Lowell Center for Sustainable Production
UNIVERSITY OF MASSACHUSETTS LOWELL

# Alternatives Assessment Webinar:

## 3D Printing: Emerging hazards and the application of alternatives assessment

**NOVEMBER 21, 2017**

**FACILITATED BY: JOEL TICKNER, SCD**

**JOEL_TICKNER@UML.EDU**
**LOWELL CENTER FOR SUSTAINABLE PRODUCTION, UMASS LOWELL**

** If you would like to ask a question or comment during this webinar please type your question in the Q&A box located in the control panel.*

# Goals

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- Continuing education and dialog
- To advance the practice of alternatives assessment for informed substitution across federal, state, and local agencies through networking, sharing of experiences, development of common approaches, tools, datasets and frameworks, and creation of a community of practice.

# Purpose of this call

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3D printing technology is developing rapidly; impacting the the commercialization of many types of industrial and consumer products

Range of benefits of additive manufacturing innovations are expected: improved performance, production efficiency and broader manufacturing access.

Potential risks?

- New and known hazards across the technology life cycle?
- New exposure scenarios for workers, users, communities?
- Readiness of our occupational health and safety infrastructure?

# Webinar questions and questions for discussion:

- What are the possible chemical and material hazards associated with 3D printing?
- What are the new challenges to protecting consumers, workers, and communities posed by this technology?
- What are important considerations to drive safer chemical/material decisions?
- How could alternatives assessment be used inform safer chemical and material choices and what is needed for this approach to be used?

# Today's Speakers

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**Gary Roth**, Health Scientist, National Institute for Occupational Safety and Health

**Justin Bours**, Materials and Polymer Scientist, Cradle to Cradle Products Innovation Institute

**Lauren Heine**, Executive Director, Northwest Green Chemistry

# Webinar Discussion Instructions

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- Due to the number of participants on the Webinar, all lines will be muted
- If you wish to ask a question, please type your question in the Q&A box located in the drop down control panel at the top of the screen
- All questions will be answered at the end of the presentations
- Call is being recorded

**Gary Roth**, Health Scientist, National Institute for Occupational Safety and Health

NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH

NTRC NANOTECHNOLOGY RESEARCH CENTER

# Additive Manufacturing: Emerging Technology, Potential Hazards, and Opportunities

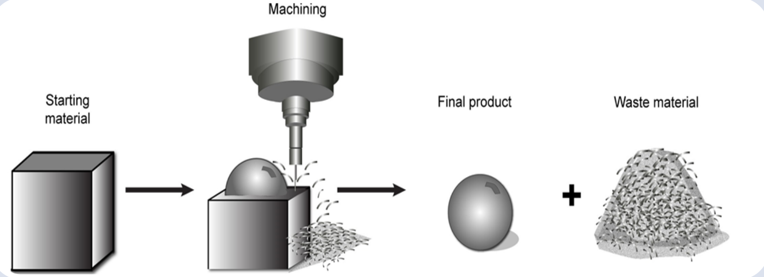
**Gary Roth, PhD**
**Health Scientist / Associate Service Fellow**

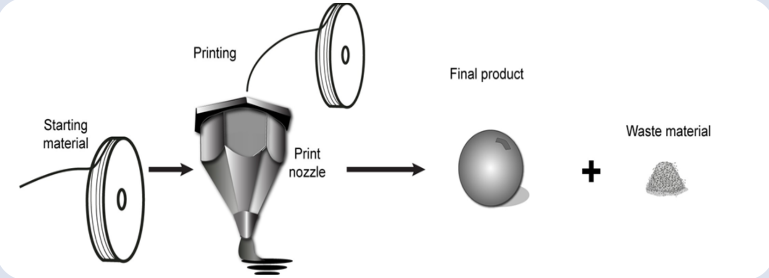
**3D Printing: Emerging Hazards and the Application of Alternatives Assessment**
**Interagency Alternatives Assessment Working Group Webinar**
**21 November 2017**



CDC Workplace Safety and Health NIOSH

# Traditional vs Additive Manufacturing




## Traditional

- Established
- More material options
- Consistent quality
- Higher throughput

## Additive

- Minimal waste material
- Complex features
- Fewer tools
- Processes easily modified

Image source: United States Government Accountability Office, 2015.

# Benefits of Additive Manufacturing

### Development

- Computer-Aided Design (CAD)
- Rapid iteration
- More innovation space

### Products

- More complex parts
- Novel geometries
- Efficiently use high-cost materials
- Customization

### Logistics

- Lower material use
- Fewer tools
- Just-in-Time fulfillment
- Distributed manufacturing

# Market Impact of Additive Manufacturing

$5 Billion market

26% CAGR

- Automotive
- Aerospace
- Medical
- Electronics
- Consumer

1. McCue 2016.

# Safety & Health is complex for Additive Manufacturing

- Additive manufacturing is a collection of technologies (not just one)
- Additive manufacturing speeds innovation, requiring continuous adaptation
- Additive manufacturing is being adopted by a wide variety of users

# Taxonomy

- Additive Manufacturing
  - *Liquid Feedstock*
    - **Vat Polymerization**
      - Stereolithography
      - Digital Light Processing
    - **Material Jetting**
  - *Solid Feedstock*
    - **Material Extrusion**
      - Fused-Filament Fabrication
    - **Sheet Lamination**
  - *Powdered Feedstock*
    - **Powder-Bed Fusion**
      - Selective Laser Sintering / Melting
      - Electron Beam Melting
      - Selective Heat Sintering
    - **Binder Jetting**

# Material Extrusion

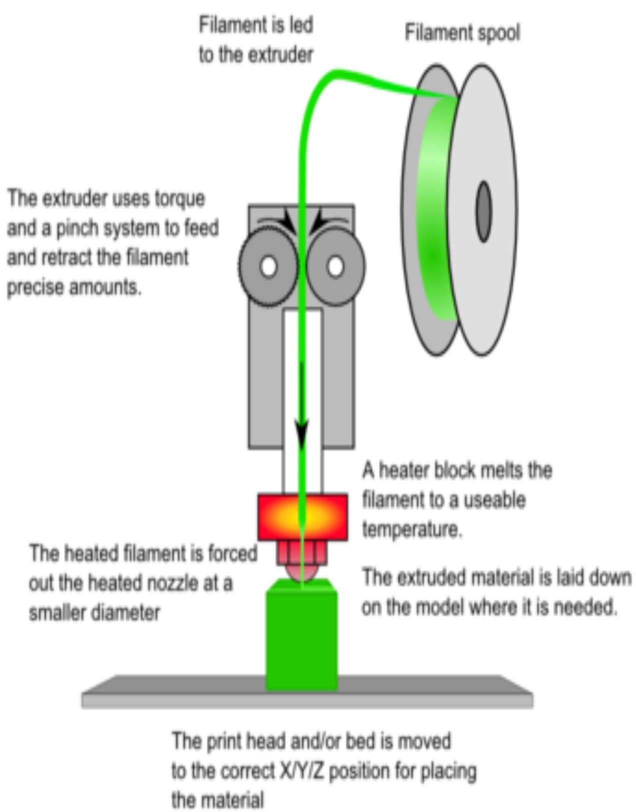



Image source: Spiritdude, 2012.

