APPLIED MATERIALS®
make possible

THE A.I. PARADOX

Biggest Opportunities and Challenges of our Lifetimes

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PRESIDENT AND CEO
APPLIED MATERIALS, INC.

A.I. Design Forum | July 9, 2019

EXTERNAL USE

PHOTO : https://commons.wikimedia.org/wiki/File:San_Francisco_Bay_Bridge_Western_Span_at_night.jpg

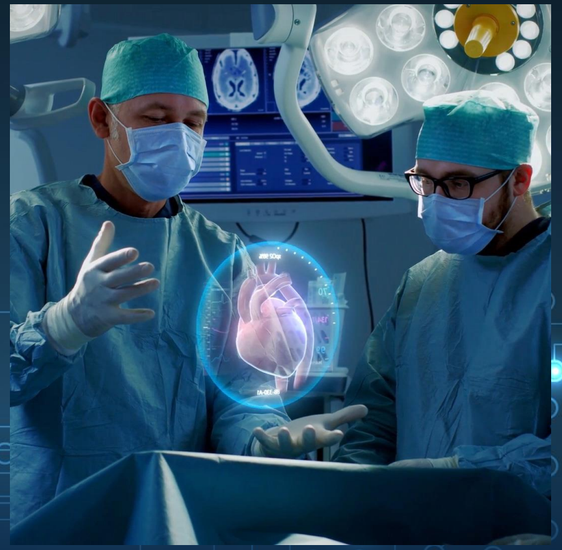
Forward-Looking Statements

This presentation contains forward-looking statements, including those regarding anticipated growth and trends in Applied’s businesses and markets, industry outlooks, technology transitions, and other statements that are not historical facts. These statements are subject to risks and uncertainties that could cause actual results to differ materially from those expressed or implied by such statements and are not guarantees of future performance. Information concerning these risks and uncertainties is contained in Applied’s most recent Form 10-Q and 8-K filings with the SEC. All forward-looking statements are based on management's current estimates, projections and assumptions, and Applied assumes no obligation to update them.

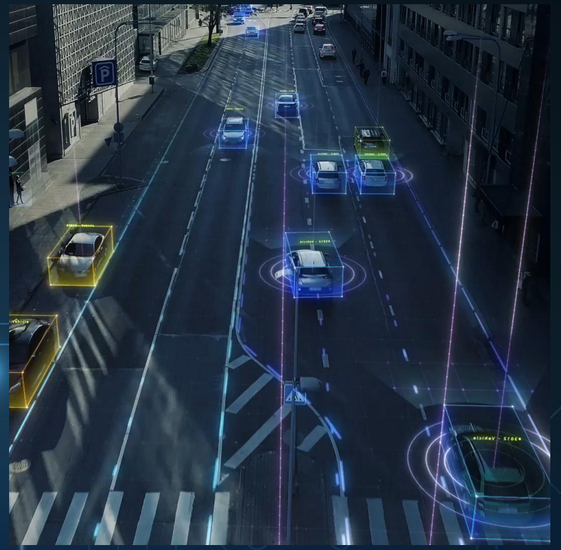
AGRICULTURE

EDUCATION

HEALTHCARE



TRANSPORTATION



“In the future, **every business** will be in the **technology business**”

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RATE OF
A.I. ADOPTION
DETERMINED BY

- **S**peed of innovation
- **S**ociety's acceptance
- **S**ecurity and safety
- **S**ustainability

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EDGE DEVICE
Compute + Storage

CLOUD DATACENTER
Compute + Storage

Compute and store at EDGE vs. CLOUD determined by 3 “laws”

