Quantifying the Use Chains of Plastics and the Sources of Plastic in the Ocean

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3) Tiwah UG, Germany

Marine Debris is a growing problem for the marine biosphere and humanity

The Plastic Challenge

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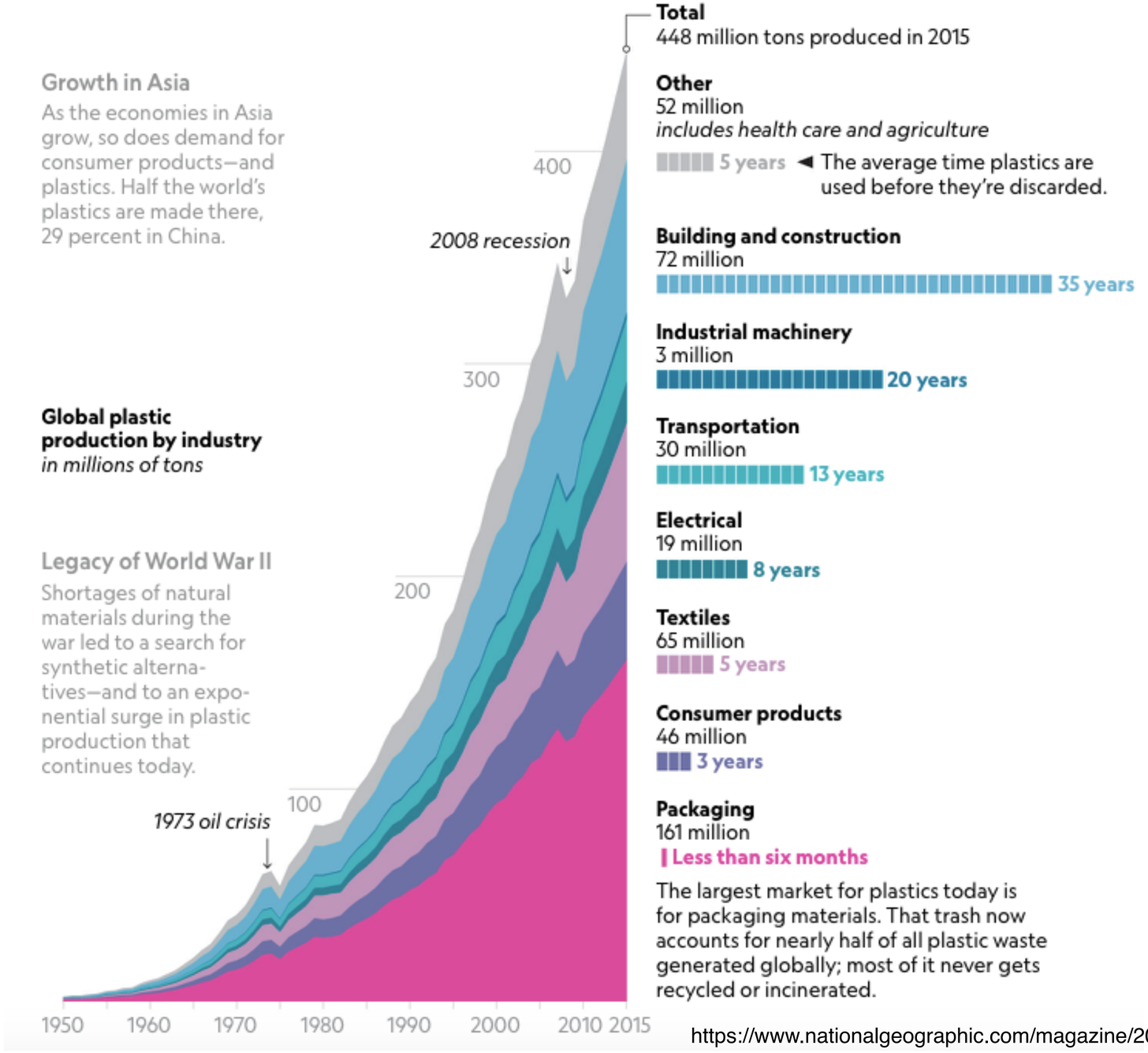
What we Know: Plastic is produced a lot

The Plastic Challenge

A LIFETIME OF PLASTIC

The first plastics made from fossil fuels are just over a century old.They came into widespread use after World War II and are found today in everything from cars to medical devices to food packaging. Their useful lifetime varies. Once disposed of, they break down into smaller fragments that linger for centuries.



JASON TREAT AND RYAN WILLIAMS, NGM STAFF
SOURCE: ROLAND GEYER, UNIVERSITY OF CALIFORNIA, SANTA BARBARA

https://www.nationalgeographic.com/magazine/2018/06/plastic-planet-waste-pollution-trash-crisis/

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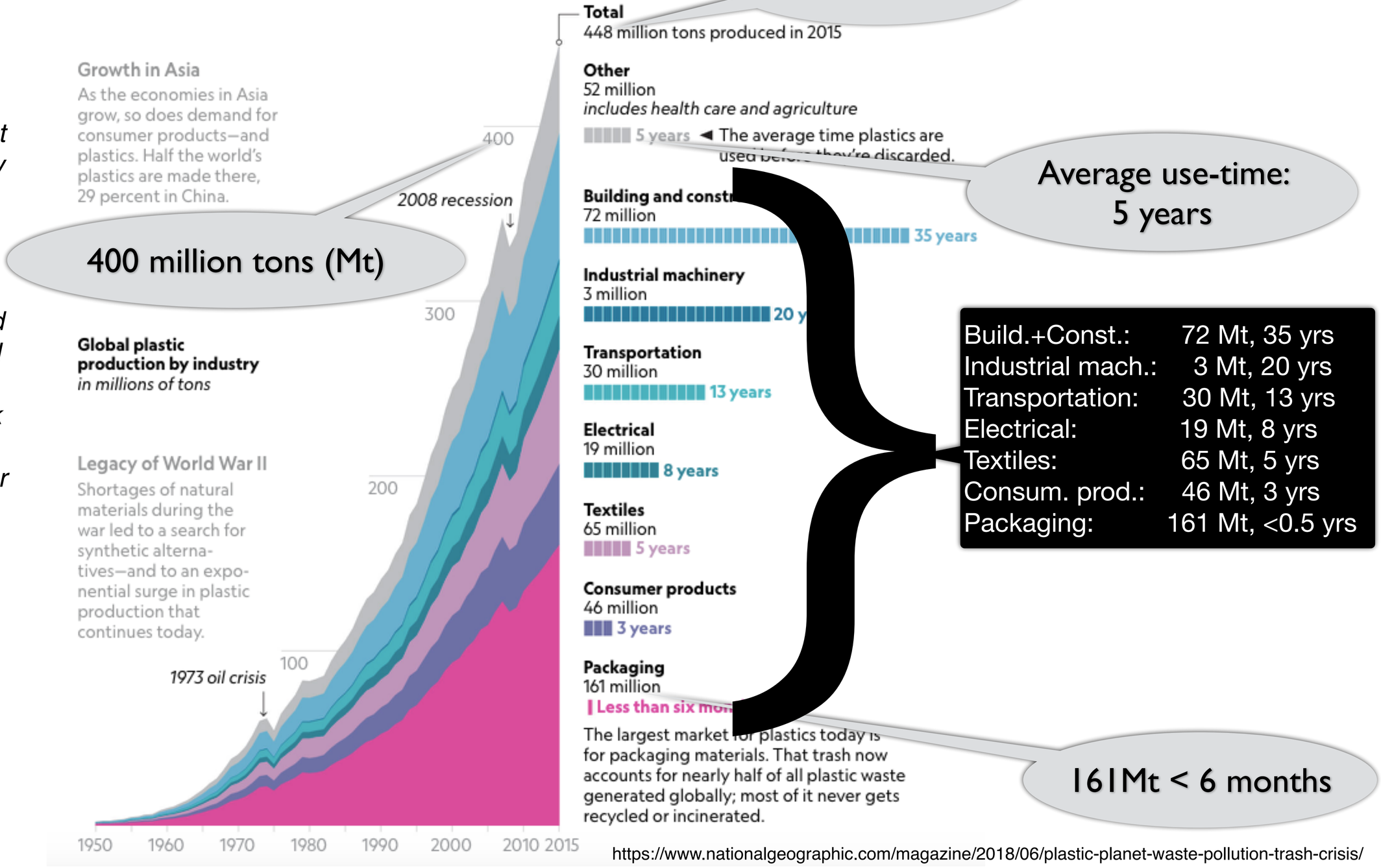

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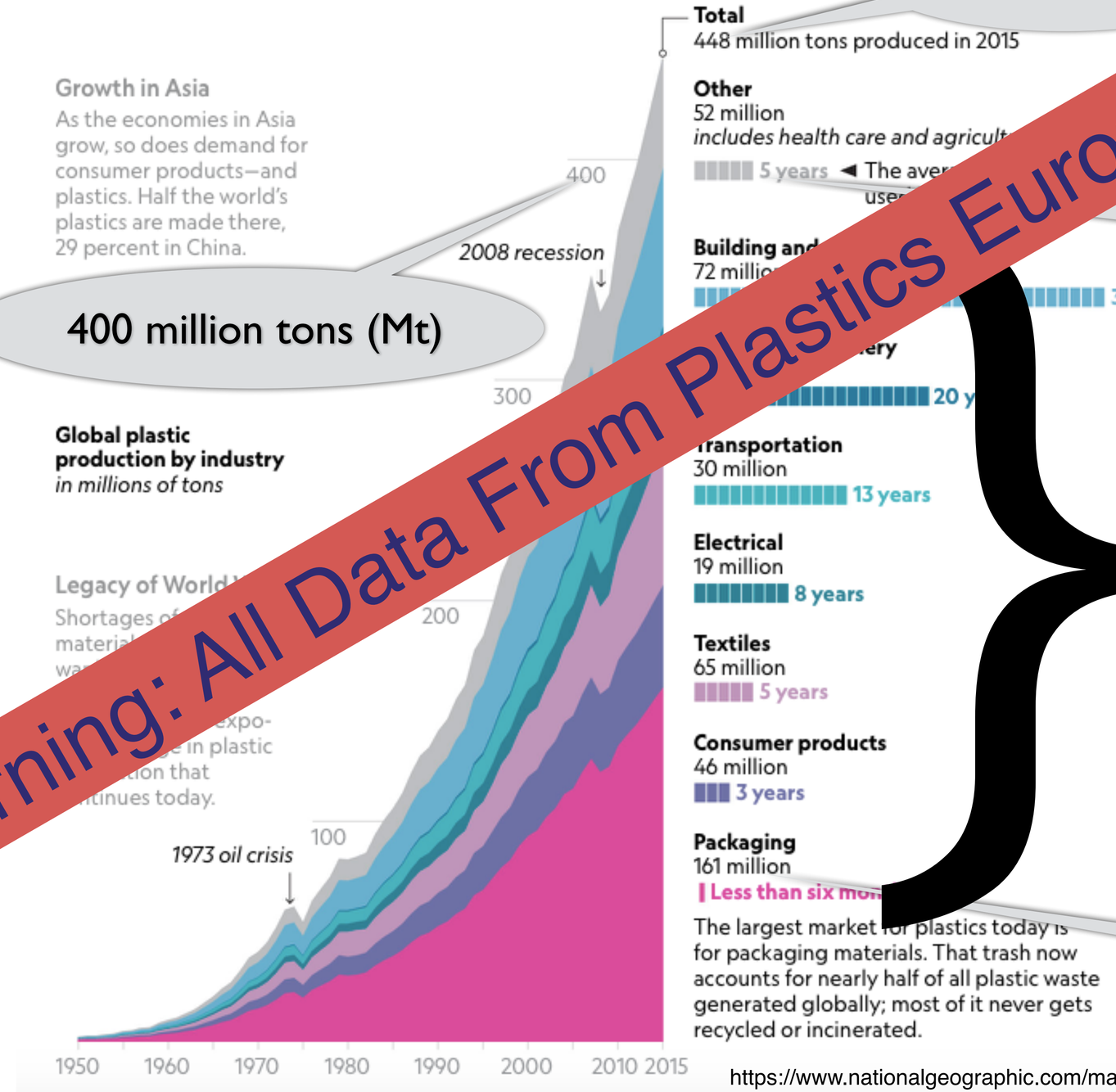

448 Mt in 2015

400 million tons (Mt)

Average use-time: 5 years

Warning: All Data From Plastics Europe

Total
448 million tons produced in 2015

Other
52 million
includes health care and agricult
5 years ◀ The aver
use
ed.

Building and
72 millio
35 years
ery
20 y

Transportation
30 million
13 years

Electrical
19 million
8 years

Textiles
65 million
5 years

Consumer products
46 million
3 years

Packaging
161 million
Less than six mo

The largest market for plastics today is for packaging materials. That trash now accounts for nearly half of all plastic waste generated globally; most of it never gets recycled or incinerated.

Build.+Const.:	72 Mt, 35 yrs
Industrial mach.:	3 Mt, 20 yrs
Transportation:	30 Mt, 13 yrs
Electrical:	19 Mt, 8 yrs
Textiles:	65 Mt, 5 yrs
Consum. prod.:	46 Mt, 3 yrs
Packaging:	161 Mt, <0.5 yrs

161Mt < 6 months

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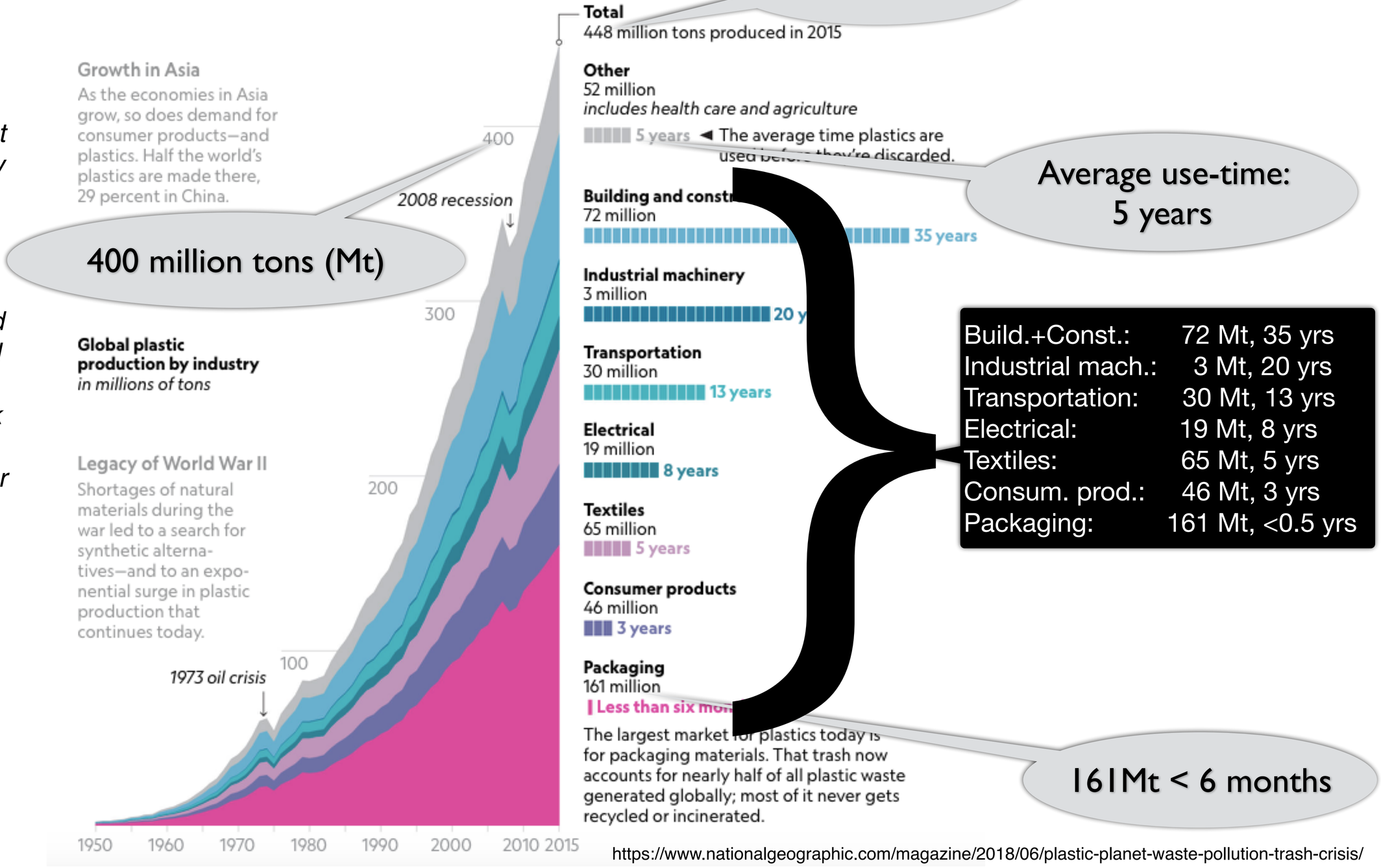

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The Ethical Challenge

2% annual increase in production:
2025: 550 Mt
2035: 670 Mt
2045: 817 Mt

Total production:
2015: 7 Bt
2045: 26 Bt

1% in the ocean: 260 Mt

In coastal built environment prone to disasters:

1.7 Bt

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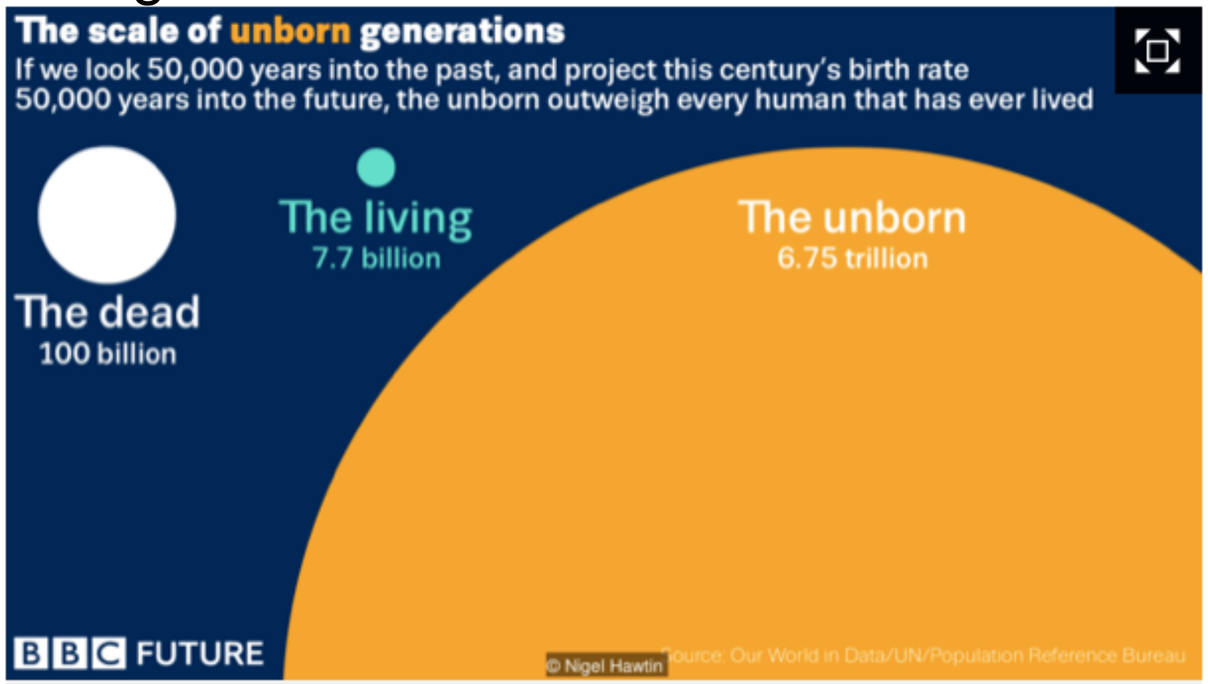

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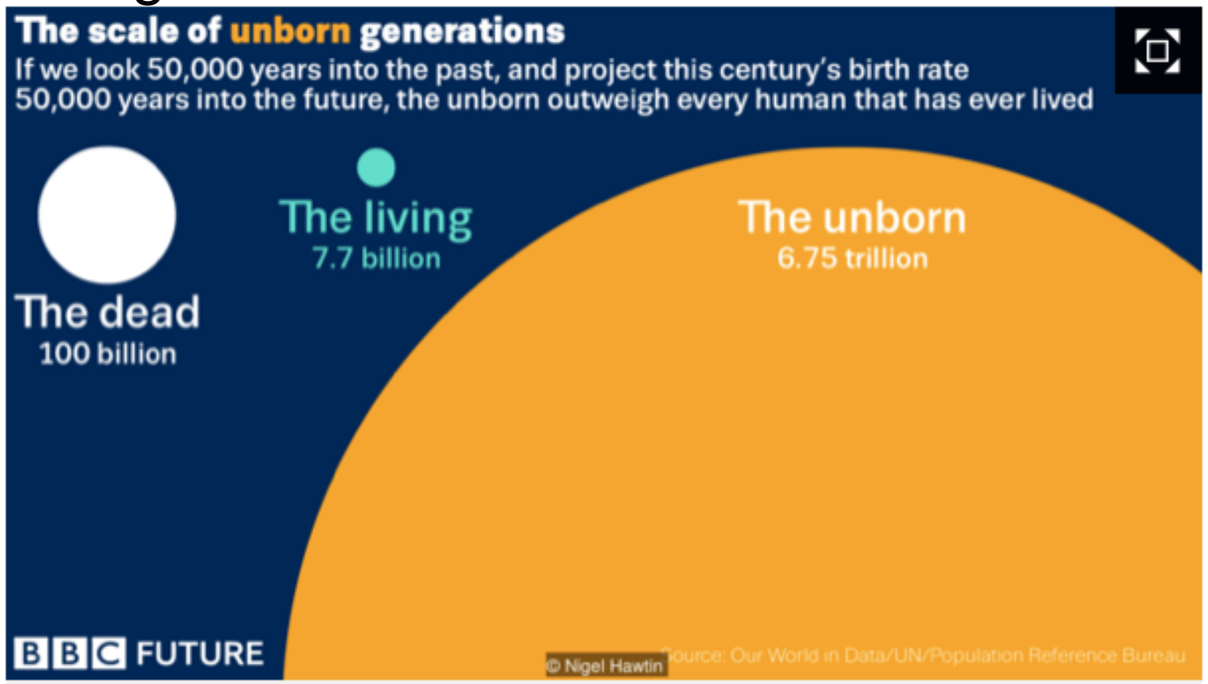

Plastics in the planetary physiology will impact the 500 billion+ to be born during the next 5,000 years.

Does the plastics crisis violate the rights of those not yet born?