**Description:** A thermoplastic filament is heated to molten state, deposited, and bound by cooling to solid.

**Recent developments:**

- Additives (metals & nanomaterials)
- Post-processing (sintering)

**Potential Health & Safety Hazards:**

- VOC & particulate inhalation
- Exposures to filament additives
- Burns

# Powder Bed Fusion

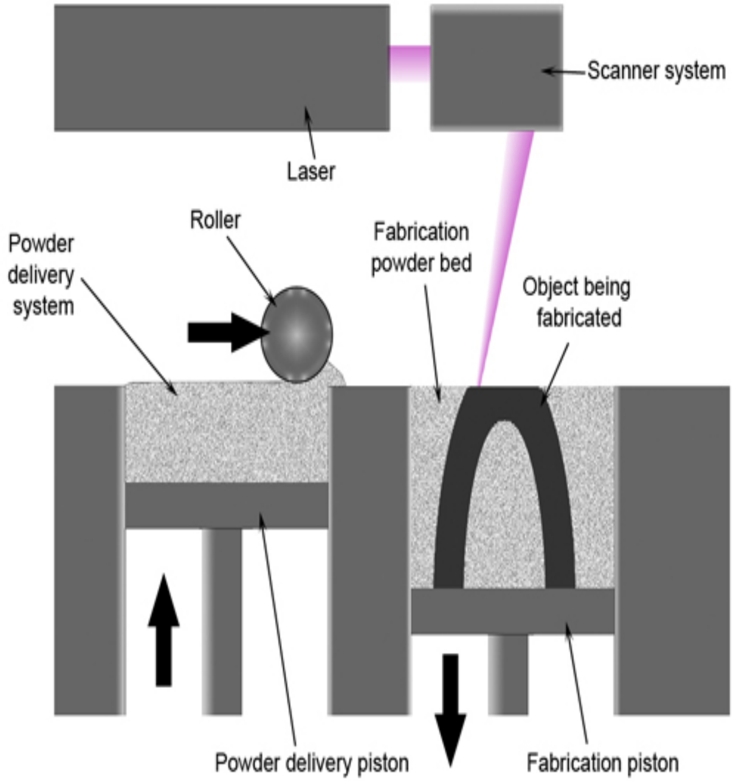



Image source: Materialgeeza, 2008.

**Description:** A powdered material (metal, ceramic, or plastic) sintered or melted by a heating element, laser beam, or electron beam.

**Recent developments:**

- New metals & alloys
- Additives
- Larger build volumes

**Potential Health & Safety Hazards:**

- Particulate & fume inhalation exposures
- Dermal exposures
- Fire & Explosion
- Laser & radiation exposure
- Asphyxiation (compressed gas usage)

# Vat Polymerization

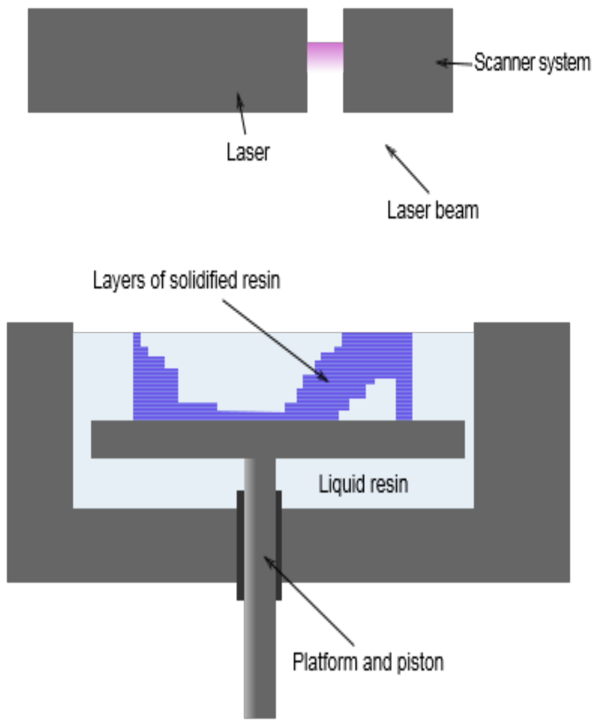



Image source: Materialgeeza, 2013.

**Description:** A vat of liquid photopolymer resin is selectively polymerized by a laser beam or projected light image.

**Recent developments:**

- New polymer resin blends
- Improved speed

**Potential Health & Safety Hazards:**

- VOC inhalation exposures
- Dermal exposures
- Fire
- Exposure to uncharacterized materials
- Laser & ultraviolet light exposure

# Potential Material Exposures from Additive Manufacturing

## Polymers

- Acrylonitrile-butadiene-styrene
- Polylactic acid
- Propylene fumarate
- Poly(vinyl alcohol)
- Polycarbonate
- Polyethylene
- Polystyrene

## Solvents

- Dimethyl fumarate
- Isopropanol
- Acetone
- Methyl Ethyl Ketone
- 2-Butanone

## Metals

- Ti-6Al-4V
- IN 625 & IN 718 (Ni, Cr)
- 17-4 PH stainless steel
- Cobalt chromium

## Nanomaterials

- nFe (steel sintering)
- nAg (sintering, conductivity)
- nCB, CNT (conductivity, stiffness, tensile strength)
- $nSiO_x$ (polymer strength)

# Users adopting Additive Manufacturing

Large Enterprises

Small-to-Medium Enterprise

Service Locations

Hospitals

Schools

Libraries

**Users may differ in terms of …**

- Budget for OSH activities (controls)
- Expertise (in both OSH and additive manufacturing)
- Synergistic exposures
- Communication preferences
- Decision-making structure
- Safety culture
- Demographics

Image sources:
GE Additive, 2017a.
Open Biomedical Initiative, 2016.
Sols Systems, 2016.
Bloomington Public Schools, 2014.
GE Additive, 2017b.
Florida Public Library, 2017.

# Additive Manufacturing Summary

- Large market impact in multiple sectors
- Includes many materials and processes, with differing hazards
- Users and applications vary, complicating analysis
- Significant opportunities for safety and health improvement

# Works Cited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- United States Government Accountability Office (2015) 3D Printing: Opportunities, Challenges, and Policy Implications of Additive Manufacturing. GAO-15-505SP.