1. Law of **the land**
2. Law of **physics**
3. Law of **economics**

Source: AWS

500B TO 1T

Connected devices by 2030

SOURCE: CISCO

Connected devices by 2030

SOURCE: ARM

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1 GB
PER DAY
4,000 GB
PER DAY
Source: Intel, Waymo
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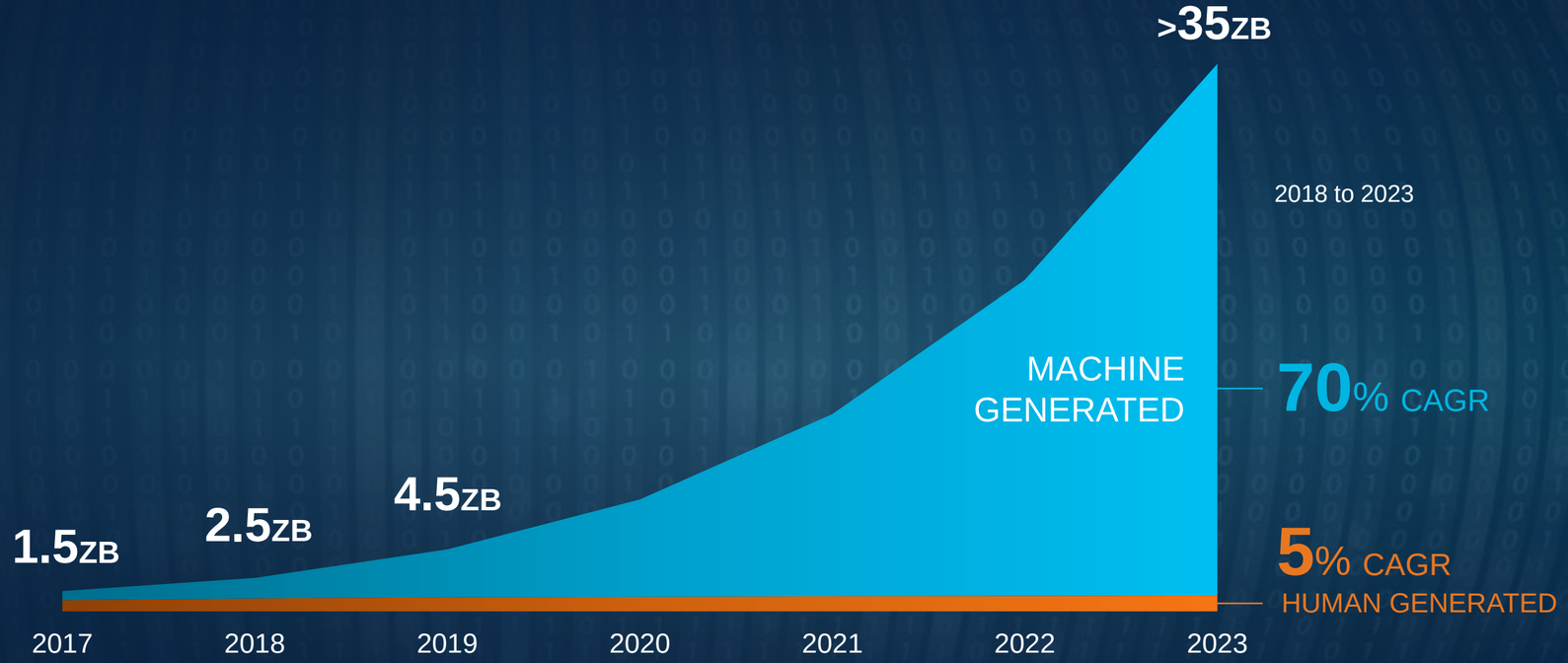
EXPLOSION OF DATA GENERATION



SOURCE: Applied Materials model based on forecasts published by Cisco, Intel, Western Digital

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GENERAL PURPOSE COMPUTING (GOOD AT MANY THINGS)	A.I. COMPUTING (CUSTOMIZED FOR SPECIALIZED TASKS)
Multi-level on-die cache architecture	**High Speed Memories** To improve memory latency and memory to logic bandwidth
Deep instruction pipeline, out-of-order execution, branch prediction, pre-fetching, …	**Extreme Parallelism** Simple operations on multiple chunks of data in parallel
64 bit or higher precision data paths	**Lower Precision** Training and inference at lower floating point (16 bit) and integer (8 bit) precision

New Computing Approaches Needed to Unlock Value of Data Explosion

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FASTEST GROWING A.I. WORKLOADS ARE VISUAL

	VISUAL	AUDIO	TEXT / NUMERIC
Examples	IP / Security cameras Autonomous vehicles Robotics	Voice assistants Wearables Call Centers	Search optimization Advertising Business intelligence
Neural Network (NN) Type	Convolutional NN (CNN)	Recurrent NN (RNN) or CNN	Multilayer Perceptron (MLP)
% of total NN use today	10%	25%	65%
% of total NN use 2025	45%	15%	40%

