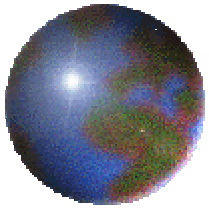


Can Industrial Physics Avoid Being Creatively Destroyed?

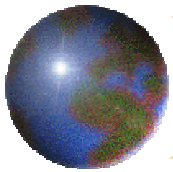
Ken Hass

Physical & Environmental Sciences Department

Ford Research and Advanced Engineering

APS March 2004

“Future of Research in Industrial Laboratories”



Predictions

- Yes, in the sense that physics/physicists will always make vital contributions to innovation-driven business success in some companies and industries

- No, in the sense that technologies, industries, and companies will continue to *evolve* (at an accelerating pace), and industrial physics/physicists may be prime fodder for creative destruction if they do not continuously adapt and prove their business value

→ *Industrial physics will be far more diverse, dynamic, and non-academic in the future*

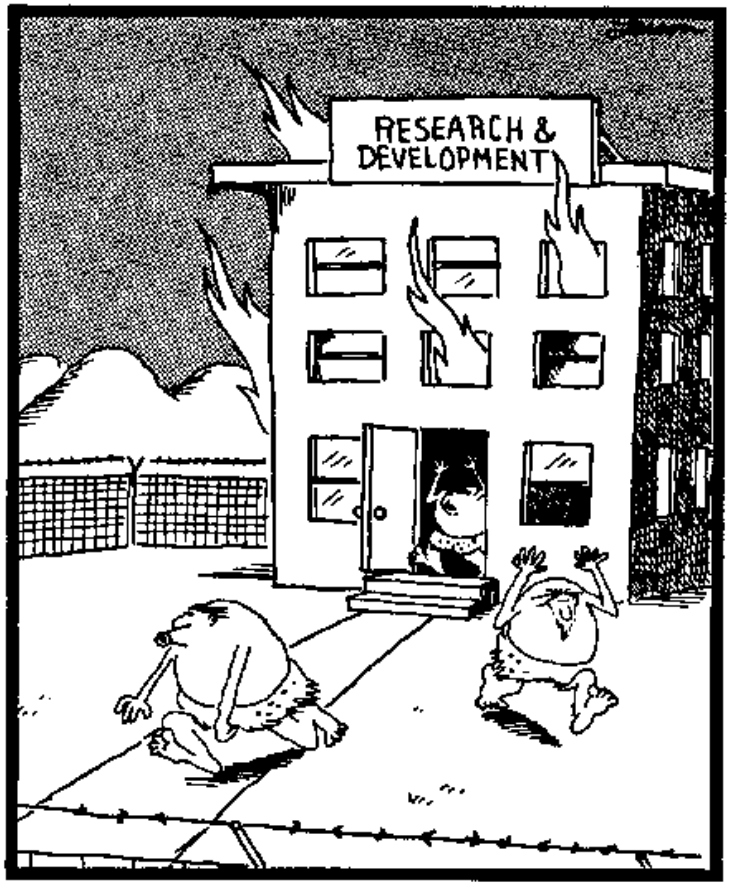
Creative Destruction

Joseph Schumpeter (1942)

- "Revolutionizing the economic structure from within"
- Driver of industrial innovation, evolution, efficiency

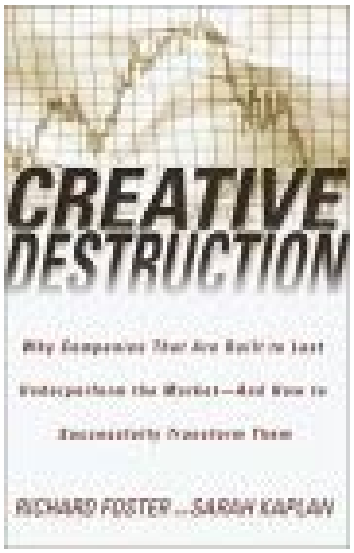
"Economists love maximum efficiency. But people don't. We want market efficiencies to make us richer, but we don't like what an efficient market feels like."