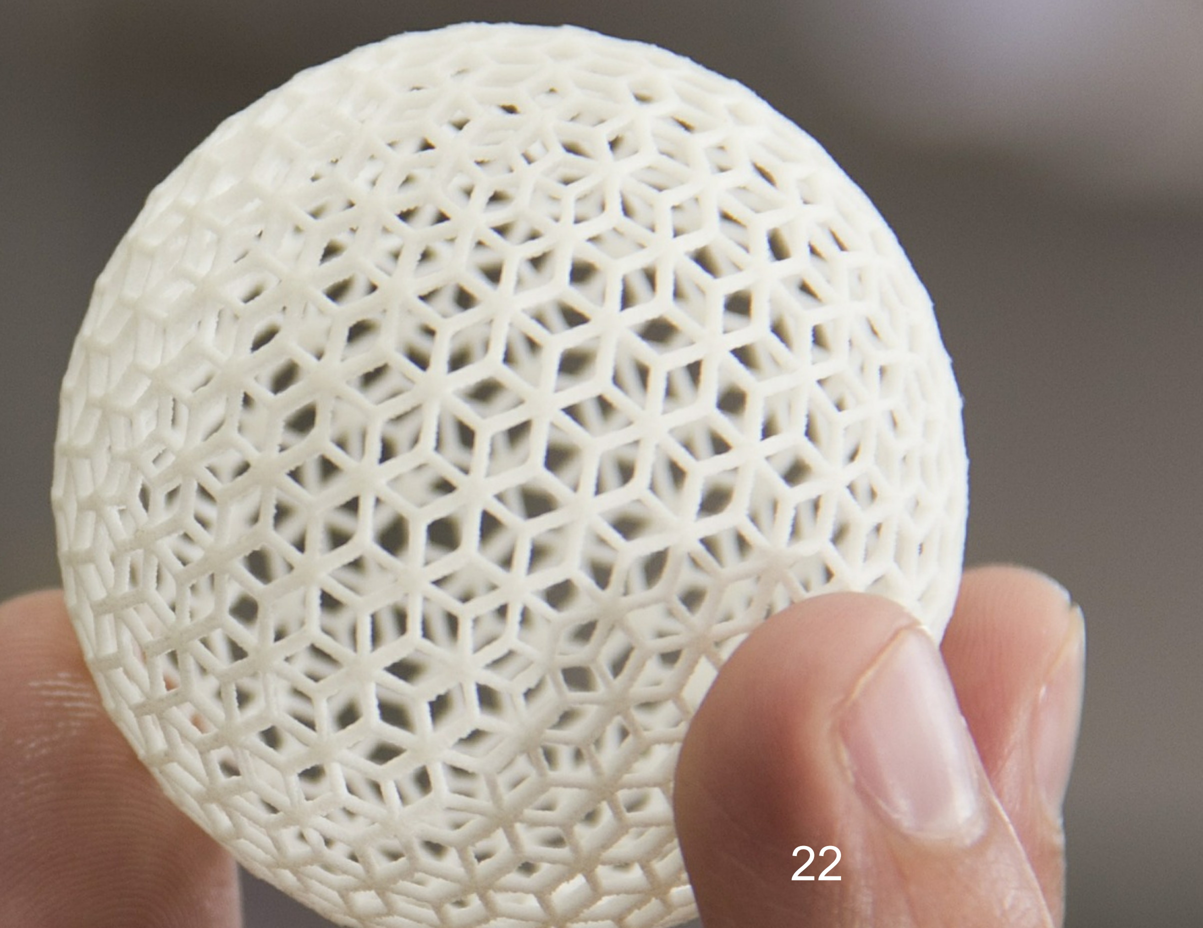
**Justin Bours**, Materials and Polymer Scientist, Cradle to Cradle Products Innovation Institute

**Lauren Heine**, Executive Director, Northwest Green Chemistry

# Measuring and Addressing the Growing Impacts of Additive Manufacturing

Justin Bours, Lauren Heine

Northwest Green Chemistry, Cradle to Cradle Products Innovation Institute



Northwest Green Chemistry

cradletocradle

AUTODESK.

Berkeley Center for Green Chemistry

# The **promise** of AM manufacturing

“**3D-electronics printers** could one day **make circuit boards a thing of the past**… You can design electronics to fit the part rather than design the part around the electronics’ dimensions”

*–Daniel Oliver, cofounder of Voxel8, Autodesk Redshift*

# **Problem:** AM materials pose new and old threats to human health and environment

**3D printing company cited by OSHA after explosion** www.3ders.org 5/22/14

**Scientists warn of 3D printing health effects as tech hits high street** Techworld 7/26/13

**How green is my 3D printer? Scientists warn of heavy metal pollution** 3Dprint.com 6/19/14

**3D Printing Indoors Is as Bad for You as Smoking a Cigarette Inside** Gizmodo 7/24/13

**The plastic used in 3D printers is toxic to some fish and possibly to humans** Popular Science 11/9/2015

**Play it safe: EU supports standardized 3D-printed toy platform** EPPM.com 5/4/2016

**Regulatory concerns hold back 3D printing on safety** Financial Times 11/23/2014

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**IN SUMMARY:**

**New exposure pathways**

**Dispersed distribution of waste**

**Sensitive populations at risk**

# **Problem:** AM materials pose new and old threats to human health and environment

### Extrusion-Based Systems

- VOCs
- Ultrafine particles
- Post-processing

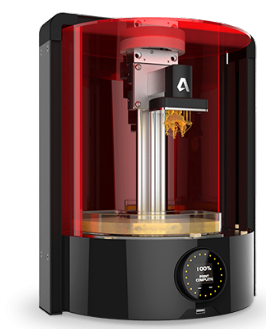
### Powder Bed Fusion

- Ultrafine particles
- Post-processing

### 3D Printing

- VOCs
- Ultrafine particles
- Post-processing

### Photopolymerization



- Dermal hazard
- Aquatic toxicity
- Post-processing

# **Problem:** AM materials pose new and old threats to human health and environment

Photoinitiator
(0.4%)

Reactive Oligomers
(79.55%)

Reactive Monomer
(19.88%)

UV-blocker
(0.16%)


Reproductive toxicant

Eye irritant

Skin irritant

Aquatic toxicant

Skin sensitizer

AUTODESK

# Background: **Publication**

**INTENT:** Provide a framework to understand impacts of additive manufacturing that combines material hazard, exposure, sustainable materials management and life-cycle thinking



## Addressing Hazardous Implications of Additive Manufacturing

### Complementing Life Cycle Assessment with a Framework for Evaluating Direct Human Health and Environmental Impacts

*Justin Bours,*[1] *Brian Adzima,*[2] *Susan Gladwin,*[2] *Julia Cabral,*[2] *and Serena Mau*[2]

[1]*University of California, Berkeley, CA, USA*
[2]*Autodesk, San Francisco, CA, USA*

