Role of Digital Twin in Semiconductor Manufacturing and AppliedTwin™ Platform

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Computational Products and Solutions (CPS) Center of Excellence

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make possible

AGENDA

- AppliedTwin™ Platform
- ChamberTwin™ Demonstration
- EcoTwin™ - Sustainability Application
- EduTwin™: Education and Training through Models

AppliedTwin™ | A Comprehensive Platform for Semi Equipment and Process DT

Digital Twin Definition

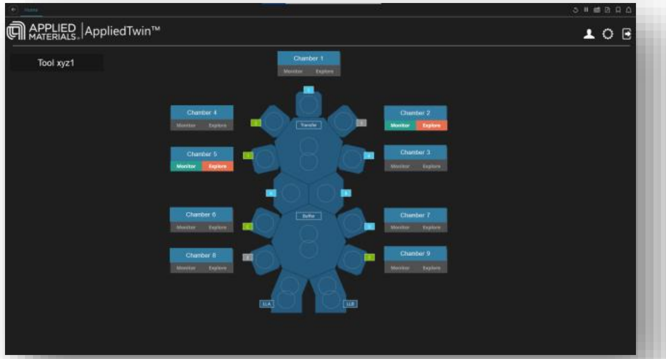
A **virtual** representation of an equipment and process based on **best available models**, informed by **sensor and metrology data**, guided by **domain knowledge**, and continuously **synchronized** with a physical counterpart. AppliedTwin is designed to predict equipment performance and process outcomes with a fidelity that provides actionable insights to the user.

Foundations

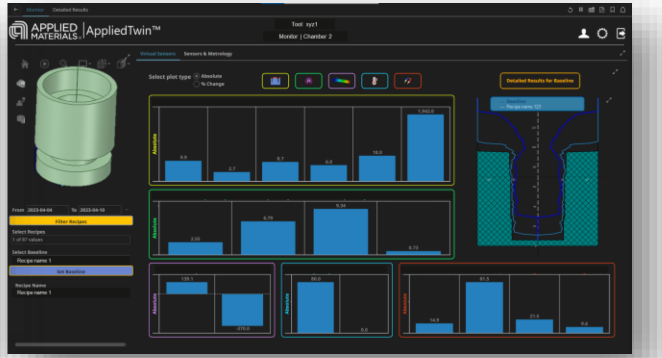
Models	Domain Knowledge	Software and Compute hardware	Sensors & Metrology

$$\nabla \times H = J + \frac{\partial D}{\partial t}$$

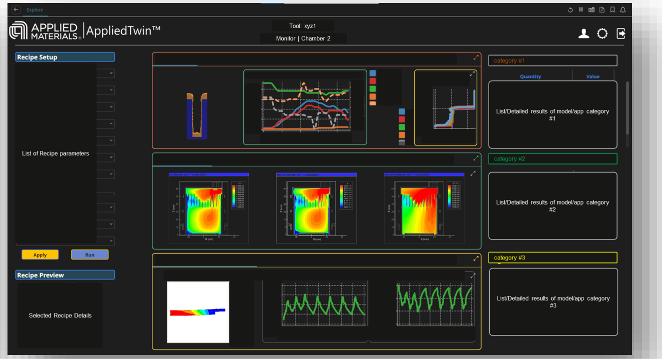
Applied Materials Blog: AppliedTwin™ Vision



Navigate



Monitor



Explore

AppliedTwin™ | **Classification**: DT for Semi Cap Equipment Manufacturing

ChamberTwin™
- EngineeringTwin™
- Architectural Element Twin

ProcessTwin™
- Unit process
- Integrated Processes
- DeviceTwin™

Tool & FleetTwin™
- Fab+Subfab

EduTwin™

Training & Education Through Digital Twins

Characteristics

- Type & Fidelity (Phys, Stats, Hybrid, ROM)
- Connectivity/Synch (Online, Offline, no data)
- Value Proposition (Capex, DPY, Opex)
- Customer (Internal/External)
- Interface (GUI, AR/VR)

