Circular Economy virtual workshop during September 23 & 24, 2020

Sustainable Materials - Innovating Our Future Beyond the Pandemic

https://bioproductscentre.com/events/SustainableMaterialsWorkshop

Circular Economy & Sustainable Materials Beyond the Pandemic

Professor Seeram Ramakrishna, *FREng, Everest Chair*

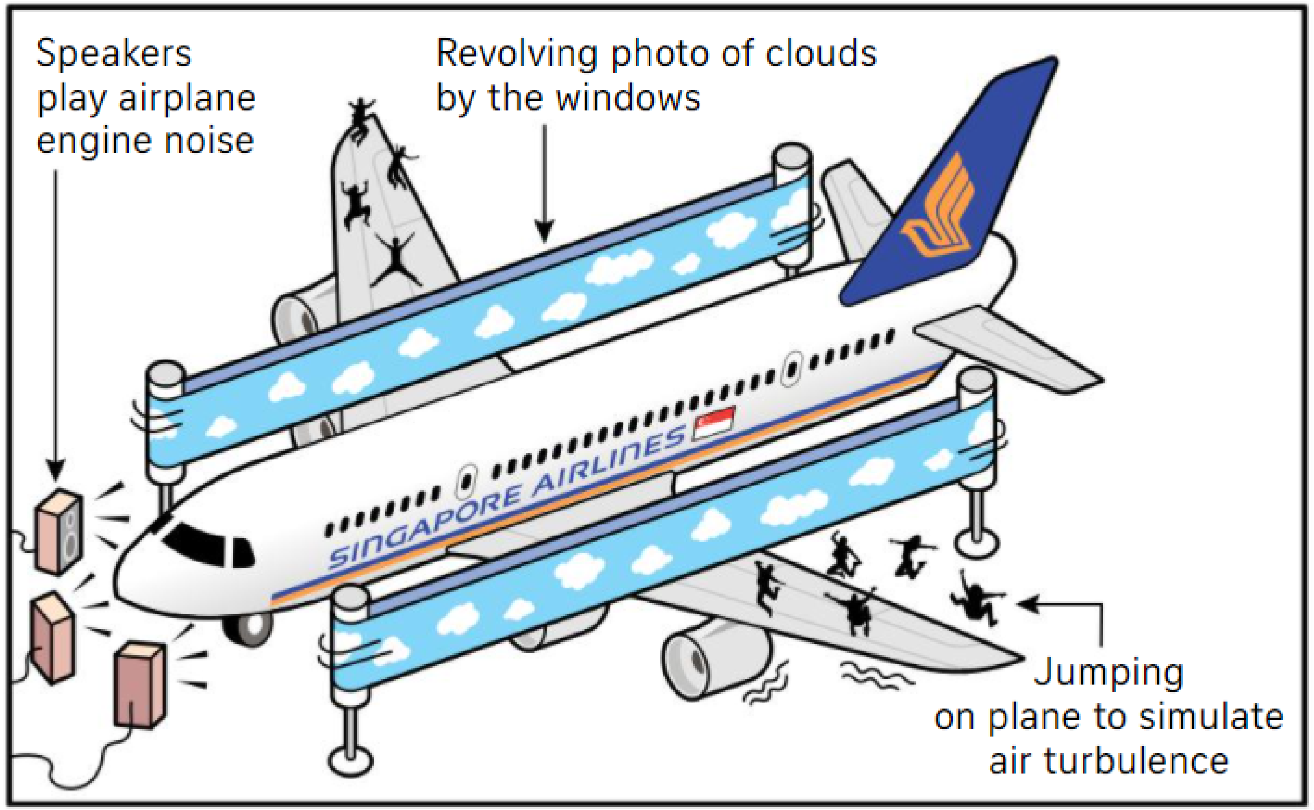
Chair, Circular Economy Taskforce, National University of Singapore

Editor-in-Chief, Materials Circular Economy (*springer.com/journal/42824*)

seeram@nus.edu.sg

Living with COVID19 and after pandemic!

How to have 'flights to nowhere' with zero carbon emissions:



The Covid-19 pandemic has accelerated the transition towards sustainability, said Clifford Capital Holdings' group chief executive office Clive Kerner. He added that with more countries onshoring their supply chains and against the backdrop of low interest rates, infrastructure as an asset class may become increasingly attractive for investors.

3.16kg

Amount of carbon dioxide released per litre of jet fuel burned. Carbon dioxide contributes to the greenhouse effect causing global warming and climate change.

https://stepaper.straitstimes.com/jr/jrpc.php?date=2020-09-18&ed=1&page=1

Living with COVID19 and after pandemic!

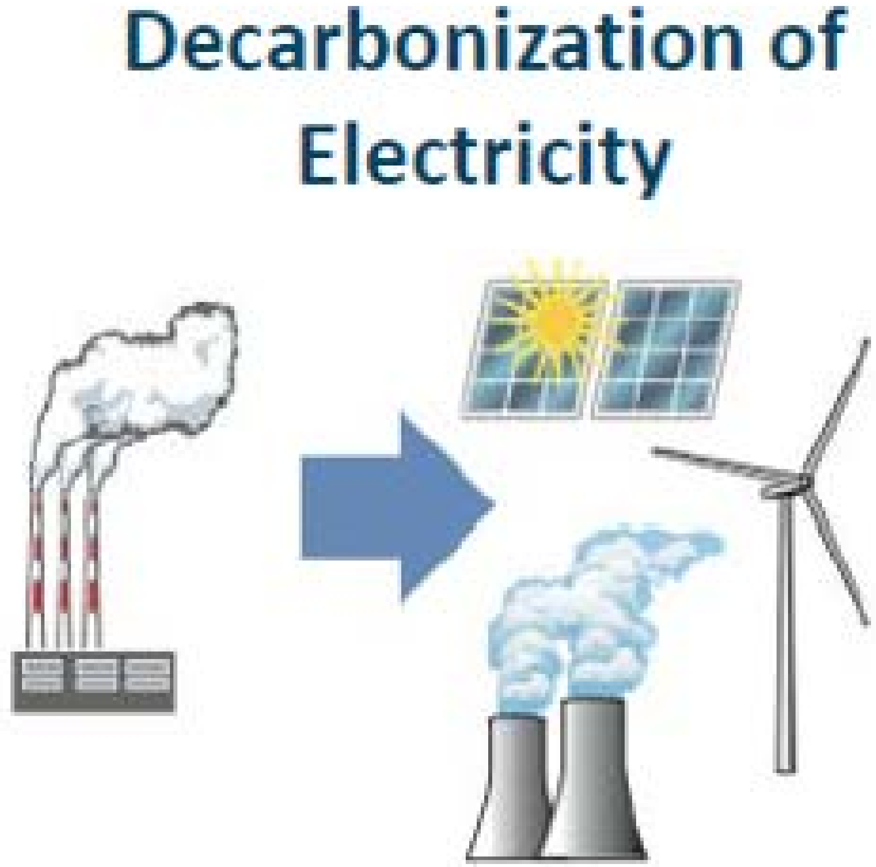
❖ COVD19 experience (negative impacts on human health & economy) underscores the need for humanity to be prepared for the next disaster.

❖ Extreme weathers caused by the climate change are the future disasters.

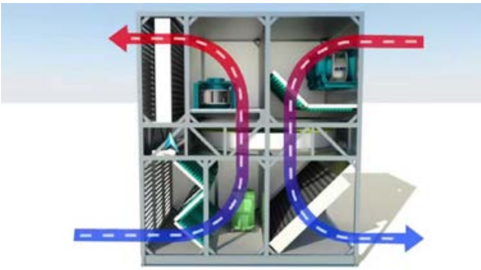
❖ Sustainable development via low-carbon or de-carbonized economies is necessary for mitigating/averting future disasters. Circular economy (CE) is a means to realize low-carbon economies. CE is akin to a sustainable development strategy to tackle challenges of environmental degradation and resource scarcity.

❖ Some common elements of diverse CE strategies include switching to renewable energies; energy efficiency; shared economy; resources efficiency; sustainable product design; environmentally friendly life style- reuse & recycle.

De-carbonization Strategies of Data Centers



De-carbonization via energy efficiency & cooling system designs



*They reduce the **operational carbon** of Data Centers*

https://www.datacenterdynamics.com/en/conferences/singapore/2020-virtual/keynote-the-circular-data-center---designing-digital-infrastructure-for-disassembly/

GHG emissions from the materials production (~11Gt CO_{2e}) is 23% of global emissions

Two fifths of materials in terms of GHGs are used in construction, and two fifths are used in the manufacturing of machinery, vehicles and other durable products.

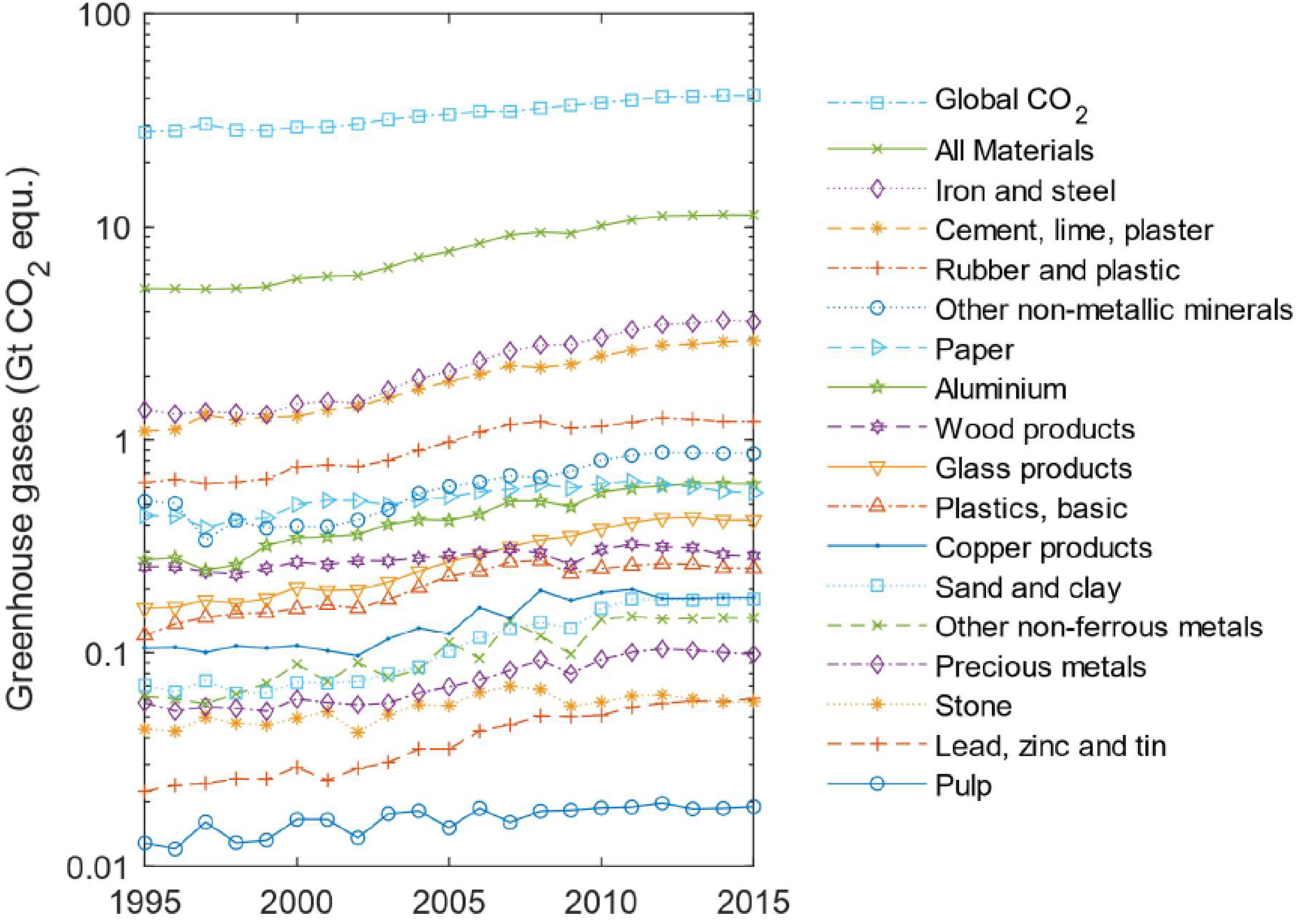
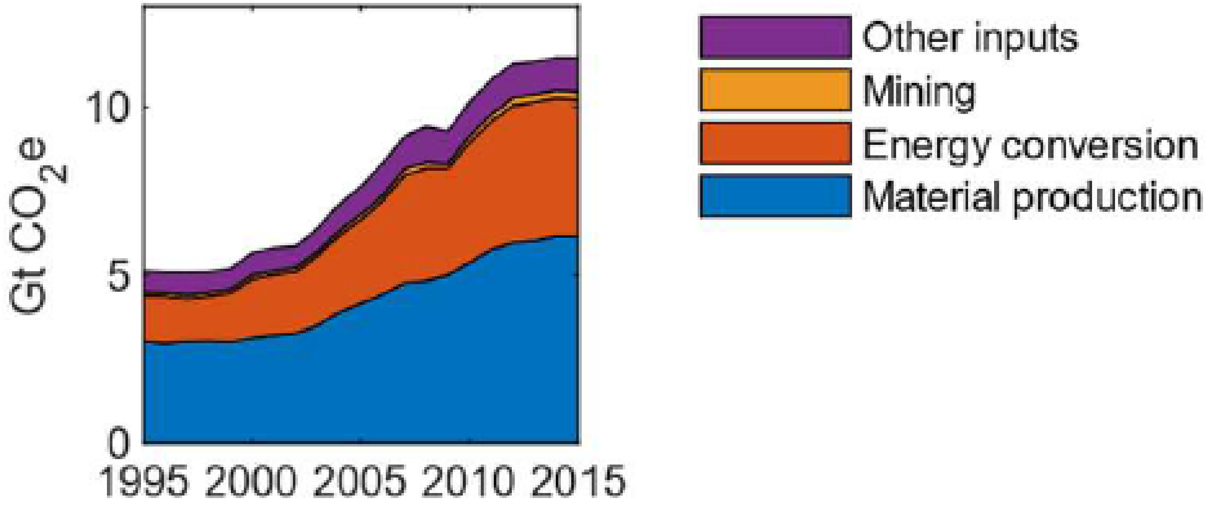


Fig. S 1: Greenhouse gas emissions from material production, compared to global CO2 emissions, over the period 1995-2015.

