Sustainability Days 2021
EcoCloud research center, EPFL

Chasing Carbon

Toward a Responsible, Sustainable Ecosystem for Computing

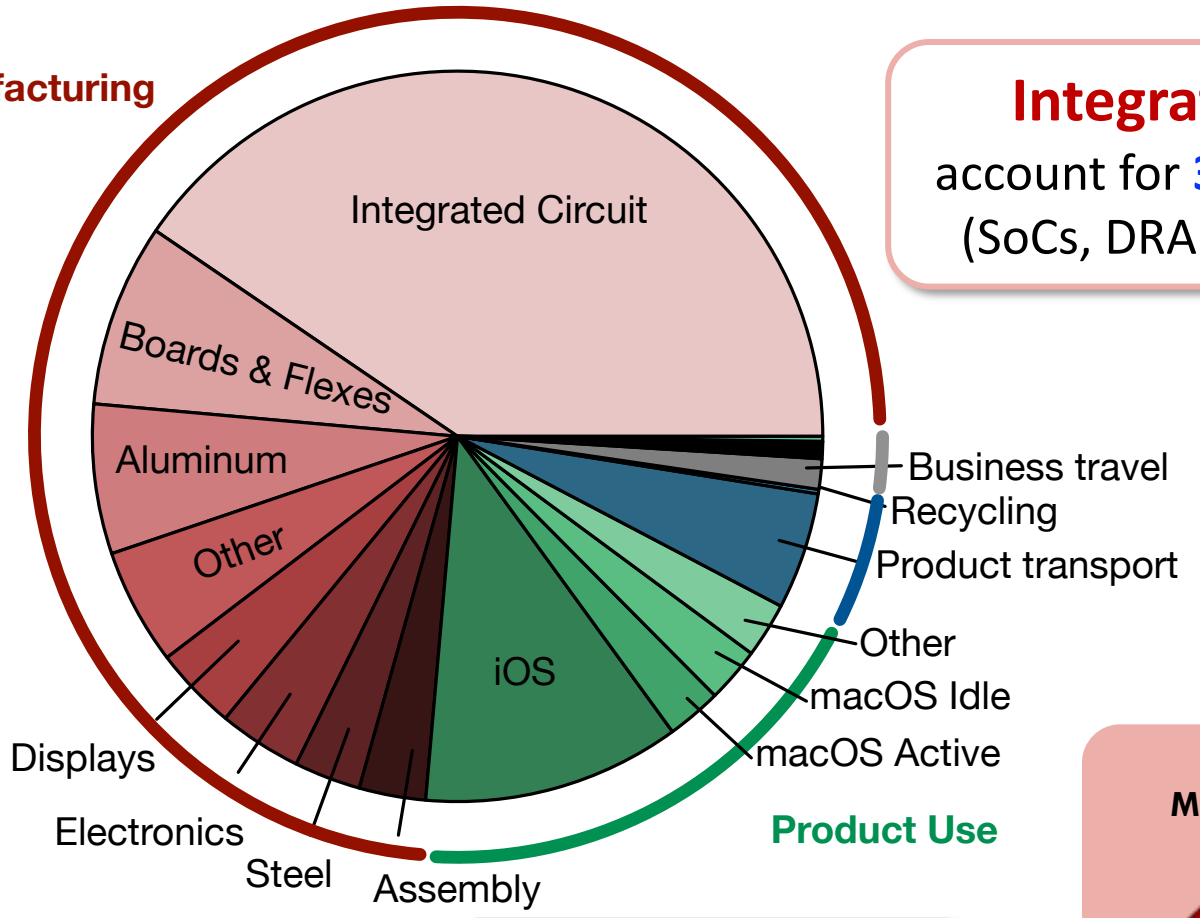
Hsien-Hsin Sean Lee
Facebook AI Research

FACEBOOK AI

Apple's Aggregated End-to-End Carbon Footprint Breakdown

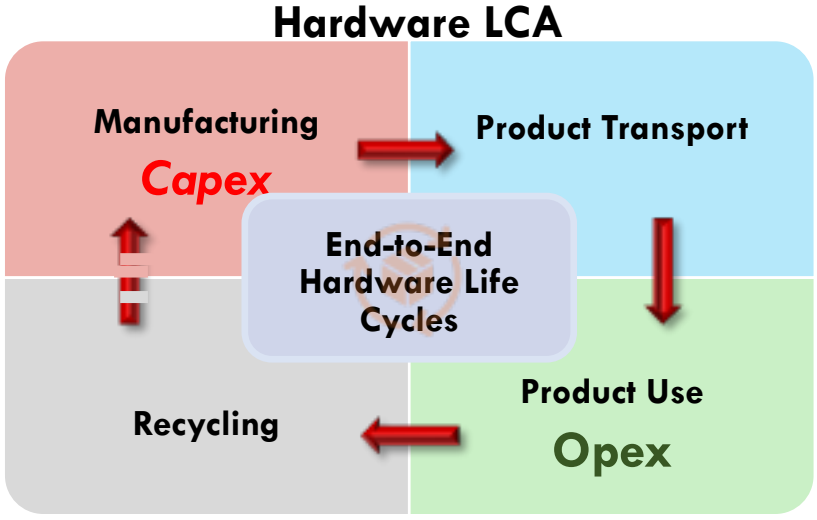
iPhone, iPad, Apple Watch, Mac, etc.

