



DigitalClone®

Your Digital Twins

# Sentient Science Mission

- ∞ Lower the cost of designing and operating [rotating] mechanical equipment
  - Digitalization of assets as digital twins
  - Providing tools to achieve life extension, sustainability and reliability
- ∞ Industry leader in advanced prognostic solutions
- ∞ Expertise in tribology, physics and data science
- ∞ Award winning solutions in Aerospace, Automotive, Defense, and Wind

# Innovative Solutions



2014 Tibbets Award



2016 New Energy Pioneer

**Bloomberg**  
NEW ENERGY FINANCE

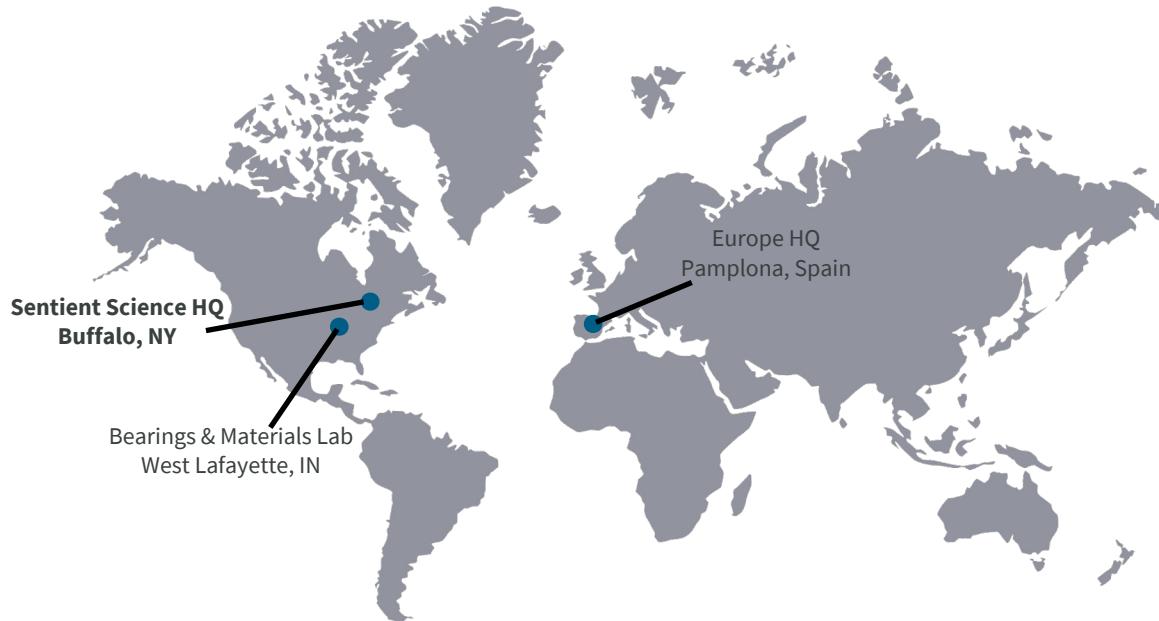


2017 North American Wind Energy Prognostics  
**New Product Innovation Award**



2020 Top 10 Companies  
Transforming Business

# Sentient Science



**Sentient Customers are in Automotive, Aerospace, Defense and Wind  
in North America and Europe**



# DigitalClone® : Your Digital Twin

DigitalClones® are digital twins of mechanical systems, such as wind turbines, rotorcraft, drivetrains and railroad tracks, that enable cost effective prediction of the short- and long-term failure rates and identification of life extension actions that reduce design and operational costs

Physics. Digitalization. Life Extension.

# DigitalClone Multi-Scale Framework



# Engineering SaaS Solutions



*DigitalClone® for*  
Engineering  
DC-E

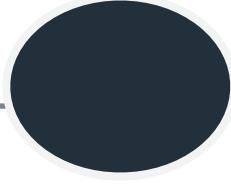
Build a model of each system and predict their life under various operating conditions

- New design
- Change in design
- Root Cause Analysis
- LifeX scenarios



*DigitalClone® for*  
Additive Manufacturing  
DC-AM

Build a model of an AM built part to predict as-built residual stress, distortion, grain distribution and porosity, as well as predict life under various loading conditions



*DigitalClone® for*  
Material Design & Discovery  
DC-MDD

Force-field (interatomic potential) generation tool kit to predict the power of the interatomic potential to design new materials and alloys, and study of the relationships between material structure, properties and processing outcomes

**Under Development**

# Enterprise-Level Maintenance SaaS Solutions



## *DigitalClone® for* Wind Operations & Maintenance DC-OM

Unified platform for assessing health status and performance of wind turbine major components and systems

Predict remaining useful life (RUL) of individual wind turbine Main Bearing (MB) and Gearbox (GBX)