**Keywords:**
3D printing
additive manufacturing
life cycle analysis (LCA)
green chemistry
materials
sustainability

Supporting information is linked to this article on the *JIE* website

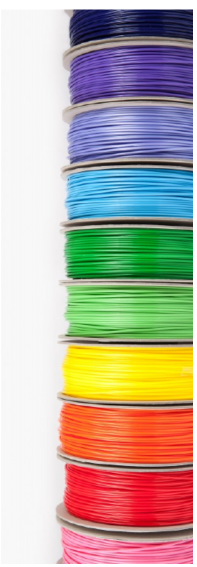
**Summary**

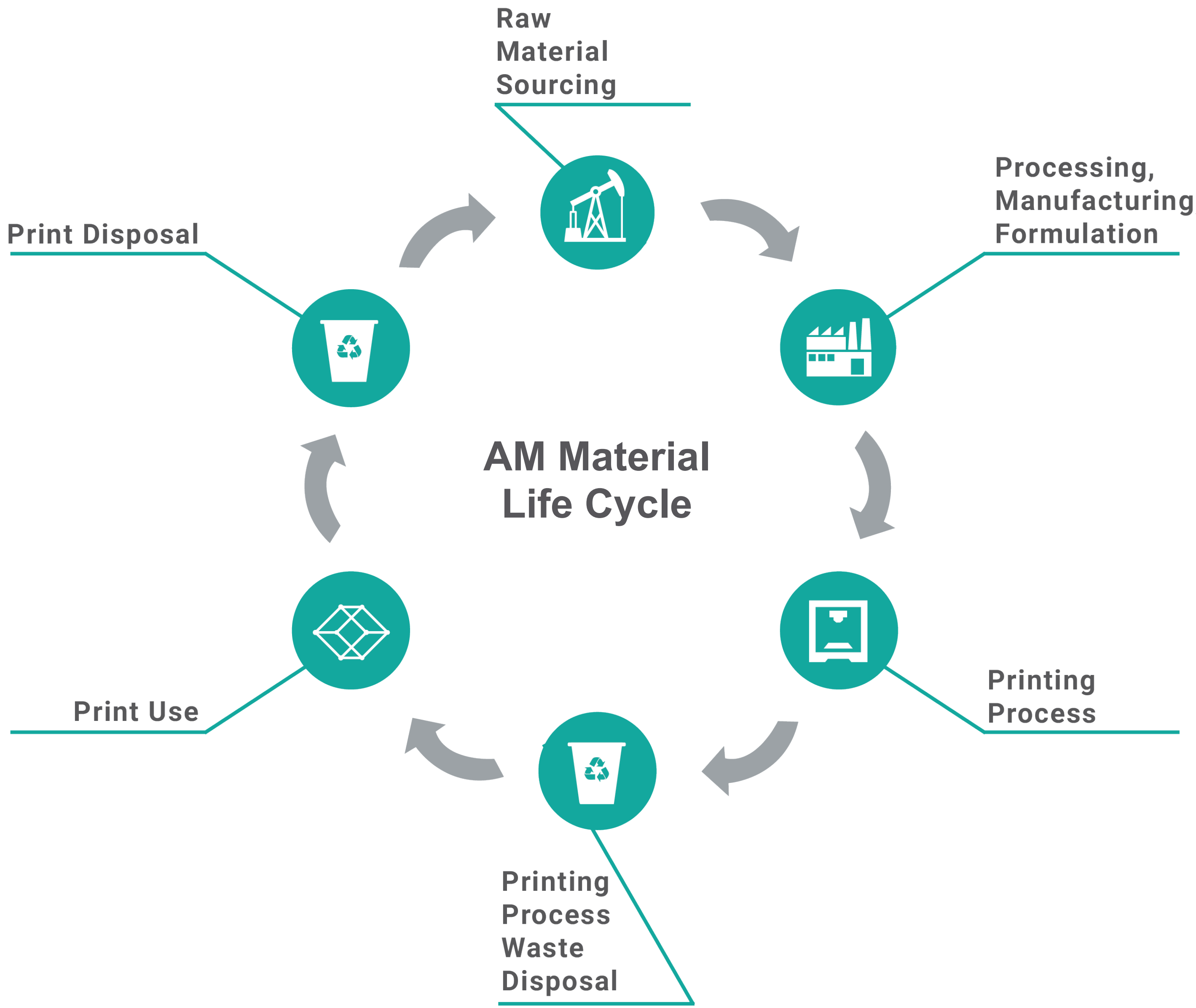
Additive manufacturing (AM) is transforming manufacturing technology and the distribution of production capital. As the use of three-dimensional printers begins to extend into homes, schools, and factories, the industry is not well equipped to address the potential for deleterious environmental and health impacts. Proactive assessment tools are needed so that materials developers and designers, printer operators, and print end users can create and choose the most appropriate and safe materials and AM processes based on their use cases. Current life cycle assessments (LCAs) do not provide sufficient information to support materials decisions based on concerns about hazard exposure. To address this shortcoming, we developed a framework that complements LCA with hazard and green design metrics derived from analyzing human health and environmental impacts in the later stages of the AM life cycle. We then identified suitable existing methodologies for evaluation across these stages and synthesized the methodologies into higher-level metrics for comparative analysis of materials. To illustrate the benefits of this framework, we compared two common AM materials: Autodesk Standard Clear Prototyping Resin (PR48), an open-source formulation used in photopolymerization processing AM, and *bio*–polylactic acid, a ubiquitous, biosourced polymer used in an extrusion-based AM system called fused filament fabrication.

