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A dynamical life cycle inventory of steel, aluminium, and composite car bodies-in-white

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Outline

- Aim
- Method
- Case study
- System Dynamics model
- Results
- Conclusions
- Recommendations

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Aim

Life cycle assessment (LCA) method that can account for **changes over time** in:

Resource consumptions

Energy *This presentation*

Water

Materials

Environmental impacts

Resource depletion

Global warming potential

Photo oxidant creation potential

Acidification potential

Ozone depletion potential

Water pollution

Solid waste

Etc.

Life cycle inventory

Life cycle assessment

Method

System Dynamics model

STELLA™

Dynamical computations

Output: car fleet distribution

Method – System Dynamics

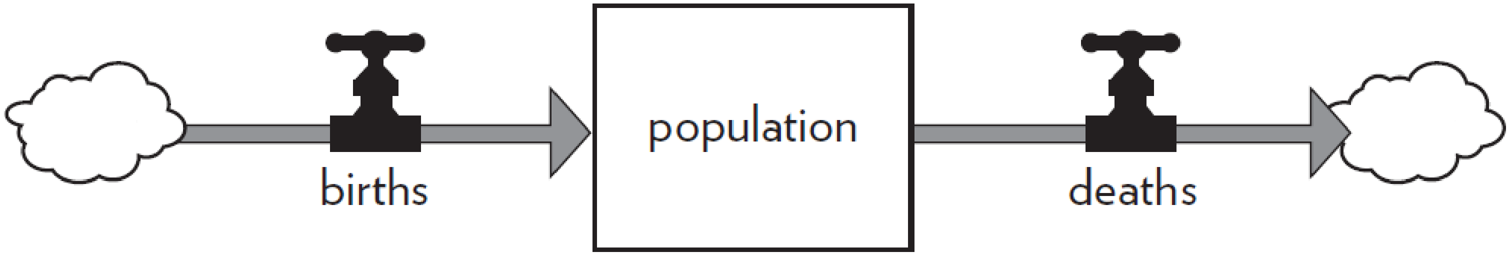
- *Dynamics*: the way that the state of a system changes over time in response to:
  - – internally-generated (endogenous) forces
  - – externally-imposed (exogenous) forces

Method – System Dynamics

DETOUR

Stocks and flows

- Filling and draining a stock



(Meadows 2009, p97)

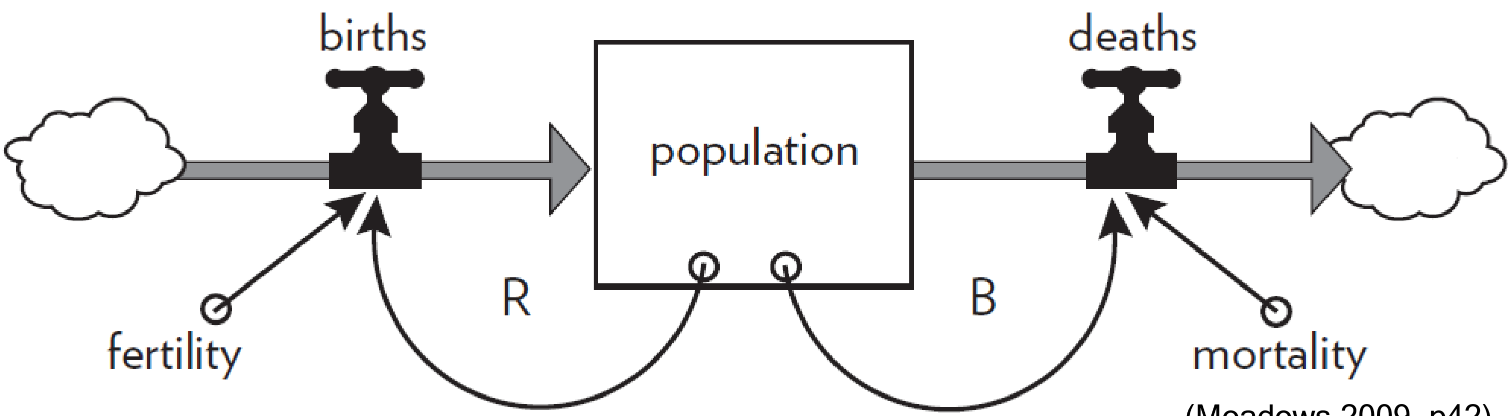
- Operate at *finite rates*
- Source of *delay*
- Source of *inertia*

Method – System Dynamics

DETOUR

Feedback loops

- A change in a stock feeds back around a loop to adjust the original change

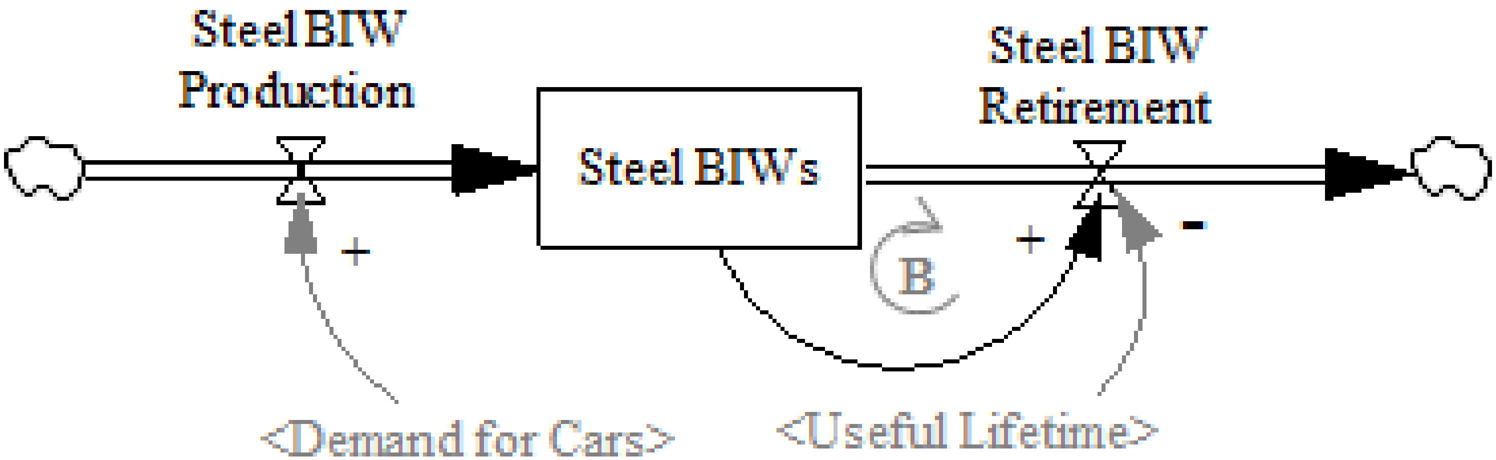


(Meadows 2009, p42)

- Reinforcing: *amplifies* change
- Balancing: *resists* change

Method – System Dynamics

The basic car life cycle



Method

System Dynamics model
STELLA™
Dynamical computations
Output: car fleet distribution

Life cycle inventory
MS Excel
Linear calculations
Output: life-cycle energy consumption

Case study

Body-in-white

Load-carrying welded frame to which other moving components are attached

Case study

2 scenarios

Steel — sub with → Aluminum

Steel — sub with → Carbon-fibre reinforced polypropylene

Lightweight

- Australian context

System Dynamics model

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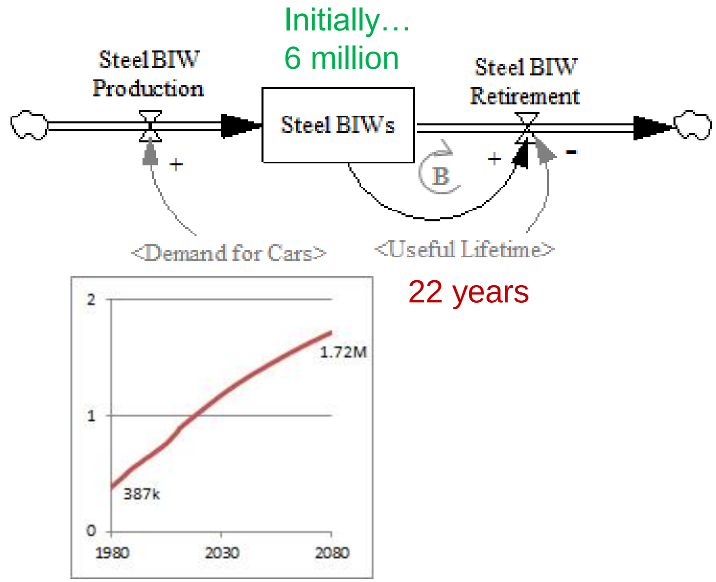
System Dynamics model