Integrate third-party models of blades and structural components to estimate remaining load cycles until failure of the component



## *DigitalClone® for* Sustainment DC-S

Integrated physics-based and ML-based for sustainment planning from cradle to grave, in data-poor to data-rich environments

Enables design of block upgrades, high fidelity root-cause analysis, and reduced re-work on engineering change requests

**Under Development**

# Solution for Production



*DigitalClone® for*  
In-Situ Defect Monitoring and  
Correction  
DC-IM

Software embedded in AM machine  
controller to increase  
productivity and parts yield  
Enable close-loop feedback control  
for defect repair at real time

Under Development

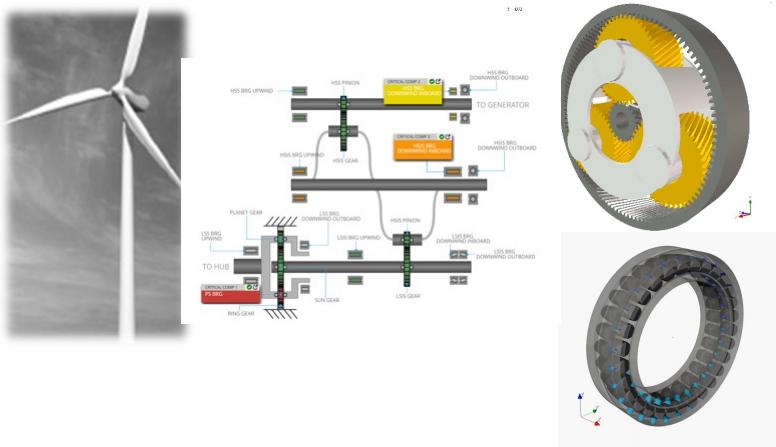


# Engineering Solutions

# Sentient Patented Critical Differentiation

## 1) System-Level Load Analysis

determine component hotspots