# Background: **Publication**

Autodesk’s PR48


PLA

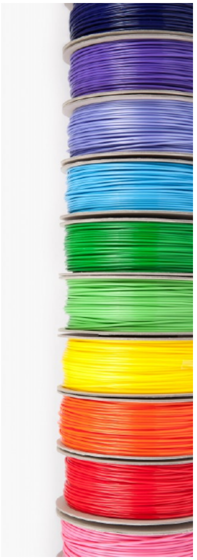


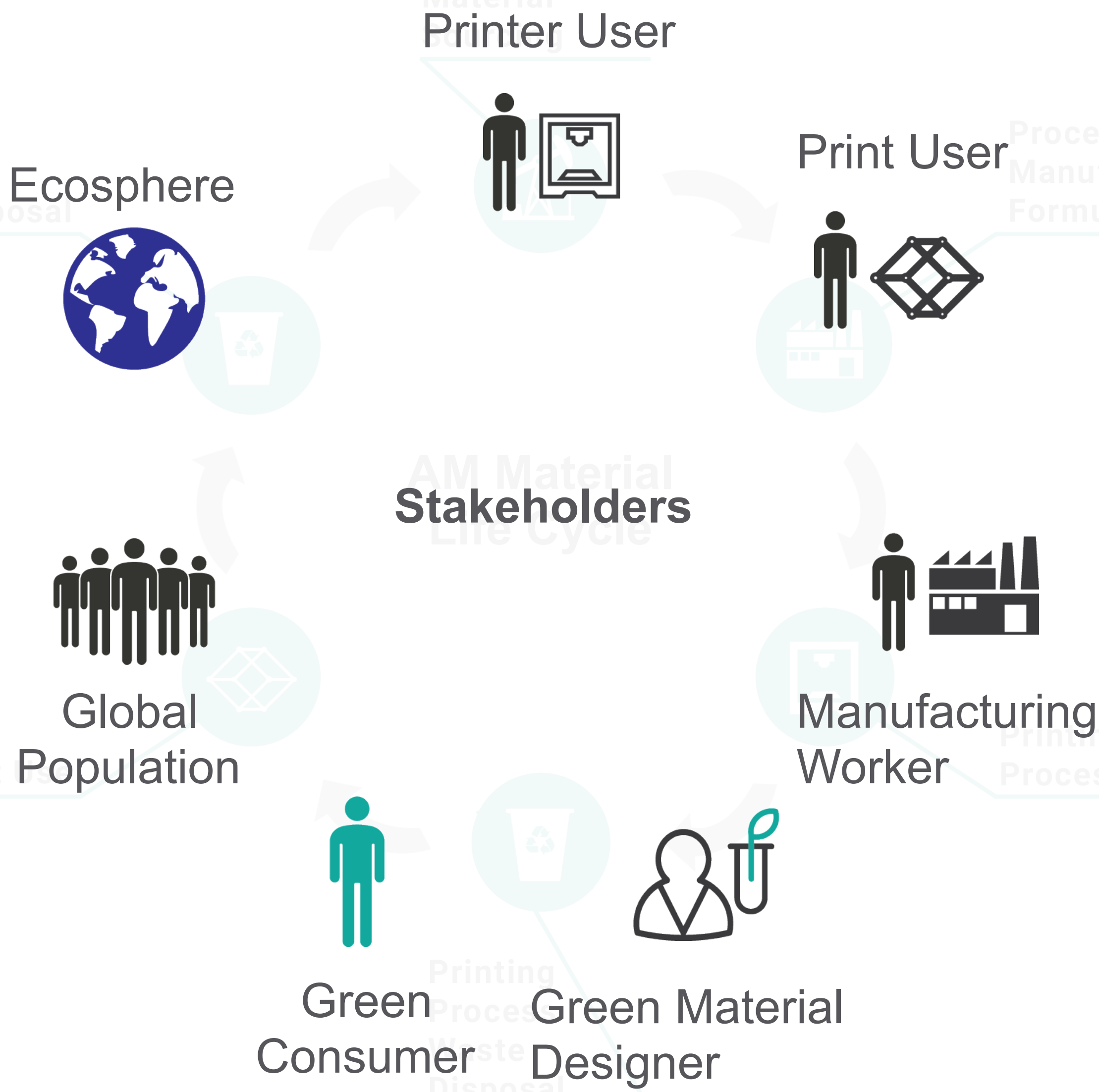


# Background: **Publication**

Autodesk's PR48


PLA

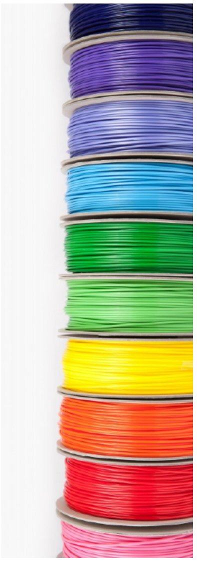


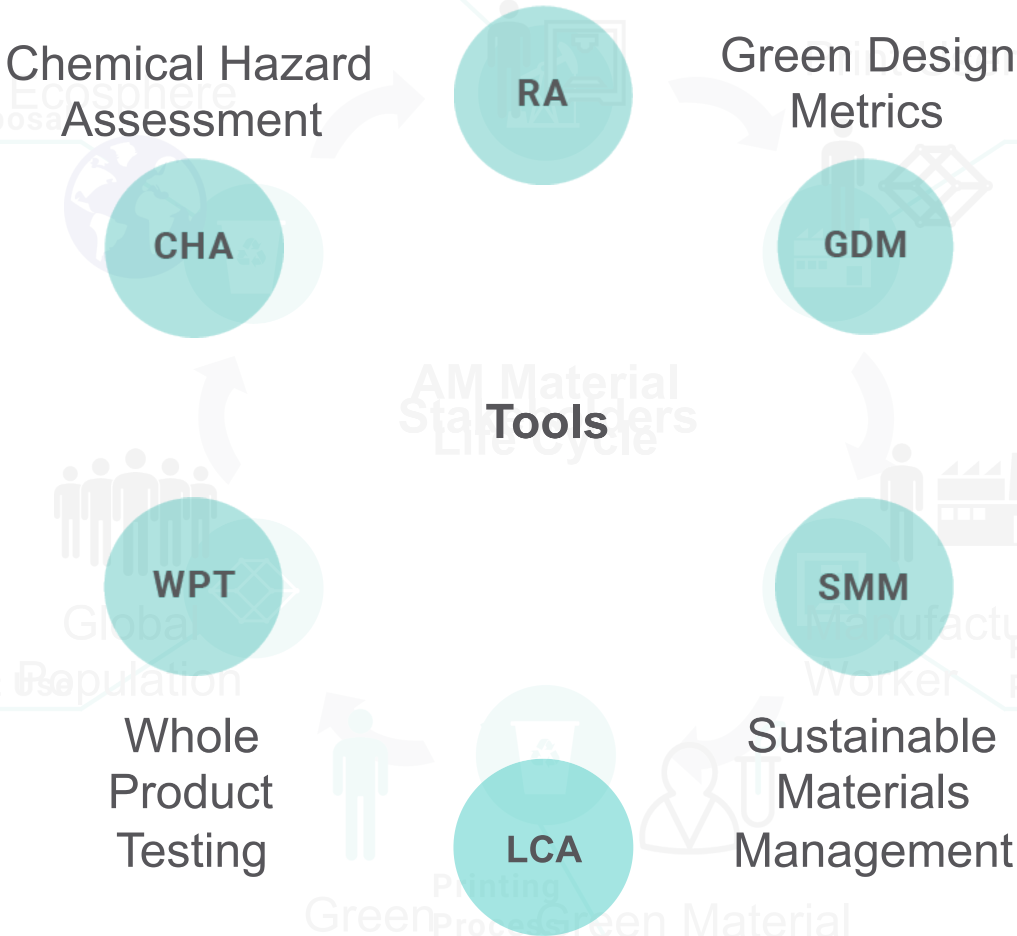


# Background: **Publication**

Autodesk's PR48


PLA





# Background: **Publication**

Autodesk's PR48


| | |
|---|---|
| Printing Process | 0 |
| Printing Process Waste Disposal | 0 |
| Print Use | 1 |
| Print Disposal | 1 |

Overall 0.5

PLA

| | |
|---|---|
| Printing Process | 1 |
| Printing Process Waste Disposal | 2 |
| Print Use | 2 |
| Print Disposal | 2 |

Overall 1.75

** Comparing materials from similar technologies will likely result in closer ratings

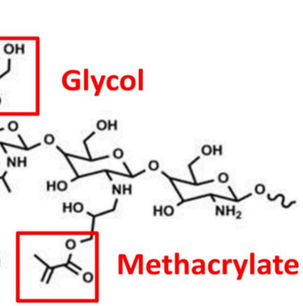
# Background: **Publication**

**Opportunity:** informed decision making, identifying improved materials, processes

Autodesk's PR48


| | Autodesk's PR48 | Acrylate resin with a bio-derived backbone |
|---|---|---|
| Printing Process | 0 | 1 |
| Printing Process Waste Disposal | 0 | 1 |
| Print Use | 1 | 2 |
| Print Disposal | 1 | 1 |
| Overall | 0.5 | 1.25 |