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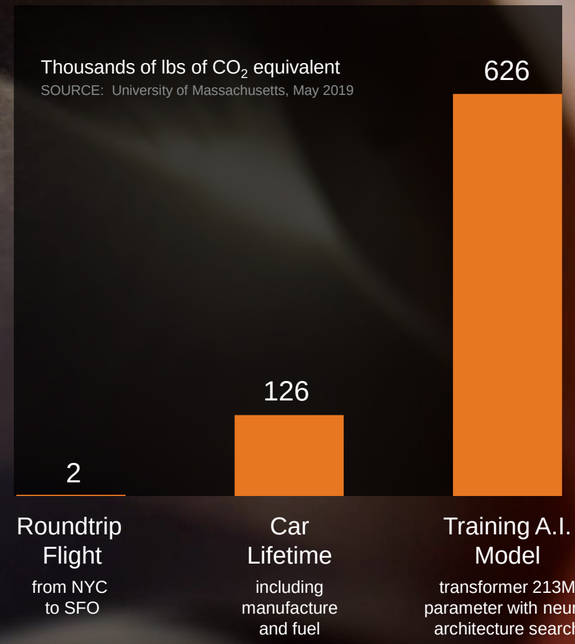
“Training a single A.I. model can emit as much carbon as five cars in their lifetimes”

MIT TECHNOLOGY REVIEW, JUNE 2019



Energy Consumption Could Become a Key Constraint to Growth of A.I.

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SHEER NUMBER OF EDGE DEVICES CAN CHANGE WORLD'S ENERGY EQUATION

5 to 8 WATTS
PER UNIT x
500M UNITS

12TWh

TYPICAL U.S.
POWER PLANT

10TWh

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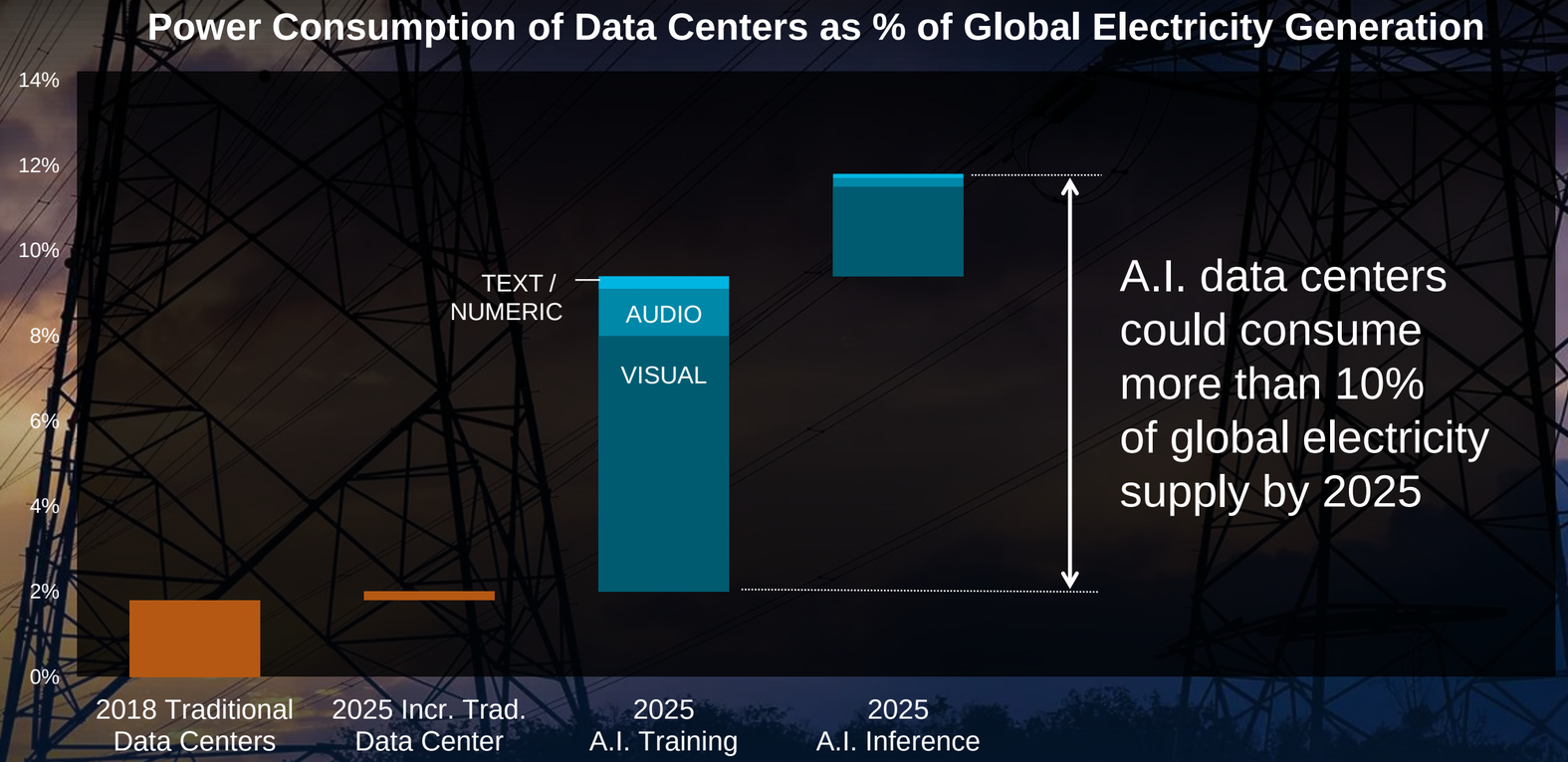
IMPACT OF SCALING THE CLOUD IS EVEN MORE SIGNIFICANT



