2015 Next Generation Manufacturing of Printed & Flexible Electronics

Official Call to Order & Welcome
Chris Jones, Georgia Tech Associate Vice President of Research

Research at Tech: 6 colleges, strong focus on connection between science & technology.
Strong engineering school, top 10 public universities, high return on investment. Engage students in the act of development and innovation
Focus on interaction with the broader community: GTRI
Enterprise Innovation Institute (EI^2): get technology development at Tech out to the community
Interdisciplinary Research Institutes (IRIs): for topics that are critically important and cannot be hold in only one school. Examples: manufacturing, energy… helps coordinate the different activities across the campus
Materials touches about 1/3 of faculties on campus
GT licenses out into the community, significant number of industry contacts
Research numbers: dominated by federal funding but second is industrial funding
GT 1.3B$, half of it is research, 25% is GTRI
Align the different skills set necessary to move techno outside the research
GT emphasizes collaborations, bringing the right experts together quickly

Flexible Hybrid Electronics Manufacturing Innovation Institute
Suresh Sitaraman, Mechanical Engineering

Government initiative to create an institute: a national focal point for supporting the translational activities that bridge the gap between fundamental research and manufacturing
IMI focuses on national impact: translation of emerging technologies to commercial practice: TRL 4 to 7 and MRL 4 to 7
Min 1:1 cost share with the industry
Self-sustaining free standing institute by year 5
DOD expectations for FHE-IMI:

- Support an end to end ecosystem in the US for flexible hybrid electronics manufacturing
- Include domestic manufacturing development facility(ies) to scale-up manufacturing processes

Topics: Wearable technology, internet of things, medical technology…
Wafer fab is not included in the program, material development is not part either
No clear way to know what will work for each substrate: how to come up with the modeling and design tools? Everything is different depending on the substrate

1. Manufacturing, Assembly and Integration: integration of foundry-based component with printed components and interconnects
   Pick and place tools must be compatible with thinned devices and flexible substrates

2. System integration demonstrators: thermal management, packaging concepts, demonstration and tools encapsulation challenges
3. Innovative printing processes: screen printing, emerging printing processes challenges are to be able to reduce the feature size, and multi-layer
4. Thin device processes
5. Materials manufacturing and scale-up
   Printed components, materials scale-up, through layer vias, CTE mismatch, delamination…
6. Modelling and design tools
   Comprehensive FHE tools
7. Education and training
   Curriculum development partnering with existing STEM programs, access to design tools and software
8. Standards, testing and metrology: no clear standard on how we test these things. In-line high speed and automated quality control tools are needed. Durability tools

GTech has substantial experience in manufacturing assembly and integration:
Extrusion on demand, compliant interconnects, various coatings, metrology for warpage and deformation
Models and design tools: mechanical tools, electrical, thermal models…
GTech has pioneered innovative printing processes: different types for various processes, inkjet printer capacity
GTRI serves as a system integrator for major Defense system: integrate wireless, solar and mechanical power harvesting devices on flexible substrates
Strength in electrical and reliability testing: how long they will last, delamination features and electrical testing
GT has a rare capabilities to address various aspects of this institute
3 legs to stand on: very good business plan, sustainability plans after 5 years and technical expertise: is this a place where there is enough capabilities, critical mass of expertise and infrastructures

How printing technologies will change the electronics industry
Ross Bringans, Palo Alto Research Center (PARC)

PARC: founded in 1970 as Xerox Palo Alto research center, spun out in 2002 as an independent research business
Pioneers in laser printing, PC workstations,
More recently: materials, semiconductor devices, artificial intelligence, computer science
Understanding how to get the performance of silicon at lower cost
Printing: conductors, dielectric, semiconductors… what can you print, what are the boundaries?
Use government funding to develop beyond the early stages to more mature and then be able to work with industry
PARC does not sell products, their product is their research: Jump start or accelerate companies into the market
How can the world of manufacturing be changed: democratization of manufacturing, mass customization, just in time delivery

