The global semiconductor industry is on the path to $1T in 2030

Global semiconductor market
USD billions

	2021	2030
Automotive	~47	~147
Computing & data storage	~224	~351
Consumer	~52	~95
Industrial	~59	~131
Wired communication	~37	~63
Wireless communication	~172	~280
Total	**~600**	**~1,000**

Growth contribution per vertical
Share of absolute industry growth

Vertical	Share	CAGR 2021-30
Automotive	~20%	13-15%
Computing & data storage	~25%	4-6%
Consumer	~10%	6-8%
Industrial	~15%	8-10%
Wired communication	~5%	5-7%
Wireless communication	~25%	5-7%

PDF/SOLUTIONS™

New paths to innovation: System Scaling... 3D, not smaller... AI at every stage

Sources: [1]Karl Rupp, [2]ASML data and projection using Rupp, [3]Mark Liu, TSMC, normalized to transistor EEP in 2005.
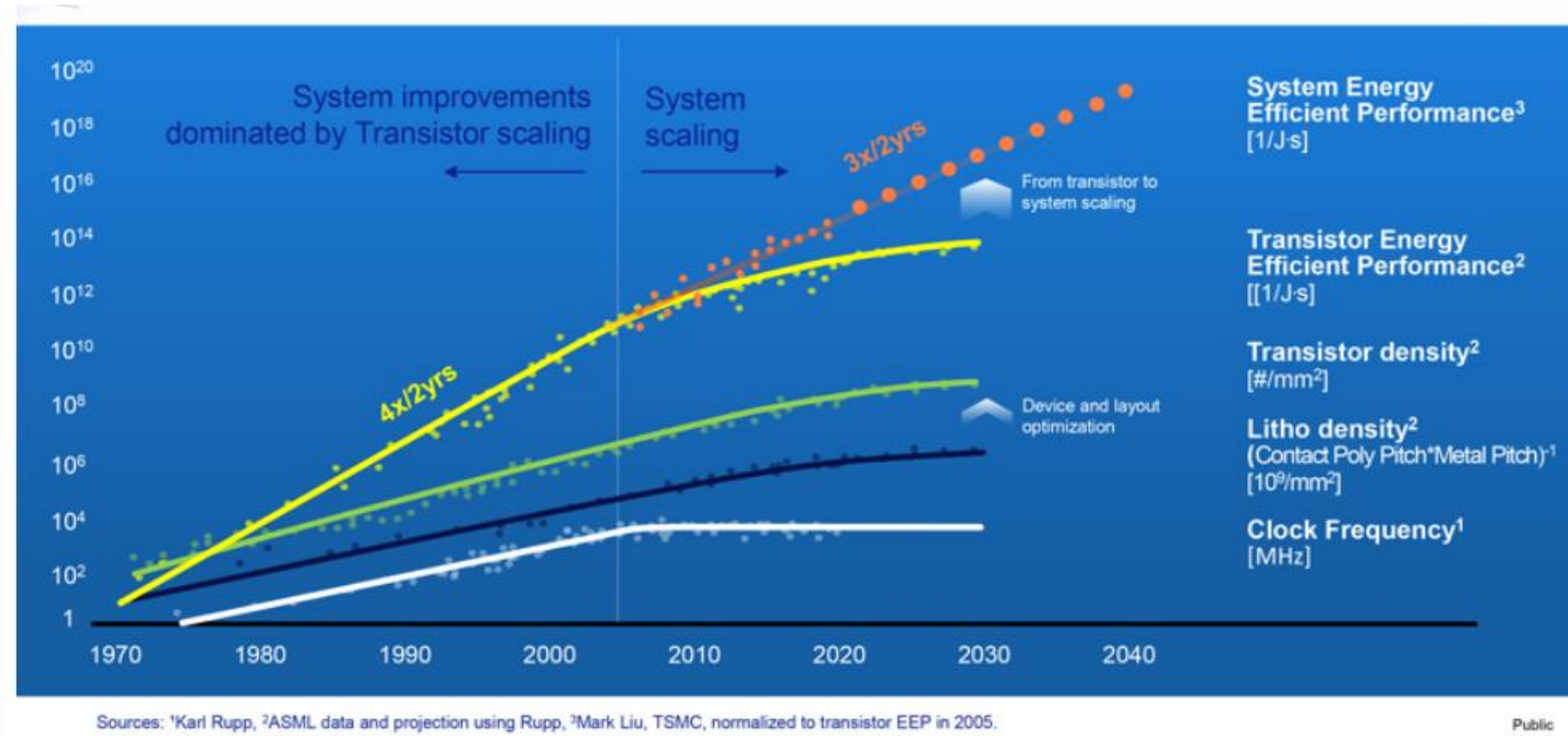
- **Material science & process architecture**

- **Chiplets and complex systems**

- **AI for development and manufacturing**

We are witnessing three important shifts in the industry
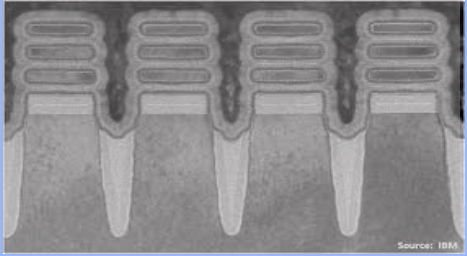
1 **Devices and nodes are changing to new architecture**
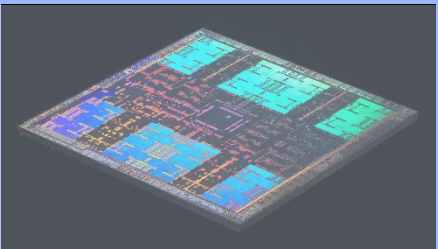
2 **Systems in package require changing test and assembly landscape**

3 **Transitioning from geographically concentrated to globally distributed industry**

More complex devices require advanced characterization capabilities
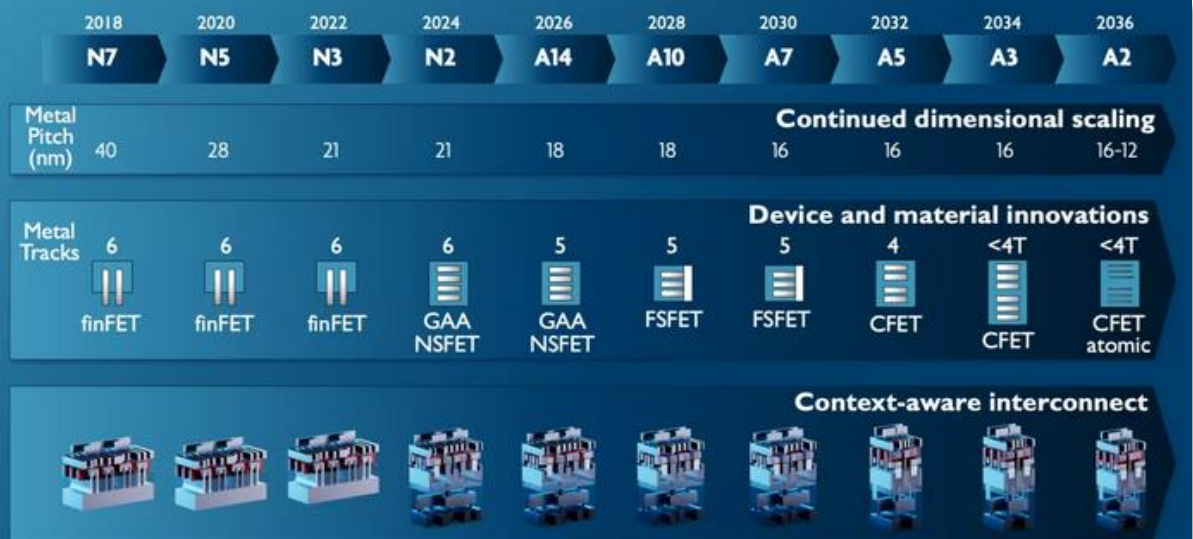
imec
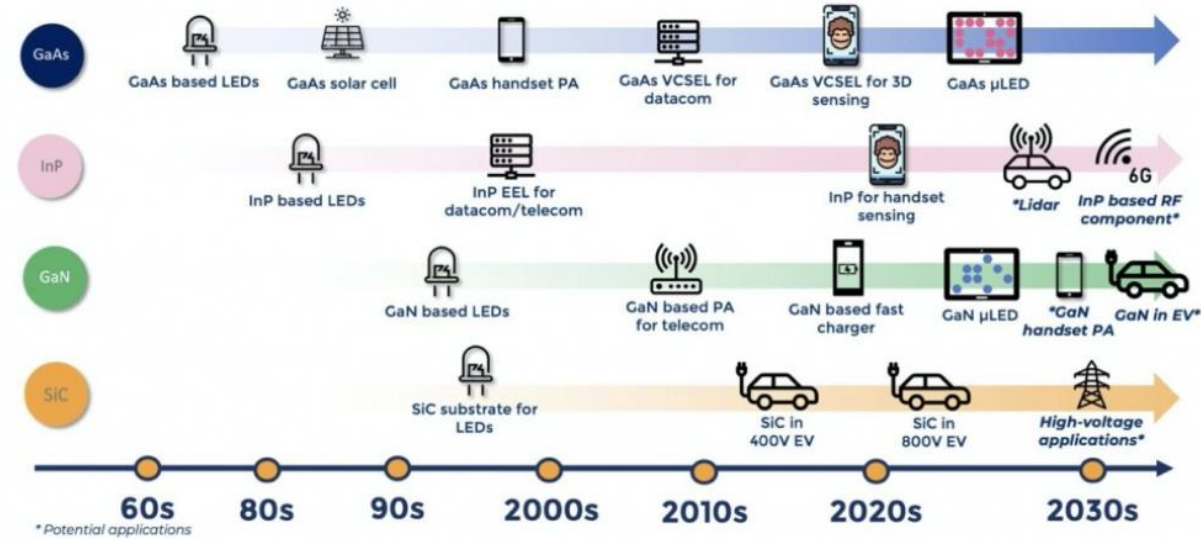
Yole 2022