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



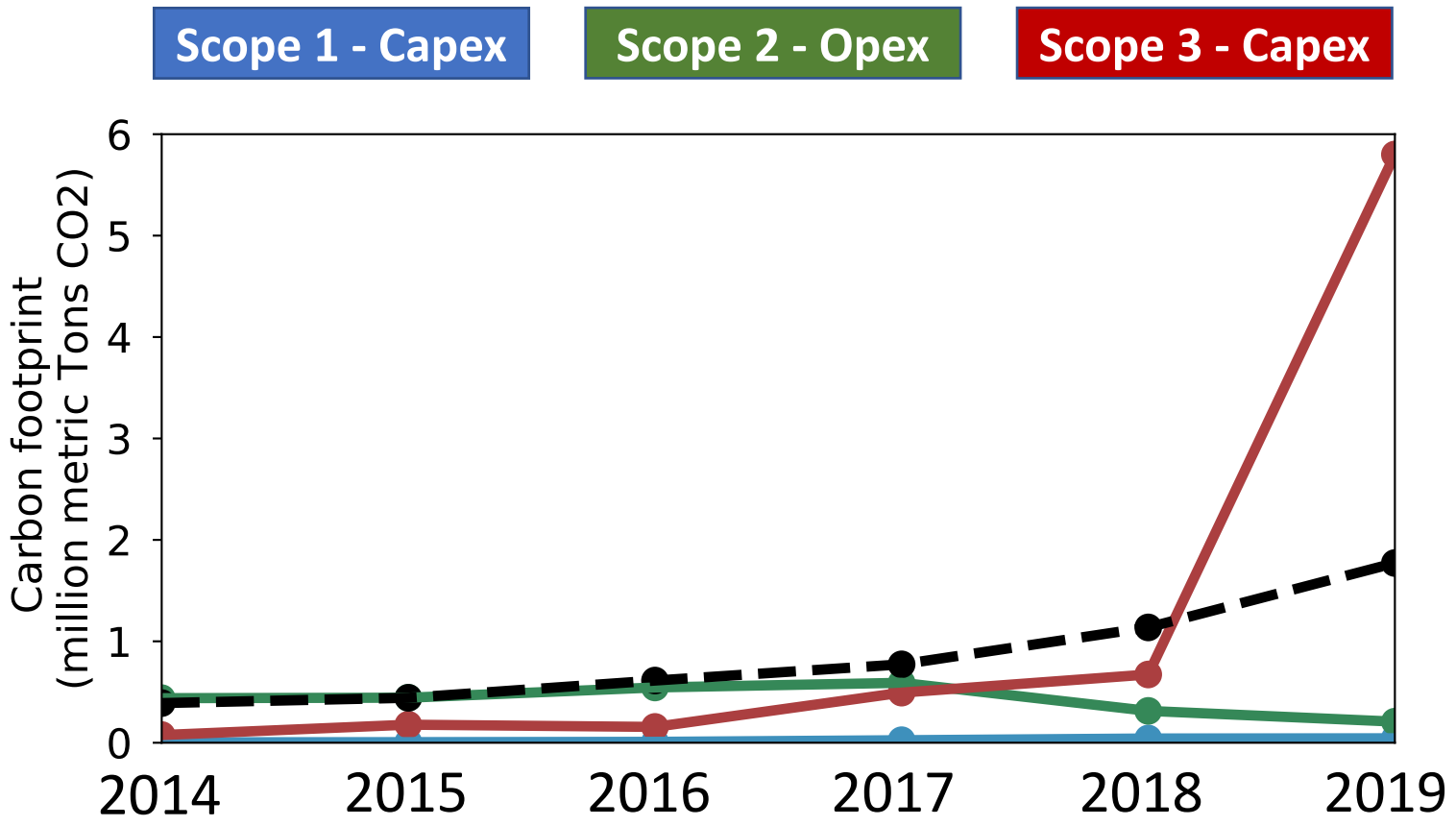
Integrated circuits
account for **33%** of emissions (SoCs, DRAM, NAND Flash)