Cost of entry to silicon is very high: printing techno is much cheaper to enter=> democratizing
Every print can be different: mass customization

For printers, there are some familiar challenges: custom products at the same price as traditional products (going to digital printing), quality that meets the requirements (not the very best but enough), speed of printing, skills mix, installed base (if equipment is depreciated, economy is not always obvious)
Printed: screen, inkjet, gravure, offset, flexo, aerosol, extrusion, 3D
Electronics: conductors, passives, semiconductors, transistors, circuits, 2D, 3D systems

Now you can print things that contains intelligence
Why people are excited: makes thin and flexible; individually customized, flexible and bendable (away from PCB limitations)

1. Dispensing: color filter on LCD displays. Inks deposited into wells
2. Patterning: additive processing
3. Assembly: instead of serial assembly steps and pick and place
4. Building: 3D printing
5. Just-in-time manufacturing: for example in the space station to make electronics when needed.
6. Ability to make really complex systems: things you cannot do otherwise!

From materials to systems:

- <u>All printed</u>: all components printed from simple inks. Size scale makes sense for that. Hard to go below 30-40 microns => not make microprocessors and not really compact.
  Printed conductors: already here. 2 to 3 B$. RFID antennas, membrane switches…
  New directions in printed conductors: Optomec techno to go to small features. Materials compatible with low temperature to avoid nanoparticles aggregating
  Printed semiconductors: print thin film transistor. New techno and know how to get this to work. P and n-type to build CMOS-equivalent
  From materials to circuits: transport curve, modeling of the circuit, print. Fast turnaround, allows for rapid manufacturing and testing
  TFT, arrays, sensors and batteries
  2 big things previously: ink jet printed active matrix backplanes and displays, RFID
  Example: Smart tags: limited logic, very high volume. Brand protection, the internet of things, medical sensors…
  Example: printed sensor tape (DARPA) to detect impact on brain during experiences in the battlefield. Cost $1 and last for 7 days….
  Moving toward commercialization: temperature sensor tag: Thin film memory, sensor test, display, parc logic
  Display Backplane, from Plastic Logix
  Limitations to 100s of transistors
- <u>Hybrid</u>: include some pre-fabricated components if needed. Take the Si techno for what it is good at and combine with printed techno
  Interconnects: the first step and put chips on top. Make horizontal connection and one up to the chip. Ex: print light sensor and temperature sensor

Power: powering low profile flexible printed systems is challenging. Energy harvesting to directly power or charge with flexible power sources
RF Energy harvesting:
Scaling up: printed silver to make energy harvesting printed devices

Manufacturing considerations: how to go from prototyping using ink jet to more modern production? Look at design rules
3D printing and printed electronics: can you print in a 3D object? Optomec, Stratasys, Aurora. Interesting challenge forward

- Assembly: large scale assembly of electronic components. Is there a way to use printing for assembly of Si components?
  Chip as ink: suspend chips in a fluid, like pigments. How do you put the chips in the right place?
  Make charged pattern on the chip and a charged pattern on the substrate
  Make simple patterns which will be the key
  Digital Fluidic Microassembly
  Improved addressing array: instead of TFT you use a phototransistor. Make the patterning with light

Summary: interesting because can democratize lot of manufacturing, mass customization in high volume. Printed people interested because it adds value to their manufacturing. Works only if people work together, work with semiconductor industry

Flexible Electronics for Industrial Applications
Aaron Couture, General Electric Global Research

GE makes very large industrial equipment, big cost, low volume
A few 1000 researchers in NY research center

In 2000: GE OLED Vision. Energy efficient, low cost, thin and flexible. New design possibilities could change the way we think about lighting. Lighting Wallpaper
Collaboration and internal program: scoping technology and roll-to-roll process feasibility
In 2007: performance and reliability proven out, make demonstrator
2008-9: GE business put the project on hold. LED techno was accelerating at the same time. The commercial market has gone to LED.