Design / System Manufacturing Co-Optimization

Characterization Requirements

Hybrid devices with requires changing test approach

Wafer 1

Wafer Test

- Test Data
- Parametric data
- AI to project forward package level performance

Complex System
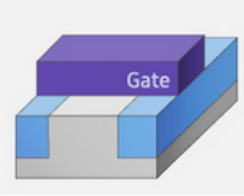
Wafer 2
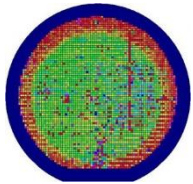
Chip on Wafer Stacking
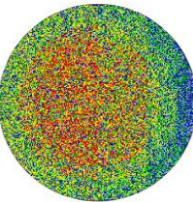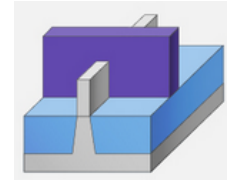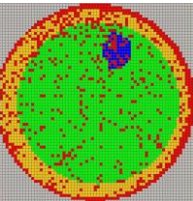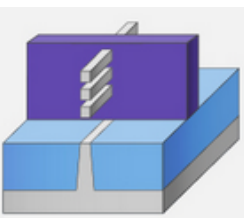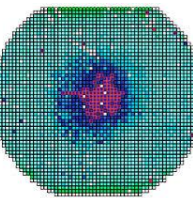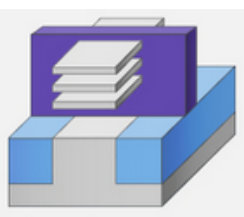
Package test

Characterized Known Good Die

2D 3D

Known Good Stack

Wafer 3

Wafer 4
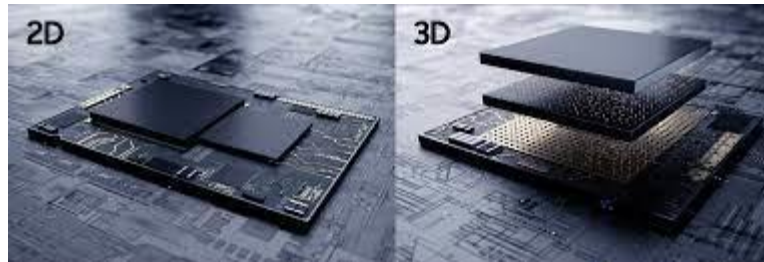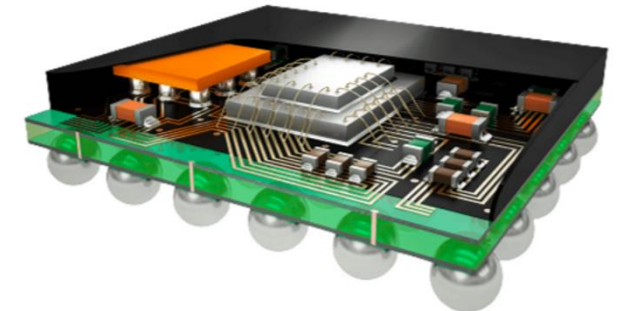
Package optimization

Investment and trade restrictions lead to geographically distributed supply chains

Non-exhaustive

European Chips Act
$45B of semi funding

German R&D Act
25% tax free subsidy of salaries for R&D

US CHIPS Act
$52B of incremental semi funding

Spain PERTE CHIP
$12B of semi funding

China Big Fund[1]
$73B of semi funding

Korea Special Act
Tax breaks up to 20%; 30-40% tax credit for R&D

India incentive scheme
$25B of semi funding

Taiwan SII amendment
Corporate income tax rate of 20%. Up to 15% of R&D tax deduction end of year

US Restrictions
US data center chip sales restrictions to China and Russia
US Export Control Reform Act restricts chip/technology transfers

EU Restrictions
Chip export restrictions on Russia due to invasion of Ukraine

China Restrictions
Data Security Law (DSL)
Applies to all data activities in China that impair the country's national security
Updates to export restriction list included cryptographic chip design

■ Incentive ■ Restriction

- **Need for global centralized view of disaggregated physical assets**

- **Right data, at the right place, at the right time for the right action**

- **Data protection and IP protection challenges**

- **Geo data sovereignty regulations**

PDF/SOLUTIONS™

PDF Solutions is your proven partner for the future of Semiconductor Technology Development and Manufacturing

Process Technology

3D Complexity

Global Supply Chain

AI and Platform

PDF Solutions End to End Platform for Semiconductor Analytics

Fully integrated solution to accelerate production ramp, improve overall yield and quality

Open, cloud native, secure, scalable architecture

PDF Solutions End to End Platform for Semiconductor Analytics

Fully integrated solution to accelerate production ramp, improve overall yield and quality

ModelOps and AI Applications

Align, Enrich, Integrate Data

Monitor, Measure, Control, Execute

Trust, Security, Scalability Across The Entire

- Partner Integration and Apps
- Customer Apps

Unique Data Creation

Inline & End of Line: CV Infrastructure	Inline: Design for Inspection

Equipment Integration & Analysis

cimetrix

Factory Dashboard

Chicago

LINE 1 - Equipment Count: 6

34.3%   34.3%   100%   32.8%   100%   50.7%

PDF/SOLUTION

PDF Solutions End to End Platform for Semiconductor Analytics

Fully integrated solution to accelerate production ramp, improve overall yield and quality

Control on the cloud and at the edge

Trust, Security, Scalability Across The Entire Platform

PDF Solutions End to End Platform for Semiconductor Analytics

Fully integrated solution to accelerate production ramp, improve overall yield and quality

Analytics & AI at Scale, BYOM, BYOA
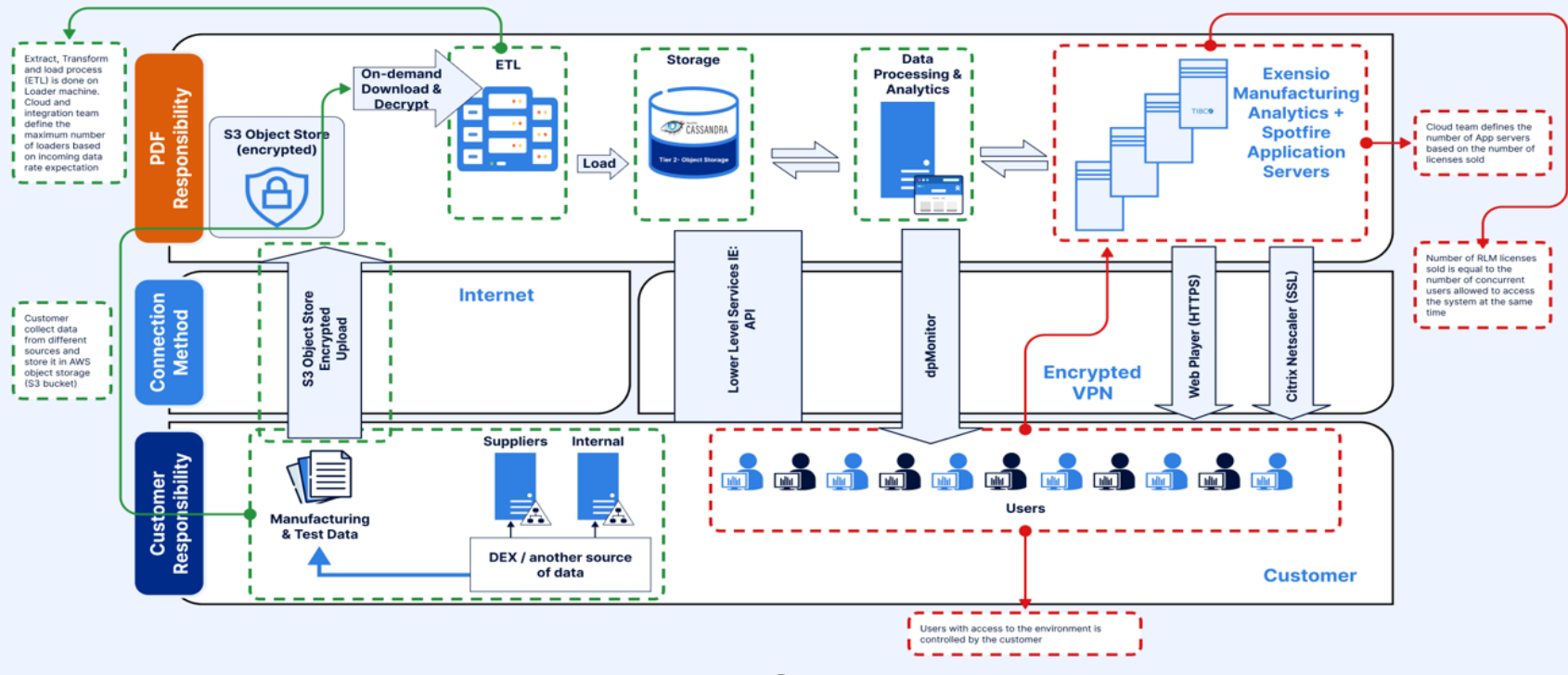
Trust, Security, Scalability Across The Entire Platform