"The Sink-or-Swim Economy,"
NY Times, June 8, 2003



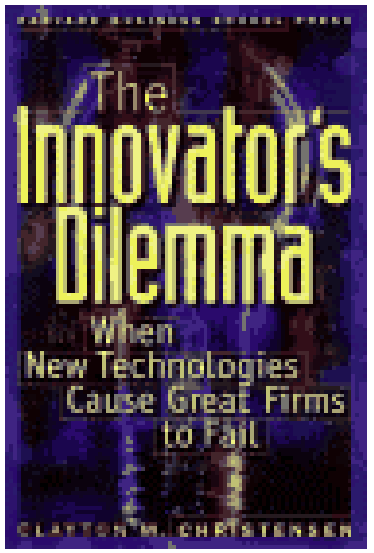
Fire is invented.

Industrial Physics:
Victim of its Own Success?



R. Foster and S. Kaplan
(Doubleday/
Currency, 2001)

C. M. Christensen
(Harvard Business
School, 1997)



Two Key Conclusions:

- Tension between continuity and discontinuity
- Mental models often limit creativity and innovation

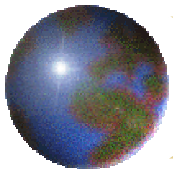
Main Themes of This Talk

- Insights from Complex Systems Research
- Evolving Mental Models for Industrial R&D
- Examples from Ford/Automotive R&D
- Challenges to the Broader Physics Community

The Emerging Science of Complex Systems

- Multiple “things” interacting in “interesting” ways
- Growing conscilience among disparate fields
  - From physical sciences to social sciences
  - Key insights from biology, computer science, economics
- Relevant to an increasingly complex world
  - Global economy and environmental challenges
  - Increasing interconnectedness and pace of change
  - Spread of capitalism and democracy
  - Increasing socioeconomic inequities
  - Increasing threats: terrorism, energy security, …

Thanks to University of Michigan’s Physics Dept. and Center for the Study of Complex Systems!



Roots of Complex Systems Research

- Physical Sciences
  - Nonlinear dynamics, chaos
  - Nonequilibrium thermodynamics
  - Random manifolds (spin glasses)
  - Self-organized criticality
- Biology
  - Evolution
  - Population dynamics, ecology
  - Origin of life
  - Animal aggregation
  - Neuroscience (consciousness)
  - Protein folding/gene expression
  - Epidemiology
- Economics
  - Game theory
  - Bounded rationality
  - Increasing returns (“lock in”)
  - Econophysics
  - Behavioral economics
- Mathematics
  - Catastrophe theory
  - Fractal geometry
  - Networks (“small worlds”)
- Organizational Science
  - Logistics
  - Systems dynamics
- Psychology
  - Group Dynamics
  - Gestalt
- Computer Science
  - Cybernetics
  - Neural networks
  - Artificial intelligence/life
  - Cellular automata
  - Evolutionary programming (GA)
  - Information theory
  - Computational complexity

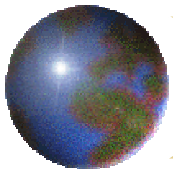
Complexity: A Bridge Between the "Two Cultures" of Physics & Business?

- Expanded/Balanced Perspective

Reductionist	↔	Holistic
Linear	↔	Nonlinear
Equilibrium	↔	Nonequilibrium
Mechanical	↔	Organic, Evolutionary
Predictable	↔	Contingent, Emergent
Optimizable	↔	Robust, Adaptive, Strategic
Centralized	↔	Distributed, Self-Organized
Quantitative	↔	Qualitative, Patterns
Simple Laws	↔	Complex Behaviors

