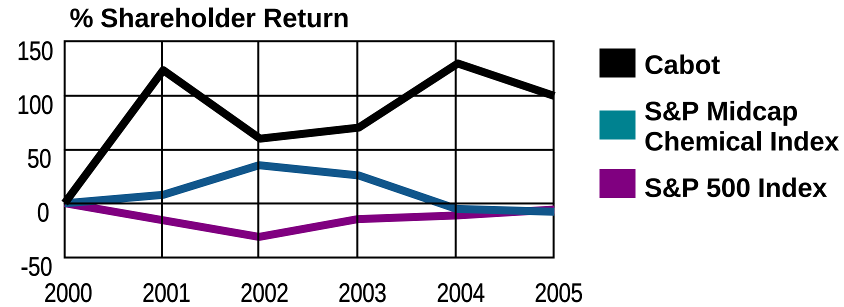
creating what matters

Positioning for Innovation and Competitiveness in Nanomaterials: Life at the Lean End

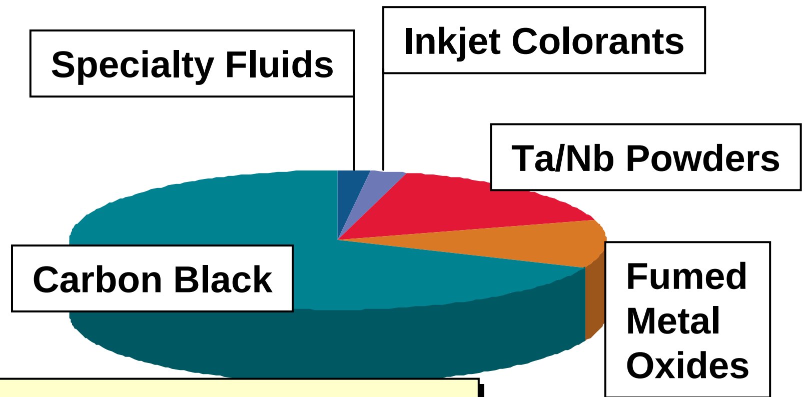
Yakov Kutsovsky

Who is Cabot Corporation?

- Founded in 1882
- Global leader in fine particles
  - Carbon Black
    - ~1,500,000 ton/yr.
  - Fumed silica
    - ~50,000 ton/yr.
- New Businesses:
  - Cabot's Cesium Formate
  - Nanogel™ silica aerogel
- Fine Particles are Performance Chemicals
  - Multiple Dimensions



Source: Bloomberg



Total Sales (2006): $2.5B

Nanotechnology Taxonomy

- BIO-SYSTEMS - Preserve Lead
  - Self-Assembly
  - How Did Nature Do It?
- MICRO-MACHINES - Preserve Lead
  - MEMS, Nanomanipulators
  - Chips
- COMPOUND MATERIALS - Catch Up
  - Nanoscale to Nanostructured
  - What They Can Be Used for?
  - Why They Perform?
  - How They Can Be Made?

Challenges

- Close the Gap between Industry and Academia
  - – Common Goals
  - – Remove Barriers
- Emphasis on Compound Materials
  - – Design and Manufacturing
- Manage SH&E Risks of Nanomaterials

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Competitiveness - Speed in Knowledge Generation and Use

- Generate and Use Knowledge
  - No IP Bottlenecks (University TTO)
  - Knowledge Sharing Networks
  - Training People
    - Explainers vs. Problem Solvers
    - Need for Critical Thinking
- Speed and Effectiveness (vs World)
  - Open Innovation
  - Align Government, Academia and Industry
    - Common Goals (SEMATECH)
    - Long Term Industry Needs
  - Unencumbered Access to Government and Academia Facilities

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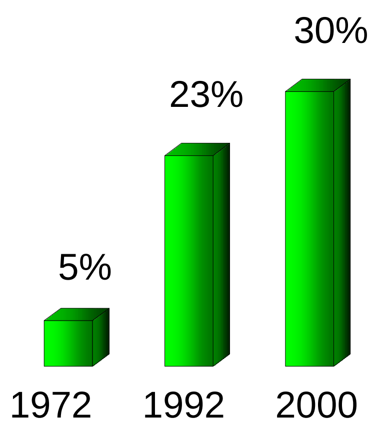
Breaking Innovation Stereotype