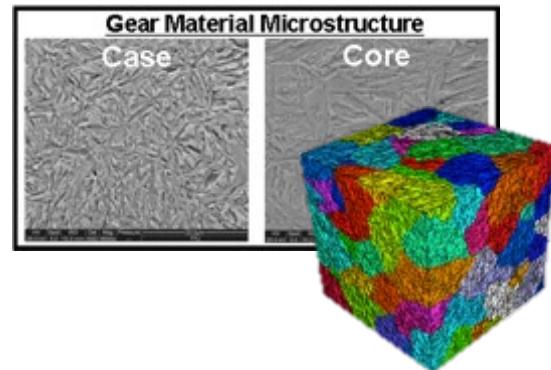


## 6) Generate Parameterized Response Surface



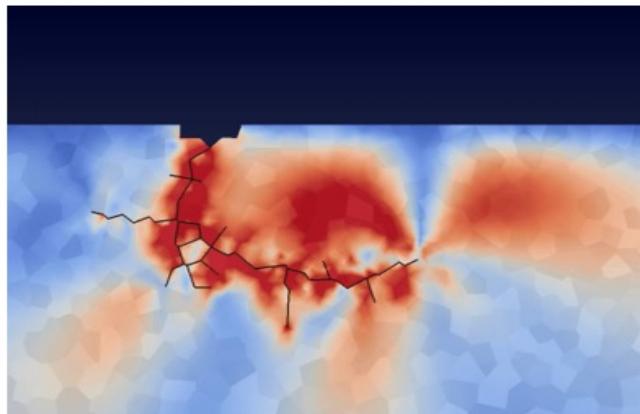
## 2) Material Model

characterize microstructure and determine bulk properties



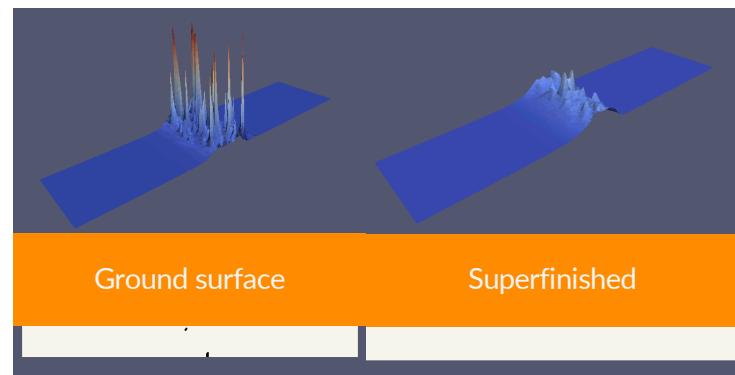
## 5) Assess Mechanical Failure

surface or subsurface initiated pitting



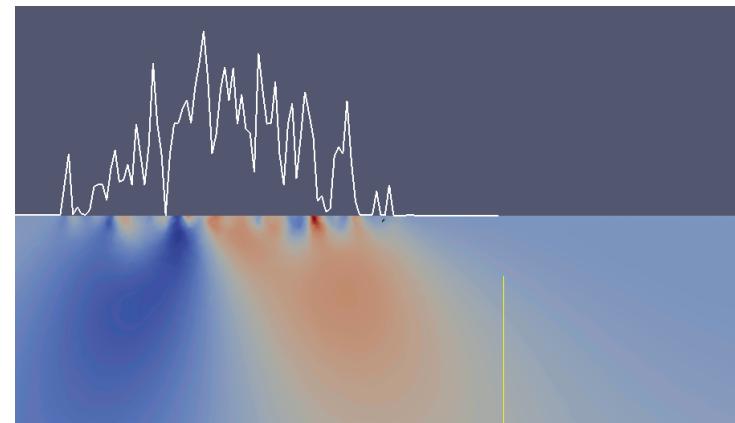
## 3) Surface Traction Analysis

surface characterization and mixed-EHL calculation



## 4) Material Response

determine damage evolution



# Components Break When Materials Fail

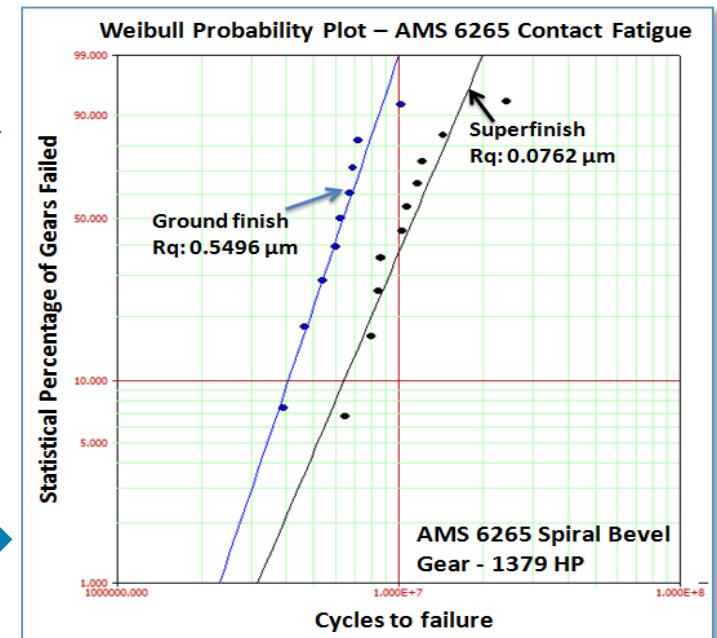
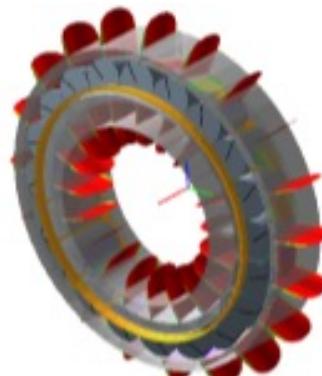
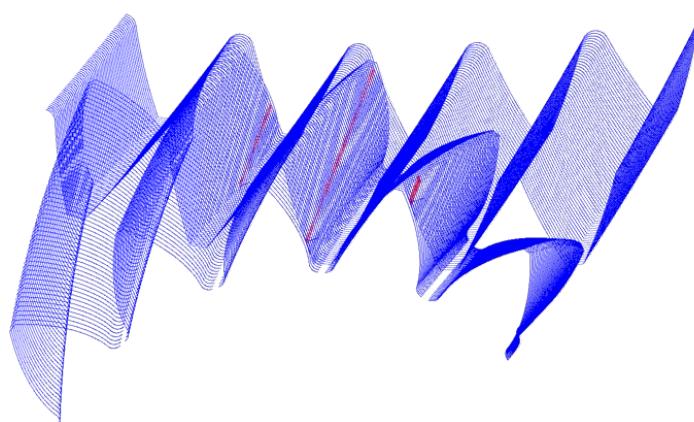
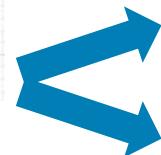
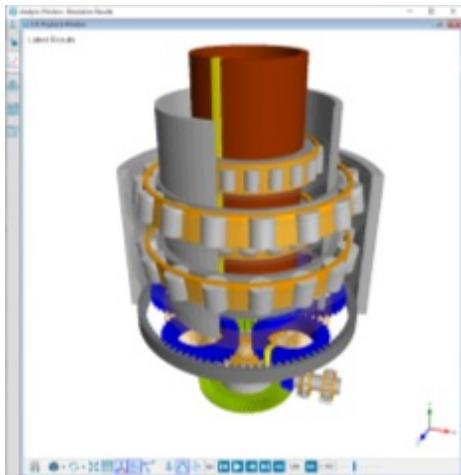
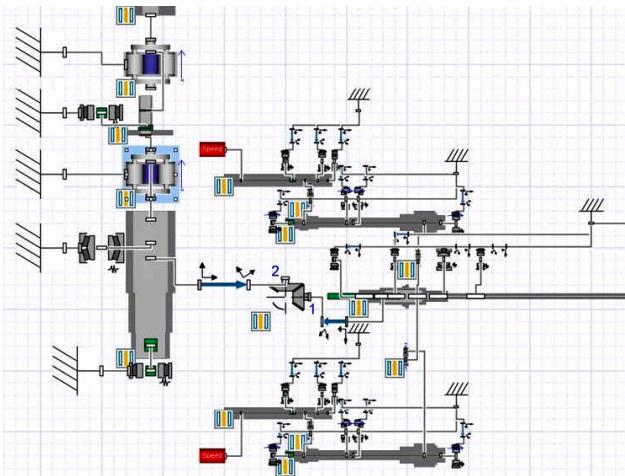
This behavior can be modeled with physics to predict the initiation of damage

