

# ACT: Architectural Carbon Modeling Tools

@ MICRO 2024  
Tutorial



**CORNELL  
TECH**

Leo Han  
Udit Gupta

# ACT Tutorial: Today



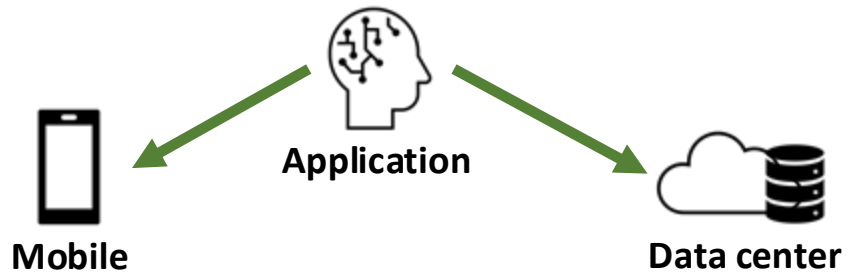
Time	Topic
1:00 – 1:15pm	Welcome to the ACT tutorial!
<b>1:15 – 1:30pm</b>	<b>Motivation: Understanding the source of computing's emissions</b>
1:30 – 2:15pm	Overview of ACT: An Architectural Carbon Modeling Tool
2:15 – 2:45pm	Hands-on ACT demo's
2:45 – 3:00pm	Extending ACT
3:00 – 3:30pm	Coffee break

# Today

Where does computing's carbon footprint come from?

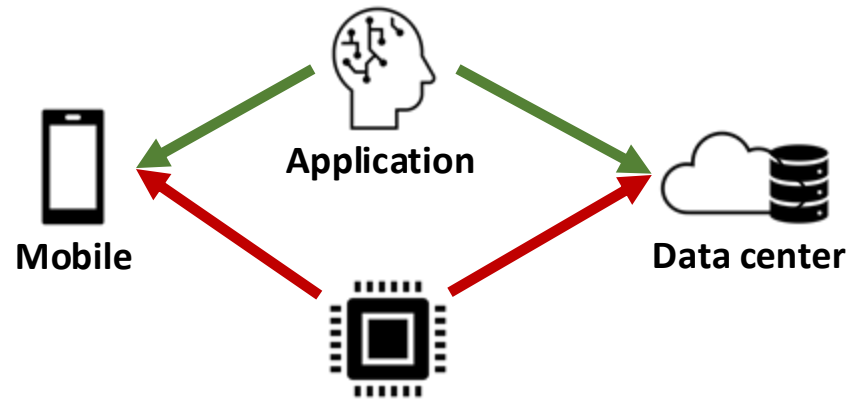
# Today

Where does computing's carbon footprint come from?



# Today

Where does computing's carbon footprint come from?  
*A combination of both **energy consumed** and **hardware manufacturing (embodied carbon)**.*

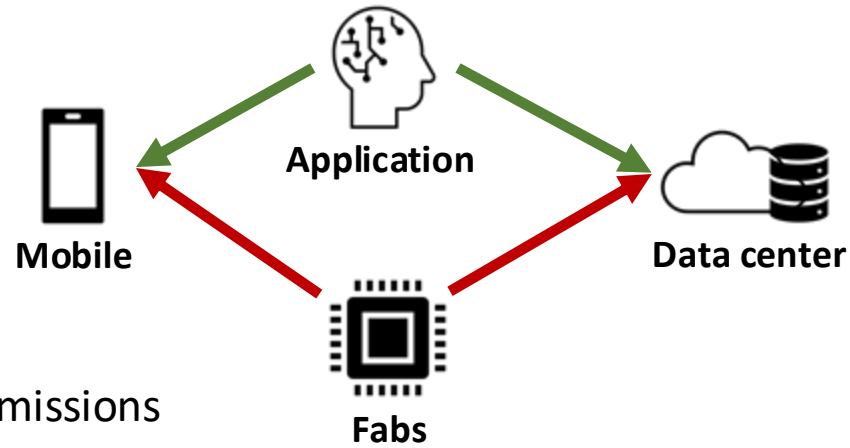


# Today

Where does computing's carbon footprint come from?  
*A combination of both **energy consumed** and **hardware manufacturing (embodied carbon)**.*



Understanding the breakdown of mobile emissions



# Today

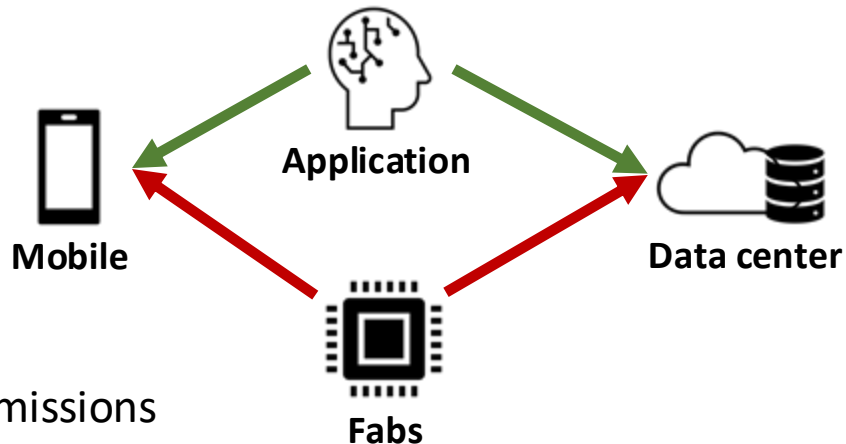
Where does computing's carbon footprint come from?  
*A combination of both **energy consumed** and **hardware manufacturing (embodied carbon)**.*



Understanding the breakdown of mobile emissions



Understanding the breakdown of data center emissions



# Today

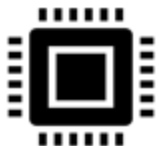
Where does computing's carbon footprint come from?  
*A combination of both **energy consumed** and **hardware manufacturing (embodied carbon)**.*



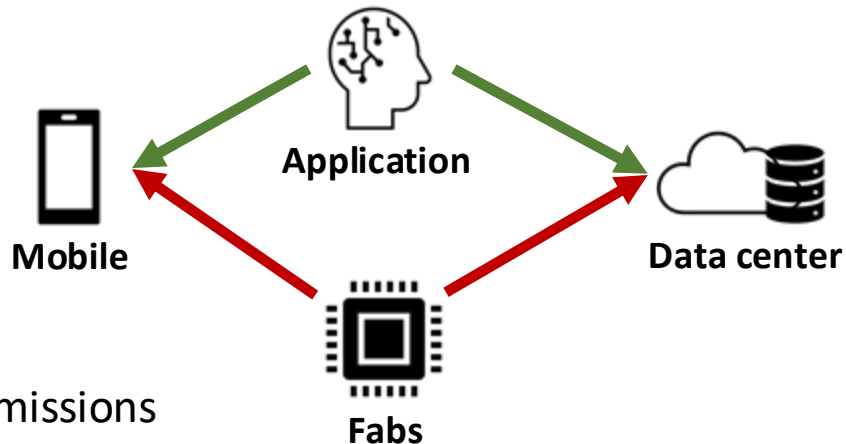
Understanding the breakdown of mobile emissions



Understanding the breakdown of data center emissions



Understanding the breakdown of semiconductor manufacturing

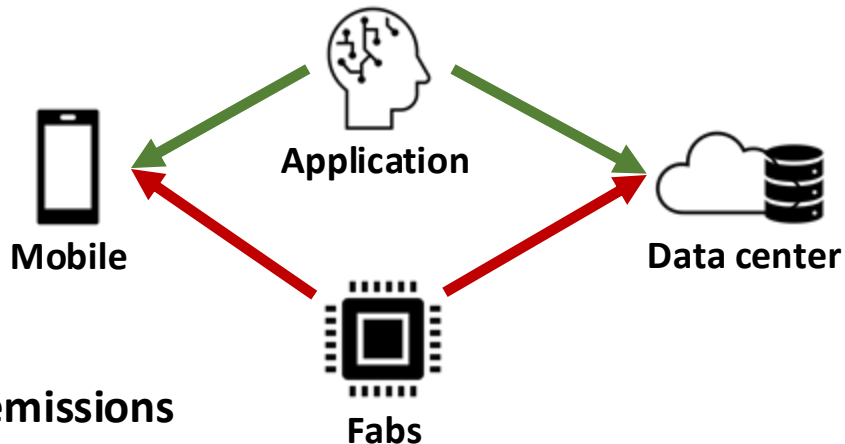




# Today

Where does computing's carbon footprint come from?

*A combination of both **energy consumed** and **hardware manufacturing (embodied carbon)**.*