Product Use
accounts for **19%** of emissions



[HPCA 2021] U. Gupta et al., "Chasing Carbon: the Elusive Environmental Footprint of Computing"

Facebook Datacenters' Carbon Footprint



Greenhouse Gas (GHG) Protocol

Scope 1 (Capex)
- Direct emission from facilities
- Diesel, gas, refrigerant
- Transport owned by Facebook

Scope 2 (Opex)
- Operation-related emission
- Emissions from electricity & heat

Scope 3 (Capex)
- Hardware and racks
- Data center construction
- Purchased Goods, Business travel
- Transportation and distribution

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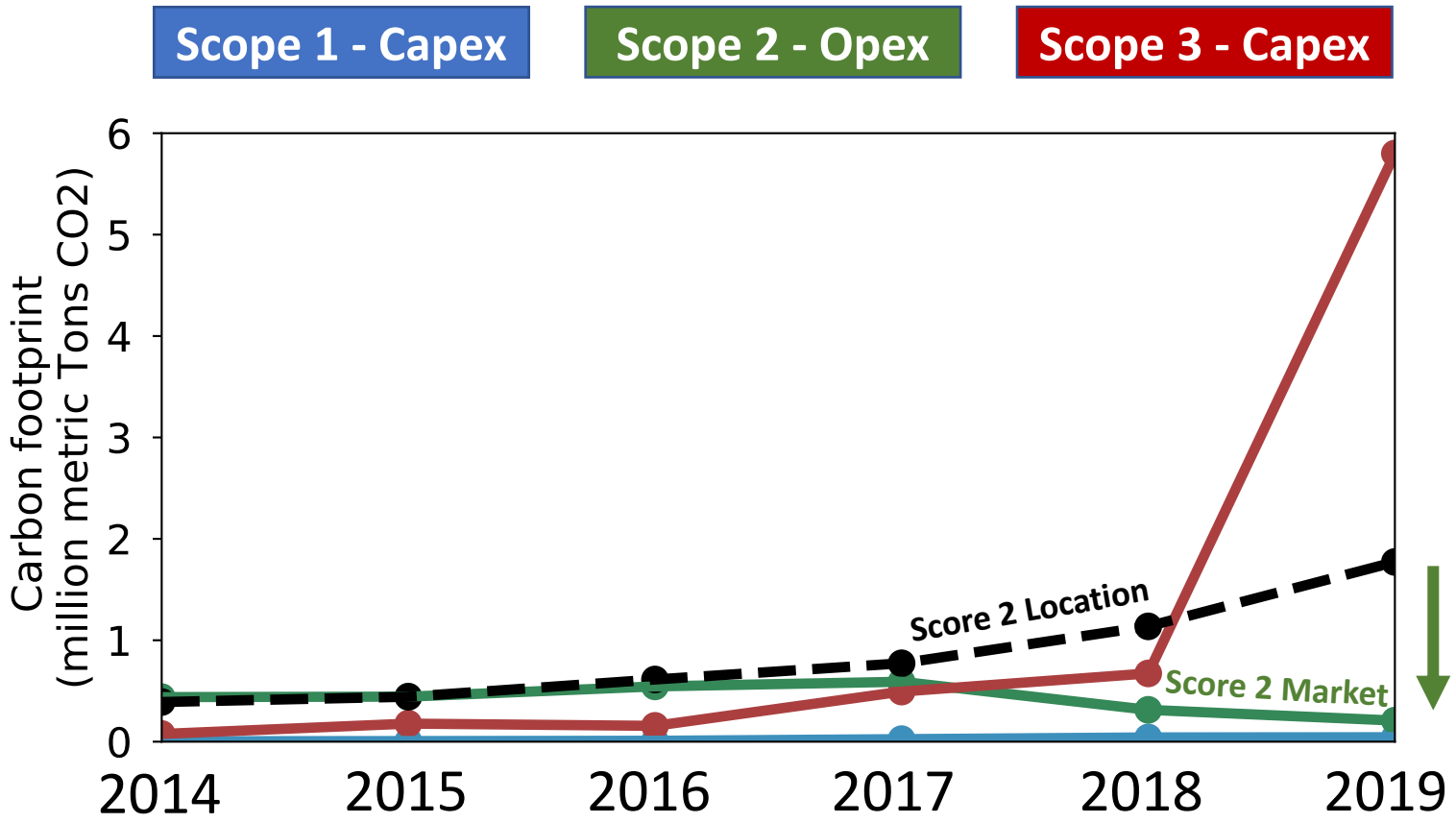
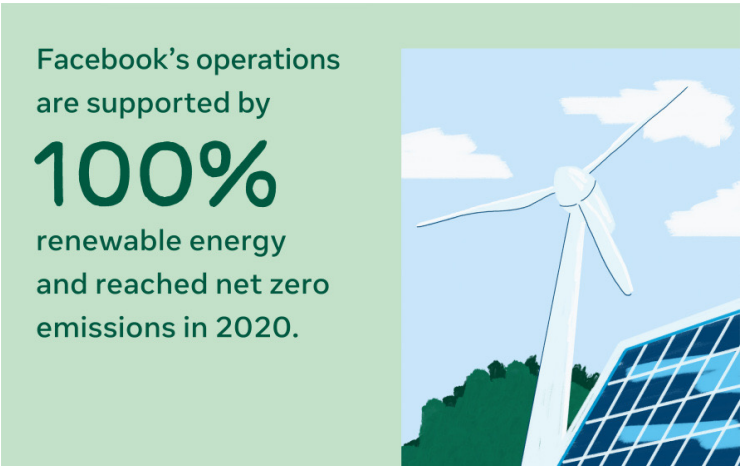
Facebook Datacenters' Carbon Footprint



