Carbon Overview
THE PROMISE OF 3D MANUFACTURING

Conventional Manufacturing:
- Centralized production
- Inflexible infrastructure
- Costly inventory & logistics
- Volume economics are limiting

3D Manufacturing:
- On-demand production
- Local for local
- Flexible factory
- Cloud-based, data centric
- Mass customization
- Any-volume economics
Company Overview

- Founded in 2013
- >250 employees, HQ in Redwood City, CA
- 200+ Patents & Patent Applications
- Global installed base (US, EU, Asia)
- >$420M raised to-date
Carbon's Journey

- **2013**: Carbon is founded
- **2015**: M1 + dual cure resins
- **2016**: M2 + Part Washer
- **2017**: New validated production resins
  - New SW features (e.g. latticing)
  - New HW (resin dispensing)
## Polymer-Based 3D Printing Processes

<table>
<thead>
<tr>
<th>SOLID-BASED (FDM, SLS, MJF)</th>
<th>LIQUID-BASED (SLA, JETTING)</th>
</tr>
</thead>
<tbody>
<tr>
<td>✔ Familiar thermoplastics</td>
<td>✔ High resolution</td>
</tr>
<tr>
<td>✗ Anisotropy</td>
<td>✔ Fully dense parts</td>
</tr>
<tr>
<td>✗ Poor resolution</td>
<td>✗ Poor mechanical properties</td>
</tr>
<tr>
<td>✗ Porosity</td>
<td>✗ Limited, unproven materials</td>
</tr>
</tbody>
</table>
Three fundamental breakthroughs:

**Our Technology**

   - Layerless
   - Injection molded qualities
   - Best-in-class printer up-time
   - US Patent 9,498,920
   - US Patent 9,360,757
   - US Patent 9,211,678
   - US Patent 9,205,601

2. Modern Software: Securely Connected Architecture
   - Cloud-based
   - Regular upgrades until production
   - Traceability of digital process
   - New design tools (lattices, textures)

   - Wide range of proprietary materials
   - Unmatched mechanical properties
   - US Patent 9,676,963
   - US Patent 9,598,606
   - US Patent 9,453,142
Breakthrough 1 Continuous Liquid Interface Production (CLIP)

CLIP
New 3D Printing Method:
- No layers
- Production-quality properties
- Final quality surface finish

Harness light + oxygen to rapidly grow parts
Continuous Liquid Interface Production (CLIP)
Digital Light Synthesis (DLS)

<table>
<thead>
<tr>
<th>Radical Formation</th>
<th>$^{h\nu} \text{PI} \rightarrow \text{PI}^* \rightarrow 2\text{R}$ $^{k_d}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monomer Initiation</td>
<td>$\text{R} \cdot + \text{M} \rightarrow \text{RM}$ $^{k_i}$</td>
</tr>
<tr>
<td>Monomer Propagation</td>
<td>$\text{RM}<em>n \cdot + \text{M} \rightarrow \text{RM}</em>{n+1}$ $^{k_p}$</td>
</tr>
<tr>
<td>$O_2$ Photoinitiator Quenching</td>
<td>$^{h\nu} \text{PI} \rightarrow \text{PI}^* + O_2 \rightarrow \text{Quenching}$ $^{k_Q}$</td>
</tr>
<tr>
<td>$O_2$ Chain Propagation Quenching</td>
<td>$\text{RM} \cdot + O_2 \rightarrow \text{RMOO}$ $^{k_Q}$</td>
</tr>
</tbody>
</table>
Breakthrough Connected Devices & Modern 3D Manufacturing Software

- Cloud Based Computing
- Regular Over-the-Air Upgrades
- Improving Throughput Digitally
- Production Design Tools Tied to DLS

- Data Feedback & Analytics
- 360 Degree View of Customer

- Predictive Service
- Minimizing Downtime
- & Maintaining Quality
Print planner

Resin properties
- Dose-to-cure
- Molar absorptivity
- Viscosity
- Green strength of resin