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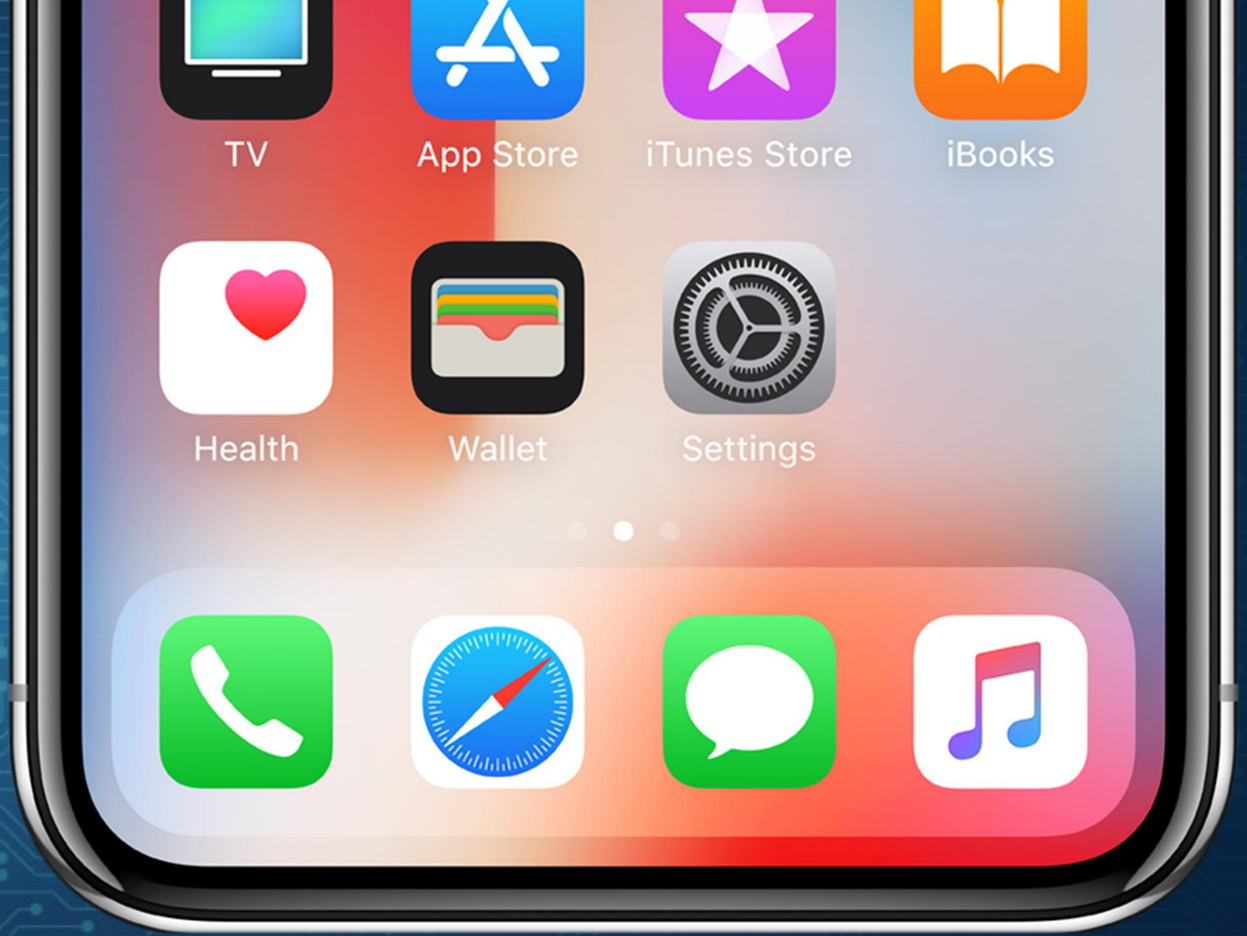
IF BUILT USING TECHNOLOGY