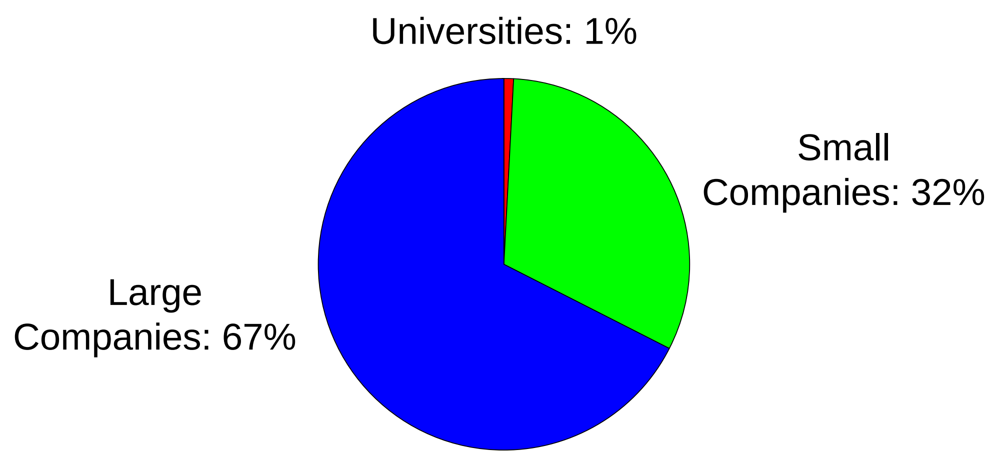
The Stereotype:

Universities	Invent
Startups	Innovate
Big industry	Commercialize

The Data:



US Patents Awarded to Small Companies

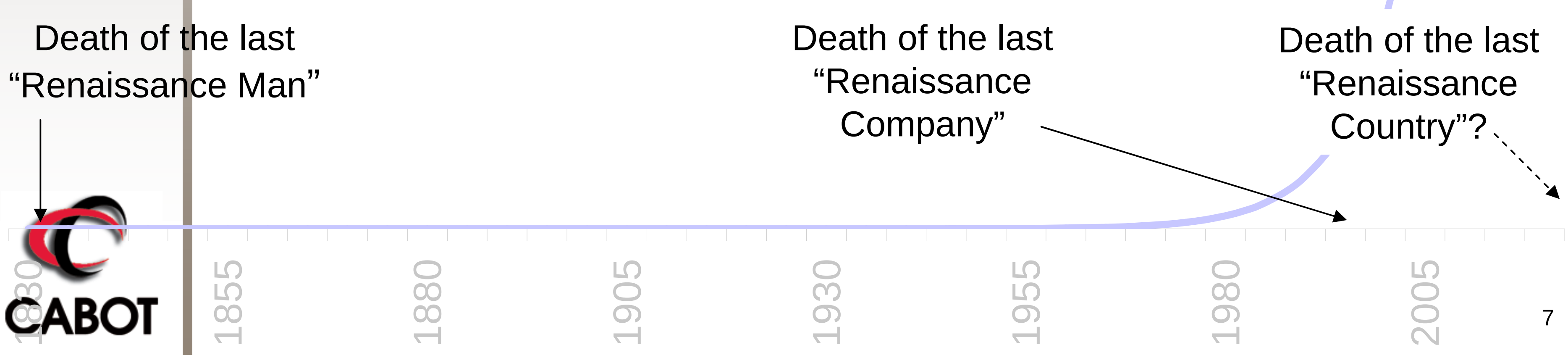


US Patent Applications in 2004 (total = 1.1M)

Much closer collaboration between all sources of invention and innovation, facilitated by government

Open Innovation Is Question of Survival

- To keep up with knowledge generation
  - the <u>right</u> education, large-scale collaboration,
  - new framework models: legal, funding, teaching, communication...
- This creates:
  - competitive advantage
  - benefits to society
- Today, Japan >> Europe > USA
  - culture and frameworks



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IP Framework: The World after Bayh-Dole Results and Opportunities

- Unquestionable success
  - for its time
- Copied worldwide
- $1.39B in licensing revenues and 10000 patent applications in 2004

- University lawsuits
- Gag orders
- Reach-through royalties
- Exclusivity
  - Should public funds create government-sanctioned monopolies?