Dominant worldview in physics and established business operations

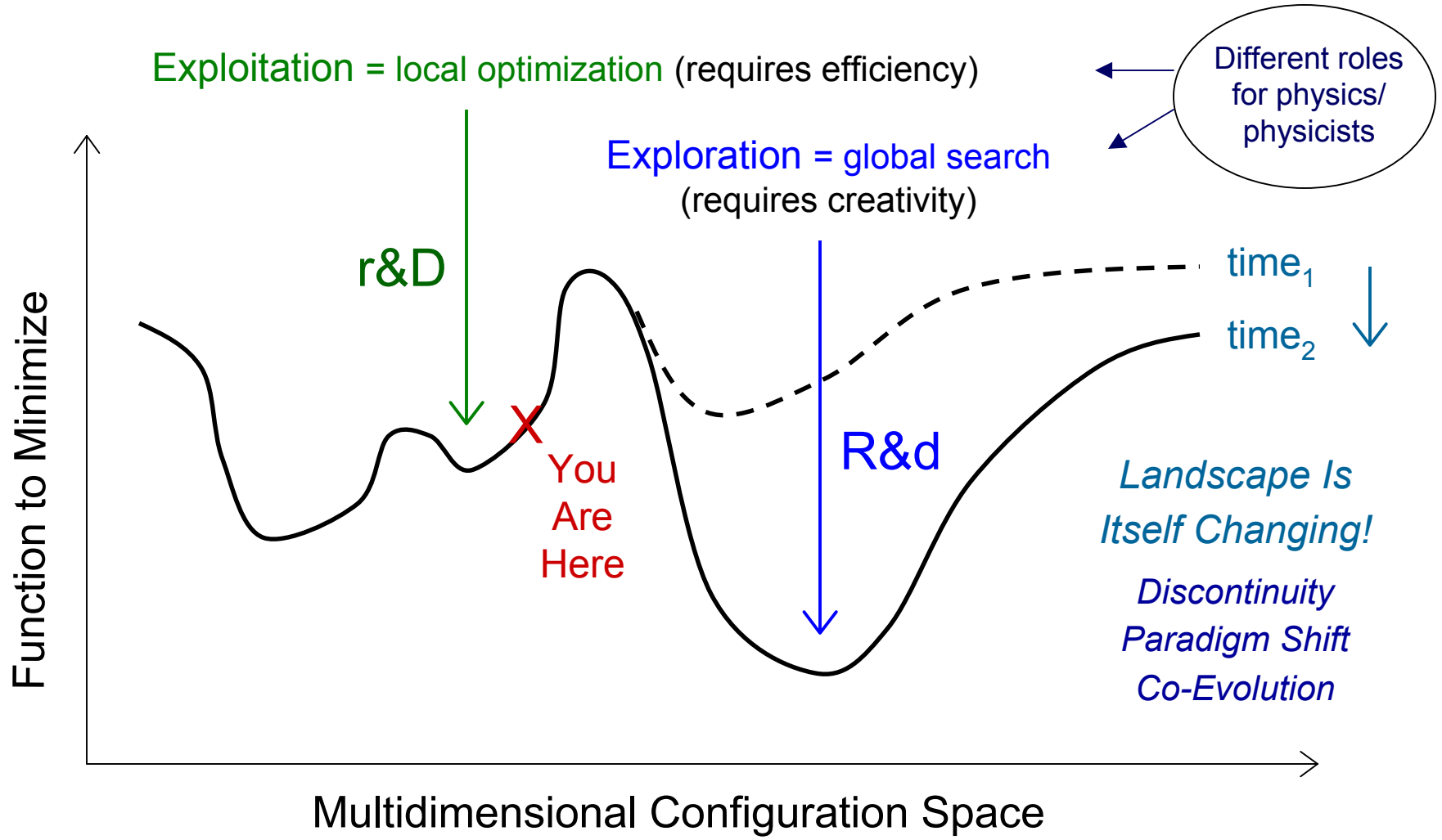
More useful for understanding, leading, and/or adapting to changes in business environment and industrial R&D!



"I can calculate the motion of heavenly bodies, but not the madness of crowds." - I. Newton

"Imagine how difficult physics would be if electrons could think." - M. Gell-Mann

Efficiency vs. Creativity: Landscape Metaphor



Prevailing, But Flawed Mental Models for R&D

Static:

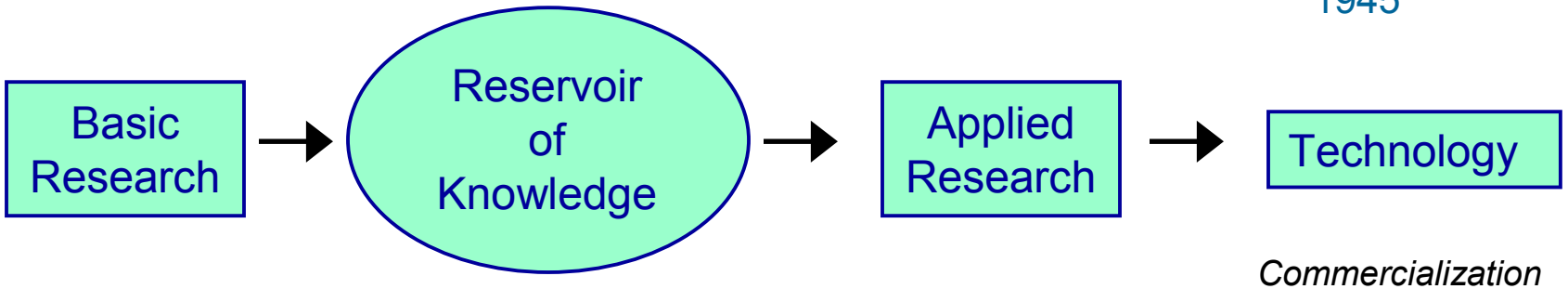
Basic vs. Applied

"vulgar"

First APS President H. Rowland's "Plea for Pure Science," 1883

Dynamic: *Linear Reservoir Model*

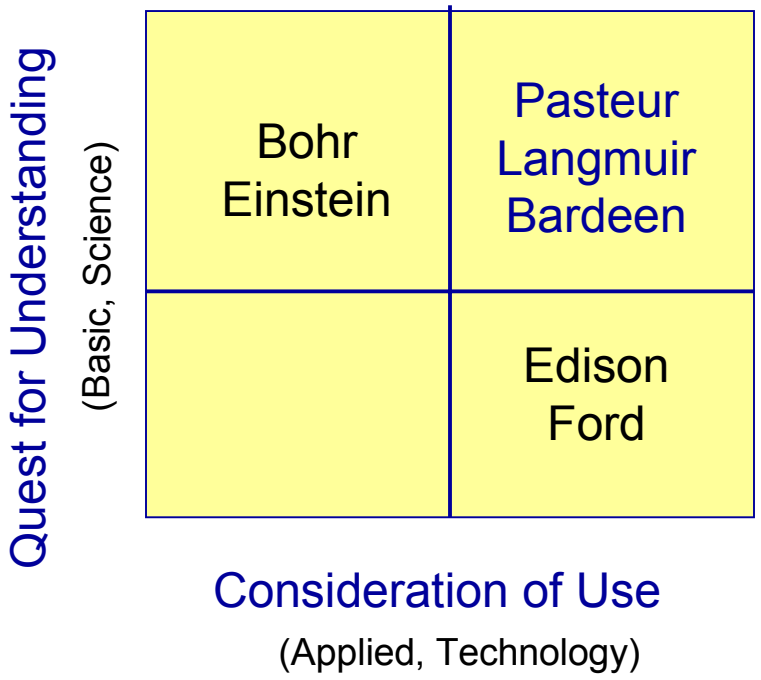
V. Bush: "Science: The Endless Frontier" 1945



Commercialization implicit!

Limitations of Linear Models

- Problem is not one dimensional:



Science
and
Technology!