from 1980s…

14 Meters

600kW

$100M



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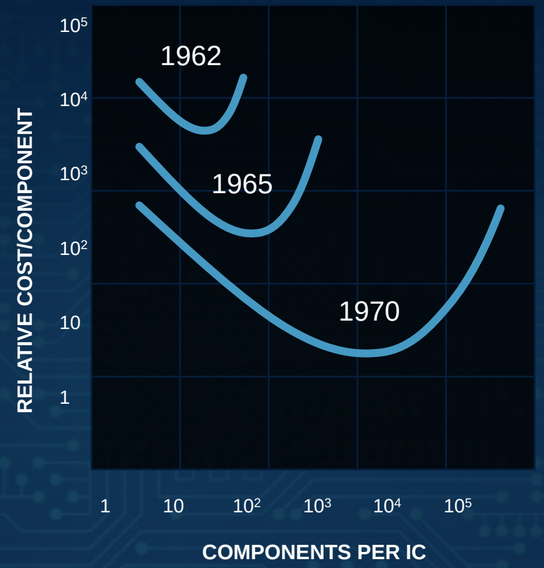
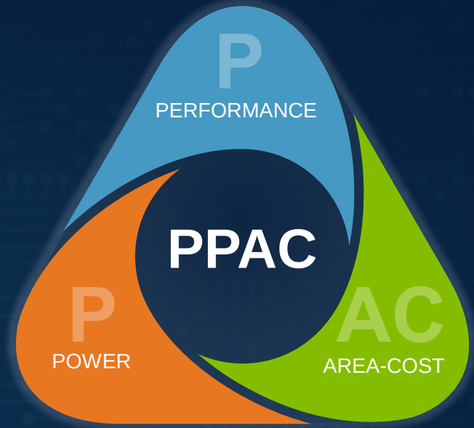
FOR

40 YEARS

MOORE'S LAW



IMPROVEMENTS IN…



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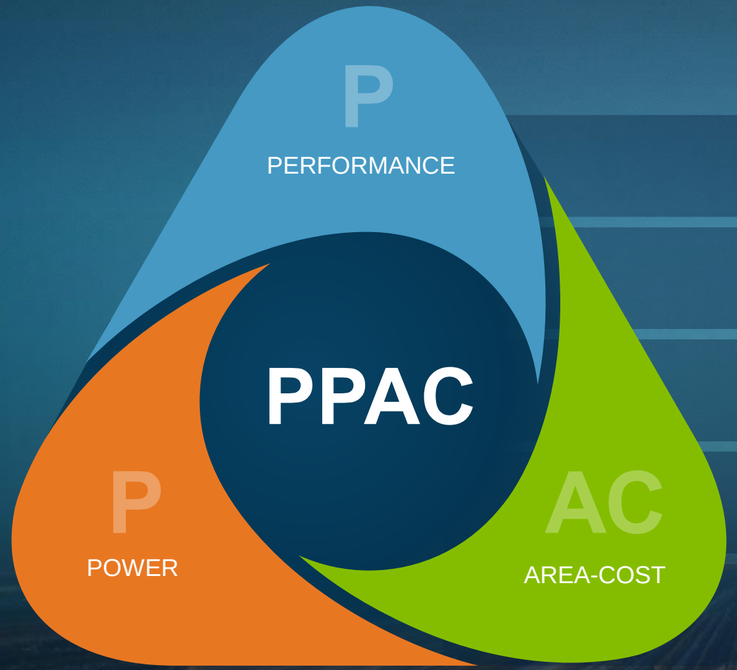