Impact of purchasing renewable energy



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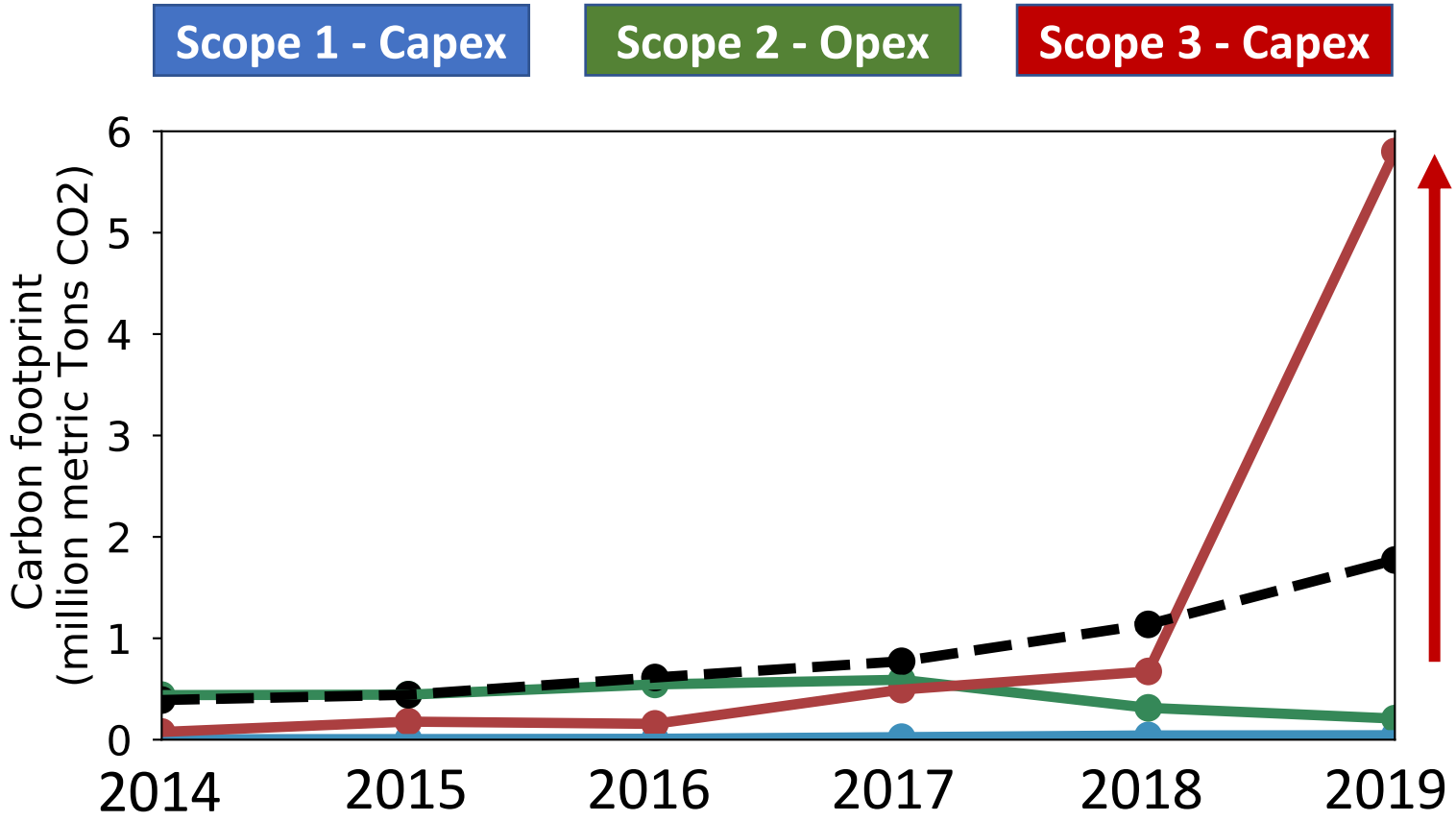