Big Data (ML, AI) and sensor-based solutions are only effective in predicting expected life after initiation of damage

# DC-E Technology Differentiators

- ∞ A multi-body dynamics digital twin that uses physics-based models to make statistical life predictions of materials (SN curve), components (bearing and gear) and drive train systems
- ∞ World's only integrated solution from system modeling to component detailed analysis to simulation-based component life prediction
- ∞ No other solution incorporates microstructure-based life predictions

# DC-E



# DC-E Benefits to Customers

- ∞ Streamline historically iterative and expensive processes required to optimize designs to achieve reliability objectives and achieved up to 35% cost savings and 65% schedule compression for drive system development programs
- ∞ Virtually evaluate reliability impacts of alternative component supplier offerings
- ∞ Forecast sustainment burden for new designs in new applications without dependence on historical data

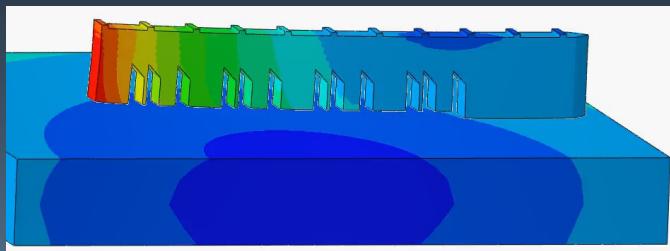
# DC-AM Technology Differentiators

- ⌚ Predict the grain structure, including porosity, to support optimal trades on required post-processing work to achieve target part properties
- ⌚ **Game-changing** patented approach to predicting onset of fatigue cracks based on microstructure-level models of damage initiation and early growth
- ⌚ Predict residual stress and distortion of a part before and after removal from the build plate to assess and ensure manufacturability

