CHASM TECHNOLOGIES

BRIDGING THE GAP

Experiential Issues Encountered While "Bridging the Nanotech Gap" Towards Commercialization

Bob Praino

NSF-NNI Workshop: Design and Manufacture of Integrated Nanosystems

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A Brief Introduction…

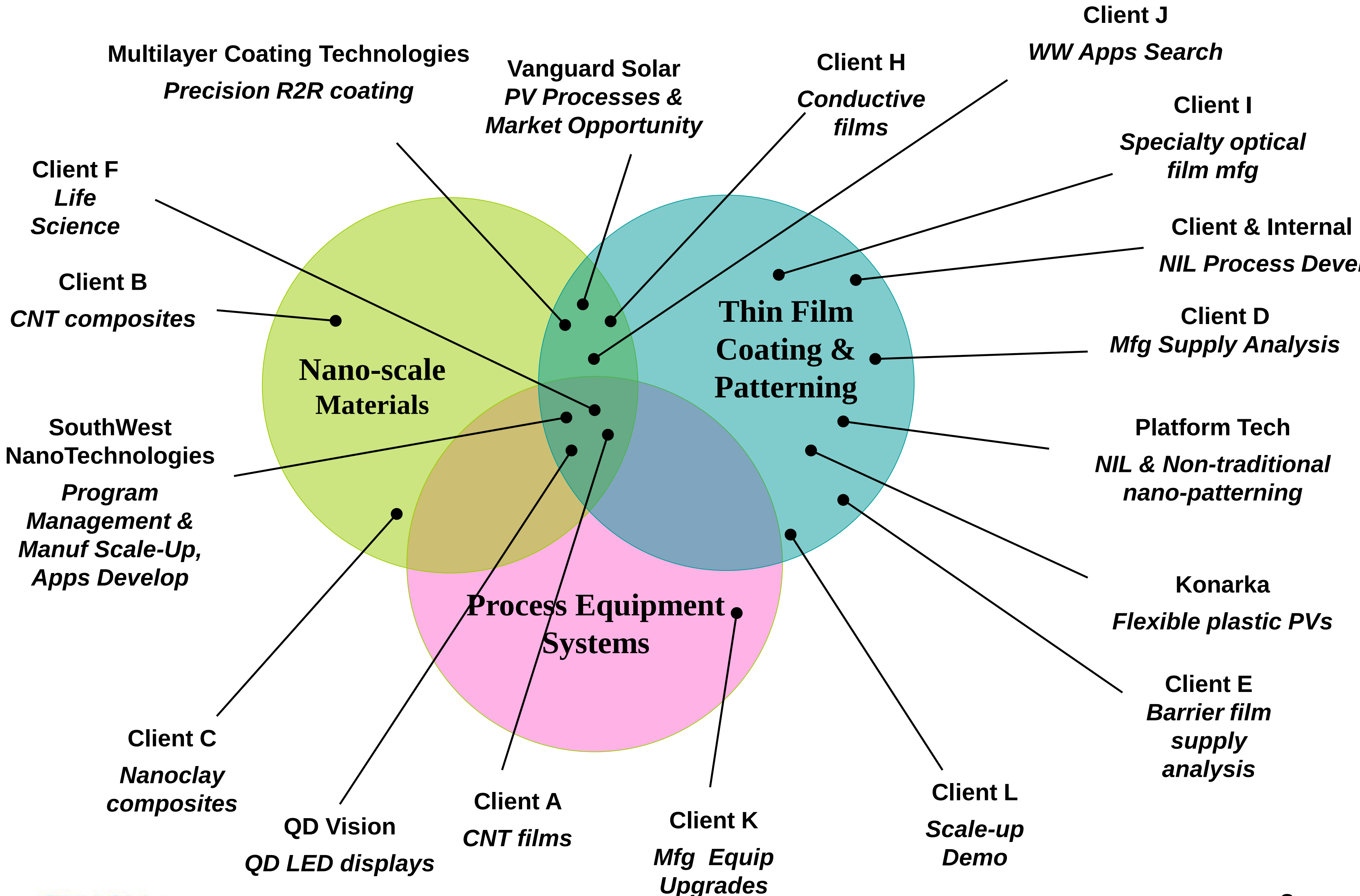
Chasm's mission is to help our clients bridge the commercialization gap through the smart application of material science, process technology and mfg equipment prototyping.

At the Intersection of Business Processes and Technology

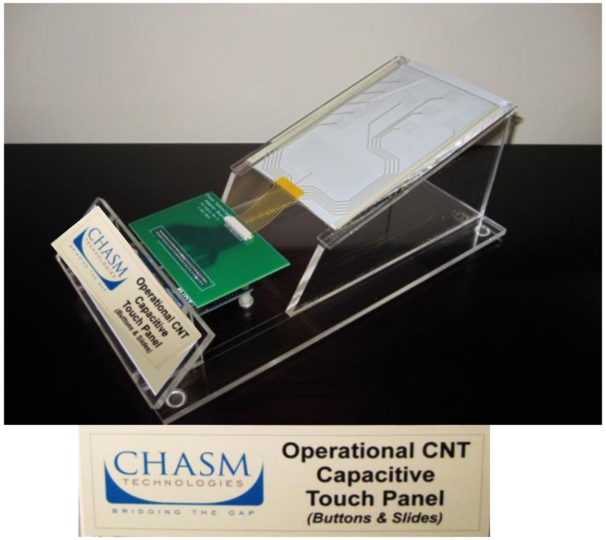
- **Opportunity Analysis & planning**
- **Product & process development**
- **Scale-up & manufacturing**
- **Commercialization**
- **Program management**
- **Corrective action systems**
- **Business development & funding**