**Understanding the breakdown of mobile emissions**

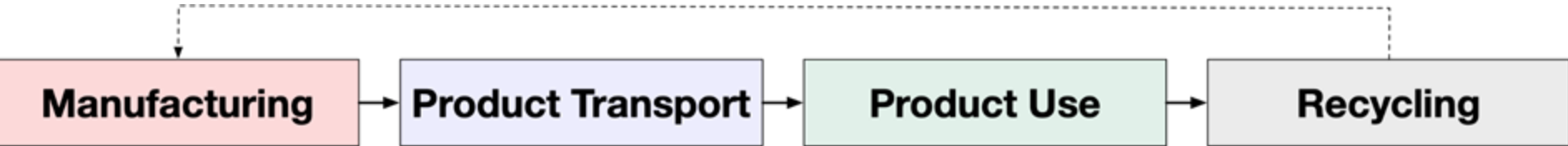


**Understanding the breakdown of data center emissions**

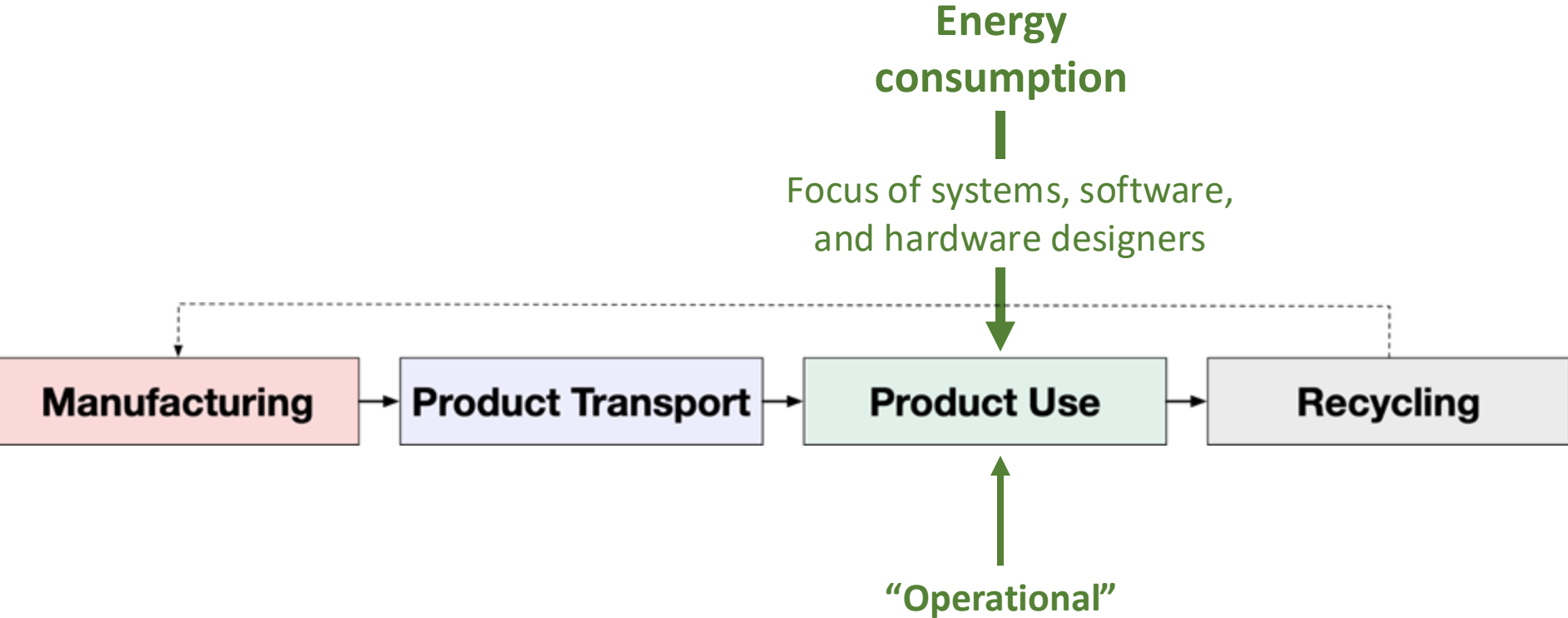


**Understanding the breakdown of semiconductor manufacturing**

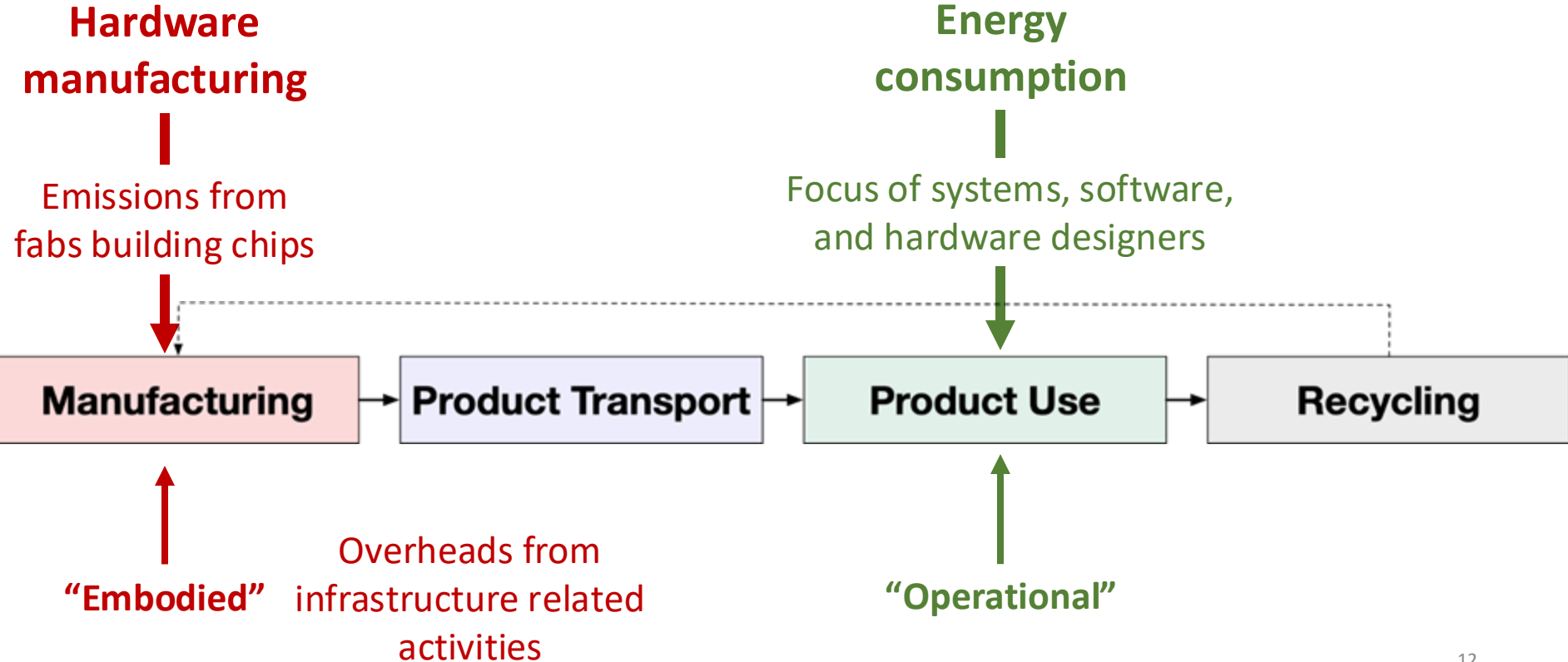
# Life Cycle Analysis: key to understanding carbon emissions



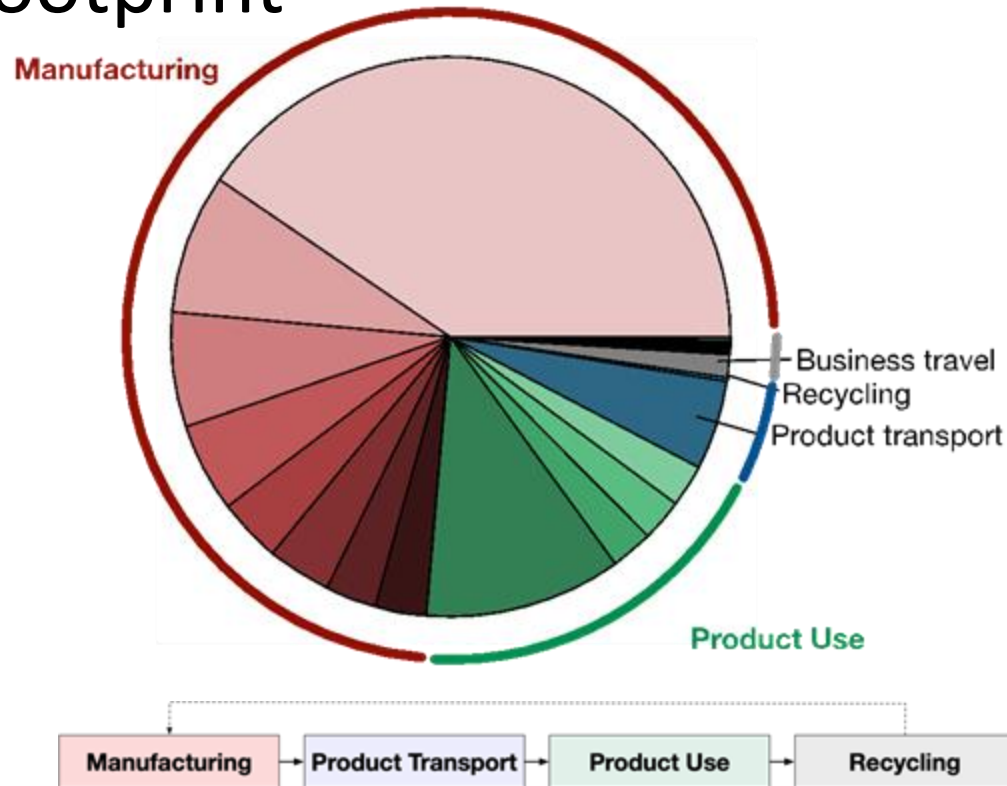
# Life Cycle Analysis: key to understanding carbon emissions



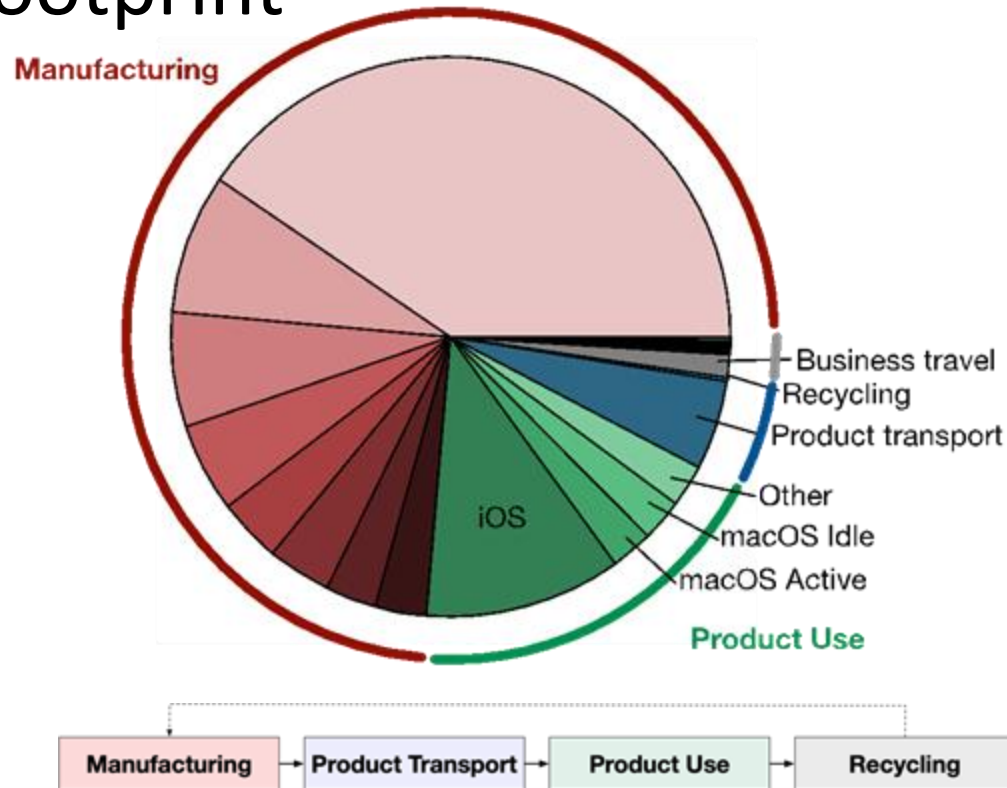
# Life Cycle Analysis: key to understanding carbon emissions



