Innovation Crossover Preliminary Research Report
Advanced Manufacturing – Additive Manufacturing

Context/Scope

This paper represents research conducted by OVO Innovation for the NSWC Crane Innovation Crossover event October 12-13, 2016. This research is intended to provide more insight into key challenges that were identified within the four technology clusters (Advanced Manufacturing, Cyber/IT, Life Sciences and DoD Technologies) first documented in the Battelle report. OVO consultants interviewed subject matter experts (SMEs) from the private sector, academia and the government identified by NSWC Crane to gather insights into key challenges in each cluster. This report is meant to inform the participants of the Innovation Crossover event and identify new research and new technologies that might address the key challenges.

This research was collected during August and September, 2016. The reports were submitted by OVO to NSWC Crane in late September 2016.

Introductory Narrative

The Innovation Crossover event, scheduled for 12-13 October 2016 in Bloomington is the culmination of months of planning and hard work. Some of this preparatory work involved the initial Battelle study which identified key technology clusters (Advanced Manufacturing, Life Sciences, Cyber/IT and DoD Technologies) in southern Indiana. From these clusters NSWC Crane and its contractor OVO Innovation conducted further, more detailed research, to examine detailed challenges and opportunities in each technology cluster. The reports attached document the research OVO conducted with subject matter experts identified by NSWC Crane in academia, industry and in the government. The reports are meant to document specific challenges within each technology cluster that could become areas of joint research and cooperation across the three constituents in southern Indiana. The reports are provided to you to help you prepare for your participation in the upcoming Innovation Crossover event and to frame both the challenges and active research underway to address these challenges.

Problem Statement

Advanced Manufacturing – Additive Manufacturing (aka 3D Printing)

- Full integration of additive manufacturing into the digital manufacturing enterprise. This could mean converting completely to additive manufacturing where appropriate or considering how to integrate additive manufacturing on an existing production line. Further:
  - Where or when is additive appropriate?
  - What products or components can be best manufactured in an additive process?
  - What materials are required in order to manufacture mission critical components?
  - What is the best approach to qualify or certify components made by additive manufacturing?

Scope

- Focus of this research was related to manufacturing processes involving polymers and metals

- What is not included:
  - Biomedical manufacturing
  - Pharmaceutical manufacturing
  - Electronics manufacturing

Problem Context

Materials: Requirement for materials that offer durability and performance that matches/exceeds alternative production methods

- Polymer process is more mature (SLS, SLA, FDM), but there is demand for more offerings within metals.
- Innovation funding for early stage development is difficult to obtain – universities are not able to bear the burden.
- Technologies not always able to result in properties in all directions (e.g., X&Y may be same, but not Z).
- Materials still lack durability and repeatability to meet the benchmark requirements of traditional manufacturing. This is especially true with critical functional areas such as aerospace and medical.
- Goal of embedding information inside a fully solid part to ensure authenticity and provide “IoT”.
- Continuation of development of multiple density and conductivity of materials.

Equipment & Processes: The need to develop processes and equipment that provide superior productivity and repeatability

- Prototyping continues to be the dominant use with production efforts in limited applications – particularly within metals.
- Systems need to increase quality and repeatability.
- Design tools (software) are still maturing as it relates to working with 3D. PTC, Siemens, Dassault, Autodesk are all working on this – but still needs to improve.
- OEMs organizations are not large enough to provide significant investments in innovation. GE’s acquisition of ARCAM/SLM and HP’s entrance into polymers will help drive more investment.
- Scanning designs are still evolving – especially related to internal geometries.

Problem Context

Qualification: Developing processes to qualify that factor the unique nature of 3D printing

- Variability of process (similar to welding) makes the qualification process difficult since each effort is unique. Indirect approaches are options, but do not address the overall issues.
- Intensity and difficulty to qualify depends on how critical the application is – simple elements such as clips and brackets are easier to qualify vs. flight or safety critical. Lower risk elements such as tooling, fixtures, and non-structural parts are easier to qualify.
- The typical 'checks and balances' of traditional manufacturing (incoming materials, specifications, process controls, equipment processes) are more difficult since the productions are unique and not always repeatable. Need to have more simulated approaches and in-situational monitoring.
- The qualify/freeze process adds complications since the multiple variables are involved in each build. It also adds costs with multiple machines required.
- Many of the current OEM machines operate with 'black box' due to IP concerns. But without full transparency it is difficult to adjust for all the critical parameters.