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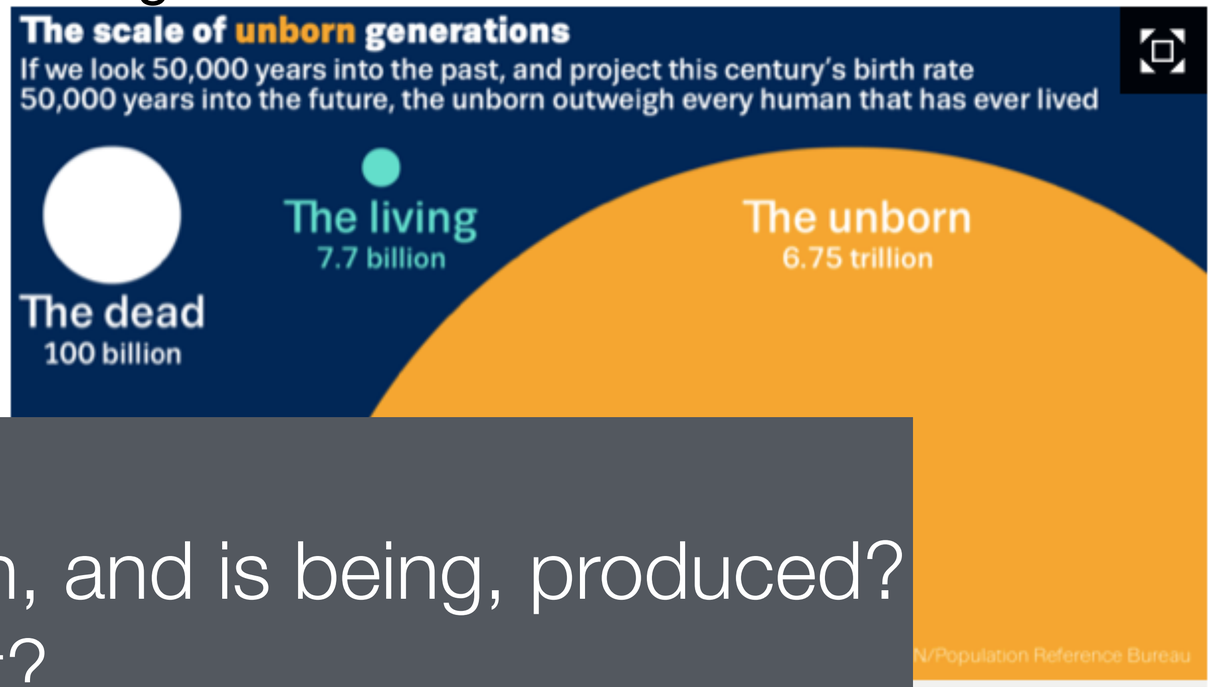
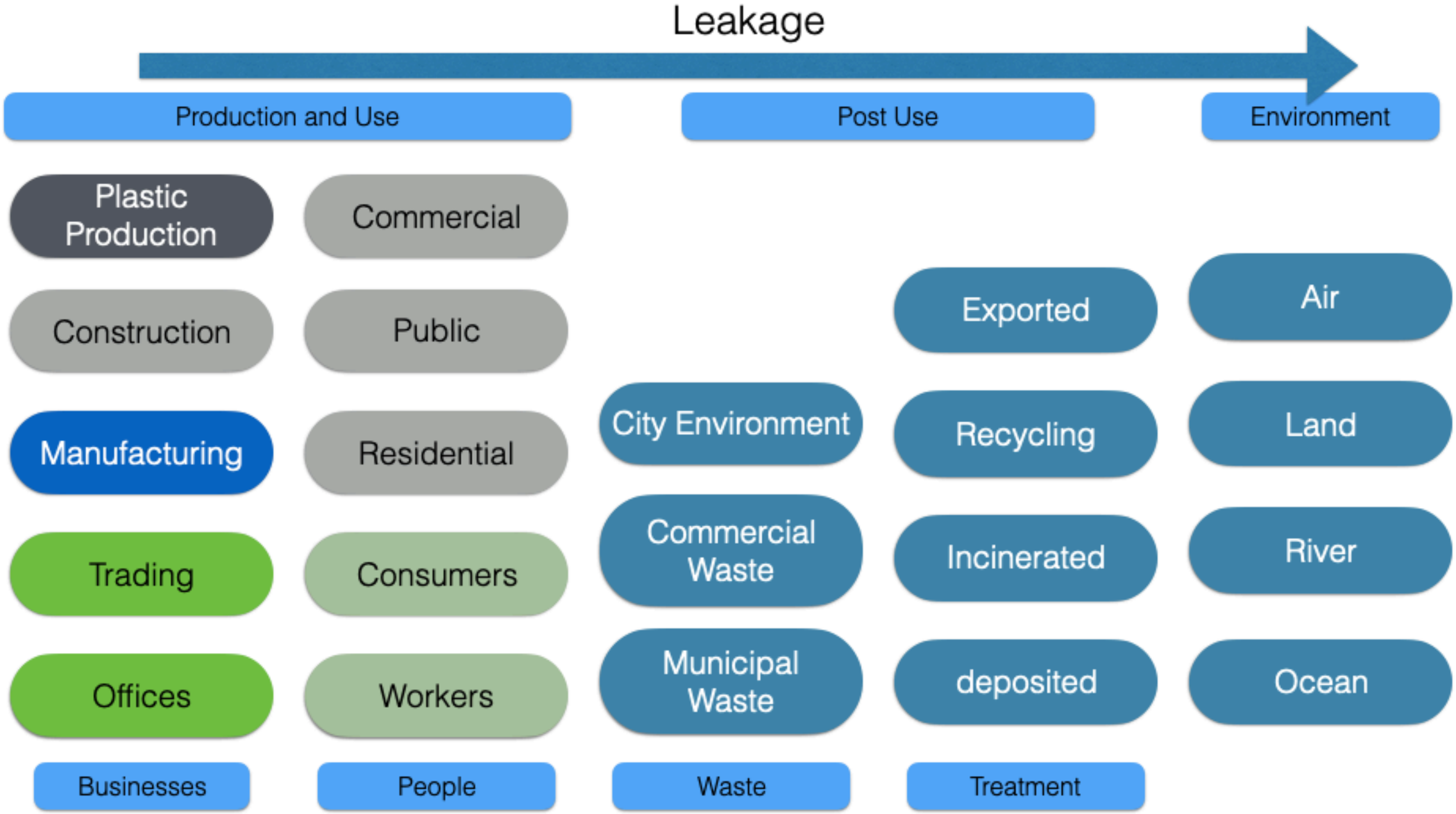


What we Don't Know Well:
How much plastic has been, and is being, produced?
How much is used for what?
How long are use times/residence times?
How large are the stocks?
How large will stocks be in the future?

Does the plastics crisis violate the rights of those not yet born?

A Stock and Flow Model …



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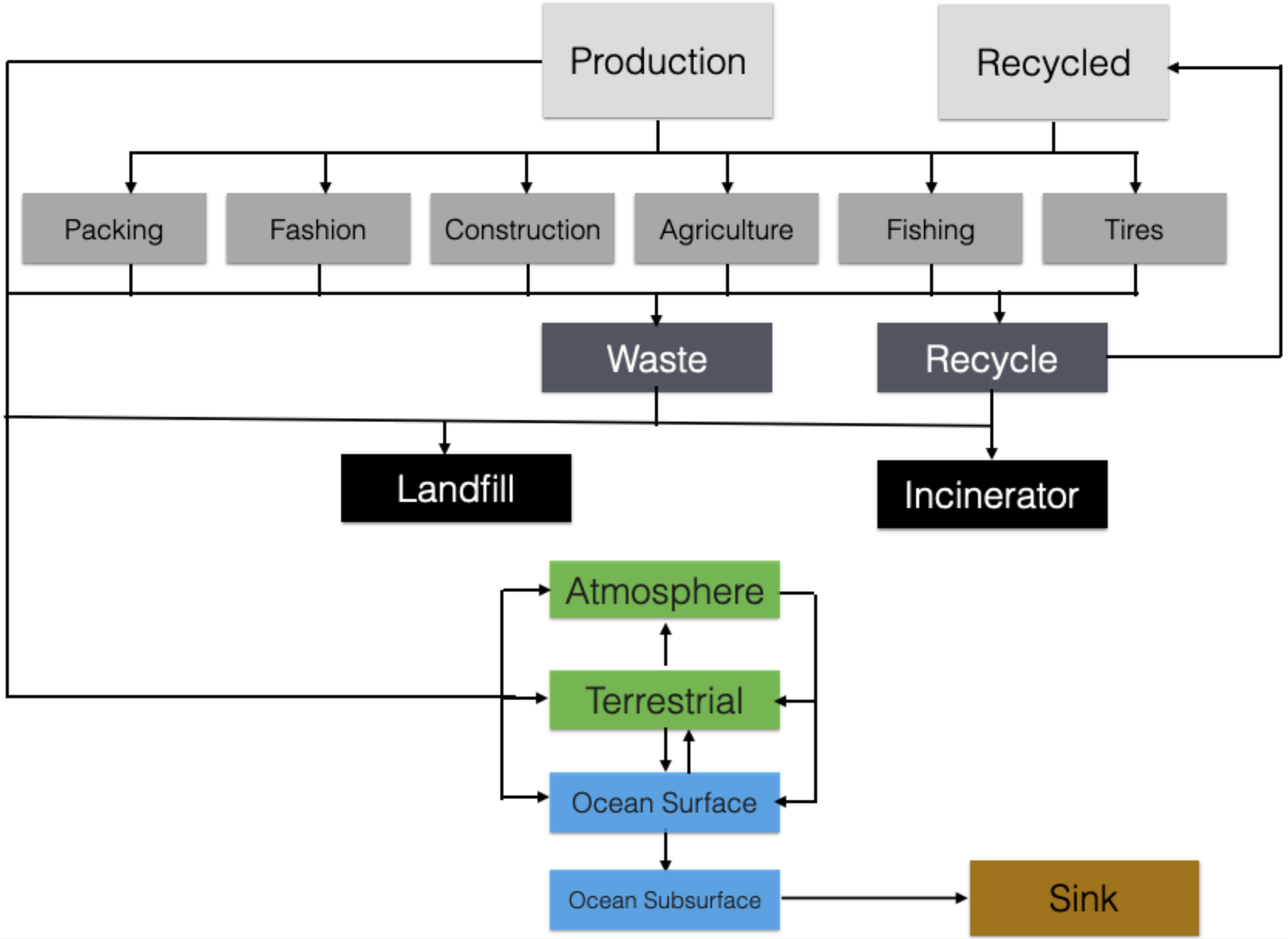

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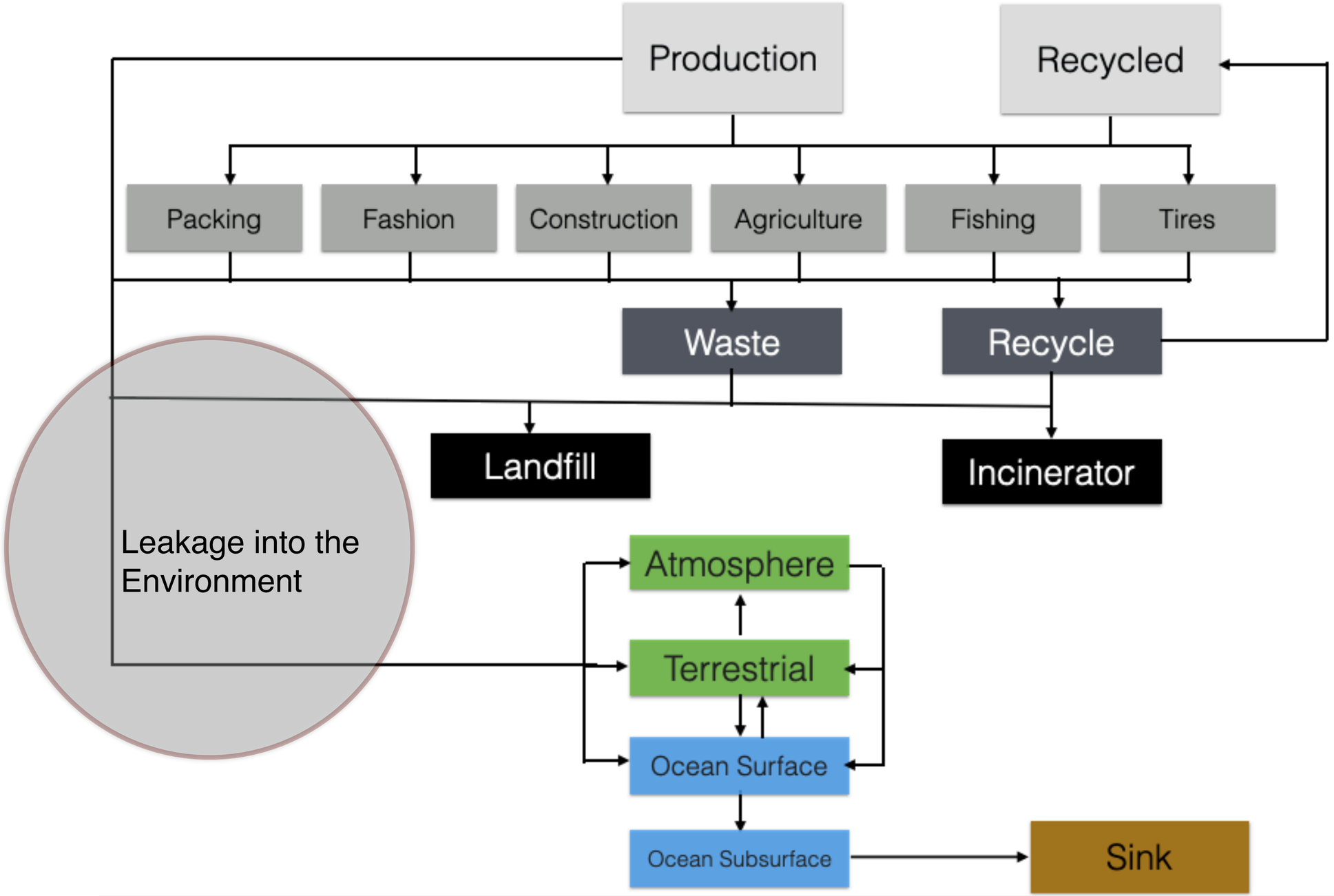

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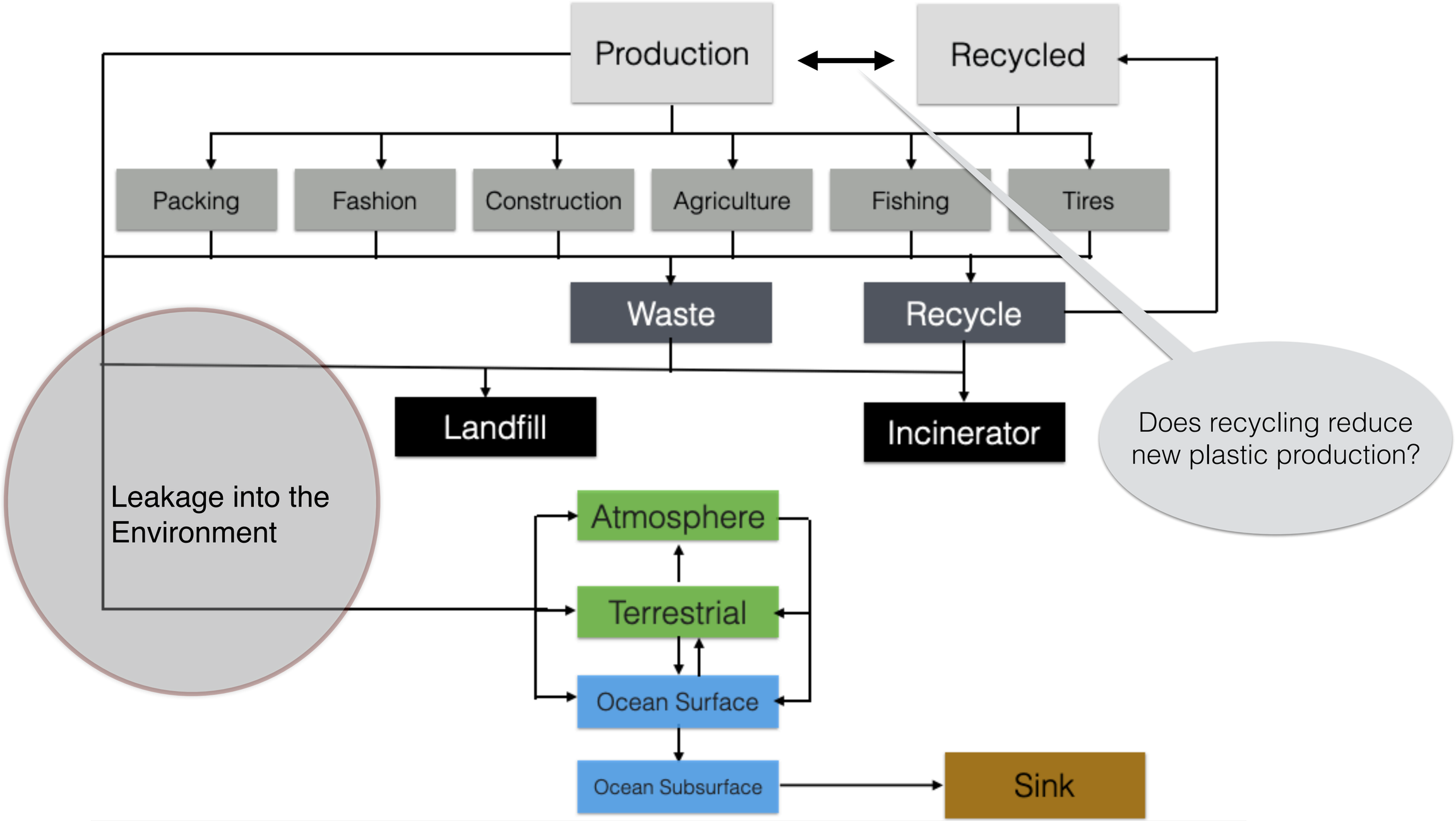

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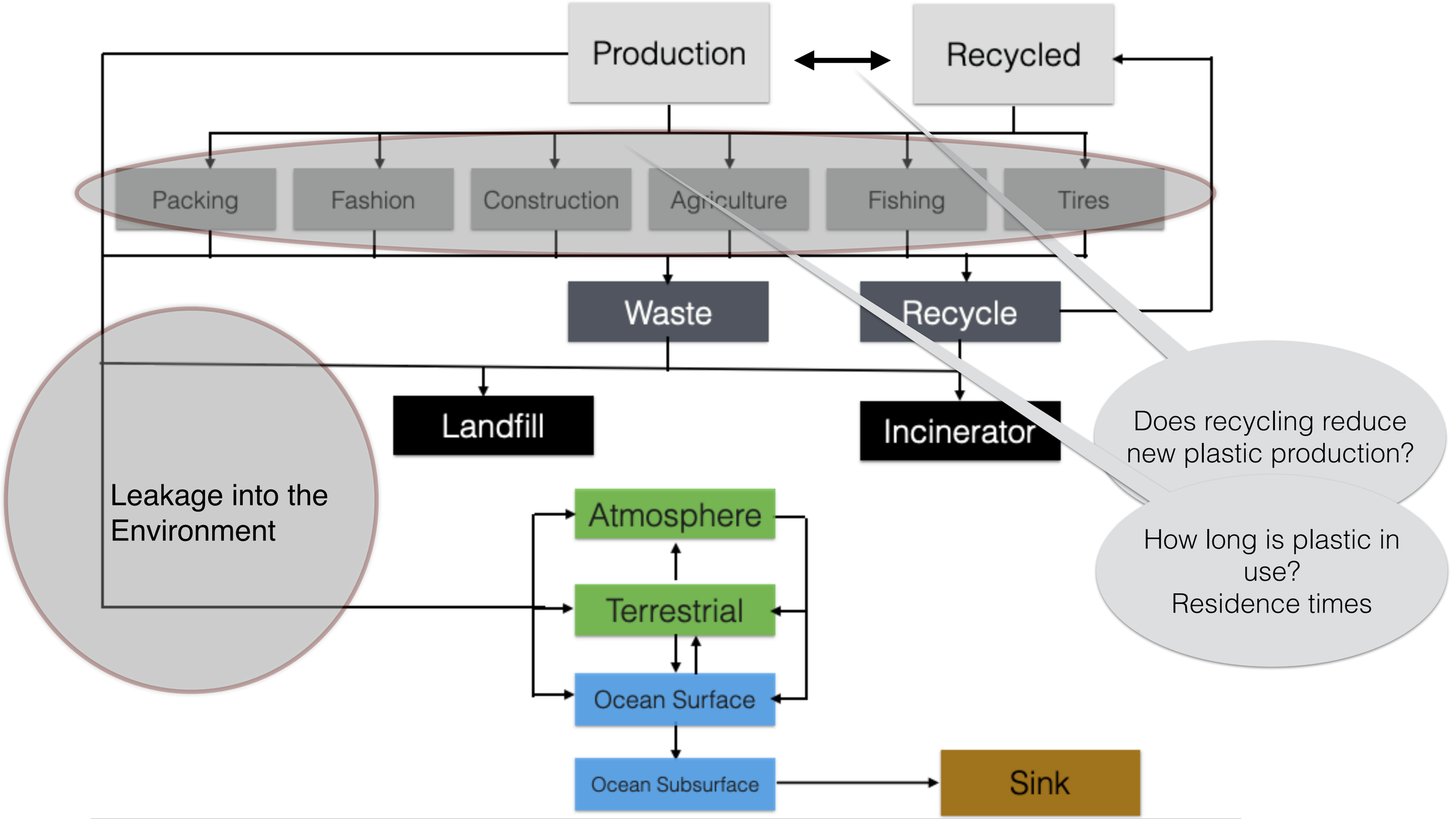