# Manufacturing dominates Apple's overall carbon footprint

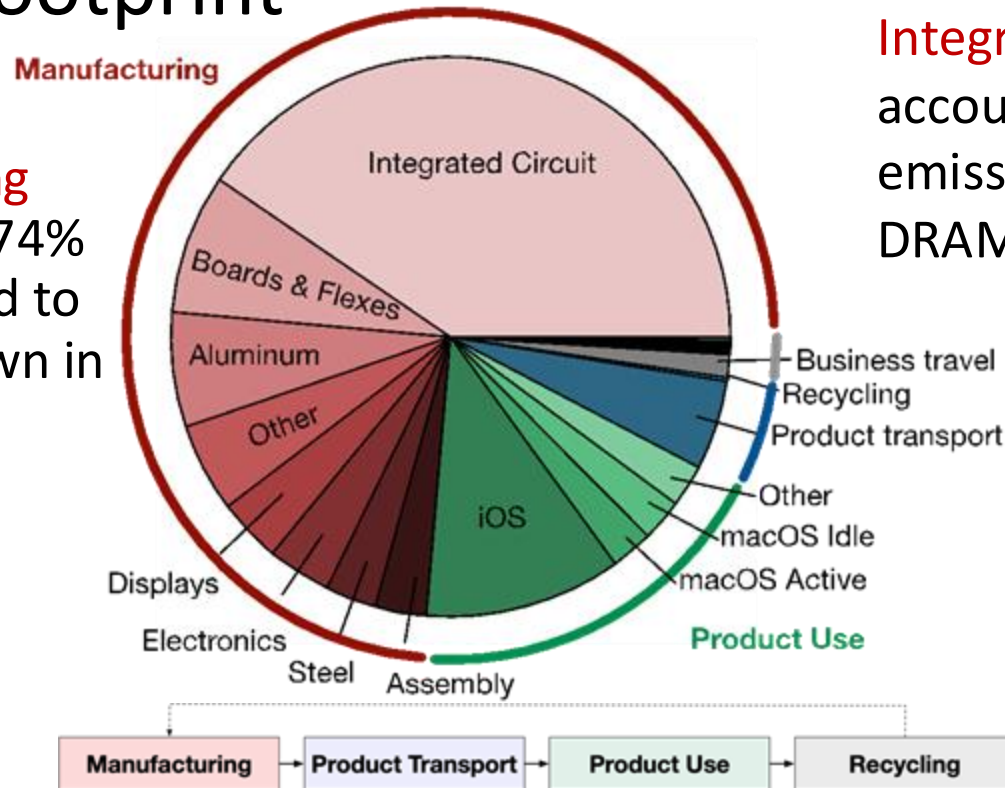


# Manufacturing dominates Apple's overall carbon footprint



# Manufacturing dominates Apple's overall carbon footprint

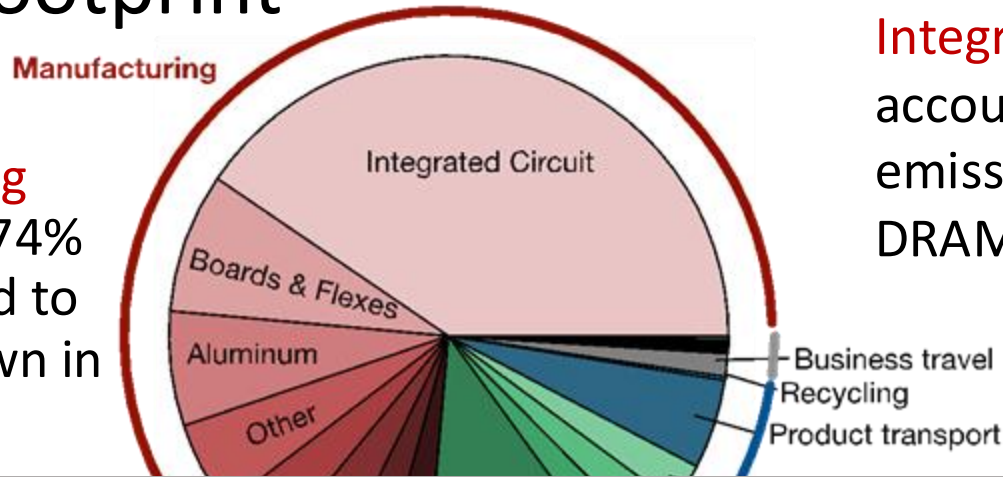
**Manufacturing** accounts for 74% of Apple's end to end breakdown in 2019



**Integrated circuits** account for 33% of emissions (SoCs, DRAMs, NAND Flash)

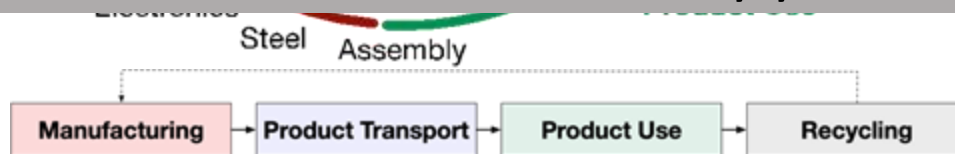
# Manufacturing dominates Apple's overall carbon footprint

**Manufacturing** accounts for 74% of Apple's end to end breakdown in 2019



**Integrated circuits** account for 33% of emissions (SoCs, DRAMs, NAND Flash)

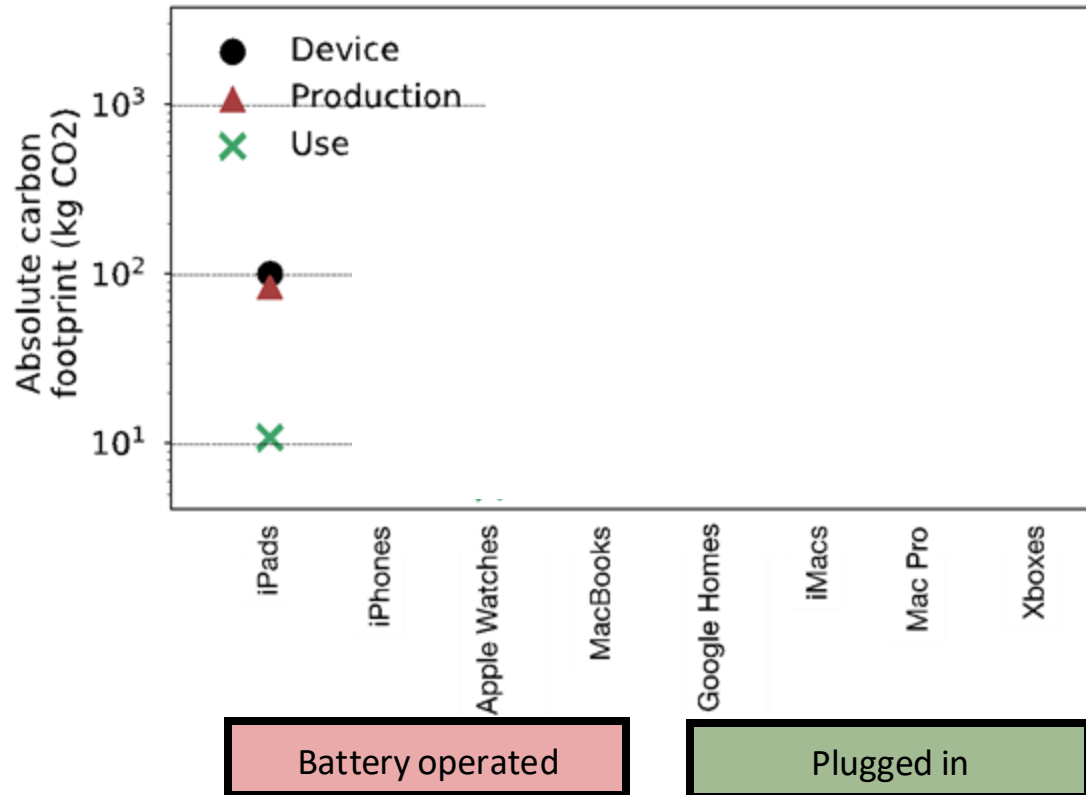
Aggregating across hundreds of millions of phones, iPads, and other consumer devices sold every year!





