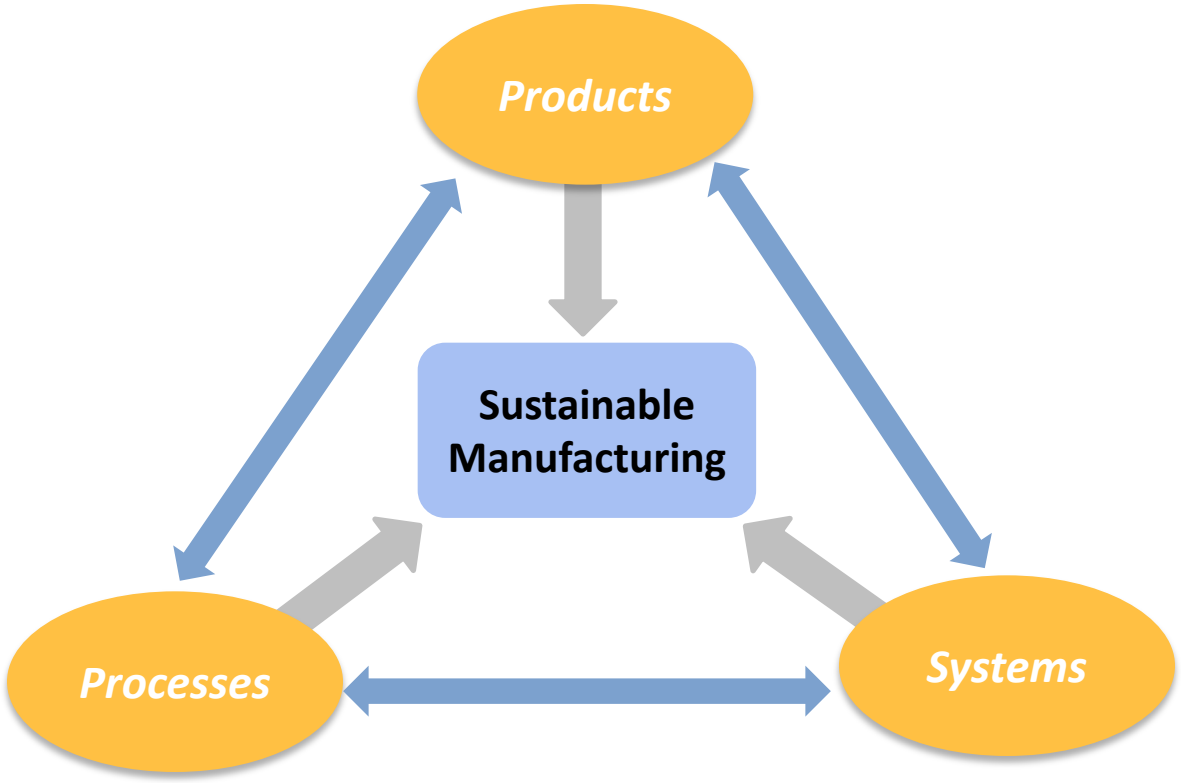
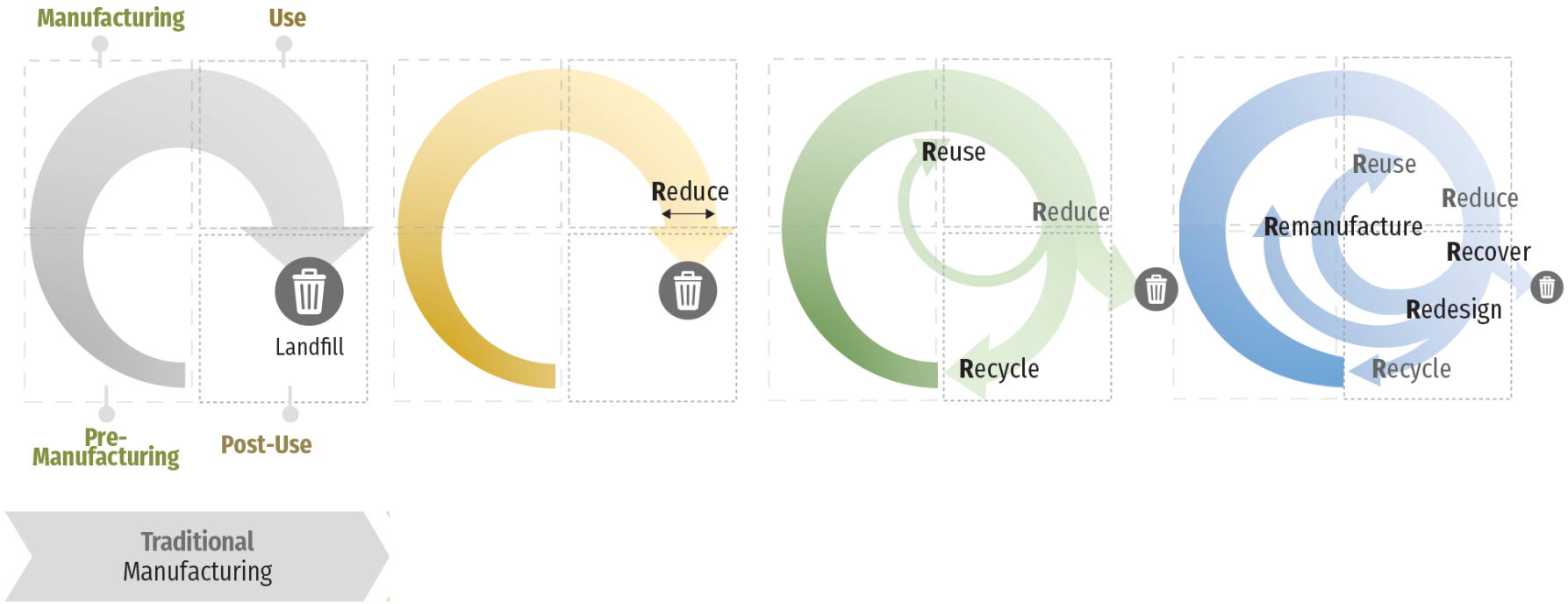
Product-Process-System Integration