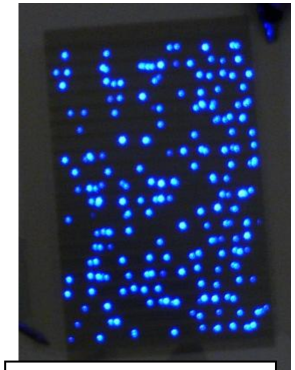
Custom materials and process development, analysis, & prototype creation

Chasm's Portfolio & "Range"



We're talking about real product targets





Printed Blue LEDs*

CNT Enhanced Cathodes

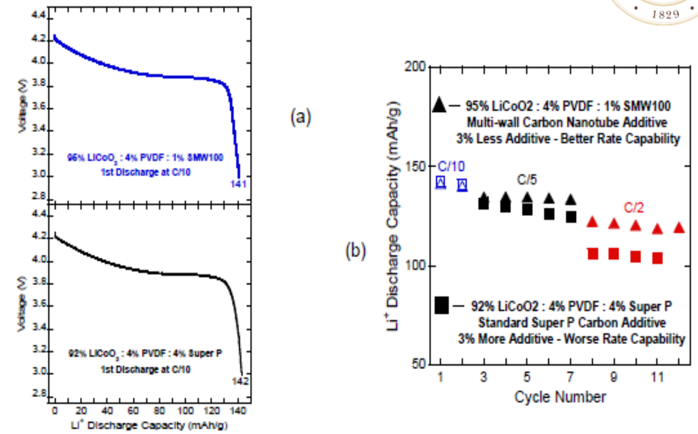
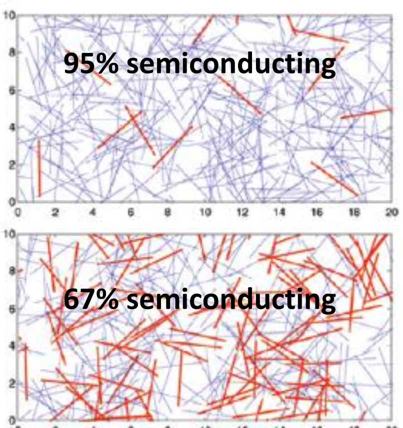
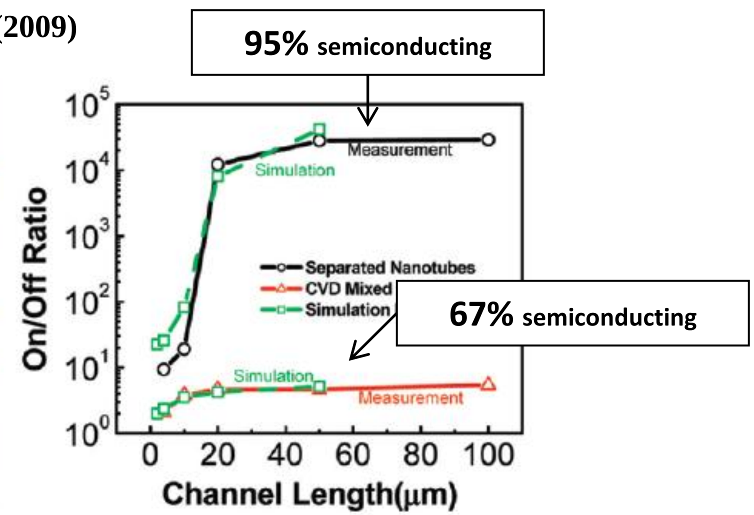


Figure 8: (a) First discharge voltage profiles for $LiCoO_2$ cathode with: (1) 4% Super P and (2) 1% SMW100 conductive additive. (b) Rate study for cathode half cells at C/10, C/5, and C/2 rates: Typical conductive additive (squares) and SMW100 (triangles)

Zhou et al, Nano Lett. 9, 4285 (2009)





Smart Fabrics*

Structural Sensors for FRP Composites!

Affordable, easy & safe to use.