New market for X-ray: mobile and portable
Phase 1: lightweight, rigid, unbreakable, thin, low power
Phase 2: curved, rigid, unbreakable, low power
Phase 3: flexible, roll-able (ultimate dream!)
There is value in all the phases
Example of new DXR Technologies: need ability to flex all of the components.
Challenge is packaging: how do you package the prototype and then how to manufacture?

New Pulse Oximeter Concepts:

Print tiny magnets on LED chips and use these magnets to position the LEDs

Wearable Impedance RF Sweat Sensors: continuous measurement of biomarkers from sweat to check someone's situation (AIR Force) => Hydration, stress, inflammation. Need a way to absorb the molecule and measure

SiC for Power Electronics enables new product capabilities: GE SIC MOSFET. Pilot production of SiC on wafers for power generation, energy conversion and distribution. For harsh environment sensors
Packaging limitations of standard power module: wire-bonded so challenging to get the heat transfer. Develop power overlay to take the SiC chip on polyimide flexible substrate and place vias by laser and distribution layer on the backside.
Plastics are not going to work in extreme environment: need glass or ceramics. Make thin ceramics that are flexible.

Future opportunities: GE is already in business in wearables for hospital. Large market pull to reduce size and cost. => get rid of the wires is the first step. Then try to make flexible packaging
Wearables market segment: sports/fitness; wellness; home health; in-hospital
GE focuses on in-hospital (general, critical care, neonatal) and then home health (general, chronic, 30 day re-admissions)
Approach to wearables: collaborative. Go out and evaluate what new sensors are on the market and see how to bring them to GE systems

GE context: the industrial internet. Consortium: for any product in the market place, you generate data and communicate and analytics about that data that tells you the health of the product in servicing. Can flow back to the product itself in optimizing the way the product works. Place sensors in industrial places where there is no sensor now. Ex: avionics engines. But prove the reliability of the sensor to put the sensors in. High bar in the industry.

Conclusions:
NMI to see new collaborations. Pick a few demonstrators to show how it works and bring that to consumers, start enough of the market to make it valuable. The pieces exist: materials, manufacturing technologies… Make sure of reliability

Empowering the industrial internet of things with 3D printed sensors and Antennas
Mike O'Reilly, Optomec

Optomec is a capital equipment manufacturer of printers. 2 areas of significant progress: printing sensors and printing antennas

What is the industrial internet of things? Two different approaches: Industrial (IIoT) and Consumer
IIoT: started by GE and collaborations with other organizations. Structural health monitoring of things in the field
On the other side, consumer IoT: how do we communicate?

IoT: millions of sensors paced on millions pf parts. 50 billion connected objects by 2020
How do I collect the data, what do I do with that data???
Wind turbine, jet engine, aircraft devices, bridges, railroad tracks, human body could all be connected.
Impact of no or limited monitoring: catastrophes!
Communicating data: antenna transfers the information
Print sensors up and down every turbine blades. Currently, they take the lowest time between failure, bring the blades down, replace and check the blades for defects. If not, the blades are mounted on another wind turbines. Monitoring what happens to the blade instead of making non necessary maintenance would save several B$ every year

Optomec offers an enabling technology for IIoT: print onto 3D structures
Print structural metals, electronic inks, add materials to existing components, micron to meter scale
Provide value across product lifecycle
Functional prototypes to volume production, preventive maintenance to part repair, cost effective
Open system approach: coexist with existing process, integrate with existing process, and use commercially available materials
Challenges for printed electronics: find materials providers that have enough consistency from batch to batch

Aerosol Jet Print Solution: Patented Materials deposition process
10 micron to mm linewidth and coatings ≥ 10 nm thickness, non-contact process, 2D and 3D printing
Additive: materials only where it needs to go=> materials only where needed, limits waste
Offer medium volume production solutions and integration into existing processes