# DC-AM

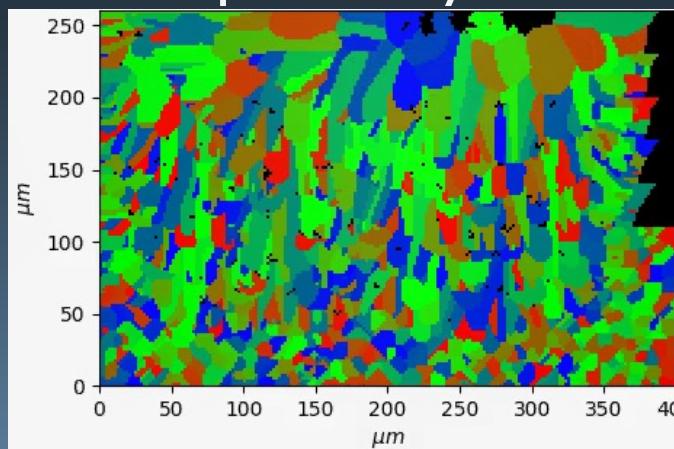
## Process Modeling

Predict residual stress and distortion



## Microstructure Modeling

Predict the grain structure and porosity



## Fatigue Modeling

Predict the fatigue damage initiation life

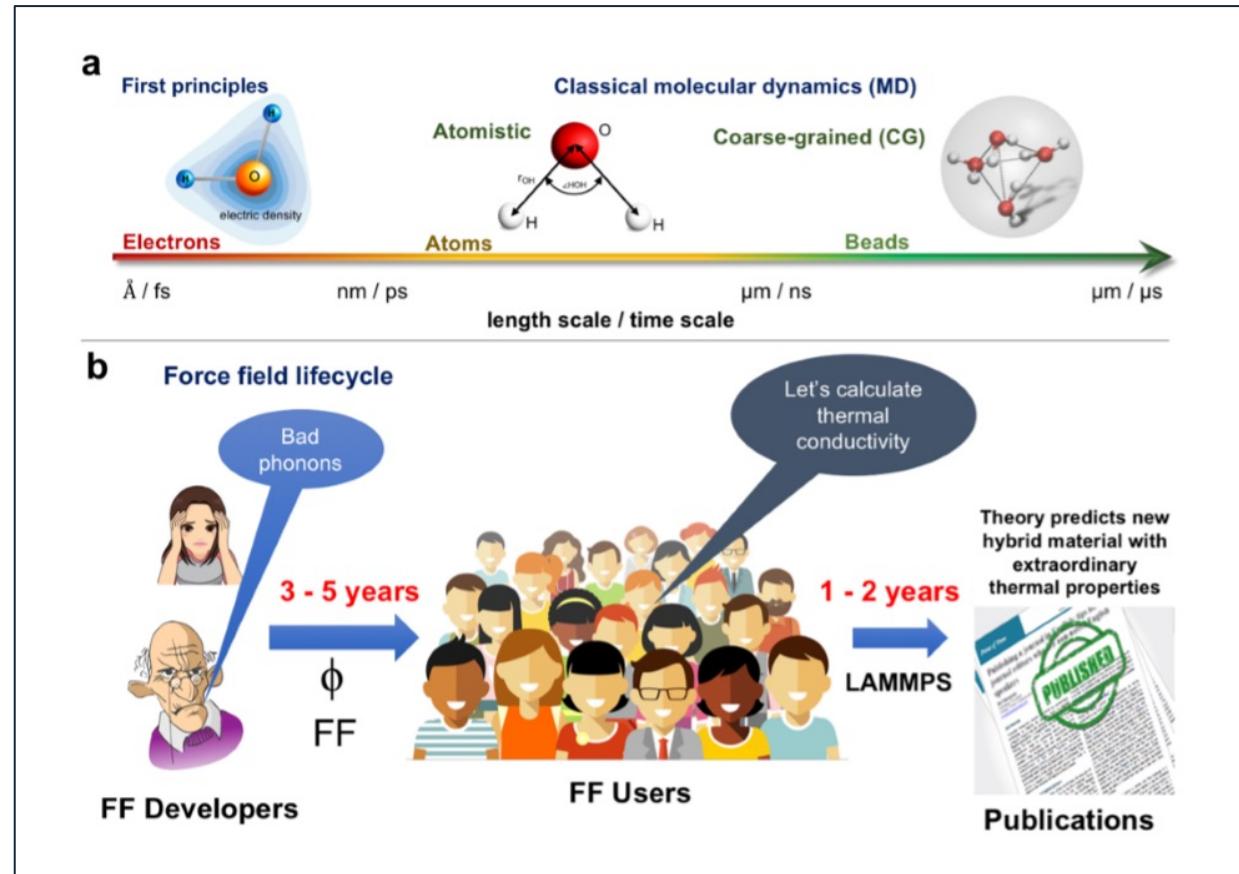


# DC-AM Benefits to Customers

- ∞ Enable “first time right” printing
- ∞ Uniquely links the process, microstructure and fatigue to reduce iterations for design optimization by 75% and decrease cost for AM part qualification by up to 50%
- ∞ Comprehensive suite of metal additive manufacturing (LPBF & DED) design and analysis support with seamless interoperability