- Bayh-Dole worked, and indeed was designed, for the lone innovator
- Open innovation is the new paradigm - do it or lose
- We've got the right spirit, but some unintended consequences
  - Technology transfer as a barrier rather than a facilitator
  - Focus on licensing revenues rather than societal good
  - Complexity and general lack of sophistication
  - Need for speed

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Improve Education and Frameworks to Drive Knowledge Generation and Application

	Education	**Framework**
Knowledge Generation	Inventors vs. explainers Open innovation models Systems thinkers Practical thinkers	Incentives (e.g. tenure) Open innovation models Cross-sector collaboration Dissemination assistance
Knowledge Application	Coop/practical programs Industrial sabbaticals Industry vets into uni's Close ongoing collaborat$^{\underline{n}}$	Technology transfer Open innovation models Patent burdens (time, $) Reward innovation (vs. invention)

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Challenges

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Compound Materials - Break Trade-offs

- Wide range of practically important materials
  - Metal and polymer alloys, fiber composites, coatings, polishing slurries, inkjet inks, filled polymers, adsorbers, insulation, etc.
- Materials are compounded to “Break Trade-Offs”
  - Light but strong; erosive but selective; high color but low viscosity; absorbing but reusable
- The state of nano-features in the compound, i.e. dispersion, is critical to performance
- Today Many, Many Compound Materials are FORMULATED not DESIGNED

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When Industry Is Faced With Problem

- "Guess" I think I know. Try this!
- "Engineer" The answer is in our technology. Do the designed experiment
- "Research" The answer is not in our technology. We need new concepts

New to us, but it exists

It will be new to the world

- **We need Academia help to get new concepts**
- **We need Academia help to train people who know how to get new concepts**

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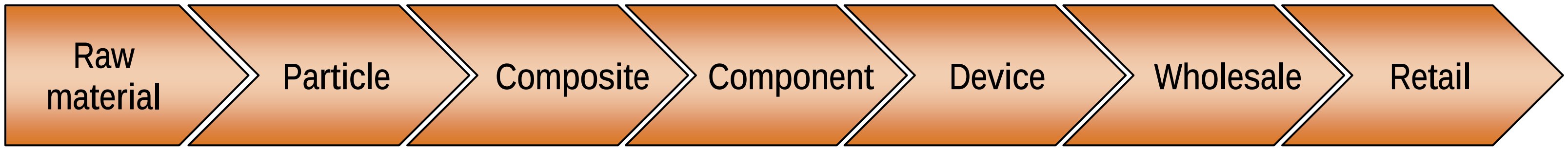
It takes a long time...



- Average time to end-user ~10 years
- Issues:
  – Each step has engineering, marketing, design, and commercialization issues/work
  – For adoption of a new material, requires focus
    - Must be in a priority for each player
  – The “One of Many” rule complicates development and implementation

The “One of Many” rule

For every

Must have:

1. Conductivity

If your customer pays a price premium, they will expect excellent quality management

There are many

Nice to haves:

1. Price (powder + process)
2. Moisture absorption (powder)
3. Moisture absorption (compound)
4. Smoothness (compound)
5. Interlayer adhesion (compound)
6. Viscosity (masterbatch)
7. Viscosity (compound)
8. Dye swell (compound)
9. Colour (compound)
10. Smell (both)
11. Tox (both)
12. An iron-clad supply guarantee

- Must “engage customers” early and aggressively
- Better understanding of particle properties and interaction in application

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Compound Materials Systems “Design” for Application

- Device ➡ Material ➡ Particle
  - Tools
    - Prediction vs. Empiricism
      - Models to understand
      - Ability to measure performance of device in application, material in device and design needed particle
    - Measurements - Its All about Interfaces
      - Surface Science of Modified Particles
      - Characterization of the particles and compound materials
  - Training
    - Systems thinking
    - Understanding and ability to resolve system contradictions
    - Strong cross-disciplinary background