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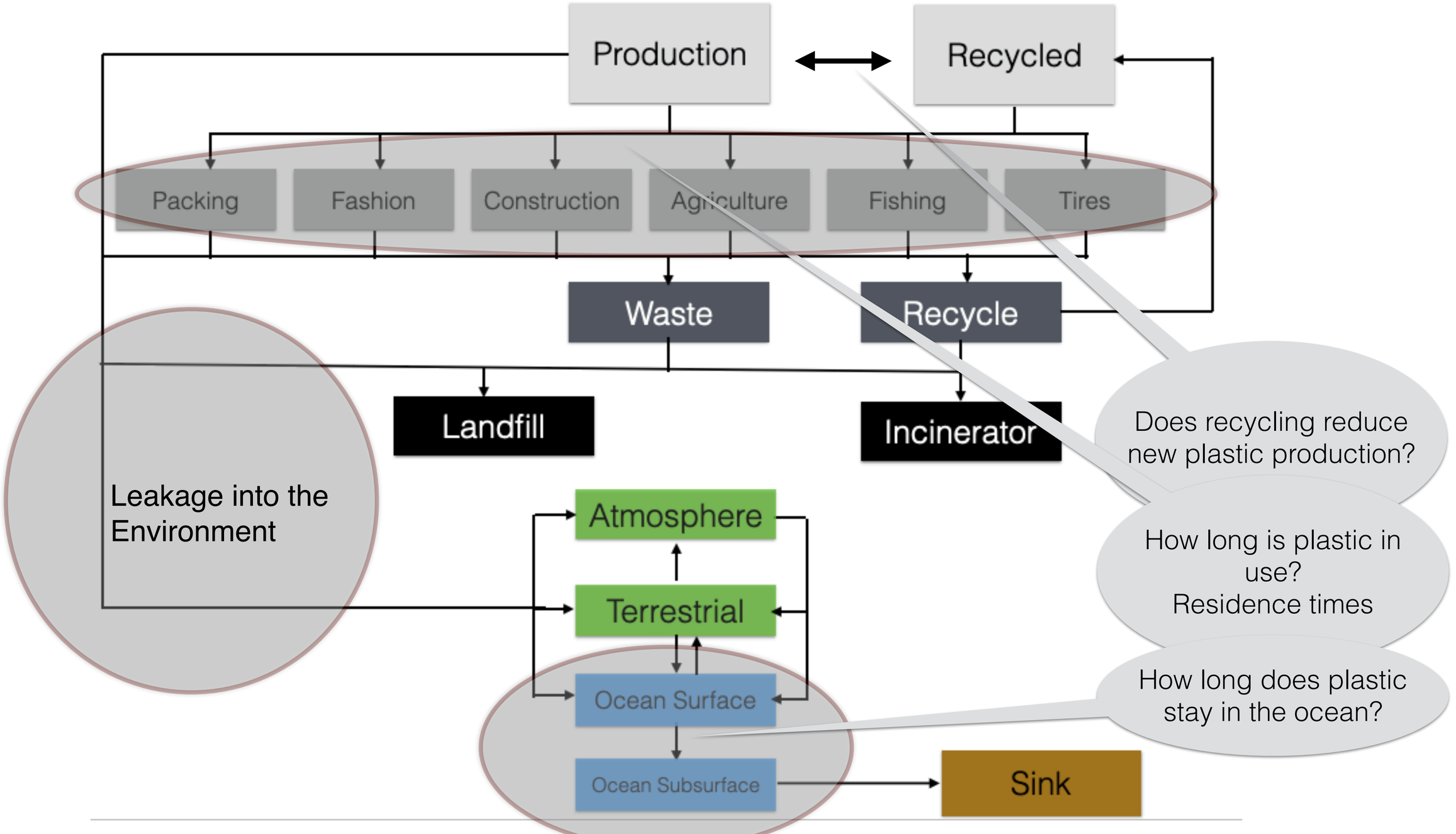

A Stock and Flow Model …

$$S_i^j = S_{i-1}^j + I_i^j - O_i^j$$

A stock at time t_i is the sum of the stock at time t_{i-1} plus inflow minus outflow

$$I_i^j = \sum_{j=1}^{N} f_{jk} \cdot O_i^k$$

The inflow into a stock is the same of the **fractions** of all outflows that go into this stock

$$O_i^j = \sum_{l=0}^{R^j} r_l^j \cdot I_{i-l}^j$$

The outflow of a stock is the sum of all fractions of previous inflows that have reached the **residence time**

$$\tilde{O}_i^j = \sum_{l=1}^{R^j} r_l^j \cdot I_{i-l}^j \quad \Rightarrow \quad \tilde{I}_i^j = \sum f_{jk} \cdot \tilde{O}_i^k$$

The **outflow resulting from past inflows** is determined first and then added to the current inflow.

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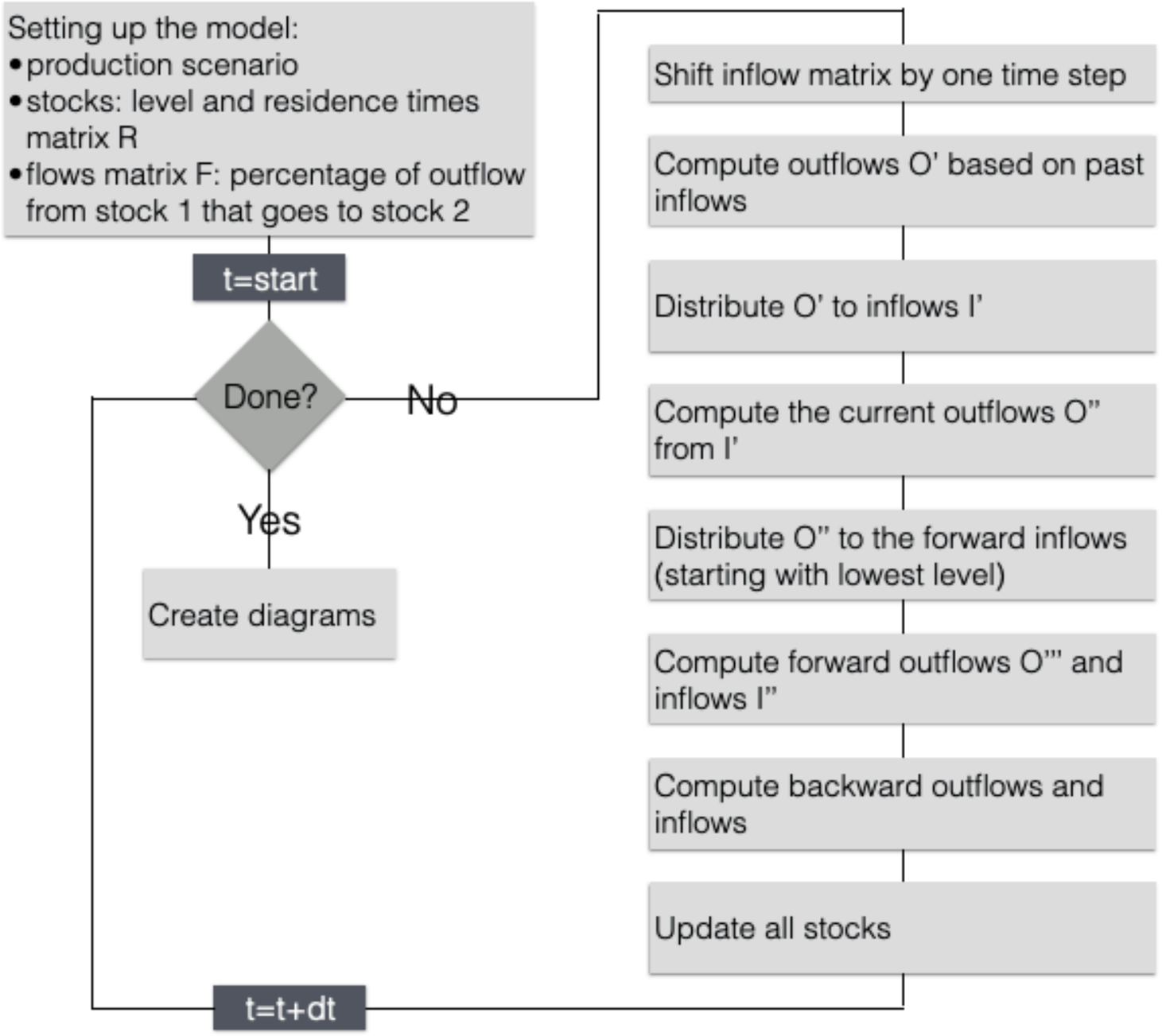

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1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Production
2	0	0	0	0	0	0	0	0	0	0	50	0	0	0	0	0	0	0	Recycled
3	33	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Single Use Packing
4	10	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Fashion
5	20	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Construction
6	16	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Consumer
7	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Agriculture
8	10	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Fishing
9	4	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Tires
10	0	0	80	90	85	80	80	80	60	0	0	0	0	0	0	0	0	0	Waste
11	0	0	15	8	8	15	15	15	15	0	0	0	0	0	0	0	0	0	Recycles
12	0	0	0	0	0	0	0	0	0	50	25	0	0	0	0	0	0	0	Incineration
13	0	0	0	0	0	0	0	0	0	40	15	0	0	0	0	0	0	0	Landfill
14	1	1	0	0	0	0	0	0	4	0	1	0	0	0	25	0	0	0	Atmosphere
15	3	2	4	1	4	4	4	0	20	6	6	0	0	33	0	50	0	0	Terrestrial
16	1	1	1	1	3	1	1	5	1	4	3	0	0	67	75	0	0	0	Ocean Surface
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	0	0	Ocean Subsurface
18	0	0	0	0	0	0	0	0	0	0	0	100	100	0	0	0	100	0	Sink
Sums	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0	

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Distribution of production to uses

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1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Production
2	0	0	0	0	0	0	0	0	0	0	50	0	0	0	0	0	0	0	Recycled
3	33	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Single Use Packing
4	10	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Fashion
5	20	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Construction
6	16	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Consumer
7	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Agriculture
8	10	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Fishing
9	4	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Tires
10	0	0	80	90	85	80	80	80	60	0	0	0	0	0	0	0	0	0	Waste
11	0	0	15	8	8	15	15	15	15	0	0	0	0	0	0	0	0	0	Recycles
12	0	0	0	0	0	0	0	0	0	50	25	0	0	0	0	0	0	0	Incineration
13	0	0	0	0	0	0	0	0	0	40	15	0	0	0	0	0	0	0	Landfill
14	1	1	0	0	0	0	0	0	4	0	1	0	0	0	25	0	0	0	Atmosphere
15	3	2	4	1	4	4	4	0	20	6	6	0	0	33	0	50	0	0	Terrestrial
16	1	1	1	1	3	1	1	5	1	4	3	0	0	67	75	0	0	0	Ocean Surface
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	0	0	Ocean Subsurface
18	0	0	0	0	0	0	0	0	0	0	0	100	100	0	0	0	100	0	Sink
Sums	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0	

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Distribution of production to uses

Post use: collected as waste or recycles

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5	20	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Construction
6	16	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Consumer
7	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Agriculture
8	10	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Fishing
9	4	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Tires
10	0	0	80	90	85	80	80	80	60	0	0	0	0	0	0	0	0	0	Waste
11	0	0	15	8	8	15	15	15	15	0	0	0	0	0	0	0	0	0	Recycles
12	0	0	0	0	0	0	0	0	0	50	25	0	0	0	0	0	0	0	Incineration
13	0	0	0	0	0	0	0	0	0	40	15	0	0	0	0	0	0	0	Landfill
14	1	1	0	0	0	0	0	0	4	0	1	0	0	0	25	0	0	0	Atmosphere
15	3	2	4	1	4	4	4	0	20	6	6	0	0	33	0	50	0	0	Terrestrial
16	1	1	1	1	3	1	1	5	1	4	3	0	0	67	75	0	0	0	Ocean Surface
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	0	0	Ocean Subsurface
18	0	0	0	0	0	0	0	0	0	0	0	100	100	0	0	0	100	0	Sink
Sums	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0	

A Stock and Flow Model …

Distribution of outflows to stocks:

$$I_i^j = \sum_{j=1}^{N} f_{jk} \cdot O_i^k$$

Fraction of outflow from stock *k* that goes into stock *j*

Distribution of production to uses

Post use: collected as waste or recycles

Leakages into the environment during production, use, and post use

Stock	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Production
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Recycled
3	33	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Single Use Packing
4	10	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Fashion
5	20	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Construction
6	16	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Consumer
7	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Agriculture
8	10	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Fishing
9	4	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Tires
10	0	0	80	90	85	80	80	0	0	0	0	0	0	0	0	0	0	0	Waste
11	0	0	15	8	8	15	15	12	0	0	0	0	0	0	0	0	0	0	Recycles
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Incineration
13	0	0	0	0	0	0	0	0	0	40	15	0	0	0	0	0	0	0	Landfill
14	1	1	0	0	0	0	0	0	4	0	1	0	0	0	25	0	0	0	Atmosphere
15	3	2	4	1	4	4	4	0	20	6	6	0	0	33	0	50	0	0	Terrestrial
16	1	1	1	1	3	1	1	5	1	4	3	0	0	67	75	0	0	0	Ocean Surface
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	0	0	Ocean Subsurface
18	0	0	0	0	0	0	0	0	0	0	0	0	100	100	0	0	0	100	Sink
Sums	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0

A Stock and Flow Model …

Distribution of outflows to stocks:

$$I_i^j = \sum_{j=1}^{N} f_{jk} \cdot O_i^k$$

Fraction of outflow from stock *k* that goes into stock *j*

Distribution of production to uses

Post use: collected as waste or recycles

Leakages into the environment during production, use, and post use

Flows and stocks in the environment

Stock	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Production
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Recycled
3	33	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Single Use Packing
4	10	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Fashi
5	20	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
6	16	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
7	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
8	10	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
9	4	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Tires
10	0	0	80	90	85	80	80	0	0	0	0	0	0	0	0	0	0	0	Waste
11	0	0	15	8	8	15	15	1	0	0	0	0	0	0	0	0	0	0	Recycles
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Incineration
13	0	0	0	0	0	0	0	0	0	40	15	0	0	0	0	0	0	0	Landfill
14	1	1	0	0	0	0	0	0	4	0	1	0	0	0	25	0	0	0	Atmosphere
15	3	2	4	1	4	4	4	0	20	6	6	0	0	33	0	50	0	0	Terrestrial
16	1	1	1	1	3	1	1	5	1	4	3	0	0	67	75	0	0	0	Ocean Surface
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	0	0	Ocean Subsurface
18	0	0	0	0	0	0	0	0	0	0	0	0	100	100	0	0	0	100	Sink
Sums	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0	

A Stock and Flow Model …

Residence Times:

$$O_i^j = \sum_{l=0}^{R^j} r_l^j \cdot I_{i-l}^j$$

A Stock and Flow Model …

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$$O_i^j = \sum_{l=0}^{R^j} r_l^j \cdot I_{i-l}^j$$

Fraction of inflow at time *i-l* released at time *i*

A Stock and Flow Model …

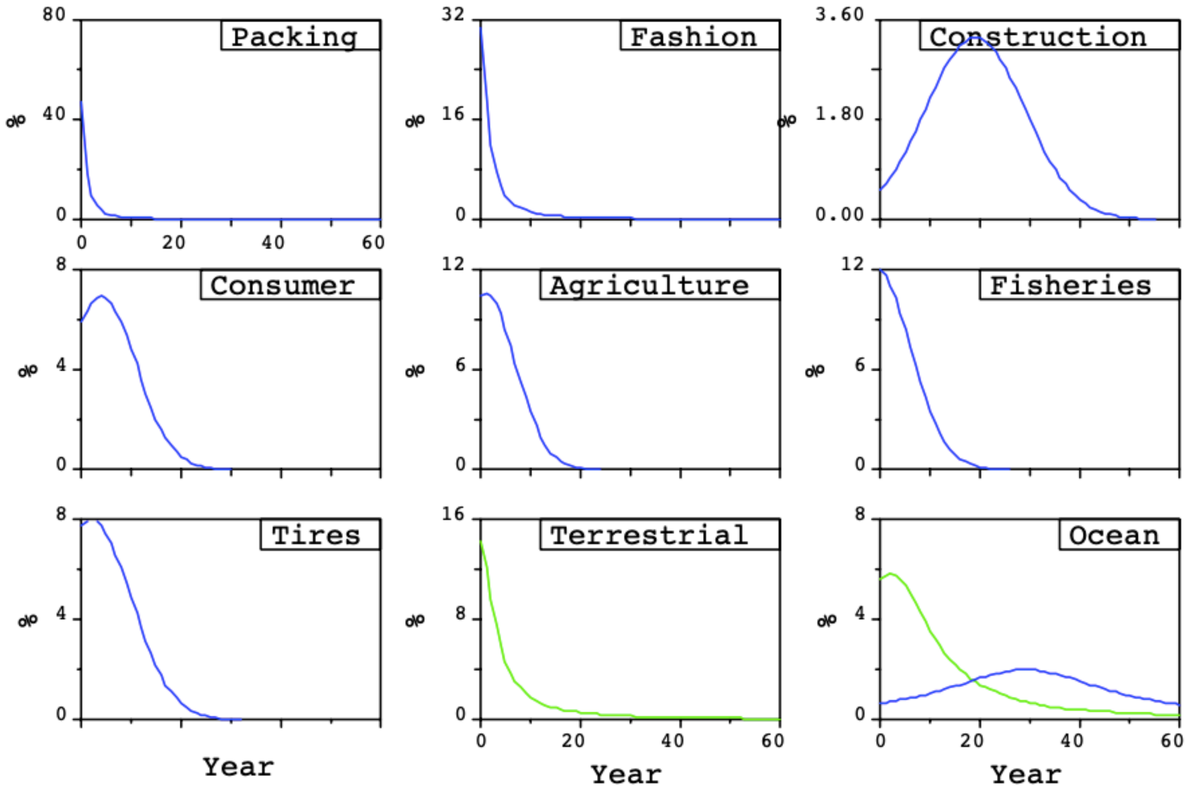
Residence Times:

$$O_i^j = \sum_{l=0}^{R^j} r_l^j \cdot I_{i-l}^j$$

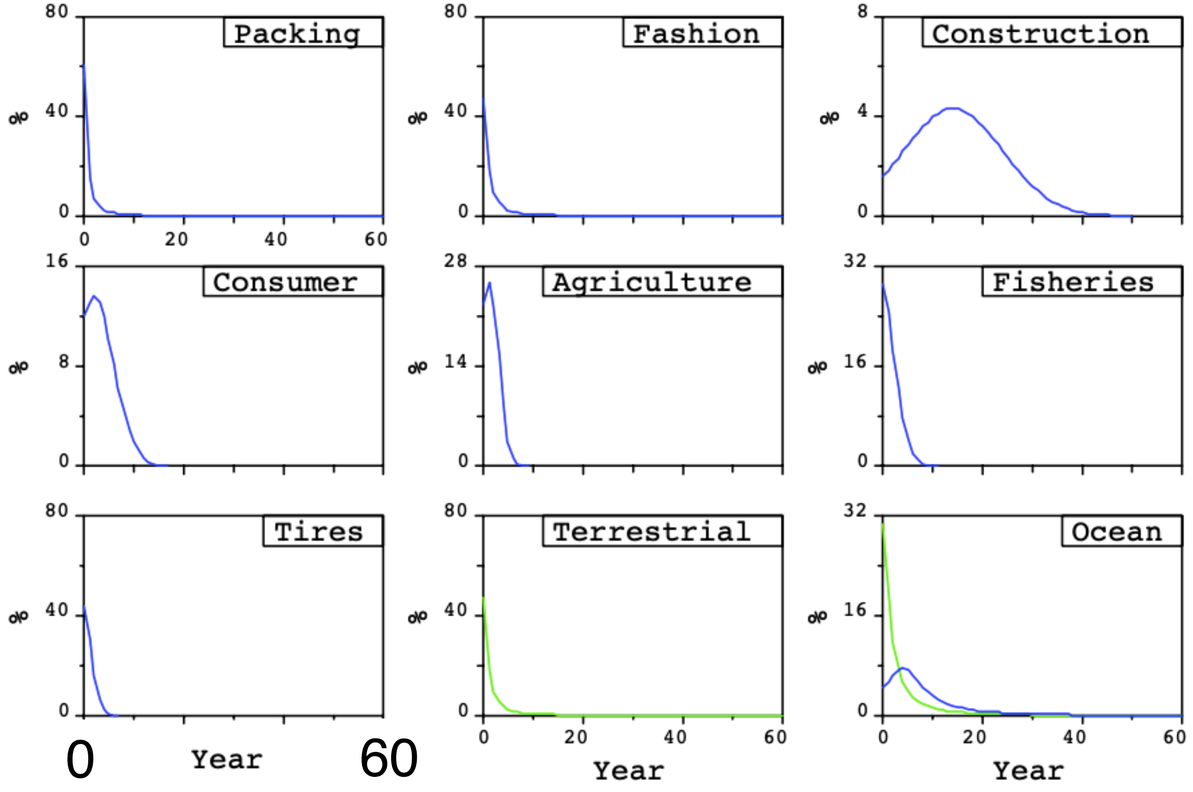
Fraction of inflow at time *i-l* released at time *i*

Ocean:
green: upper ocean
blue: deep ocean

Long



Short



Simulations

Three production scenarios:

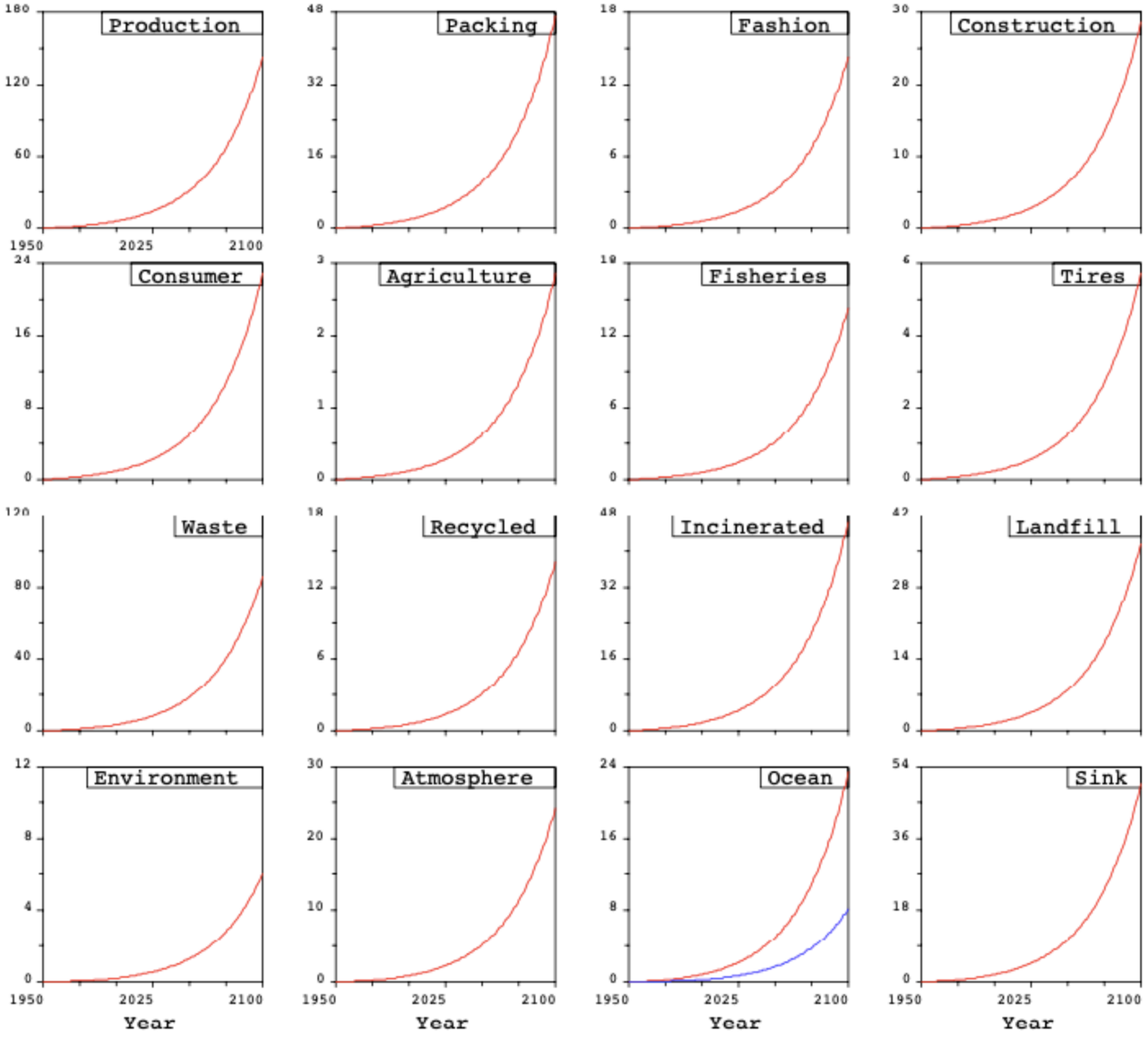
1. Business as usual: 3% annual increase from 1950 to 2100
2. Disciplined: 3% annual increase up to 2025,
   no increase from 2026 to 2050
   -3% change in production from 2050 to 2100
3. Transformative: 3% annual increase up to 2025,
   No new plastic production after 2025