Working principle: Create fine mist of particles, carry to printhead, secondary stream of gas and by focusing gas you have high distance and focus. Scale up distance 2 to 5 mm
Disadvantage: only one nozzle (sometimes only two to three). Go for applications where only one nozzle throughput is enough. Not scalable technology for multinozzle

Digital point to point printing, generate tool path and build the part
Key advantages:

- Print on 3D structures: conformal antenna for consumer and industrial applications
- Condensed packaging
- Reduce time to service and focus on pending failures vs needless replacement of expensive components

Partners for material availability: large corporation did not want to make the investment to develop the required materials.
Printed Antenna capability: laser direct sputtering. Commercial applications in smart phones
Process is moving to a one-shot injection molding. Silver nanoparticles, patterns are 2D or3D
Benefits: fewer process steps, environment friendly, lower cost high throughput 40000 antenna/week/system

Sensors: print everywhere on every thing

Printing sensors on turbine blades: multiple sensors up and down turbine blade. Health monitoring for high value components.

Summary:

- Conformal printing 10 micron to mm linewidth
- Full range of conductive materials, dielectrics, epoxies
- Digital process: no tooling
- Platform flexibility: 2d and 3D antenna and sensors
- Complimentary: fill gaps where current solution and deficient
- Environment friendly
- Cost effective: scalable print engine to full solutions with lower overall operating cost

GTMI Research in Printed Electronics

Chuck Zhang, GTMI

In GTMI increasing effort to work on technologies at 4-6 TRL level
The government identified 11 cross-cutting technology areas for advanced manufacturing: 1 is directly printed electronics and 5 others relate to this

Printed electronics for smart material with advanced sensing
Integration of 3D printing and printed electronics
Printed electronics for medical applications
ICNE-base PE process Modeling, monitoring and control
Scalable manufacturing

In lab: Optomec Aerosol Jet Printing
Worked with a wide variety of ink and substrate materials

Example1: direct printing of sensors on laminate for composite manufacturing. Results: 10% pre-cure retained full mechanical performance
Integrated composite design, manufacturing process monitoring and service with printed electronics: monitor curing process during manufacturing

Example2: A case for medical applications of additive manufacturing technology: heart valve phantom. For patient education, physical objects for medical imaging and computational models validation, models for pre-surgery planning and practice. Better design the valves.

Example3: Next generation of personalized prosthetic products and services: Help to improve the comfort level by monitoring. Data are helpful for the doctors to improve the design and maintenance. Data transmitted through mobile service to the doctor's office.

Integration of 3D printing and printed electronics for smart materials fabrication: print on inner surface is hard. Some students develop printing sensors of a substrate that has very low surface tension (e.g. Teflon) and then transfer onto the desired surface.
Scalable and continuous manufacturing of smart materials: print the sensor and do embedding.

Example4: Collaborative project: Fabrication of CNT-based high sensitivity gas sensors for Homeland security applications and develop high frequency antenna and transmission lines, 3D packaging gap filling

Panel discussion #1: Georgia Tech – Emerging Research and Applications

Printed Chem/BioSensor – *Judy Song, GTRI*
Work at GTRI on

- Nano-based sensing: RF, electrical and optical
- Electrochemical sensing
- Optical interferometric sensing

Motivations: Long-term monitoring of chemical vapors, standoff detection, low vapor pressure of explosives requires high sensitivity, deployed on building

Nano-based sensing: RF CNT and graphene; Impedance CNTs/graphene: optical
Gas sensor with aerojet printing. Applied for environmental, industrial waste gas detection
Sensor array: impedance. A novel sensor integrating paper antennas and printed CNTs
Electrochemical sensing: well established materials and technology. GTRI integrated screen-printing to make it more robust and provide more detection capabilities.
Interferometric waveguide sensor: not completely printed but the sensing field is polymer based and printing can be used. Long list of capabilities. Spun off in external start-up company