# Carbon footprint characteristics vary across devices

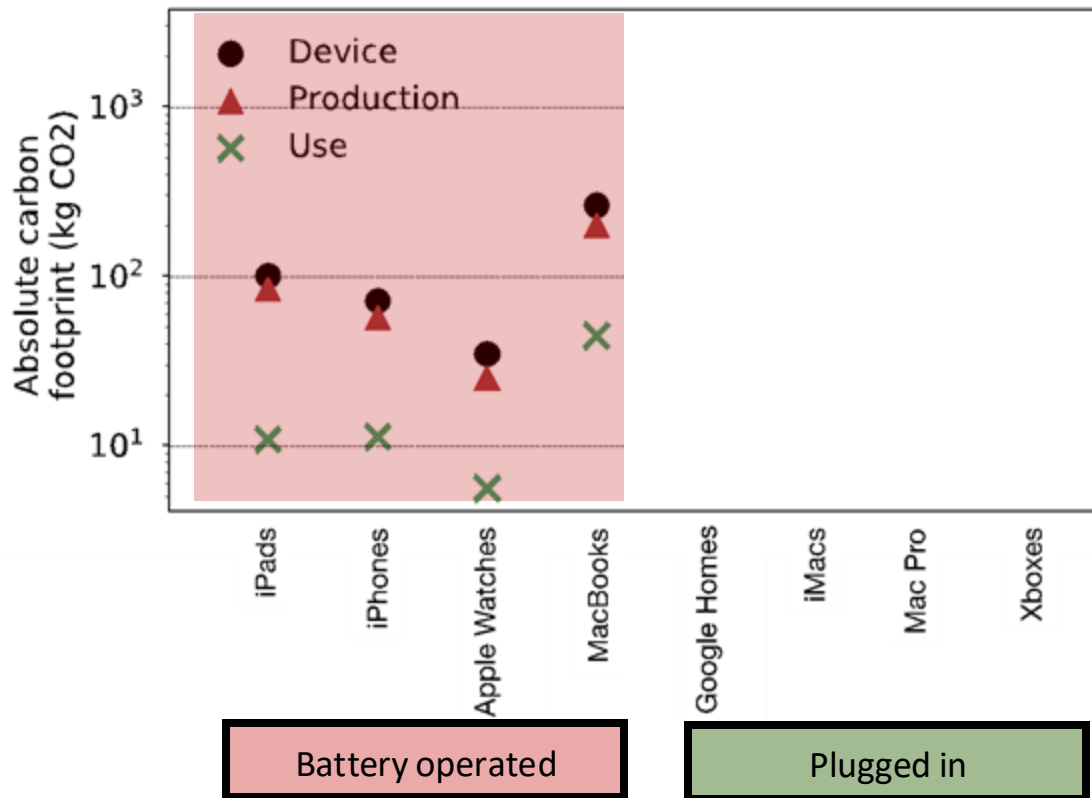
*Data from public industry validated sustainability reports and life cycle analyses*



# Carbon footprint characteristics vary across devices

*Data from public industry validated sustainability reports and life cycle analyses*

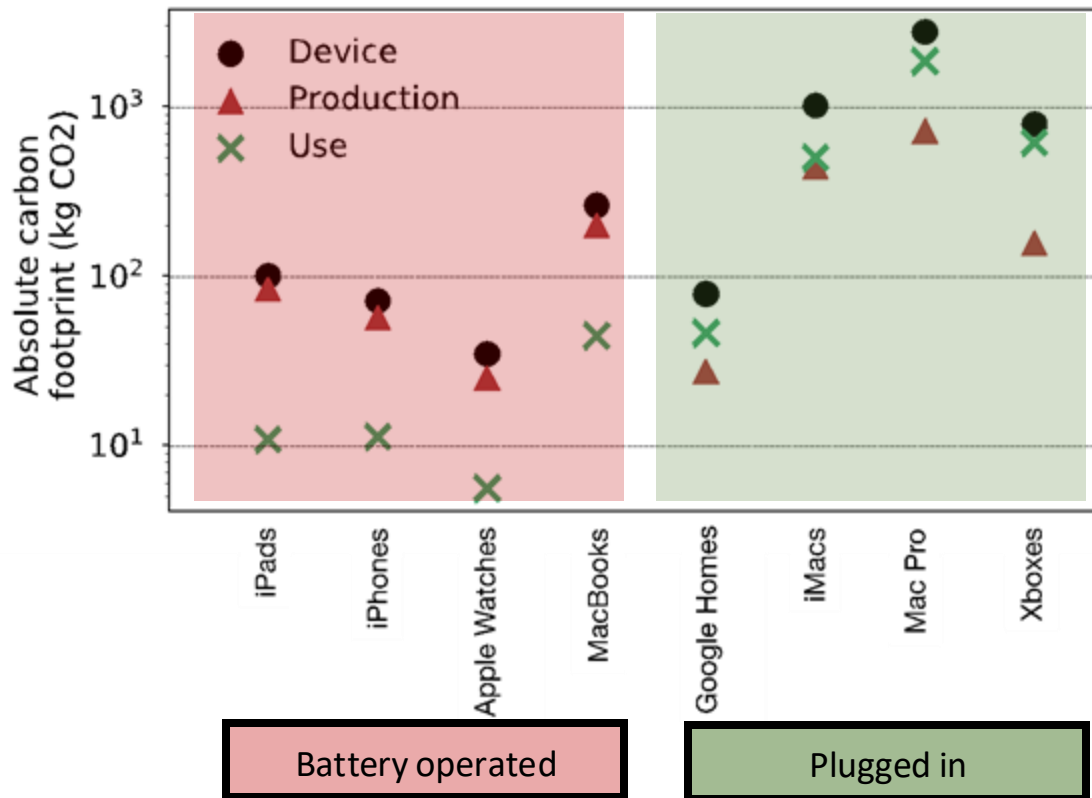
Roughly **75%** life cycle emissions for **battery operated devices** comes from hardware manufacturing.



# Carbon footprint characteristics vary across devices

*Data from public industry validated sustainability reports and life cycle analyses*

Roughly **75%** life cycle emissions for **battery operated devices** comes from hardware manufacturing.



Emissions for **always-connected devices** come mainly from **energy consumption**

# Today

Where does computing's carbon footprint come from?  
*A combination of both **energy consumed** and **hardware manufacturing (embodied carbon)**.*



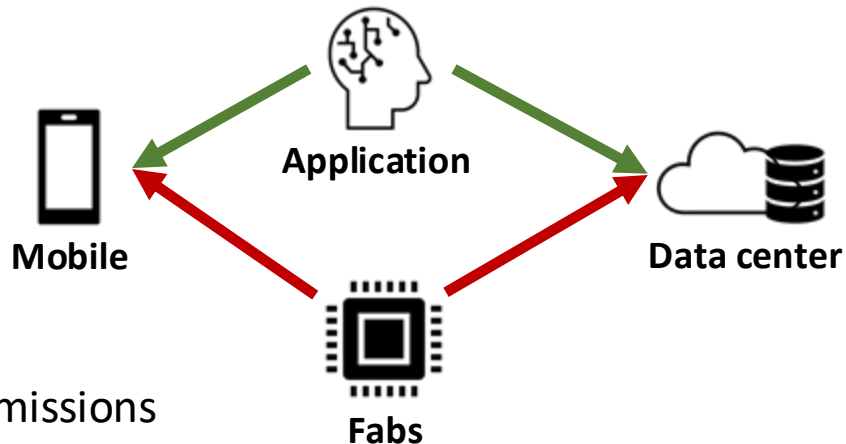
Understanding the breakdown of mobile emissions



Understanding the breakdown of data center emissions



Understanding the breakdown of semiconductor manufacturing



# Greenhouse gas (GHG) Protocol



Technology company

# Greenhouse gas (GHG) Protocol



## Scope 1

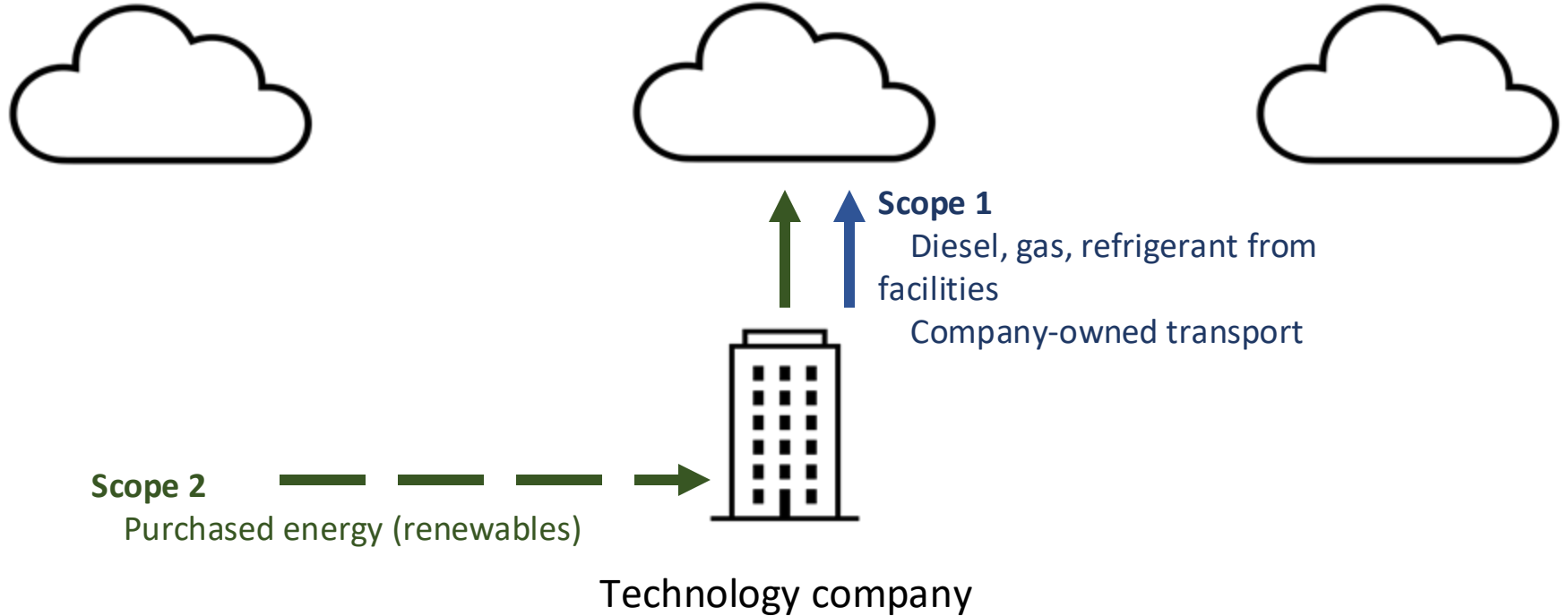
Diesel, gas, refrigerant from  
facilities