Machine configuration
- Available light intensity
- Oxygen flux
- Pixel size

Part geometry
- Cross-sectional area
- Cavities
- “Hero” surface orientation

Desired operating conditions
- Accuracy
- Trade-off between resolution and speed
- Use of latent heat
- General Purpose Printer mode vs Manufacturing mode

“Print Button”
Key Problem: Most polymers aren’t light curable. How can we adapt other chemistries to a broader platform?
Dual Cure

New 3D Materials Method:

- Game-changing range of material choices
- Proprietary, unmatched mechanical performance characteristics
- US Patent 9,676,963
Programmable Liquid Resins

1. Liquid Programmable Resin

2. UV Light Cured Green Part
   - Continuous Liquid Interface Production shapes the part
   - Thermal curing locks mechanical properties
   - GREEN YOUNG'S MODULUS: 250-280 MPa

3. Thermally Cured Strong Part
   - CURED YOUNG'S MODULUS: 3800-4000 MPa
   - Post-bake an interpenetrating network of UV System and thermal system forms

Liquid resin with no cross-links

Cross-Linked UV system with an unreacted thermal system

Post-bake an interpenetrating network of UV System and thermal system forms

US Patent 9,676,963
Dual-Cure Resin Features

- Adhesive-free Bonding
- Broad range of chemistries
- Access to full color spectrum
- Production Scale & Pricing
- Automated Dispensing
Carbon Resin Families
CARBON’S EXPANDING FAMILY OF RESINS

**RPU** Rigid Polyurethane (Similar to ABS)
- Tough + abrasion resistant, stiff

**EPU** Elastomeric Polyurethane (Similar to TPU)
- Highly elastic, resilient

**EPX** Epoxy (Similar to 10% glass-filled PBT)
- Temperature resistant, strong, accurate

**FPU** Flexible Polyurethane (Similar to PolyPro)
- Tough, impact + abrasion resistant, moderate stiffness

**CE** Cyanate Ester (Similar to Ultem)
- High temperature resistant, strong, stiff

**SIL** Silicone-Urethane
- Soft touch, biocompatible, and tear resistant

**UMA** Urethane Methacrylate
- Rigid, fast prints

**Dental production**

**Third-party Materials**
- Clear, biocompatible, and prints fast and accurately
Expanding portfolio of dental resins

Family: Surgical guides
Resin: Whip Mix Surgical Guides for carbon printers

Family: Gingiva masks
Resin: Dreve Fotodent® gingiva for Carbon printers

Family: Impression trays
Resin: Dreve Fotodent® tray for Carbon printers

Family: Model production
Resin: Carbon’s DPR 10

Family: Impression trays
Resin: Carbon’s DPR 10

Family: Denture base
Resin: DENTCA Denture Base II for Carbon printers

Family: Denture teeth
Resin: DENTCA Denture Teeth for Carbon printers

First FDA-cleared 3D printed dentures

FDA-cleared (Class II) material, available in multiple shades

Green in color; ideal for fast production

Clear, biocompatible, prints fast and accurately

Pink in color, ideal for fast production

Prints fast and accurately
Carbon resins pass ISO 10993-5, -10

<table>
<thead>
<tr>
<th>METHOD</th>
<th>STATUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cytotoxicity</td>
<td>All resins pass</td>
</tr>
<tr>
<td>Irritation</td>
<td>UMA, RPU, CE, EPX, SIL, EPU</td>
</tr>
<tr>
<td></td>
<td>Other resins not yet tested</td>
</tr>
<tr>
<td>Sensitization</td>
<td>UMA, RPU, CE, EPX, SIL, EPU*</td>
</tr>
<tr>
<td></td>
<td>Other resins not yet tested</td>
</tr>
</tbody>
</table>

Note: Tests conducted in Q4 2016 by NAMSA
*Dermal contact only
**RPU Rigid Polyurethane**

RPU is our stiffest and most versatile polyurethane-based resin. It performs well under stress, combining strength, stiffness, and toughness.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate Tensile Strength</td>
<td>45 ± 2 MPa</td>
</tr>
<tr>
<td>Elongation at Break</td>
<td>100 ± 20%</td>
</tr>
<tr>
<td>Young’s Modulus</td>
<td>1900 ± 200 MPa</td>
</tr>
<tr>
<td>Impact Strength (Notched)</td>
<td>22 ± 1 J/m</td>
</tr>
</tbody>
</table>