Using an acrylate resin with a bio-derived backbone

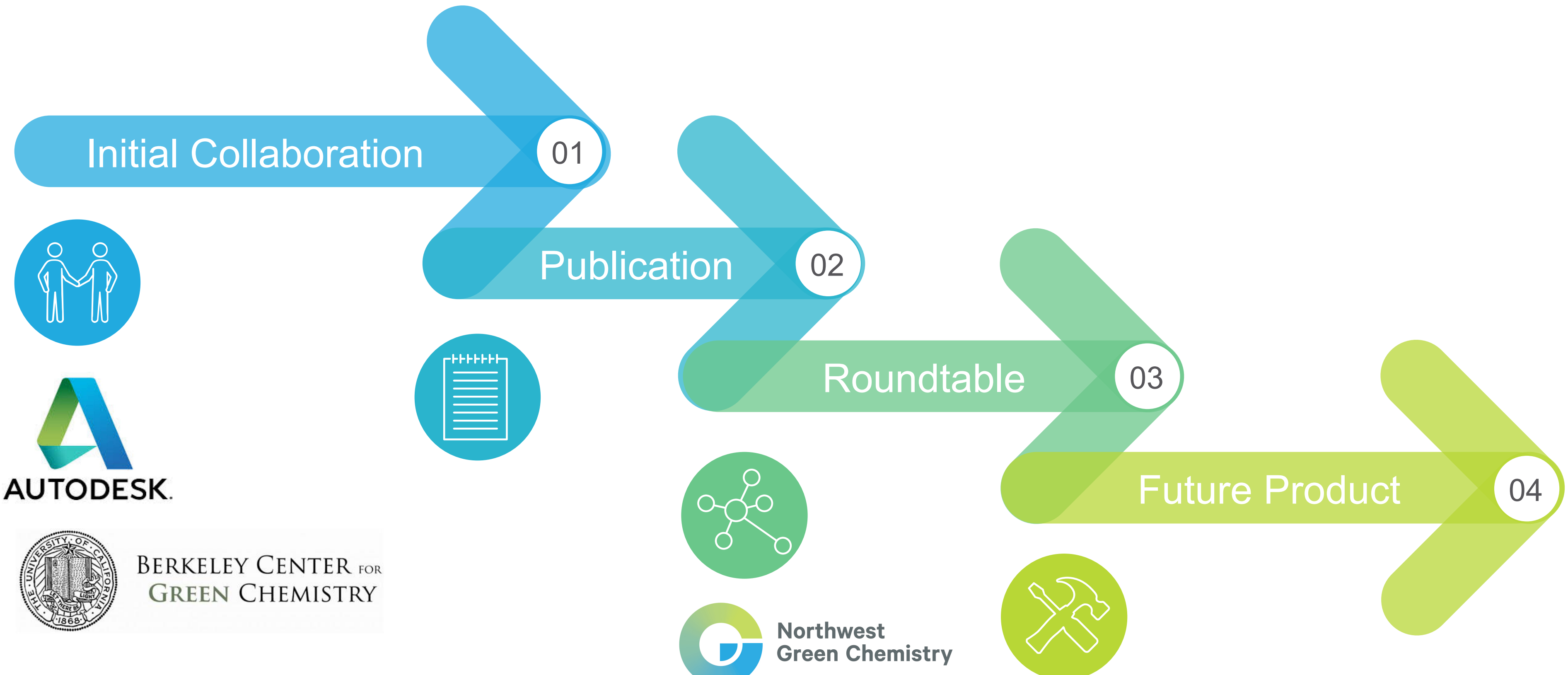



Methacrylated glycol chitosan

Arakawa, Christopher Kenji. "A Novel Photopolymerizable Chitosan Collagen Hydrogel for Bone Tissue Engineering," 2012. http://escholarship.org/uc/item/1wp7v2g2.pdf.

# Refining the framework: next steps after publication

**Motivation:** Publication was first step – need to understand **practicality** of framework to identify safer and more sustainable AM materials and processes for industry, academia, and public institutions