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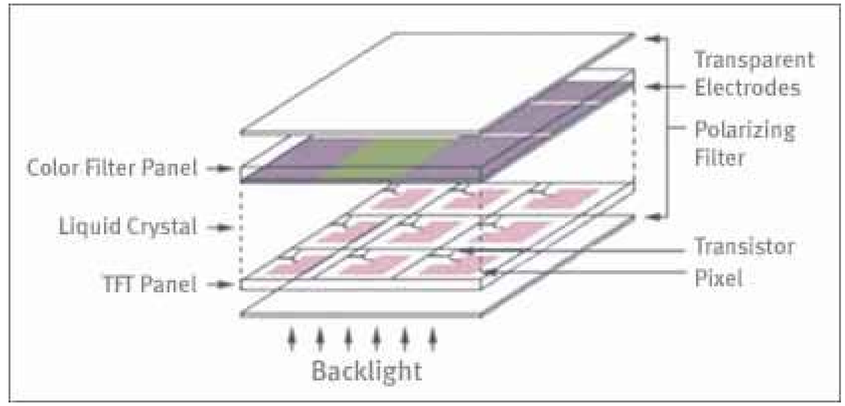
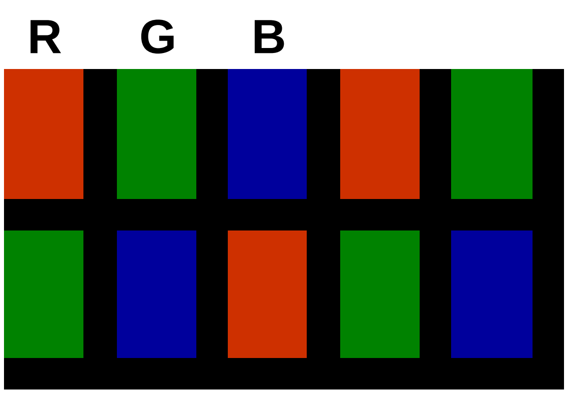
Compound Material - Black Matrix

Trends in LCD technology:

- Control light transmission through color filter to improve brightness, chromaticity, and contrast ratio at various viewing angles
- Reduce manufacturing cost

Source: http://www.avdeals.com/classroom/what_is_tft_lcd.htm





"Black Matrix"

Thickness ~ 1 μ

Black Matrix Film Requirements:

– Stable Millbase and Resist

– Patternable Coating

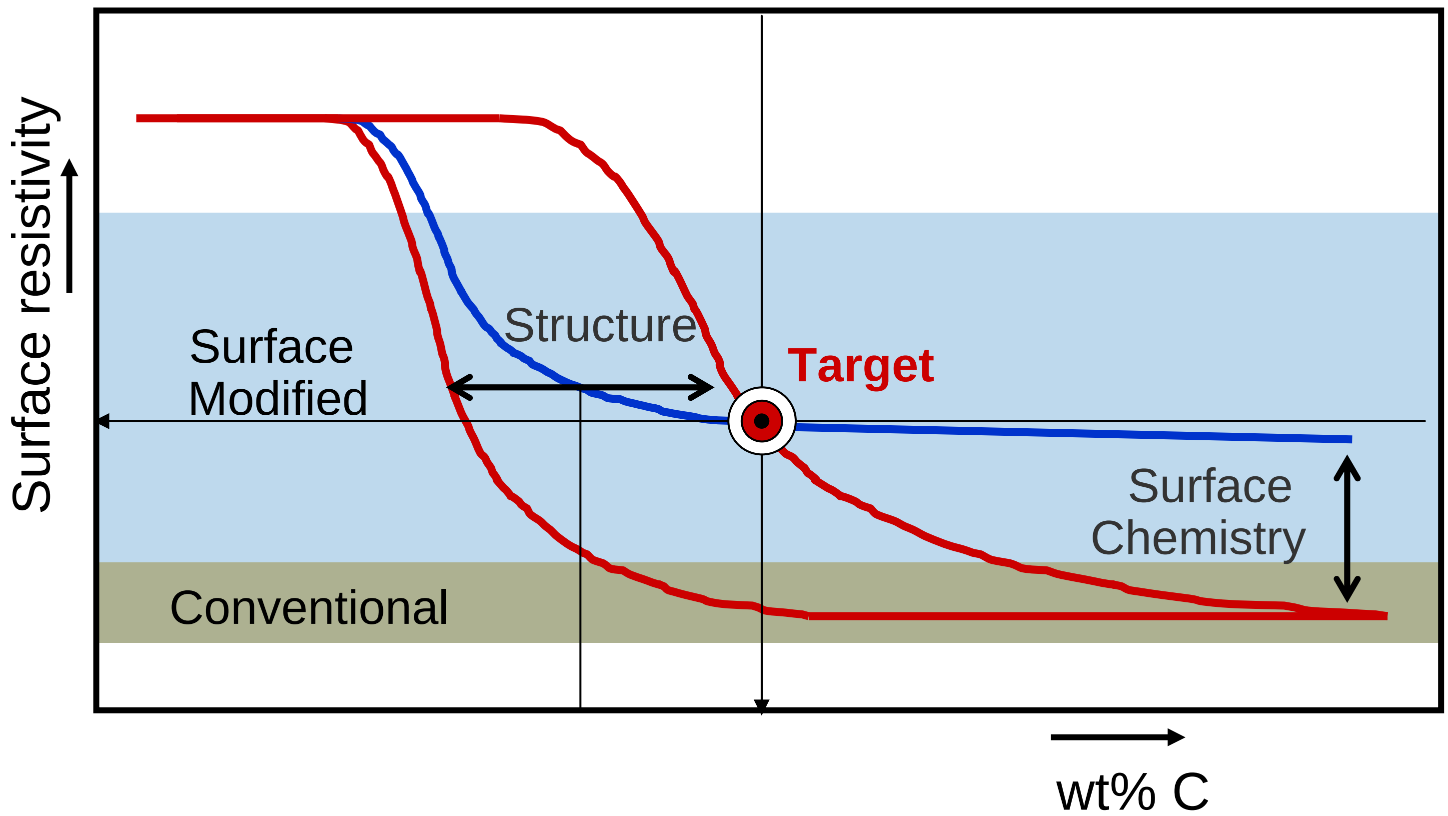
– High Optical Density (> 3.0/ μ)