- Scope 3 (capex) dominates Facebook's carbon emissions.
- **49%** of Scope 3 come from HW manufacturing, infrastructure and data center construction

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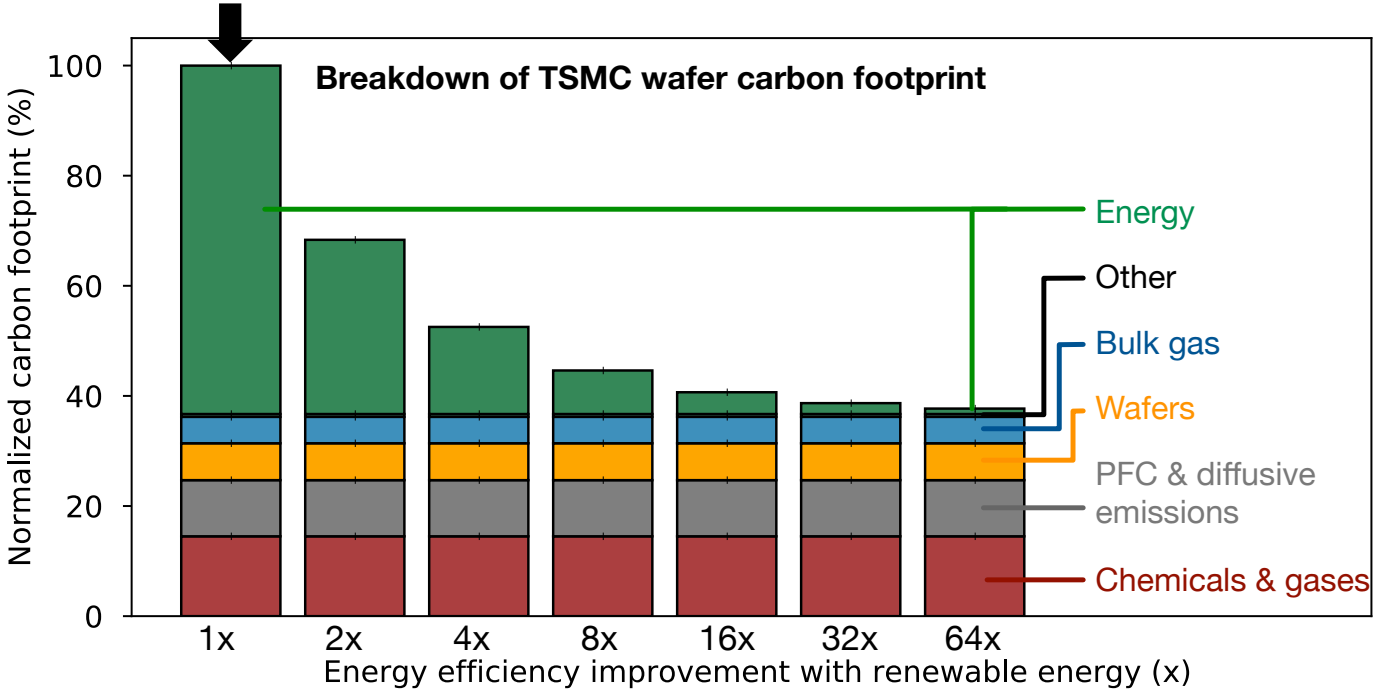
Semiconductor Manufacturing