Main assumptions

- **Production**
  - ***Demand for cars*** grows with ***population***
  - ***Demand for cars*** is met first by ***recycled LW***, then ***virgin LW***, then ***steel***
- **Adoption**
  - Lightweight BIWs are adopted (***S-shaped***) in ***2010-2030***
  - ***Market share*** of each type of car is a function of ***total cost of ownership***
- **Use**
  - ***Driving intensity*** is the same for all cars (15,500 km/year)
- **Retirement**
  - ***Useful life*** is the same for all cars (22 years)
  - ***BIW retirement rate*** is 1/22nd of ***car fleet*** per year
- **Recycling**
  - ***Recycled lightweight materials*** are used only for ***new BIWs***

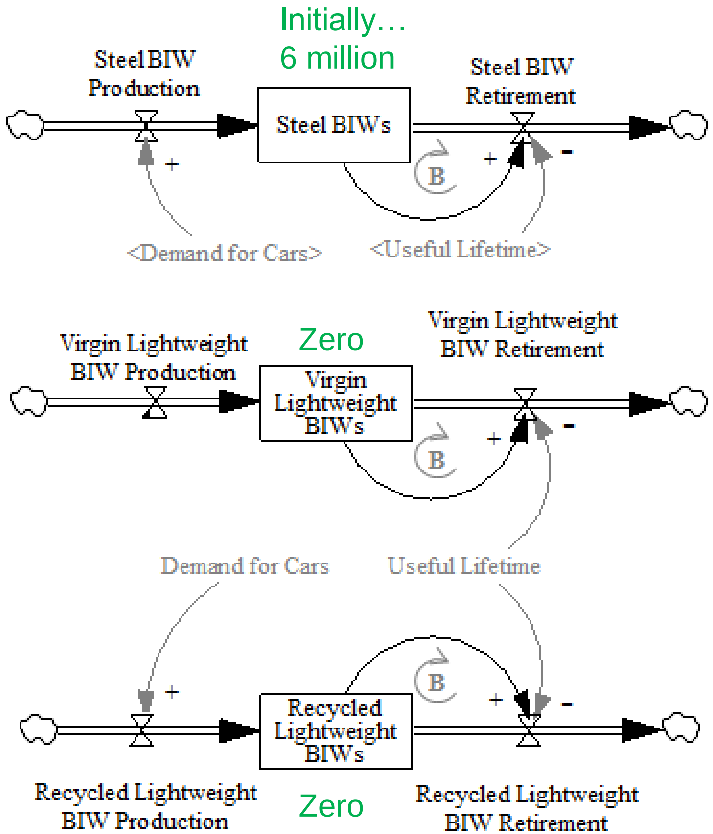
System Dynamics model



The basic car life cycle

System Dynamics model

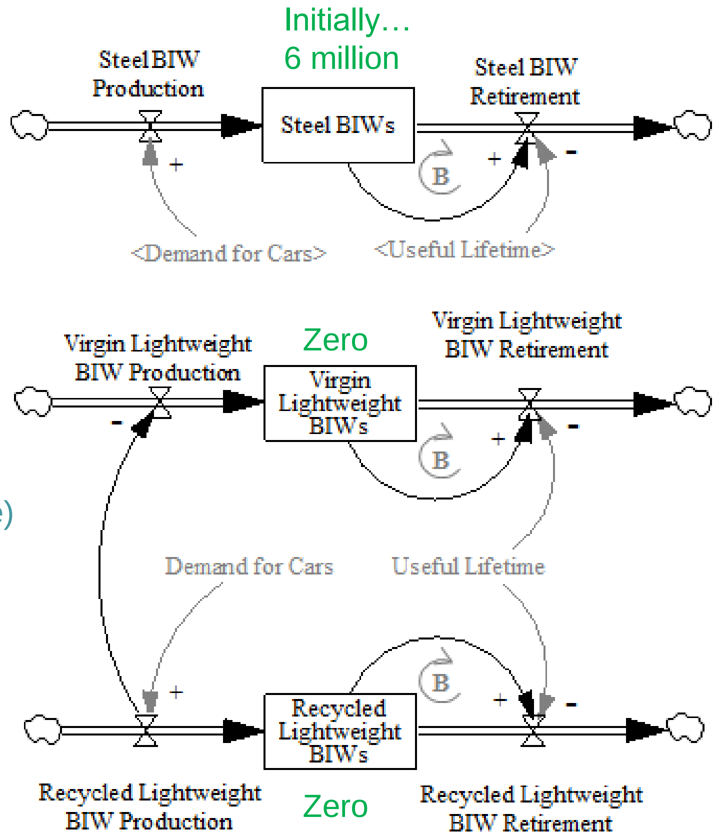
The life cycle of each type of car



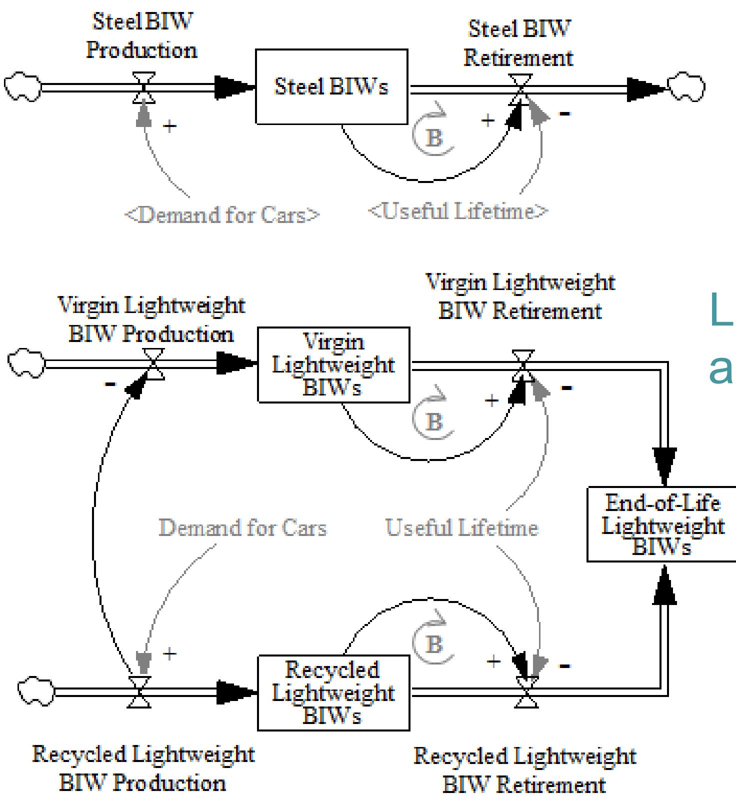
System Dynamics model

Production priority:

1. Recycled lightweight
   (if raw material is available)
2. Virgin lightweight
   (if manufacturing capacity is available)
3. Steel
   (meet the remaining demand)