Benefit: R&D Acceleration, Ramp-up, HVM, Diagnostics, Control, Productivity

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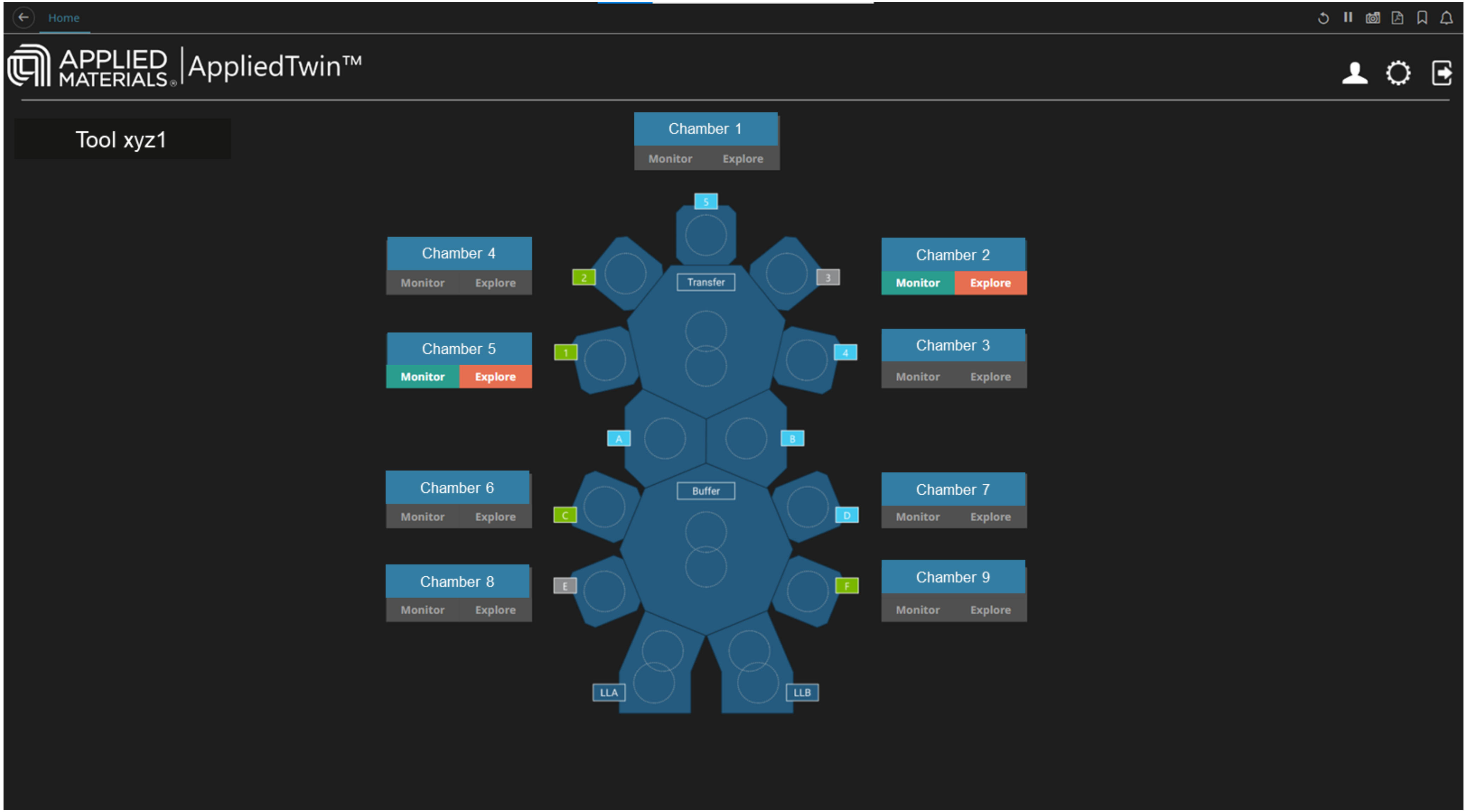
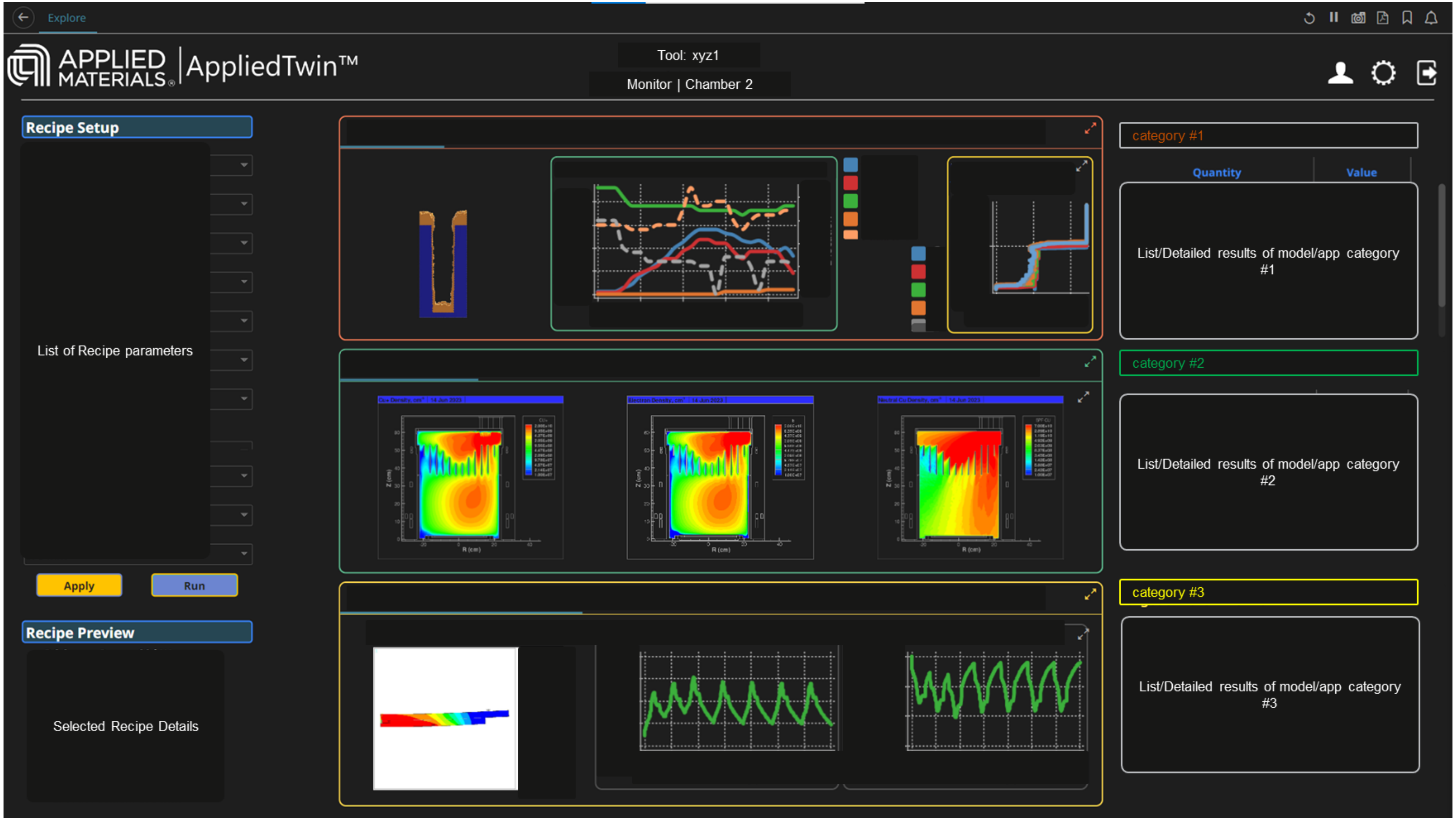
AppliedTwin™ | Chamber-level page