* Patents pending

3/2/11

The backdrop for this presentation...
Nanotech Initiatives and Goals

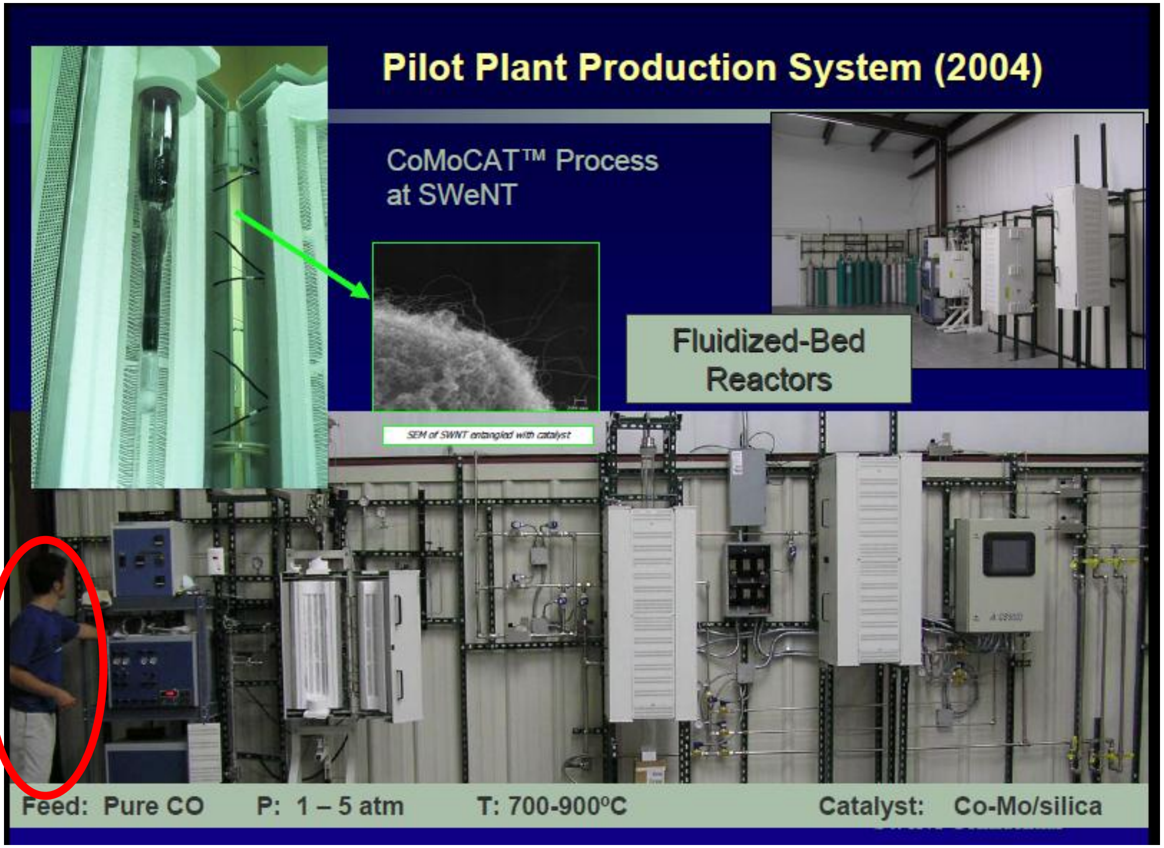
- **First 3 nanotech initiatives are renewable energy, sustainable manufacturing and next gen electronics**
- **Goals**
  - **Advance a world-class nanotechnology research and development program**
  - **Foster the transfer of new technologies into products for commercial and public benefit**
  - **Develop and sustain educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology**
  - **Support responsible development of nanotechnology**

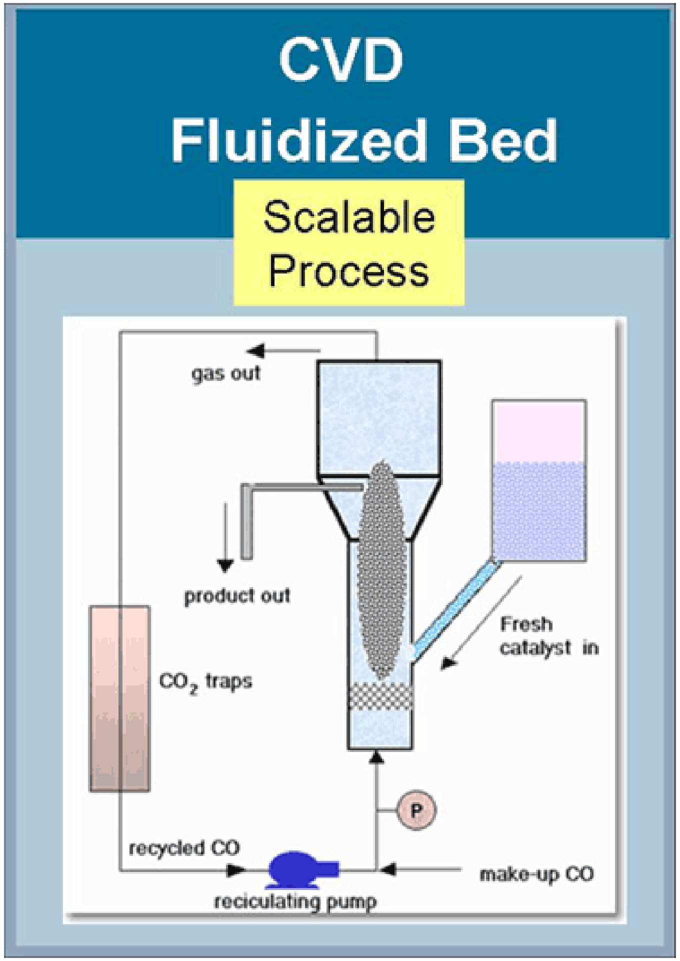
Consider two startup companies and a view of their challenges from the "lab" to the customer…