System Dynamics model



Lightweight cars are retired…

Initially… Zero

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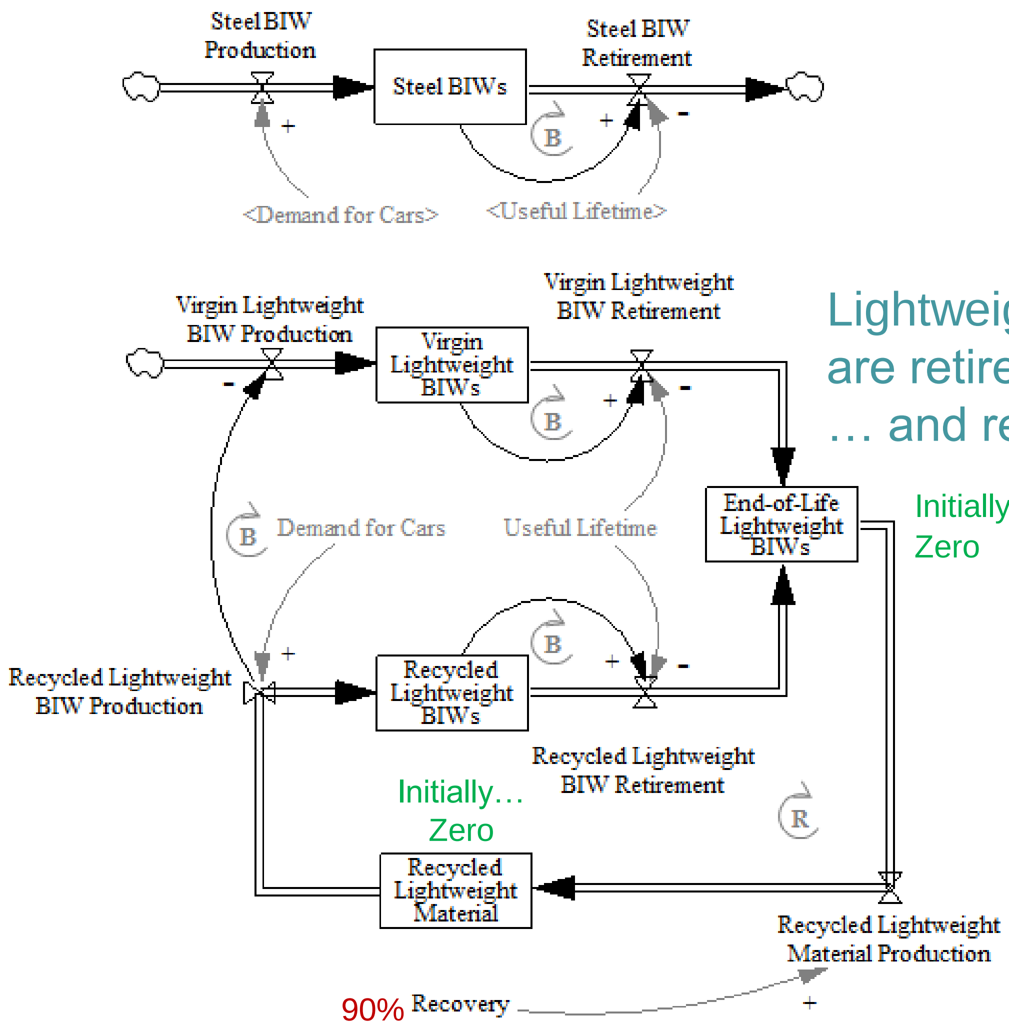
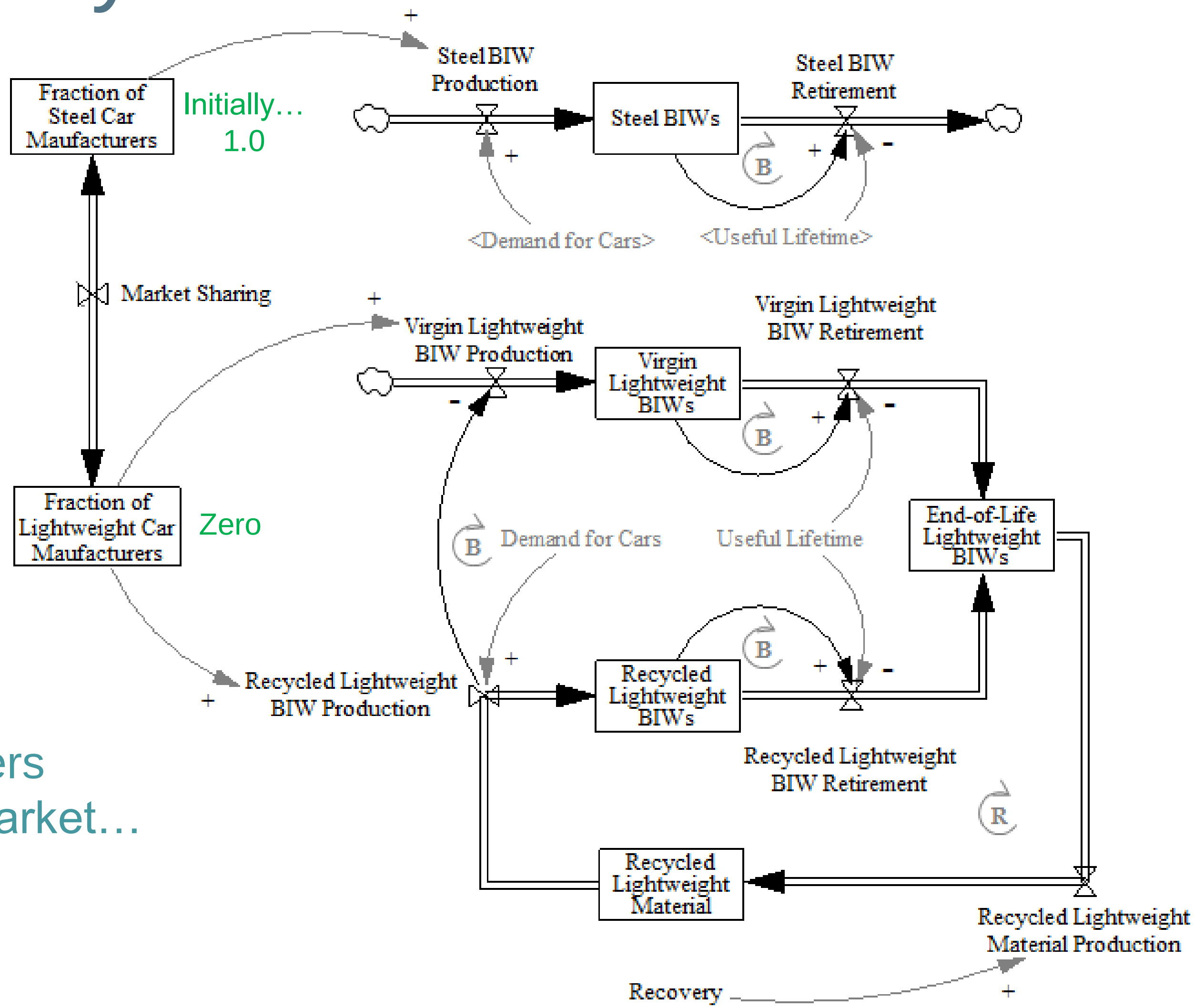
System Dynamics model



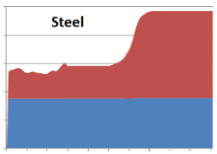
Lightweight cars are retired…
… and recycled