Labor: Grow the workforce that is able to design, operate, and support 3D printed products

- Labor force with knowledge of additive machine or design tool operation is limited.
- Changes from current processes are significant and not easily adopted by current operators.
- Need well trained operators and designers – both represent a challenge.
- Service Bureaus are available – but most focus on prototyping and polymers. Very few are well equipped for metals.

Problem Context

<u>Fragmented Approaches: Multiple efforts around development</u>

- Multiple technologies and processes are involved in additive – it is not simply one approach.
- Fragmented approach with numerous organizations working on it and duplicating efforts.
- AmericaMakes is helping within US, but challenge is that most of the 3D manufacturers are European.
- Standards organizations are working to develop qualification processes, but still needs coordination.
- Many of the organizations making significant progress see the technology as a competitive advantage and do not share all the details.

Problem Context

Sample of Barriers to Business Adoption

<u>HIGH PRICES & INVESTMENT</u>

Price of 3D printing systems – metal printing in particular can be cost prohibitive at $1M+ per system.

Price of materials and related services – operational costs are high vs. traditional materials. Polymers can be 20-100x more than the injection molding equivalents.

<u>TECHNOLOGICAL LIMITATIONS</u>

Build envelope and product size – adoption will depend on how many of its products can be produced with additive technology. Powder beds have limits that don't meet product needs – for metals, printing standard is 800mm by 400mm.

Limitations on materials and multi materials – most printing is limited to a single 'family' per print. Serial production will require more integration and different materials.

Concerns on product quality – additive products must meet specific standards and customer expectations. The layering process of the build creates material properties that are not always evenly distributed.

<u>BUSINESS CHALLENGES</u>

Lack of in-house expertise – introducing 3DP requires additive manufacturing experts internally. Product engineers will need to change their way of designing, operators will need to change approach for manufacturing, and service will require different types of support.

Integration into the operations status quo – introducing additive into serial manufacturing requires integration into the existing structures – both vertically and horizontally (IT, operations, etc.)

Intellectual property – Additive raises concerns related to patent infringement with anyone being able to 'scan' and print. As the value of digital (vs. physical) increases, IP discussions will be more relevant.

Source: EY Global 3D Report

Technologies

Process Type	Technique Definition	Example Technology	Material
Vat Photopolymerisation	Liquid photopolymer in a vat is selectively cured by light-activated polymerisation.	Stereo lithography (SLA), digital light processing (DLP)	Polymers and ceramics
Material Jetting	Droplets of build material are selectively deposited.	3D inkjet printing	Polymers and composites
Binder Jetting	Liquid bonding agent is selectively deposited to join powder materials.	3D inkjet printing	Metals, polymers, and ceramics
Material Extrusion	Material is selectively dispensed through a nozzle or orifice.	Fused deposition modelling (FDM)	Polymers
Powder Bed Fusion	Thermal energy selectively fuses regions of a powder bed.	Selective laser sintering (SLS), Selective laser melting (SLM), electron beam melting (EBM)	Metal, polymer, composites and ceramics
Sheet Lamination	A process in which sheets of material are bonded to form an object.	Ultrasonic Consolidation (UC)	Hybrids, metals and ceramics
Directed Energy Deposition	A process that focused thermal energy and fuses materials by melting as the material is being deposited.	Laser metal deposition (LMD)	Metals and hybrid metals