Digital Direct Manufacturing and Flexible Electronics for RF/mm-wave Applications – *John Papapolymerou, Electrical and Computer Engineering*

Radars for Environmental sensing: example to measure snow
MM-wave wireless applications: high speeds, up to 15 gbps
Defense and space but also anti-collision radars for cars.
Requirements: integrate on a platform, embedded, flexible, light weight and thin
Aerosol Jet printing process: more materials, do different 3D structures
3D print of D-band transmission lines, liquid crystal polymer LCP substrate. Seems promising technology
Can we build 3D RF transmission lines in mm-wave. Substrate and 10 micron polyamide
Full 3D printing: build 3D transmission lines
Direct printed additive manufacturing Ka Band Antennas: 3 layers ABS. Good resonance, 25 GHz

Flexible Hybrid Electronics at the Center for Organic Photonics and Electronics (COPE) - *Canek Fuentes, Electrical and Computer Engineering*

Printed electronics is believed to become a huge market in the future. OLED dominated the market
COPE works on power, human machine interfaces, logic, sensing… established in 2003
Multidisciplinary research. 36 faculty from 7 different schools. Shared facilities and innovation partner for industry
Material to synthesis, processing characterization, manufacturing
Close to ATDC, ventureLab, etc.,
Develop a scale-up facility, new materials partnership with Sigma Aldrich
Develop pilot manufacturing lines: organic vapor deposition system. ALD, MOCVD, OVPD
Institut Lafayette, devoted to translational research. Establish collaborations, goes beyond printed electronics
OVPD pilot manufacturing, AIXTRON equipment
Research: interfacial science, thin films science. There is a class of polymers that can be deposited in aqueous solutions. More renewable substrates: work on paper.
Develop film transfer lamination
COPE sensor platforms: ALD functional layers. Transistors stable in water and oxidizing environment.
Ultrabarriers: encapsulating for long term durability

The Development of Barrier Films for Packaging Flexible Electronics - *Samuel Graham, Mechanical Engineering*
Applications of Barrier Layers: all these devices are susceptible to failure when exposed to oxygen.
Develop a level of passivation to give semi-hermetic or hermetic package
Not only true for organic
Ex: LEDs can degrade, Solar cells should last 20 to 25 years. Implantable devices
Barrier film requirements: high quality single layer or multi-layer to prevent oxidation
Issues: nucleation of the polymer films can cause defects and high diffusion on grain boundaries.
ALD-based hybrid barriers for photovoltaics: flexible and target properties of glass films. Nanolaminate coatings, alternate
Spatial ALD of Barrier Films: using rapid ALD systems. Coatings to be deposited in 10 minute instead of hours. Roll to roll can get this even much faster.
Mechanical reliability: see the cracks forming in films and track it

High Performance Flexible Electronics using 2D materials – *Eric Vogel, Materials Science and Engineering*
Moore's law: achieve the performance with energy efficiency
IoT energy efficiency is going to be a challenge, especially energy efficiency devices.
Combining small tech with flexible tech. On the long run, how to get high performances at low power consumption directly integrated?
Organic electronics with inkjet printing: cheap, high throughput but low performance at high operating voltage
Conventional 3D materials very thin and moving to new substrates. 3D materials thin always surface defects

2D materials (Graphene, MoS2, hBN): there is a range of materials that can be processed. Because of crystal structure: no dangling bonds, monolayer, thickness control, no strain. High performance. High throughput if you can do roll to roll

Fabrication of flexible devices of any substrates. Fabricate the device and then transfer to any arbitrary substrate

Physical characterization to make sure the transfer process does not impact the part's performances

After many bending cycles, the devices are still operating. MoS2 transistors still operating after 200 cycles

Build thing you cannot do with 3D: vertical heterostructures with 2D semiconductor, Low power devices. Objective is to move to flexible substrates.