ENABLED BY

New **architectures**

New **structures / 3D**

New **materials**

New ways to **shrink**

Advanced **packaging**

A New Playbook for Semiconductor Design and Manufacturing is Needed

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Major advances at edge and in cloud needed
to realize potential of A.I. without impacting world's energy equation

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	INITIAL DEPLOYMENT	CLOUD	EDGE
Accelerators GPU, TPU, ASICS, FPGAs	Now	✓	Autos
Near Memory DDR, SRAM, HBM, NAND, SCM	Now to 2 years	✓	✓
New Memory MRAM, ReRAM, PCRAM, FeRAM	Now to 5 years	✓ ←	✓
In-Memory Compute Analog, ReRAM, PCRAM	2 to 5 years	✓ ←	✓
Novel HPC Quantum, Synaptic	5 to 10 years	✓ →	✓

Promising Pipeline of New Hardware Innovations

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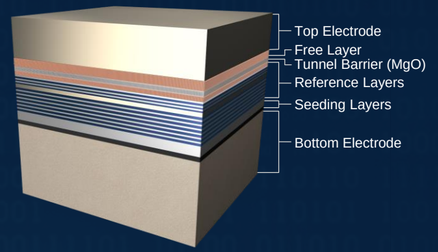
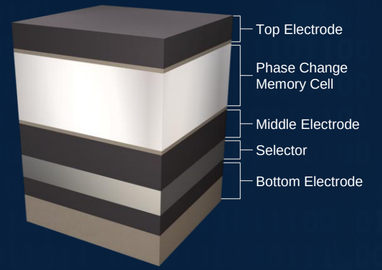
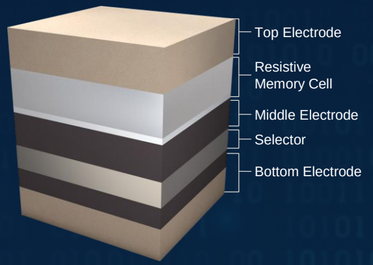
ENABLING ROADMAP REQUIRES NEW APPROACHES TO MANUFACTURING







	MRAM Magnetic RAM	**PCRAM** Phase Change RAM	**ReRAM** Resistive RAM
INITIAL DEPLOYMENT	Edge	Cloud	
KEY ATTRIBUTES	✓ Extremely fast (as fast as L3 cache) ✓ High density (one transistor per cell) ✓ Non-volatile	✓ Faster than NAND ✓ Lower cost than DRAM ✓ Non-volatile ✓ Ideal for storage class memory	
ENABLED BY	New materials, 3D structures, Sub atomic-level precision films		

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Endura® Clover™ MRAM PVD platform