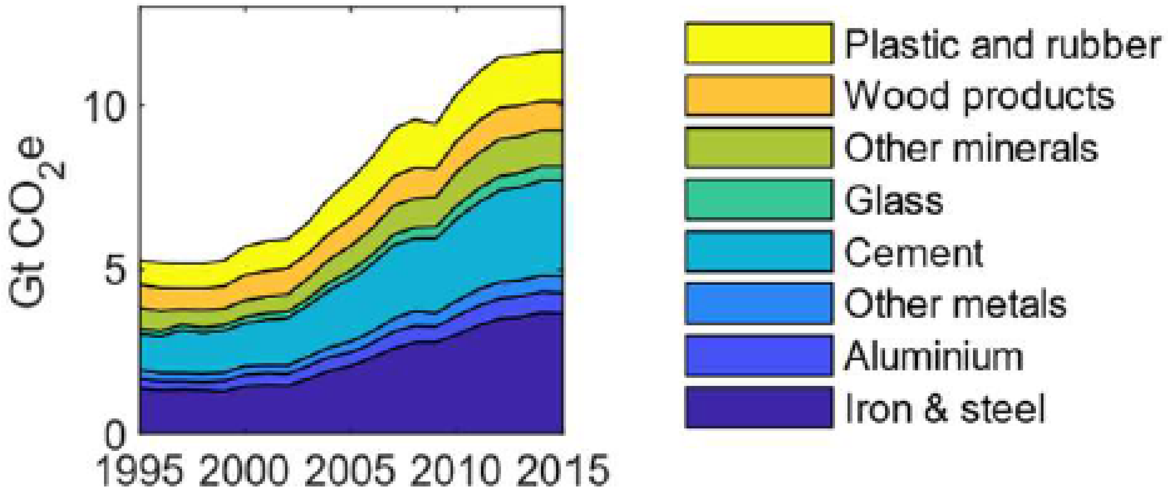
Hertwich, E. (2019, August 30). The Carbon Footprint of Material Production Rises to 23% of Global Greenhouse Gas Emissions. https://doi.org/10.31235/osf.io/n9ecw

Three perspectives on the GHG emission of materials production:

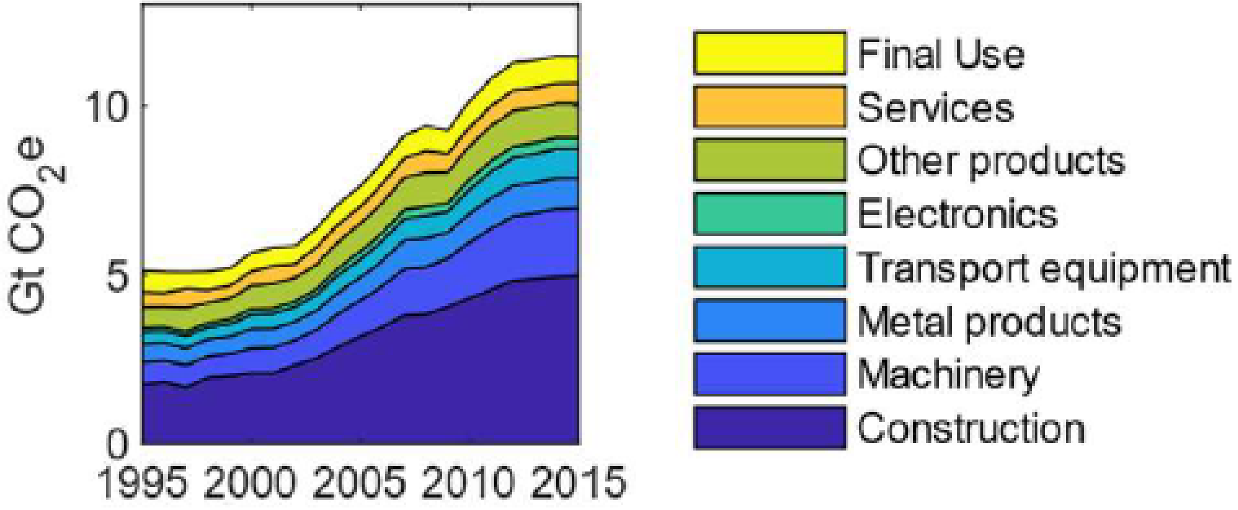
A by emitting process.



B by class of material.



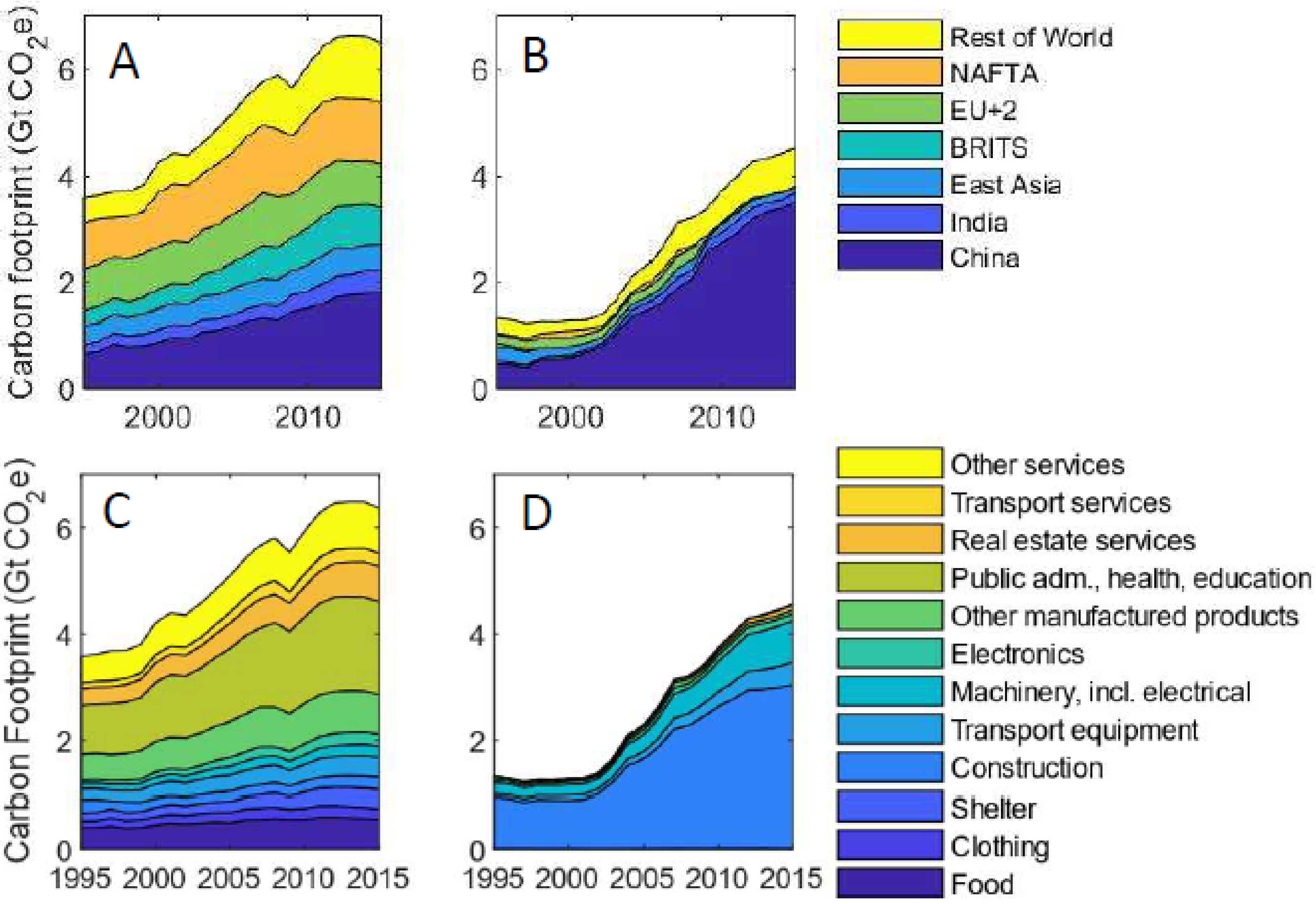
C Carbon footprint of materials by using industry.



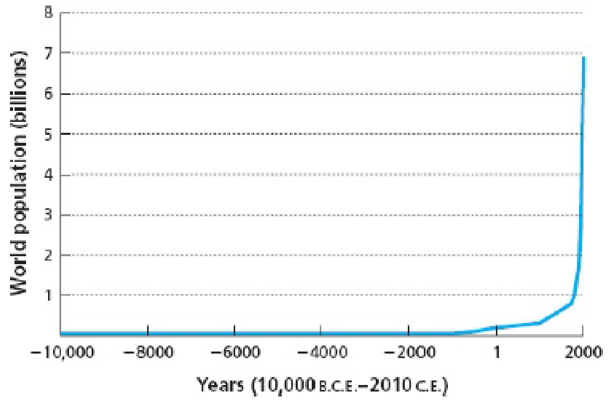
Hertwich, E. (2019, August 30). The Carbon Footprint of Material Production Rises to 23% of Global Greenhouse Gas Emissions. https://doi.org/10.31235/osf.io/n9ecw

The material-related carbon footprint of consumption (A,C) and net capital formation (B,D).

BRITS = Brazil, Russia, Indonesia, Turkey, South Africa. EU+2 is the 28 EU countries plus Switzerland and Norway. NAFTA is Canada, Mexico and the US.