http://www.rm-platform.com/linkdoc/EC%20AM%20Workshop%20Report%202014.pdf

Adoption Maturity Curve

Most companies are in the early stages of adoption and have limited experience

Maturity level	Strategic direction	Organization and processes	Technology enablement	Value and performance management	% of Companies
4 **Strategic application across company**	▸ Application of 3DP embedded in company's strategy ▸ C-level sponsorship	▸ 3DP embedded in relevant operational areas with clear organization and processes	▸ Own or joint ventures with 3DP production locations ▸ Own or joint 3DP research centers	▸ Embedded measurement of how applying 3DP improves efficiency	4%
3 **Application in "champion" departments**	▸ Clear direction on application of 3DP in a certain department	▸ "Champion" departments have integrated 3DP into operations ▸ First cross-functional teams	▸ Own systems from rele-vant technology ▸ Established collaborations	▸ Measurable results within specific departments or areas of application	9%
2 **Experimenting and testing**	▸ Department leaders start to invest, test and understand the technology	▸ Teams of enthusiasts test the 3DP technology ▸ No structured processes for application of 3DP	▸ Testing different technologies with service provider, research groups or own cheep systems	▸ First own use cases with measurable results	11%
1 **No experience**	▸ Leadership has no or low awareness about 3DP and application in the company	▸ Possibly, first evaluation and consideration of possible form of 3DP application	▸ Possibly first considerations of form of application (own system, cooperation)	▸ No own experience. Possibly, review of experience from other companies	76%

Source: EY Global 3D Report

Relevance of Additive Manufacturing

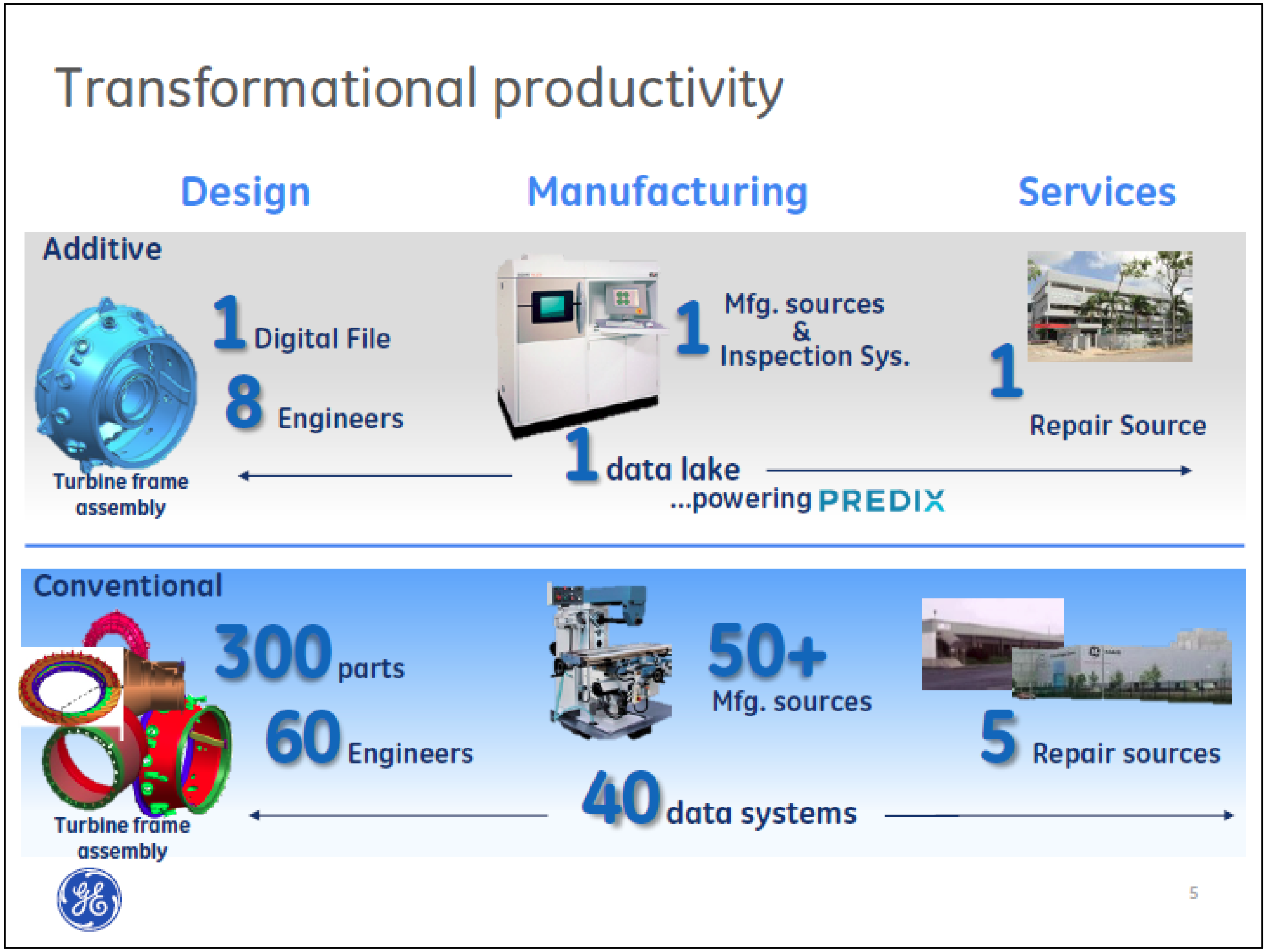
Additive manufacturing offers alternatives to traditional approaches (CNC, injection molding, etc.) that provide significant advantages. Some samples below:

- **Design Freedom**: The ability to design for the function the part will perform, not the manufacturing process. Develop shapes that cannot be cost effectively produced from conventional manufacturing processes such as casting, molding, and forging.
- **Cost Advantages**: Reduce lead time and cost of tools. No incremental cost for design complexity.
- **Part Consolidation & Complexity**: Provides approach for building parts that would have otherwise been impossible or cost prohibitive (e.g., heat management, nozzles, etc.).
- **Weight Optimization**: Use of new design approaches (e.g., lattice structures) to reduce weight.
- **Supply Chain Compression**: Minimize waste and tooling requirements.
- **Rapid Prototyping**: Iterate designs quickly to improve design, form, fit, and function.
- **Tooling:** Develop tooling for use within manufacturing environment.
- **Indirect Manufacturing**: Use to design parts that can be sacrificed to make molds.
- **Direct Manufacturing**: Use within low volume and high value add production.
- **Custom Manufacturing**: Ability for mass customization within medical or aerospace.
- **Forward Deployment**: Logistics management for locations without manufacturing abilities.
- **Obsolete Parts**: Replacement parts for obsolete offerings.

Relevance of Additive Manufacturing

Additive manufacturing offers improved productivity related to design, manufacturing, and services

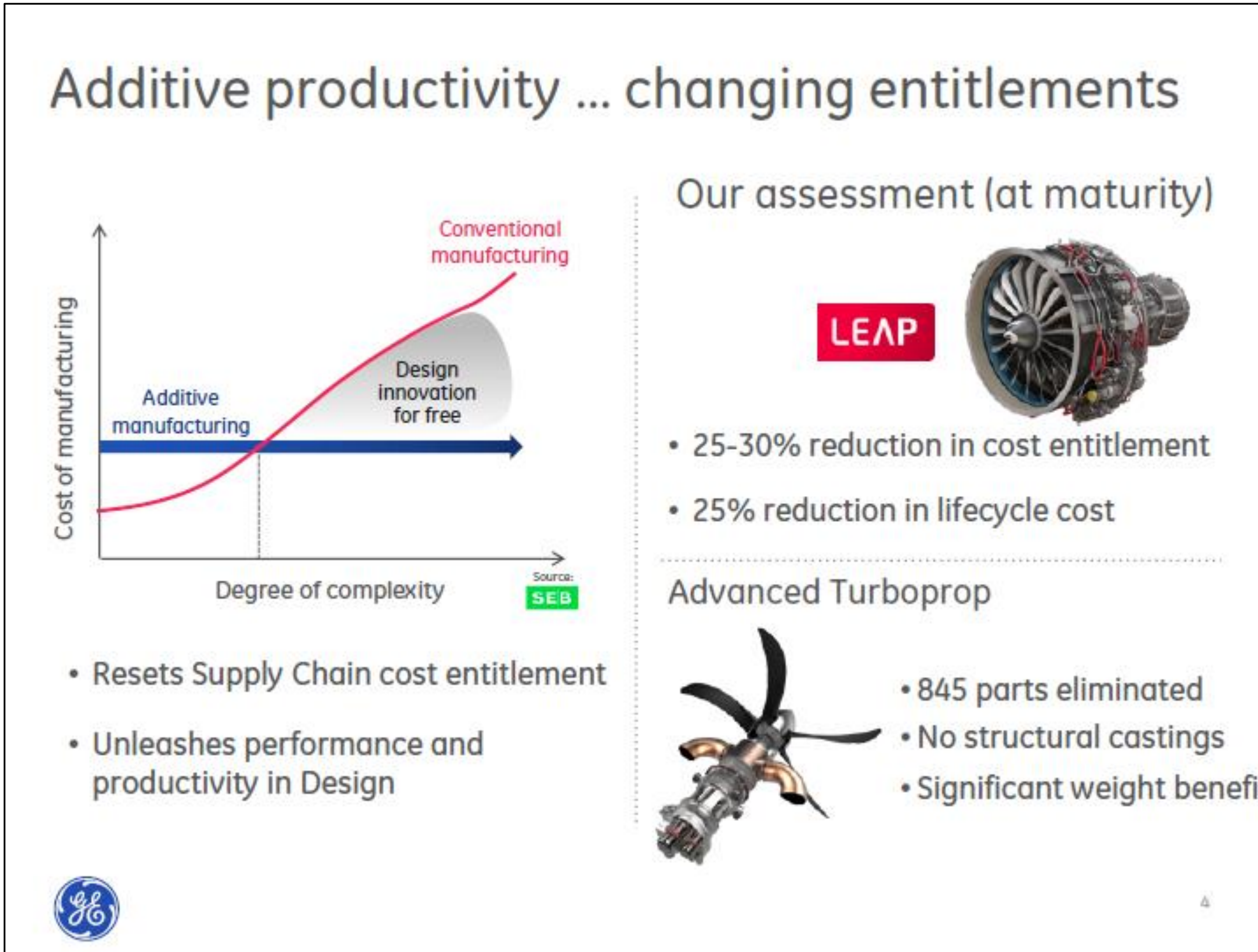
GE Investors Presentation describing the benefit of the SLM/ARCAM acquisition
(Public information)



http://www.ge.com/investor-relations/ir-events/ge-investor-webcast-2016

Relevance of Additive Manufacturing

Additive improves productivity across core areas