System Dynamics model

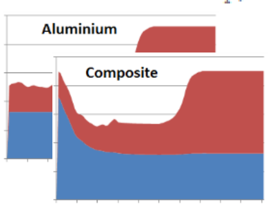


Manufacturers share the market…

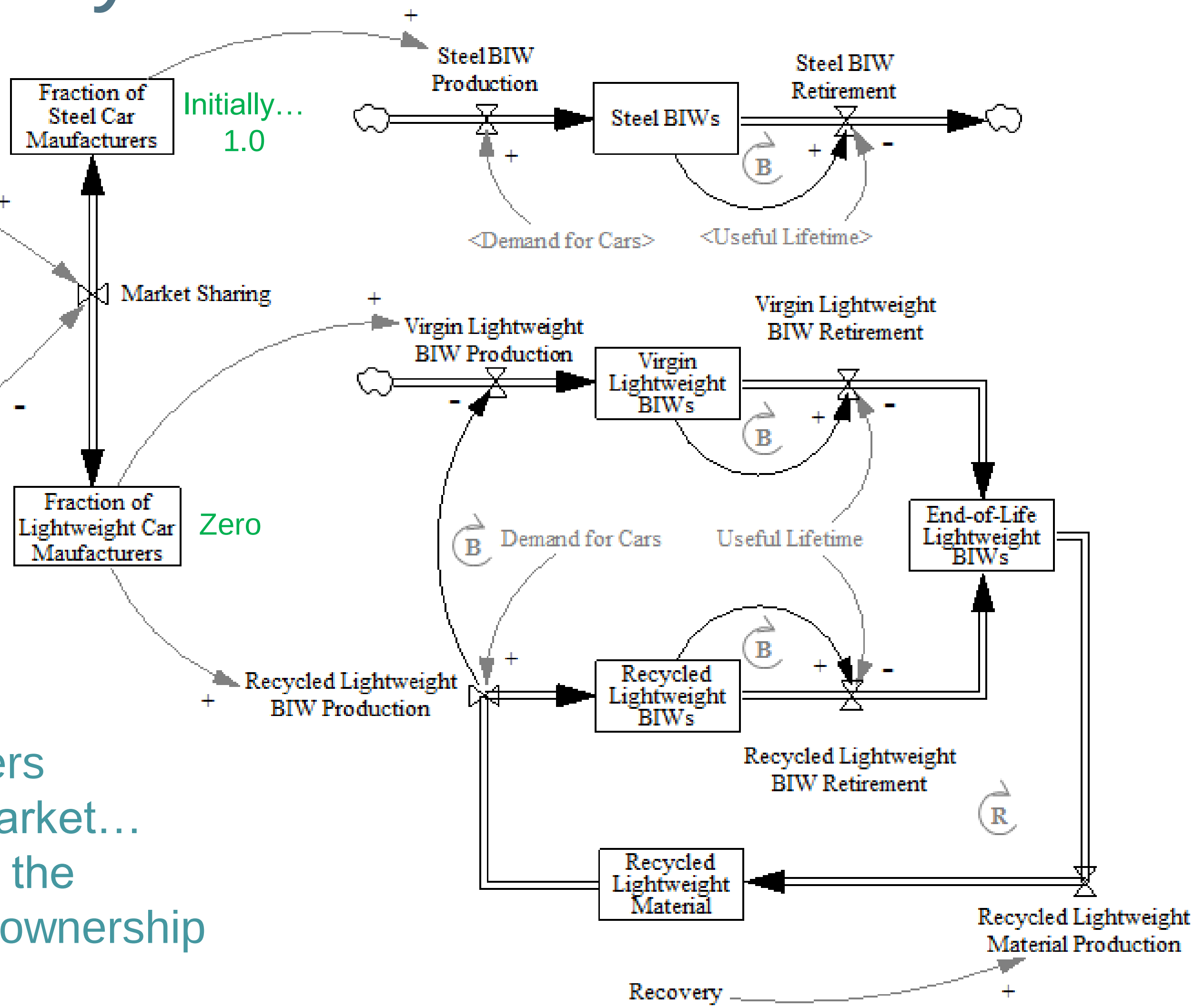
System Dynamics model



Total Cost of Ownership, Steel

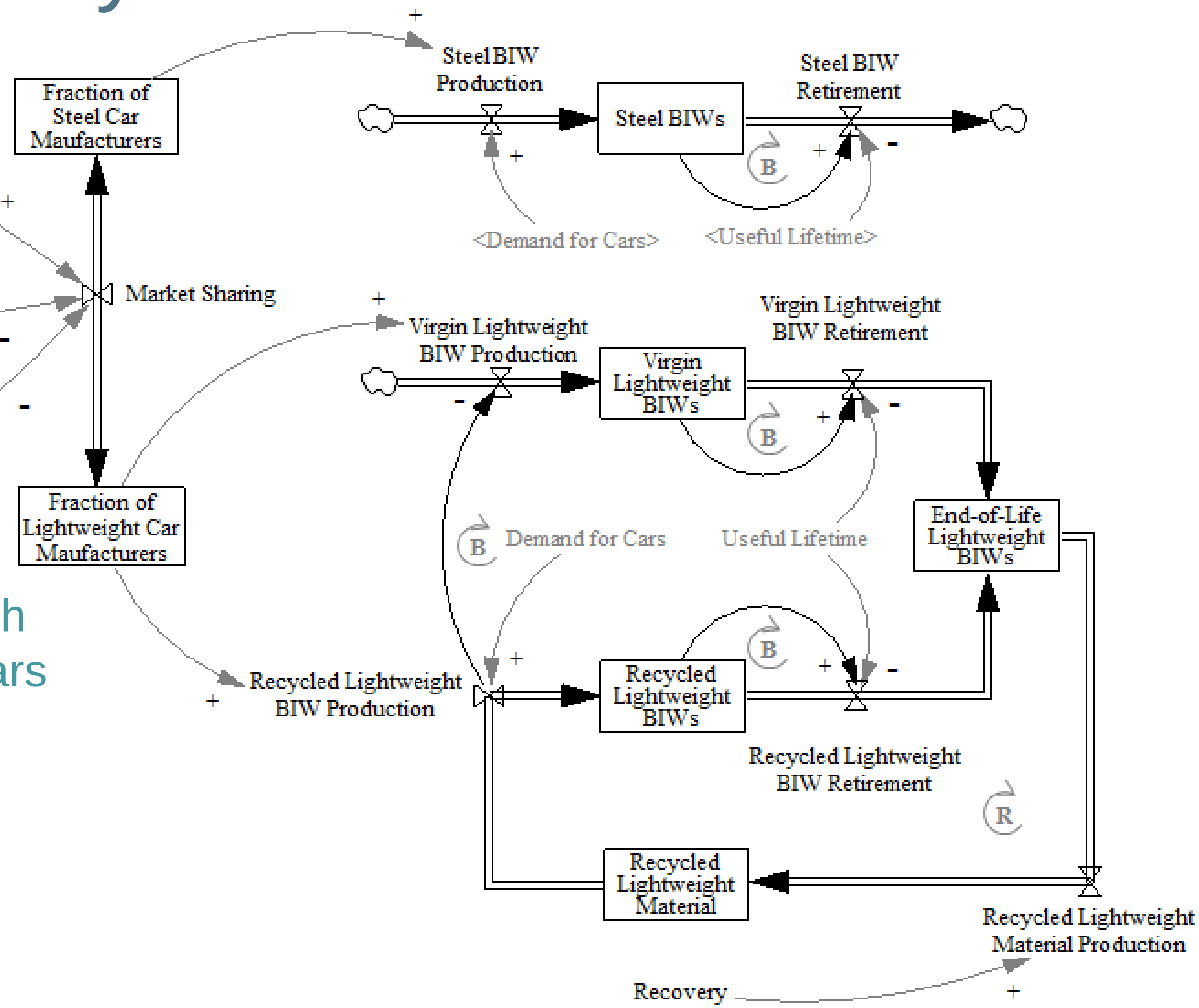


Total Cost of Ownership, Lightweight

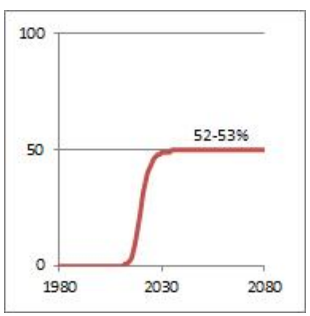


Manufacturers
share the market…
… based on the
total cost of ownership

System Dynamics model

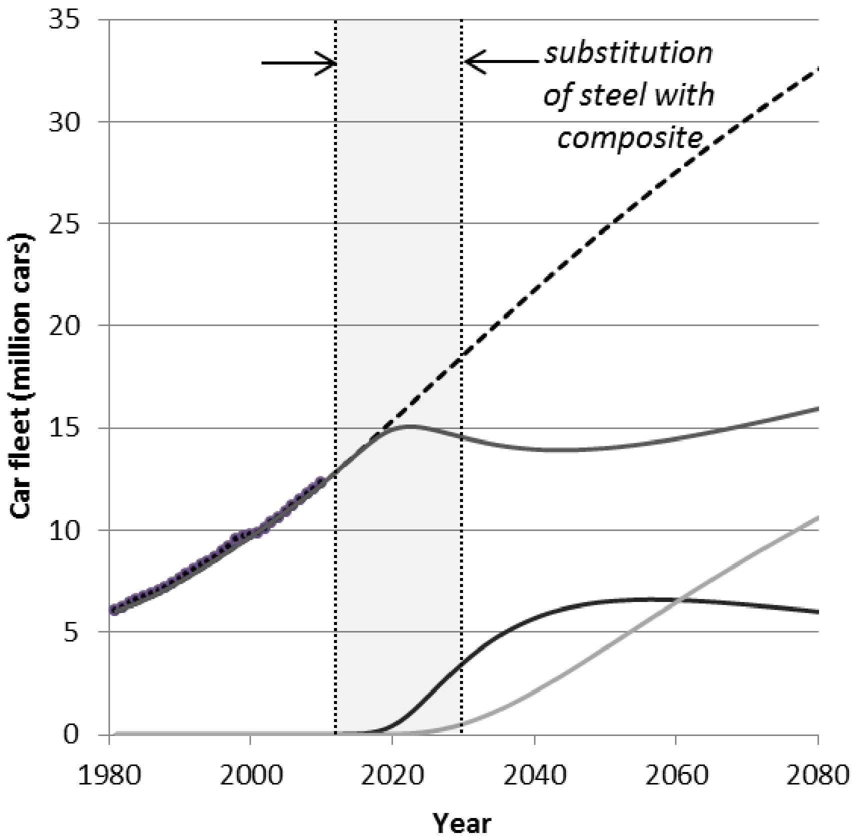


Transition is S-shaped growth of lightweight cars