TSMC

Leftmost bar from TSMC Corporate Social Responsibility Report, 2018



** TSMC 5nm fab in Tainan Science Park

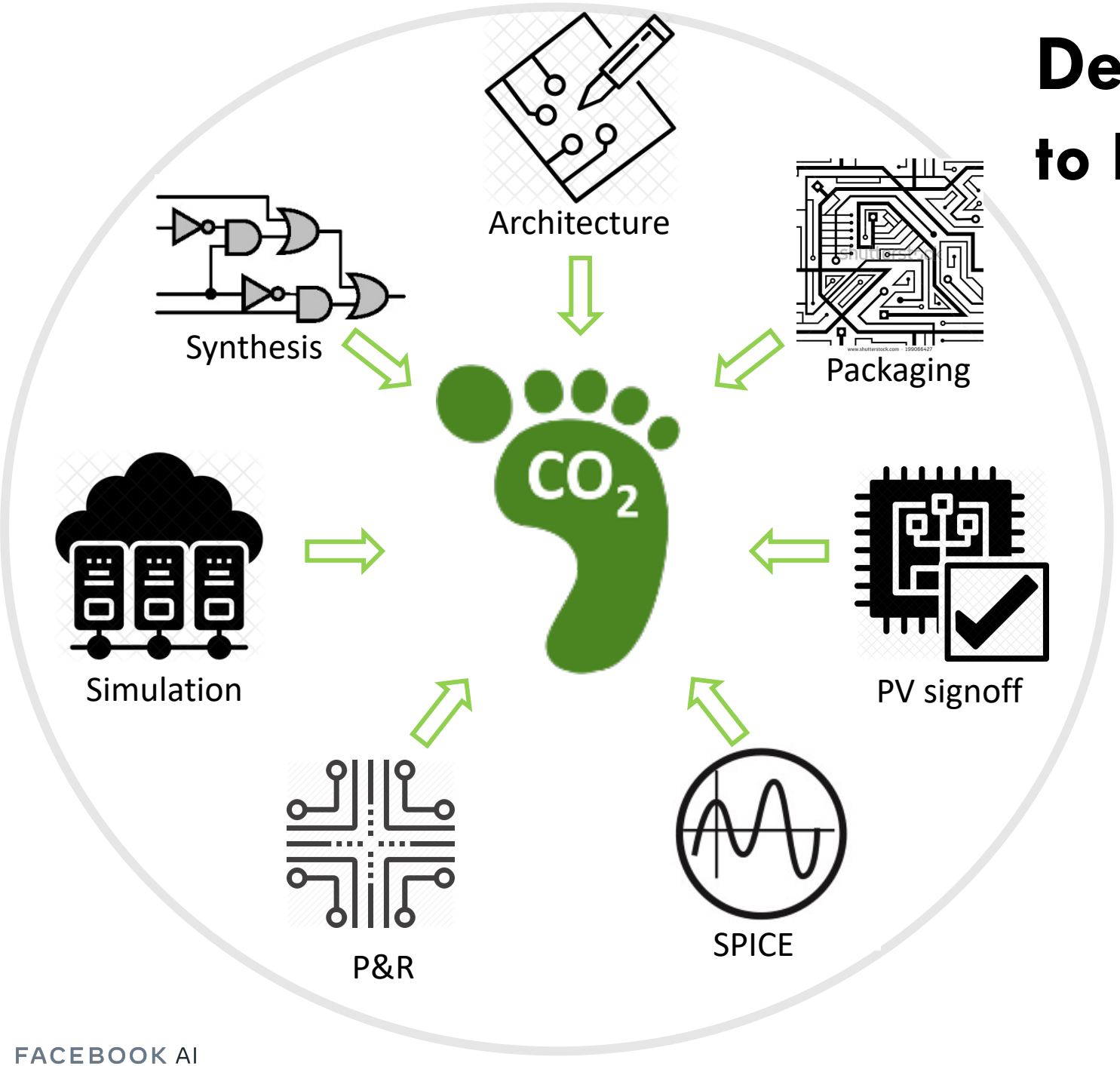
TSMC fab operation

- 5nm: 720MW = 6.3 billion kWh annually
- **3nm**: 880MW = **7.7 billion kWh** annually
- 3nm = ~730,000 household consumption

Carbon footprint of TSMC's wafer manufacturing process

- **63%** comes from energy consumption which renewable energy can reduce
- By 2025, TSMC plans to power **20%** of the electricity using renewable energy to drive upcoming 3nm fab.

Design Methodology to Include Carbon Footprint



- IC and packaging tools
- Report Opex for
  - Design tools themselves
  - Chip functional operations
- Report Capex for fabrication
- **PPA + Carbon = Low-Carb PPA**