GE Investors Presentation describing the benefit of the SLM/ARCAM acquisition

(Public information)

http://www.ge.com/investor-relations/ir-events/ge-investor-webcast-2016

Research

Sample of universities involved in Additive

- **Carnegie Mellon** – Metal Powder Bed Laser Fusion (DMP)
- **Georgia Tech** – Computer design and manufacturing
- **Katholieke Universiteit Leuven** – SLM, ceramics, aluminum, post-build control
- **MIT** – Invented color jet printing
- **Penn State University** – Metal Powder Bed Laser Fusion (DMP)
- **UCLA** – Additive for alternative energy
- **University of California, Berkeley** – Stereolithography materials
- **University of Delaware** – Leading research institution for polymers and composites (SLS, MJP, SLA) building an Additive Manufacturing laboratory
- **University of Louisville** – (polymer) Selective Laser Sintering (and building Additive Manufacturing lab)
- **University of Nottingham** – Major Additive Manufacturing institution and has major R&D in a range of AM tech including jetting and design for manufacturing
- **University of Pittsburgh** – Work in AM materials (both polymers and metals) as well as bio printing
- **University of Texas Austin** – Invented (polymer) Selective Laser Sintering
- **University of Texas El Paso** – Stereolithography and electronics printing

Organizations

- **AmericaMakes:** Public/Private partnership across industry, government, and universities to build infrastructure and adoption. Members include major aerospace/defense manufacturers, materials producers, and key universities. Funded by government and industry, and invested in accelerating technology in specific industries. IP can be shared or licensed across the 200+members.