AppliedTwin™ | Monitor

Each box/color represents a category of results – e.g., related to temperature, plasma, stress, etc.

AppliedTwin™ | Explore



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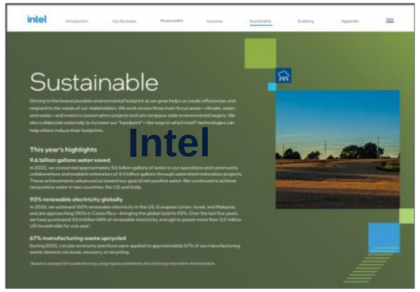
EcoTwin™ | Industry Drivers & Trends

Customer ESG Commitments

https://esg.tsmc.com/download/file/2022_sustainabilityReport/english/e-all.pdf

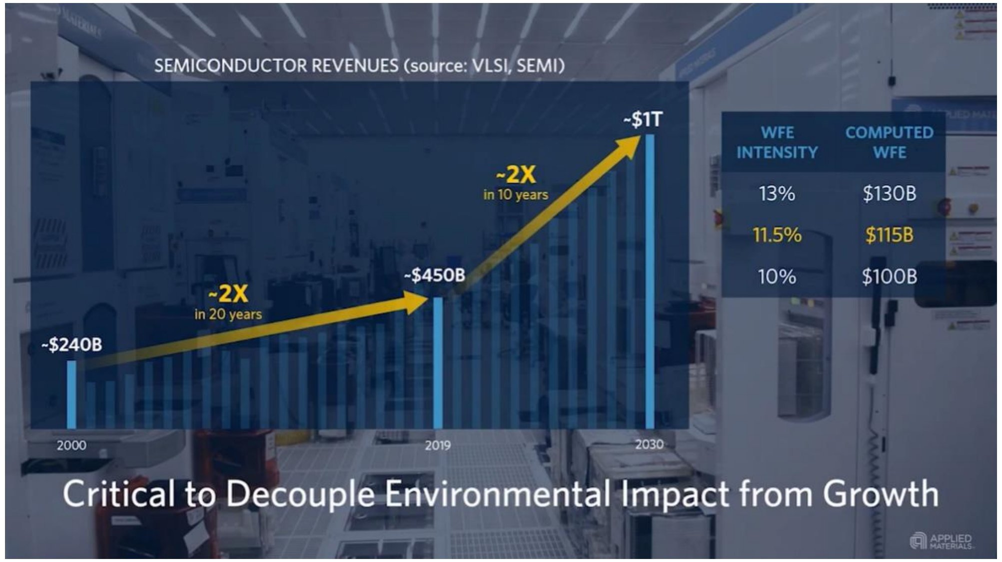
https://images.samsung.com/is/content/samsung/assets/uk/sustainability/overview/Samsung_Electronics_Sustainability_Report_2022.pdf

https://media-www.micron.com/-/media/client/global/documents/general/about/2023/2023_micron_progress_summary.pdf?la=en&rev=7869f9b55011499f94859812bd501b37



https://csrreportbuilder.intel.com/pdfbuilder/pdfs/CSR-2022-23-Full-Report.pdf

Scale & Complexity driving higher emissions



Gary Dickerson, Applied Materials, SEMICON West 2020

Companies already have made aggressive commitments and are making tremendous progress towards their goals