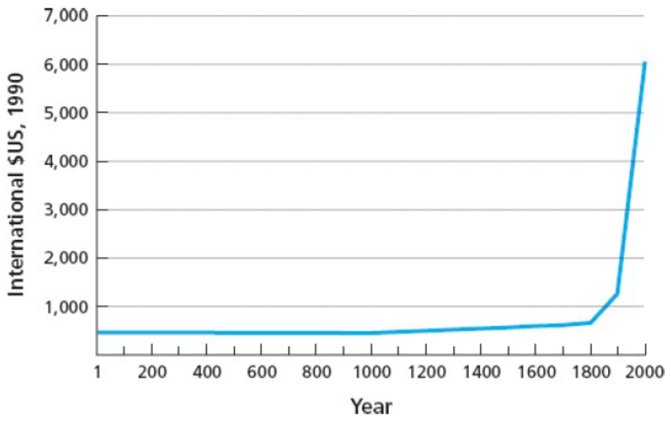


Hertwich, E. (2019, August 30). The Carbon Footprint of Material Production Rises to 23% of Global Greenhouse Gas Emissions. https://doi.org/10.31235/osf.io/n9ecw



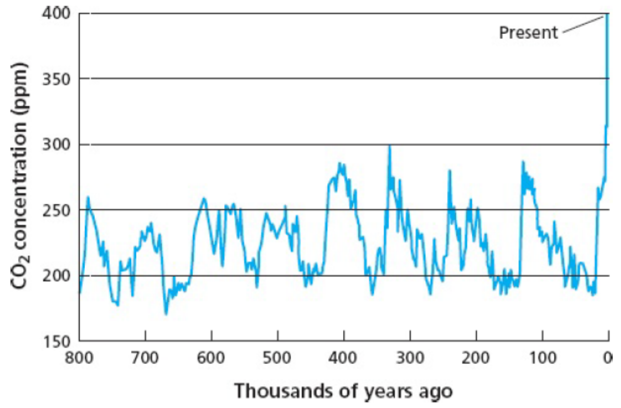
1.3 Global population (10,000 B.C.E.–present)

Source: Bolt, J., and J. L. van Zanden. 2013. "The First Update of the Maddison Project: Re-



1.2 Gross world product per capita (1990 International Dollars)

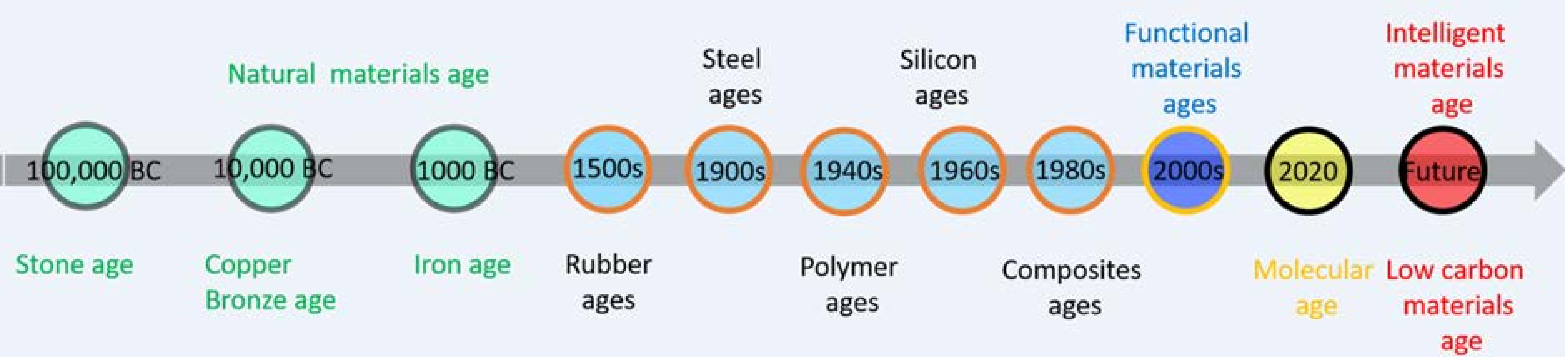
Source: Bolt, J., and J. L. van Zanden. 2013. "The First Update of the Maddison Project: Re-Estimating Growth Before 1820." Maddison Project Working Paper 4.



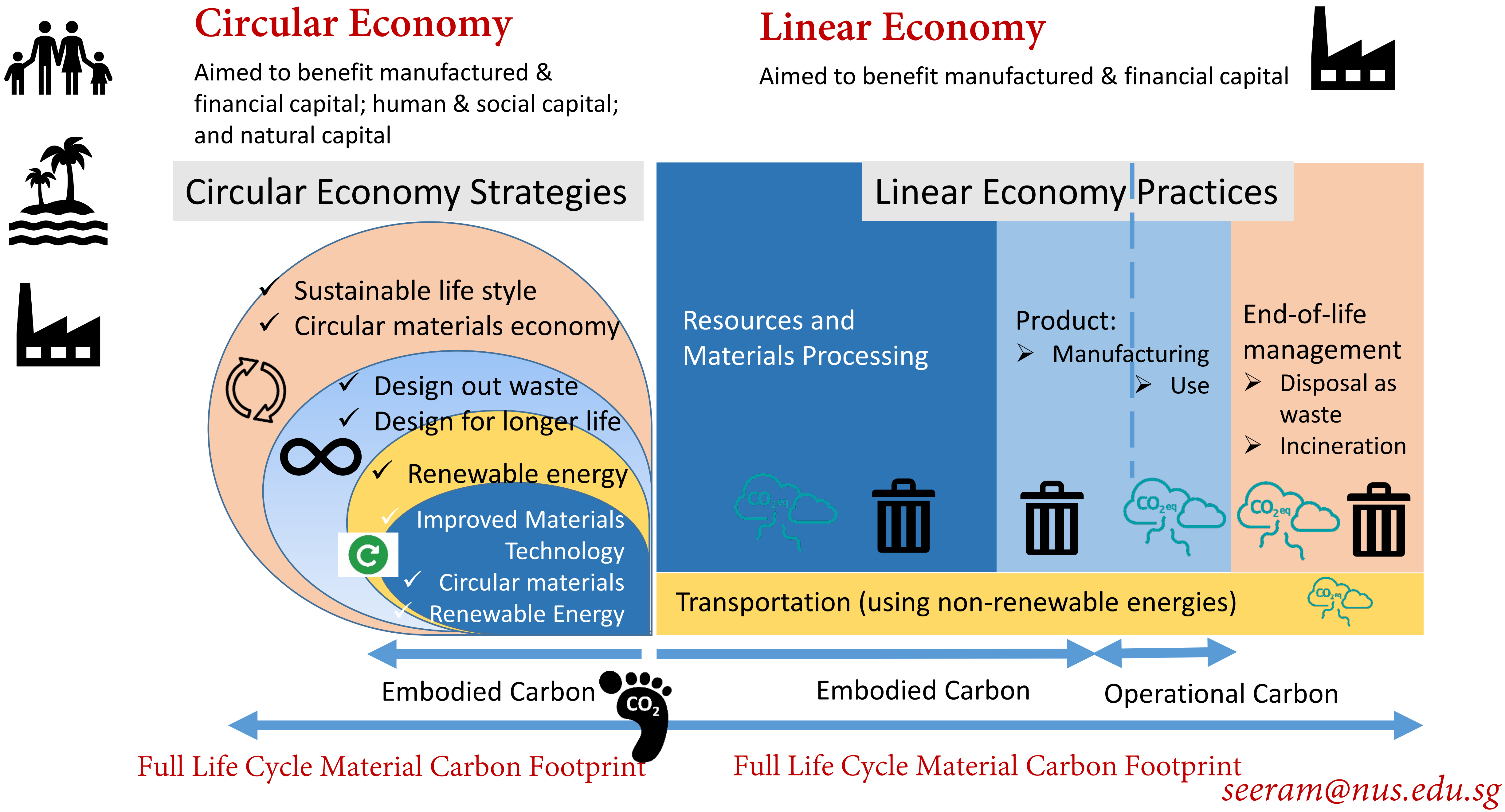
1.15 CO_2 in the atmosphere over the past 800,000 years

Reprinted by permission from Macmillan Publishers Ltd: Nature, *Lüthi, Dieter, Martine Le Floch, Bernhard Bereiter, Thomas Blunier, Jean-Marc Barnola et al. "High-resolution Carbon Dioxide Concentration Record 650,000–800,000 years Before Present," copyright 2008.*

Since the industrial revolution, human population grew by ten times

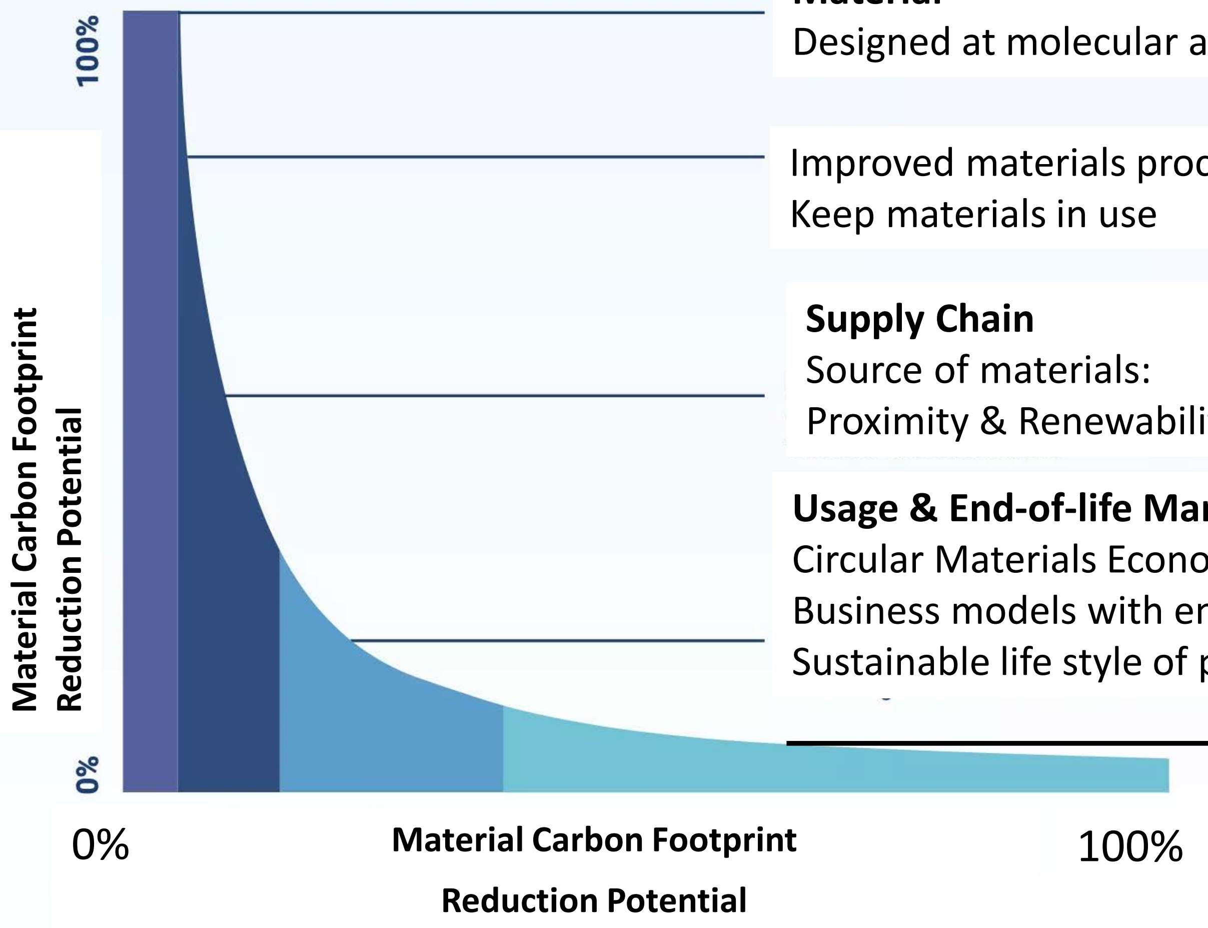


Intelligent Materials, Kai Liu, Mike Tebyetekerwa, Dongxiao Ji and SeeramRamakrishna, Matter, V3, Issue 3, 2, (590-593) 2020 (https://doi.org/10.1016/j.matt.2020.07.003).



Circular Economy
Aimed to benefit manufactured & financial capital; human & social capital; and natural capital
Linear Economy
Aimed to benefit manufactured & financial capital
Circular Economy Strategies
✓ Sustainable life style
✓ Circular materials economy
✓ Design out waste
✓ Design for longer life
✓ Renewable energy
✓ Improved Materials Technology
✓ Circular materials
✓ Renewable Energy
Linear Economy Practices
Resources and Materials Processing
Product:
➢ Manufacturing
➢ Use
End-of-life management
➢ Disposal as waste
➢ Incineration
Transportation (using non-renewable energies)
Embodied Carbon
Embodied Carbon
Operational Carbon
CO2
Full Life Cycle Material Carbon Footprint
Full Life Cycle Material Carbon Footprint
seeram@nus.edu.sg

Potential domains of impact



Material
Designed at molecular and atoms scale for higher material circularity

Improved materials processing technologies
Keep materials in use

Supply Chain
Source of materials:
Proximity & Renewability

Usage & End-of-life Management
Circular Materials Economy
Business models with enhanced circular credentials
Sustainable life style of people