System Dynamics model – results

Car fleet



Reference — *Historical*

Total

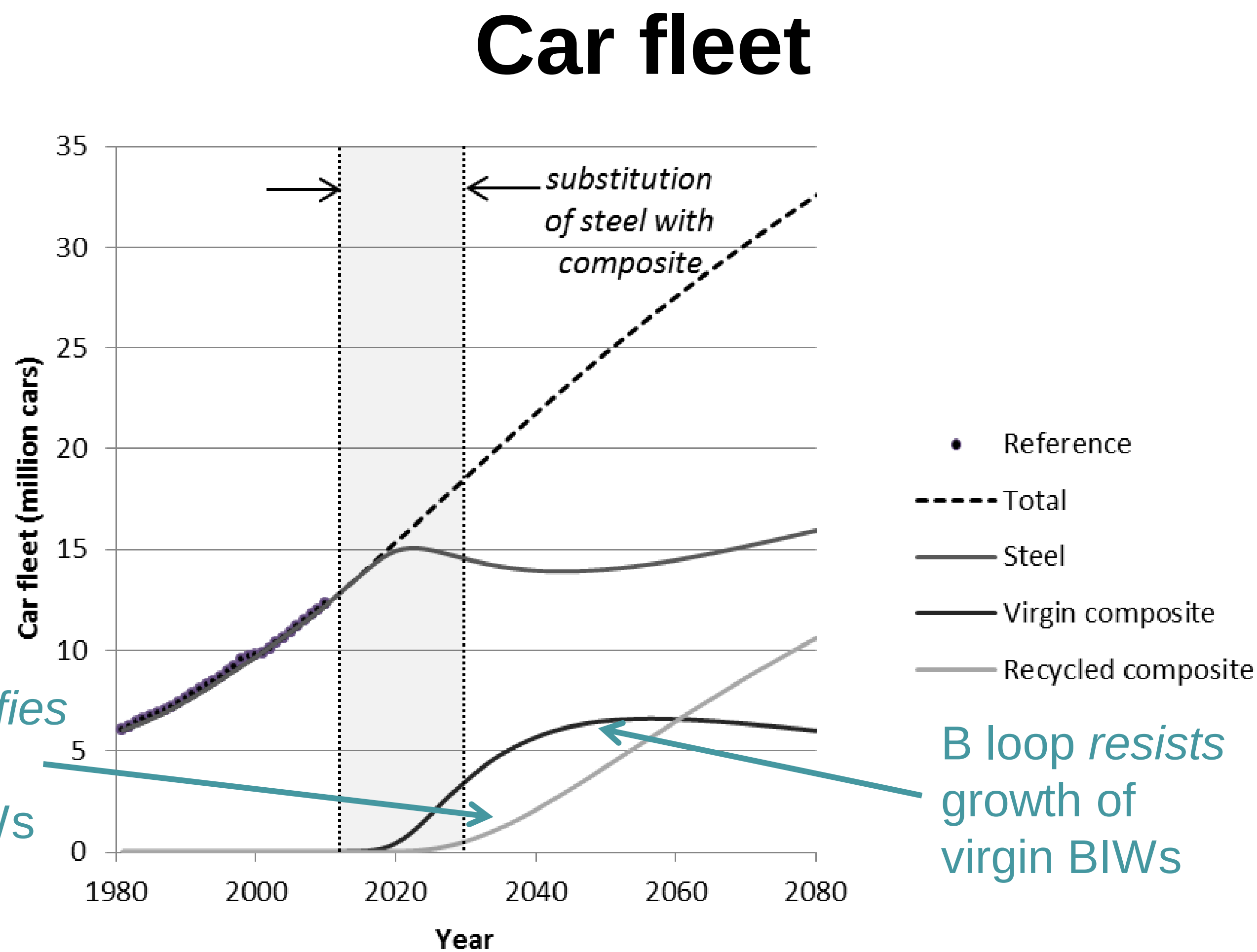
Steel

Virgin composite

Recycled composite — *CFR-PP scenario*

Aluminium graph is similar

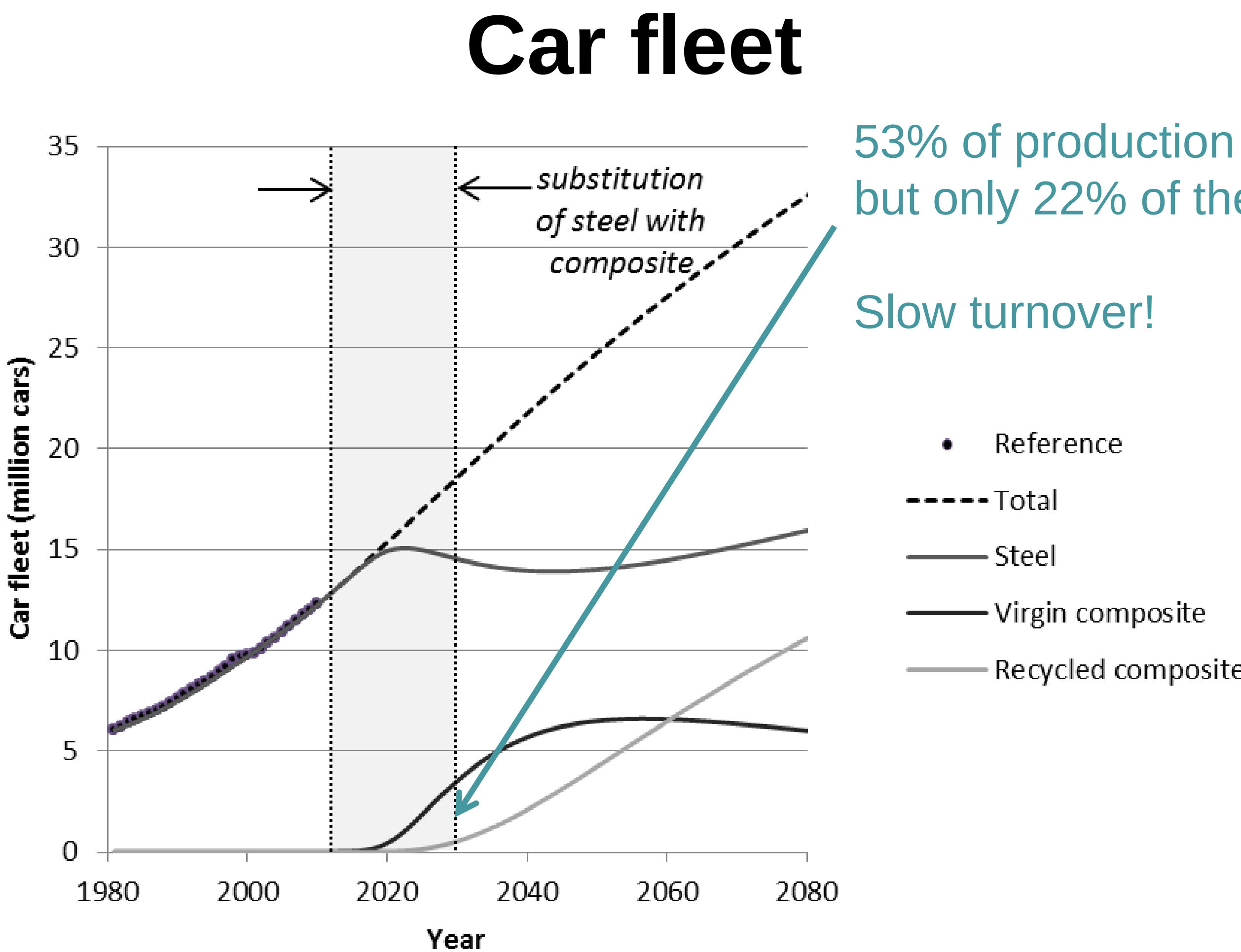
System Dynamics model – results



R loop *amplifies* growth of recycled BIWs

B loop *resists* growth of virgin BIWs

System Dynamics model – results

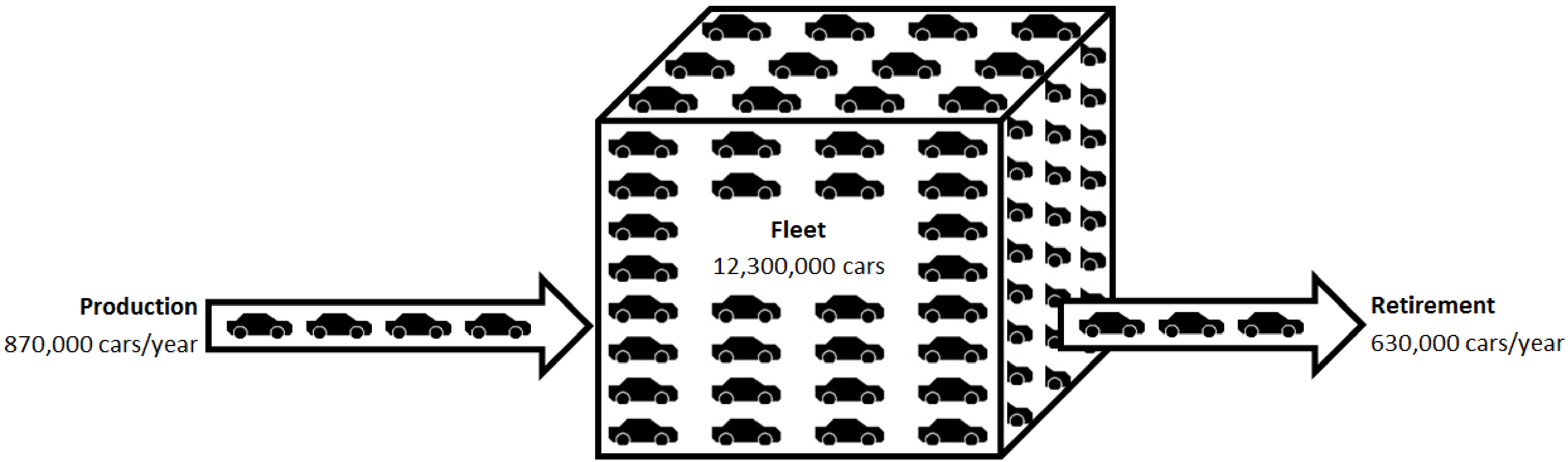


53% of production is LW,
but only 22% of the fleet is LW

Slow turnover!