- For a Circular Economy, sustainable manufacturing requires emphasis across different domains



Evolution of Sustainable Manufacturing



Exponential Increase in Value for all Stakeholders by Managing Embodied Energy and Material Flow in Closed-Loop Lifecycles

6R-based approach enables operationalizing the 'Circular Economy'

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(Badurdeen, F. and Jawahir, I.S., "Strategies for Value Creation through Sustainable Manufacturing", *Proceedia Manufacturing*, Vol. 8, 2017, pp. 20-27)

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Sustainable Manufacturing - Definition

Sustainable manufacturing at ***product, process and systems*** levels must:

- demonstrate reduced ***negative environmental impact,***
- offer improved ***energy and resource efficiency,***
- generate ***minimum quantity of wastes,***
- provide ***operational safety,*** and
- offer improved ***personnel health;***

- All while maintaining and/or improving the ***product and process quality*** with overall ***lifecycle cost benefits***

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(Source: Jawahir, I.S., Badurdeen, F. and Rouch, K.E., "Innovation in sustainable manufacturing education", Proceedings of the11thGlobal Conference on Sustainable Manufacturing-Innovative Solution, 2014, pp. 9-16).

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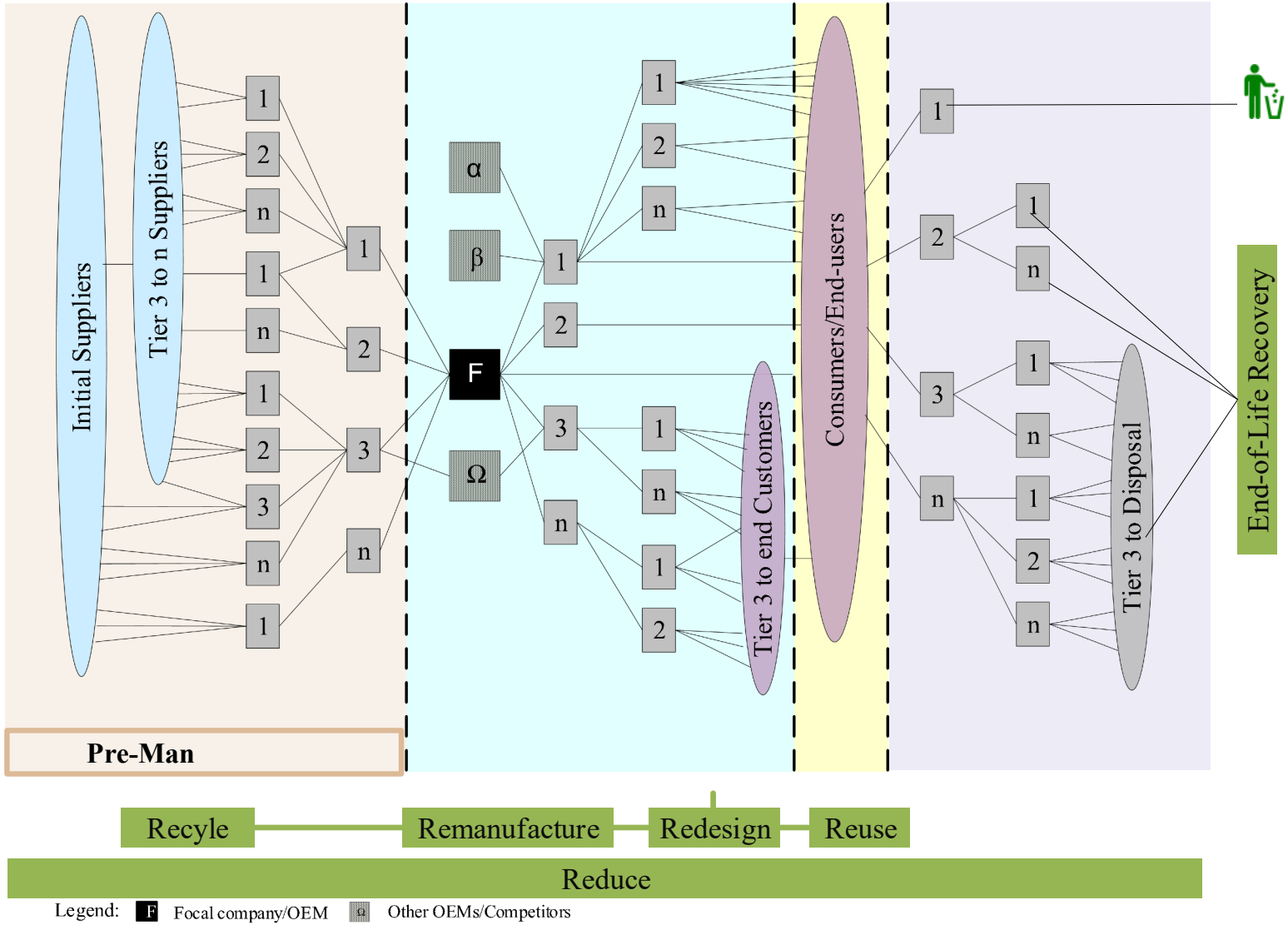
Operationalizing the Circular Economy through the Supply Chain



(Badurdeen et al., 2009, "Extending total lifecycle thinking to sustainable supply chain design", *IJPLM*, Vol. 4, Nos 1/2/3, 2009)

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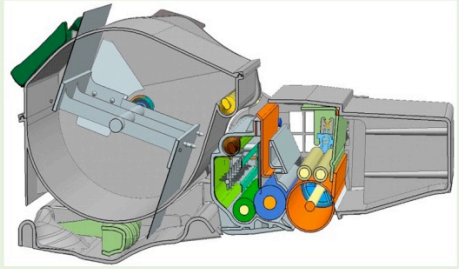
Circular Economy Business Model Impacts

Laser Toner Cartridges

Pre-Manufacturing — Component Level

- Toner housing
- Toner level
- Toner adder roll
- Bushings/Bearings
- Auger
- Dev roll (foam on metal shaft)
- Doctor blade
- Toner paddle
- Waste toner housing
- Photo conductive (PC) drum
- Cleaner blade
- Charge roll