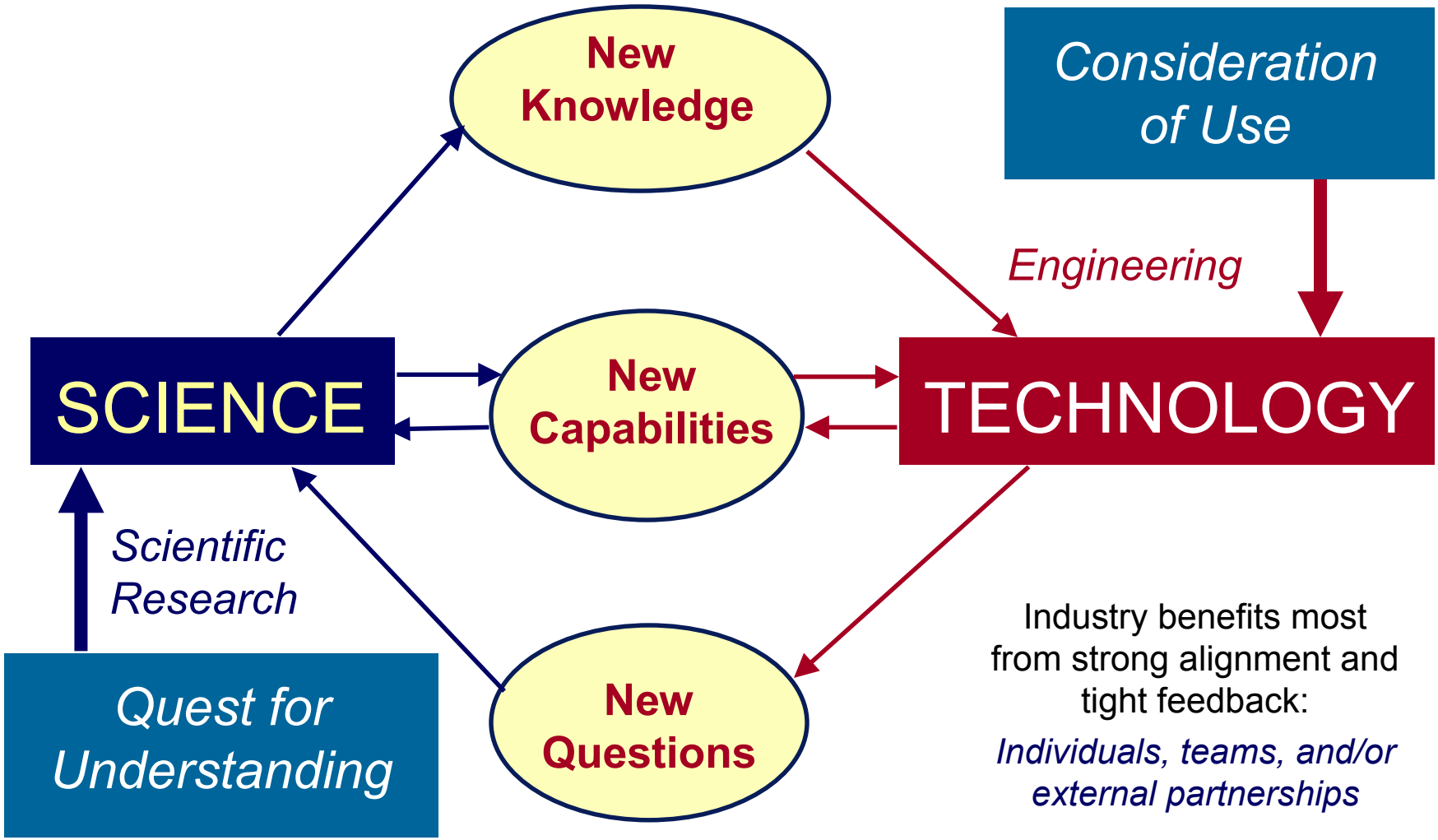
Most fertile ground
for industrial physics?

"Pasteur's Quadrant"
D. Stokes (1997)

- Flow is not unidirectional:

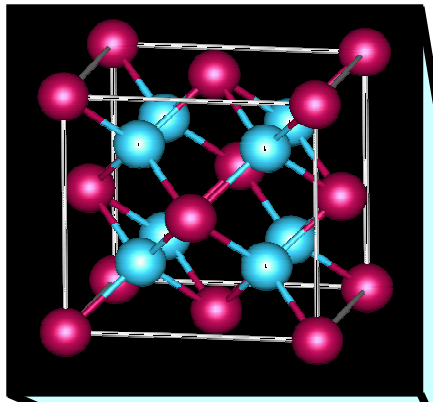
Steam Engine (Applied) → Thermodynamics (Basic)

Complex Dynamical Interactions

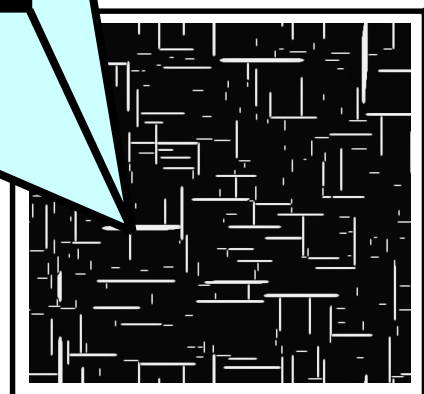


Industry benefits most from strong alignment and tight feedback:

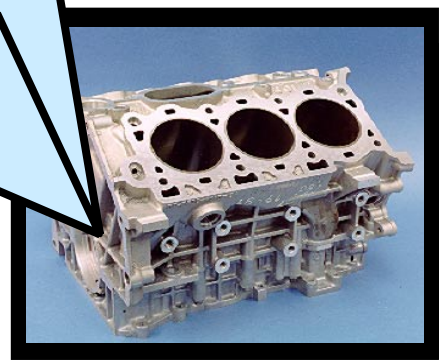
Individuals, teams, and/or external partnerships



Bottoms-Up Materials
Theory & Computation
(Chris Wolverton, et al.)