System Dynamics model – results

Car fleet



(adapted from Australian Bureau of Statistics 2011)

- Source of *delay* (slow turnover!)
- Production > Retirement → *Growth*

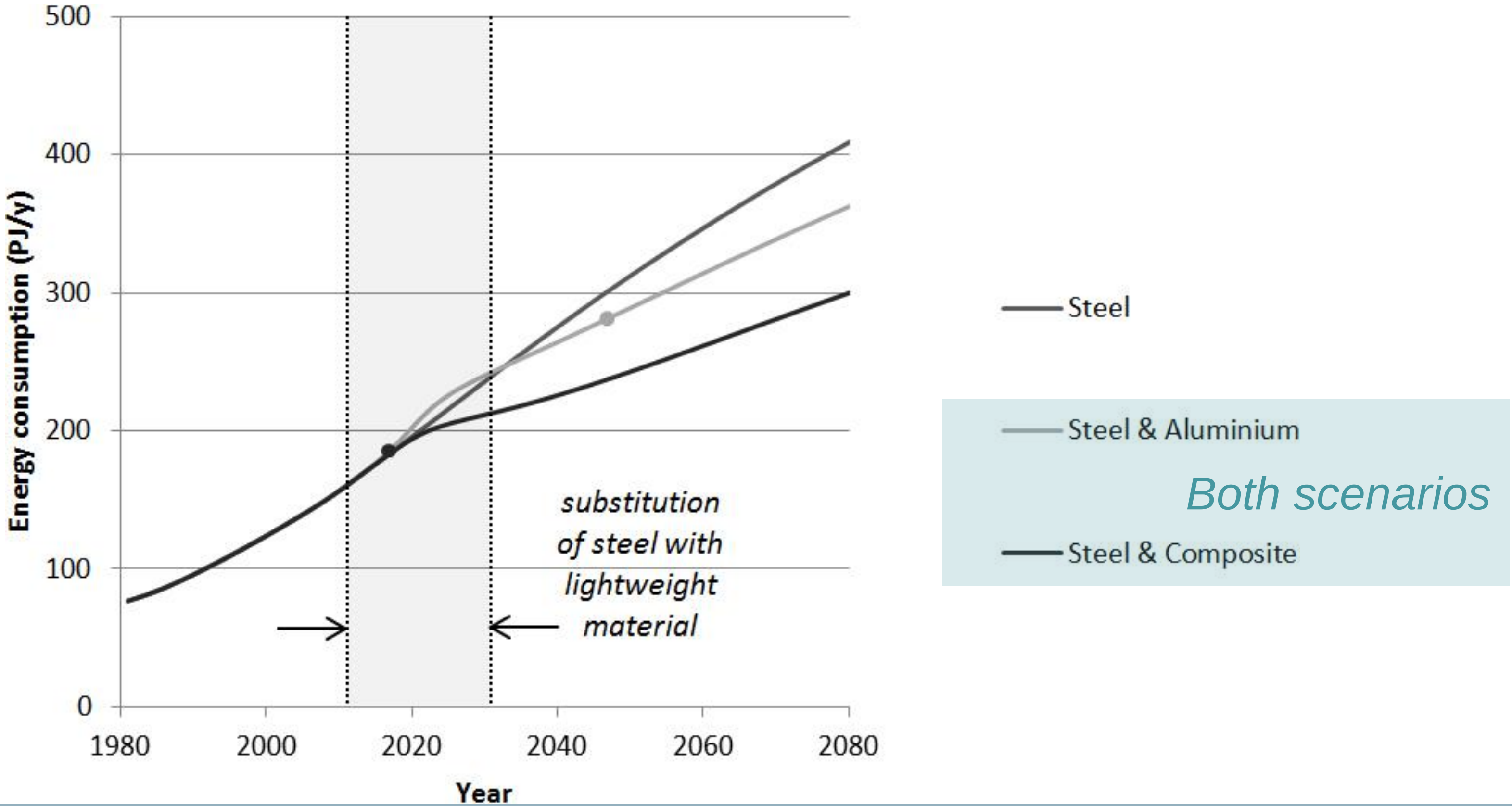
Life cycle inventory

Key data

Parameter	Steel	Aluminium	Composite	Units
BIW mass	430	300	230	kg
Car mass	1720	1590	1520	kg
Car fuel consumption	9.0	8.67	8.48	l/100km
Total cost of ownership				
Initial (2010)	58,000	54,900	54,300	$
Final	96,900	92,500	90,300	$
Energy flow, production				
Virgin	35.2	190	102	MJ/kg
Recycled	19.0	57.5	77.4	MJ/kg
Energy flow, use	2.47	2.57	2.64	kJ/km/kg