Product- design out waste and pollution
Design of product for reuse, remanufacturing & recycling
Design for longer product life or keep products in use
Materials selection
Manufacturing with resources efficiency
No products or less products

seeram@nus.edu.sg

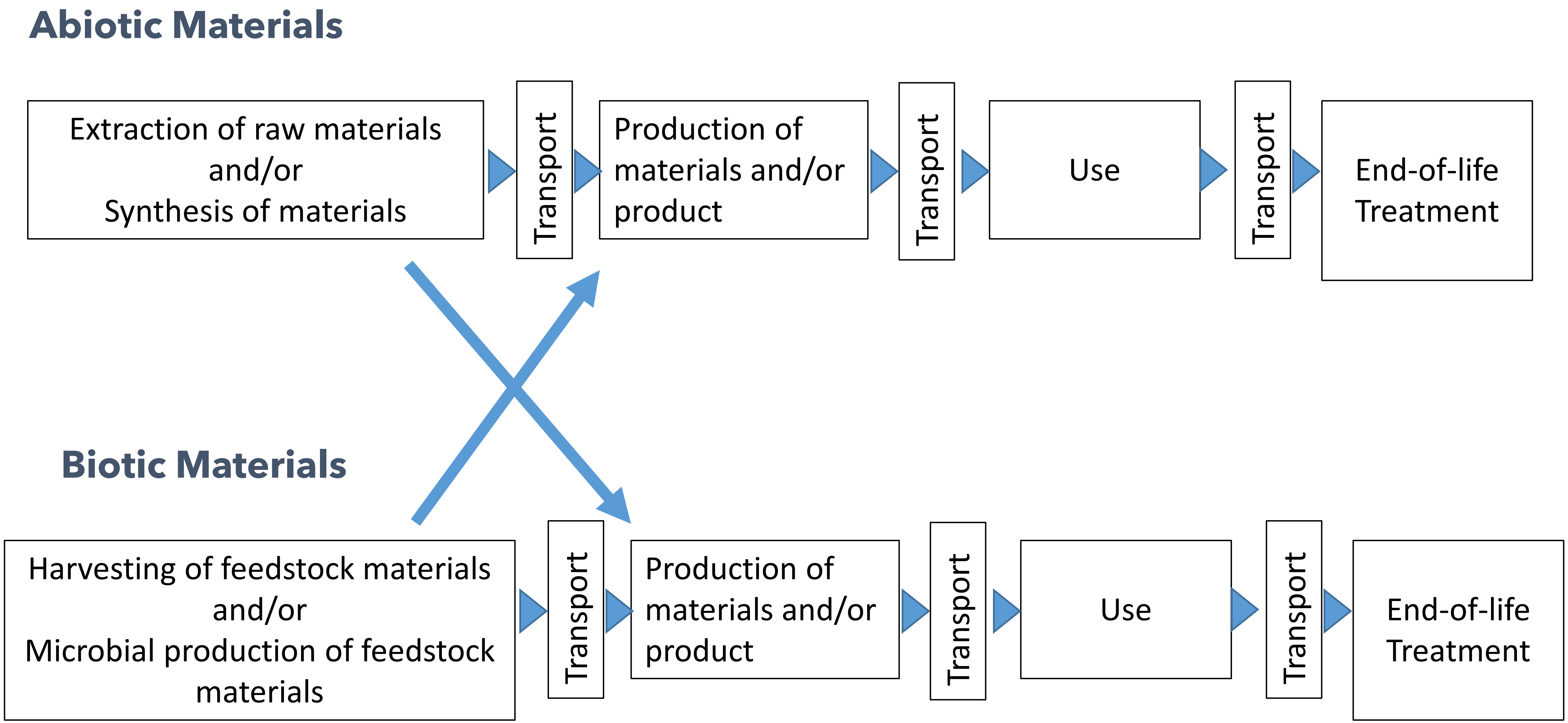
Matter is a material substance that occupies space and has mass

Abiotic Materials

- Metals
- Polymers (plastics)
- Ceramics
- Composites
- Natural or bio-based materials
- Electronic materials
- Advanced materials
- Intelligent materials

Biotic Materials

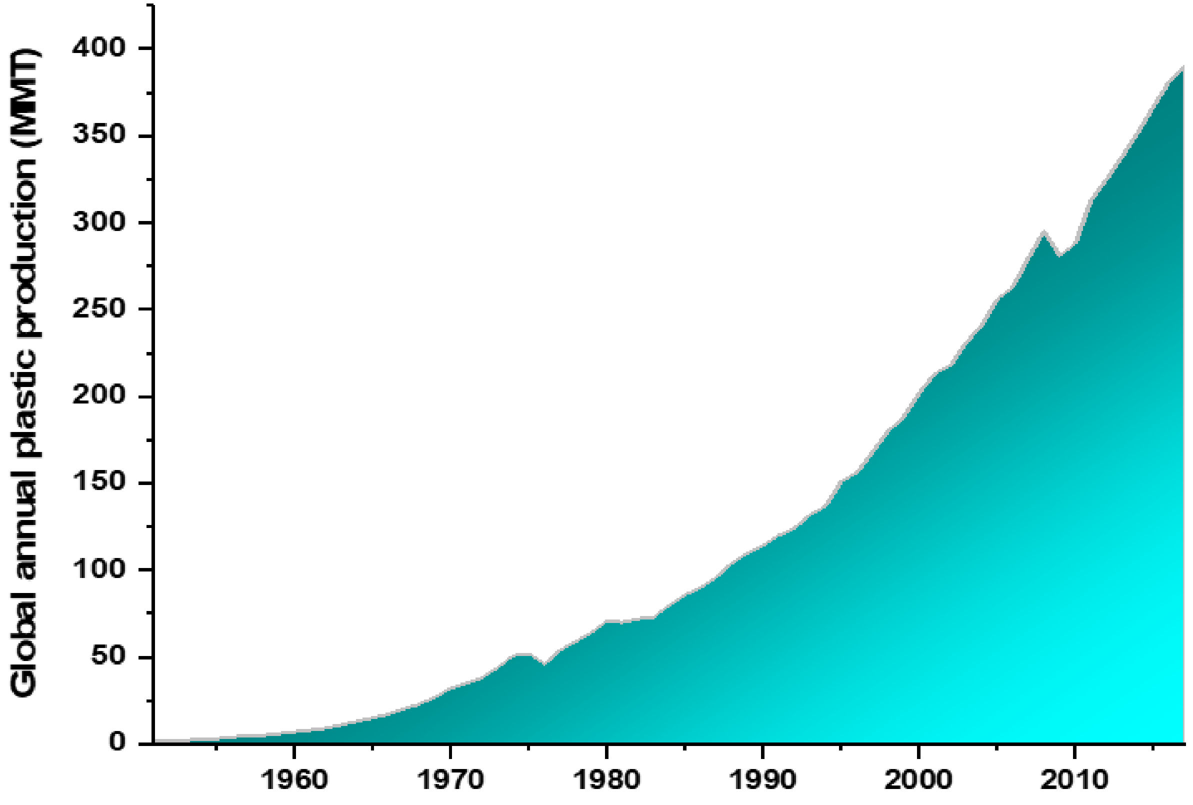
- Forest/plant derived materials
- Agriculturally produced/derived materials
- Microorganism produced/derived materials



Abiotic Materials
Extraction of raw materials and/or Synthesis of materials
Transport
Production of materials and/or product
Transport
Use
Transport
End-of-life Treatment
Biotic Materials
Harvesting of feedstock materials and/or Microbial production of feedstock materials
Transport
Production of materials and/or product
Transport
Use
Transport
End-of-life Treatment

Global annual plastic production in million metric tons (MMT) from 1950-2015

Contribution of each plastic in total global plastic production in 2015



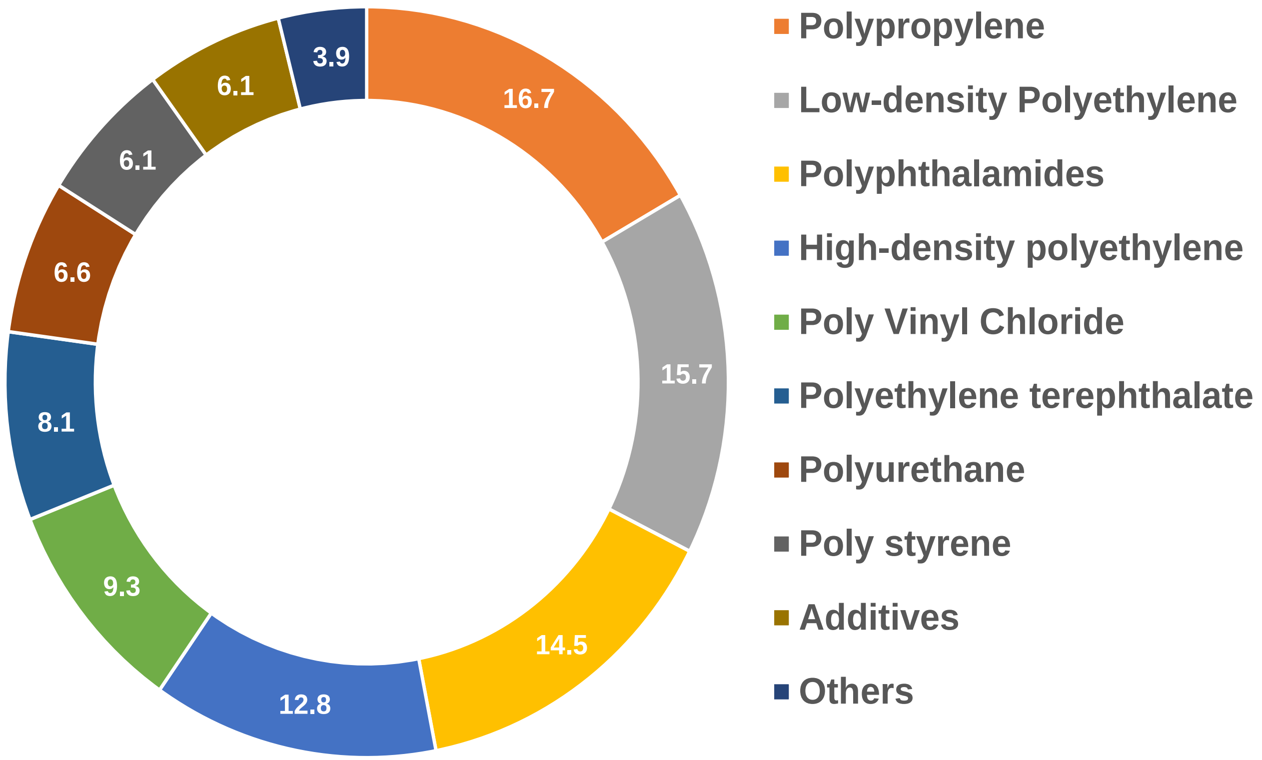


Table 8.1 Biopolymers and Commodity Oil-Based Polymers

• Biopolymers •	• Oil-Based Polymers •
Bio-PP (made from ethanol)	PP (Polypropylene)
Bio-PE (made from ethanol)	PE (Polyethylene)
PLA (Polylactic acid)*	Polyvinylchloride
PHA (Polyhydroxyalkanoate)*	Polyurethane
PTT (Polytrimethylene terephthalate)	PET (Polyethylene terephthalate)
CA (Cellulose acetate)	PS (Polystyrene)
PA11 Nylon 11	PA6 Nylon 6
TPS (Thermoplastic starch)*	PCL (Polycaprolactone)*

*PLA, PHA, TPS, PCL and blends of these with PE, PP and PET are biodegradable.