– Controlled electrical properties

Carbon Black Morphology

Carbon Black Surface Chemistry

Surface Chemistry for Breaking Trade-off Between Conductivity and Optical Density



Selection of the morphology and surface chemistry leads to optimized electrical and mechanical properties of films and composites

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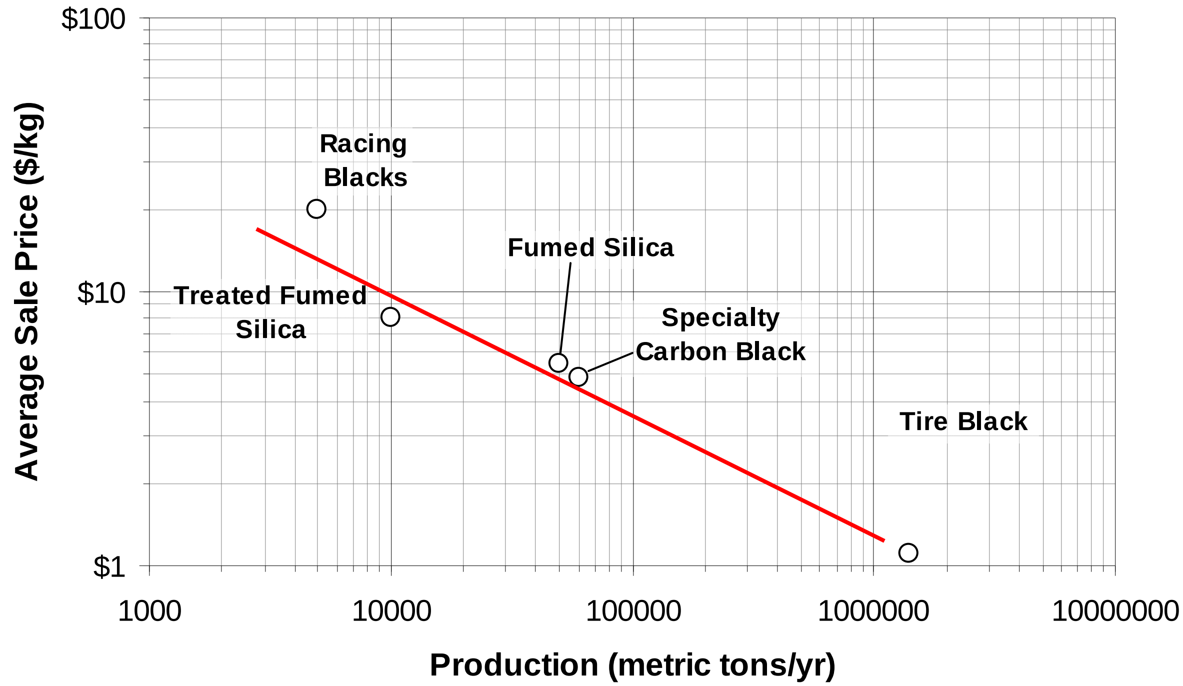
Need For Technologies to Scale up Manufacturing of Nanomaterials