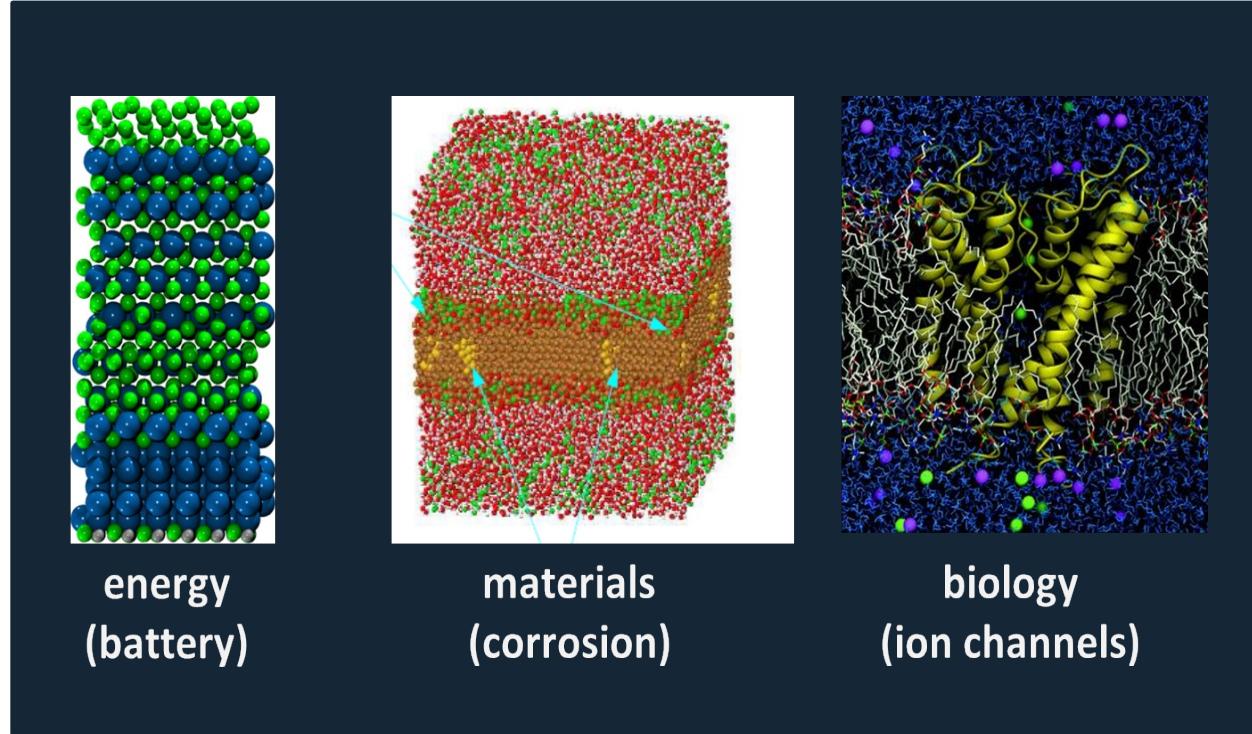
# DC-MDD Technical Differentiators

- ∞ DC-MDD addresses one of the most critical aspect of molecular dynamic simulations i.e. its predictive power of the interatomic potential used to describe the atomistic interactions in the system
  - Few research groups that focus on development of interatomic potential models
  - Development efforts often entail several human years of effort to generate a single robust and accurate potential model for any given system
  - Scientifically, existing force-fields have several limitations some of which are as follows:
    - Training set generated in most cases does not adequately represent the potential energy space
    - Substantial lack of quantitative cross-validation using properties that were not used in the fitting procedure



# DC-MDD Benefits to Customers

- ∞ DC-MDD enable users to overcome the timescale challenges without sacrificing accuracy
- ∞ DC-MDD empower users to develop their own force field
  - Heart of any molecular dynamics scheme is the force model used to analytically describe the atomistic interactions





# Maintenance Solutions

# DC-OM Technology Differentiators

- ∞ World's only holistic platform of physics-based, machine learning and data science-based models providing a visual representation of model outputs and estimating remaining useful life across many wind turbine technologies for major components and systems
- ∞ Powerful data ingestion, diversity and validation system to ensure the right data and quality at scale for structured and unstructured data.
- ∞ Customizable models to meet business unit objectives with expansion into physics driven models of structural and non-structural components for life extension options.

# DC-OM



Start with our standard models, customizable to what is most important for **YOUR** business unit. Visualization of a customized model, your way...



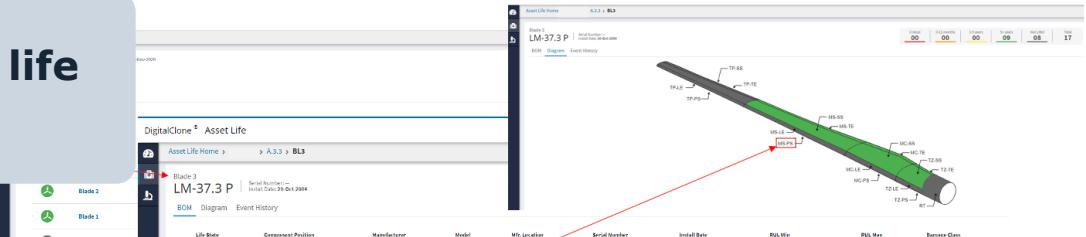
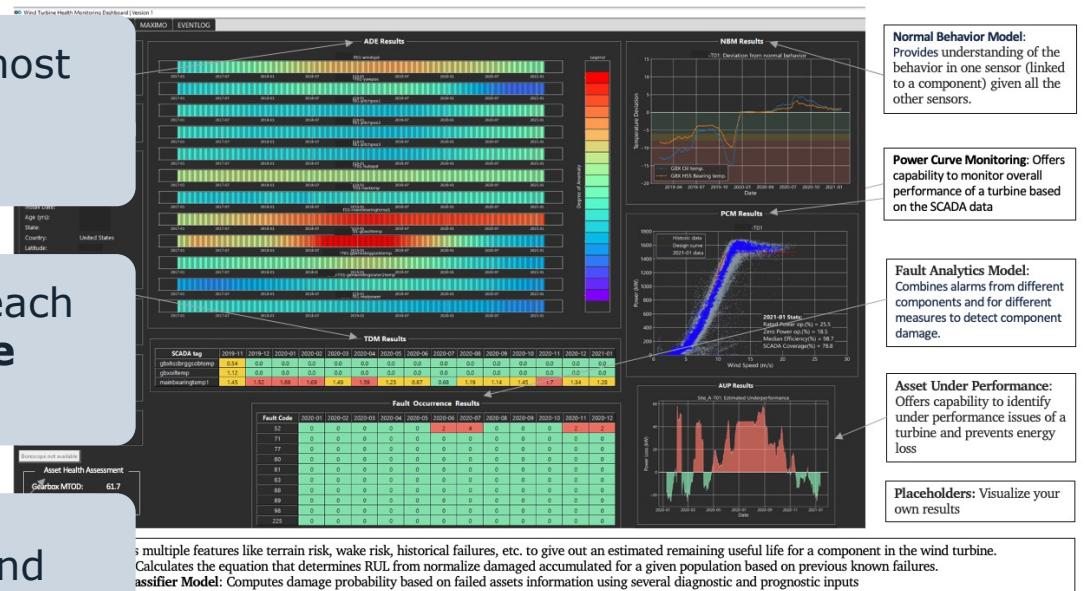
Use 'Turbine Storyteller' to discover the narrative behind each turbine using **Physics, Machine Learning, Data Science** Models