and Supply Chain
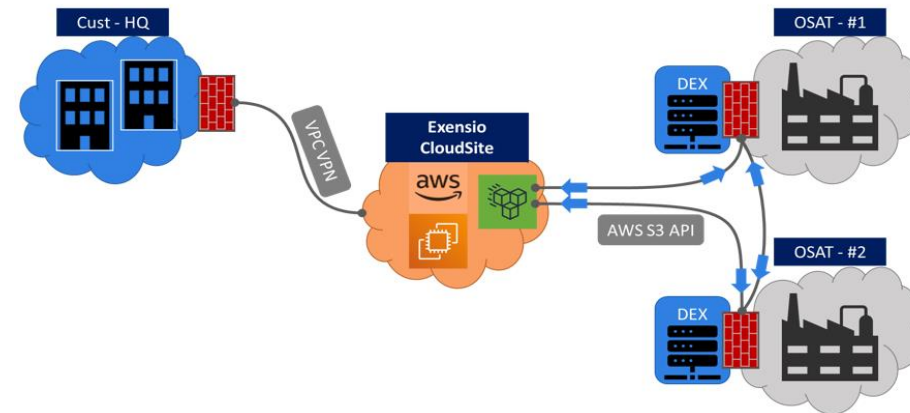
Apps
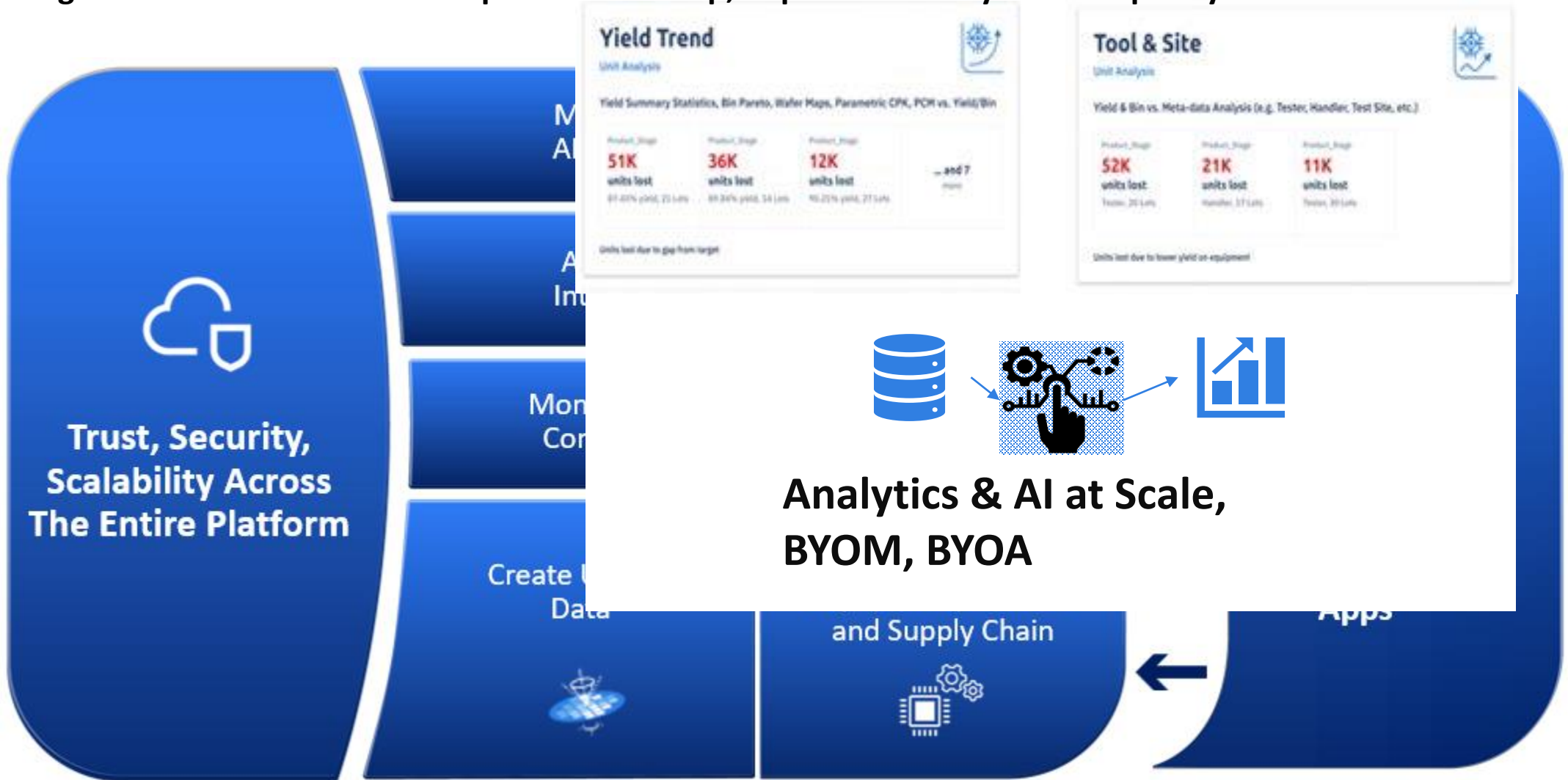
PDF Solutions End to End Platform for Semiconductor Analytics

Fully integrated solution to accelerate production ramp, improve overall yield and quality
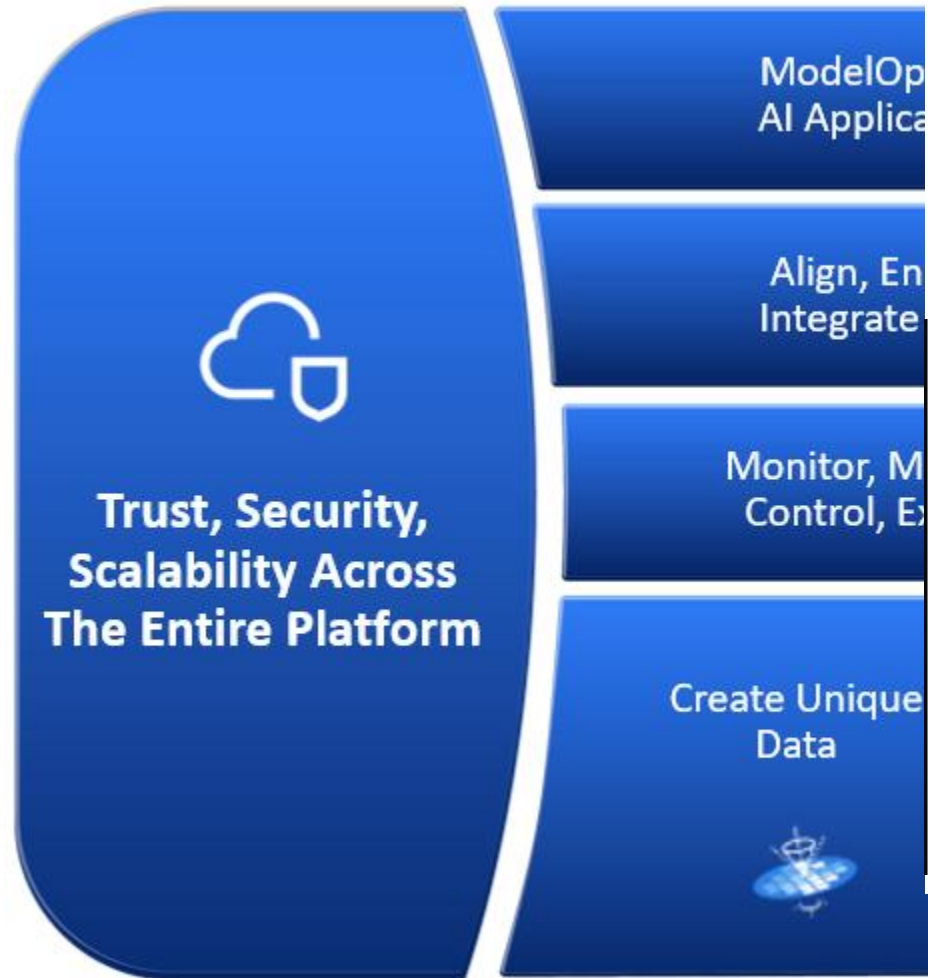
Process and enterprise applications integration