UL-94 HB rating
FPU Flexible Polyurethane

FPU is a semi-rigid material with good impact, abrasion and fatigue resistance. This versatile material was designed for applications that require the toughness to withstand repetitive stresses such as hinging mechanisms and friction fits.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate tensile strength</td>
<td>29 ± 1 MPa</td>
</tr>
<tr>
<td>Elongation at break</td>
<td>280 ± 15%</td>
</tr>
<tr>
<td>Young's modulus</td>
<td>860 ± 110 MPa</td>
</tr>
<tr>
<td>Impact strength (notched)</td>
<td>40 ± 5 J/m</td>
</tr>
</tbody>
</table>
EPU Elastomeric Polyurethane

EPU is a high performance polyurethane elastomer. It exhibits excellent elastic behavior under cyclic tensile and compressive loads. EPU is useful for demanding applications where high elasticity, impact and tear resistance are needed such as cushioning, gaskets, and seals.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tear Strength</td>
<td>23 ± 3 kN/m</td>
</tr>
<tr>
<td>Elongation at Break</td>
<td>310 ± 25%</td>
</tr>
<tr>
<td>Compression Set</td>
<td>23%</td>
</tr>
<tr>
<td>Durometer</td>
<td>68, Shore A</td>
</tr>
</tbody>
</table>
**EPX Epoxy**

EPX is our most accurate high-strength engineering material. It has a heat deflection temperature of 140 °C, making it useful in a variety of automotive, industrial, and consumer applications.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ULTIMATE TENSILE STRENGTH</strong></td>
<td>88 ± 3 MPa</td>
</tr>
<tr>
<td><strong>ELONGATION AT BREAK</strong></td>
<td>5.2 ± 0.7%</td>
</tr>
<tr>
<td><strong>YOUNG’S MODULUS</strong></td>
<td>3140 ± 105 MPa</td>
</tr>
<tr>
<td><strong>IMPACT STRENGTH (NOTCHED)</strong></td>
<td>23 ± 5 J/m</td>
</tr>
</tbody>
</table>
Our Cyanate Ester-based resin is a high performance material marked by excellent strength, stiffness and long-term thermal stability.

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ULTIMATE TENSILE STRENGTH</strong></td>
<td>92 ± 13 MPa</td>
</tr>
<tr>
<td><strong>ELONGATION AT BREAK</strong></td>
<td>3.3 ± 0.8%</td>
</tr>
<tr>
<td><strong>YOUNG'S MODULUS</strong></td>
<td>3870 ± 140 MPa</td>
</tr>
<tr>
<td><strong>HEAT DEFLECTION TEMPERATURE</strong></td>
<td>230 ºC</td>
</tr>
</tbody>
</table>
**SIL Silicone Urethane**

SIL is a soft elastomeric material offering a unique combination of biocompatibility, low durometer, and tear-resistance. It is ideal for skin contact products such as headphones, armbands, and various attachments for wearables.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEAR STRENGTH</td>
<td>9.6 kN/m</td>
</tr>
<tr>
<td>ELONGATION AT BREAK</td>
<td>330%</td>
</tr>
<tr>
<td>ULTIMATE TENSILE STRENGTH</td>
<td>3.4 MPa</td>
</tr>
<tr>
<td>DUROMETER</td>
<td>35, Shore A</td>
</tr>
</tbody>
</table>
Applications
Adidas
Adidas Futurecraft 4D

- Breakthrough design and performance
- 10x number of design iterations
- Scale up:
  - 400,000 pairs in 2018
  - 2 million in 2019
  - 5 million 2020
- Path to mass

"With Digital Light Synthesis, we venture beyond limitations of the past, unlocking a new era in design and manufacturing. One driven by athlete data and agile manufacturing processes."