Increased resource utilization efficiency is necessary to capture future growth

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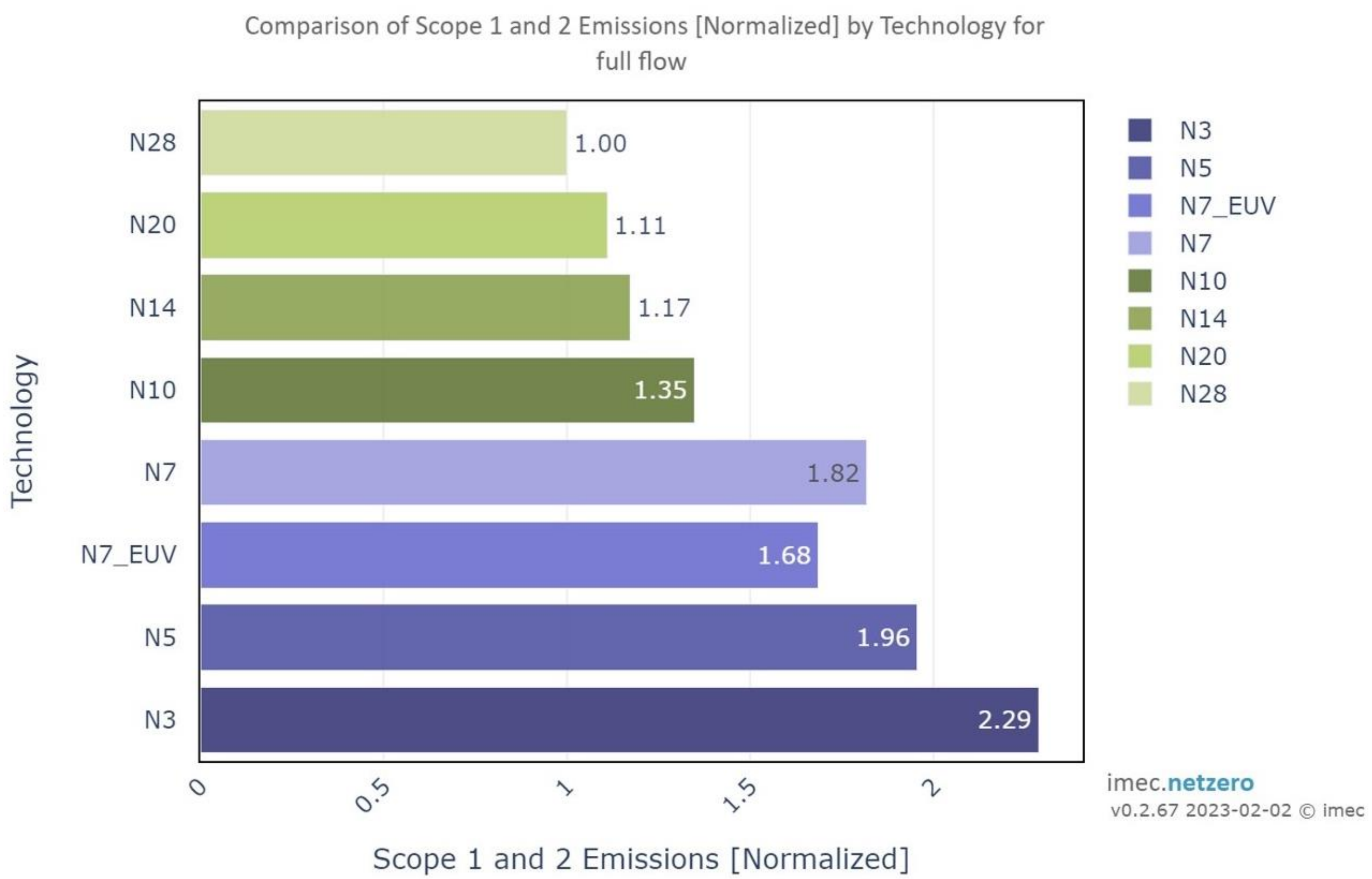
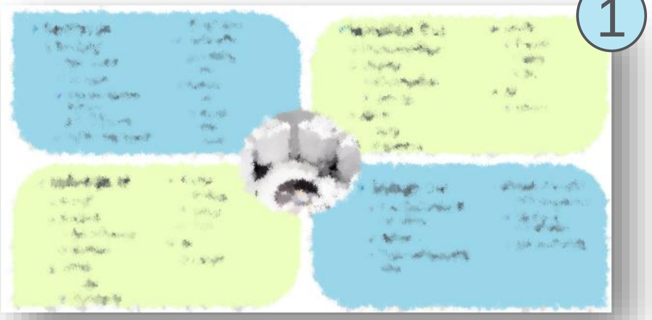
EcoTwin™ | Technology Node versus Consumption Trends



Ref.: https://www.imec-int.com/en/press/imecs-virtual-fab-underpins-strategies-reduce-carbon-footprint-lithography-and-etch-process

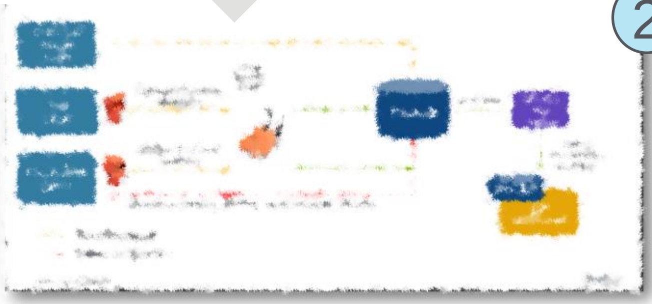
EcoTwin™ | Development Overview – In a Nutshell