ModelOp
AI Applica

Align, En
Integrate

Monitor, M
Control, E

Create Unique
Data

Trust, Security, Scalability Across The Entire Platform

SOURCE LAYER

MES

shutterstock.com - 1796623816

Data Collection from MES systems

Connectivity Layer

ORCHESTRATION LAYER

Sapience® Manufacturing Hub

- Data Flow Management
- Data Governance
- Job Assignment
- Data Routing

TRANSFORMATION LAYER

- User interface & configuration
- Data transformation
- Job definition
- Security

DATA STORAGE LAYER

Semantic Data Storage DB

Streaming Data

Data Extraction & Load

Data Registration to SAP

Connectivity Layer

APPLICATIONS LAYER

SAP S/4 HANA

Product Costing

Cost of Yield Analytics

Custom & 3rd Party Applications

Data Warehouse

PDF/SOLUTIONS™

An open platform based on industry standards and integrated with leading solutions providers

SIEMENS
Integrated circuit (IC) test and yield analysis

IBM
MES Solutions for fabs and assembly

Kulicke & Soffa®
Assembly operations

voltaiq Battery Intelligence
Enterprise Battery Intelligence

aws
Global cloud infrastructure

- **Partner Integration and Apps**
- **Customer Apps**
- **Third Party Apps**

ModelOps and AI Applications

Align, Enrich, Integrate Data

Monitor, Measure, Control, Execute

Create Unique Data

Integrate Across Equipment, Process and Supply Chain

Trust, Security, Scalability Across The Entire Platform
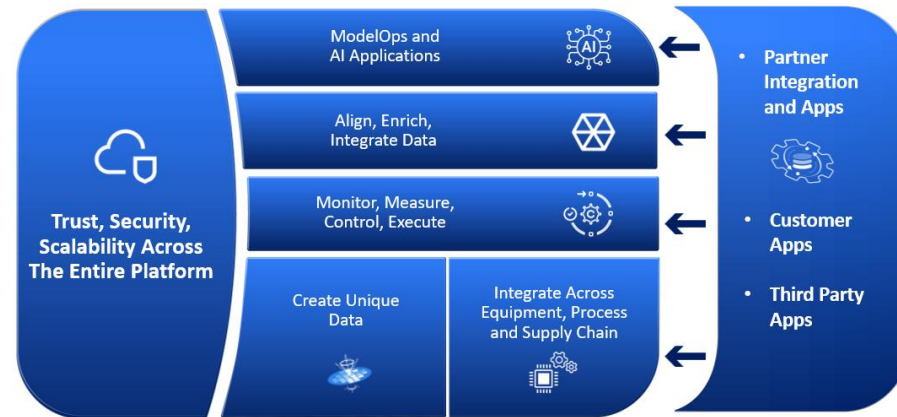
SAP
Business & supply chain data and process integration with E2E automation for quality & cost

proteanTecs
Deep data analytics

TERADYNE
Edge AI for test, test operations

ADVANTEST
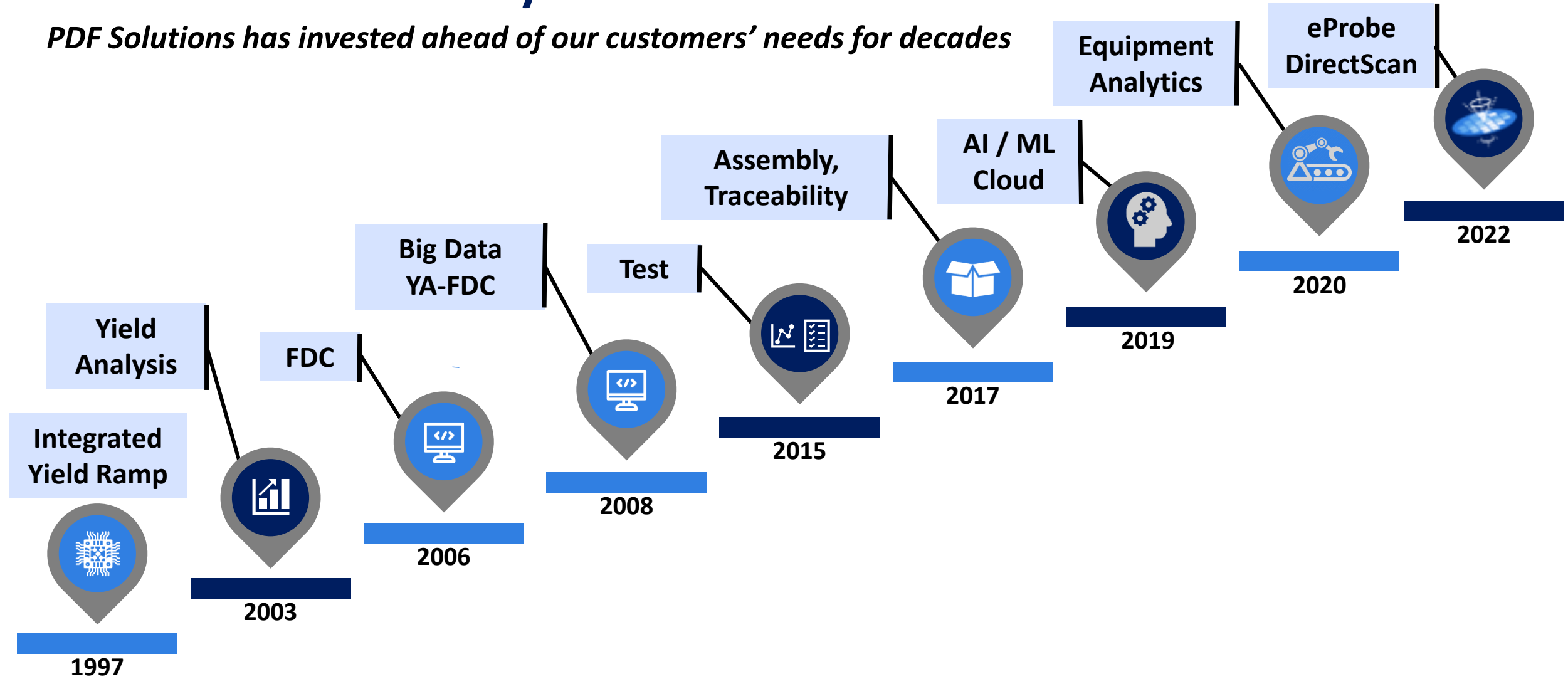Edge AI for test, test operations

PDF/SOLUTIONS™

PDF Leads Standards for Analytics & Equipment Data Collection

- **SEMI** NA Regional Standards Committee Assistant Co-Chair

- **SEMI** NA Information & Control Committee Co-Chair

- **SEMI** NA GEM 300 Task Force Leader

- **SEMI** NA DDA Task Force Leader

- **SEMI** NA Advanced Backend Factory Integration (ABFI) Task Force Leader

- **SEMI** NA GUI Task Force Leader

- **SEMI** NA Fab & Equipment Computer and Device Security (CDS) Task Force Leader