Centralized platform to **monitor turbine performance** and component health state.



Predictive maintenance planning using **remaining useful life** multi-model health state estimations.



**Run Models vs Labor Hours...Automated Insight → Inference → Action** to reduce overhead spend in Engineering, Asset Mgmt. & Operations



Physics. Digitalization. Life Extension.

[sentientscience.com](http://sentientscience.com)

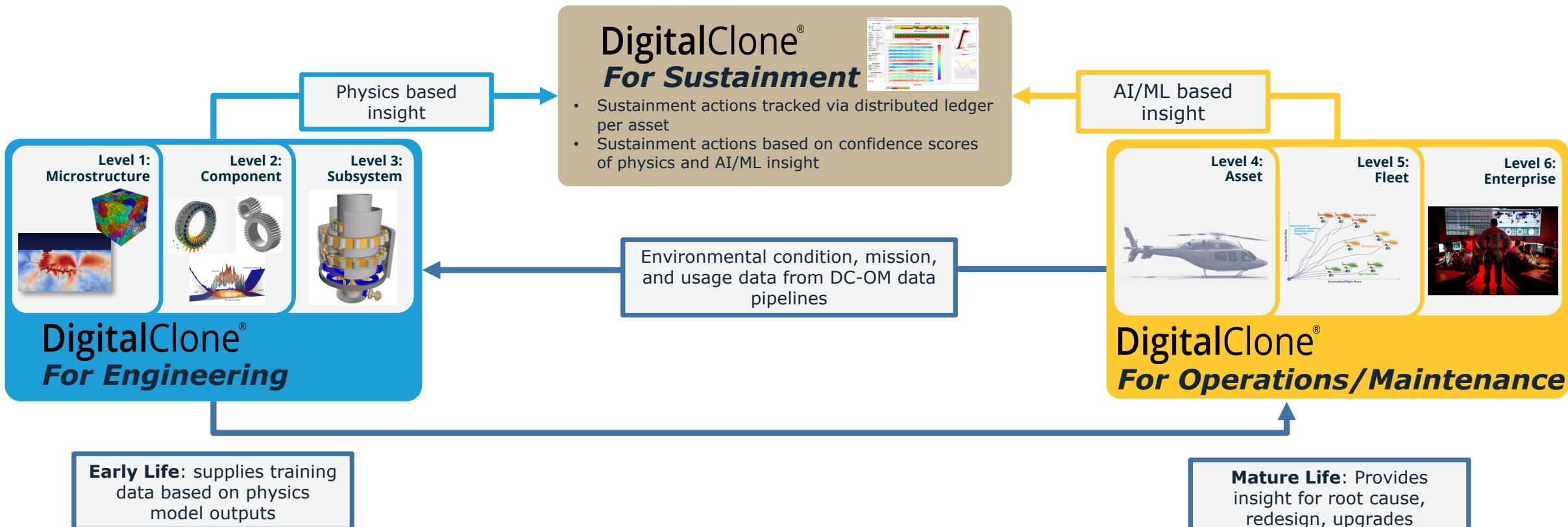
# DC-OM Benefits to Customers

- ∞ Deliver a predictive maintenance program to capture anomalies of turbine performance and emergent conditions that impact Engineering, Asset Management & Operations
- ∞ Increase production and turbine availability by identifying assets with component damage for intervention prior to high wind season
- ∞ Deliver a rolling long-term component life forecast for decisions that impact end of life strategy decisions for Repair, Replace, Retrofit