1



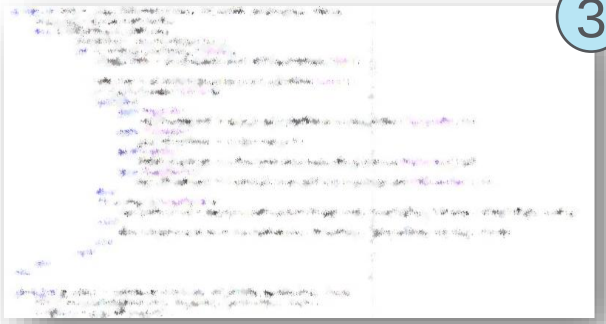
Detailed energy & Mass Balance

2

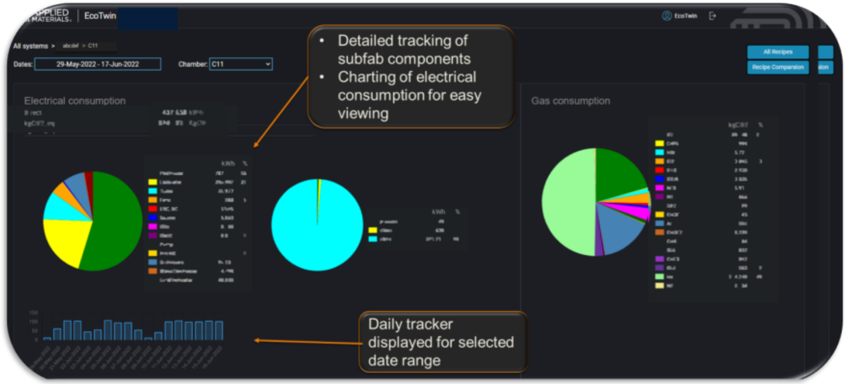


Aggregating Multiple Data Streams

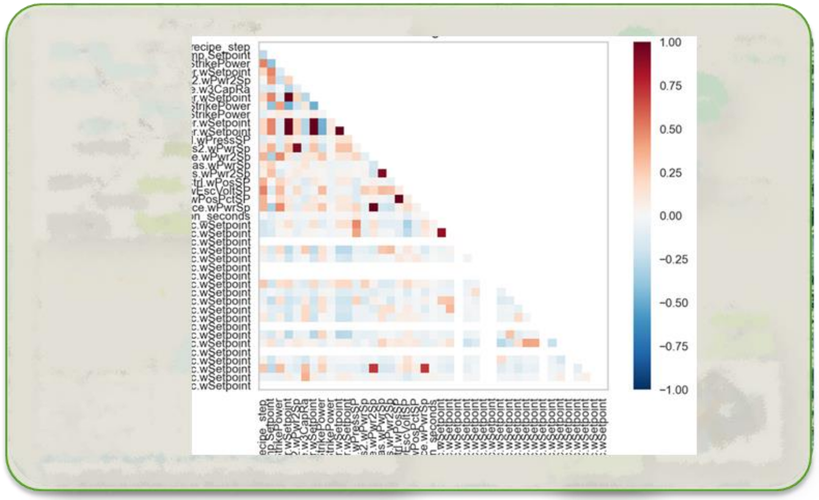
3