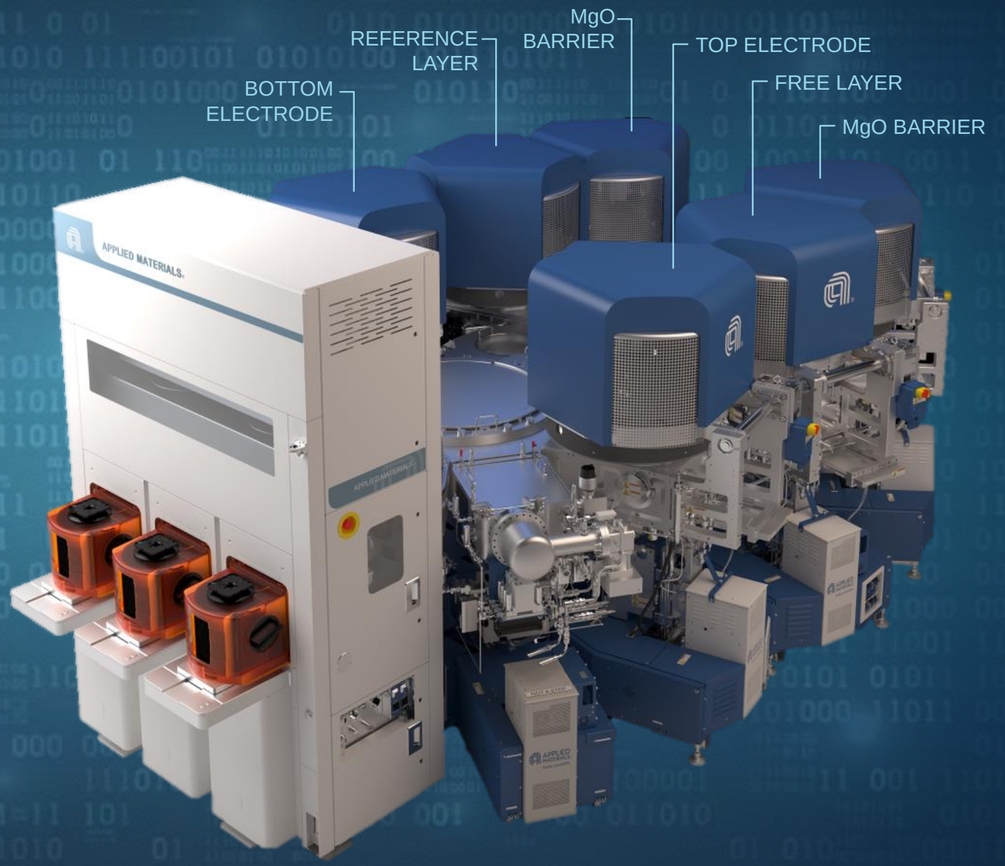
Integrated Materials Solution

9 chambers

Up to 5 materials per chamber

On-board metrology

“Fab inside a fab”



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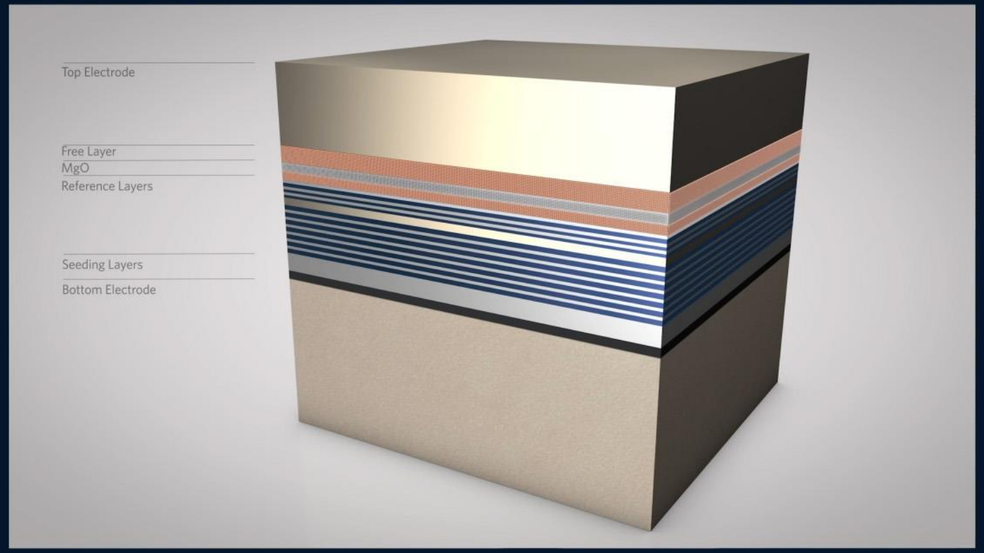

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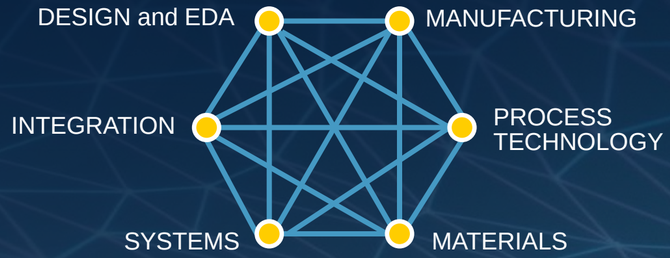
“Von Neumann” mindset vs. “Neuromorphic” mindset