- **SouthWest NanoTechnologies:**
  - **Carbon nanotube manufacturing**

- **Liquidia Technologies**
  - **Technology platform for drug delivery**

Carbon Nanotube Pilot Manufacturing





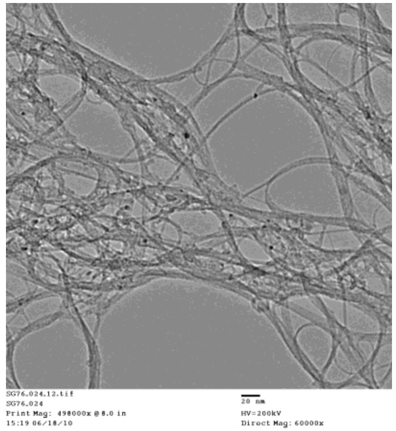
Courtesy of SWeNT

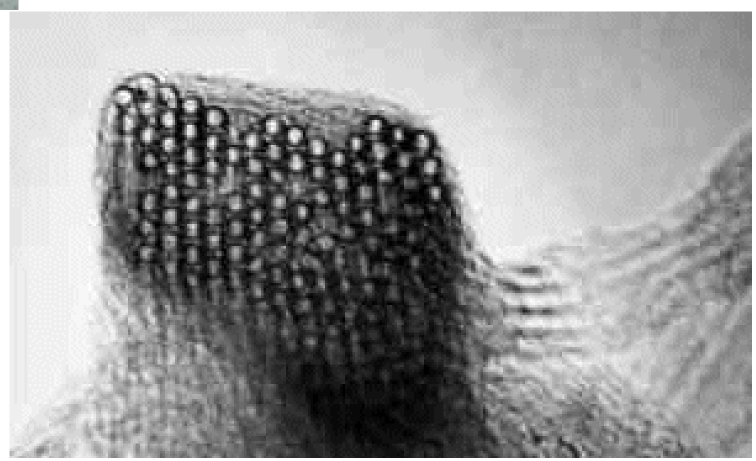
Transition to a full scale plant

Courtesy of SWeNT

The SWCNT Product

From the reactor

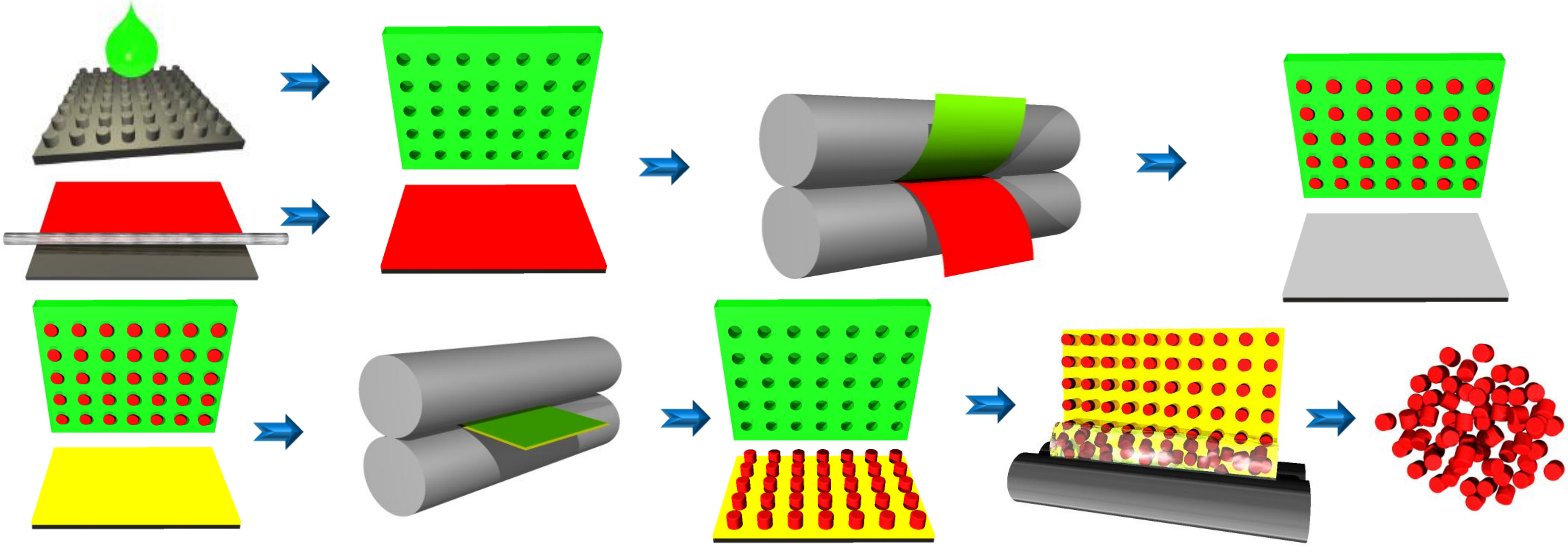




Above: A single nanotube rope, made of about 100 SWNTs of uniform diameter. The SWNTs pack in a triangular lattice. [2]

Courtesy of SWeNT

Particle Replication in Non-wetting Templates (PRINT® Platform) – *Liquidia Technologies*