Company-owned transport

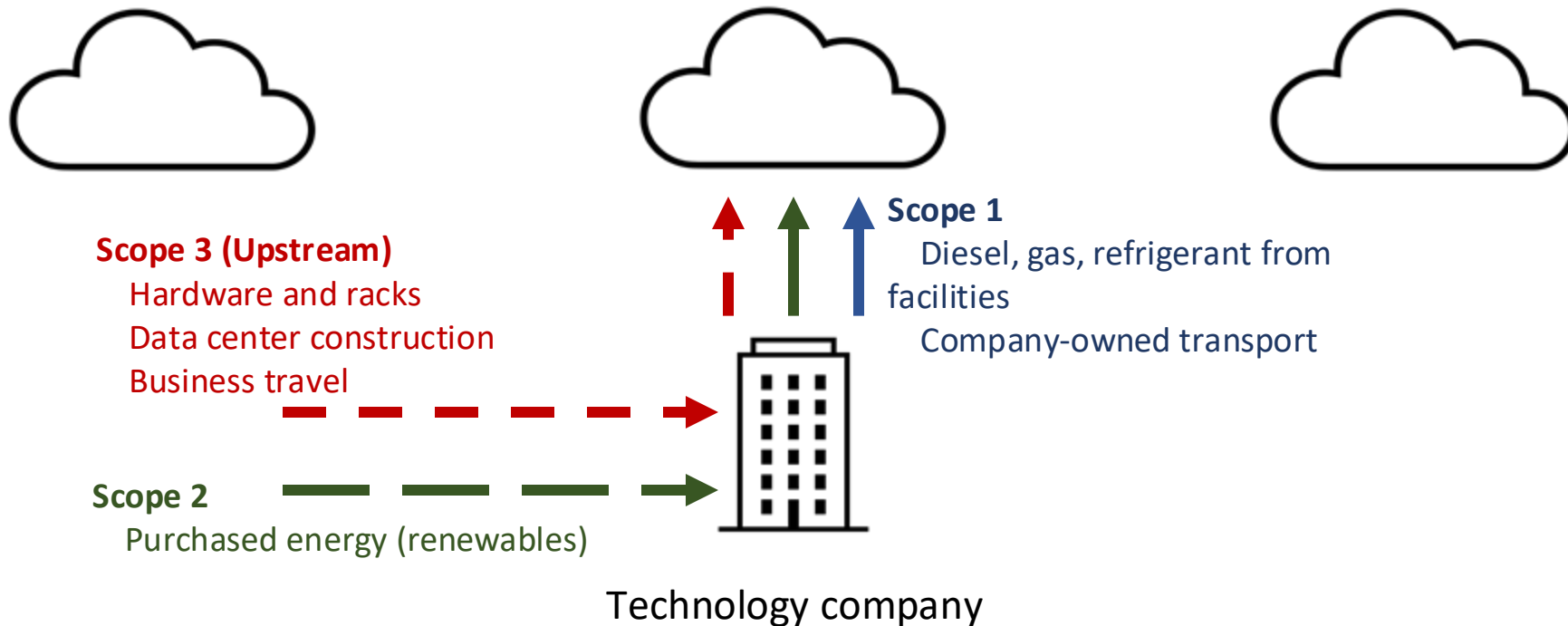


Technology company

# Greenhouse gas (GHG) Protocol

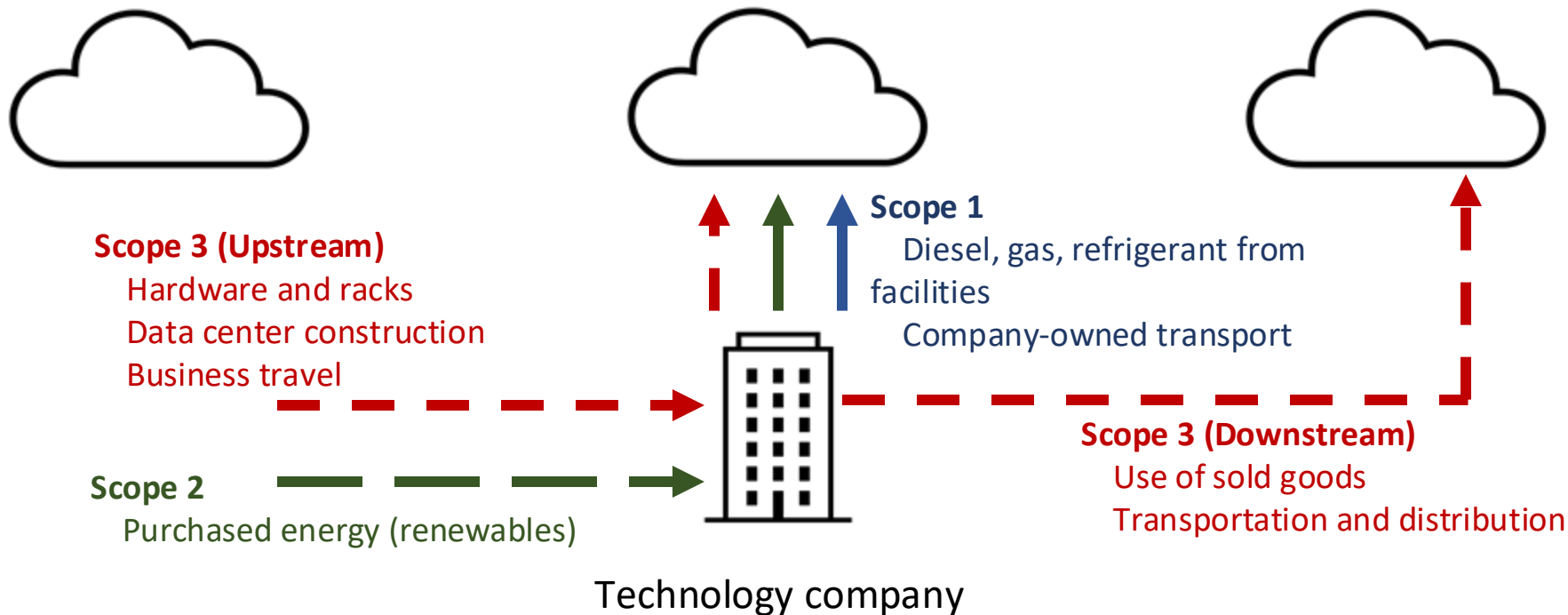


# Greenhouse gas (GHG) Protocol

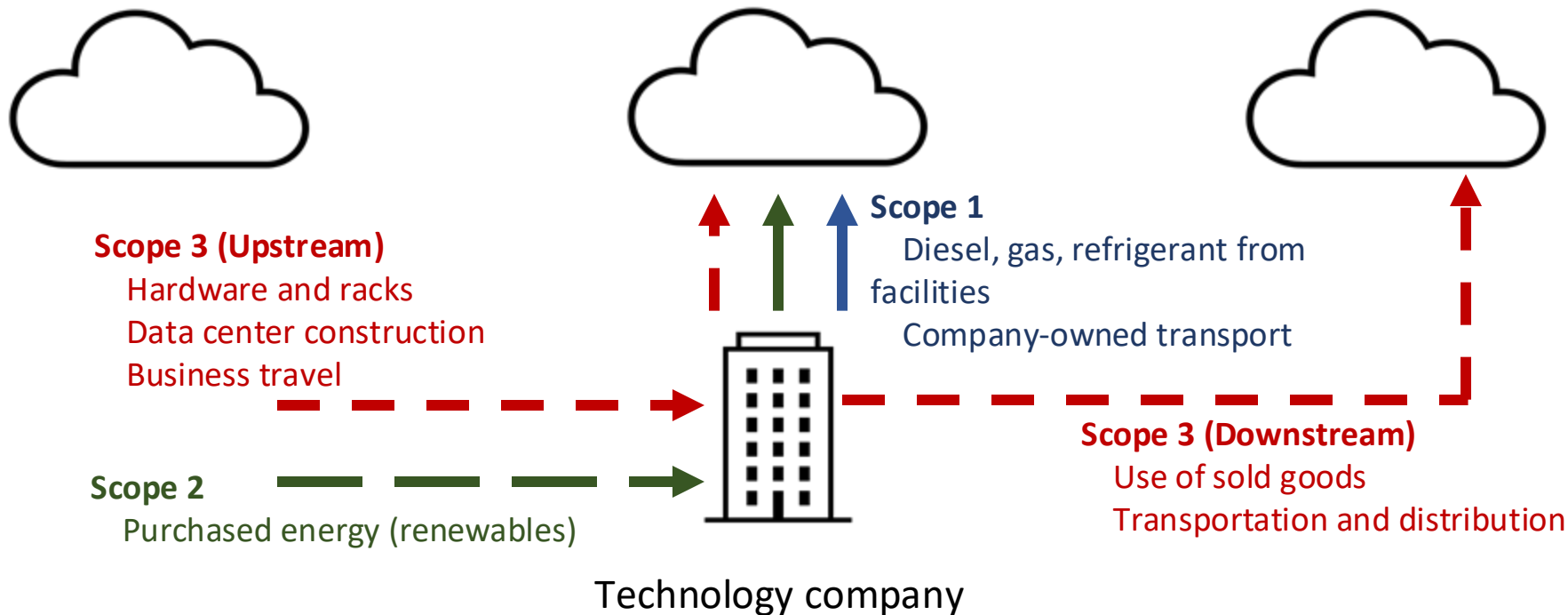




# Greenhouse gas (GHG) Protocol

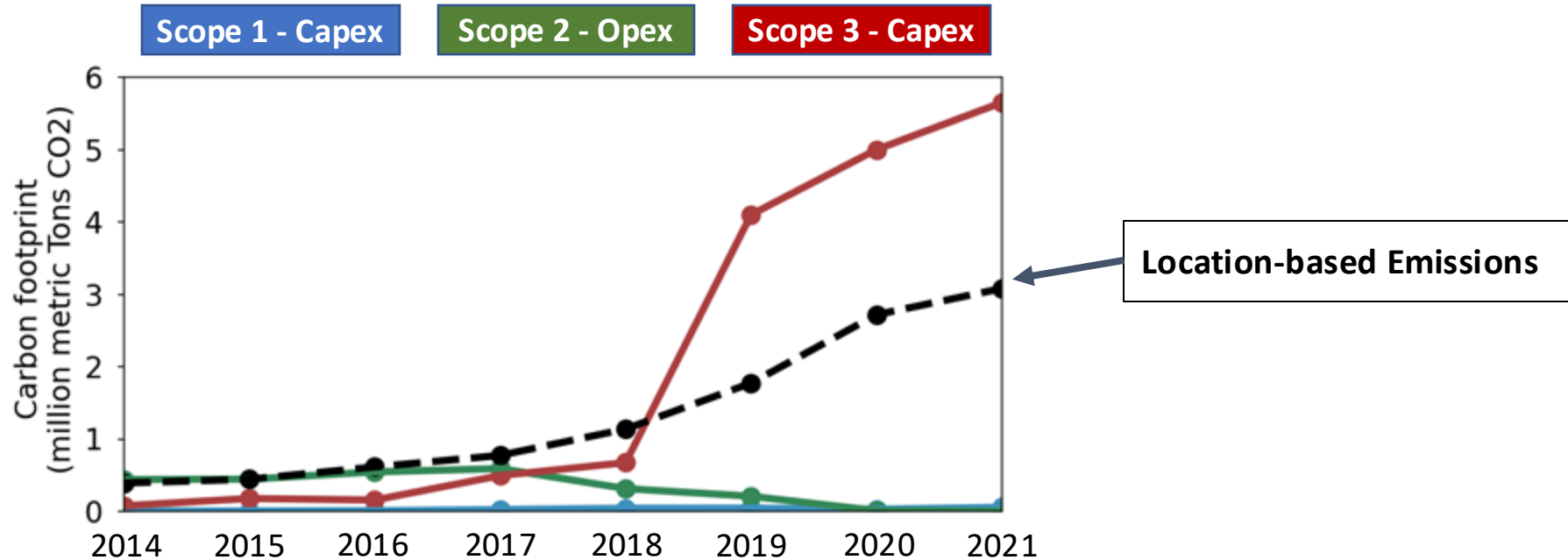