- Eric Liedtke
Adidas Group Executive Board Member Responsible For Global Brands
High Energy EPU Elastomeric Polyurethane

EPU41 is our next-generation elastomeric engineering material. It has higher energy return and improved cold temperature performance, making it useful in a variety of industrial and consumer applications.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHORE HARDNESS</td>
<td>76A</td>
</tr>
<tr>
<td>ELONGATION AT BREAK</td>
<td>190%</td>
</tr>
<tr>
<td>TEAR STRENGTH</td>
<td>19 kN/m</td>
</tr>
<tr>
<td>ULTIMATE TENSILE STRENGTH</td>
<td>13 MPa</td>
</tr>
<tr>
<td>ENERGY RETURN</td>
<td>84%</td>
</tr>
<tr>
<td>GLASS TRANSITION TEMPERATURE</td>
<td>-9°C</td>
</tr>
</tbody>
</table>

![Stress-strain graph](image)

![Energy Return graph](image)
## EPU Durability Testing for Footwear

<table>
<thead>
<tr>
<th>Validation Test</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>UV stability (550W, 70°C, 2hrs)</td>
<td>Pass (both color fastness and properties)</td>
</tr>
<tr>
<td>Hydrolytic stability (70°C, 95% RH, 7 days)</td>
<td>Pass</td>
</tr>
<tr>
<td>Temperature cycling (-20°C to 40°C)</td>
<td>Pass</td>
</tr>
<tr>
<td>Compression cycle testing (100,000 cycles)</td>
<td>Pass</td>
</tr>
<tr>
<td>Wear testing (machine &amp; athlete)</td>
<td>Pass</td>
</tr>
<tr>
<td>Notched fatigue cycling (100,000 cycles)</td>
<td>Pass</td>
</tr>
<tr>
<td>Plastic deformation (20% strain, 1000 cycles)</td>
<td>Pass</td>
</tr>
</tbody>
</table>
DURABILITY PERFORMANCE

Cycles to failure

- SLS: < 30,000 cycles
- Carbon: > 100,000 cycles
EXAMPLE LATTICE ELASTOMER STRUCTURES
ELASTOMER LATTICE UNIT-CELL LIBRARY: TUNABLE STRESS/STRAIN BEHAVIOR BY APPLICATION
Automotive
### Developing for automotive-specific requirements

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>CONSIDERATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical</td>
<td>Modulus, yield strength</td>
</tr>
<tr>
<td>Impact</td>
<td>Izod, Charpy &amp; Gardner/Dupont across temperature range</td>
</tr>
<tr>
<td>Thermal</td>
<td>Heat deflection and Vicat softening temperatures</td>
</tr>
<tr>
<td>Climactic Aging</td>
<td>Ability to withstand thermal/humidity cycling</td>
</tr>
<tr>
<td>Chemical Resistance</td>
<td>Ability to withstand exposure to common interior/exterior chemicals</td>
</tr>
<tr>
<td>Emissions</td>
<td>Smell and emissions tests (VDA 270, VDA 276, VDA 278)</td>
</tr>
<tr>
<td>UV Stability</td>
<td>Color fastness and gloss after accelerated UV exposure</td>
</tr>
<tr>
<td>Flammability</td>
<td>Passes horizontal burn testing (FMVSS 302)</td>
</tr>
<tr>
<td>Scratch/Mar/Abrasion</td>
<td>Ability to resist surface damage</td>
</tr>
</tbody>
</table>
2 Categories of Auto Resins Identified:

- **Rigid, High Temp:**
  Carbon Resins: New EPX, Auto-I
  Thermoplastic targets: Glass-Filled Nylon/PBT
  Applications: Connectors, brackets, harnesses

- **UV-stable, flexible, impact resistant:**
  Carbon Resins: Auto-D
  Thermoplastic targets: Polypropylene, ABS
  Applications: Badges, buttons, vents, hard trim, console
**RPU70 Rigid Polyurethane**

General purpose tough, rigid plastic
Comparable to ABS

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Modulus</td>
<td>1400-1600 MPa</td>
</tr>
<tr>
<td>Tensile Yield Strength</td>
<td>40-45 MPa</td>
</tr>
<tr>
<td>Elongation at Break</td>
<td>120-140%</td>
</tr>
<tr>
<td>Impact Strength (Notched)</td>
<td>28-30 J/m</td>
</tr>
<tr>
<td>Heat Deflection Temperature</td>
<td>70°C</td>
</tr>
</tbody>
</table>

Passed UV colorfastness testing “...for all interior/exterior zones”

14 months of elemental exposure
Next Gen Epoxy Resin

Our next-generation epoxy is a high-strength engineering material offering long-term durability. It has functional toughness, high heat deflection temperature, and good abrasion resistance making it useful in a variety of automotive and industrial applications.