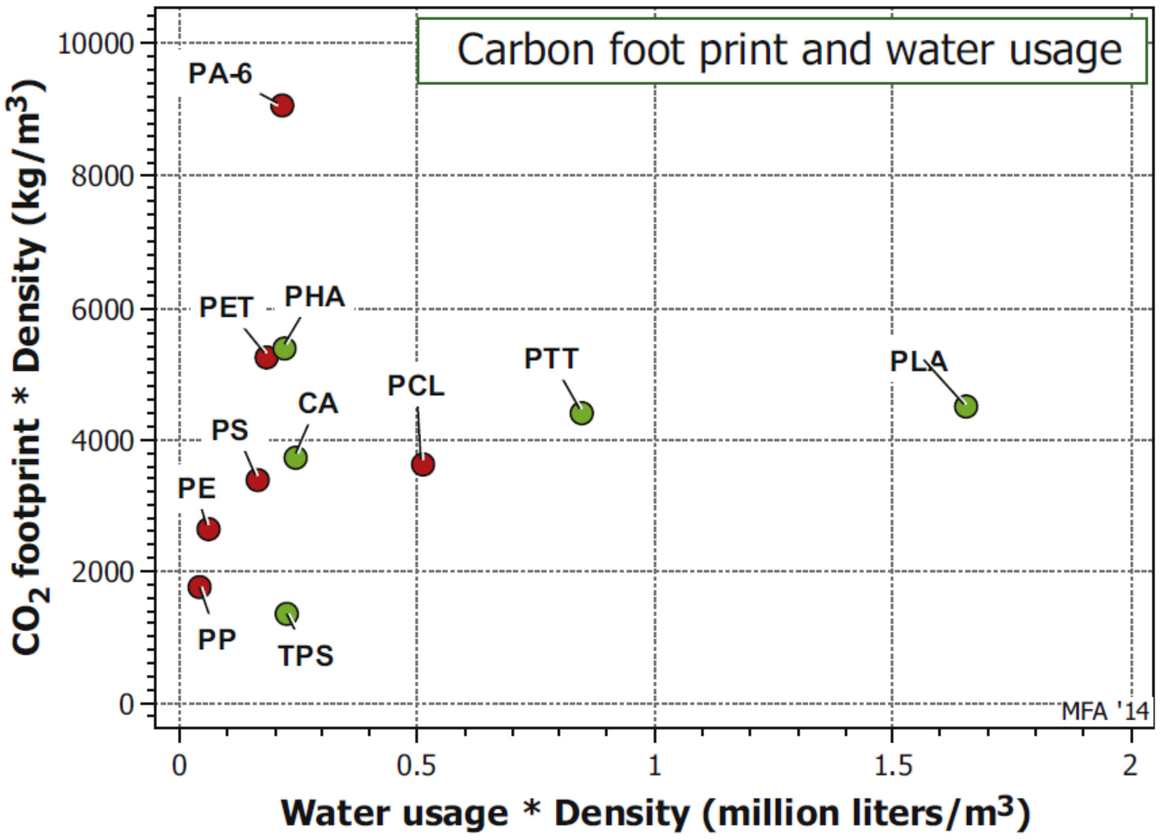
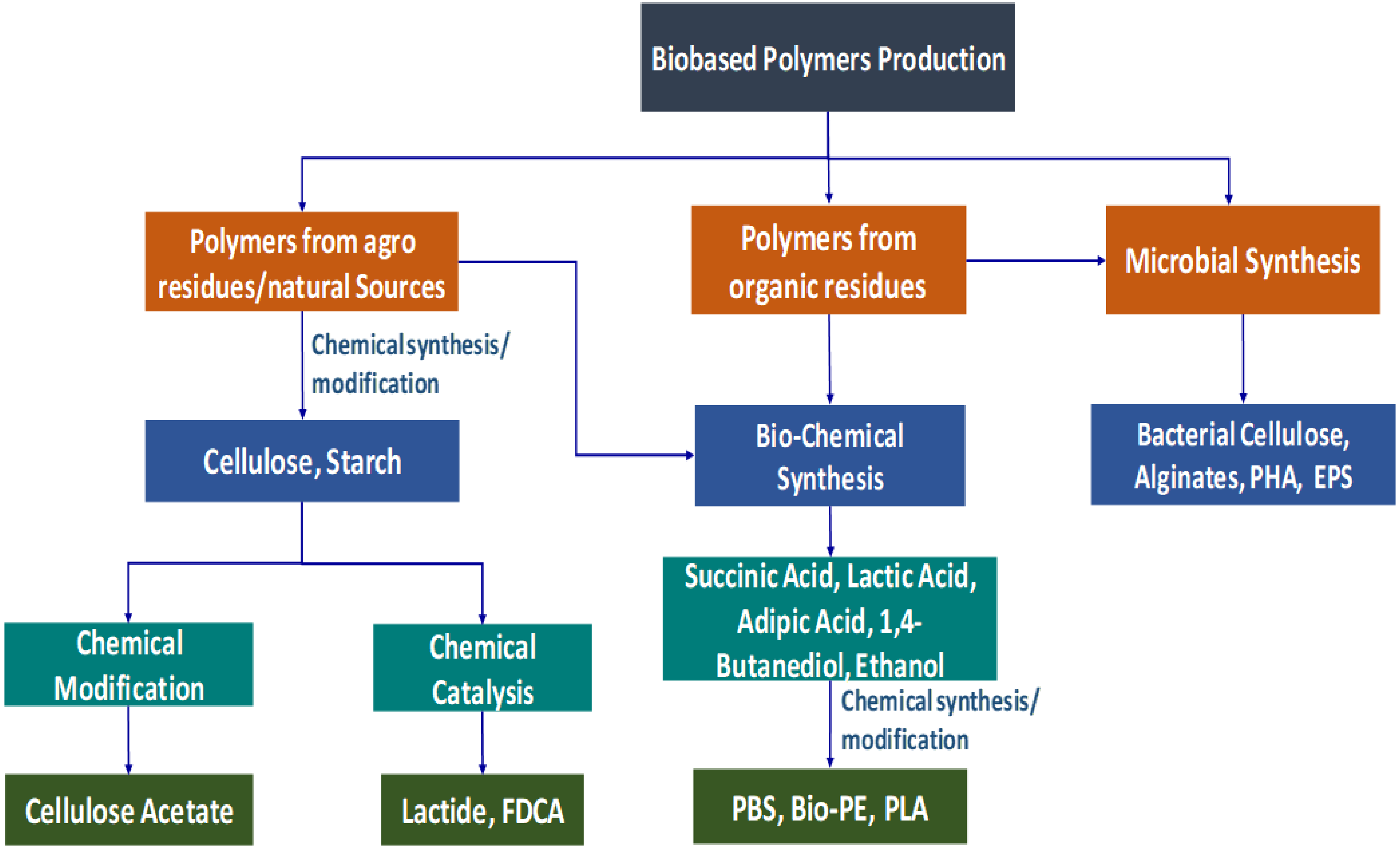
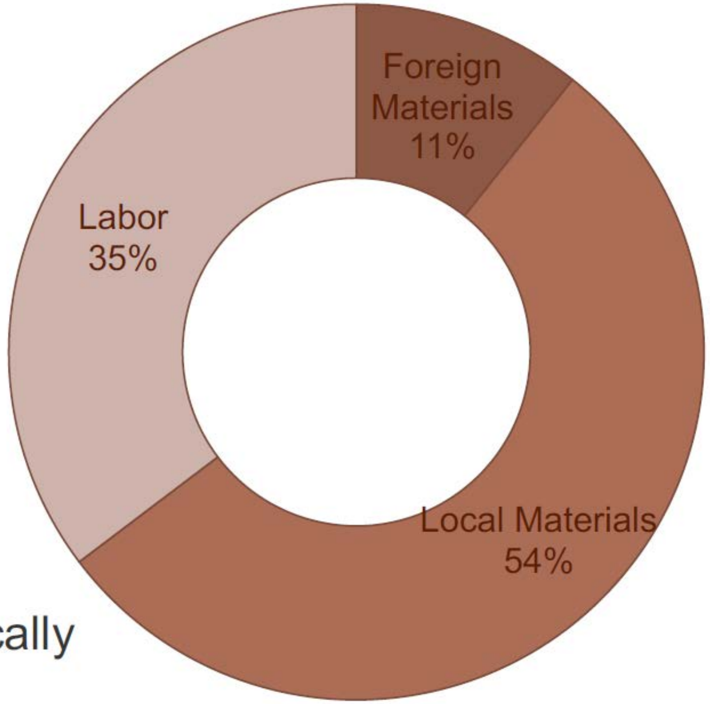


FIGURE 8.6
The carbon footprint and water usage of oil-based polymers (red) and biopolymers (green).

Michael F. Ashby, Book "Materials and Sustainable Development", Elsevier Publishers, (2016), 328 pages, https://doi.org/10.1016/C2014-0-01670-X, ISBN 978-0-08-100176-9

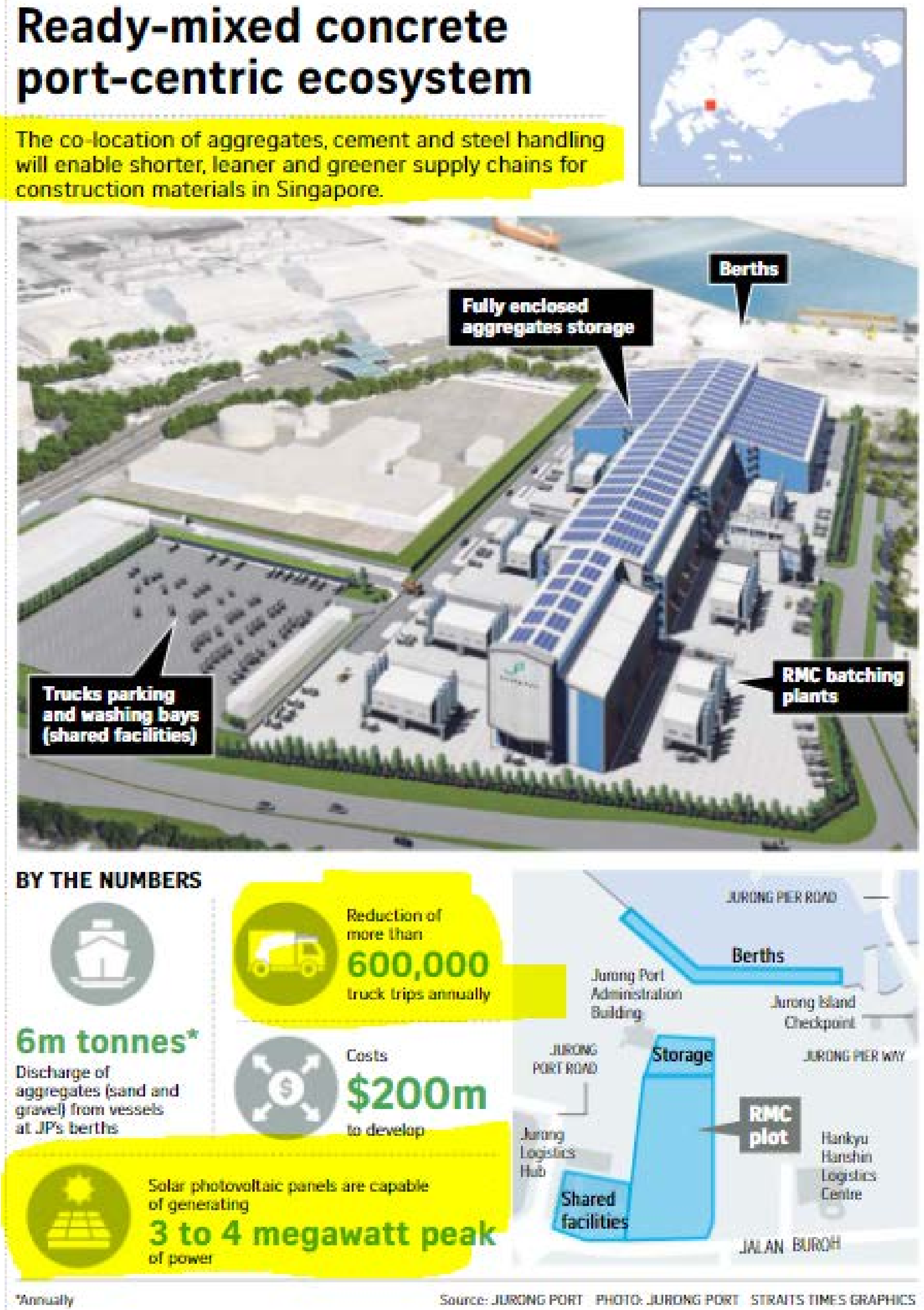
Production of bio-based plastics by various routes





Foreign Materials 11%
Labor 35%
Local Materials 54%

locally

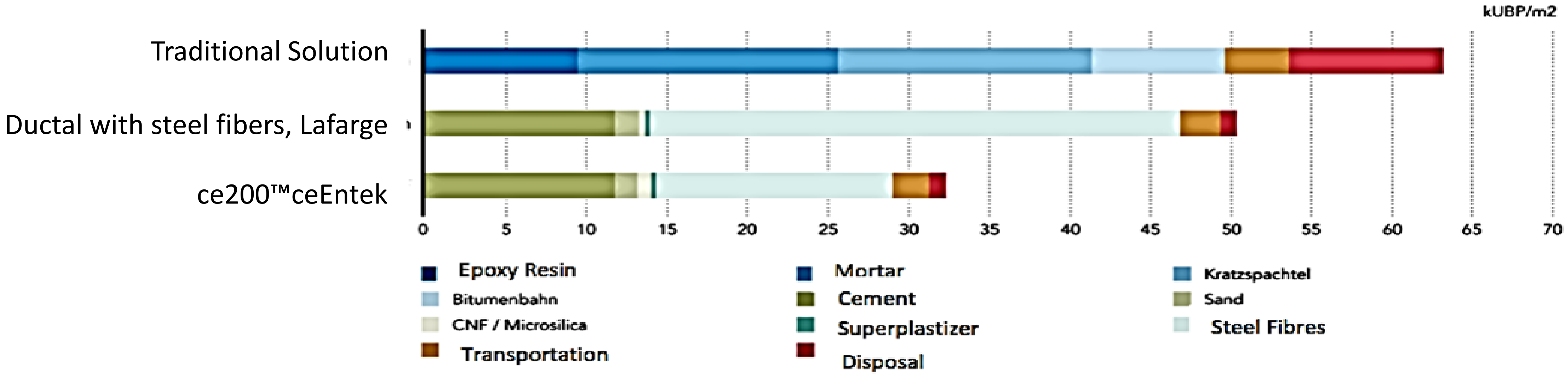


Ready-mixed concrete port-centric ecosystem
The co-location of aggregates, cement and steel handling will enable shorter, leaner and greener supply chains for construction materials in Singapore.
Berths
Fully enclosed aggregates storage
Trucks parking and washing bays (shared facilities)
RMC batching plants
BY THE NUMBERS
6m tonnes*
Discharge of aggregates (sand and gravel) from vessels at JP's berths
Reduction of more than
600,000
truck trips annually
Costs
$200m
to develop
Solar photovoltaic panels are capable of generating
3 to 4 megawatt peak
of power
JURONG PIER ROAD
Berths
Jurong Port Administration Building
Jurong Island Checkpoint
JURONG PORT ROAD
Storage
JURONG PIER WAY
RMC plot
Jurong Logistics Hub
Hankyu Hanshin Logistics Centre
Shared facilities
JALAN BUROH
*Annually
Source: JURONG PORT PHOTO: JURONG PORT STRAITS TIMES GRAPHICS

UHPC2.0™ VS UHPC and CONVENTIONAL CONCRETE

Carbon Footprint of ce200SF™ evaluated by Carbotech, Switzerland for Swiss Railway (SBB)

Results for Environmental Footprint: Detailed Comparison in kUBP, per m²



For UHPC Applications with steel fibers, micro silica plus steel fibers manufacturing are the largest contributor, followed by cement production

Environmental Footprint of UHPC2.0™ with CNF similarly has principle impact from steel fibres followed by cement production

In conventional solution, cement production contribute to environmental footprint, followed by epoxy resins, bituminous layer and disposal

For UHPC, Remaining Contributions from transportation and disposal are insignificant

Step one to lower CO_2 emissions: Reduce Carbon Footprint with advanced Materials

THE WAY TO FURTHER REDUCE CO_2

Sustainability

The world is moving forward on emissions reduction goals. The Paris Climate Agreement established global CO2 emissions reduction goals for all nations. UHPC can significantly contribute to this with its low carbon footprint.