# Greenhouse gas (GHG) Protocol

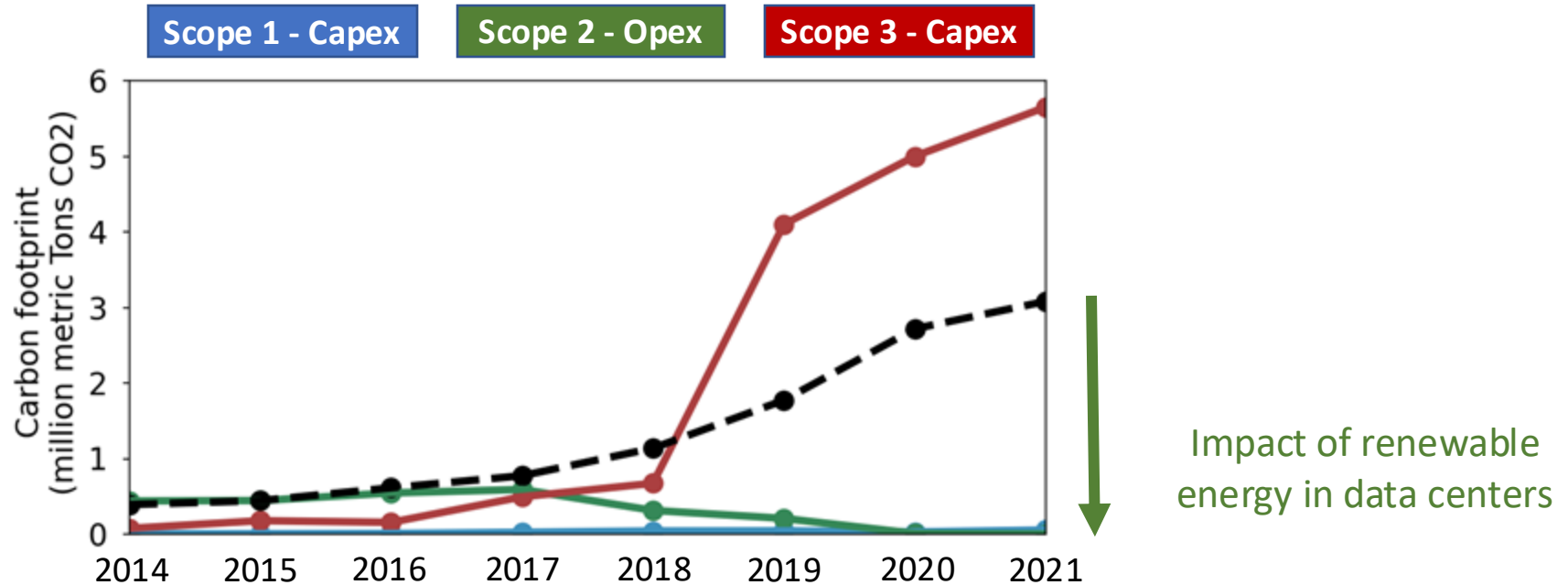


Scope 2 emissions come from opex-related activities  
Scope 1 and Scope 3 emissions come from capex-related activities

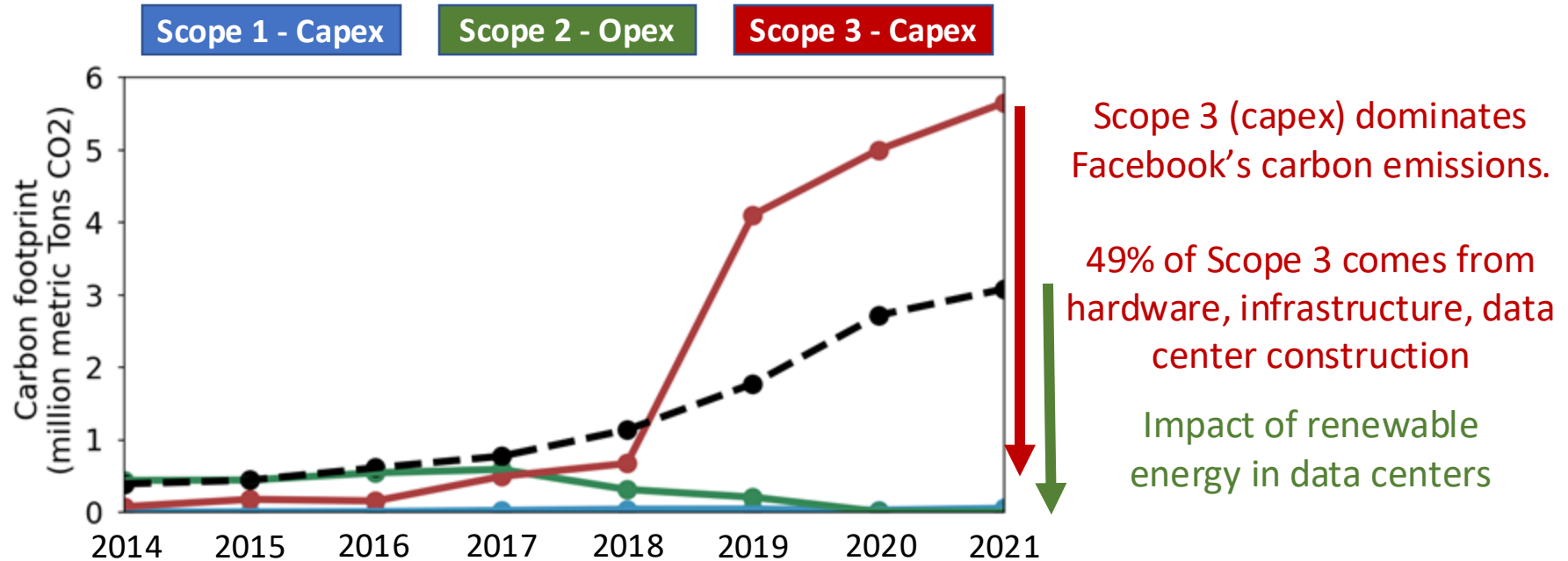
# Historical analysis of Facebook's carbon footprint



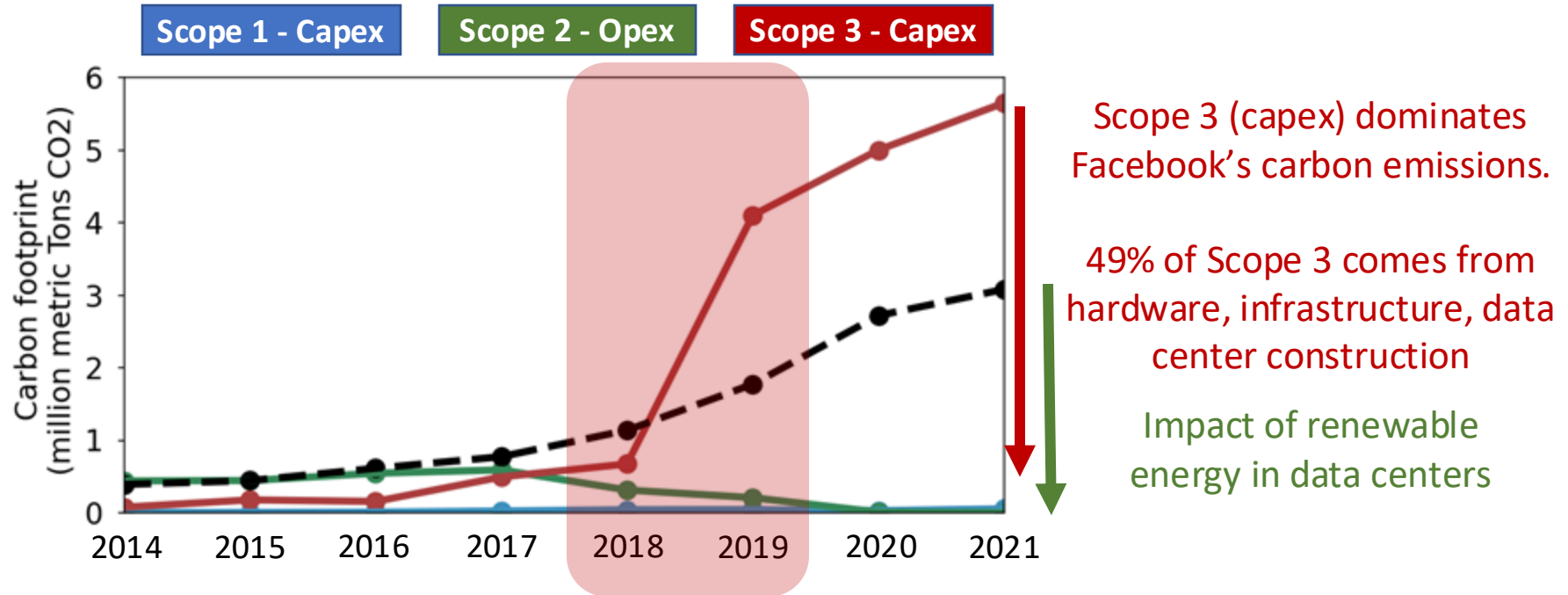
# Historical analysis of Facebook's carbon footprint