Each scenario run for short and long residence times

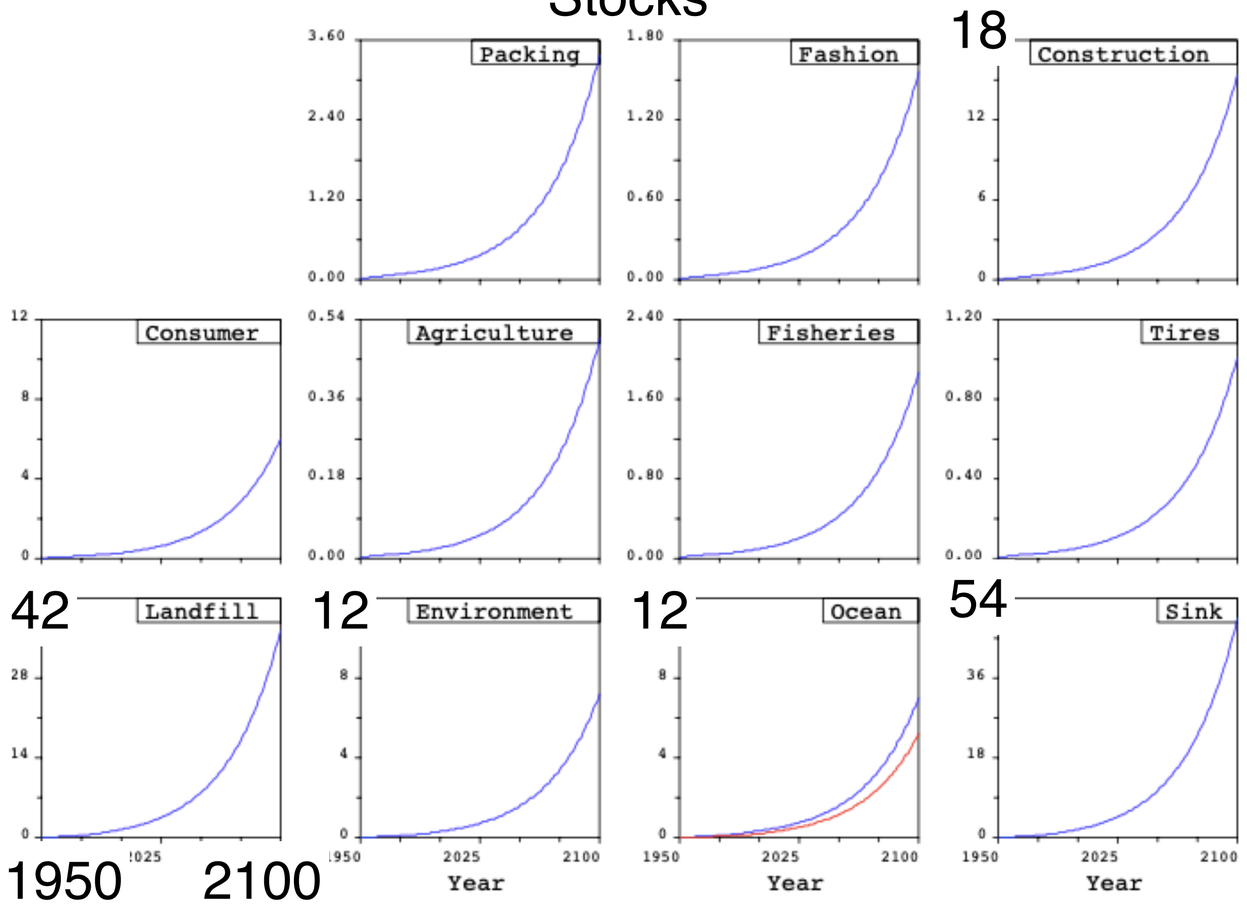
Simulations

All quantities are in billion tonnes: GT

Accumulated Flows Into Stocks



Stocks



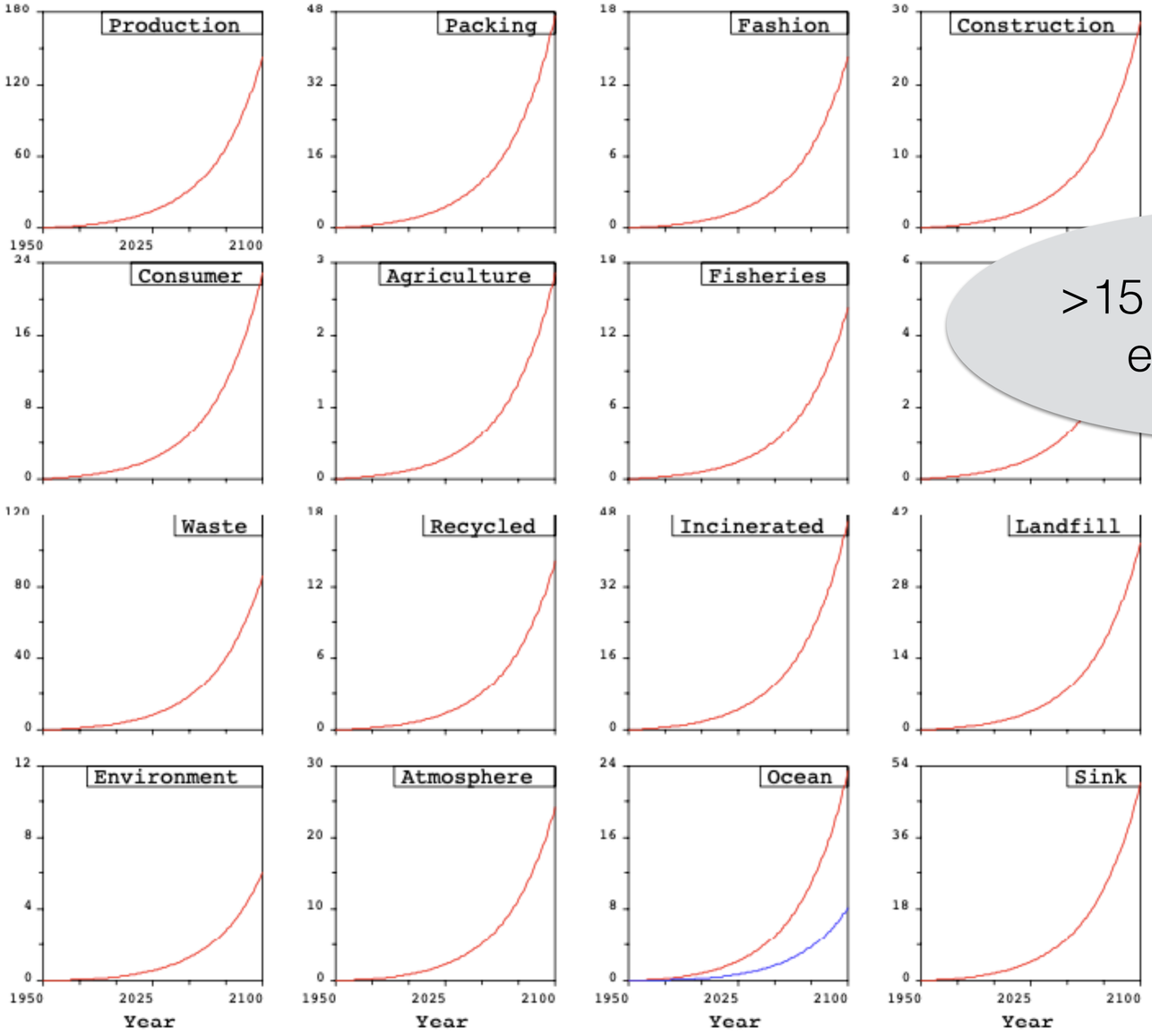
Residence Times: Long

Production Scenario 1: 3% annual increase

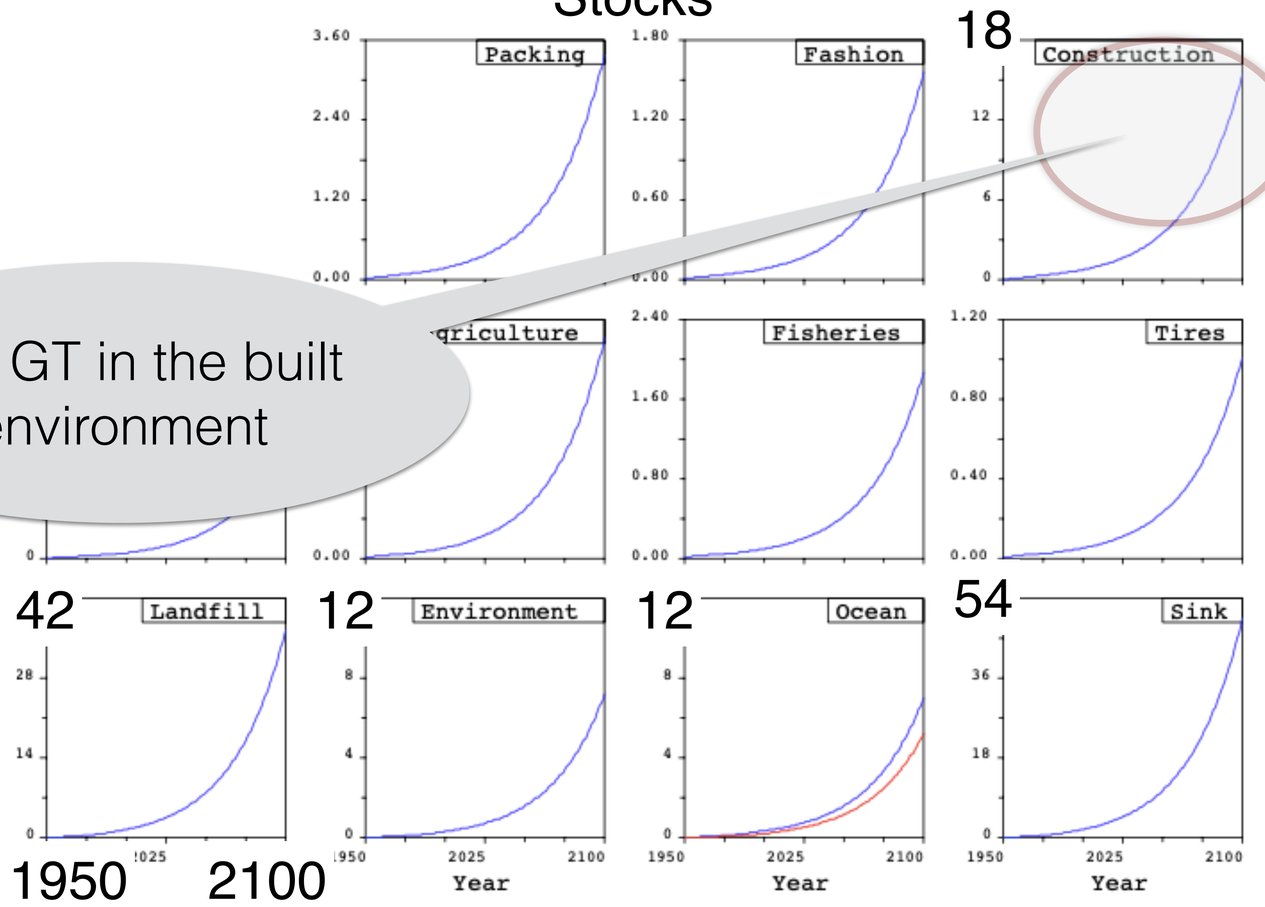
Simulations

All quantities are in billion tonnes: GT

Accumulated Flows Into Stocks



Stocks



>15 GT in the built environment

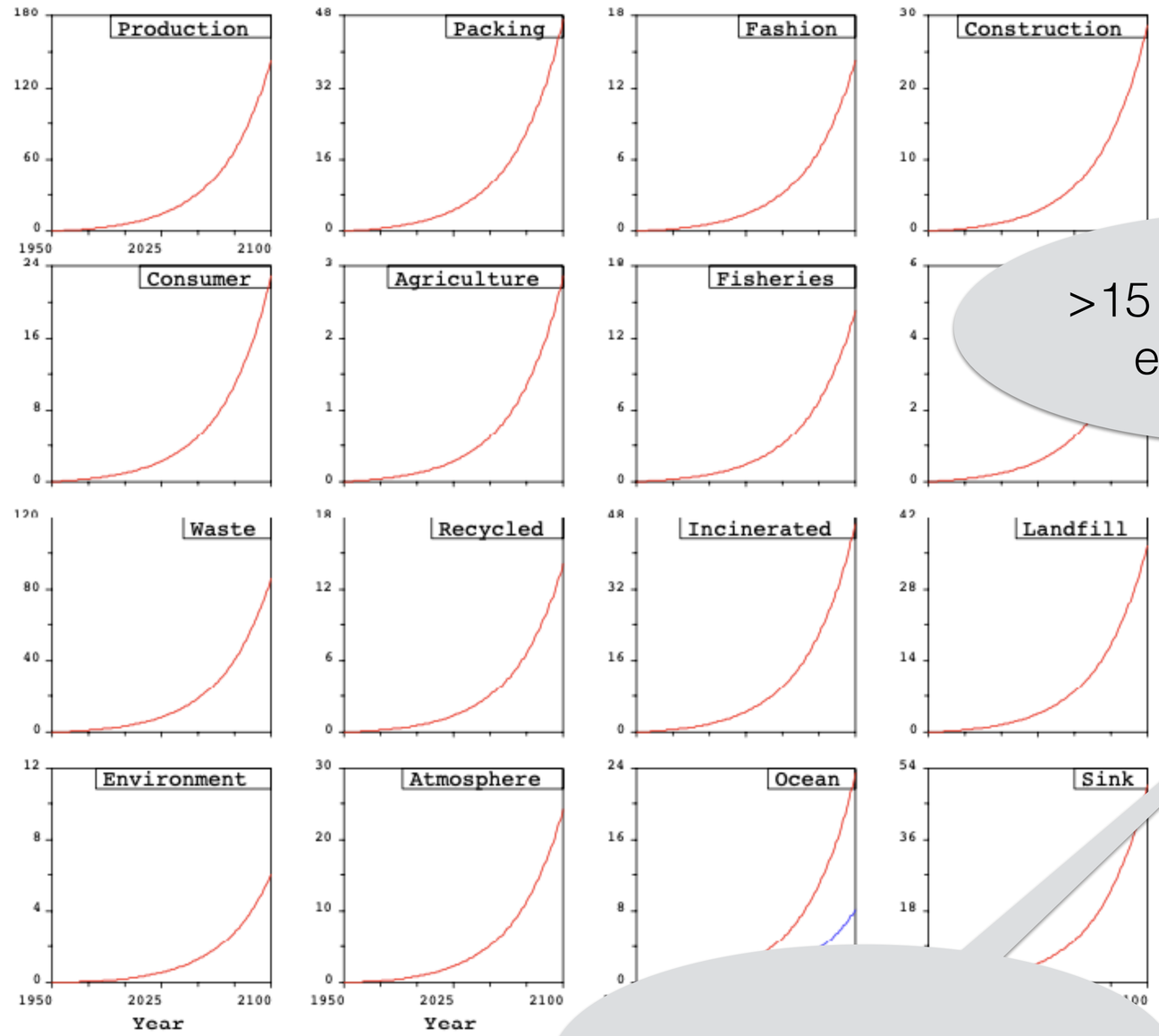
Residence Times: Long

Production Scenario 1: 3% annual increase

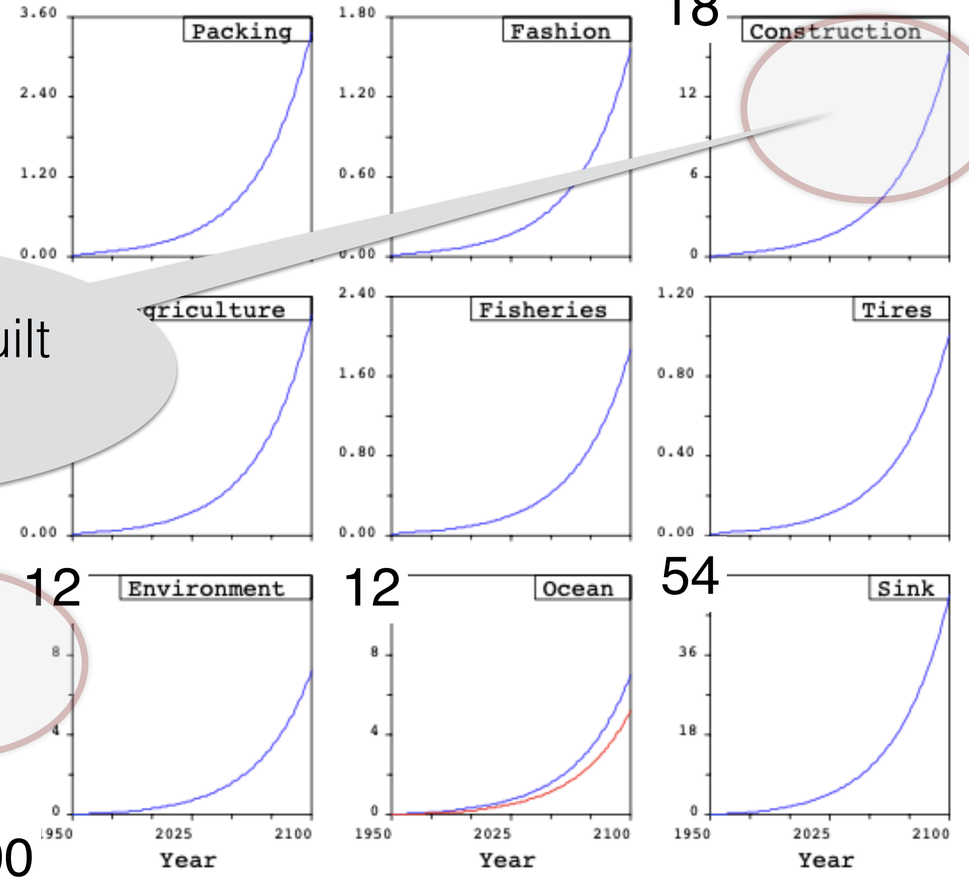
Simulations

All quantities are in billion tonnes: GT

Accumulated Flows Into Stocks



Stocks



>15 GT in the built environment

>30 GT in the landfills

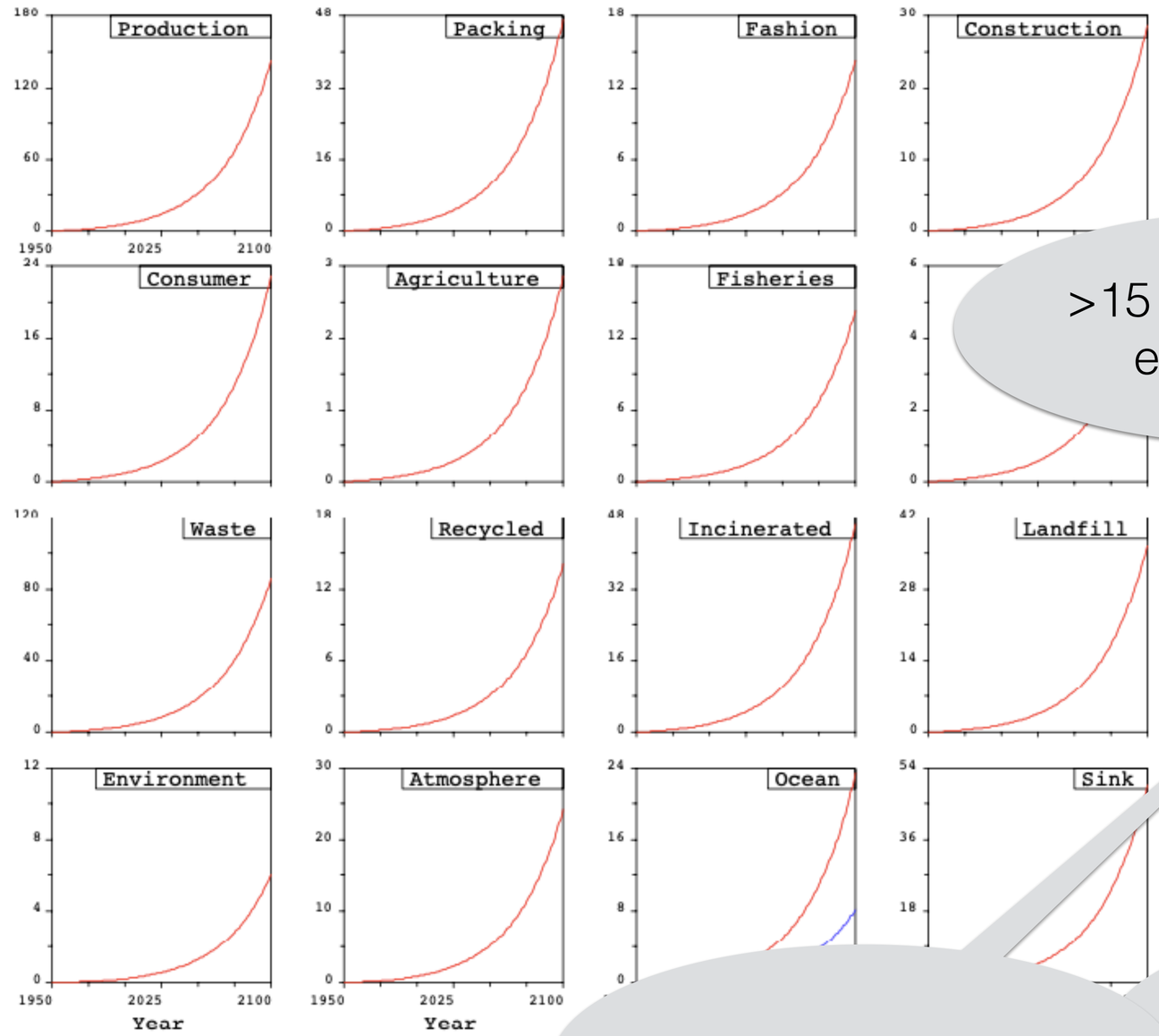
Residence Times: Long

Production Scenario 1: 3% annual increase

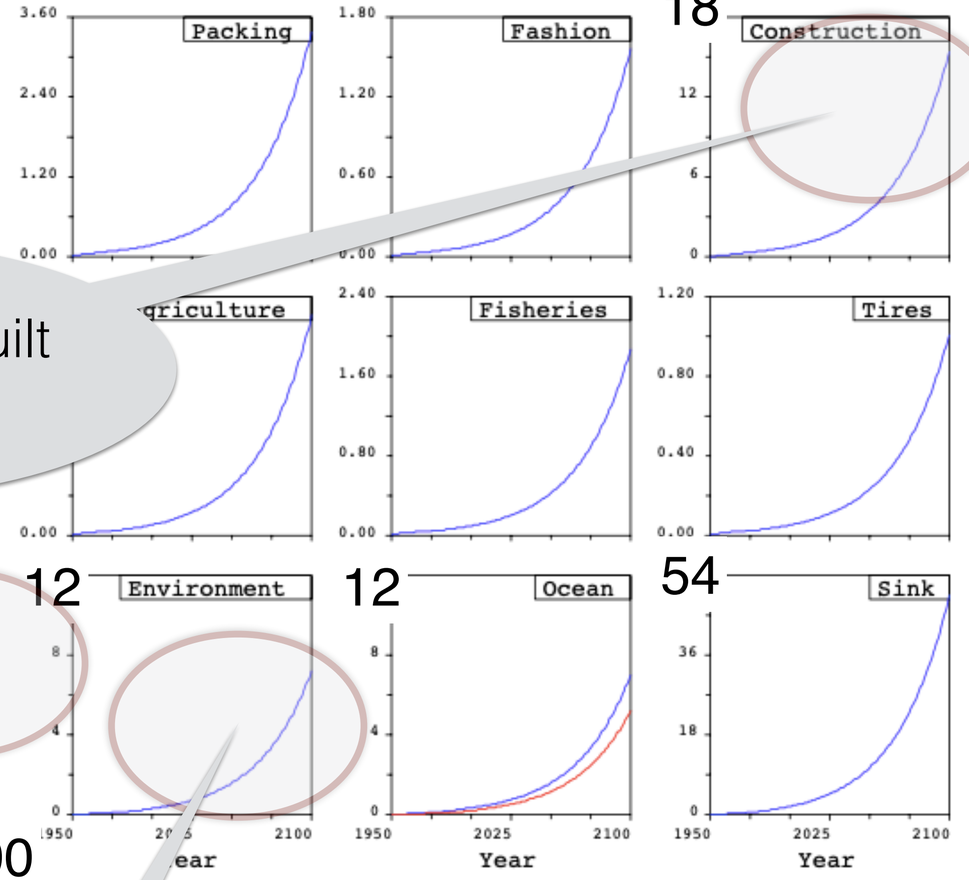
Simulations