- **SEMI** Japan F-GEM Task Force Leader

- **NEMI** Board of Directors

- Task Group Leader of **IPC** Connected Factor Initiative Subcommittee

- Co-Chair of the Smart Manufacturing Technical Working Group of **iNEMI**

- **SEMI** NA Traceability Committee Co-Chair

- **SEMI** NA Advanced Backend Factory Integration (ABFI) Task Force Leader

- **SEMI** NA Single Device Tracking (SDT) TF Leader

- **GSA TIES** SWG-07 Liaison Team Leader

- **GSA TIES** SWG-07 M345 Working Group Co-Leader

The result of over 20 years of Innovation

PDF Solutions has invested ahead of our customers' needs for decades

Integrated Yield Ramp — **1997**

Yield Analysis — **2003**

FDC — **2006**

Big Data YA-FDC — **2008**

Test — **2015**

Assembly, Traceability — **2017**

AI / ML Cloud — **2019**

Equipment Analytics — **2020**

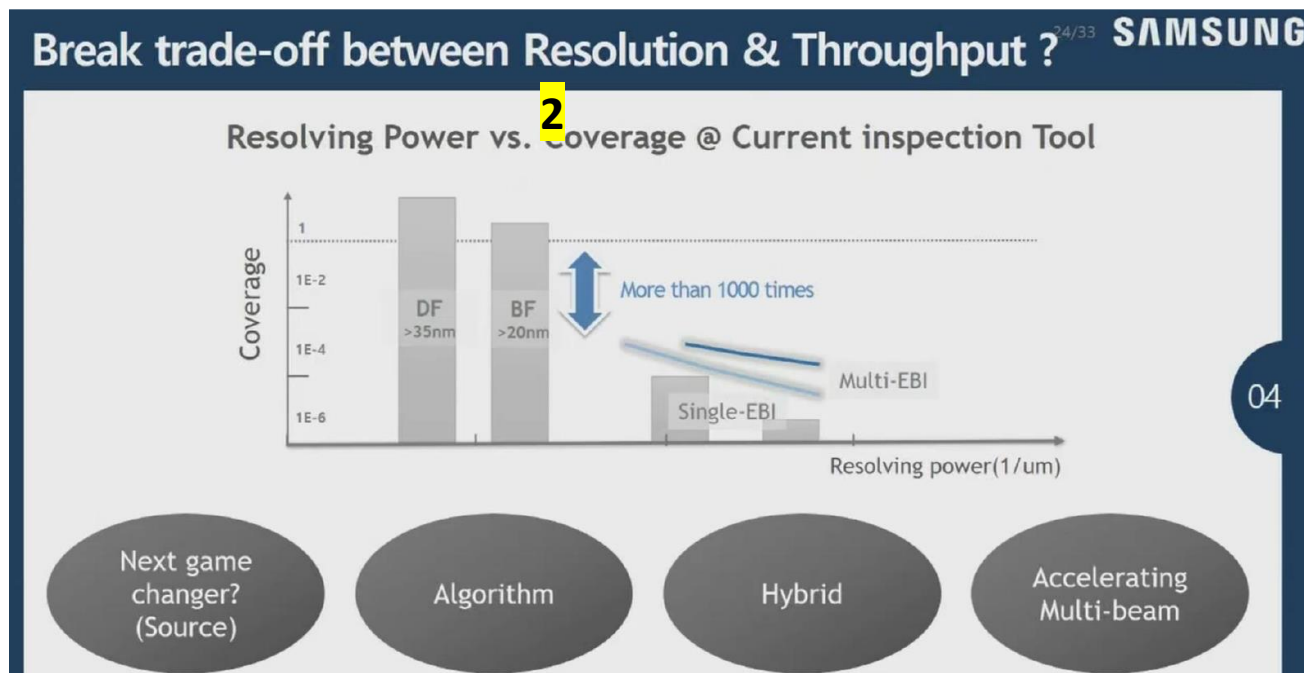eProbe DirectScan — **2022**

Enhancing Yield Ramp

Semi Supply Chain Analytics

PDF Solutions Innovation

- **eProbe and direct scan**

- **ML model base test deployment**

- **PDF Solutions unique approach to ModelOps**

Testing for 3D Defects - Problem Statement

- Optical inspection cannot resolve critical 3D defects at 7nm node and below
- eBeam inspection lacks throughput to measure PPB yield loss sources
- Solution also needs to detect buried (sub-surface) defects
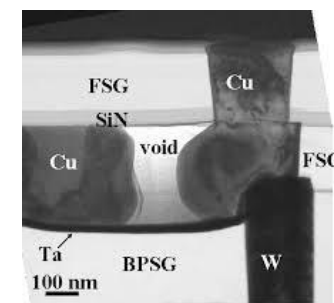

Via void
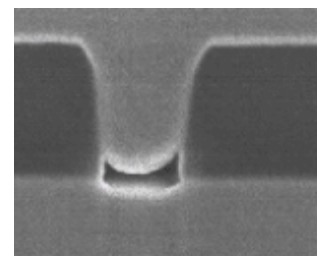
Buried defects

Fig. 5. TEM micrograph of void in M1 copper.

Source: Chungsam Jun, 2021 SPIE Keynote

PDF DirectScan System Overview

Fire™ Product Layout Scan For Related Patterns

Example for Mx line ends

eProbe DirectScan product wafer at layer

Unique Vector Scan performs Billions of measurements/wafer

Exensio and Fire Analytics
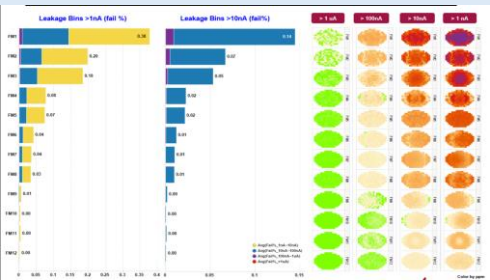
➢ Quantify yield impact in PPB statistics

➢ Analyze key fail modes across full product layout

➢ Characterize product pattern neighborhood dependence for each fail mode

➢ Identify layer stack and neighborhood combinations that drive systematic yield

➢ Scan ~10B features/hour

Conventional ebeam Inspection
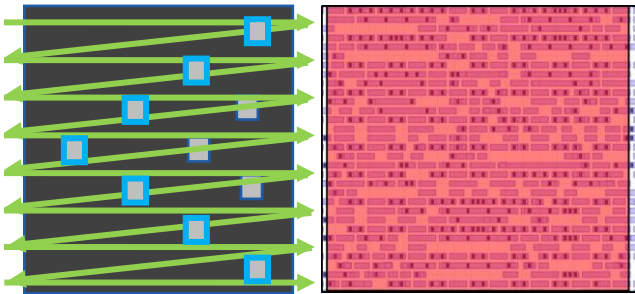
eProbe Inspection

Product Ramp : Conventional vs. DirectScan Learning Cycle

Learning Cycle Time →

(resulting in 1 fail site of data)
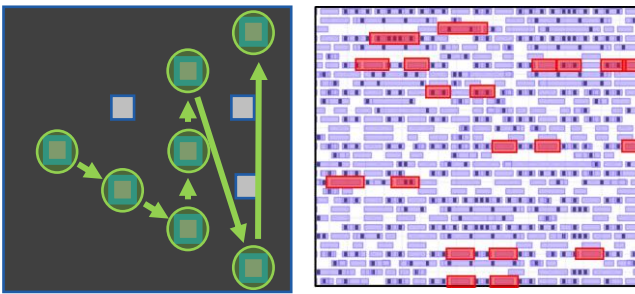
(3-5 weeks including logistics) — EFA / PFA
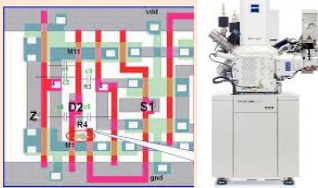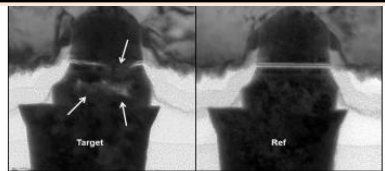
(2-4 weeks w/ logistics) — Wafer Sort Test

(4-6 weeks) — BEOL processing
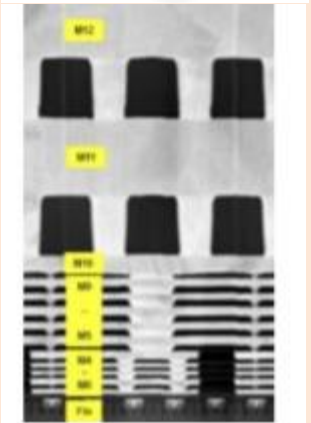
(1-2 weeks) — MOL processing

(1-2 weeks) — FEOL processing
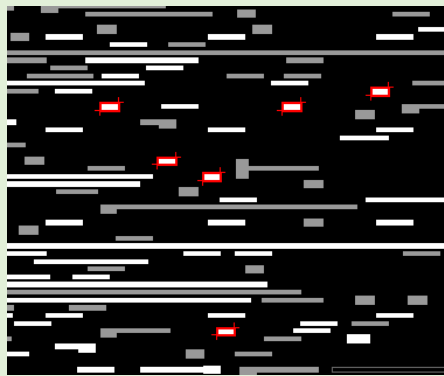
- eProbe inline Point scanning

- Inspect **full wafer within days of process split** (CIP, OPC, or DFM).

- Inspect >200B patterns per day

- "Short flow" learning mode possible (skip unrelated FEOL & MOL processing) to further accelerate learning cycle