# Historical analysis of Facebook's carbon footprint



# Historical analysis of Facebook's carbon footprint



# Economic incentives and carbon sequestration

## How Microsoft is using an internal carbon fee to reach its carbon negative goal

March 24, 2022 • 2 min read

Share ▾



[Elizabeth Willmott](#)

Carbon Program Director, Microsoft

[Thought leadership, Sustainability](#)



Microsoft: **\$100/tCO<sub>2</sub>e** to incentivize reductions

- Projecting future annual cost of over **\$1 billion**

Google: Estimates **\$50-\$300/tCO<sub>2</sub>e** as carbon sequestration scales up to **20%** of the cost of a server!

# Today

Where does computing's carbon footprint come from?  
*A combination of both **energy consumed** and **hardware manufacturing (embodied carbon)**.*



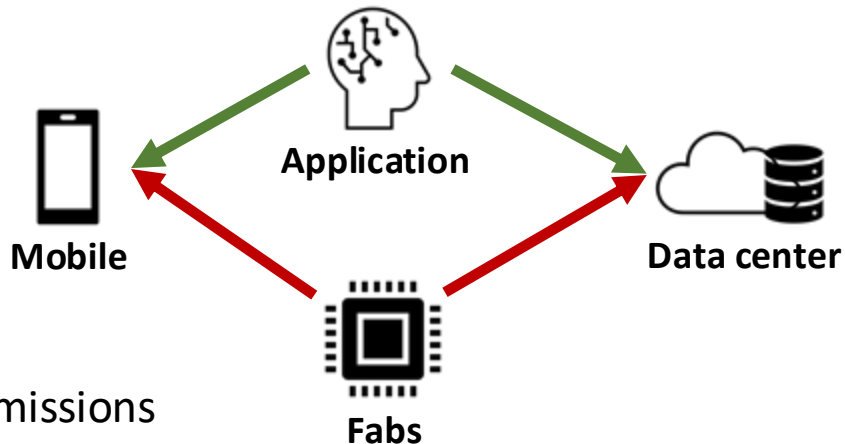
Understanding the breakdown of mobile emissions



Understanding the breakdown of data center emissions

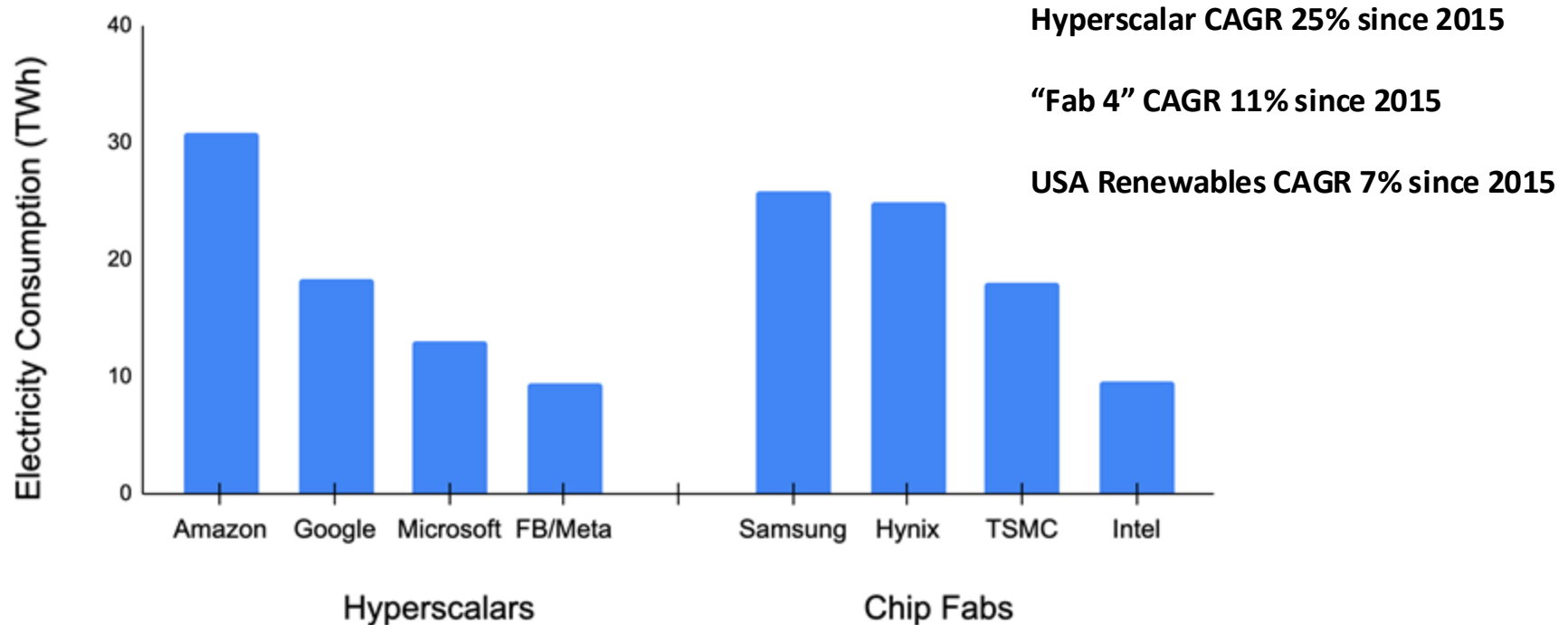


Understanding the breakdown of semiconductor manufacturing





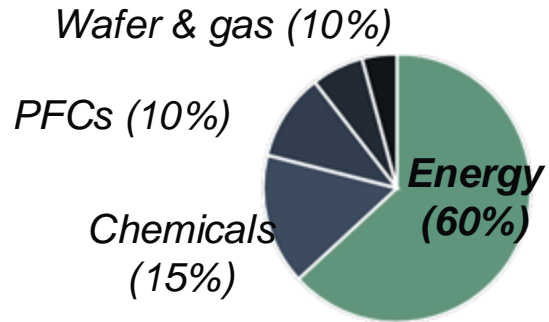
# Chip manufacturing is energy intensive



Source: 2021 corporate sustainability reports



*Semiconductor  
fab*



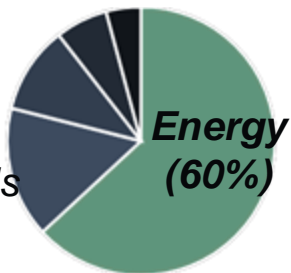


*Semiconductor  
fab*

*Wafer & gas (10%)*

*PFCs (10%)*

*Chemicals  
(15%)*



***100% Renewable** powered  
semiconductor fab*



*Reduces manufacturing footprint by **2.5x***

# “Green” powered fabs are not enough

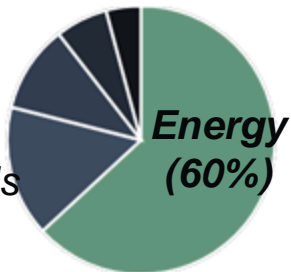


Semiconductor  
fab

Wafer & gas (10%)

PFCs (10%)

Chemicals  
(15%)



TSMC plans for  
**25% renewable by 2025** and  
**100% renewable by 2050**.



**100% Renewable** powered  
semiconductor fab



Reduces manufacturing footprint by **2.5x**

**We must elevate carbon as a first order design target and constraint alongside performance, power, energy, and area**

# ACT Tutorial: Today

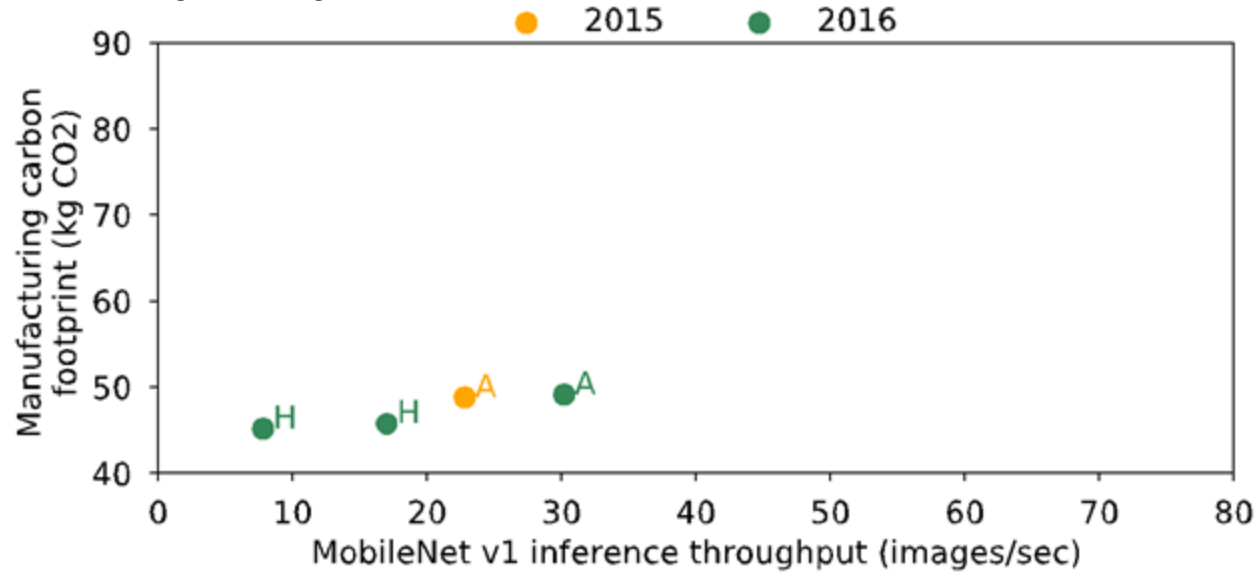


Time	Topic
1:00 – 1:15pm	Welcome to the ACT tutorial!
1:15 – 1:30pm	Motivation: Understanding the source of computing's emissions
<b>1:30 – 2:15pm</b>	<b>Overview of ACT: An Architectural Carbon Modeling Tool</b>
2:15 – 2:45pm	Hands-on ACT demo's
2:45 – 3:00pm	Extending ACT
3:00 – 3:30pm	Coffee break