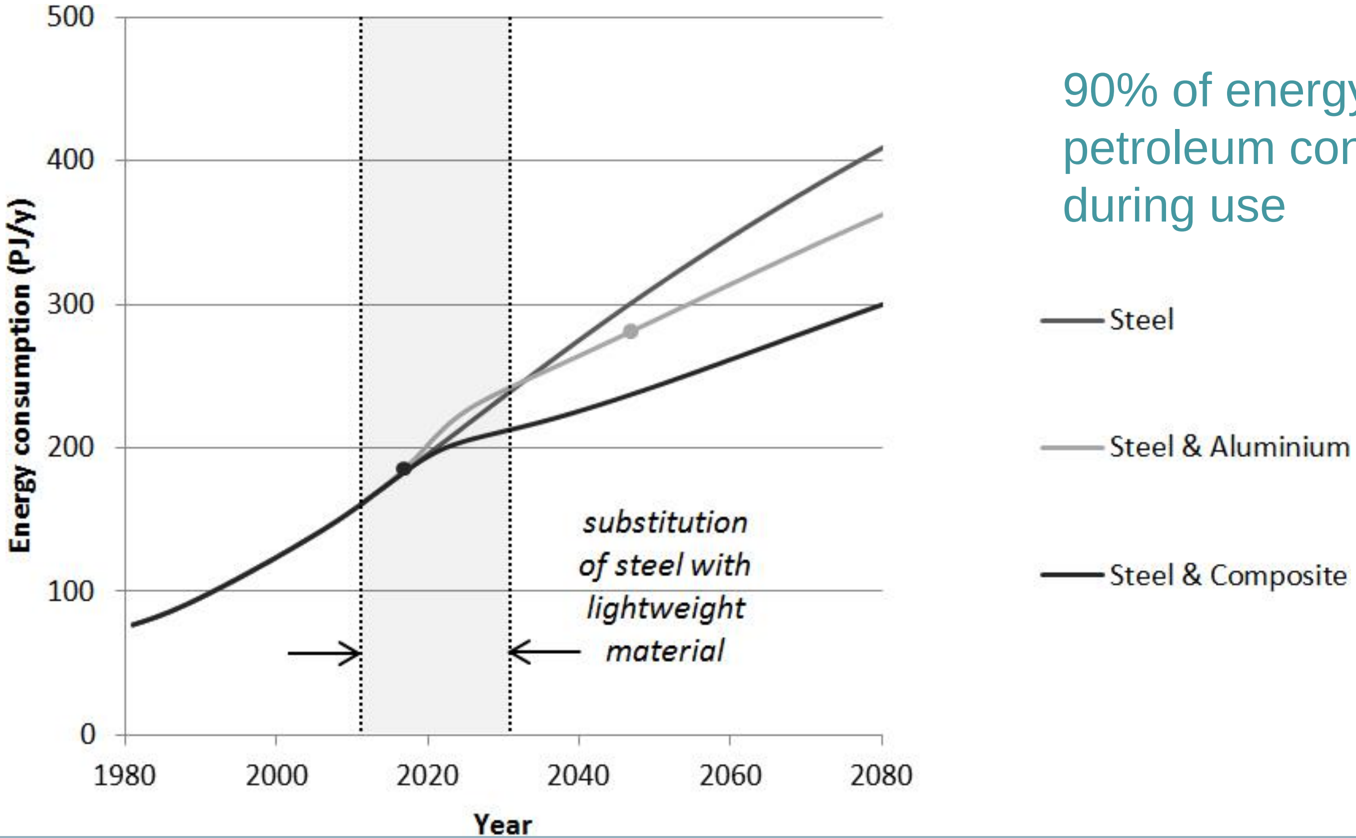
Life cycle inventory – results

Energy consumption



Life cycle inventory – results

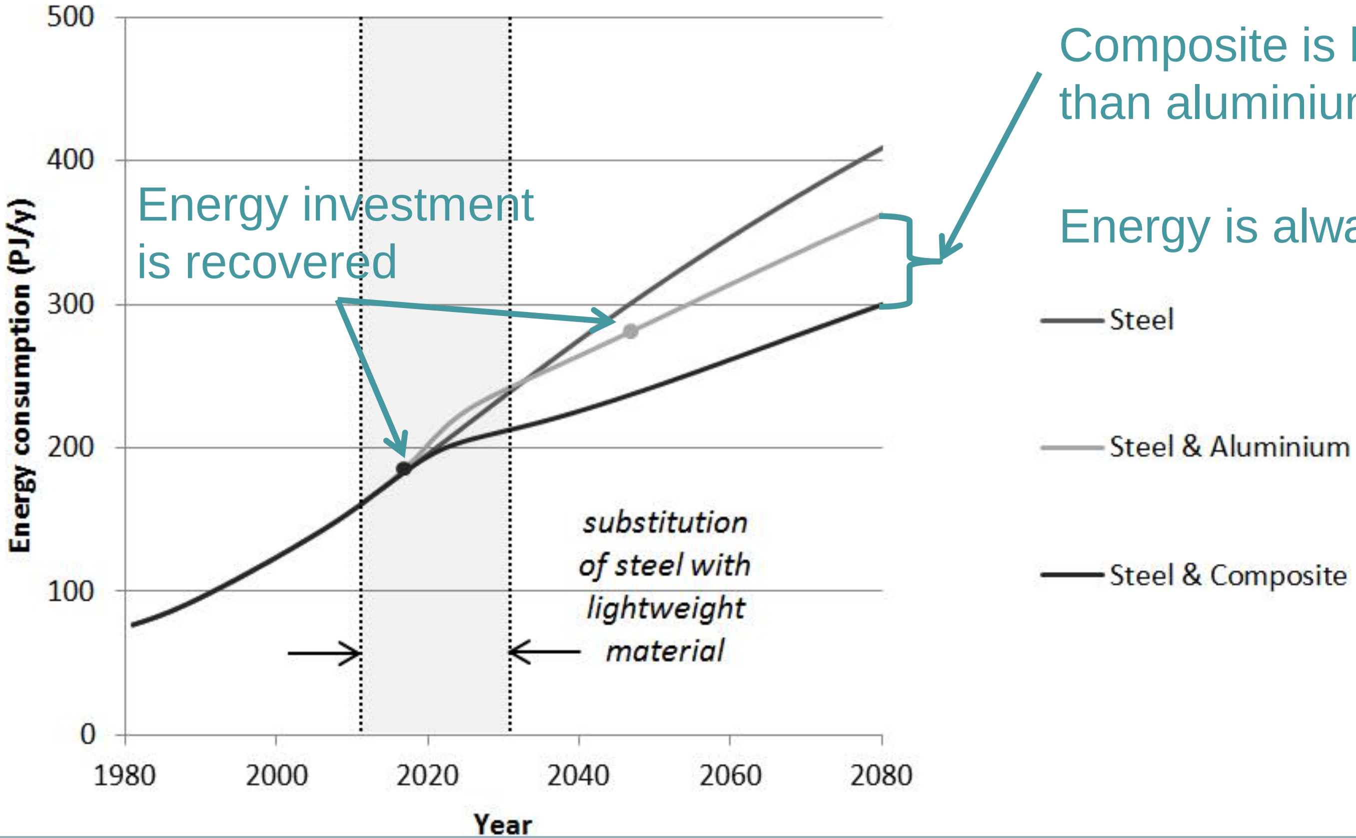
Energy consumption



90% of energy is from petroleum consumption during use

Life cycle inventory – results

Energy consumption



Composite is better than aluminium

Energy is always growing!

Conclusions

- A System Dynamics approach provides greater ***insight*** than standard life cycle inventory
- A SD approach reveals:
  - a long ***delay*** in the transition to lightweight cars
  - material-substitution's small effect on the ***fleet***'s energy, rather than its large effect on a ***single product***'s energy
- Case study simulations show:
  - the ***energy benefits*** of composite cars emerge ***much sooner*** and are about ***twice as large*** in the long-term as those of aluminium cars
  - energy consumption always ***grows***

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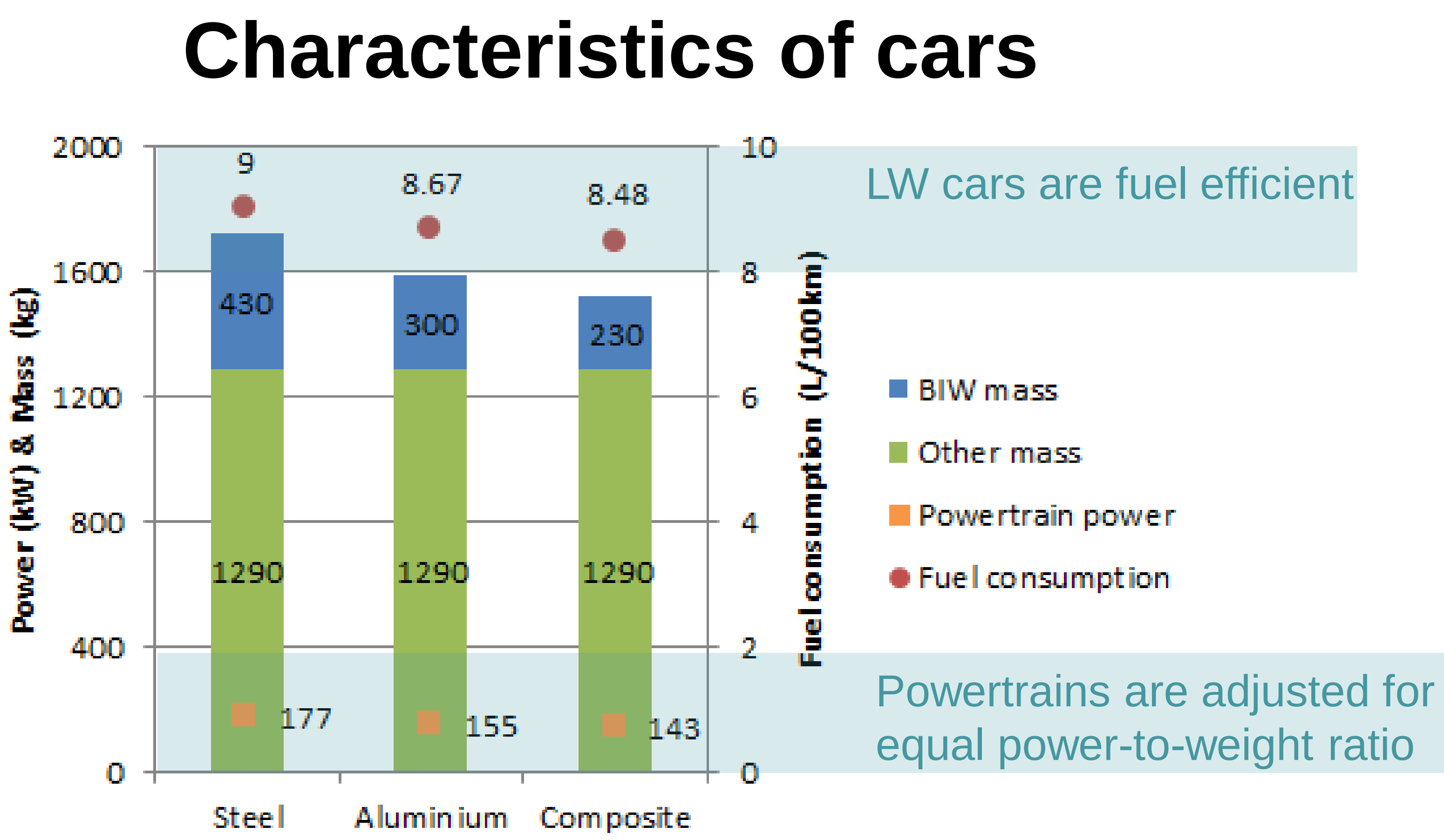
Recommendations