All quantities are in billion tonnes: GT

Accumulated Flows Into Stocks



Stocks



>15 GT in the built environment

Residence Times: Long

Production Scenario 1: 3% annual increase

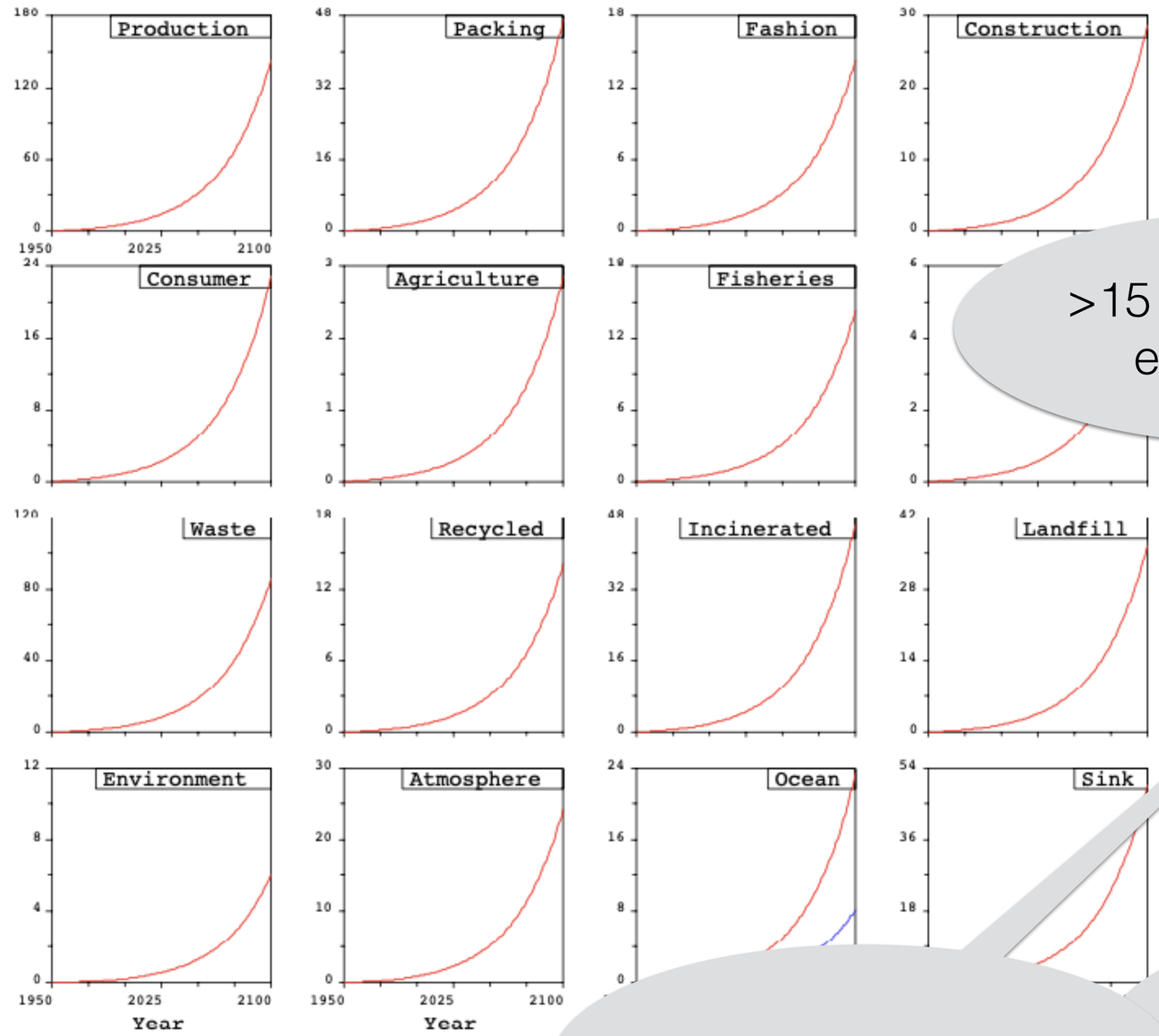
>30 GT in the landfills

>7 GT in the terrestrial environmentocean

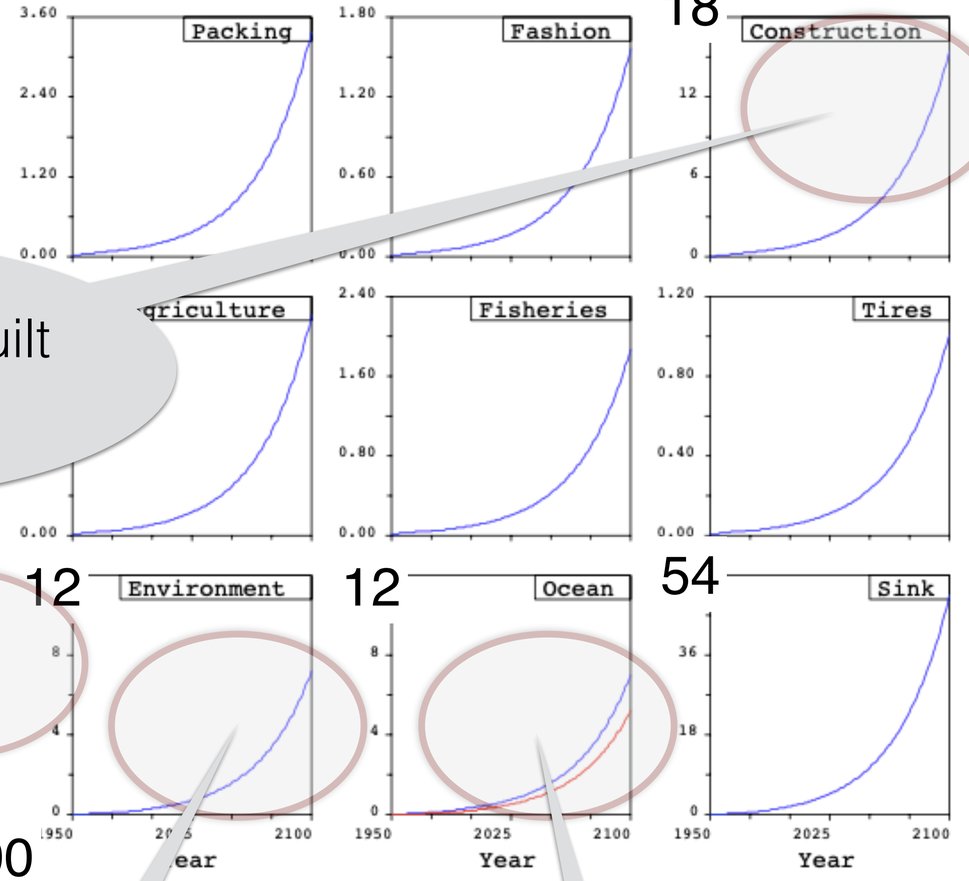
Simulations

All quantities are in billion tonnes: GT

Accumulated Flows Into Stocks



Stocks



>15 GT in the built environment

Residence Times: Long

Production Scenario 1: 3% annual increase

>30 GT in the landfills

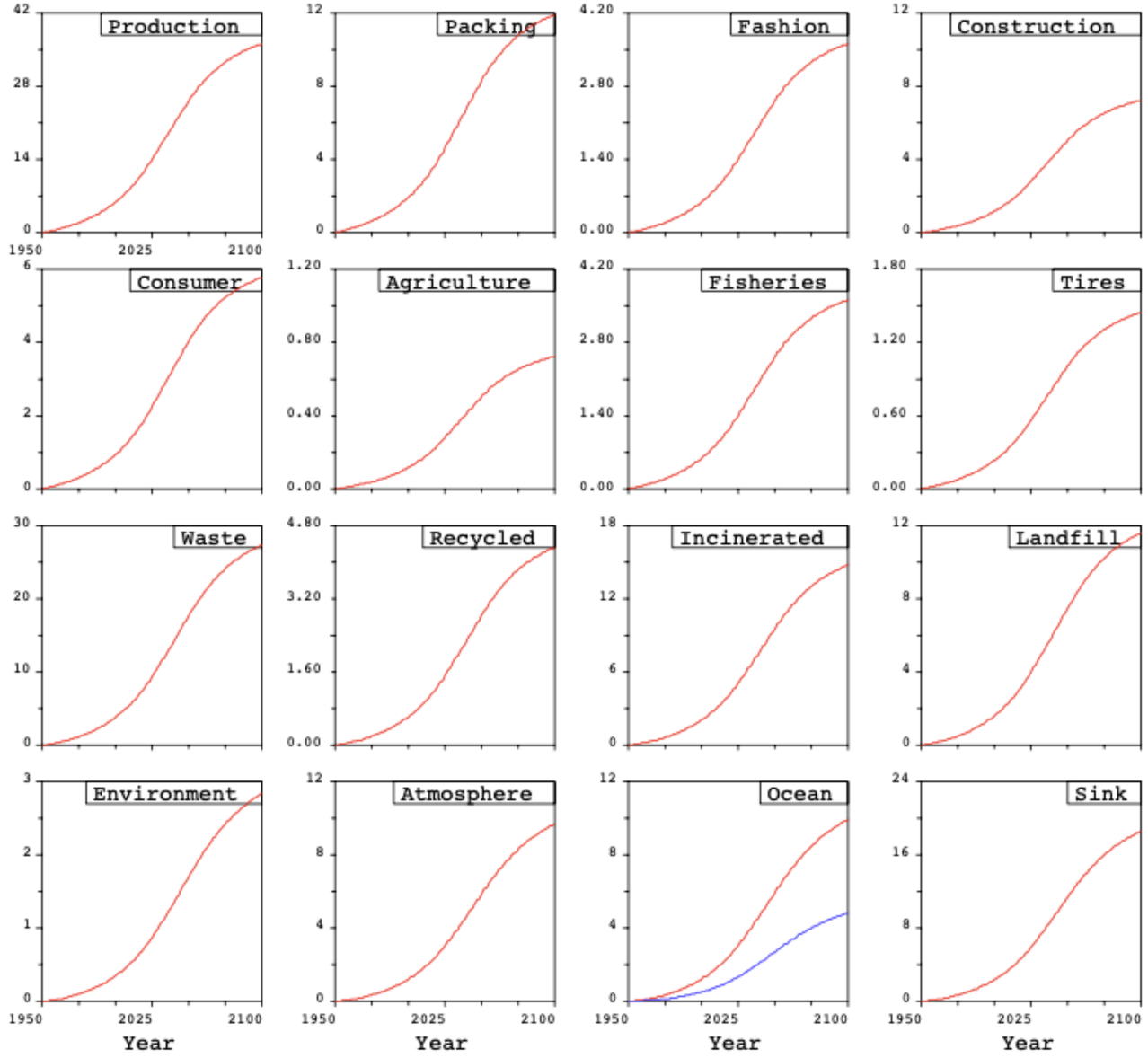
>7 GT in the terrestrial environmentocean

>10 GT in the ocean

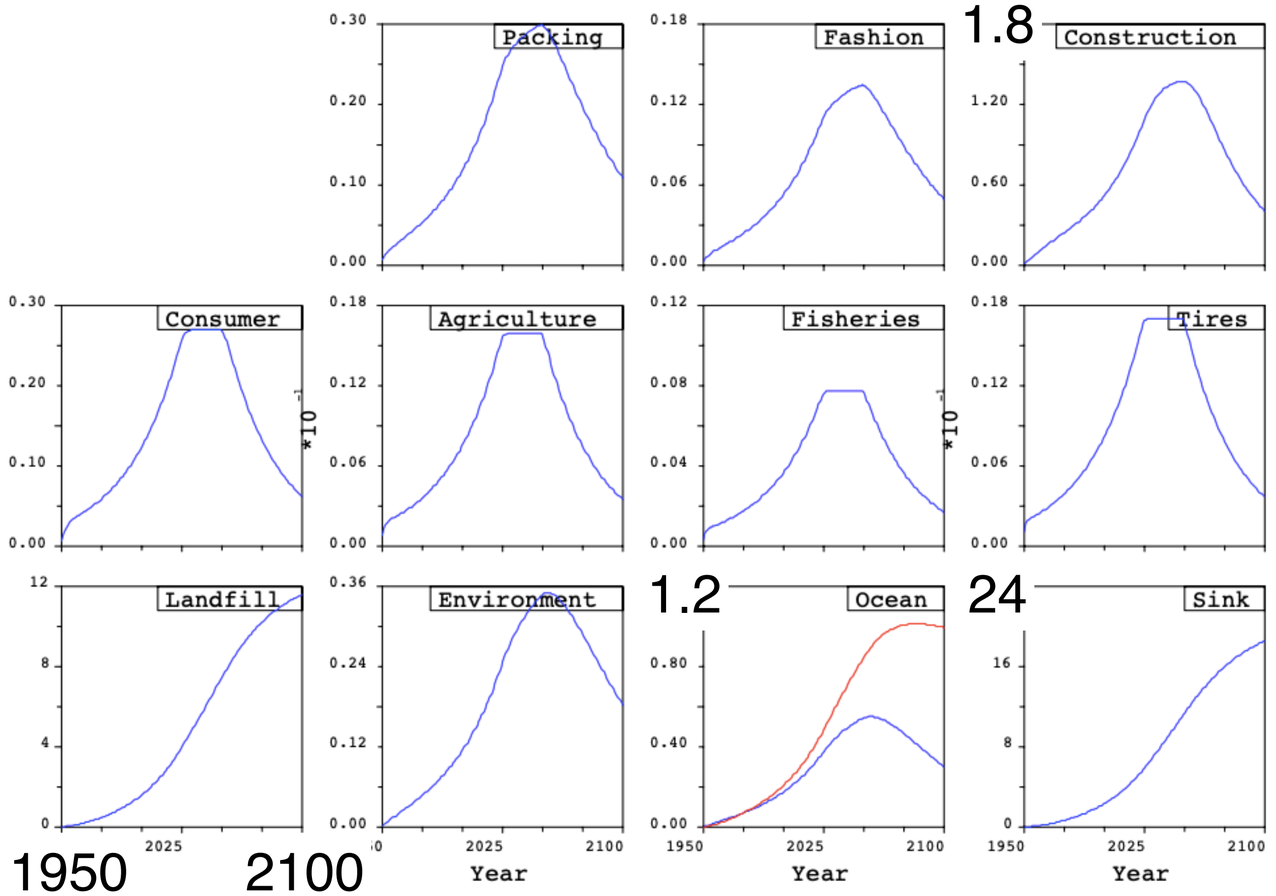
Simulations

All quantities are in billion metric tons

Accumulated Flows Into Stocks



Stocks



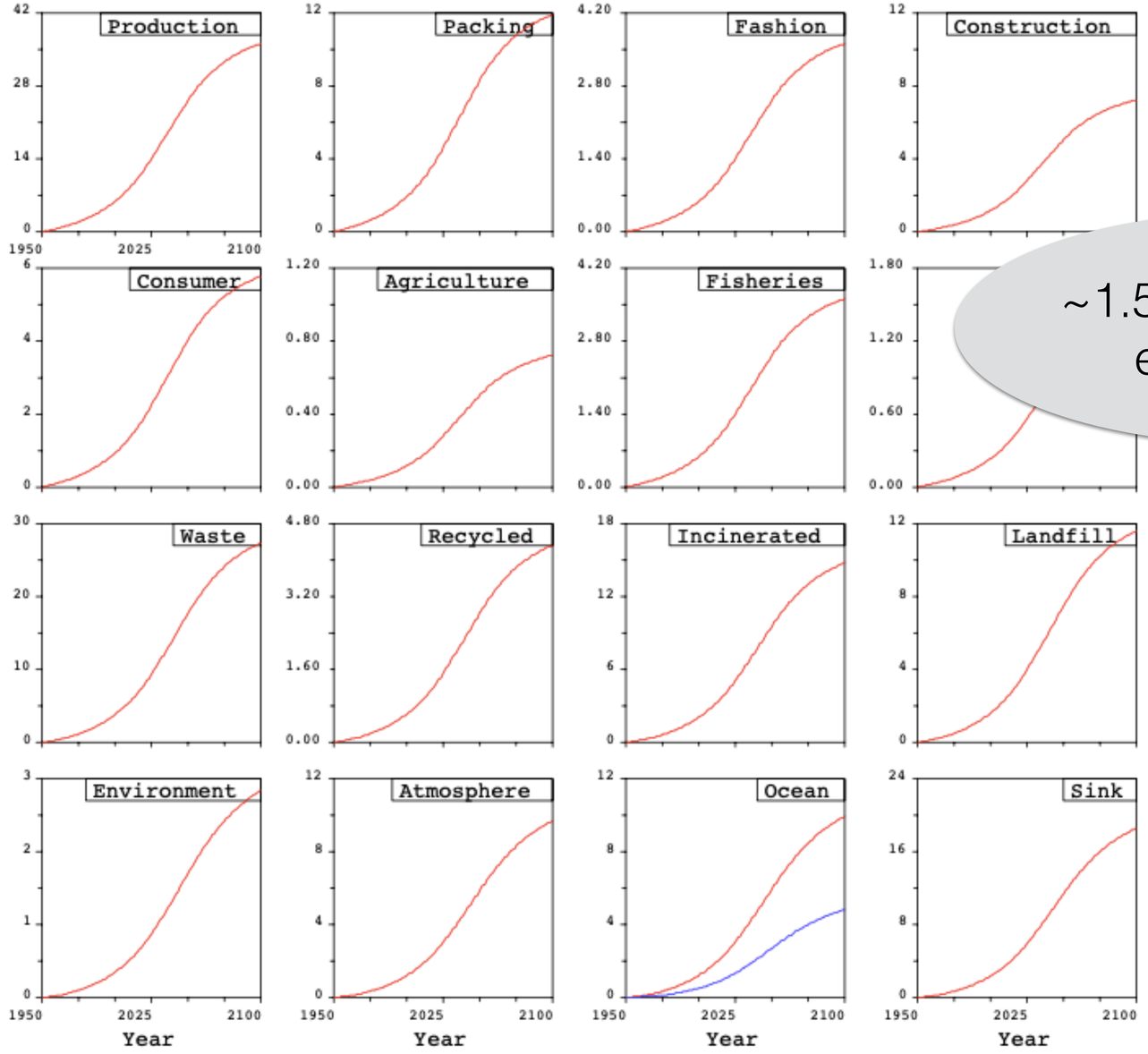
Residence Times: Short

Production Scenario 2: 3% annual increase until 2025, no increase up to 2050, 3% annual decrease afterwards