Durability

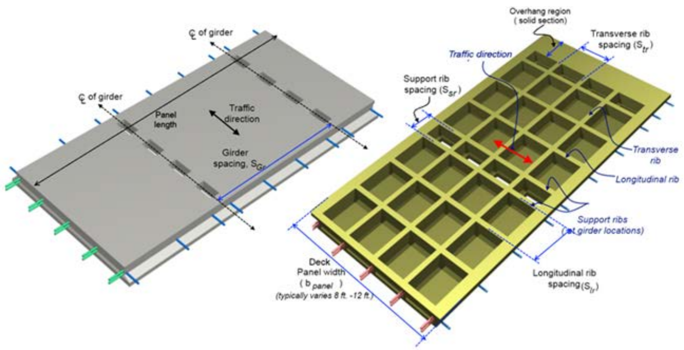
Due to the dense mixture of the constituents, UHPC demonstrates a low permeability and high chemicals resistance. The performance of UHPC is enhanced accordingly, including freeze-thaw resistance, reduced corrosion of reinforcing steel and very low carbonation of the UHPC. Expected lifetime is 100+ years.

Superior Mechanical Properties with less Steel

Table A1. Typical comparison of engineering properties of UHPC with normal and high strength concrete (compiled based on Ahlborn et al. 2008)

Property	Normal concrete	High strength concrete	UHPC
Compressive strength	3,000-6,000 psi	6,000-14,000 psi	25,000-33,000 psi
Tensile strength	400-500 psi	-	1,000-3,500 psi
Elastic modulus	2,000-6,000 ksi	4,500-8,000 ksi	8,000-9,000 ksi
Poisson's ratio	0.11-0.21	-	0.19-0.24
Porosity	20-25%	10-15%	2-6%
Chloride penetration	>2000	500-2000	<100
Water-cement ratio	0.40-0.70	0.24-0.35	0.14-0.27

Lower Cost via less Material



FHWA: UHPC waffle deck

Total cost of a UHPC-based solution can be lower than a traditional one given a new approach to the design of a structure.

Recyclable

Due to its low Porosity, UHPC can be recycled in concrete replacing Aggregates and Sand

Aluminum

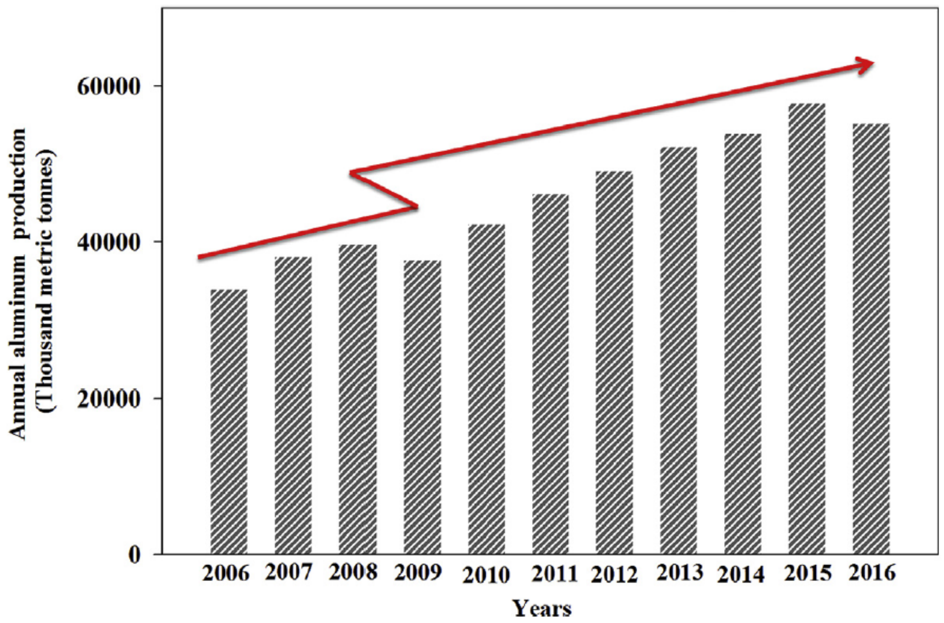


Figure 8.4 Global annual production of aluminum in last 11 years. *(Reproduced from http://www.world-aluminium.org/statistics/#data.)*

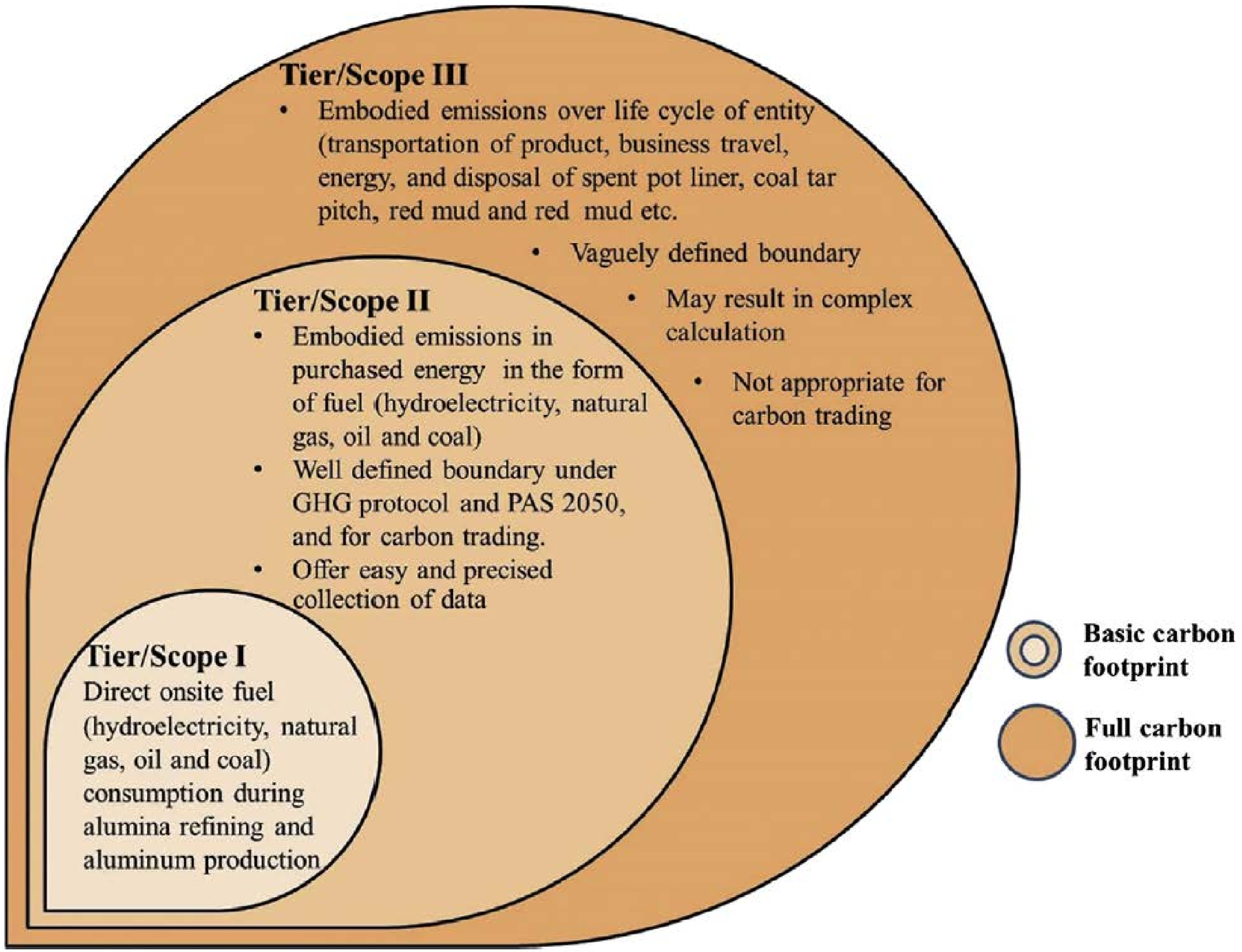
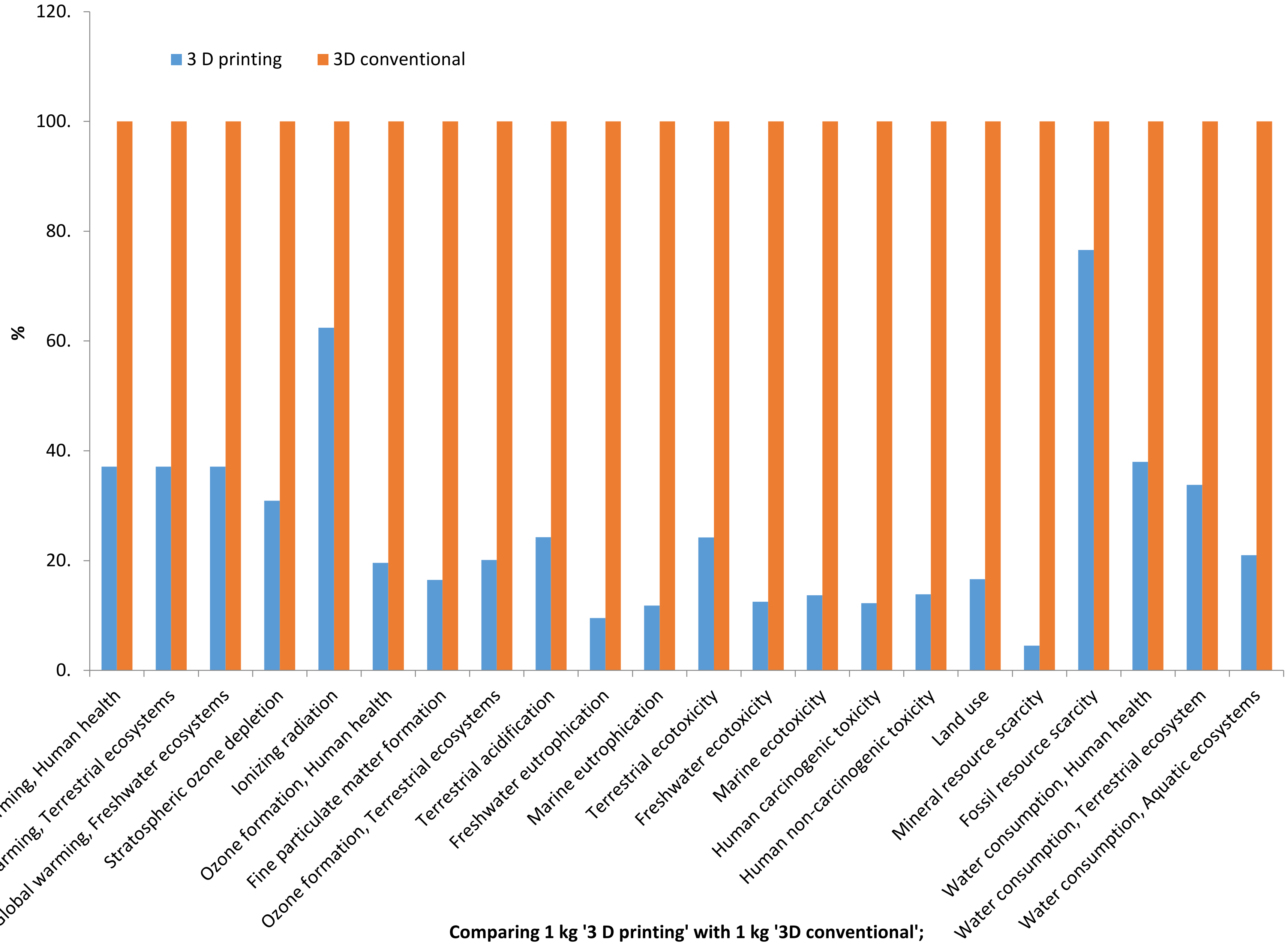


Figure 8.6 Boundaries for calculation of carbon footprint from aluminum industries.