Carbon-aware Resource Provisioning
e.g., Exploiting (EDA) Cloud Heterogeneity

Google Cloud Platform

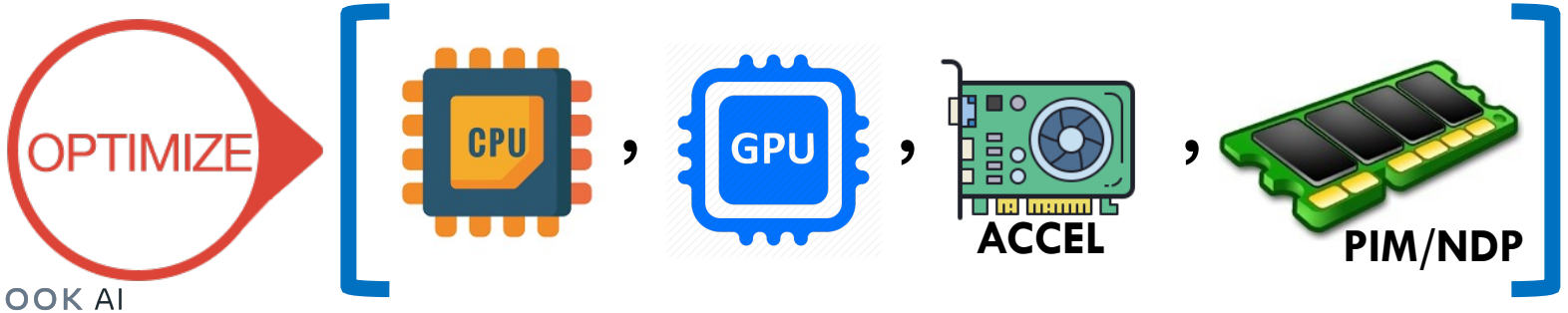
Region	Country	City	Estimated gCO2e/kWh)
asia-east1	Taiwan	Changhua County	557
asia-east2	China	Hong Kong	702
asia-northeast1	Japan	Tokyo	516
asia-northeast2	Japan	Osaka	516
asia-south1	India	Mumbai	920
asia-southeast1	Singapore	Jurong West	419
australia-southeast1	Australia	Sydney	802
europe-north1	Finland	Hamina	211
europe-west1	Belgium	St. Ghislain	267
europe-west2	United Kingdom	London	623
europe-west3	Germany	Frankfurt	615
europe-west4	Netherlands	Eemshaven	569
europe-west6	Switzerland	Zürich	16
northamerica-northeast1	Canada	Montréal	20
southamerica-east1	Brazil	São Paulo	205
us-central1	USA	Council Bluffs	566.3
us-east1	USA	Moncks Corner	367.8
us-east4	USA	Ashburn	367.8
us-west1	USA	The Dalles	297.6
us-west2	USA	Los Angeles	240.6

Amazon Web Services

Region	Country	City	gCO2e/kWh
us-east-2	USA	Columbus	568.2
us-east-1	USA	Ashburn	367.8
us-west-1	USA	San Francisco	240.6
us-west-2	USA	Portland	297.6
ap-east-1	China	Hong Kong	702
ap-south-1	India	Mumbai	920
ap-northeast-3	Japan	Osaka	516
ap-northeast-2	South Korea	Seoul	517
ap-southeast-1	Singapore	Singapore	419
ap-southeast-2	Australia	Sydney	802
ap-northeast-1	Japan	Tokyo	516
ca-central-1	Canada	Montreal	20
cn-north-1	China	Beijing	680
cn-northwest-1	China	Zhongwei	680
eu-central-1	Germany	Frankfurt am Main	615
eu-west-1	Ireland	Dublin	617
eu-west-2	United Kingdom	London	623
eu-west-3	France	Paris	105
eu-north-1	Sweden	Stockholm	47
sa-east-1	Brazil	Sao Paulo	205
us-gov-east-1	USA	Dublin	568.2
us-gov-west-1	USA	Seattle	297.6

Microsoft Azure

Region	Country	City	gCO2e/kWh
eastasia	Hong Kong	Wan Chai	702
southeastasia	Singapore	Singapore	419
centralus	USA	Des Moines	736.6
eastus	USA	Blue Ridge	367.8
eastus2	USA	Boydton	367.8
westus	USA	San Francisco	240.6
northcentralus	USA	Chicago	568.2
southcentralus	USA	San Antonio	460.4
northeurope	Ireland	Dublin	617
westeurope	Netherlands	Amsterdam	569
japanwest	Japan	Osaka-shi	516
japaneast	Japan	Tokyo	516
brazilsouth	Brazil	Sao Paulo	205
australiaeast	Australia	Sydney	802
australiasoutheast	Australia	Melbourne	805
southindia	India	Pallavaram	920
centralindia	India	Lohogaon	920
westindia	India	Mumbai	920
canadacentral	Canada	Toronto	69.3
canadaeast	Canada	Quebec	20
uksouth	United Kingdom	Midhurst	623
ukwest	United Kingdom	Wallasey	623
westcentralus	USA	Mountain View	297.6
westus2	USA	Quincy	297.6
koreacentral	South Korea	Seoul	517
koreasouth	South Korea	Busan	517
francecentral	France	Huriel	105
francesouth	France	Realmont	105
australiacentral	Australia	Forrest	900
australiacentral2	Australia	Forrest	900
southafricanorth	South Africa	Pretoria	1009
southafricawest	South Africa	Stellenbosch	1009



Disruptive Energy-Efficient Technologies

Deep Learning with Coherent Nanophotonic Circuits

Yichen Shen[1*], Nicholas C. Harris[1*], Scott Skirlo[1], Mihika Prabhu[1], Tom Baehr-Jones[2], Michael Hochberg[2], Xin Sun[3], Shijie Zhao[4], Hugo Larochelle[5], Dirk Englund[1], and Marin Soljačić[1]

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[*] ***These authors contributed equally to this work.***

Artificial Neural Networks are computational network models inspired by signal processing in the brain. These models have dramatically improved the performance of many learning tasks, including speech and object recognition. However, today's computing hardware is inefficient at implementing neural networks, in large part because much of it was designed for von Neumann computing schemes. Significant effort has been made to develop electronic architectures tuned to implement artificial neural networks that improve upon both computational speed and energy efficiency. Here, we propose a new architecture for a fully-optical neural network that, using unique advantages of optics, promises a computational speed enhancement of at least two orders of magnitude over the state-of-the-art and three orders of magnitude in power efficiency for conventional learning tasks. We experimentally demonstrate essential parts of our architecture using a programmable nanophotonic processor.