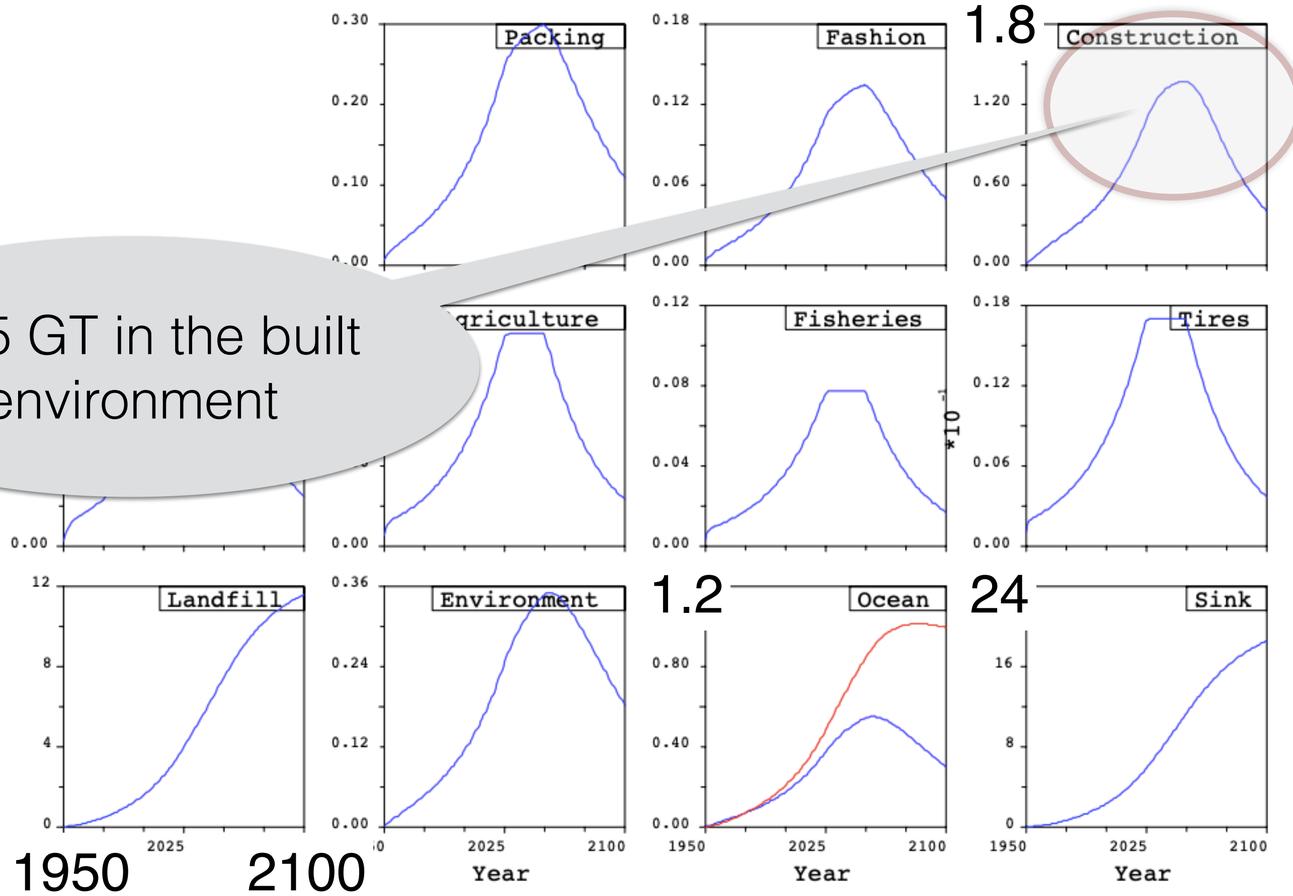
Simulations

All quantities are in billion metric tons

Accumulated Flows Into Stocks



Stocks



~1.5 GT in the built environment

1950 2100

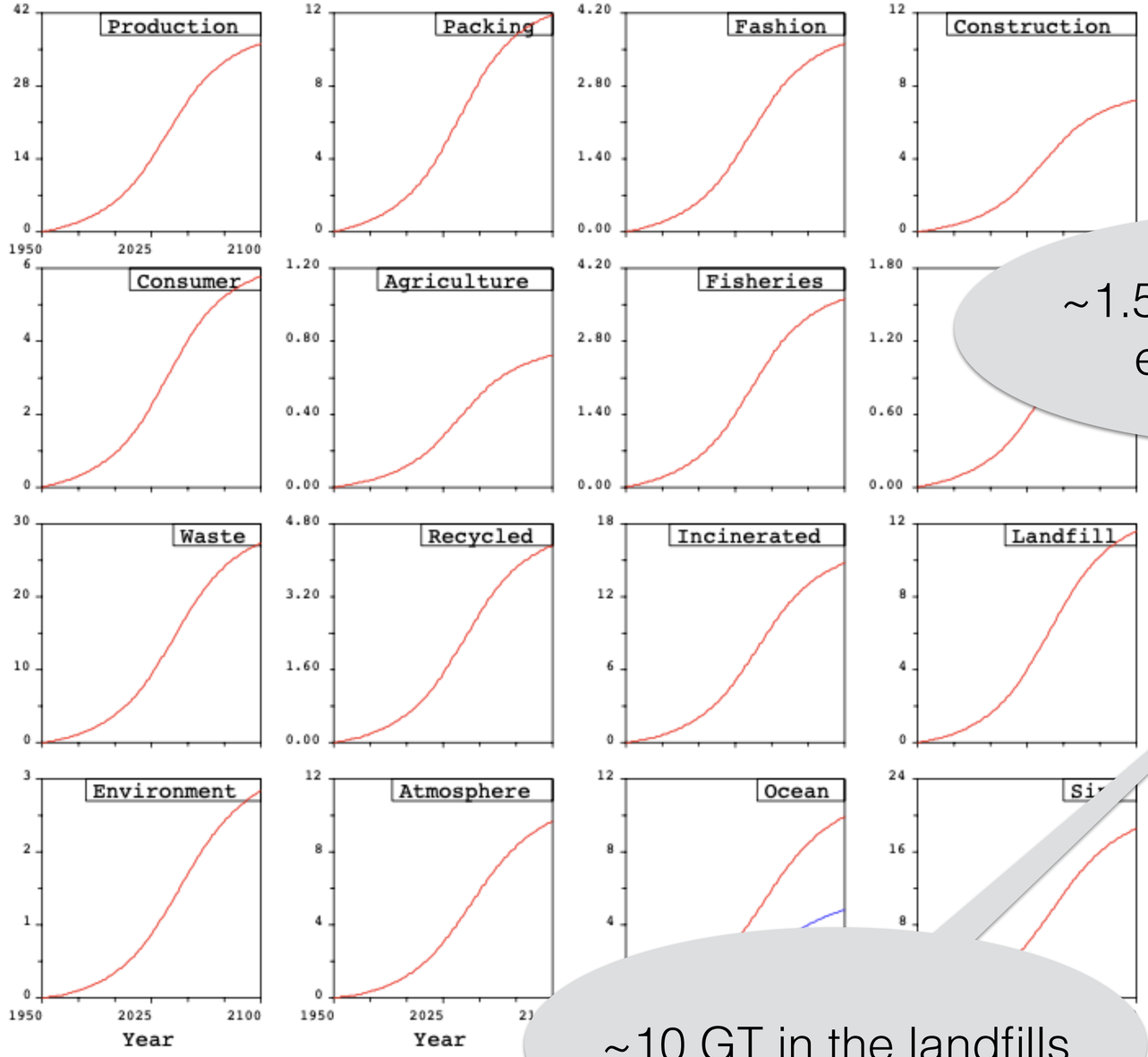
Residence Times: Short

Production Scenario 2: 3% annual increase until 2025, no increase up to 2050, 3% annual decrease afterwards

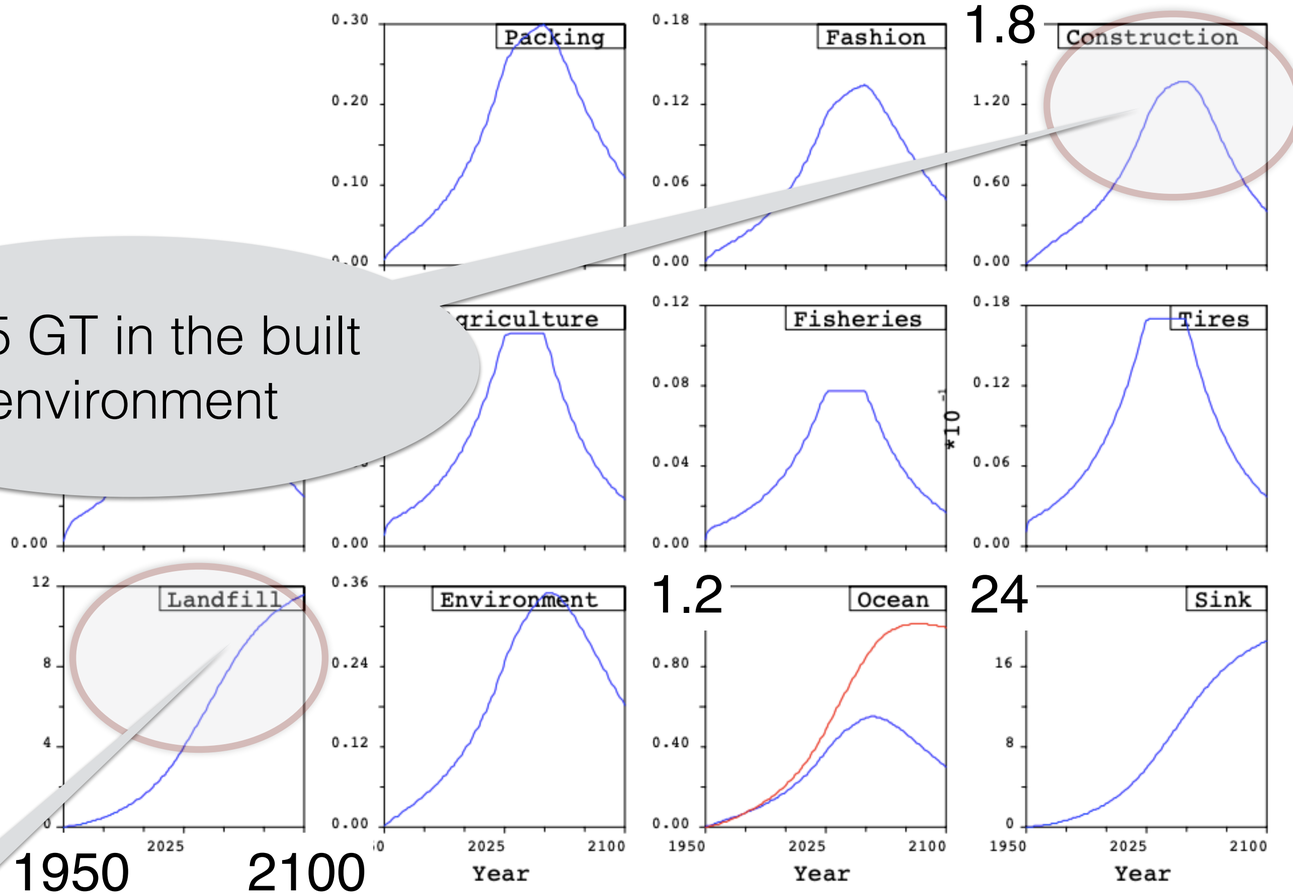
Simulations

All quantities are in billion metric tons

Accumulated Flows Into Stocks



Stocks



~1.5 GT in the built environment

~10 GT in the landfills

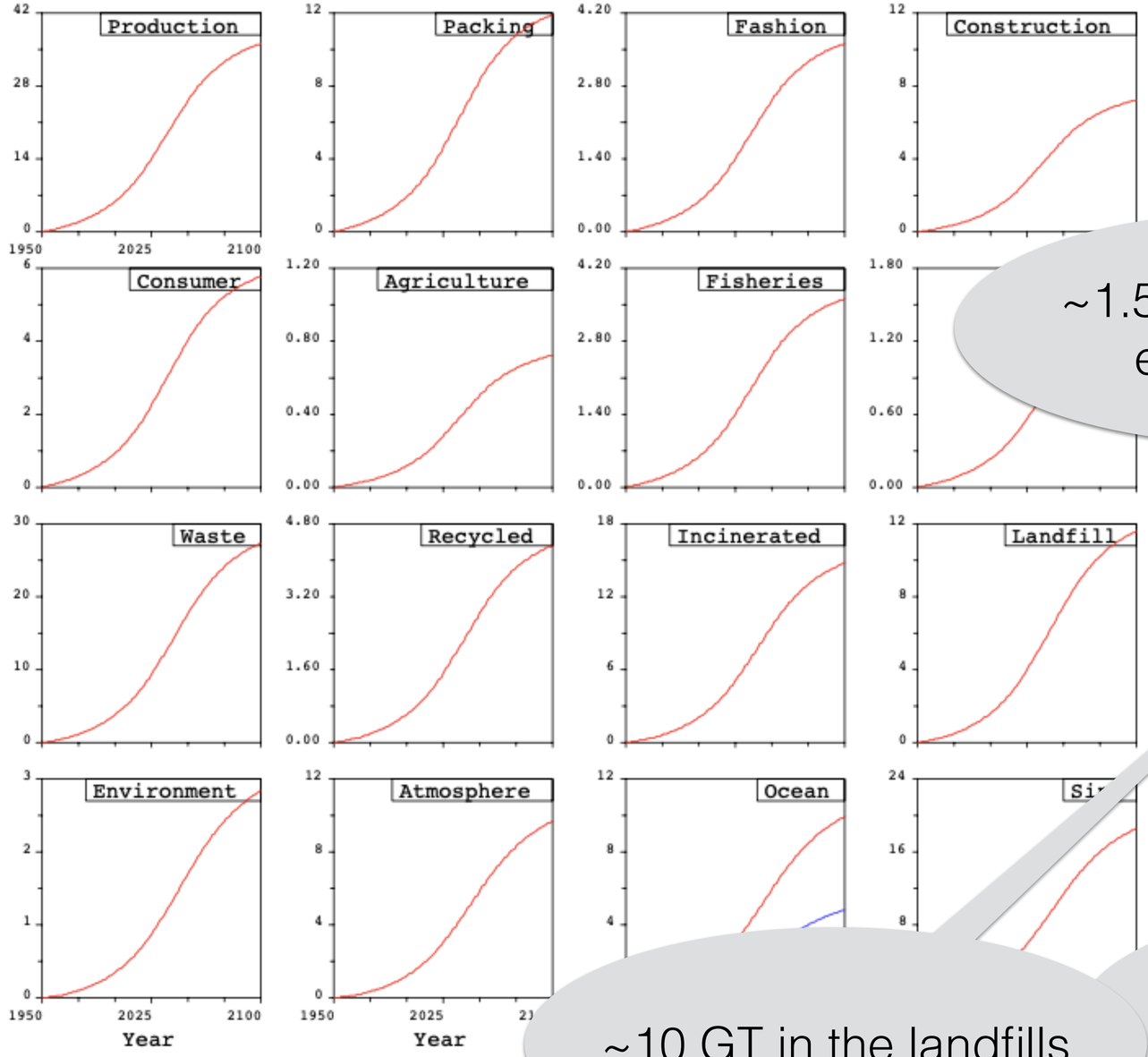
Residence Times: Short

Production Scenario 2: 3% annual increase until 2025, no increase up to 2050, 3% annual decrease afterwards