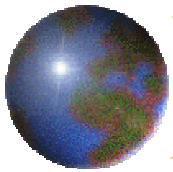
Virtual Al Castings
(John Allison, et al.)



Deeper
Understanding

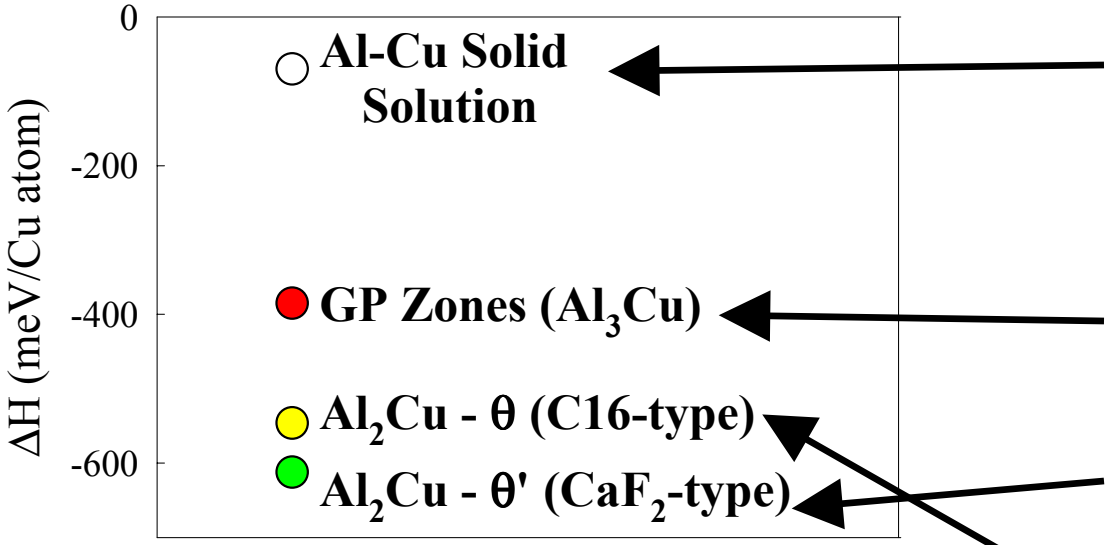
More
"Useful"

Ford
Example:
"Atoms to Engines"