In Nature Photonics

LIGHTMATTER

LIGHTELLIGECE

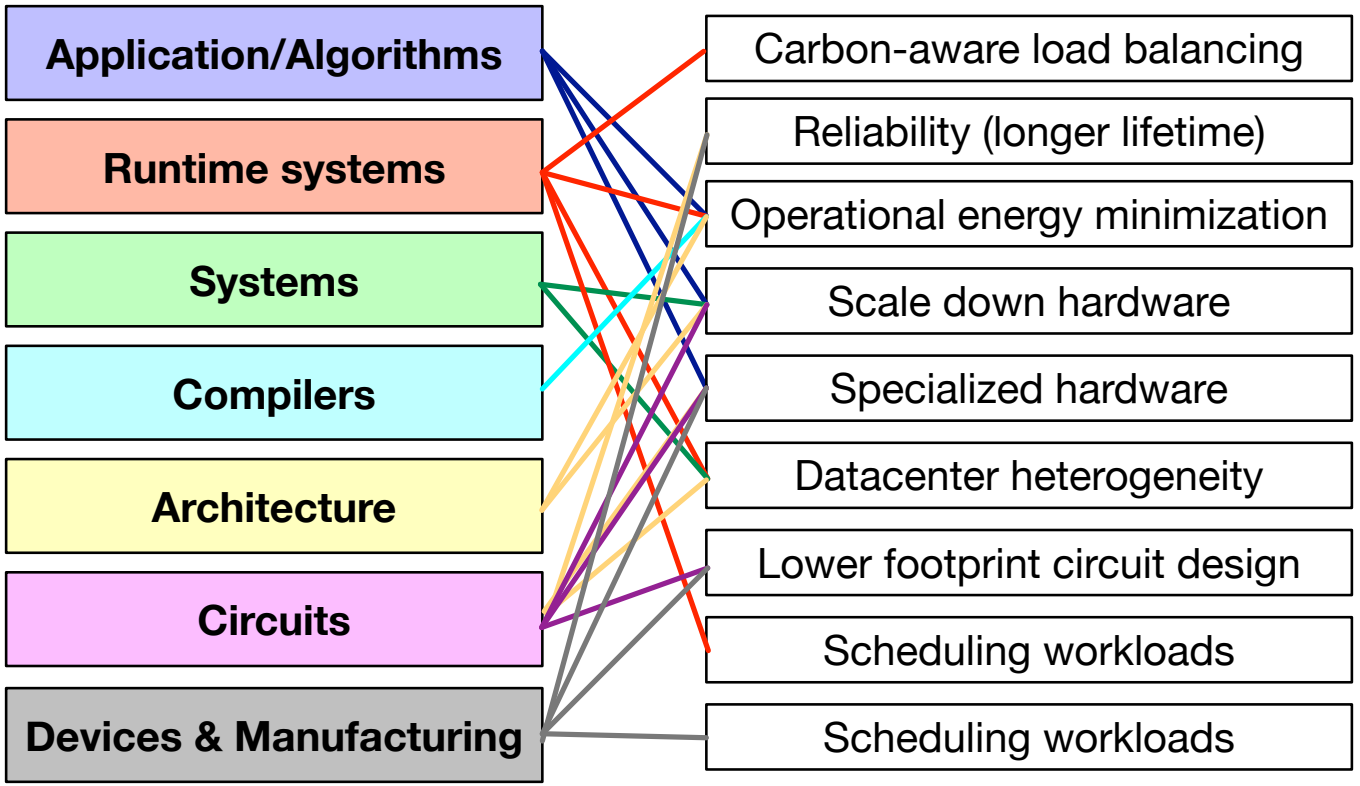
LIGHTON

OPTALYSUS

FATHOM COMPUTING

- 10,000x improvement in latency for **matrix multiply**
- Energy at the atto-joule level (10^{-18})
- 5G will enable more offloading to datacenters
- Eco-friendly, speaking of carbon footprint

Looking Ahead



Addressing computing's carbon footprint requires **cross-layer optimizations** across the computing stack.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