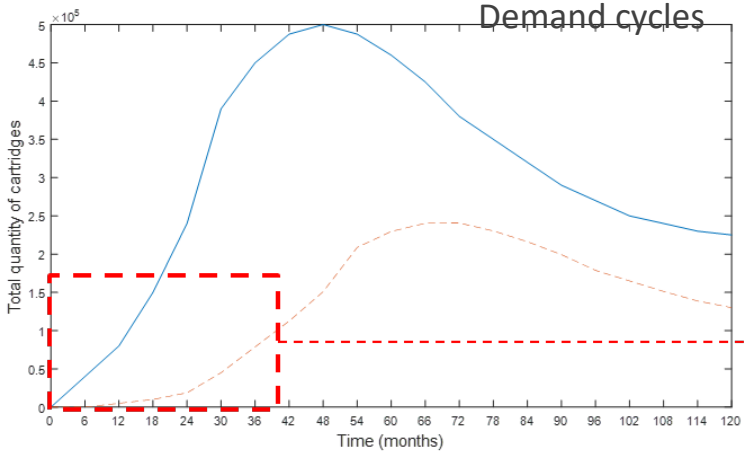
Manufacturing — Product Level

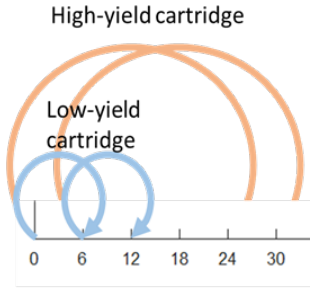


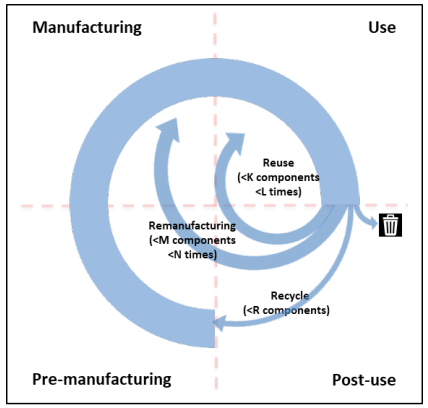
Use

Post-Use

Emphasis on all lifecycle stages







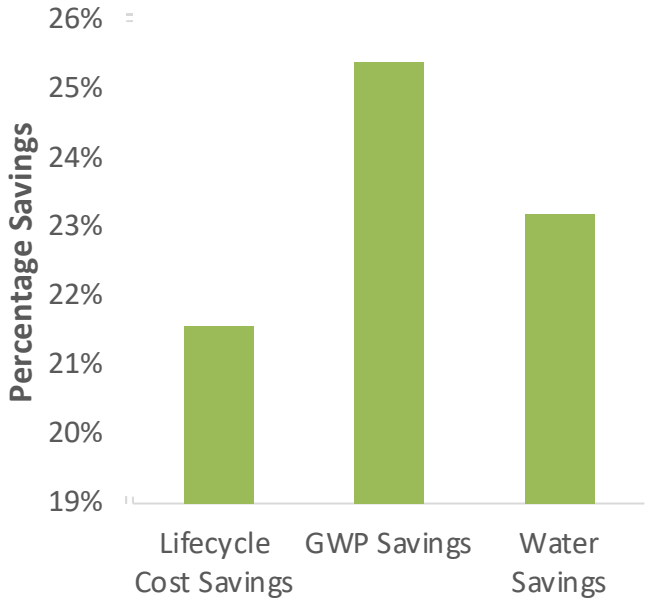
Multi-lifecycle Material Flow

(Source: Badurdeen, F., Aydin, R. and Brown, A., "A Multiple Lifecycle-based Approach to Sustainable Product Design", *Journal of Cleaner Production,* Vol. 200, 2018, pp. 756 – 769).

Circular Economy Business Model Impacts

Laser Toner Cartridges

Benefits Multi-lifecycle Products for Circular Economy*



*Compared to baseline design without 6R application

- Value recovery potential varies: Reuse > Remanufacturing > Recycling
- Success depends on ability to enable end-of-life takeback from customer
- Supply chain partnerships essential
- Business case for Circular Economy is very clear; challenges will vary from one industry to another

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(Source: Badurdeen, F., Aydin, R. and Brown, A., "A Multiple Lifecycle-based Approach to Sustainable Product Design", *Journal of Cleaner Production,* Vol. 200, 2018, pp. 756 – 769).

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