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Northwest Green Chemistry

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**Roundtable Participants**

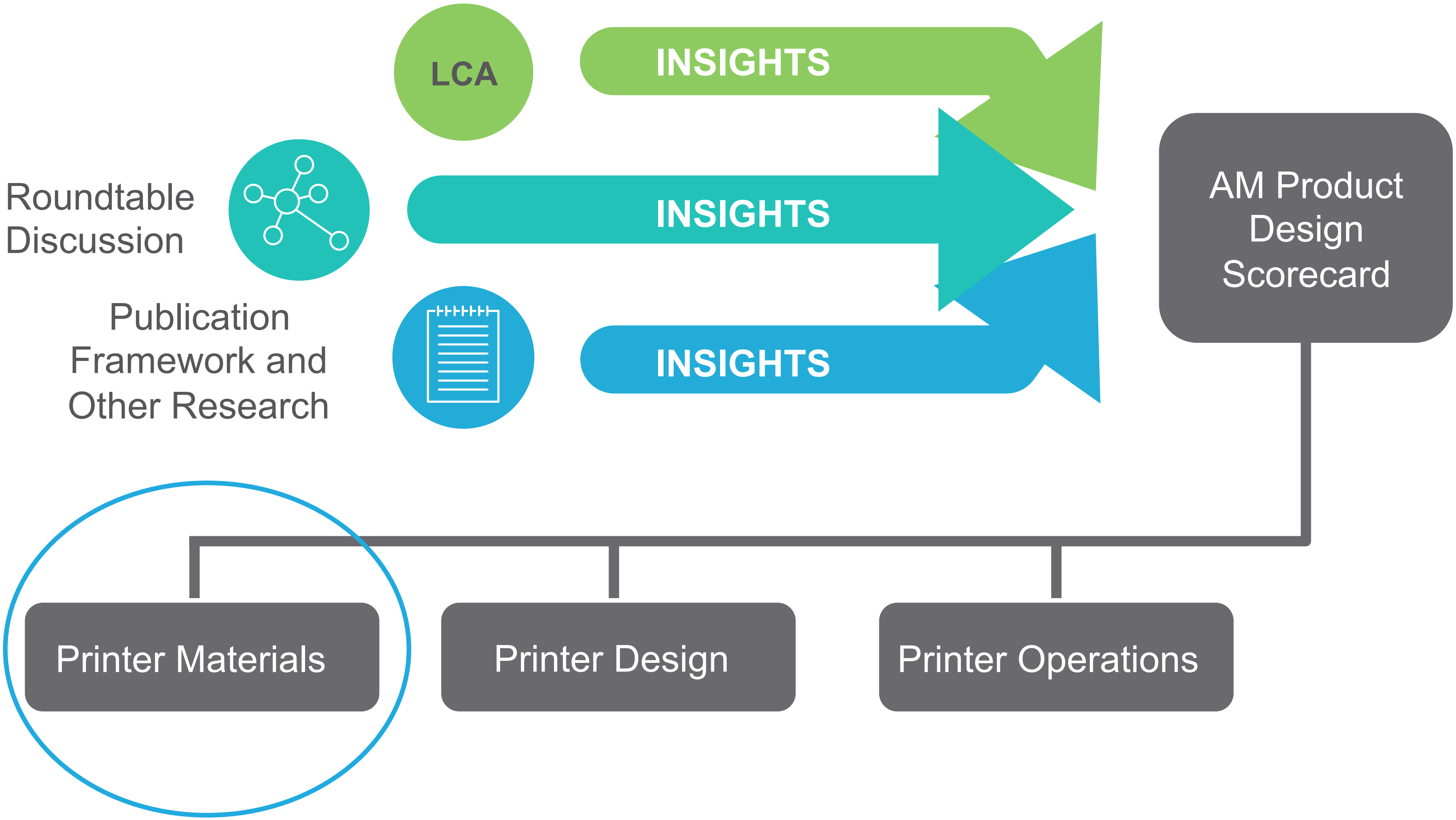
# Roundtable

**Intent:** Conducting calls to solicit feedback on manuscript w/ Autodesk funding

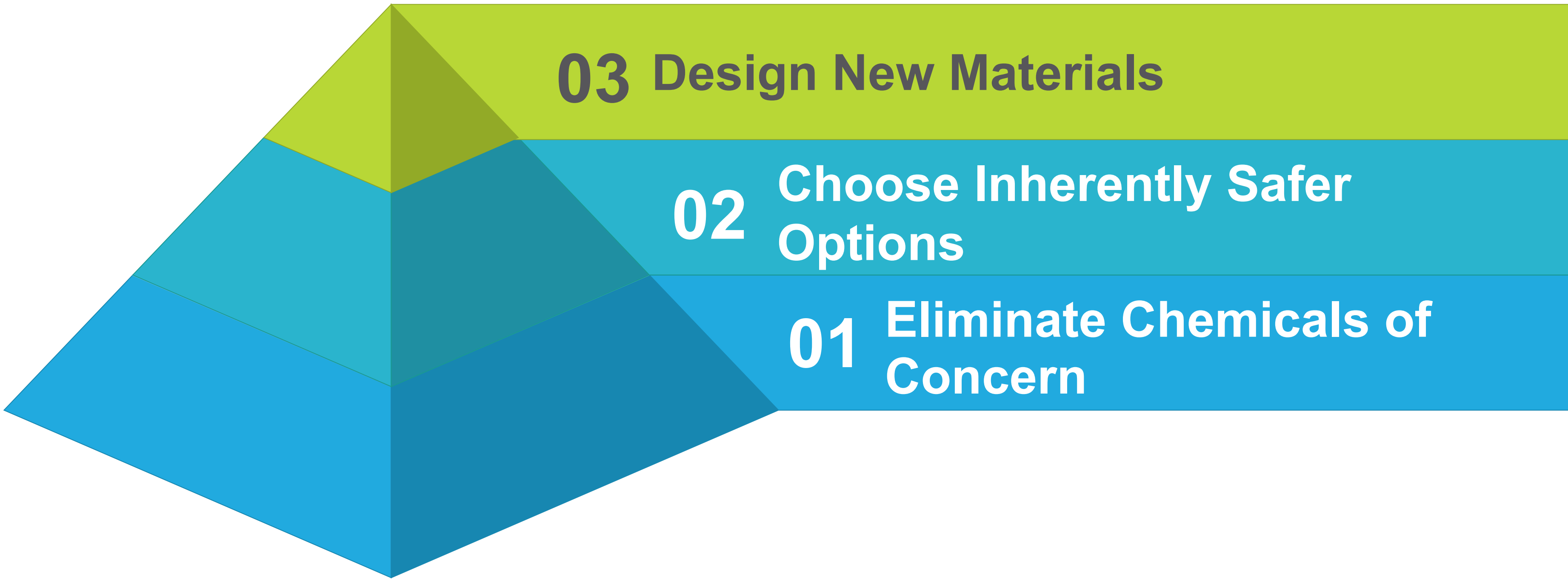
## Key Learnings

1. An appropriate assessment tool should support decision making for both:
   - material selection and
   - product design
2. Results should be **simple** and **visual;** prefer
   - **Checklists**
   - **Simple metrics**
3. Tradeoffs should be **transparent**
4. No **one** assessment tool can provide all answers on sustainability (LCA, CHA, Exposure, Risk Assessment, Sustainable Materials Management)
   - How to use these tools in combination

# **Future Product**: Designing an AM product design scorecard



# Steps to Greener Materials




Eliminate use of the **"known bads".** Screen products and processes and avoid chemicals known to have adverse impacts to human health and the environment

Practice **informed substitution**. Assess chemicals to gain better data and understanding of what is safe and appropriate for **specific applications** adverse impacts to human health and the environment

**Aim for the top**. Develop new, greener chemical products and processes; prefer chemicals and materials that are fully assessed, of low hazard, and optimized across the full life cycle.