# DC-S Technology Differentiators

- ∞ Hybrid solution relying on physics at the early data-poor stage and increasingly on machine learning at the data-rich operational stage
- ∞ Supported by a secure infrastructure providing constant feedback on operational data confidence level and prediction confidence level
- ∞ Distributed ledger and data confidence fabric technology insure model and data provenance

# DigitalClone for Fleet Sustainment



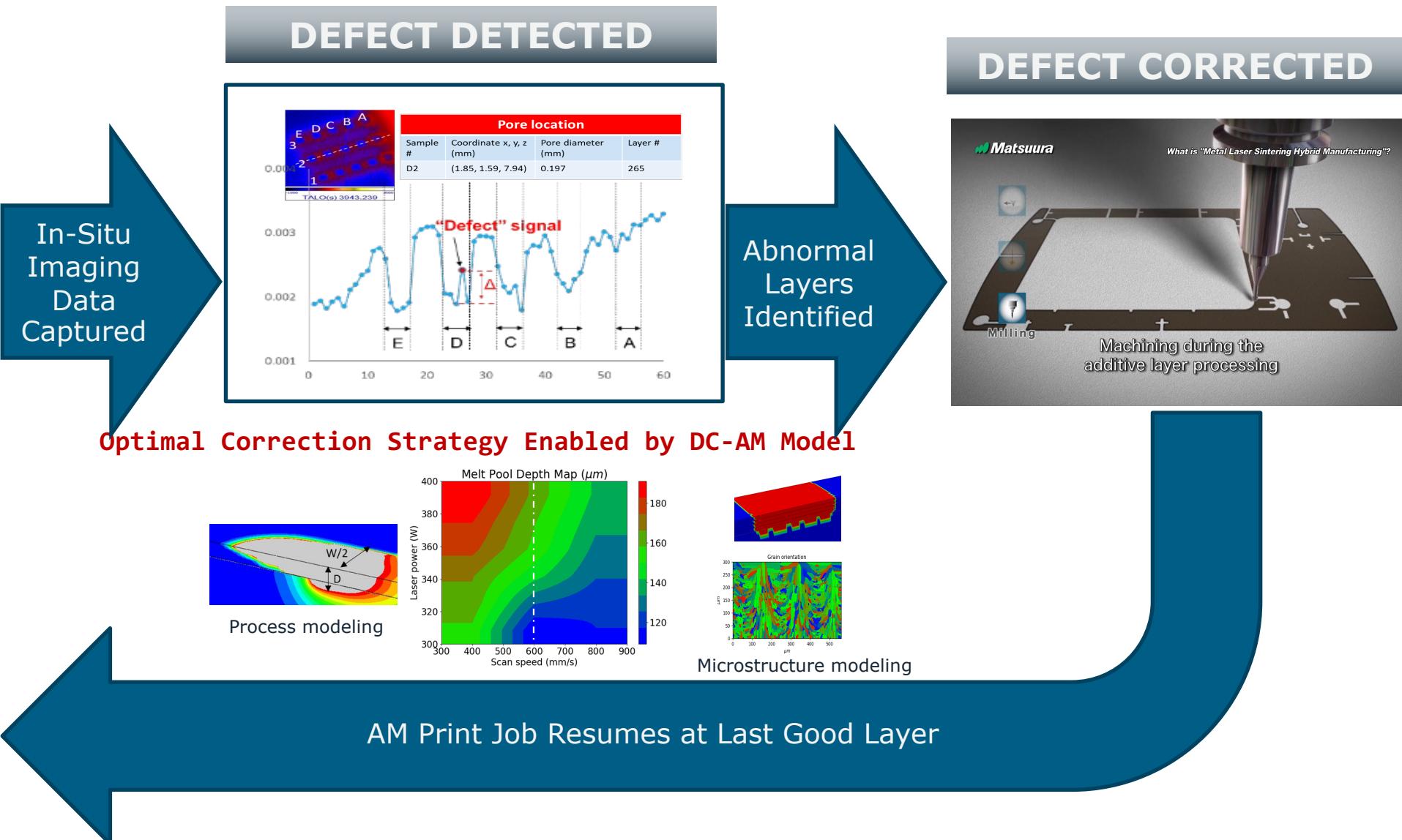
# DC-S Benefits to Customers

- ∞ Calibrate engineering models from field data, allowing for design of block upgrades, high fidelity root-cause analysis, and reducing re-work on engineering change requests
- ∞ Manage and track per tail sustainment actions, data, and model history for a comprehensive view of drivetrain state
- ∞ Compare parts from suppliers and choose replacement parts based on its effect on remaining useful life, lead time, and cost



# Solution for AM Production

# In-Situ Defect Detection & Correction for Additive Manufacturing



# Thank You