Environmental Carbon Footprints, ISBN 978-0-12-812849-7http://dx.doi.org/10.1016/B978-0-12-812849-7.00008-8

Lifecycle impact assessment of Aluminium part by casting and 3D Printing



Comparing 1 kg '3 D printing' with 1 kg '3D conventional';
Method: ReCiPe 2016 Endpoint (E) V1.03 / World (2010) E/A / Characterization

C Build Tool URL | www.cbuildtech.com

Click on it !

C-BUILD

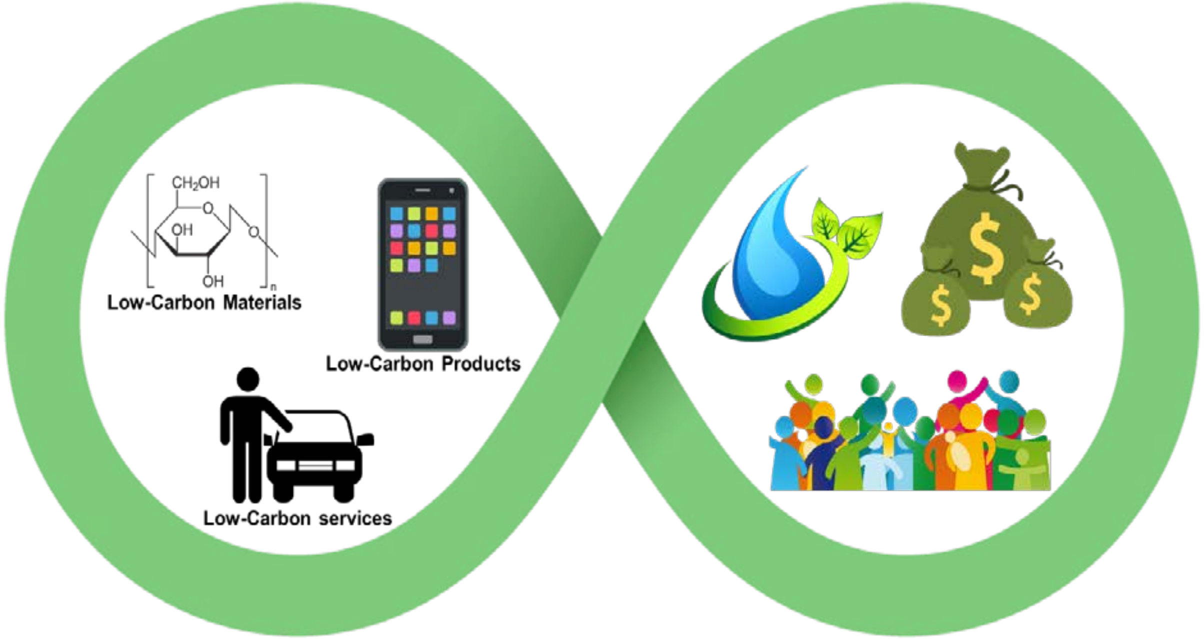
Purpose

» C-Building rating tool is designed to rate circular buildings design. It functions on the design considerations and selected indicators which are derived from Circular Economy concept and architect pioneers.

» This tool rates the circularity of the building starting from design phase, construction towards service life, end-of-life leading to planned reuse of products

seeram@nus.edu.sg

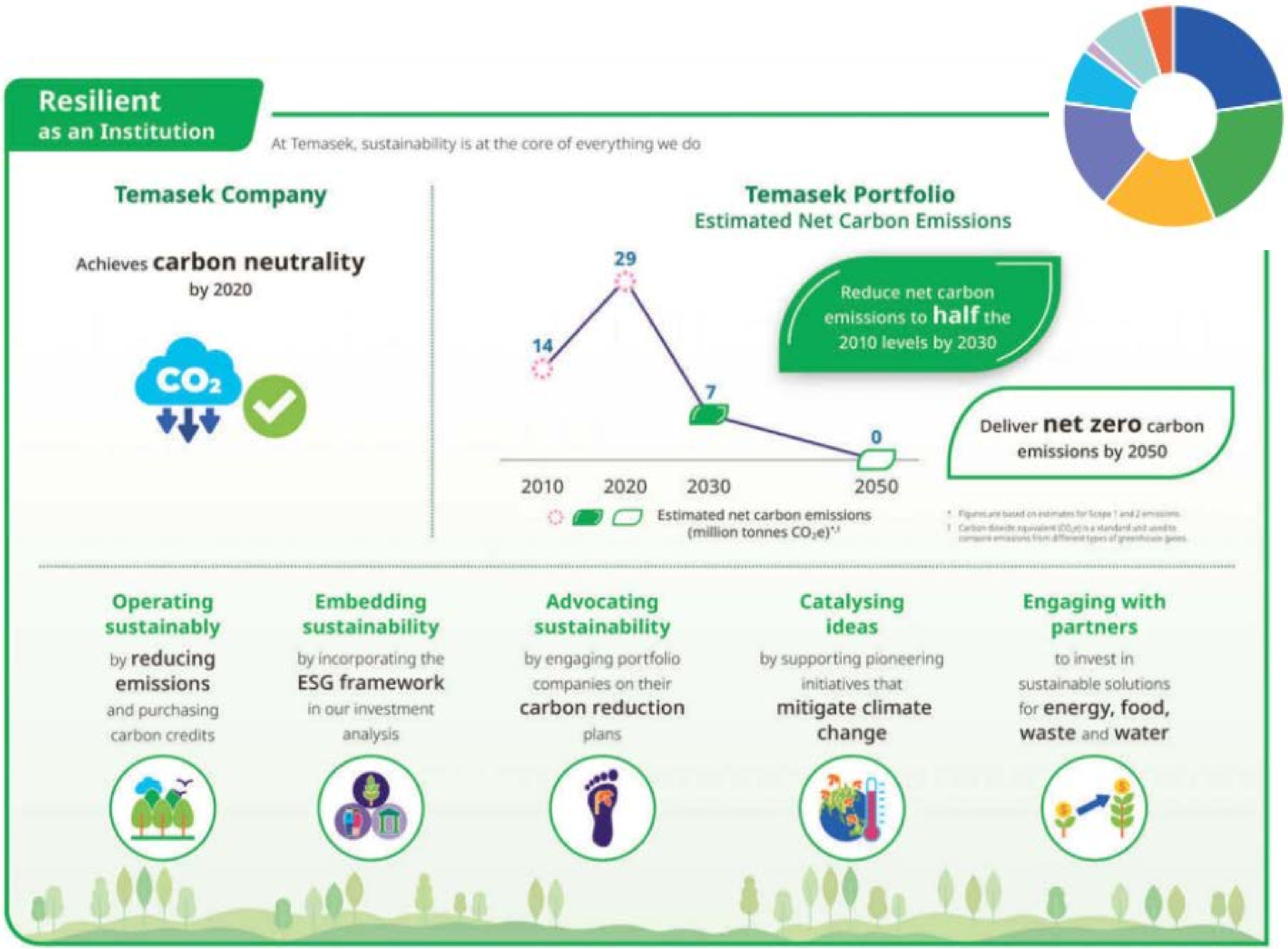
Singapore



CH2OH
OH
O
OH
Low-Carbon Materials
Low-Carbon Products
Low-Carbon services

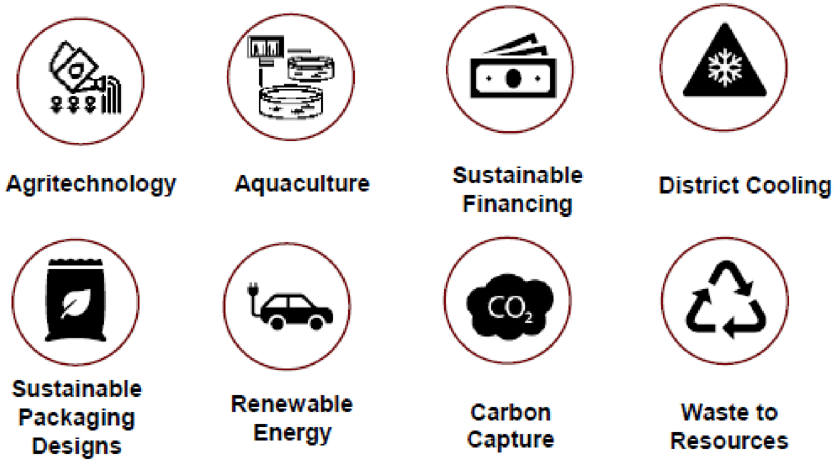
https://www.rhtacademy.com/wp-content/uploads/2020/08/Gail-2020-Brochure-24Aug.pdf

$300 billion company Temasek, Singapore is investing in sustainability projects



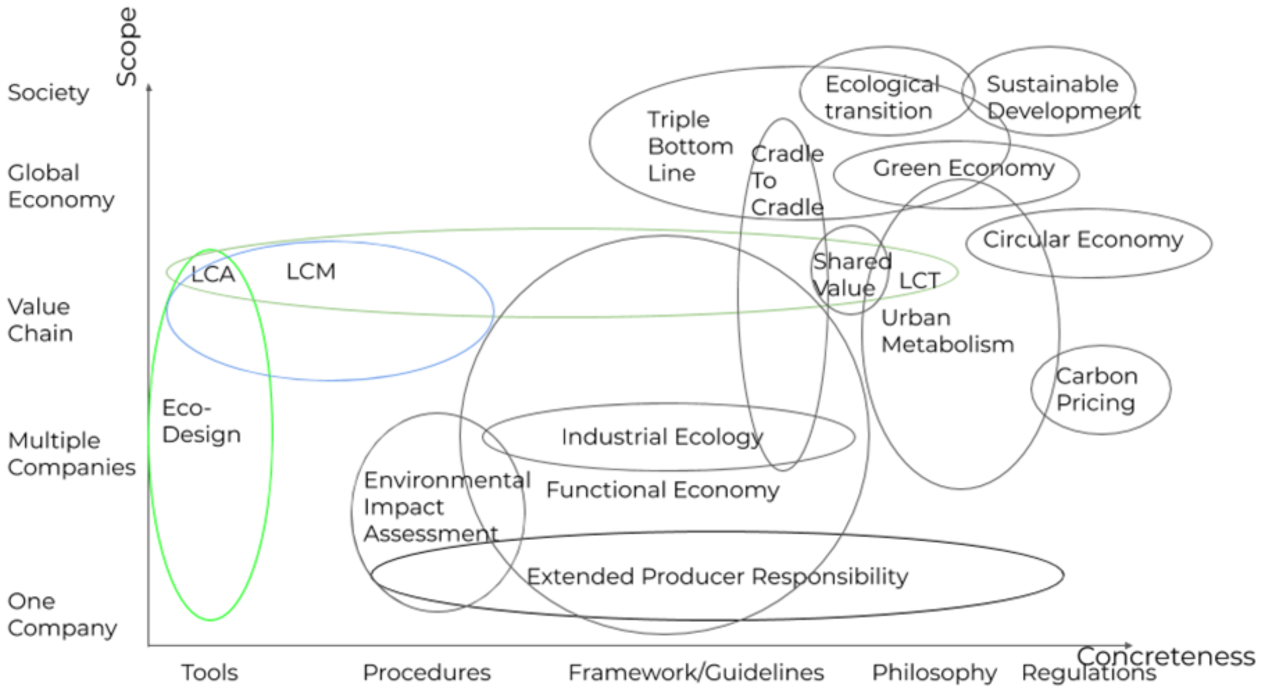
Sector*

Financial services	23
Telecommunications, media and technology	21
Consumer and real estate	17
Transportation and industrials	16
Life sciences and agribusiness	8
Energy and resources	2
Multi-sector funds	8
Others (including credit)	5