PDF Solutions Innovation

- **eProbe and direct scan**

- **ML model base test deployment**

- **PDF Solutions unique approach to ModelOps**

The system in package testing challenge

Leverage upstream data to optimize downstream decisions

Chiplet 1 | Wafer Fab → WAT (PCM) → Wafer Sort 1 → Wafer Sort 2 → Wafer Sort 3 →

Chiplet 2 | Wafer Fab → WAT (PCM) → Wafer Sort 1 → Wafer Sort 2 →

Chiplet 3 | Wafer Fab → WAT (PCM) → Wafer Sort 1 →

Chiplet n | Known Good Die (external supplier) →

3D Packaging → Final Test 1 → Burn-in → Final Test 2 → SLT

Why do companies want to use ML at test? System in Package
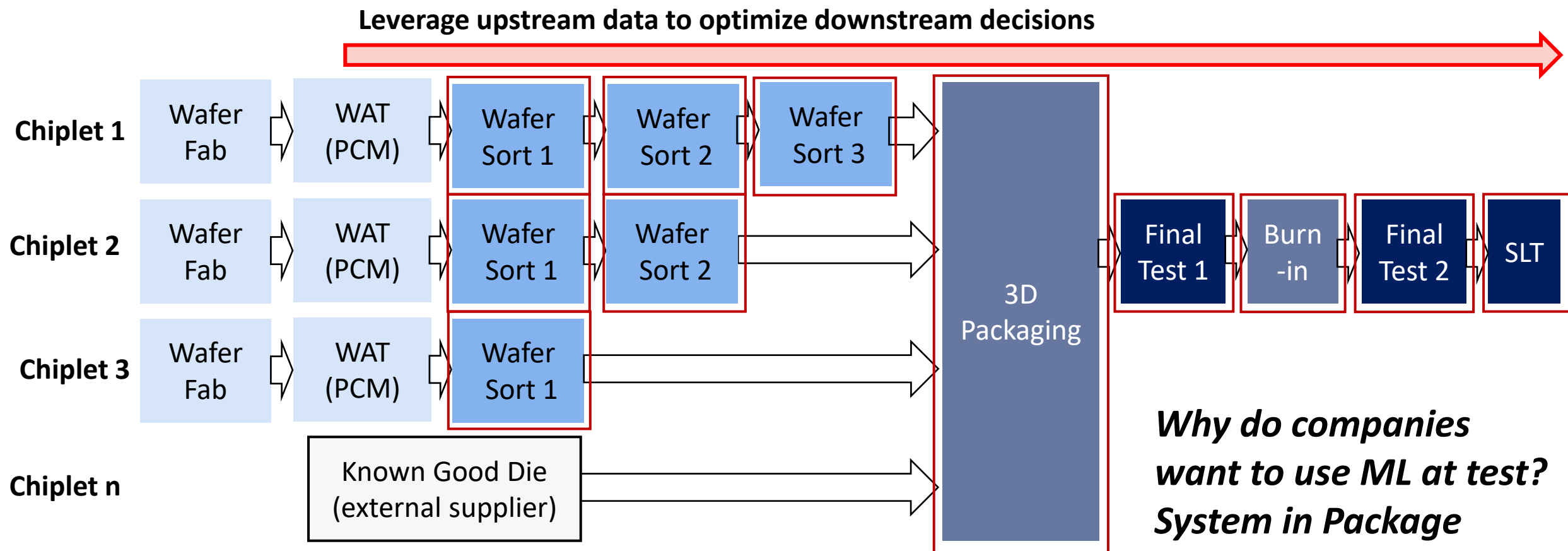
Exensio ML solution to scale prediction model training and deploy inference engine at the edge

Centralized management of the globally distributed supply chain

Enterprise Applications:
ERP, SCM, Financials, Procurement, PLM, HR

Manufacturing Analytics

Process Control	Test Operations	Assembly Operations	Process Characterization

Big Data Infrastructure

Traceability of wafers, die, & multichip modules through assembly & packaging

Fab 2

Fab 1

Manufacturing Data Warehouse

MES **SPC** **R2R** **FDC**

ata

FDC

AI enabled Applications

Global Infrastructure

DEX

DEX

OSAT 3

OSAT 2

OSAT 1

TEST
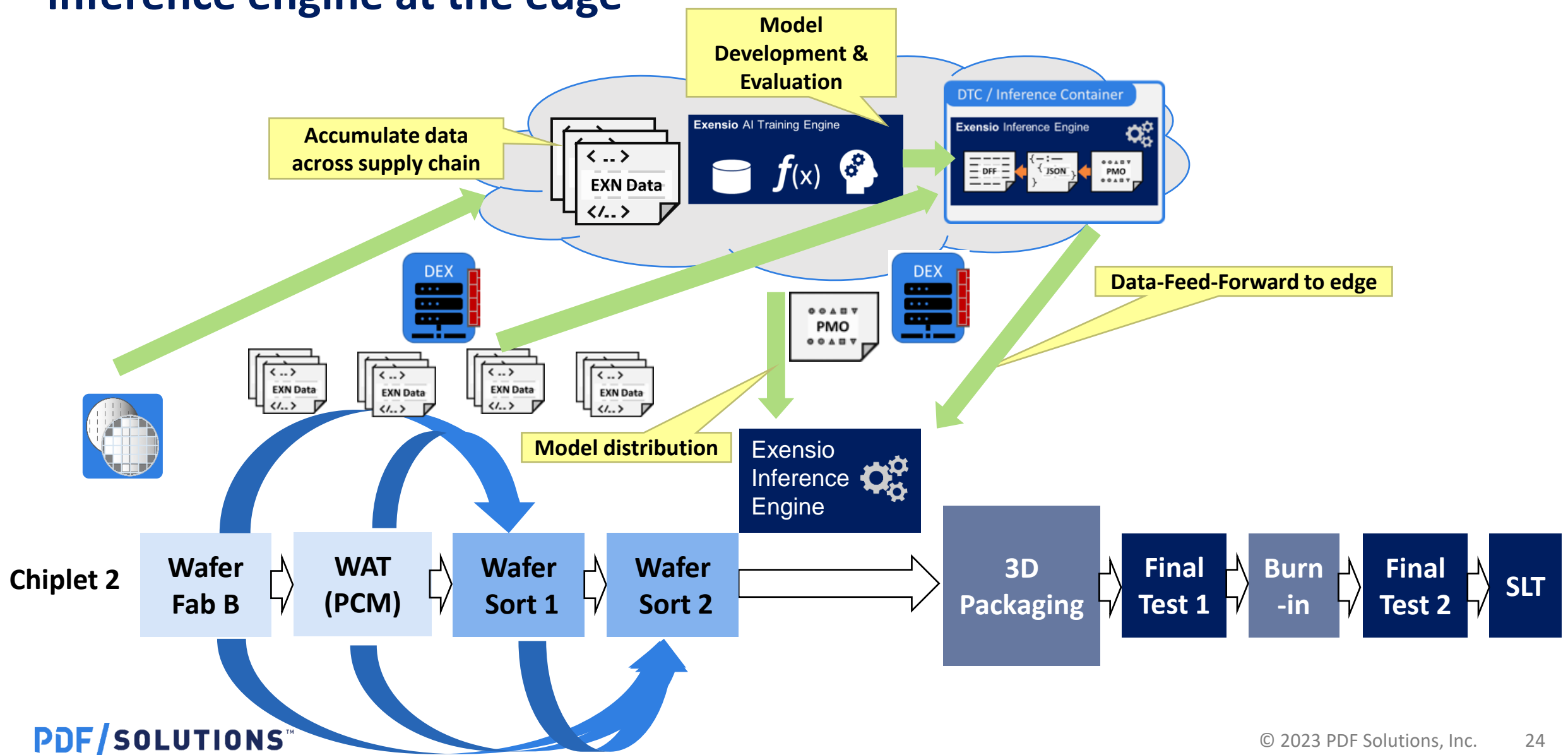
Assembly

ssembly

ssembly

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PDF Solutions Innovation

- **eProbe and direct scan**

- **ML model base test deployment**
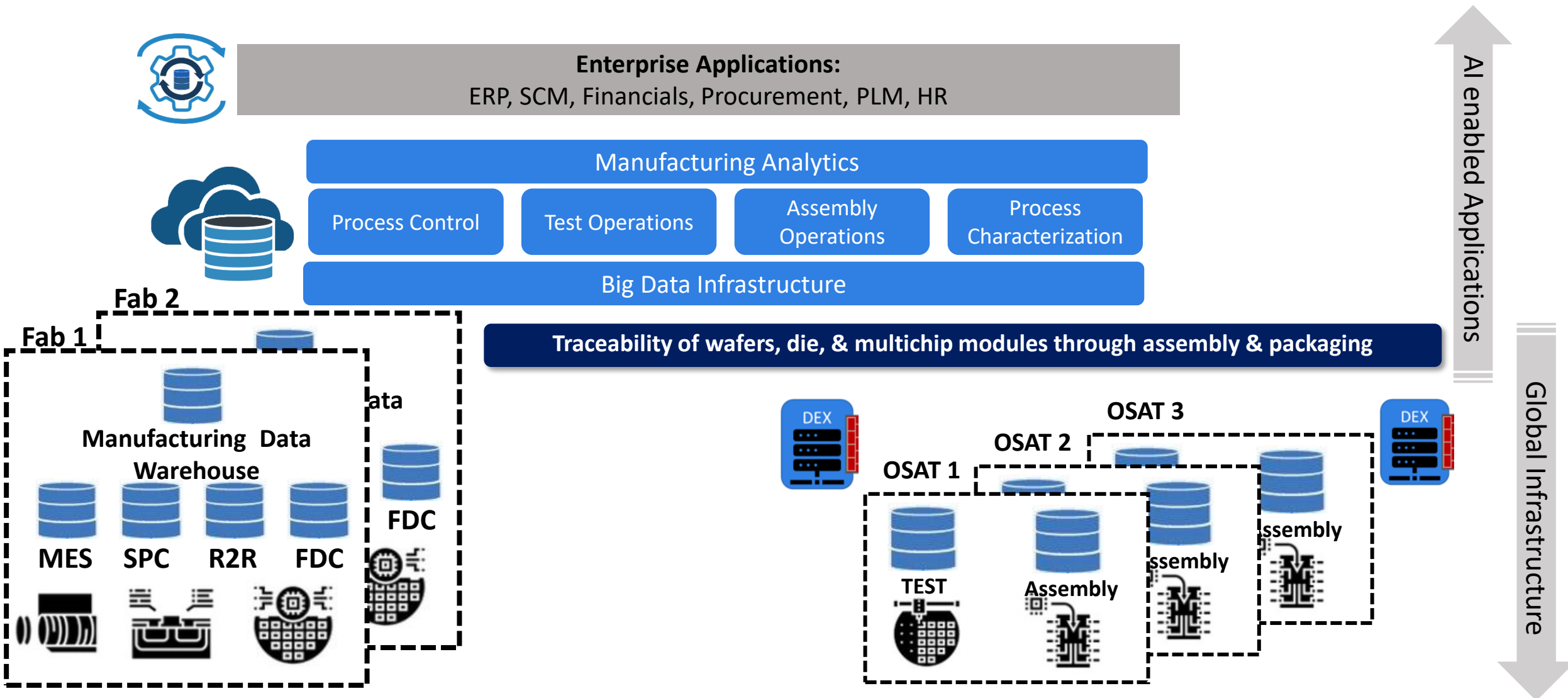
- **PDF Solutions unique approach to ModelOps**

What problems are we solving with ModelOps?