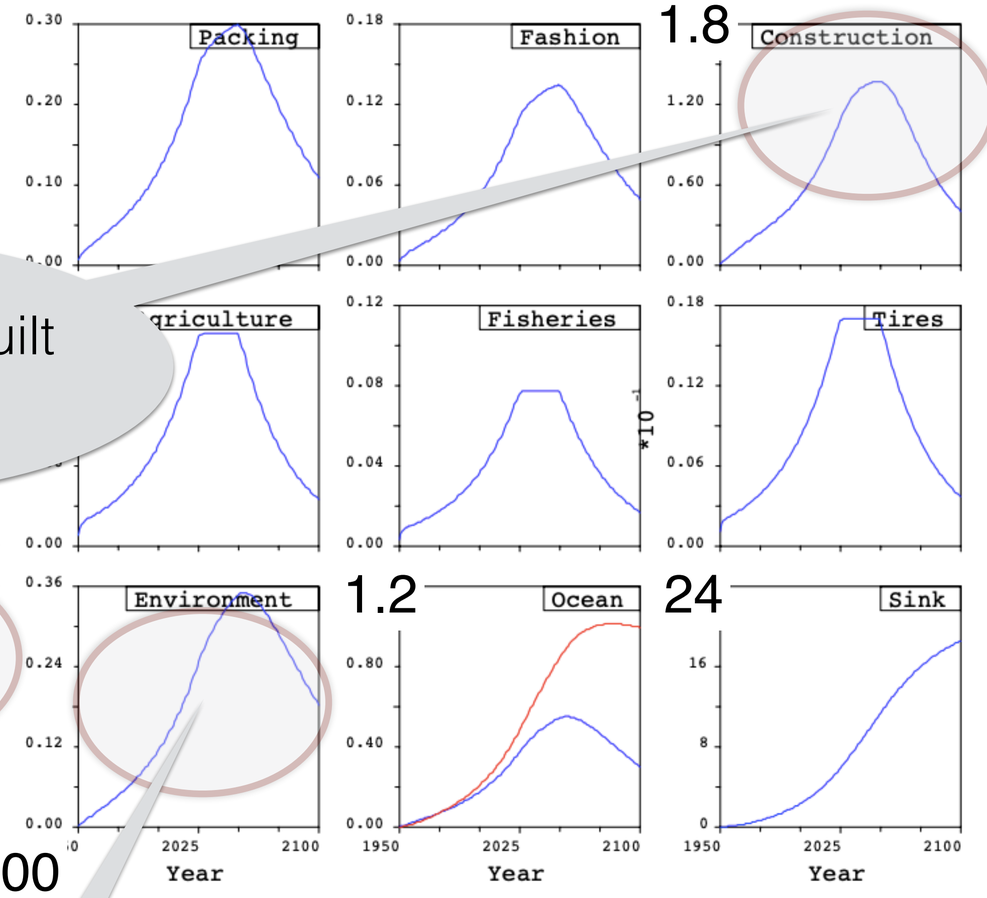
Simulations

All quantities are in billion metric tons

Accumulated Flows Into Stocks



Stocks



~1.5 GT in the built environment

~10 GT in the landfills

<1 GT in the terrestrial environmentocean

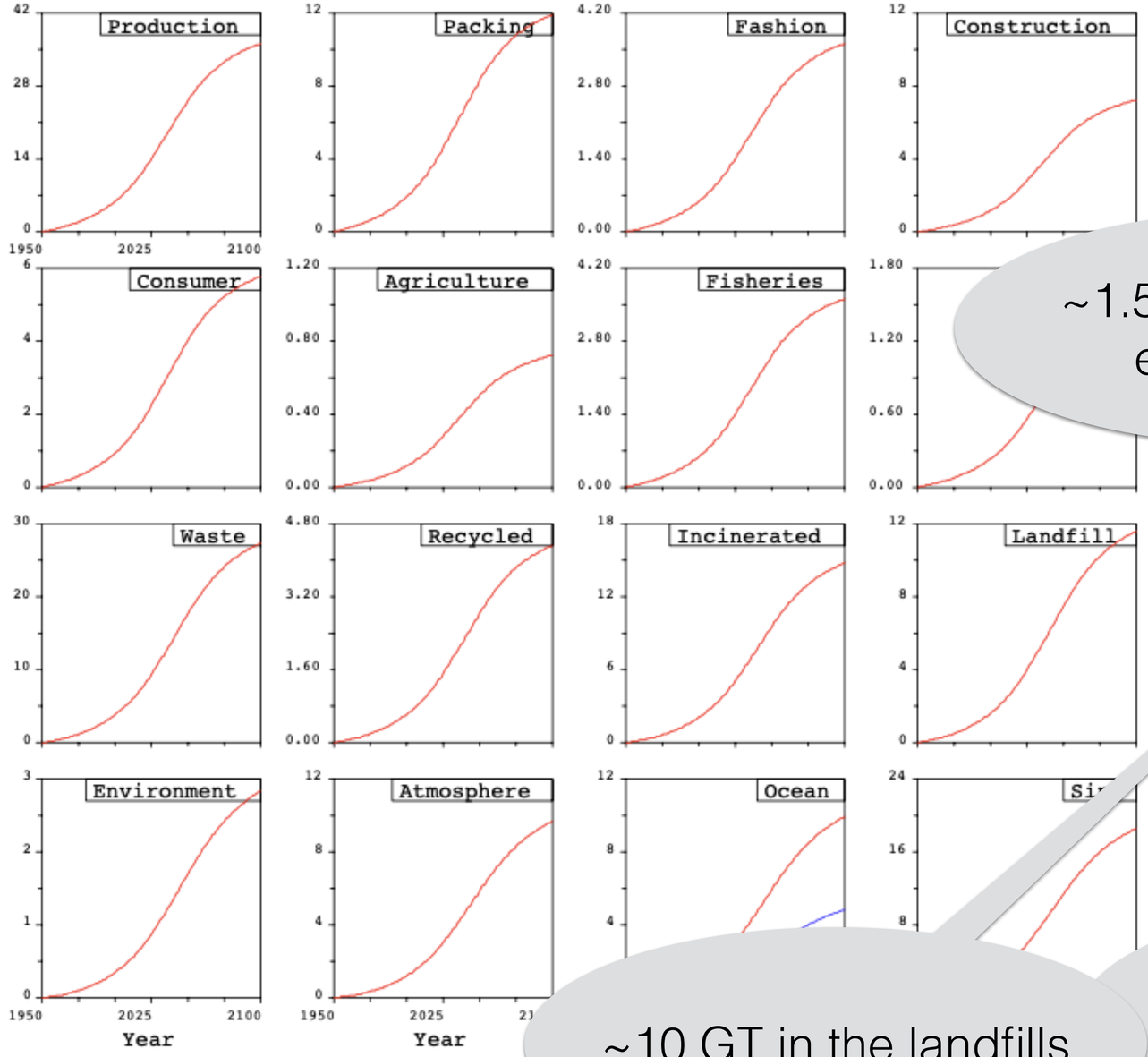
Residence Times: Short

2: 3% annual increase until 2050, 3% annual decrease

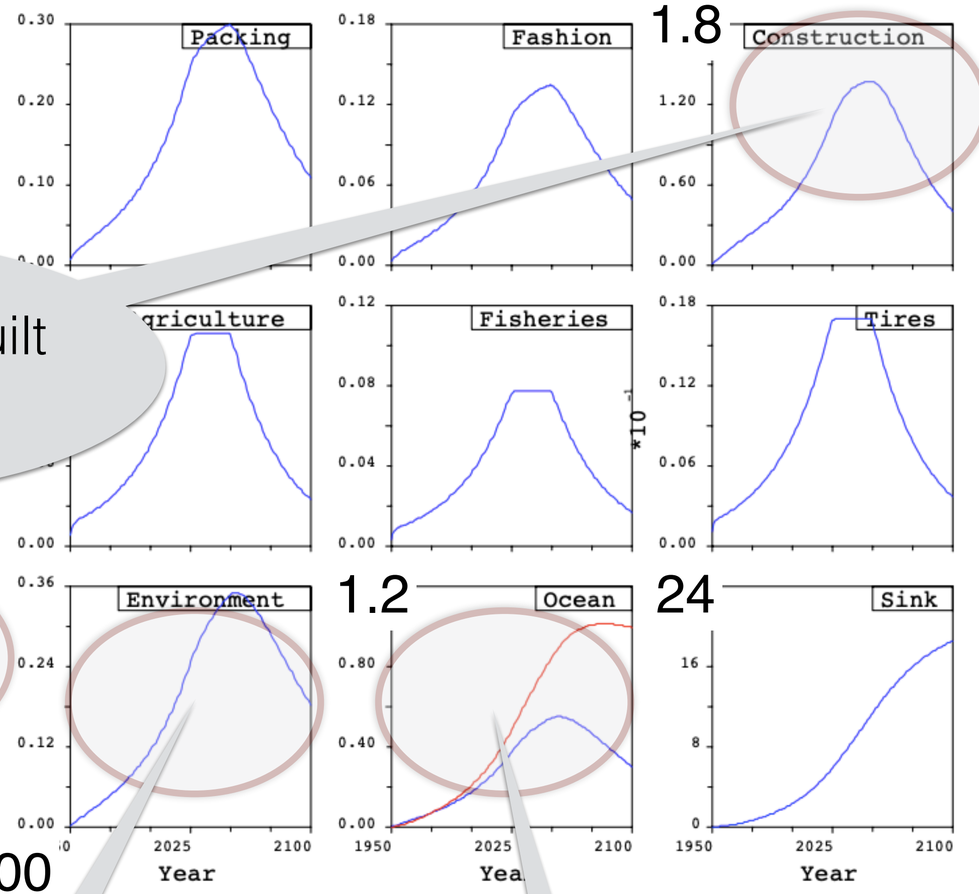
Simulations

All quantities are in billion metric tons

Accumulated Flows Into Stocks



Stocks



~1.5 GT in the built environment

1950 2100

Residence Times: Short

~10 GT in the landfills

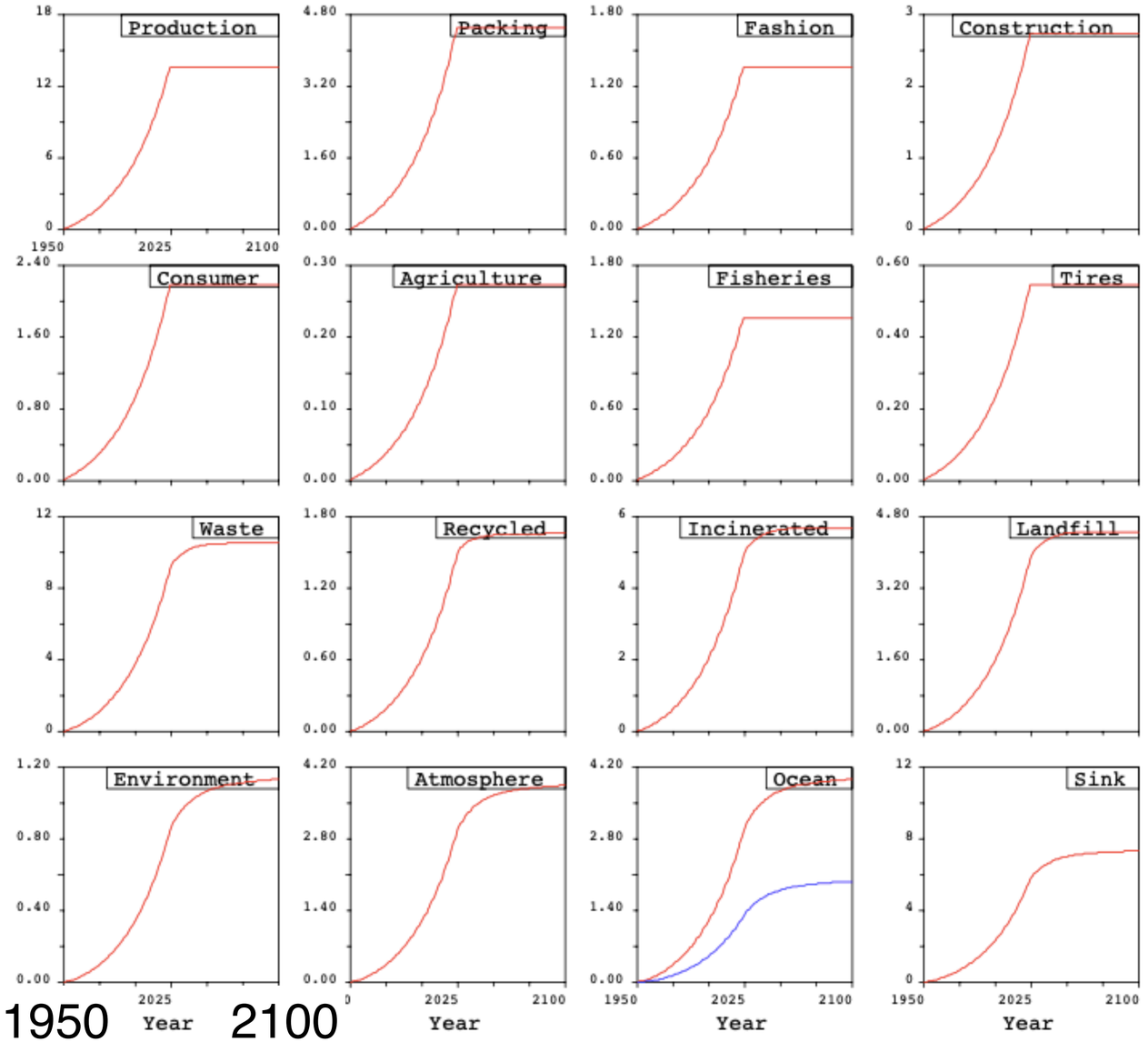
<1 GT in the terrestrial environmentocean