Materials/Devices for Neuromorphic computing on flexible substrates: like the brain, you can make them highly parallelizable

No high frequencies: build associate learning circuits, could be useful to sensors

Panel Discussion – Questions from the audience:

- Are there technologies envisioned to bridge the gap between digital printing techno and photolithography at submicron resolution?

Nanoimprint: has a possibility, but still need to produce the template

Probably you will not beat silicon in some aspects, consider what you get and need

- Graphene: where are its applications in the near term?

What can it bring that we don't have? High conductivity and flexibility: touchscreens using graphene

High performance and flexible, high throughput manufacturing is longer term vision

Graphene is also very low noise than other materials, very good for sensors to lower noise/signal ratio

Carbon nanomaterial increases dramatically the sensitivity for sensing applications.

For sensor performance the repeatability and reliability is key factors, and nanomaterials can help to achieve to control the quality of the sensing films.

High frequency applications can also use graphene

Printing tools are helpful to get better reliability but CNT properties ae not always consistent from batch to batch.

Nanotubes and nanowires: properties are very sensitive to lateral dimensions

Critical depends on the application

Very little gets through graphene: peel strength is good. Barrier properties when mixed with polymers you get barrier enhancement. Prevent damage from occurring during transfer.

- Big weaknesses in deposition methods, what are the gaps?

Further reduce the features (higher frequencies, things get denser)

ALD: issue is inspection. How do I inspect very thin films on large areas? Time needed to do the whole inspection? There are other techniques to qualify, but even there you are looking at small blocks

The technology y is not there yet for super straight edge.

- Recyclability, sustainability, environmental concern?

Make the processes from materials and remove materials not sustainable. Paper-like substrate recyclability of electronics. Big push but where is the demand of consumer for recyclable devices. Awareness is coming, COPE tries to use green chemistries. Trying to push the technology towards that but where are the big markets for that?
The additive materials has a clear advantage: you deposit the materials where you need them. Limit material waste.
CNT, graphene: how safe it is? Do more research on public health to make sure they are safe
Body exposure is a big concern

Energy efficiency: restarting Moore's law. Over the years, more and more integration, you will see the same energy performance limitations. Energy efficiency is the challenge in integration. Example of batteries in textile fibers. Lots of ideas on where you can embed energy storage and energy harvesting.

- Efficiency of flexible Solar Cells vs other?

Currently organics PV efficiencies are not near III-V's or Si's but theoretical possibility. Steady growth in efficiency in the last ten years, but not clear how to reach 20%. Consider also energy payback time to evaluate the long term potential. Si has put out of business promising technologies

Panel Discussion #2: Industry – Requirements, Challenges, and Solutions for Commercialization

Ross Bringans, PARC
Research and helping other people develop. Challenges: what is the real application that is going to consolidate everybody around the technology? Work with materials people, printing companies and companies that want to go to a new area. Challenge: is the volume going to be large enough to bring things forward? Come with a sort of platform to accommodate different design.

Aaron Couture, GE
Thin films lab, overlap with flexible and printed technologies. ASIC chips and integrating these chips into packages, solar cells (pilot lines). Focus on medical imaging and X-ray.

Mike O'Reilly, Optomec
Optomec builds printers for printed electronics. Base challenges is applications: everybody comes with a new application but materials from a certain vendor, how to deposit, what are the physics around … Grown to 175 systems installed today but has to understand all the applications:. Challenge is scale-up, materials (difficult to get consistent batch to batch materials), understand the processes.

Mark Buccini, Texas Instruments
Expertise on product strategy side. Put together the strategies and the vision. TI is a semiconductor company, commercializes a broad range of semiconductor and industry products. Over 100,000 different semiconductor products in production today. Every day TI ships about 14M semiconductor chips. Cost, reliability, predictability are key.

45 nm – 65 nm gap to bridge
Immediate opportunity with Tech and TI : add passives, antennas… on the semiconductor chip. We add what we want instead of adding all and then remove. Printing improves efficiency, green
1-3 years out: embed battery
Move to System-in-Package (SiP): a self-powered chip.
Challenge: Ecosystem for printing => semiconductor manufacturing is established versus printing is still a lot of R&D as well as displacing the installed solution. It has to be very predictable.