Key Challenges

<50%

< 50% of the best models get deployed

―――――

Overcome the barriers to deploying at Edge

90%

90% of models take > 3 months to deploy

―――――

Stage upstream model input data for real-time inference

44%

44% of models take over 7 months to be put into production

―――――

Manual processes slow deployment
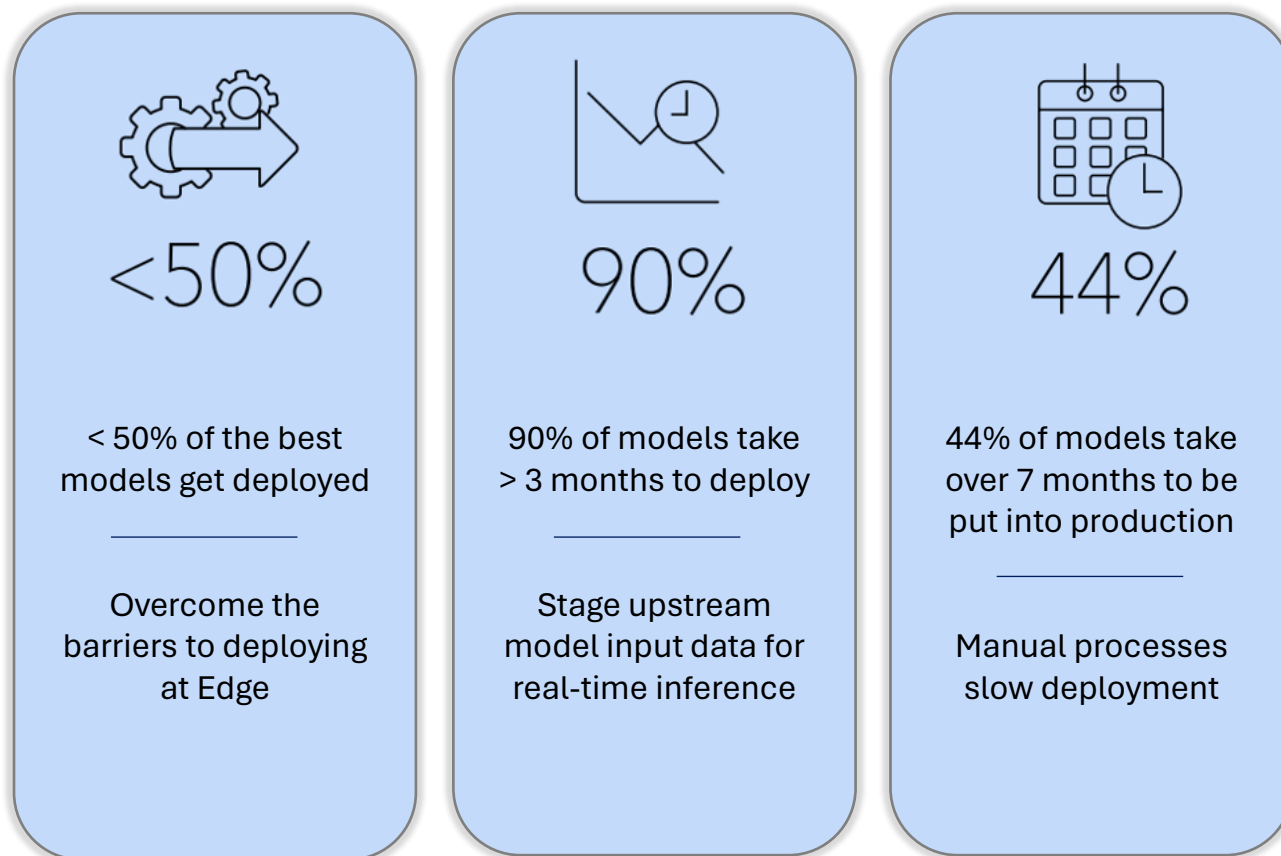
Statistics from Worldwide Semiannual Big Data and Analytics Spending Guide, IDC, April 2019.

Large numbers of Models are needed for a wide range of Semiconductor use cases

Examples:

- **Products:**
  - Predict test response results
  - Identify design to process risks / yield loss
  - Detect anomalous behavior
- **Machines:**
  - Detect anomalous behavior
  - Predict maintenance events
  - Feedback / Feedforward compensation
- **Processes:**
  - Virtual metrology
  - Classify defect images
- **Fabs and Supply Chains:**
  - Maximize throughput
  - Balance supply and demand
  - Supply chain predictability

Why use PDF's platform for AI / ML Ops?

- **Data generation, curation, and semantic data model** built on over 30-years industry experience

- **Big Data Platform to Train, Deploy, Monitor and Manage** thousands of models for volume manufacturing across the semiconductor life cycle

- **Common UI and workflow to Facilitate Collaboration** between Data Scientists, IT, and Engineers

- **APIs to allow you to integrate with existing systems** and deploy to diverse endpoints: i.e., edge, cloud, OSAT's

- **Security & Traceability** to protect your IP

How ModelOps increases Business Value

Integrated, scalable infrastructure to develop, monitor, control and operationalize AI /ML decision models

Value Of Analytics

Automation accelerates deployments

Ongoing management sustains value in production

MODEL RE-TRAINING / REPLACEMENT

AUTOMATED DATA PREPARTION FOR REAL-TIME DATA ACCESS & INFERENCE

AUTOMATED DATA ACCESS, PREPARATION, FEATURE EXTRACTION, MODEL CREATION

MODEL MONITORING

PDF ModelOps Value

AUTOMATED MODEL DEPLOYMENT – CLOUD & EDGE

Time
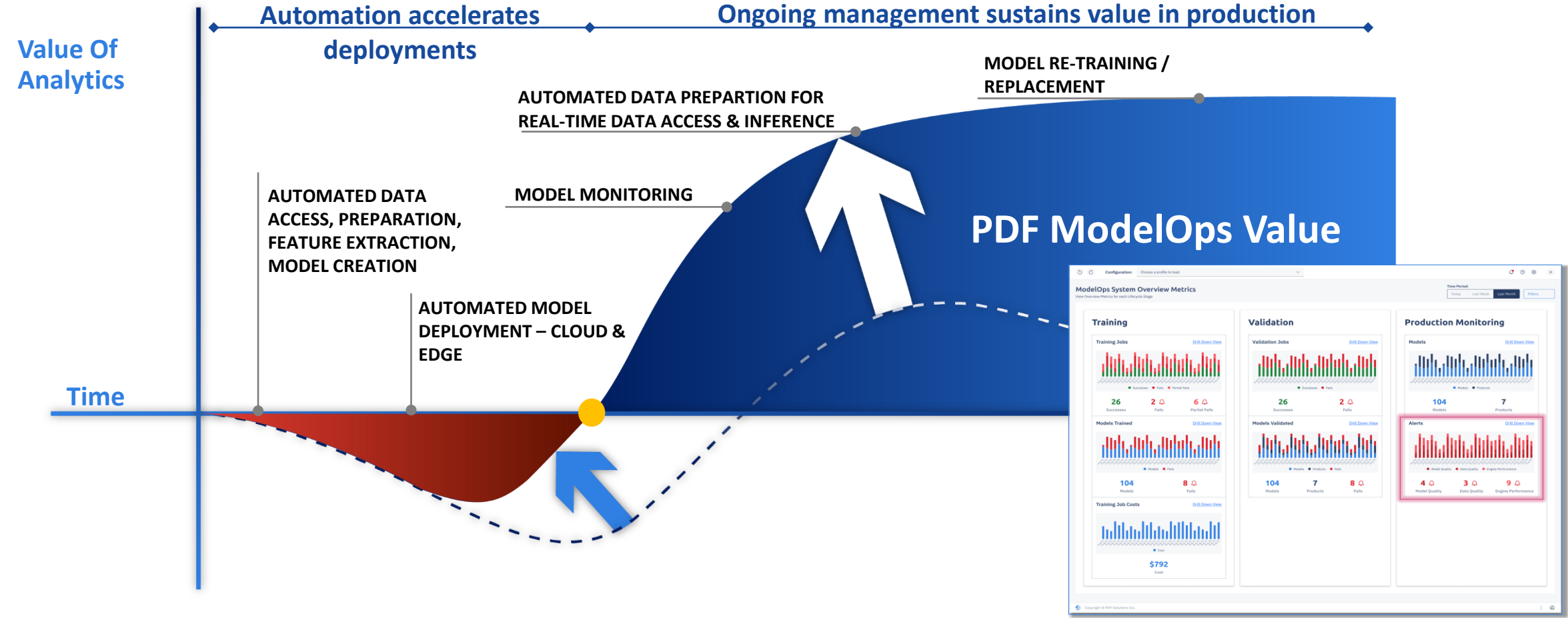
Accelerate & scale the process of putting large numbers models into production

AI is critical in achieving increased employee productivity and breach the skills gap

Jobs to date | Projected

Industry to add 114,800 jobs by 2030

CHIPS Act enacted

Design

Manufacturing

2010-2022 | 2023-2030

67,000, or 58%, of new jobs across **manufacturing** and **design** will risk going unfilled by 2030.