~1 GT in the ocean

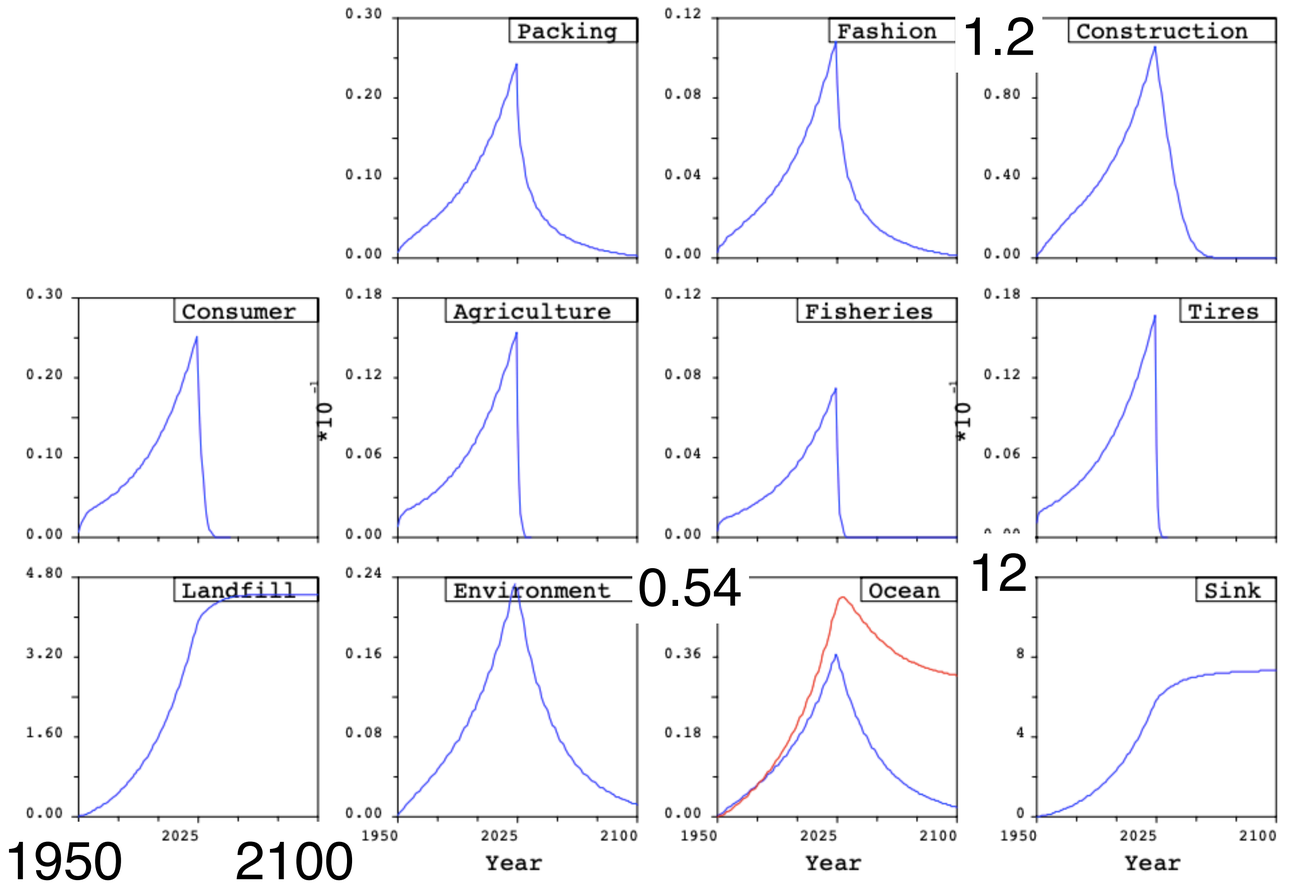
Simulations

All quantities are in billion metric tons

Accumulated Flows Into Stocks



Stocks



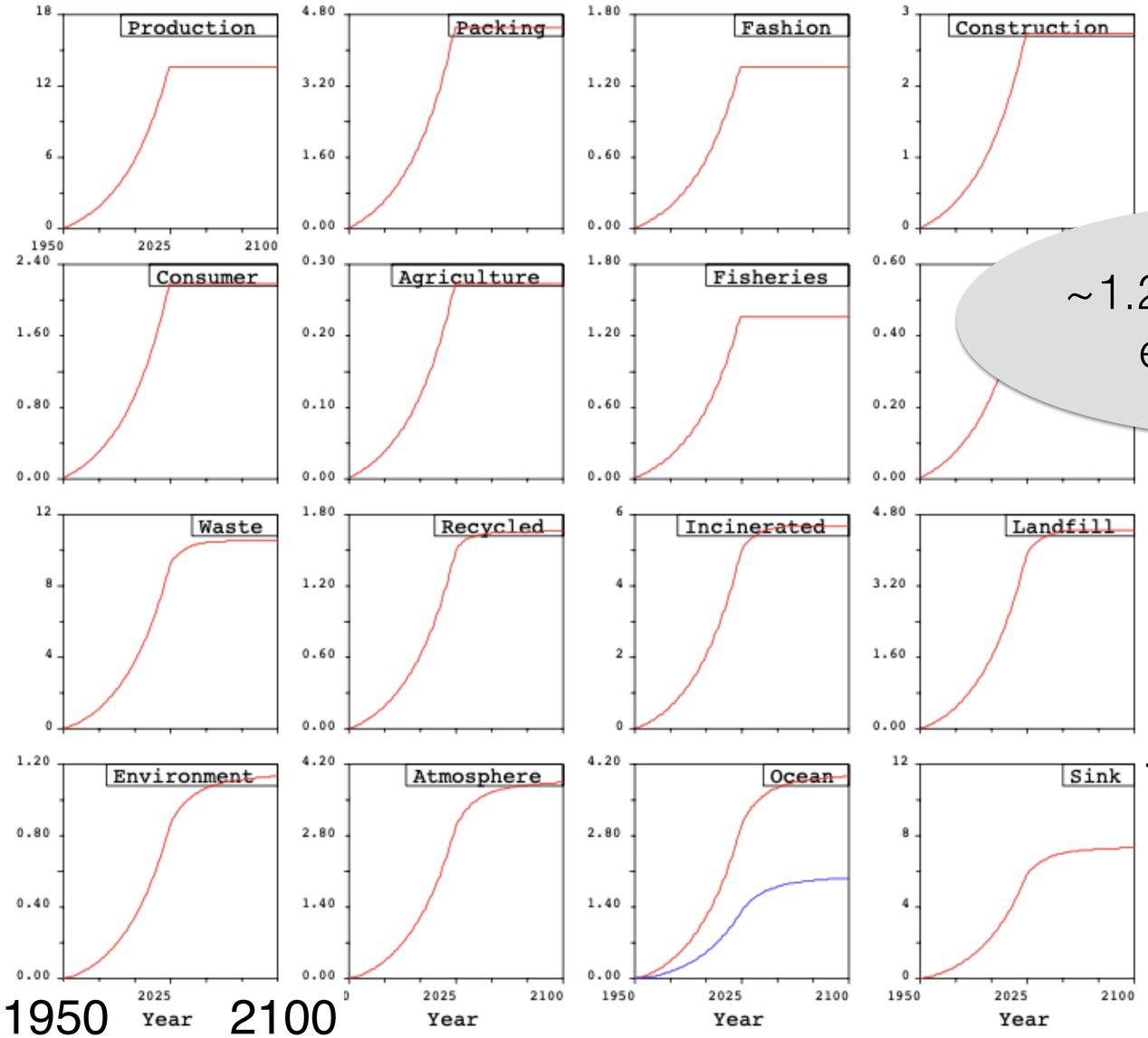
Residence Times: Short

Production Scenario 3: 3% annual increase until 2025, zero production afterwards

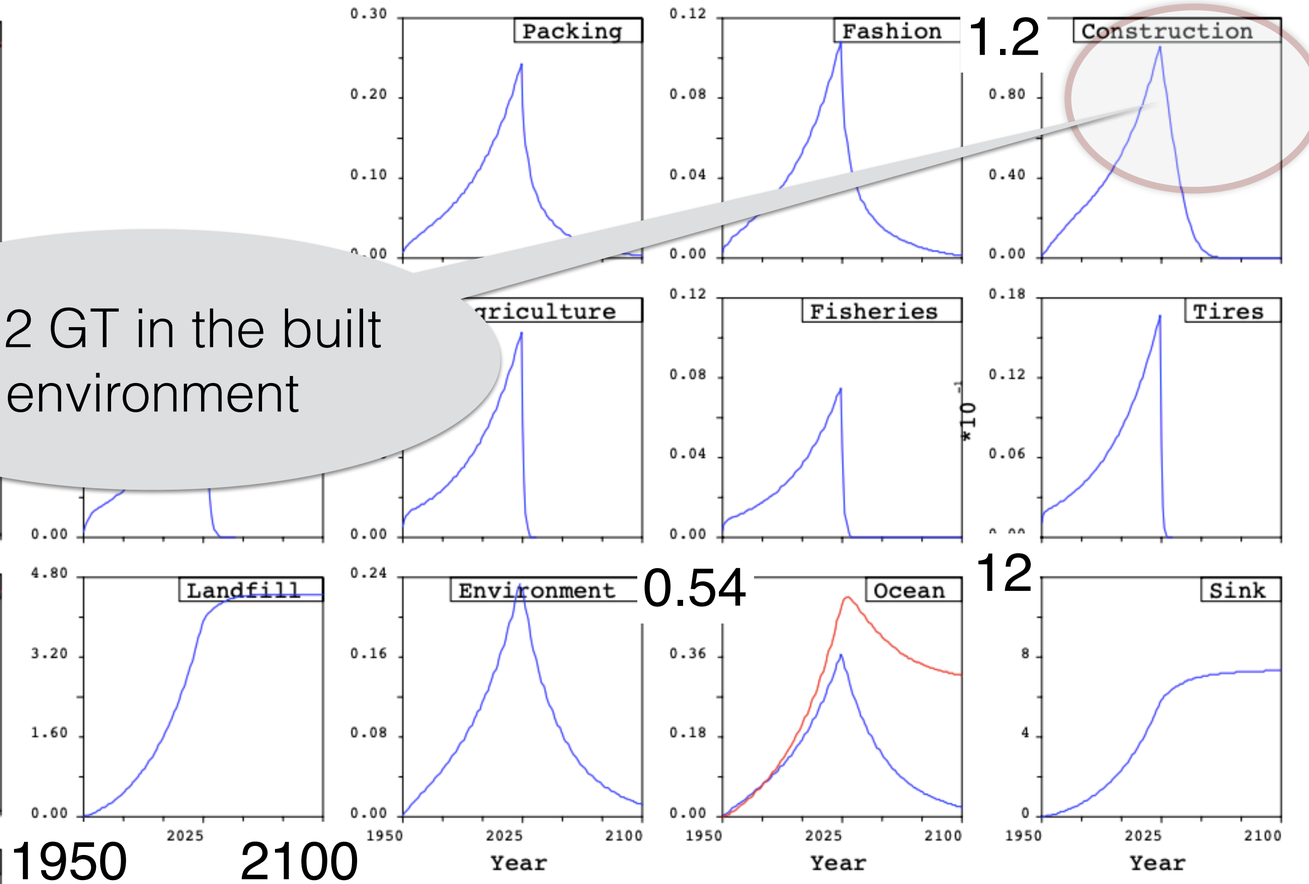
Simulations

All quantities are in billion metric tons

Accumulated Flows Into Stocks



Stocks



~1.2 GT in the built environment

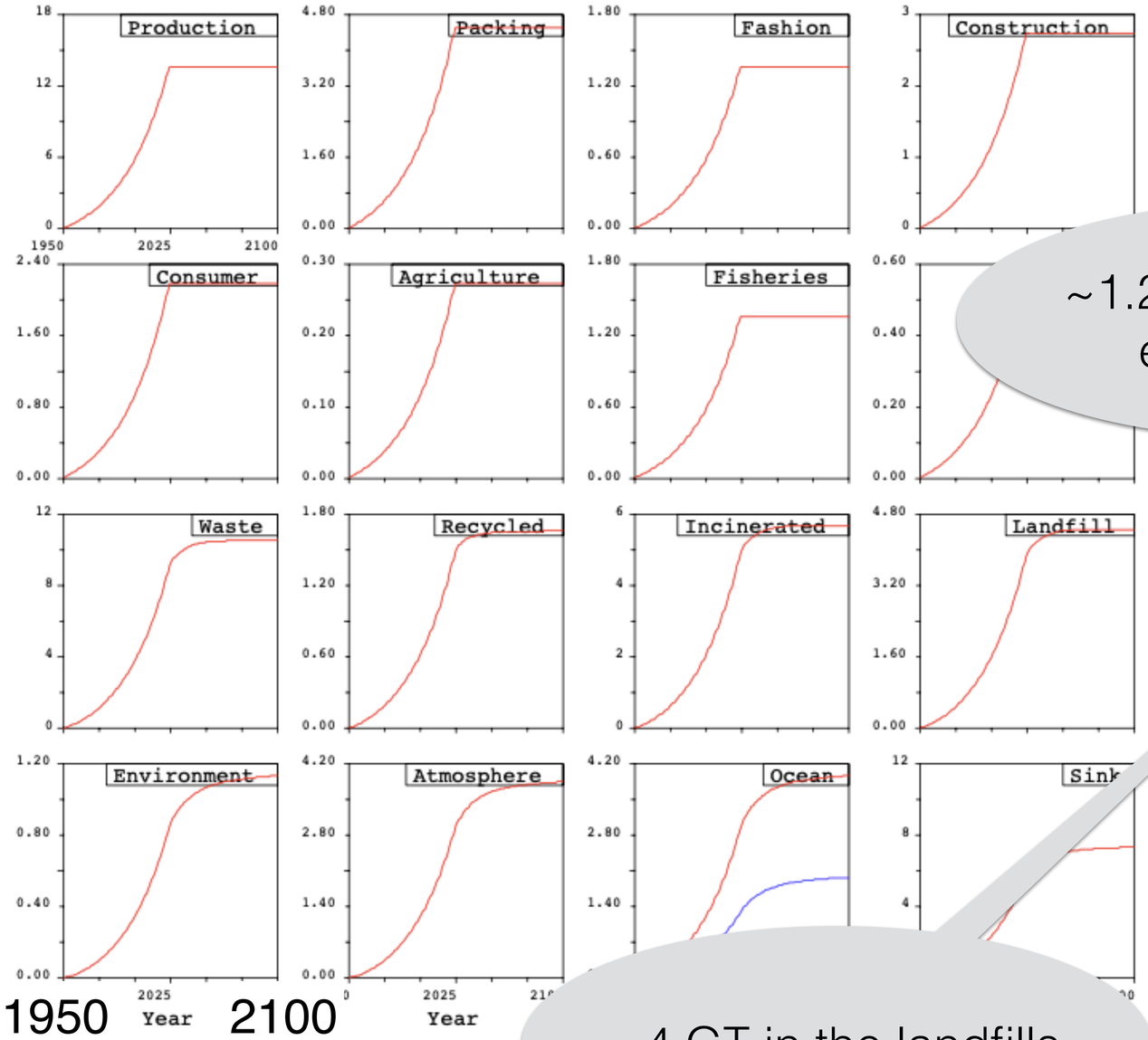
Residence Times: Short

Production Scenario 3: 3% annual increase until 2025, zero production afterwards

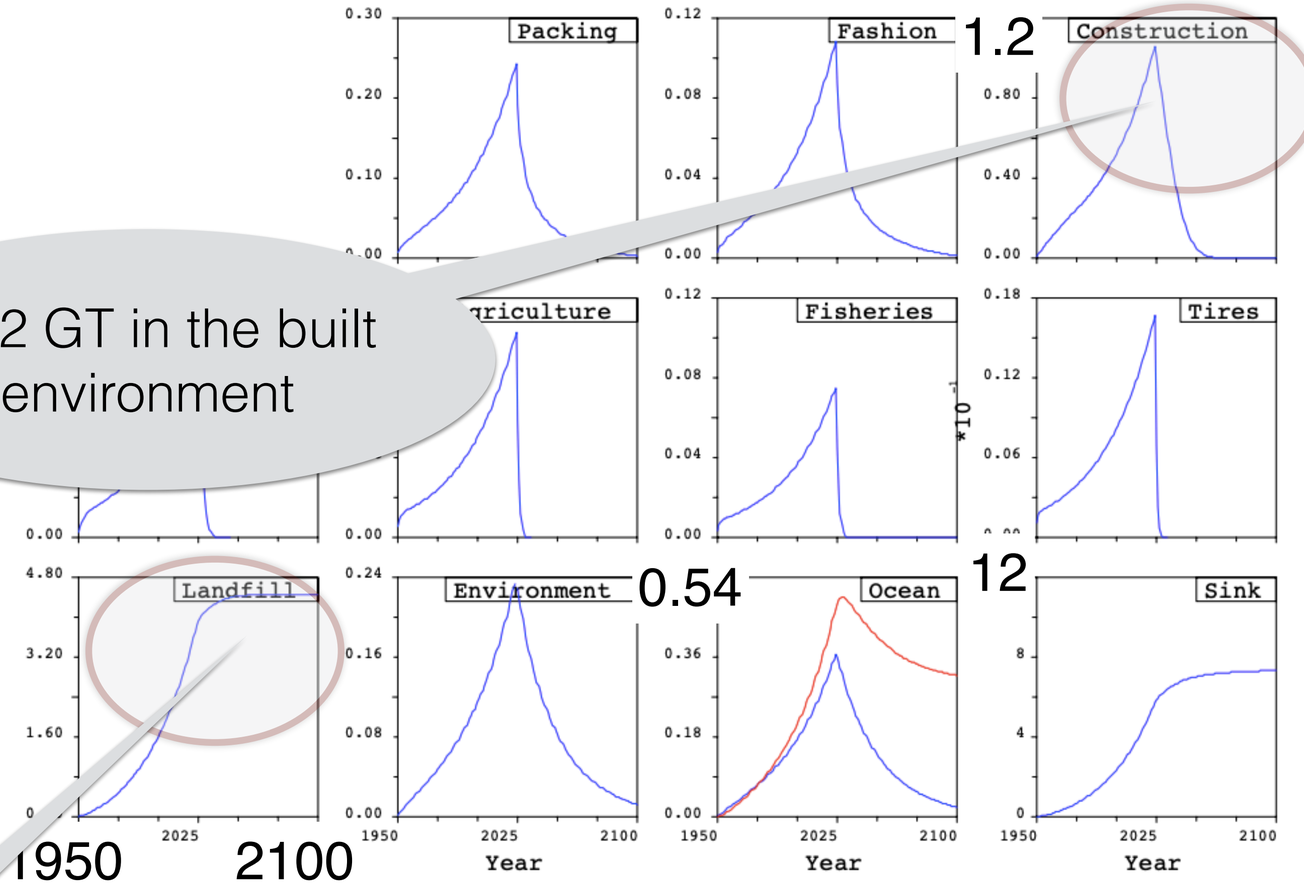
Simulations

All quantities are in billion metric tons

Accumulated Flows Into Stocks



Stocks



~1.2 GT in the built environment

~4 GT in the landfills

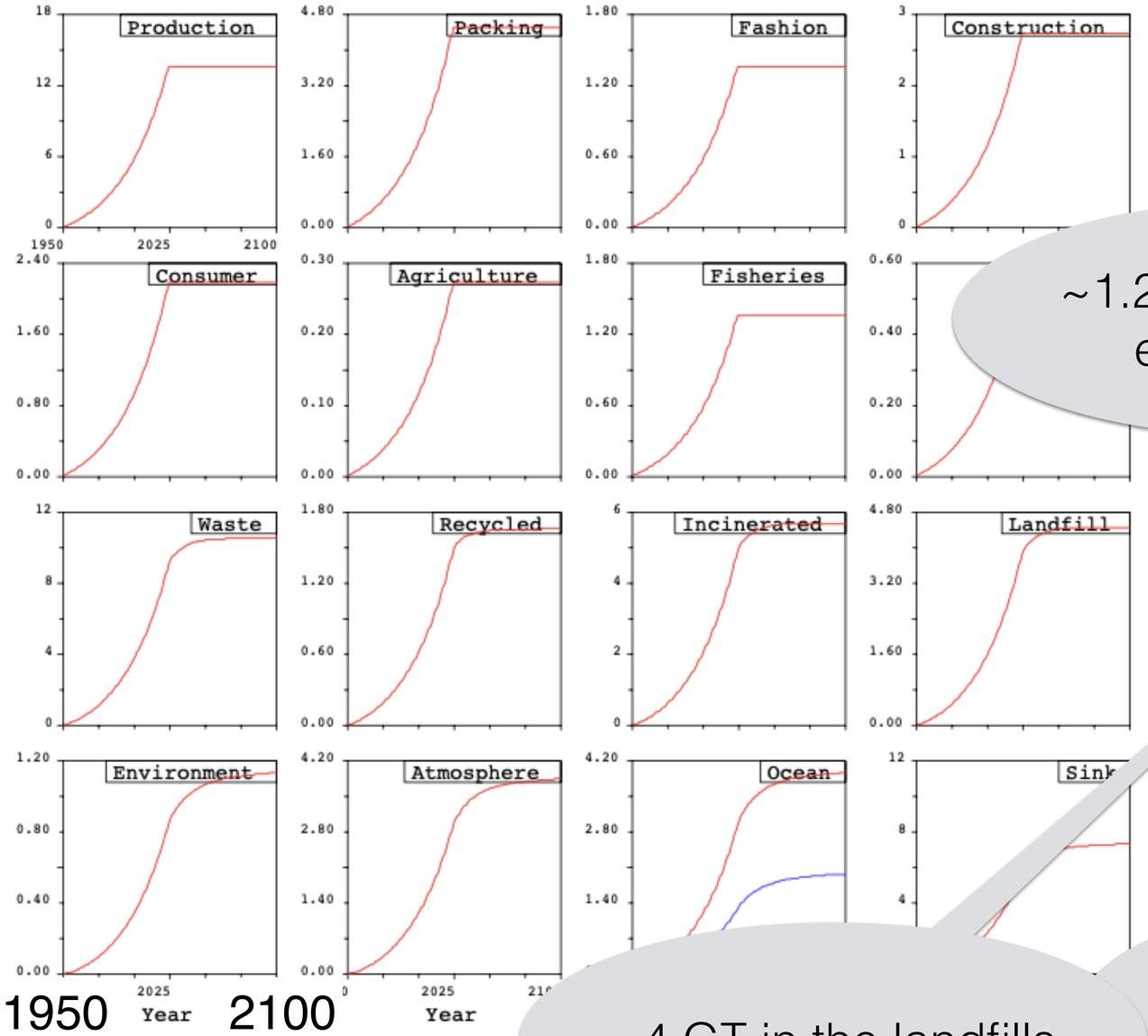
Residence Times: Short

Production Scenario 3: 3% annual increase until 2025, zero production afterwards

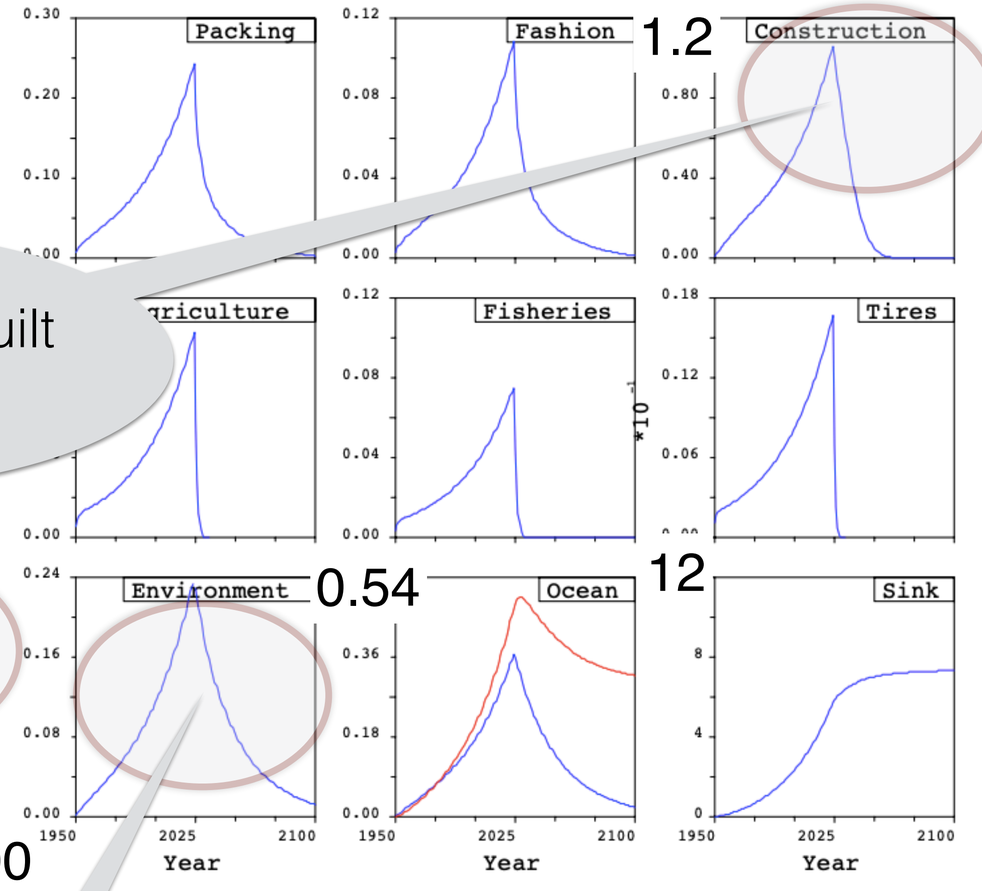
Simulations

All quantities are in billion metric tons

Accumulated Flows Into Stocks



Stocks



~1.2 GT in the built environment

~4 GT in the landfills

~0.2 GT in the terrestrial environmentocean

Short

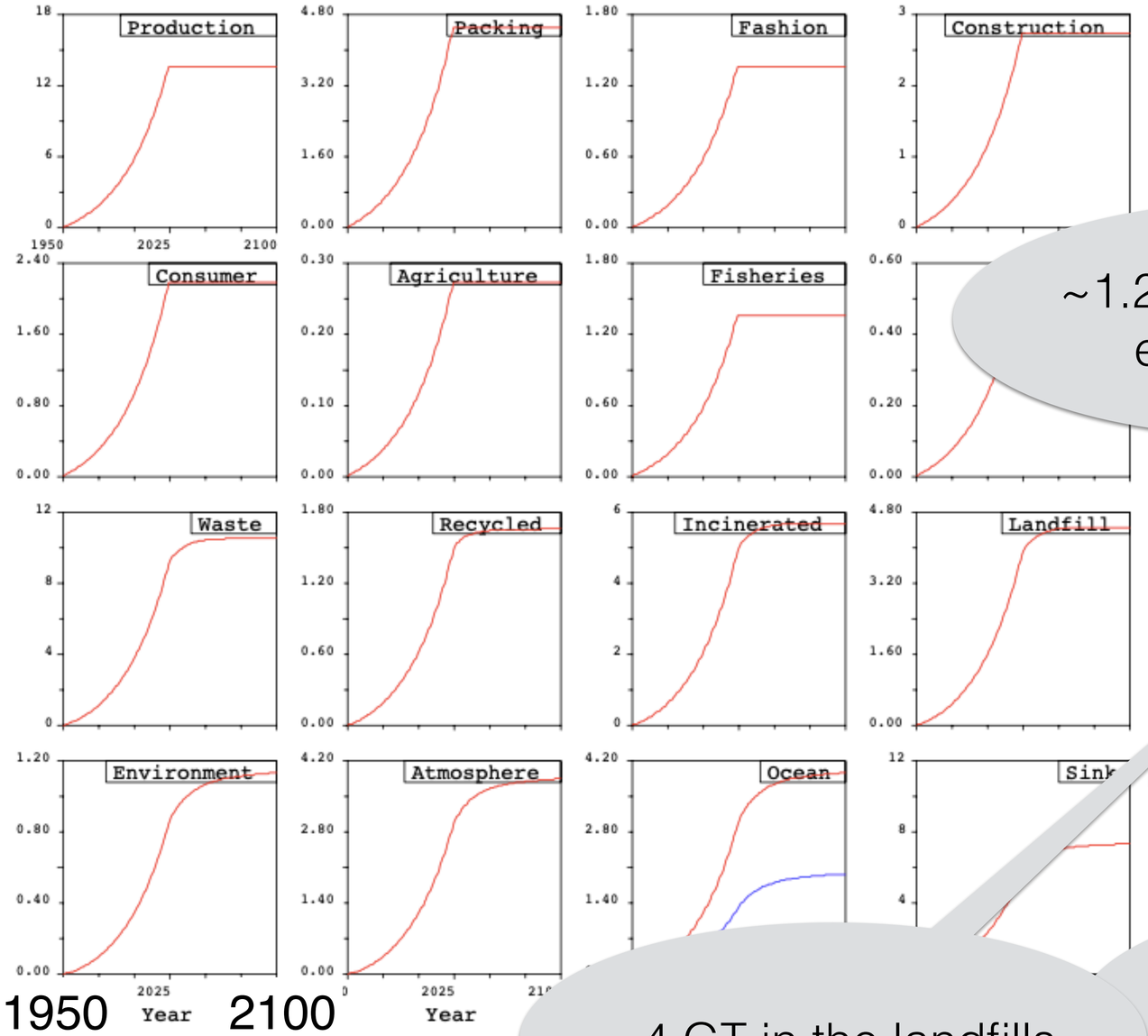
: 3% annual increase until

fterwards

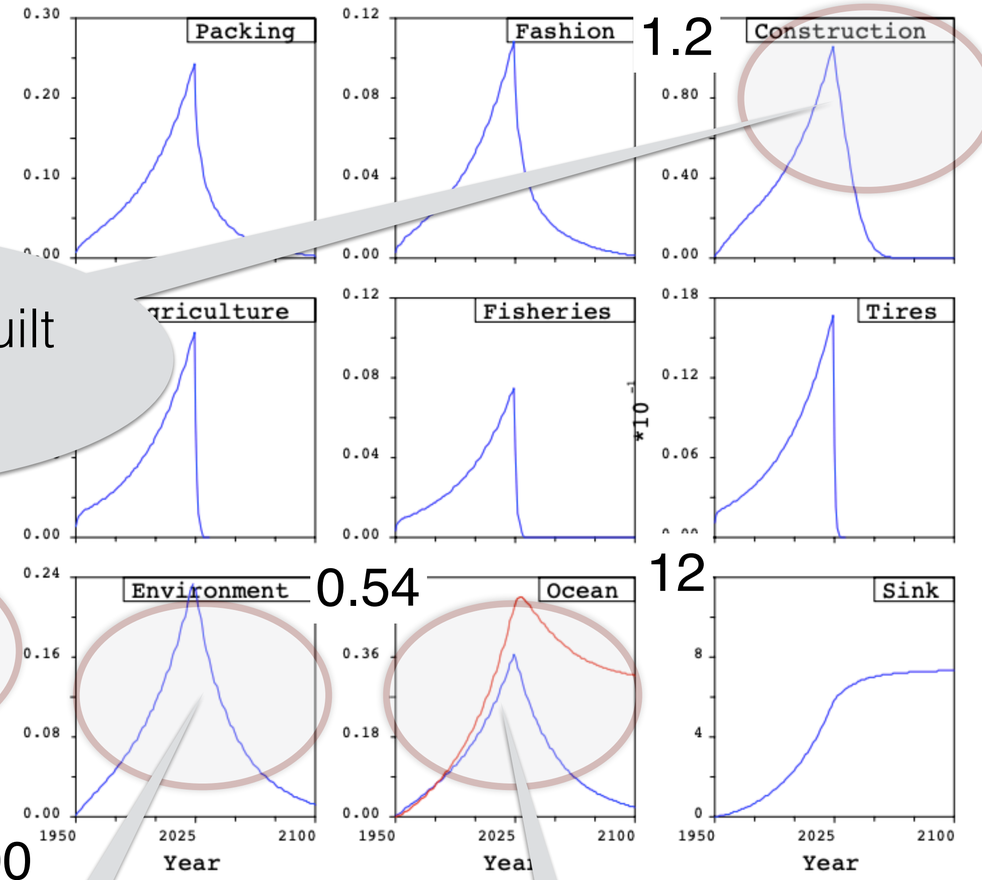
Simulations

All quantities are in billion metric tons

Accumulated Flows Into Stocks



Stocks



~1.2 GT in the built environment

~4 GT in the landfills

~0.2 GT in the terrestrial environmentocean

~0.4 GT in the ocean

Conclusions and Recommendations

Conclusions:

- The current trends in production and use of plastic lead to a cataclysmic plastic pollution present over the next centuries and millenniums
- Reducing the rate of increase in production and slow decrease of production does not change this future significantly
- Circular economy is not going to improve the probable future much
- Only aiming for zero new production of plastic can avoid a plastic-polluted environment

Conclusions and Recommendations

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- The current trends in production and use of plastic lead to a cataclysmic plastic pollution present over the next centuries and millenniums
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- Circular economy is not going to improve the probable future much
- Only aiming for zero new production of plastic can avoid a plastic-polluted environment

Recommendation:

- Declare plastic a polluting substance
- Require registration of all production and use of plastic with realistic rates of leakage into the environment
- Ensure that all plastic used in products can be recovered and recycled
- Avoid plastic in products with high rates of leakage (e.g., cloths, car tires)
- Change building codes to avoid as much as possible the use of plastic in construction
- Ensure that recycling plastic leads to a reduction in the production of new plastic

Maybe not New York

but

Jakarta may look like that before the end of the century

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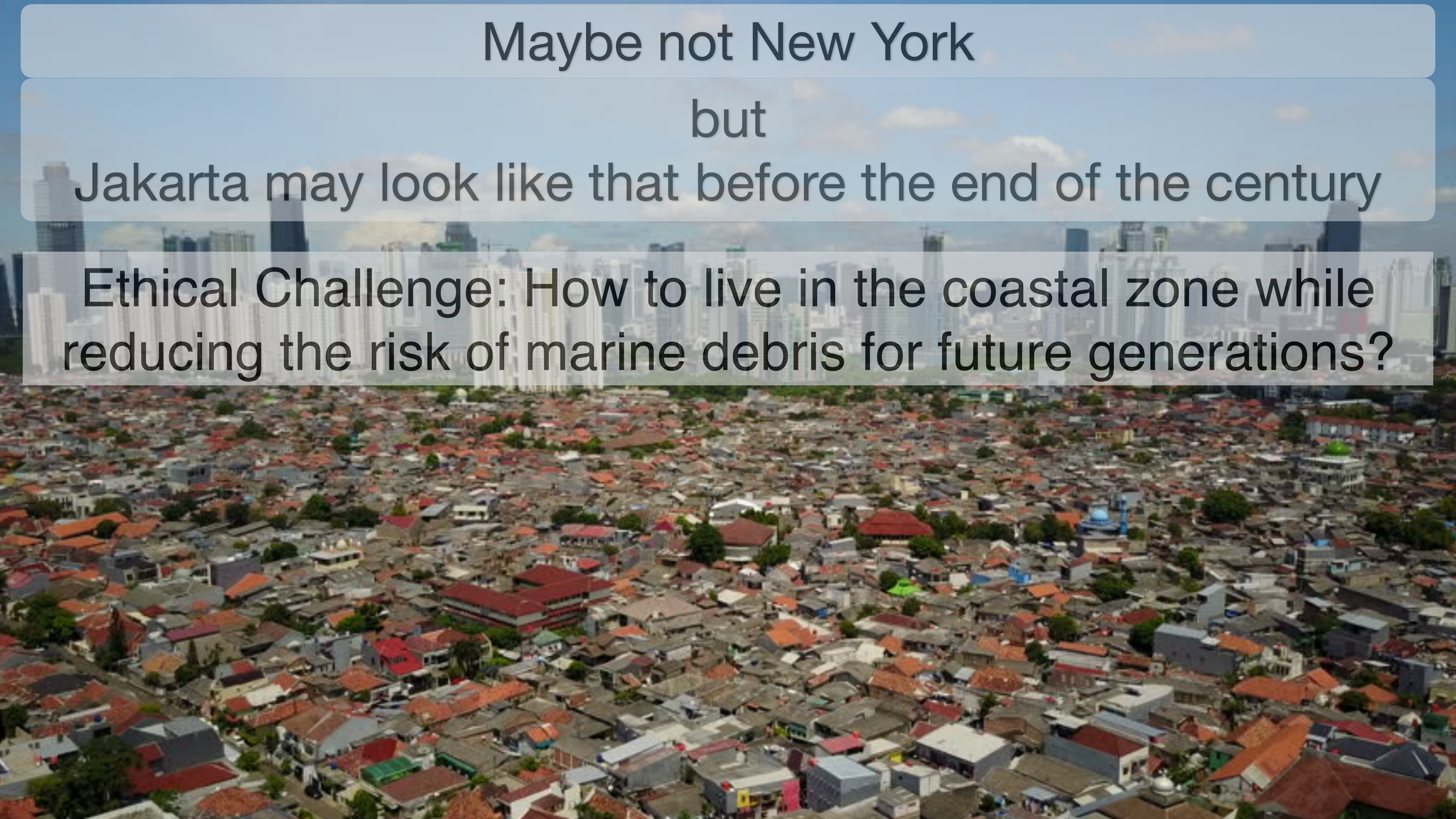
Ethical Challenge: How to live in the coastal zone while reducing the risk of marine debris for future generations?



Maybe not New York

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Ethical Challenge: How to live in the coastal zone while reducing the risk of marine debris for future generations?

Two ethical principles:

- A duty not to participate in creating massive harm
- A duty to justice

Maybe not New York

but

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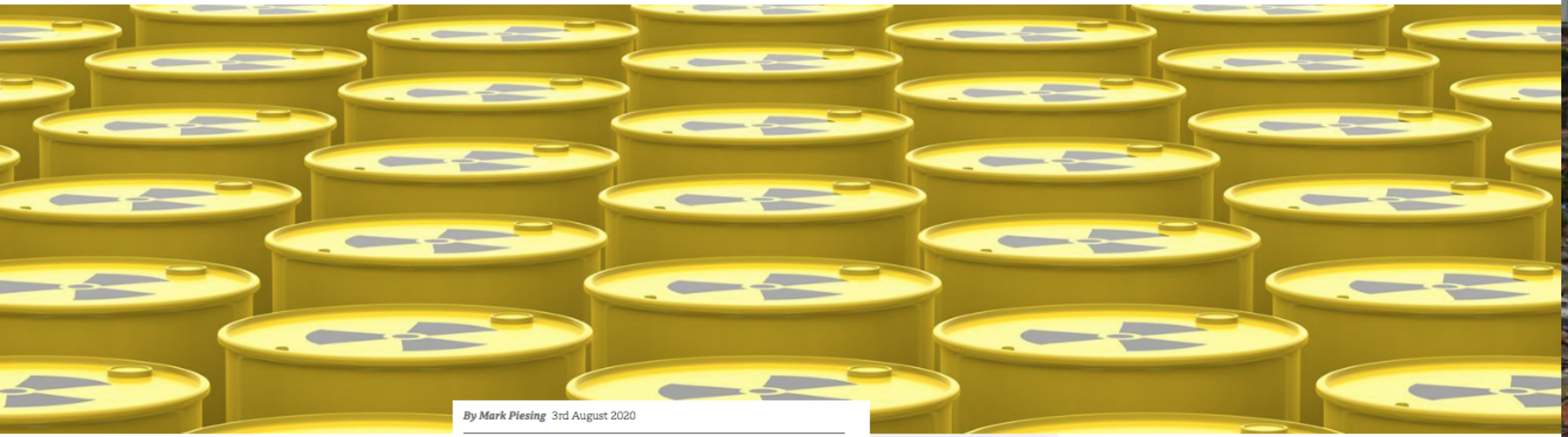
NUCLEAR

How to build a nuclear warning for 10,000 years' time



By Mark Piesing 3rd August 2020

The nuclear waste buried far beneath the earth will be toxic for thousands of years. How do you build a warning now that can be understood in the far future?