# Growing the Supply of Materials Based on **Green Chemistry and Engineering**

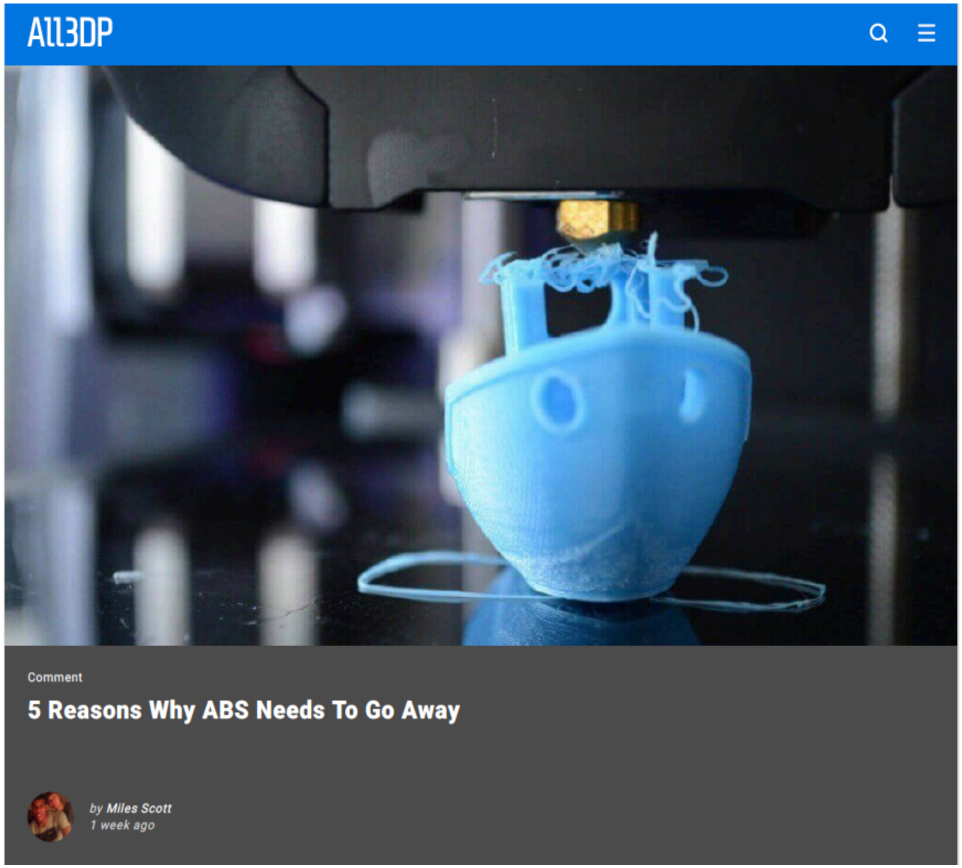

**Weed –** identify and eliminate chemicals of high concern

**Harvest** – promote adoption of inherently safer existing options

**Cultivate** – enhance and improve existing options

**Plant** – guide new material and product development

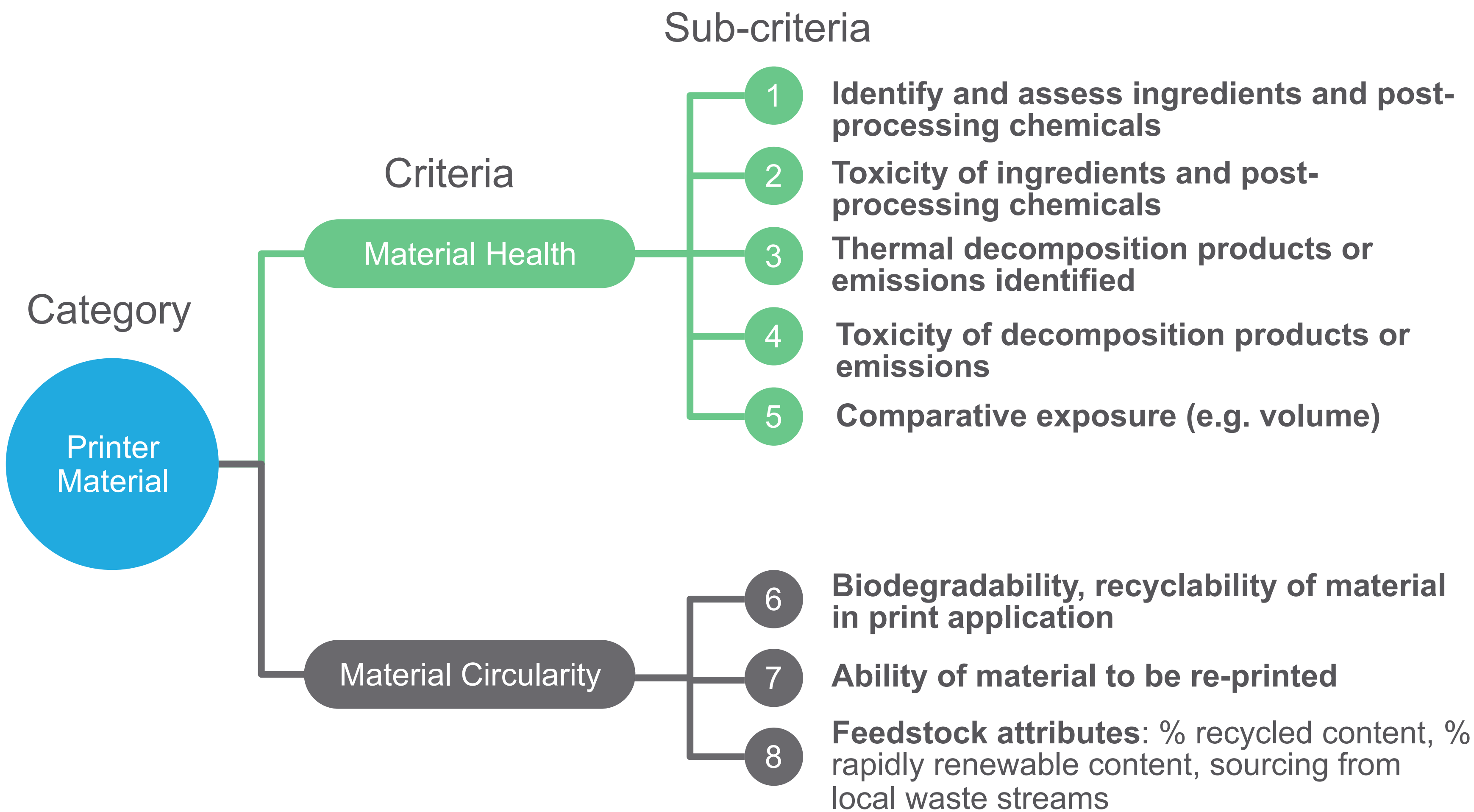
# Eliminate Known Chemicals of Concern




1. “ABS is Definitely Poisoning You
2. There are Stronger and Easier-to-Print Materials
3. Warping, Warping, Warping!
4. There are Environmental Concerns
5. Post-Processing Uses Dangerous Chemicals”

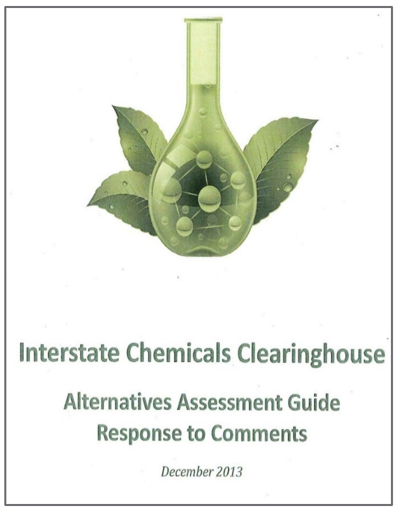
https://all3dp.com/5-reasons-why-abs-needs-to-go-away/

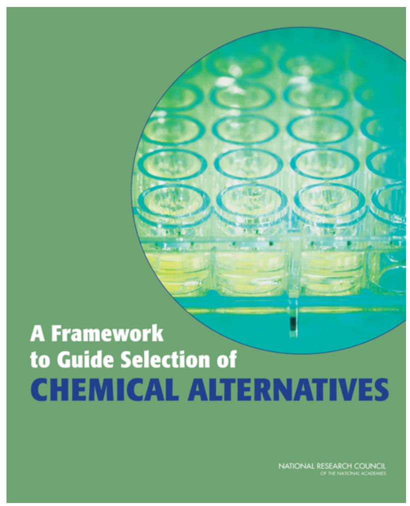
# **Choose Inherently Safer Options**: Narrowing down to key material criteria

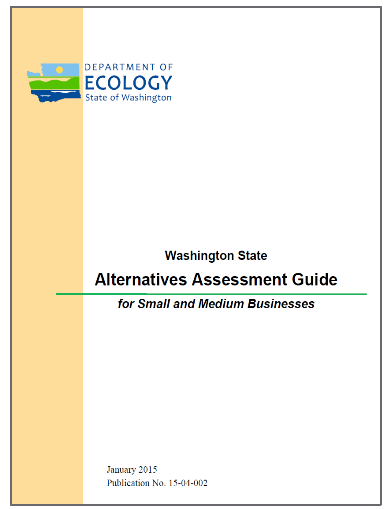


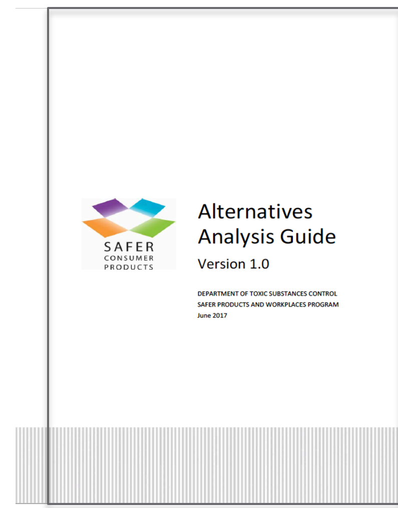
# **Designing New Materials:** Role for Alternatives Assessment

Alternatives Assessment: process for identifying and comparing potential chemical and non-chemical alternatives that can be used as substitutes to replace chemicals or technologies of high concern. (IC2 AA Guide)



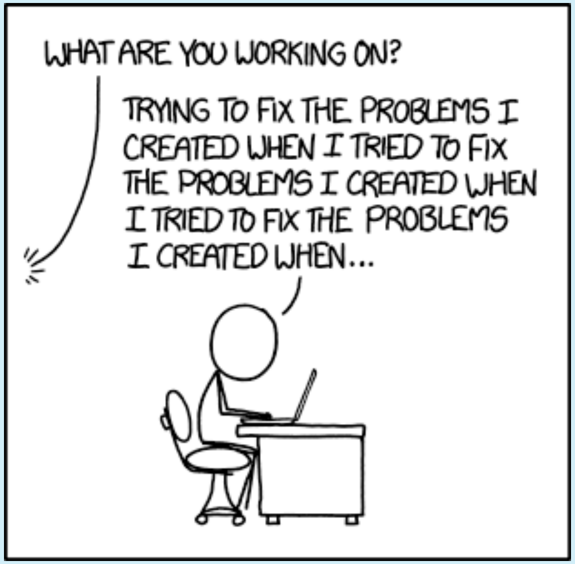




NAS: https://www.nap.edu/catalog/18872/a-framework-to-guide-selection-of-chemical-alternatives
IC2: http://theic2.org/alternatives_assessment_guide
WA: http://www.ecy.wa.gov/greenchemistry/WAA2Guide.html
CA: http://www.dtsc.ca.gov/SCP/upload/AA-Guide-Version-1-0_June-2017.pdf

# Sustainable AM Materials and AA

## Role for Alternatives Assessment

1. Scoping the assessment is critical
2. AA guides decision-making with respect to (at a minimum):
   1. Hazard
   2. Exposure
   3. Cost
   4. Performance
3. What about:
   1. Circularity
   2. Local/sustainable feedstock
   3. Social impact assessment
4. Challenges include
   1. Evaluating hazard for mixtures and polymers
   2. Decision analysis or “Selection Guide” approach?
   3. Best practices in optimization of multiple variables
      1. Carbon, chemistry AND circularity




# Discussion Questions:

- What are specific chemical and material hazards associated with 3D printing?
- What are the new challenges to protecting consumers, workers, and communities posed by this technology?
  - Specific challenges for government agencies?
- Reactions/additional thoughts – How could alternatives assessment be used inform safer chemical and material choices and what is needed for this approach to be used?

# Next Webinar

Registration link/announcement forthcoming –

**Wednesday, December 13, 2017, 10am PT/1pm ET**:

**Lessons and insights for the role of alternatives assessment in unlocking the potential of emerging technologies**

Panelists:

- **Dave Rejeski** (Environmental Law Institute)
- **Chuck Geraci** (National Institute for Occupational Safety and Health)
- **Treye Thomas** (Consumer Product Safety Commission)