Wayde Schmidt, United Technologies Research Corporation
Aerospace and commercial industrial business group (Sikorski, Pratt & Whitney, United Techno, Building and industrial system, OTI S elevator, fire extinguisher)
Aerospace: highly reliable, harsh environmental conditions
Building: more distributed, lower cost, ex of air quality sensors and communicate with each other

Panel Discussion – Questions from the audience:

- Comparison to MEMS structures: integrated and manufacturing capabilities. MEMS market boosted when integrated into cell phones

- Expectations from industry for a center like IMI:

Standardization will enable a larger base but is not a pre-requisite. It is application-depend: perhaps methodology for TFT printing but how to standardize antenna? Effort on standardization on materials, how they behave… deposition process will be different for each one of us: customization is required.
Opportunity for additive manufacturing to customize circuits with capacitors, sensors…
Semiconductor started the same way: 100 transistors and today millions. Does not have to be this big step at first.
Analog: very attractive space used in everything, needs to be accurate
Chance to bring people together

- Motivations to use printing technologies:

2 different things:
-customized, application-specific solution: on 3D objects
- dispensing for electronics: one chip at a time, not millions
There will be different standard for different applications.
Ex of smart phone: Electrical performance, frequency, environmental, humidity, temp test? If I pass the test, there will be standard on the materials not the deposition process
High cost, high precision, high functionality vs low cost, low functionality. As industrial user, we want all kind of options to be able to choose what is best. Putting the technology in more people's hands will help accelerate the distinction of the applications
Examples: CMOS Imaging: organic photosensors on CMOS chips to improve the resolution and photosensor layer on the semiconductor. Use a manufacturing base that exists today: if tools are there for manufacturing and then add on top of it your printing.

Add just what you want: microprocessor are distributed everywhere but simple stuff uses less than 1% of chip capability. Super cheap semiconductor manufacturing will be done forever. The vast majority of a chip's capability is not used, it is just cheap so you use it. But you could print just what you want.
Big opportunity is to bridge all these "dirty" analog pieces with printing.

The microprocessor is becoming inexpensive. The printing should be used to distribute these things. It is not a competition but a choice to mix and match.

Driving motivators to get greener: sometimes happen under government rules (ex of after-waste). Move to full scale production because print only what you need to print, limit materials waste.
Stability of the input materials is the key point to make your process successful.

1-3 years: there are applications, backlog of applications. Not complex, application space for just improving a system but opportunity to integrate it into a simple package.
Beyond that: far-fetched, come in different stages but huge opportunity for less fancy applications.

- How do you get from a non-production tech to production tech?

Someone has to pay for it but will only pay if there is an application that will drive the move. The government is funding how you bring all that together. Users and suppliers will come together to build the production line. In-between, to grow, you ask for investors and government is a big investor to help building the technology.

- Do the US lead the game in Printed Electronics?

European Union has put large amounts of money. US are not in lead in printed electronics. Turned the corner around the hype of printed electronics, now people are looking at more realistic applications. Not necessarily be in the lead but find the applications. Opportunity is to have a new model center, a single center that people come to but heavily rely on collaborations to make it move. See industry participate in the creation of demonstrators.

Where do we go from here? GT approach to industry Partnerships
Bill Cutts, GT IC

Research is inseparable from Tech's public purpose and mission
Government funding is going down and work has to be done in concert with industry
Changes in how industry wants to work with universities: how to make sure companies get return on their investment. Not work with a large number of universities anymore but now and downselect. Fewer number of universities but get a larger range of things to get from them. How do we meet the expectations of what the companies are asking for.
Portal for companies to come to Georgia Tech
Sustained focus on enabling commercial outcomes
Many synergistic forms: large companies for major sponsored research, companies looking for new technologies, hire new students…