Back-end Algorithm to Process the Data

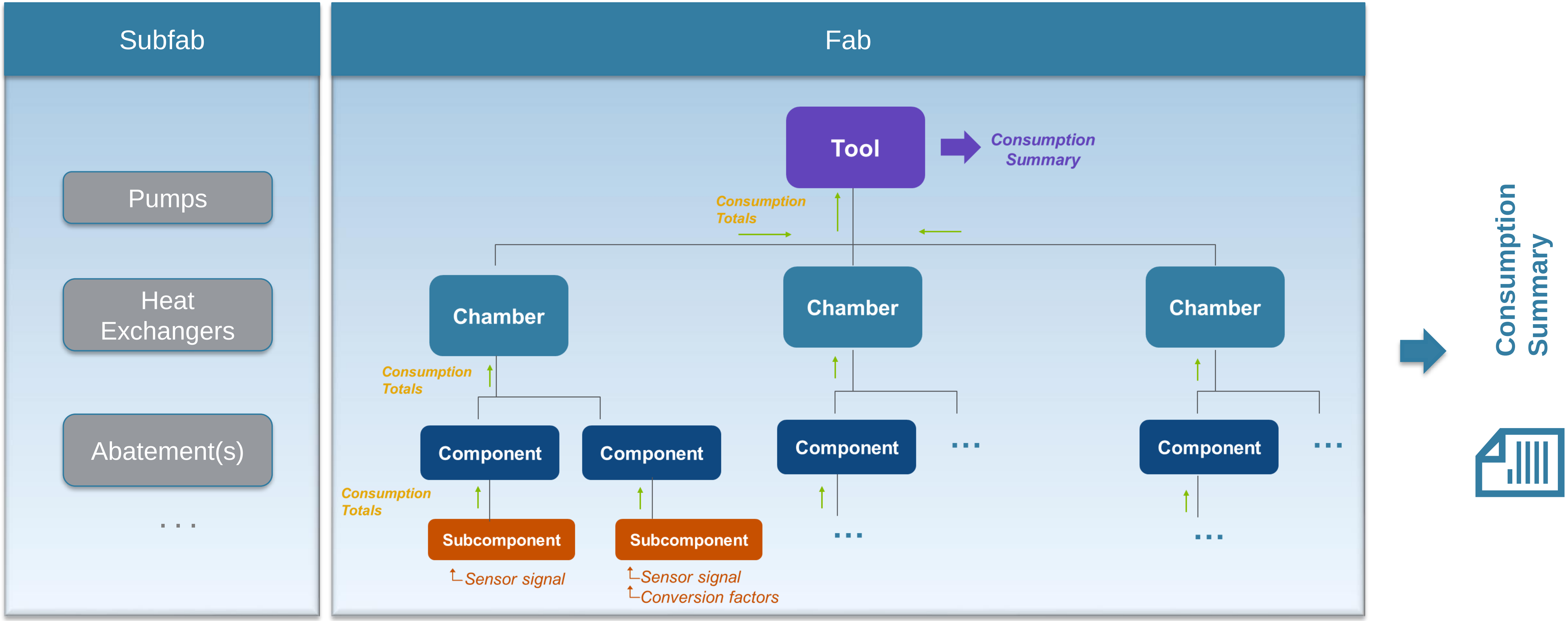


EcoTwin Dashboard

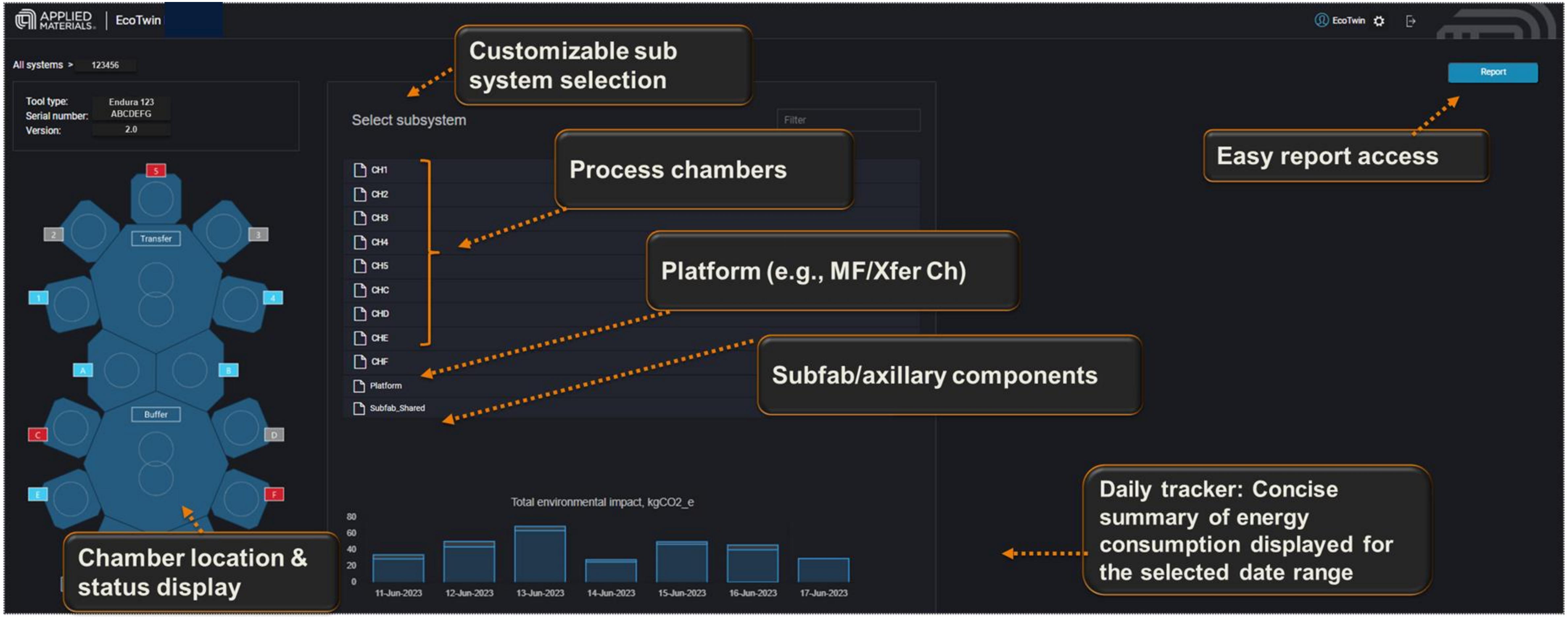


Extensive Quality and Reliability Analyses