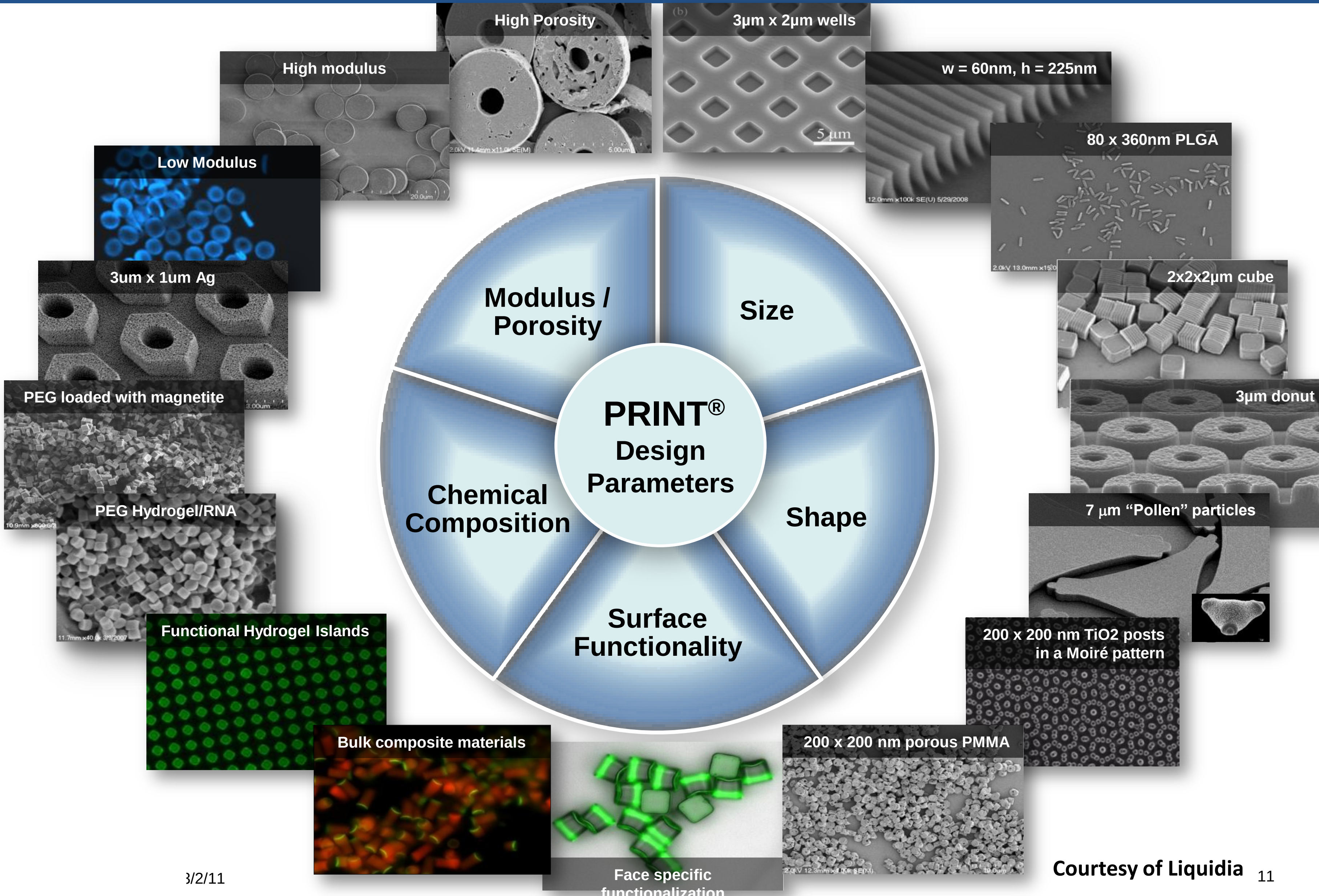


"Direct Fabrication and Harvesting of Monodisperse, Shape Specific Nano-Biomaterials"; Rolland, J. P.; Maynor, B. W.; Euliss, L. E.; Exner, A. E.; Denison, G. M.; DeSimone, J. M *J. Am. Chem. Soc.* 2005, 127, 10096