TODAY: Serial / compartmentalized interaction between key parts of ecosystem



OPPORTUNITY: Parallel development to get powerful tools to designers faster

Ecosystem Collaboration is Key to Accelerating A.I. Adoption

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MATERIALS | PROCESS TECHNOLOGY | DEVICES & STRUCTURES | DESIGN | ARCHITECTURE | ALGORITHMS | SYSTEMS

MAYDAN TECHNOLOGY CENTER

State of the art 300mm process technology lab

ADVANCED PACKAGING LAB

Fully integrated 300mm advanced wafer level packaging lab

META CENTER

opening fall 2019

'Lab to fab' accelerator

ADVANCED MATERIALS LAB

Foundational materials engineering R&D

Applied's Collaborative R&D Platform to Accelerate Materials to Systems 10x

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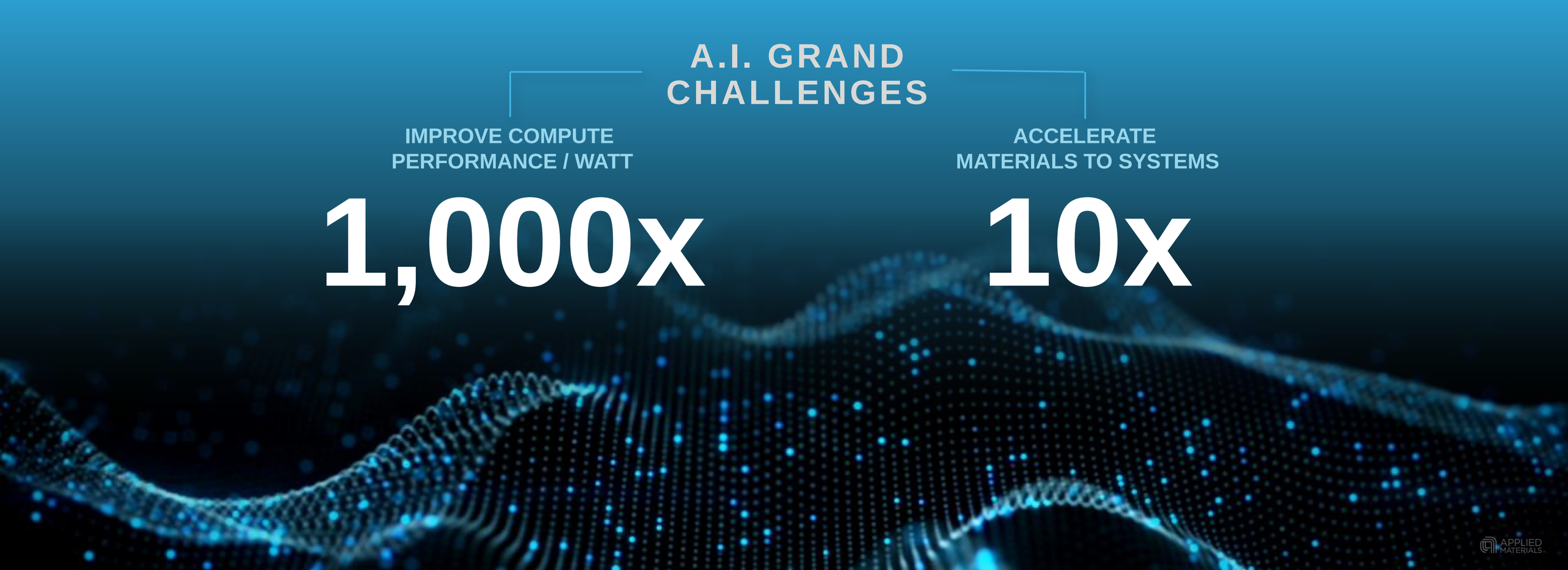
A.I. GRAND CHALLENGES

IMPROVE COMPUTE PERFORMANCE / WATT

1,000x

ACCELERATE MATERIALS TO SYSTEMS

10x