- **Fraunhofer Generativ:** German alliance focused on several areas within additive http://www.generativ.fraunhofer.de/en.html

- **European Additive Manufacturing Group (EAMG):** Principally focused on advancing joint tech development and standards

- **Canadian-European Consortium:** Focused around aerospace repair technology, AMOS- http://amos-project.com/News/NewsItem?NewsItemID=3&NewsType=GeneralNews

- **Standards:** Multiple bodies are working to consolidate approaches for qualifying the technology:
  - http://www.iso.org/iso/standards_development/technical_committees/other_bodies/iso_technical_committee.htm?commid=629086
  - https://www.astm.org/Standards/additive-manufacturing-technology-standards.html
  - http://www.sae.org/events/ams/
  - https://www.ansi.org/standards_activities/standards_boards_panels/amsc/default.aspx?menuid=3
  - https://www.aws.org/standards/CommitteesAndStandardsProgram/d20-committee-on-additive-manufacturing-2

Summary

- Additive manufacturing has existed since the early 80s, but is reaching an inflection point where processes, equipment, and materials are positioned to increase usage in low volume production environments.
- The value of additive manufacturing is design freedom that allows users to design for the function of the part vs. the manufacturing process. The result is improved products with improved performance that impact the users, supply chain, and service requirements.
- The challenge is that while companies are increasingly aware of the value, the barriers are significant - variety of choices, technology limitations, cost requirements, and integration barriers. The lack of knowledge and confidence about where to invest limits the ability to clearly define the cost benefit analysis.

Summary

- Additive will not replace the full manufacturing footprint. CNC, injection molding, forging, etc., still offer advantages in many situations. Rather, additive offers the opportunity to improve the speed of prototyping iteration and provide an alternative for low volume production of parts that are well suited for this approach.

- Aerospace and healthcare are poised to move more into low volume production – but qualification and certification is a barrier. The unique process of each build does not lend itself to traditional approaches. The complexity of the problem grows due to the number of different entities involved in developing new approaches and standards.

Summary

- Large companies are investing in the technology and universities are continuing to pioneer innovations – but the translation to midsize industry is still difficult. Most companies are not experienced and are low on the adoption curve.

- The majority of businesses remain unaware of the opportunities of additive. We must find ways to pursue this technology on two paths – not only continuing the advancement of the technology and materials – but also help industry to determine the best approach for evaluating which specific applications are relevant.

Sources

Subject Matter Experts Consulted / Interviewed:

Additive

- Eric St. Ours, NSWC Crane
- Dr. Thomas Starr, University of Louisville
- Dr. Mary Kinsella, ARFL/RXMS
- Chris Sensenbrenner, Flanders
- Chris Brack, George Koch Sons

Manufacturing Process Modeling & Optimization

- Rachel Wiseman, NSWC Crane
- Jacob Chapman, NSWC Crane
- Dan Hartman, Rolls-Royce, DDMI
- Dr. Marlon Pierce, Indiana University
- Dr. I.S. Jawahir, University of Kentucky

Sources

GE Review of Additive Acquisition

http://www.ge.com/investor-relations/ir-events/ge-investor-webcast-2016 (Sep 6)

America Makes Roadmaps

https://www.americamakes.us/technology/techroadmap

E&Y Global 3D Printing Report

http://www.de.ey.com/Publication/vwLUAssets/ey-global-3d-printing-report-2016-full-report/$FILE/ey-global-3d-printing-report-2016-full-report.pdf

Background on 3D Printing

https://all3dp.com/types-of-3d-printer-technology-explained/

Discussion of European Commission Investment into Additive (2014)

http://www.rm-platform.com/linkdoc/EC%20AM%20Workshop%20Report%202014.pdf

Wohler's Report

https://www.wohlersassociates.com/