# Performance versus manufacturing footprint

Data from industry (Apple, Google, Huawei) life cycle analyses and GeekBench performance measurements

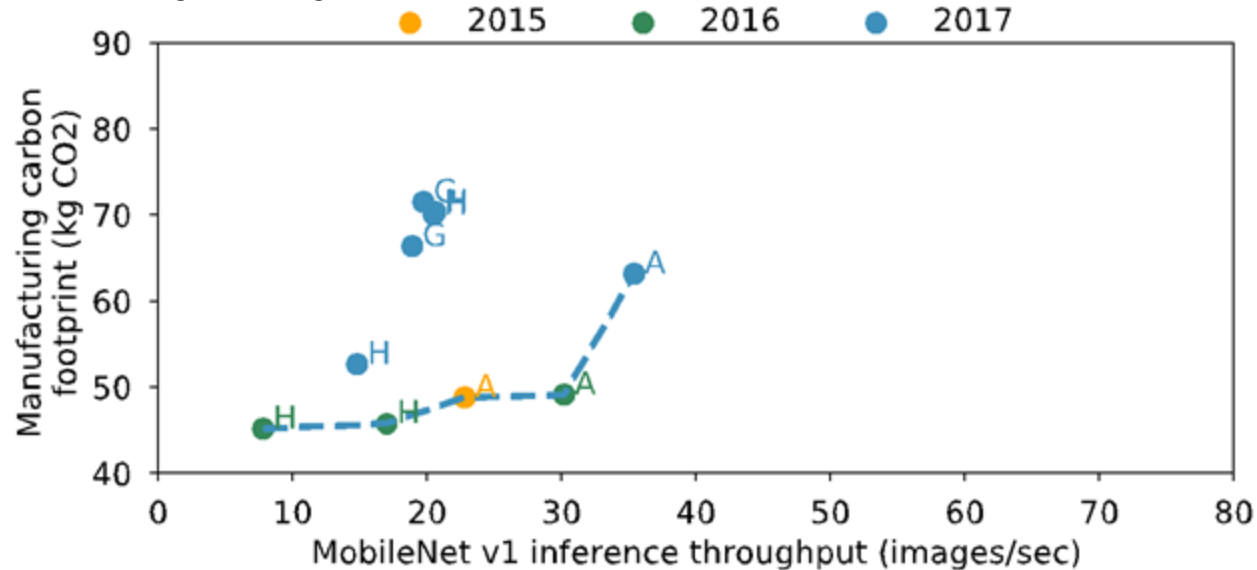
<https://www.geekbench.com/blog/2019/09/geekbench-5/>



# Performance versus manufacturing footprint

Data from industry (Apple, Google, Huawei) life cycle analyses and GeekBench performance measurements

<https://www.geekbench.com/blog/2019/09/geekbench-5/>

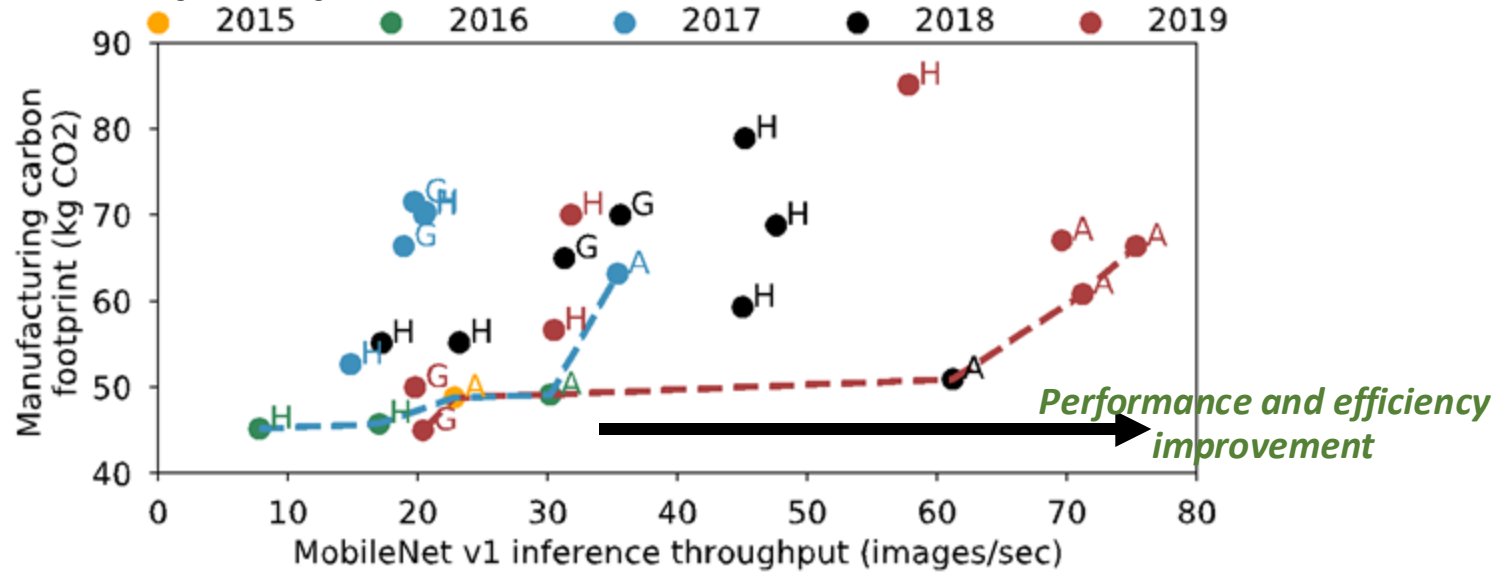




# Performance versus manufacturing footprint

Data from industry (Apple, Google, Huawei) life cycle analyses and GeekBench performance measurements

<https://www.geekbench.com/blog/2019/09/geekbench-5/>



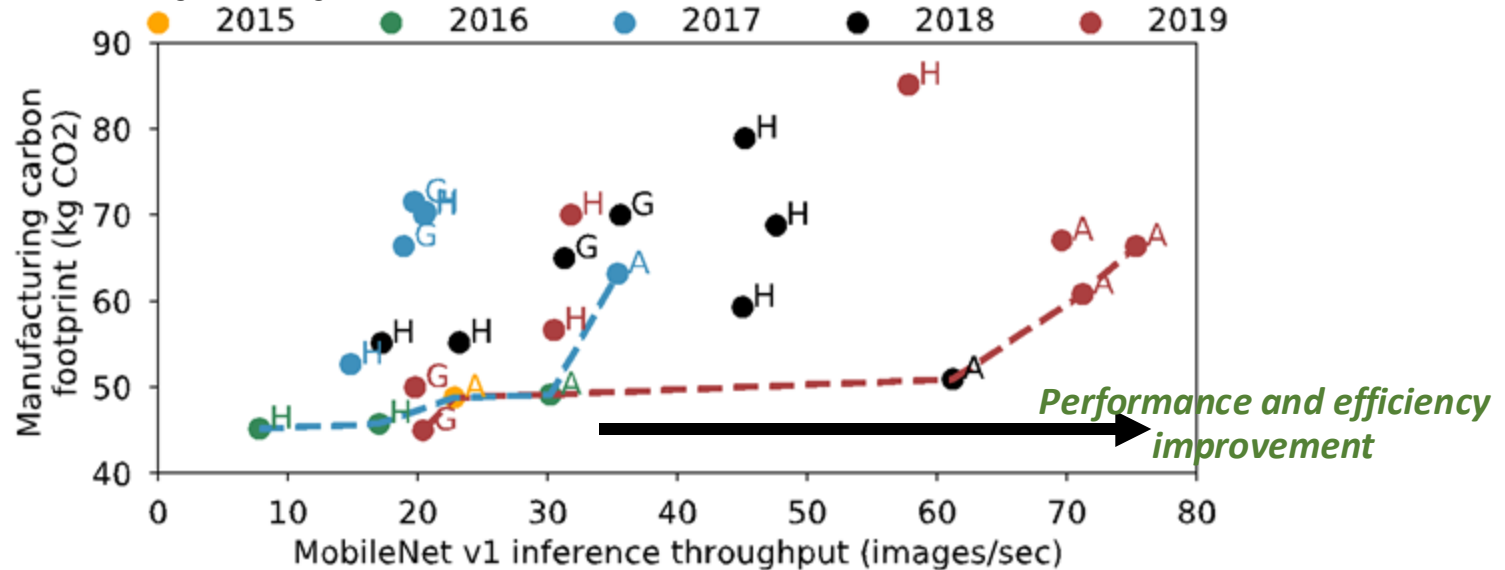
Between 2017 and 2019 the Pareto frontier has shifted to the right prioritizing performance.

Designing sustainable systems requires shifting the frontier down.

# Performance versus manufacturing footprint

Data from industry (Apple, Google, Huawei) life cycle analyses and GeekBench performance measurements

<https://www.geekbench.com/blog/2019/09/geekbench-5/>



Between 2017 and 2019 the Pareto frontier has shifted to the right prioritizing performance.

Designing sustainable systems requires shifting the frontier down.