EcoTwin™ | Technology Node versus Consumption Trends

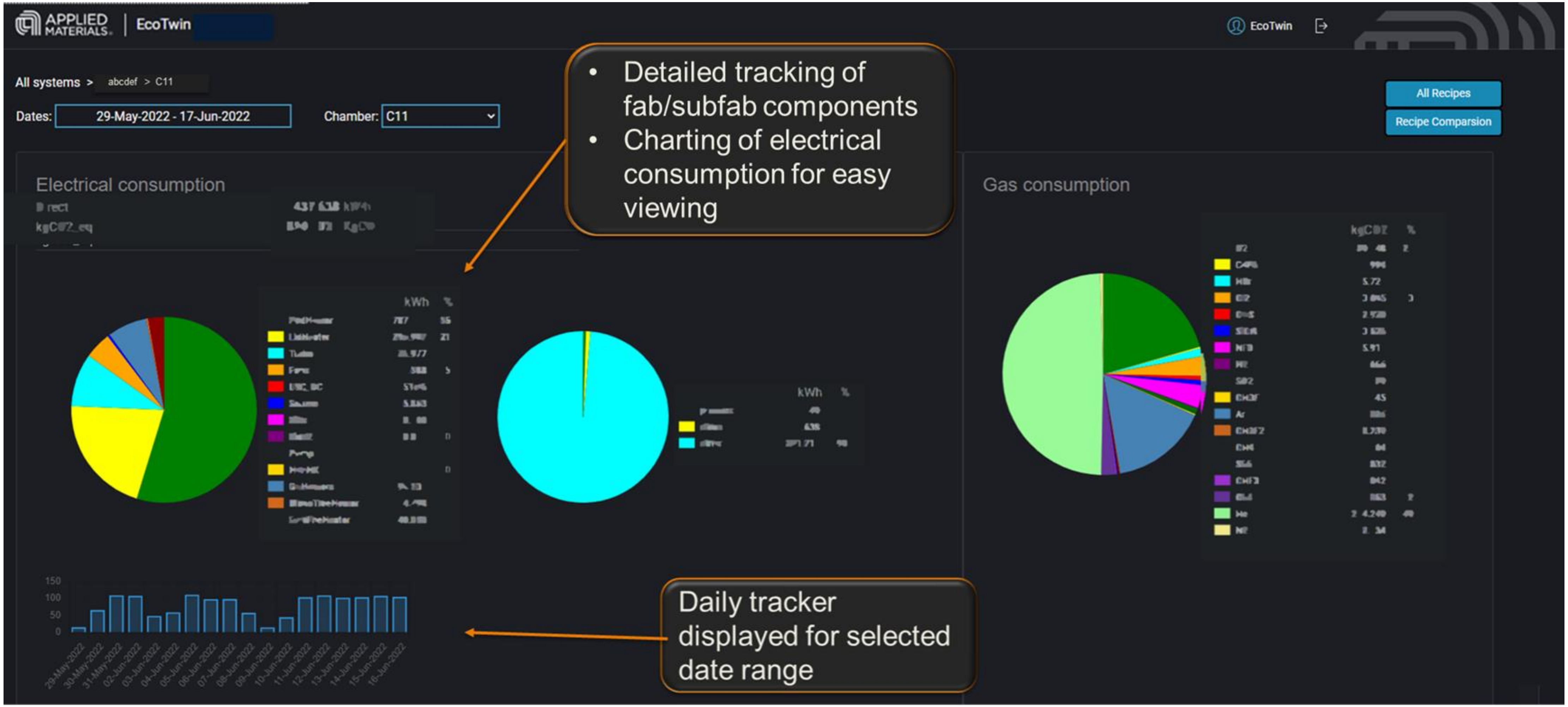


EcoTwin™ | Overall Consumption



A user-friendly visualization of overall consumption at fleet/tool/chamber at a glance