Courtesy of Liquidia

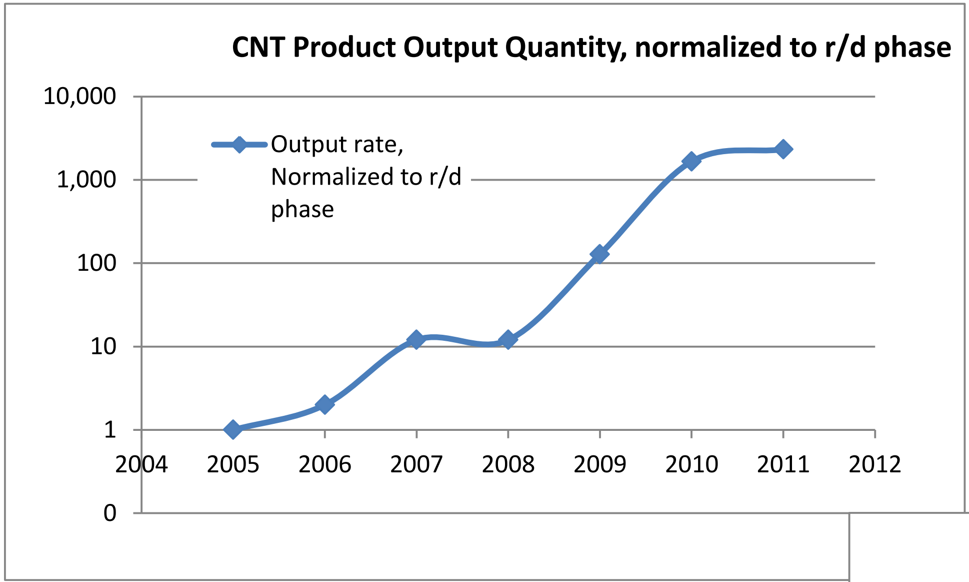
PRINT® Platform Control

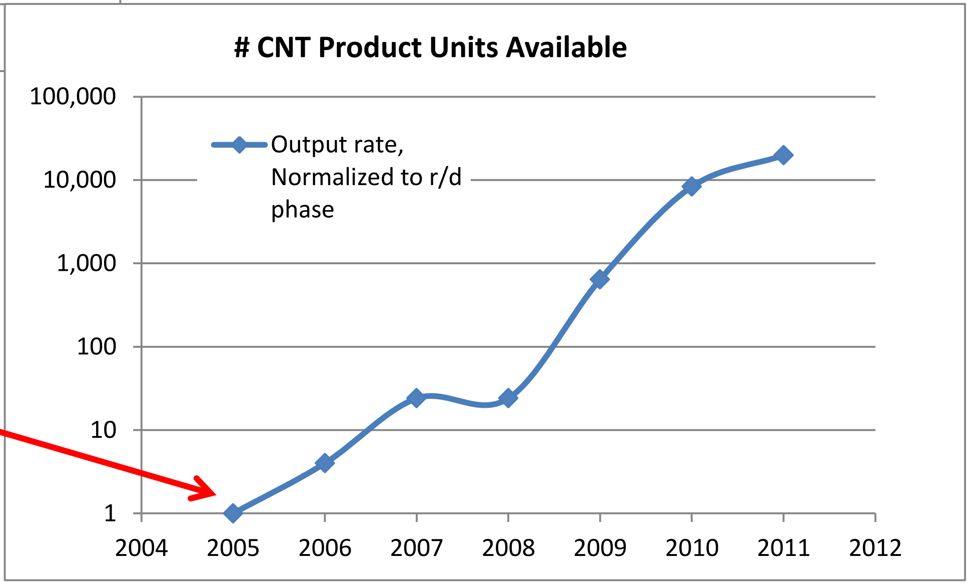
Independent and precise control of multiple particle design attributes



Courtesy of Liquidia

Relative Output Scale – SWCNTs: 2005 - 2011

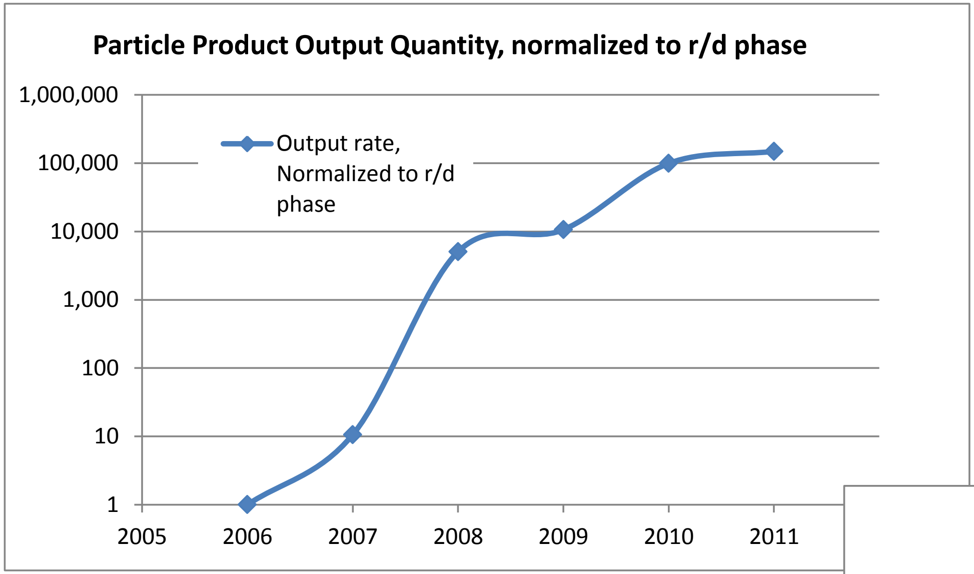


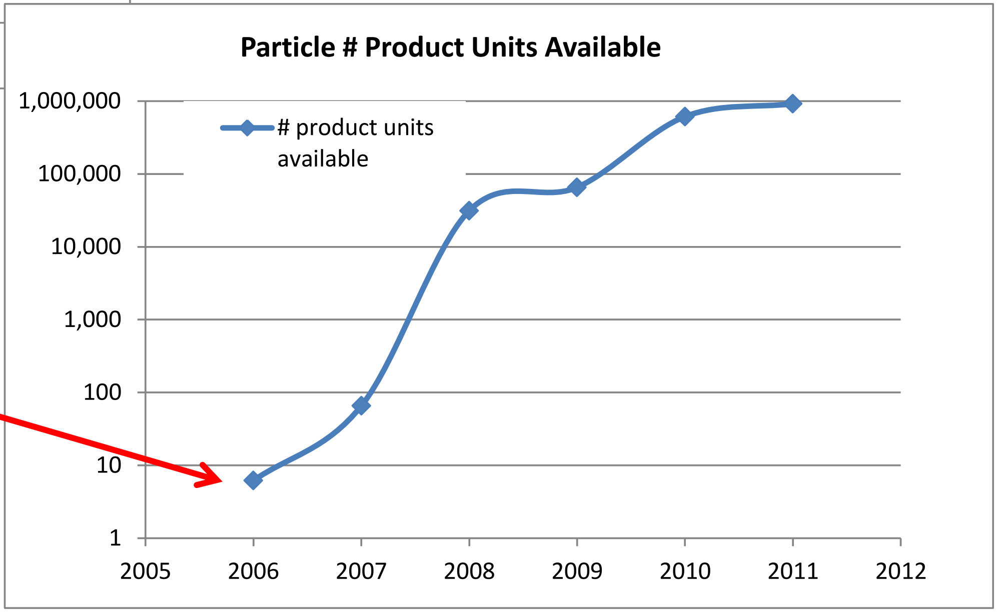


1 day of "product" samples per month

Results Courtesy of SWeNT

Relative Output Scale – Particles: 2006 - 2011





Not enough to test 1 mouse

Results Courtesy of Liquidia

What did we observe during these journeys?