- Three Rates that Count
  - Reaction Kinetics
  - Mass Transport
  - Time to Turn off the Reaction
- Fine Particles and Pores are Expensive

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Safety, Health, and the Environment: Issues

Millions of new materials with new properties	X	8 years + 7 figures 1 TOX test	=	Impossible

Needs:

- Measurement & monitoring
  - exposure and in systems
  - you can't manage what you can't measure
- Model systems & material classes
  - morphology, composition, surface properties
- Fast, cheap, TOX screening
  - High Throughput Screening (HTS)
  - *In vivo* protocols
- Red flags/green flags
  - morphology, [inhalables], solubility, known systems
- Appropriate, defined regulation processes
  - proportional to risk, including product form and volume in commerce
- Public education
  - real vs. perceived risks

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Safety, Health, and the Environment: Need for Collaboration and Sharing

	Academia	Industry	Government
Real Risk	Measurement HT TOX Model systems NanoTOX fundamentals	Direction for academia (models) Application of... Product toxicology Lifecycle analyses	Funding Facilitation Research Regulation
Risk Perception	Public education Student education	Supply chain ed^{n} Staff education Community ed^{n}	Public education Consumer education

A Few Summary Points

- Competitiveness Requires Both
  Inspiration and Perspiration

- There Is A Gap Between Industry and Academia

  Substance

  — Compound Material Properties Concepts
  — Reducing the Cost of "Going Fine"
  — Systems Understanding

  Behaviors

  — Tenure Track - "Cooperation with Industry Counts for Zero"
  — IP Policies
  — Open Innovation and Access to Facilities
  — Training Creative Problem Solvers

- SH&E needs more attention to enable broad use

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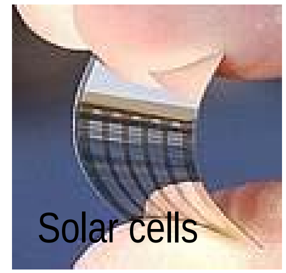
We continue to see potential



Electronics

Computing

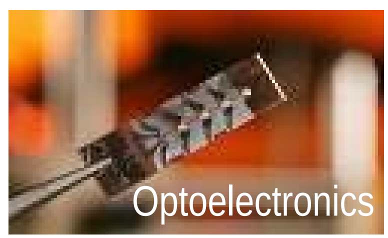
Composite materials

Chemistry

Consumer goods

Medicine

Energy generation/efficiency



Fuel cells

…But, there is a long difficult road ahead.

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creating what matters

Backup

The "One of Many" rule

For every

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SH&E issues must be addressed

- Need to develop tools for measurements
  - Airborne Nanostuctured Materials
  - Nanomaterials in water and soil
  - Degradation products from composite materials
- Need to develop methods for testing
  - Validated, Commonly acceptable In Vitro Models
  - Robust protocols for dermal and inhalation studies In Vivo of fine particle materials
- Education of Society
  - Communicating Risks and Benefits
  - Information has to be provided for Decision makers and Consumers

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Close The Academic - Industrial Gap

- Institutional Arrangement to Provide Collaboration
  - EU, Japan, IFPRI
  - Include Manufacturing Excellence
- Intellectual Property
  - Establish/Require Mechanisms for Easy Cooperation and Facility Use
  - EU and Japan advanced in this area
- Value Industry Liaison and Cooperation
  - Experience
  - Tenure Track
  - Industrial Sabbaticals

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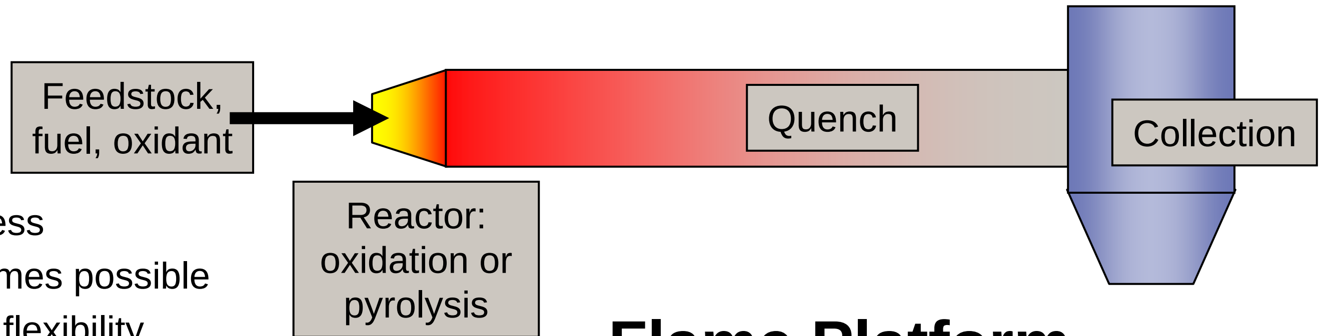
Cabot Particle Production Technology