CONCLUSIONS

❖ Sustainability is the new frontier of innovation



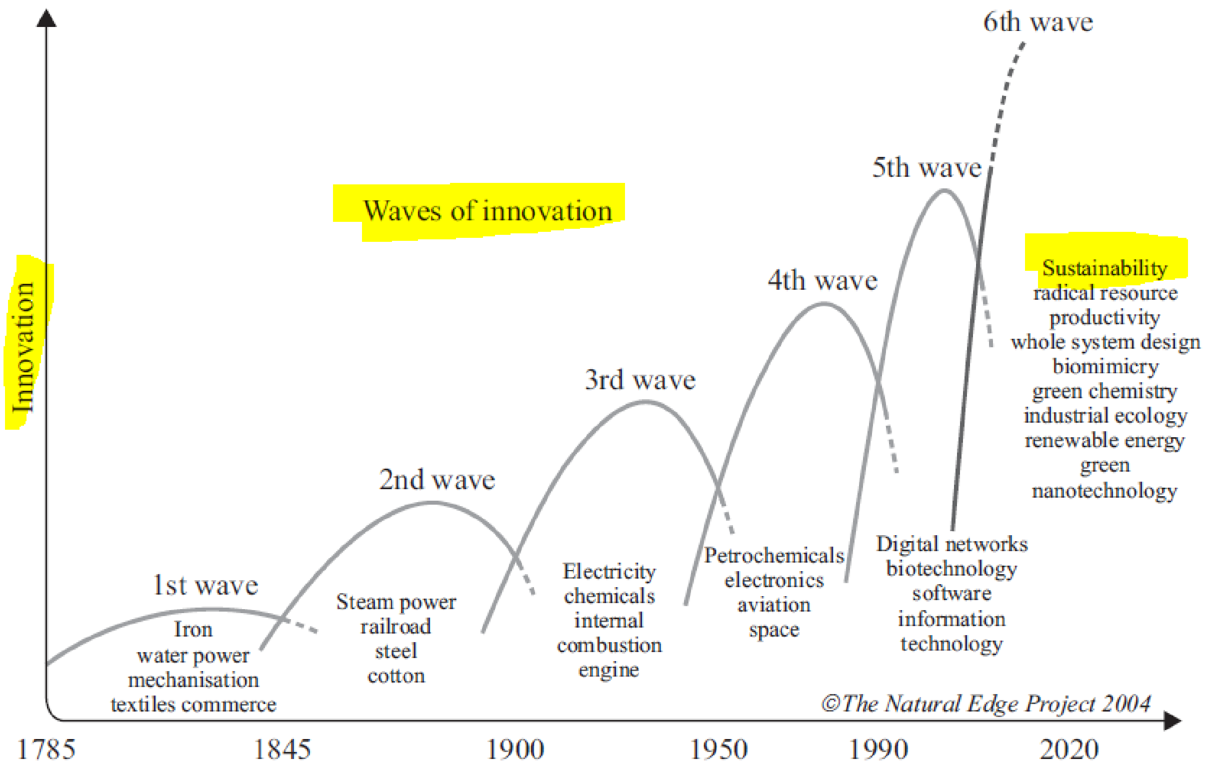


Figure 4.1 Waves of innovation (Source: Hargroves and Smith [9])

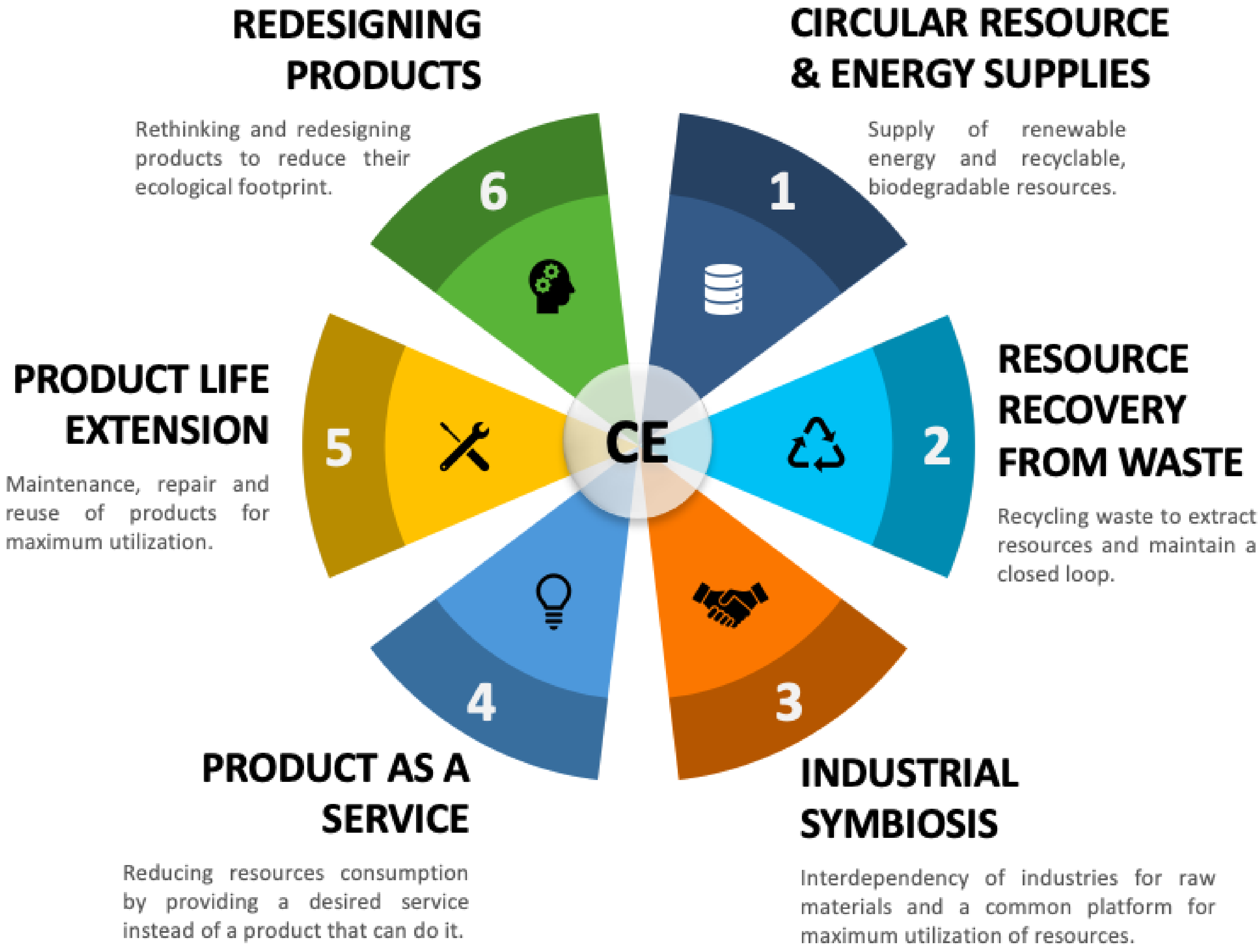
Carrière, S., Weigend Rodríguez, R., Pey, P., Pomponi, F. and Ramakrishna, S. (2020), "Circular cities: the case of Singapore", Built Environment Project and Asset Management, Vol. 10 No. 4, pp. 491-507. https://doi.org/10.1108/BEPAM-12-2019-0137

Low Carbon Mobility for Future Cities: Principles and applications, Edited by Hussein Dia, The Institution of Engineering and Technology, 378 pages, 2017, ISBN 978-1-78561-198-8

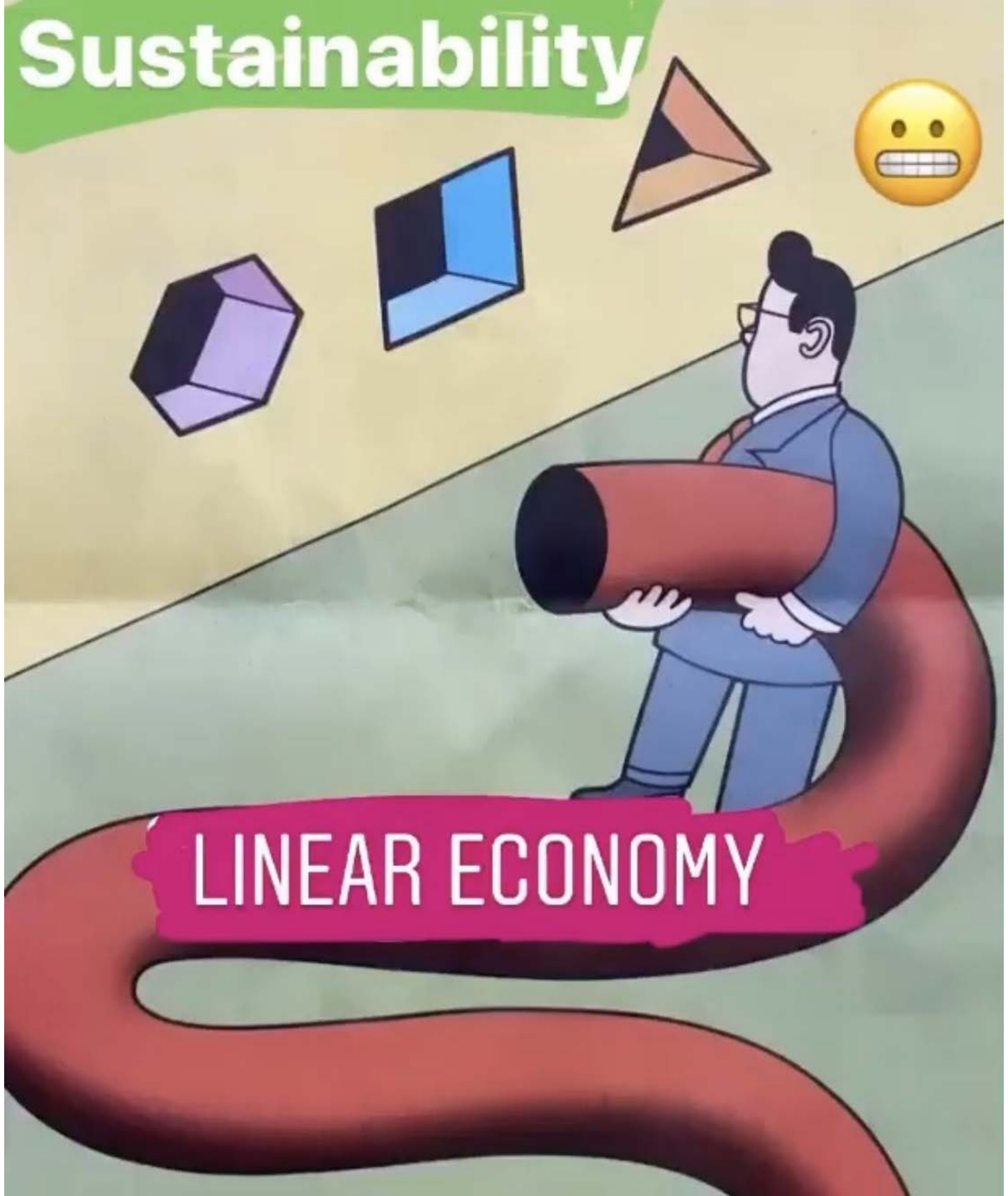
CONCLUSIONS

- **Low-carbon materials** are less detrimental to the Earth's ecosystem.
- Envisaged low-carbon materials age is enabled by the sustainable materials with lower carbon footprint. Several articulations include a) materials efficiency, b) light weight design, c) design for recycling, d) design for reuse, e) design for longer life, f) renewable materials, g) urban mining or recovery of critical materials, h) ethical materials sourcing, i) limiting hazardous substances, and j) circular materials economy.
- Sustainability/Circular Economy should be integrated ubiquitously into diverse economic and social systems thus becoming widespread and cost-effective.

Business Opportunities

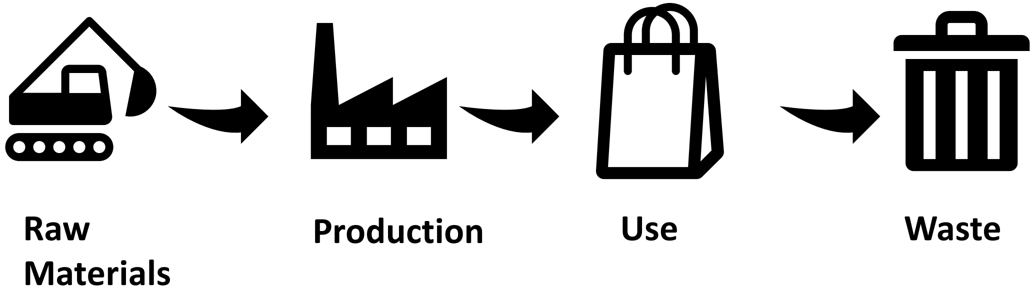


https://www.europeanbusinessreview.com/circular-economy-sustainability-and-business-opportunities/



Circular Economy

Linear Economy



https://www.europeanbusinessreview.com/circular-economy-sustainability-and-business-opportunities/