EcoTwin™ | Chamber Electrical and Chemical Consumption



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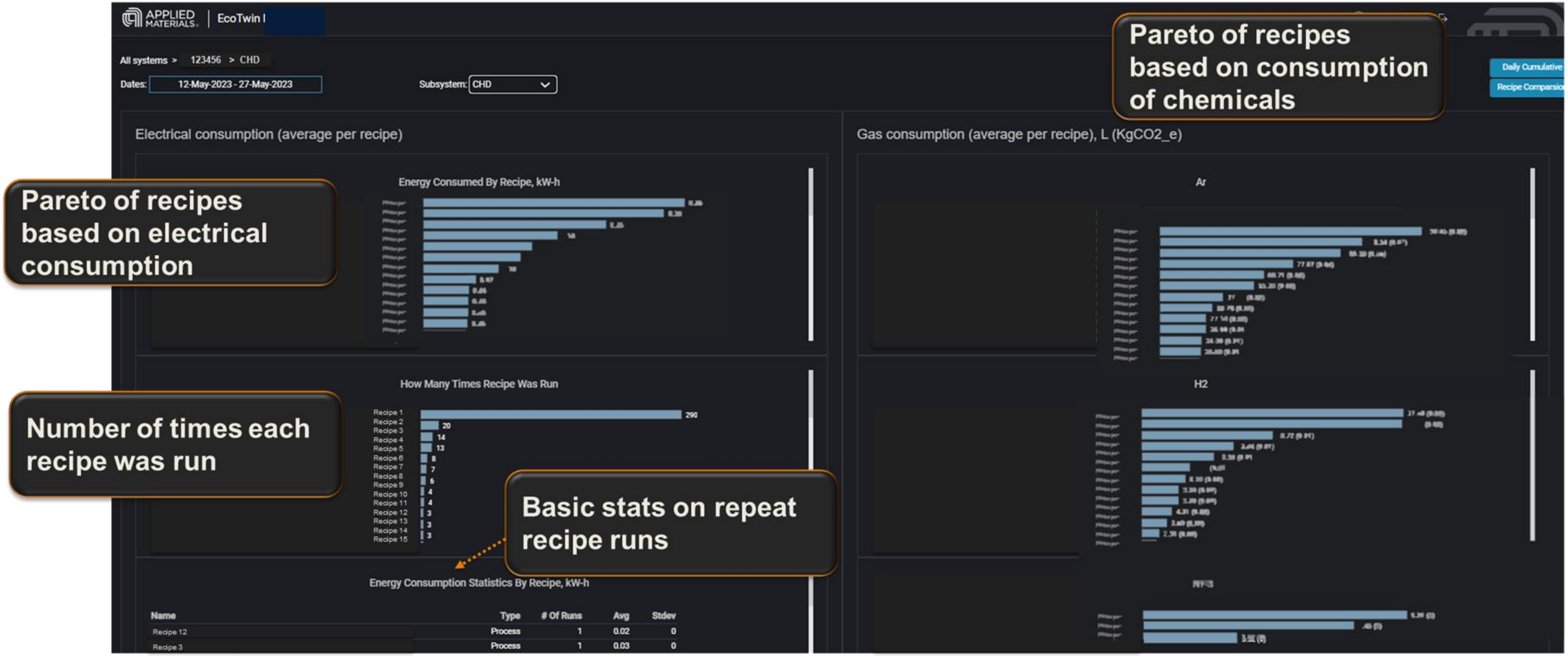
EcoTwin™ | All Recipes: Consumption Analysis



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EduTwin™ | Training and Education Through Models

There is a growing demand for workforce development

- While hands-on training is the most effective way
- Considering tool time availability is limited and costly
- And technology (process and hardware) Knowledge is scattered among busy experts

"US needs STEM workers to win semiconductor race."

USA Today 2023

"By 2030, more than one million additional skilled workers will be needed to meet demand in the semiconductor industry." *Deloitte* 2023

"US Universities are building new semiconductor workforce" *IEEE Spectrum* 2023

"America Faces Significant Shortage of Tech Workers in Semiconductor Industry and Throughout U.S. Economy"

Semiconductor Industry Association 2023

Developing a training platform based on digital twins to train fundamentals of semiconductor manufacturing

AppliedTwin™ | Summary and Take-aways

- **AppliedTwin framework was introduced** and examples of ChamberTwin, EcoTwin, and the concept of EduTwin was briefly discussed.
- At Applied, our vision is **a holistic digital twin architecture** representing the entire semiconductor process flow.
- Digital twins give us **opportunities** to accelerate concept creation, process exploration, prototyping, testing, knowledge sharing and talent development.
- While the opportunities of digital twins in semiconductor industry is immense, the **challenges are great** also. Understanding and incorporating proper physics, chemistry, domain knowledge, sensor accuracy, data strategy, ROM development, etc. will remain as highest priority.
- Physics alone won't be able to be accurate and predictive, and therefore, incorporating data-based (e.g., AI/ML) and hybrid (**physics and data**) models remains essential.

AppliedTwin™ | Challenges To Enable A True Virtual Fabrication

- Digital Twin Development
  - **Data Acquisition & Integration:** Stringent specs for devices directly impact process chamber requirements in terms of precision monitoring (sensors) and control of temperature, flow, concentration of precursors
  - **Materials:** property measurement and control (new materials)
  - **Model Complexity and Fidelity** (the physics and modeling approach): wide range of physical phenomena, including fluid flow, heat transfer, and electro-mechanics, and would necessarily include material properties.
  - **Real-time Synchronization and Updates**
  - **System-level approach:** Connecting reactor-level process knobs to on-wafer (or feature-level) characteristics
  - **Security and Privacy**
  - **Verification and Validation**
  - **Visualization and User Interfaces**

AppliedTwin™ | Challenges To Enable A True Virtual Fabrication

- Packaging specific challenges for Equipment
  - Wafers can be composed of **several materials** (Si, metals, dielectrics, epoxy, polymers, organics…), which demands for frequent and complex chamber clean, more difficult predictive maintenance, etc. This can be a major issue to customers who are especially more cost conscious in the packaging market due to many small players or ‘OSATs’ (Outsourced Semiconductor Assembly and Testing firms).
  - Due to the presence of organic material, **temperature overshoot** is carefully considered in designs. High temperatures may cause polymer glass transition and hence degradation/defects or destruction of device itself. This would potentially require more advanced temperature ramp control and prediction capabilities.
  - **Wafer warpage** monitoring and management can become more challenging.
  - Some **technologies are unique to HI** – microwave heating and curing of polymers, spray coating, and thermal curing in ovens need more sophisticated models.
  - **Device integration related** - Ability to predict the electrical performance of a specific structure or combination of packaging layers such as Through Silicon Via (TSV) + hybrid bonding under different process conditions. It is more challenging predict the performance of a truly heterogenous integrated package – with different chips, devices and vendors coming together.

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