**TENSILE YIELD STRENGTH**  
75 MPa

**ELONGATION AT BREAK**  
10%

**YOUNG'S MODULUS**  
2900 MPa

**IMPACT STRENGTH (NOTCHED IZOD)**  
50 J/m

**HEAT DEFLECTION TEMPERATURE**  
130°C

**THERMAL STABILITY**  
Passes 1000hr heat stability test at 125 °C
**Properties comparison**

<table>
<thead>
<tr>
<th></th>
<th>RPU 70</th>
<th>New EPX</th>
<th>EPX 81</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Modulus</td>
<td>1600 MPa</td>
<td>2900 MPa</td>
<td>3400 MPa</td>
</tr>
<tr>
<td>Yield Strength</td>
<td>46 MPa</td>
<td>79 MPa</td>
<td>86 MPa</td>
</tr>
<tr>
<td>Elongation (break)</td>
<td>100%</td>
<td>12%</td>
<td>5%</td>
</tr>
<tr>
<td>Izod (notched)</td>
<td>25 J/m</td>
<td>55 J/m</td>
<td>20 J/m</td>
</tr>
<tr>
<td>Izod (unnotched)</td>
<td>500 J/m</td>
<td>450 J/m</td>
<td>300 J/m</td>
</tr>
<tr>
<td>HDT (64 psi)</td>
<td>70°C</td>
<td>130°C</td>
<td>145°C</td>
</tr>
</tbody>
</table>

*Dot size represents tensile modulus*
New EPX vs. EPX 81: Key Improvements

- Higher functional toughness, New EPX exhibits ductile fracture
- Significantly better long-term durability

New EPX Impact strength: 50 J/m, exhibits ductile fracture

EPX81 Impact strength: 20 J/m, exhibits brittle fracture

Fracture surfaces after notched Izod impact
New EPX Chemical Compatibility

**Results:** Test New EPX to USCAR-2 fluids compatibility standards

Excellent chemical compatibility with >95% retained mechanical properties for almost all chemicals
Auto-Interior Resin (in development)

Temperature & impact resistance, UV stable
Comparable to unfilled thermoplastics

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TENSILE MODULUS</strong></td>
<td>1000-1200 MPa</td>
</tr>
<tr>
<td><strong>TENSILE YIELD STRENGTH</strong></td>
<td>30-40 MPa</td>
</tr>
<tr>
<td><strong>ELONGATION AT BREAK</strong></td>
<td>&gt;50%</td>
</tr>
<tr>
<td><strong>IZOD IMPACT (NOTCHED, RT)</strong></td>
<td>&gt;100 J/m</td>
</tr>
<tr>
<td><strong>IZOD IMPACT (NOTCHED, -40°C)</strong></td>
<td>50 J/m</td>
</tr>
<tr>
<td><strong>GARDNER IMPACT (TEST GC, RT)</strong></td>
<td>&gt;25 J</td>
</tr>
<tr>
<td><strong>HEAT DEFLECTION TEMPERATURE</strong></td>
<td>&gt;120°C+</td>
</tr>
</tbody>
</table>

Passes interior UV zones
Passes interior/exterior thermal cycling
Passes interior chemical resistance
Passes interior odor & fogging
Materials Roadmap
New resins are the biggest lever to increase Carbon’s TAM

2016 - 2017 Resins: General use and Early Adopter Production

- EPX - connectors
- FPU - enclosures
- CE - fluidics
- RPU - nozzle
- EPU - foam replacement
- Surgical guides
- DPR - models
- EPU - midsoles

2018 - 2019 Resins: Validated Production Focus

- Auto
- Dental
- Medical
- Aero