Who is missing?

- 13,400 computer scientists
- 5,100 PhDs
- 12,300 master's
- 9,900 bachelor's — 27,300 engineers
- 26,400 technicians
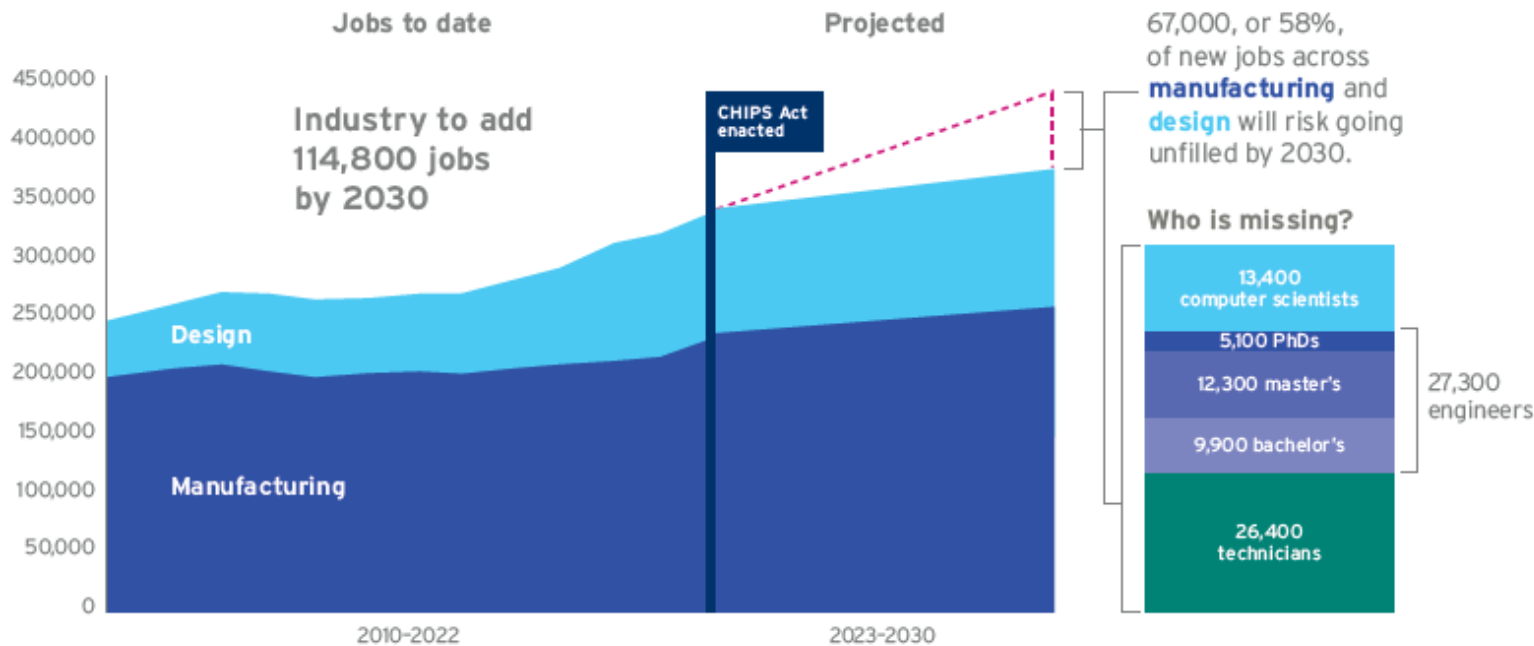
SIA & Oxford Analytics 2023

- **Develop workforce to use software to bring to scale where foundries use human capital**
- **Opportunity to leverage AI to revive student interest in Semi jobs**
- **AI for semi university program**
- **Corporate training program**

A stable platform built on latest available IT
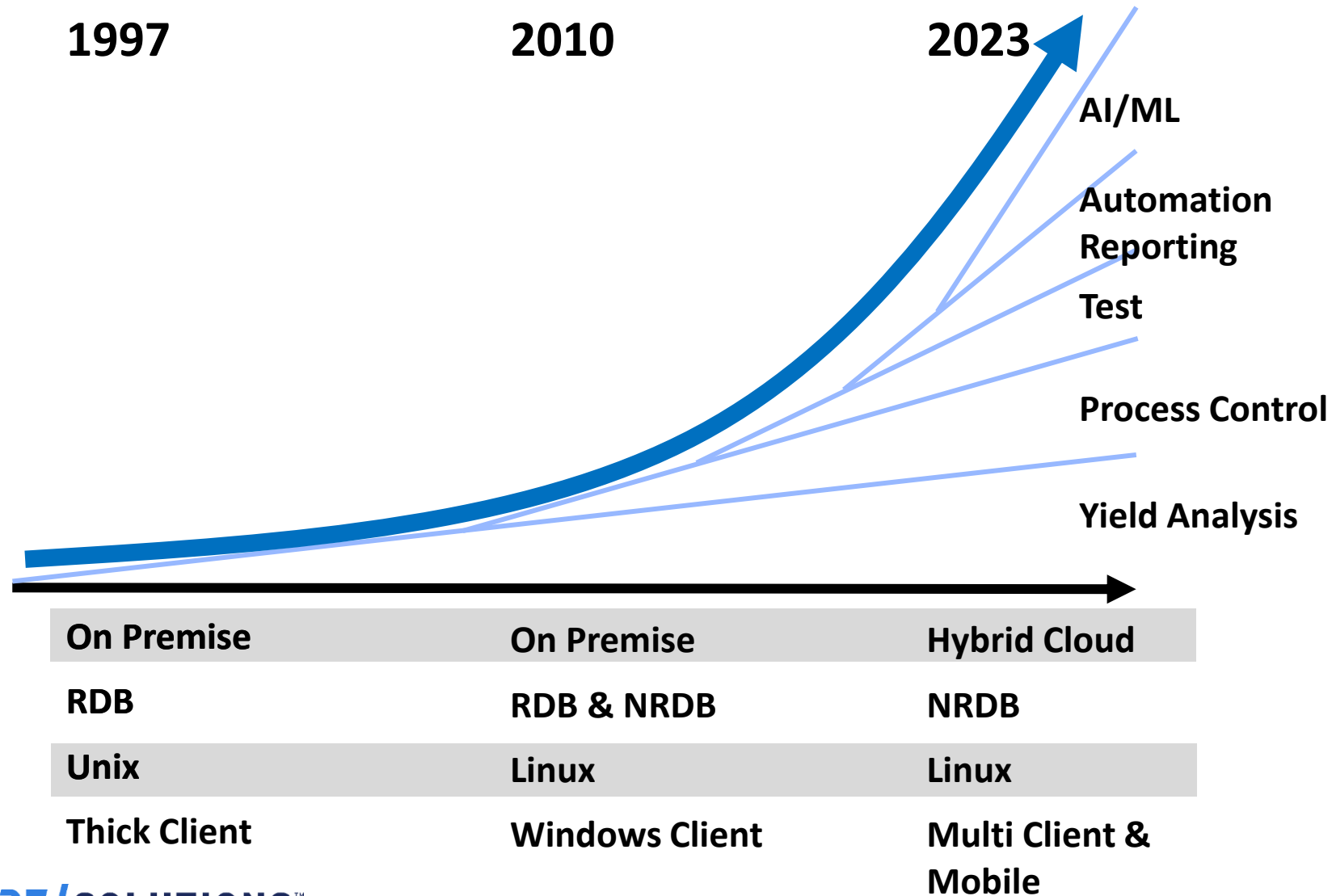
- **The functionality delivered by the platform has rapidly increased**

- **The platform continuously evolves to take advantage of the latest IT innovation**

- **As the IT stack evolves, we maintain full compatibility of the customer workloads, control and test plans**

1997	2010	2023
On Premise	On Premise	Hybrid Cloud
RDB	RDB & NRDB	NRDB
Unix	Linux	Linux
Thick Client	Windows Client	Multi Client & Mobile

AI/ML

Automation
Reporting

Test

Process Control

Yield Analysis

PDF/SOLUTIONS™

Your success is how we measure ourselves

Intel
Moore's Law in Action: Accelerating Semiconductor Process Technology

ST
Test cell automation, a holistic view

GlobalFoundries
Business and digital transformation

RENESAS
Guided Analytics to improve yield, test and quality

ANALOG DEVICES
Deploying an analytics platform to drive the digital transformation of Semiconductor manufacturing

MULTIBEAM
MULTICOLUMN E-BEAM LITHOGRAPHY
Leveraging Cimetrix equipment connectivity solution

Thank You

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