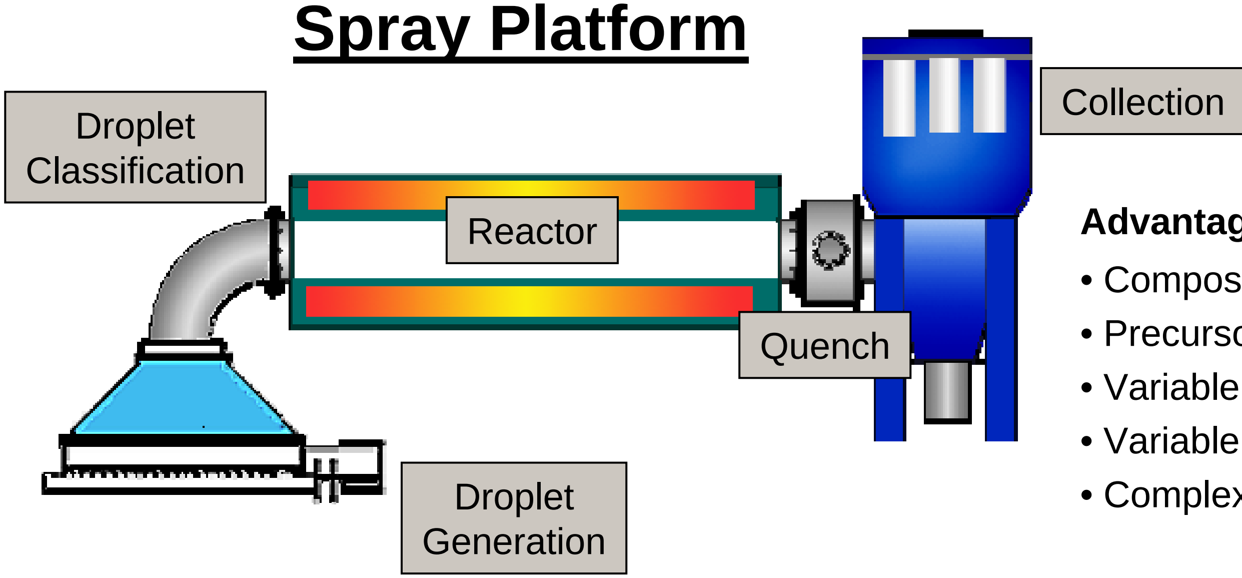
Advantages:

- Low cost process
- Very high volumes possible
- Compositional flexibility
- Particle size control



Flame Platform

Spray Platform



Advantages:

- Compositional flexibility
- Precursor flexibility
- Variable reactor temperature
- Variable reactor atmosphere
- Complex hierarchy control

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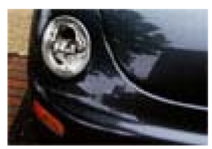
Cabot Pigment Treatment Technology

Commercial



DIAMOND BOND
A New Class of HPLC Columns

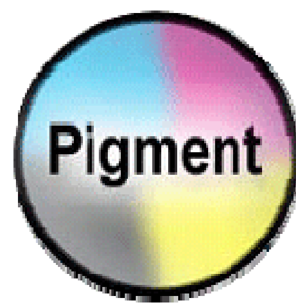
R&D

Treatment Type

- Ionic (+ and -)
- Non-ionic
- Hydrophilic/Hydrophobic
- Polymers

Counterion Type

- Negative/Positive
- Organic/inorganic
- Small molecules/polymers



$$—(R\ X)_n$$

Pigment Type

Black
Cyan
Magenta
Yellow ...

Treatment Level

adjusted for desired properties

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Making Particles + Application Understanding

Surface Modification Platform

↓

Create Value