- Material-substitution, alone, has ***low leverage*** for reducing energy consumption
  - Too much investment for too little benefit
- Might get ***better results*** from adjusting:
  - synergistic tech innovations (e.g., LW + electrification)
  - fuel supply
  - driving intensity
  - driving behaviour

Future work

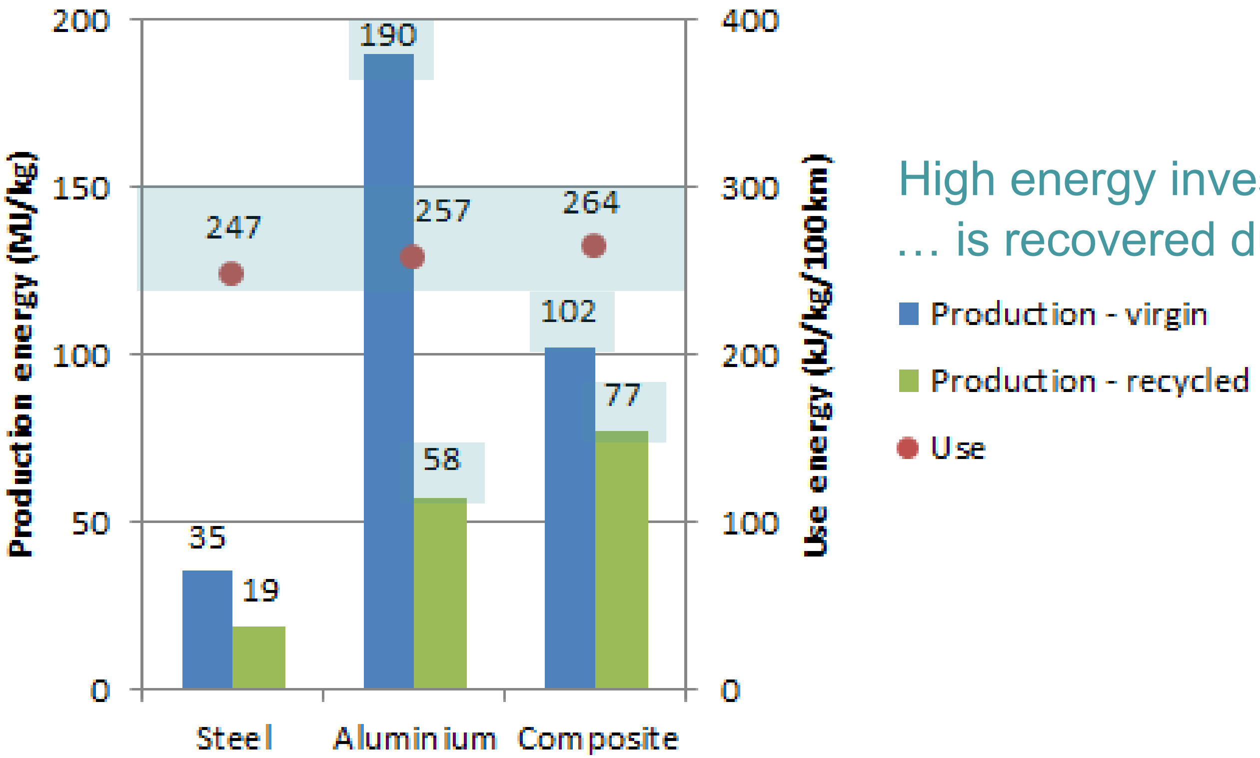
Questions?

Life cycle inventory – key data



Life cycle inventory – key data

Energy consumption of materials

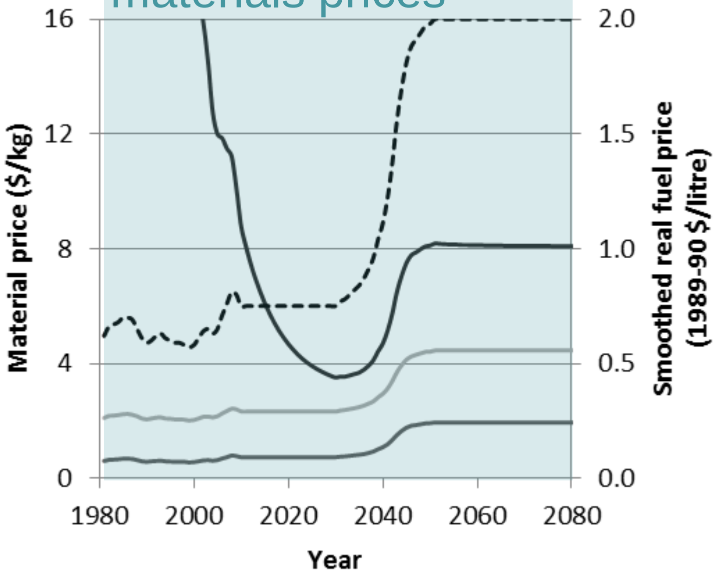


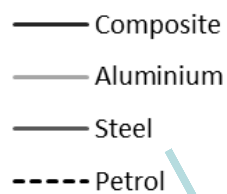
(Puri et al. 2009)

High energy investment…
… is recovered during use

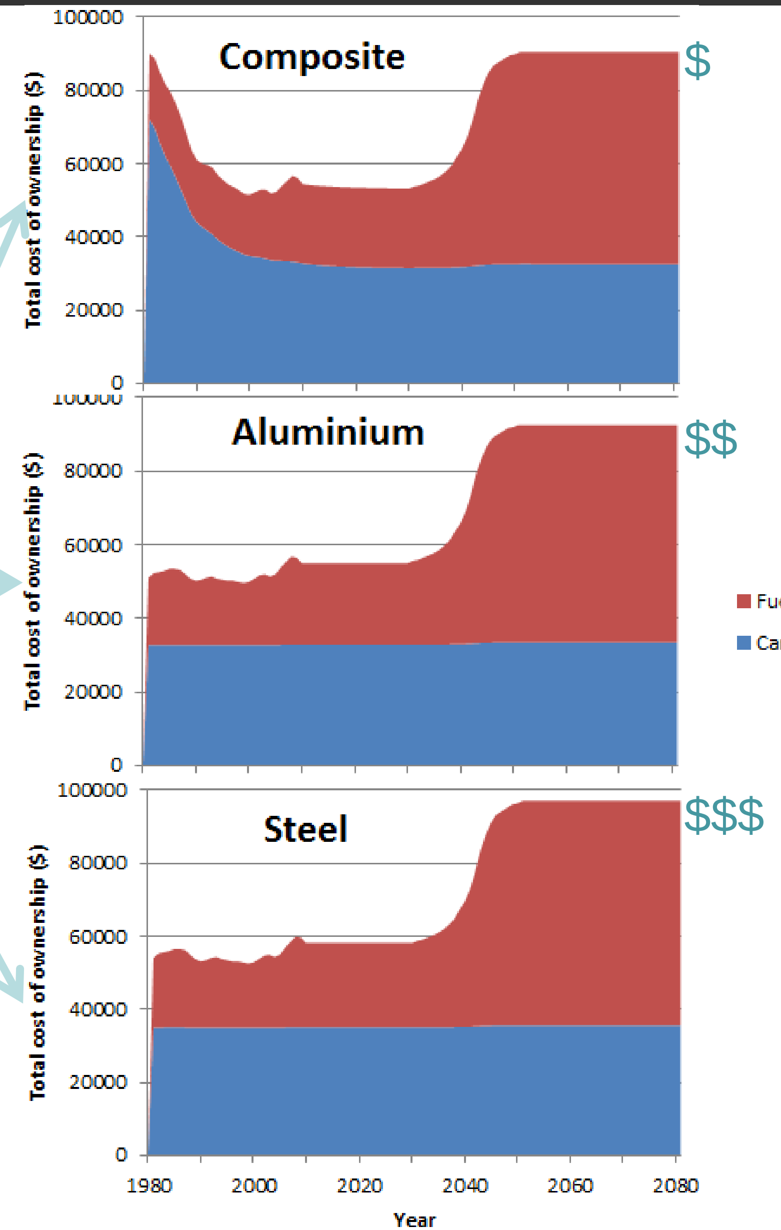
SD model – key data

Fuel price drives materials prices





And all prices drive TCO



Total cost of ownership