Framework – Business Success Factors

- **Common Issues**
  - **Long development and implementation cycle**
  - **Requires demonstration in a product application for adoption**
  - **Generally requires integration well downstream of the starting point**
    - **SWCNTs**
      - **Coatings**
      - **Other functional performance advantages? (mech, optical, elec, chem)**
      - **Process and device fabrication**
      - **Electronic device function**
    - **Pharma**
      - **Efficacy?**
      - **Improvement over existing pathways?**
      - **FDA approval**

Framework – Judgments Early On

- Time is significantly underestimated vis-à-vis investor expectations
  - From R/d to r/D
  - From D/m to d/M
- Customer interviews and best case market analysis comes late,
  - Heavily “constrained” by the need to deliver “POC”
  - But the POC takes more time than expected
- Early incorporation of good financial management to ensure survival is critical
  - Both companies acted on this early and thus far has been key to survival
  - This is still not a guarantee

Barriers – Technology Realities

- **Materials availability**
  - **The initial small scale still requires much testing and characterization**
  - **“Nano amounts” make it challenging to explore processes required for scale up (for either materials manufacturing or product applications)**

- **Equipment suitability**
  - **For R/d and r/D, a gallery of processes is important to allow assessment of options for a manufacturing pathway early**
  - **At the early R/d phase, there is limited visibility into larger scale industry options (especially for startups coming out of the educational environment) ➔ requires a change**

- **Process pathways**
  - **There is a tension between the processes being developed and demonstrated “on the bench” with what may be more easily available in the broader industry environment**
  - **Much of the R/d phase has involved transforming the “R” into another process which produces the same product**

Barriers - Measurement Issues

- Measurement options are limited & new techniques are required
  - Even existing techniques have a learning curve ➔ validation is needed
- For Materials
  - Composition?
  - Physical characteristics?
  - To execute analysis, processing is required, which may change the material
    - For CNTs, chemistry & size are compromised
    - For particles, only spherical standards exist ➔ control of shape is new
- For Processes
  - How to tell if what you are making is good in real time
  - Validation that process scale up has not changed the “champion” material
  - Integration of data into process controls ➔ how much is enough?

Barriers – Technology Trends Take Time

Evolution of a segment of US industry

Trends In The Coating Industry and The Transition To Printed Electronics			
	Pre-semiconductor	**Semiconductor Dominated**	**Goal of the Transition to the Future**
Product character	Large	Small	Small
Coating environment	Atmospheric	Vacuum	Atmospheric
Substrate	Paper, plastic film (PET and PE)	Silicon wafers, plastic film	Plastic film & paper
Processing	r2r & batch	Batch	r2r
Processing	Additive (coating)	Additive w/subtractive	Additive
Dominant processes	Coating & chemical bath	Coating, CVD, sputtering, others, etching	Coating & Printing
Capex	"Millions"	"Billions"	"Millions"
Process Rate (area / unit time)	High	Low	High
Materials	Organic	Inorganic	Organic
Product "area density"	Low	High	Moderate
Cost ($/unit area)	Low	High	Low

Cost is king

Barriers – Products: The "chicken and egg"

- New materials require validated platforms for acceptance
- Existing platforms are hesitant to take the risk with new materials
- Materials must establish a relevant platform which can deliver an equivalent or better product (relative to the existing platform)
- Because of the above, the materials groups delayed "access" to the market

Barriers – Products: The "chicken and egg"

- **Example:**
  - **For Li batteries, the battery companies want a battery as POC**
  - **The materials group doesn't know how to make the battery and has to either find someone who will or do it alone**
  - **The functioning delivered battery will convince the battery company that it's worth investing**
  - **But the company still doesn't know how to make the battery**

- **If the company tries to deliver the POC product too early, it is likely that the demonstrator will not be "full featured"**
  - **The risk is that the customer will be "tainted" by "inferior performance" unless they have good vision**
  - **It is critical to manage expectations for what the POC will be**
  - **Investors are still reeling from the "dot-bomb" and require more proof**

Barriers – Business Issues Affecting Time

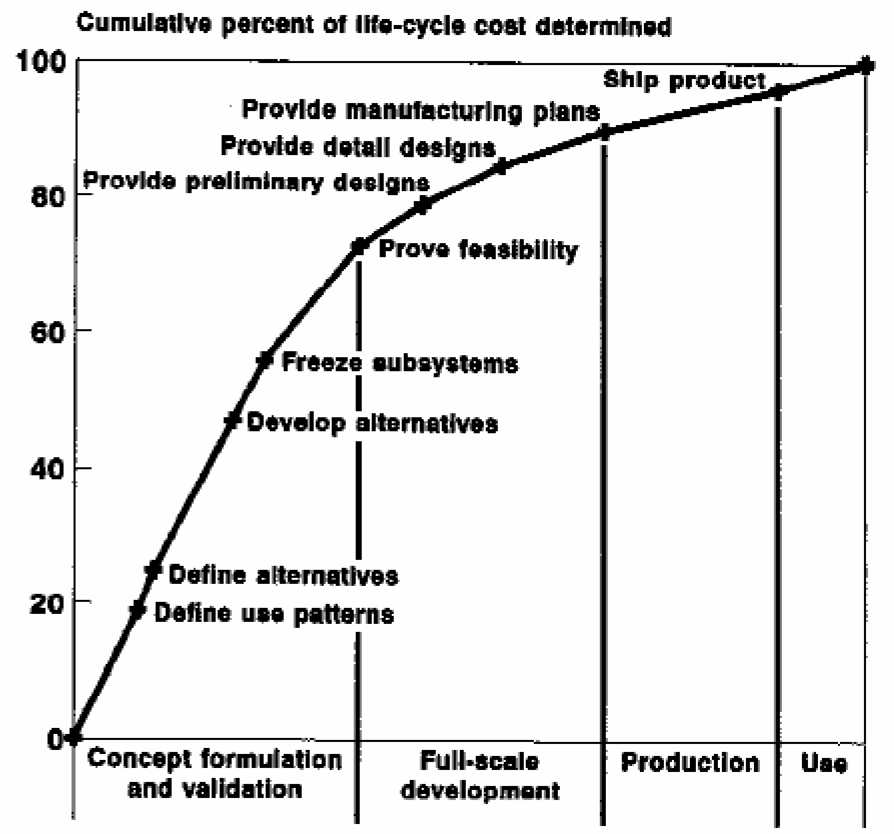
- Managing investor expectations
  - The lost "exuberance" of the dot-bomb era
  - Matching (and obtaining) adequate funding w/realistic goals
  - Adequate specific resources after funding is secured
  - Infusion of business discipline early to survive

- In the case of partnering:
  - Industry ➔ Up-front agreement on IP
  - Industry/University ➔ Up-front agreement on IP

The total cost implication needs sound action early, even using an "old" model

- **Recognize the impact of time vs. cost in the development cycle:**
  - Early design decisions drive manufacturing costs later
  - POC delivery sometimes compromise the decision making process with inadequate consideration of downstream cost implications

- **Process equipment systems are being placed in academia**
  - But there is conflicting incentive for industry to move this down the learning curve without funding & protection
  - Thus, schools will be slower relative to "industrial effectiveness"



Product life-cycle costs are locked in at an early stage of development, when fundamental design choices are made. These choices, which include process issues, also influence a product's development time. *From Nevins et al., Concurrent Design of Products and Processes, McGraw-Hill, Inc., 1989, with permission.*

These observations vs. the NNI 2011 Strategy Plan

- The NNI is pushing for nurturing leadership in nanotech and particularly in manufacturing in this arena

- A generally accepted theme is that the US economy relies heavily on small businesses

- NNI has described a strategic mission to provide facilities which have sophisticated systems available to support the nanotech innovation in the US

- Such facilities generally require additional contribution of funding from the "customers" (ie. Interested industrial parties)

- Unfortunately in today's environment, many small companies don't have the $ to take adequate advantage of such facilities)

- This leads to slower development cycles and a distraction for the technologist trying to deliver "nanotech" is a form which can move into manufacturing

- In the course of the development path, stronger guidance must be provided to circumvent the traps described above

Thank You

Acknowledgement and thanks also to:

SouthWest NanoTechnologies

Liquidia Technologies

Appendix – Excerpts From
"National Nanotechnology Initiative Strategy Plan"
February 2011

Nanotech Initiatives and Goals

- **First 3 nanotech initiatives are renewable energy, sustainable manufacturing and next gen electronics**
- **Goals**
  - **Advance a world-class nanotechnology research and development program**
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  - **Support responsible development of nanotechnology**

NIOSH, NIST & NSF
"Selected Highlights"

- **NIOSH**
  - **Conduct research & provide guidance to protect the HSE of people at work**
- **NIST**
  - **Advancing nanoscale measurement science, standards, and nanotechnology to promote US Innovation and industrial competitiveness**
- **NSF**
  - **Support fundamental nanoscale science and engineering in and across all disciplines.**
  - **Advance nanotech innovation through a variety of translational research programs and by partnering with industry, states, and other agencies**
  - **Major 2011 initiative in high-rate manufacturing**

NNI Goals

- **Develop scalable nano-manufacturing methods necessary to facilitate commercialization**
- **Increase focus on nano-tech based commercialization and related support for public-private partnerships**
- **Establish and/or sustain national user facilities and centers to accelerate the transfer of nanoscale science from discovery to commercial products**
- **Assist the nanotech-based business community, including small and medium sized enterprises in understanding Federal government r/d funding and regulatory environment**

Sustainable Nano-manufacturing
Creating Industries of the Future

- **Need suitable manufacturing technologies to economically and reliably produce nanotech based products on a commercial scale**
  - **Accommodate diverse materials at the small volume and length scales**
  - **Processes must be sustainable by design**
  - **Target production of carbon-based nanomaterials, optical meta-materials, and cellulosic nanomaterials**
  - **High throughput, inline metrology to enable closed loop control and quality assurance**
  - **Accurate measurement techniques will require new standards at the appropriate scale**
  - **Leverage the US's considerable experience in roll-to-roll manufacturing into the world of nano-manufacturing**

Nanoeletronics for 2020 and beyond

- **Physical dimensions are approaching a limit via Moore's law…materials begin to behave differently**