First-Principles Calculated Precipitate Energetics

Experimentally Observed Precipitation Sequence



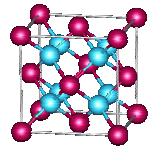
Solid Solution

↓

GP Zones

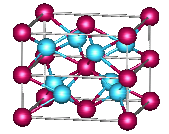
↓

$Al_2Cu - \theta'$



↓

$Al_2Cu - \theta$

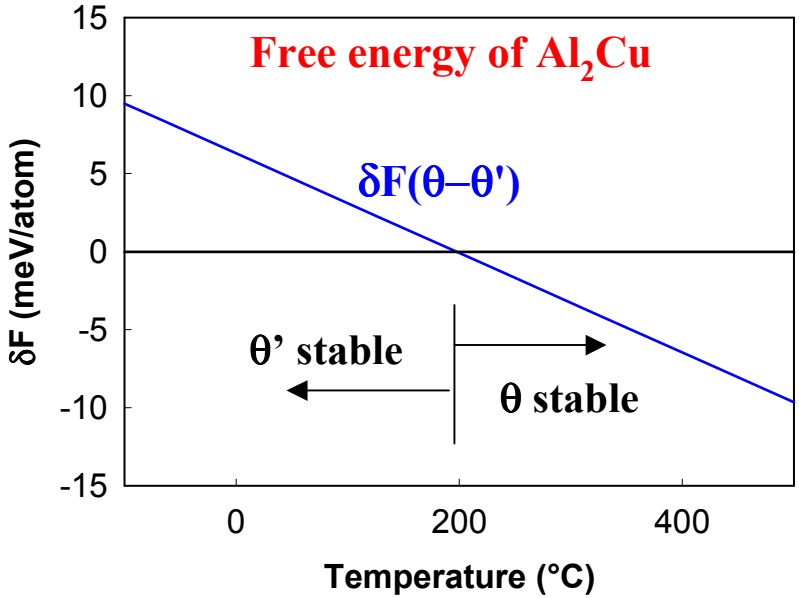


Why Discrepancy for Relative Stabilities of θ/θ' ?!

Vibrational Entropy!!! Wolverton and Ozolins, PRL **86**, 5518 (2001)

Significant Impact on "Downstream" Models

First-principles calculations



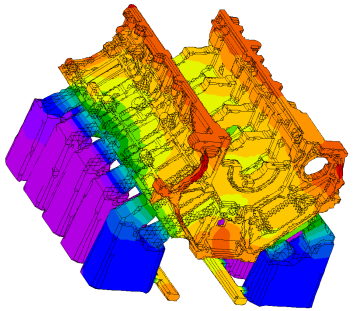
Unexpected temperature-dependence of free energy

Computational Thermodynamics

$f_{\theta'}(x,T)$

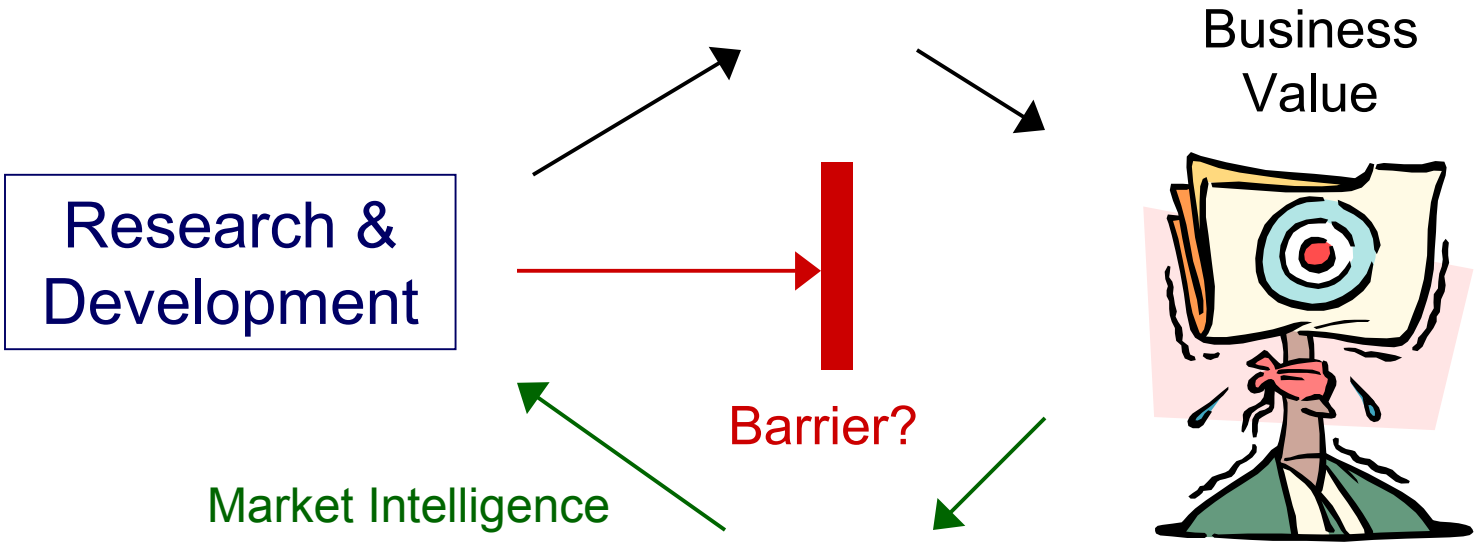
Yield Strength Model

Thermal Growth Model



Both Extremely Successful!

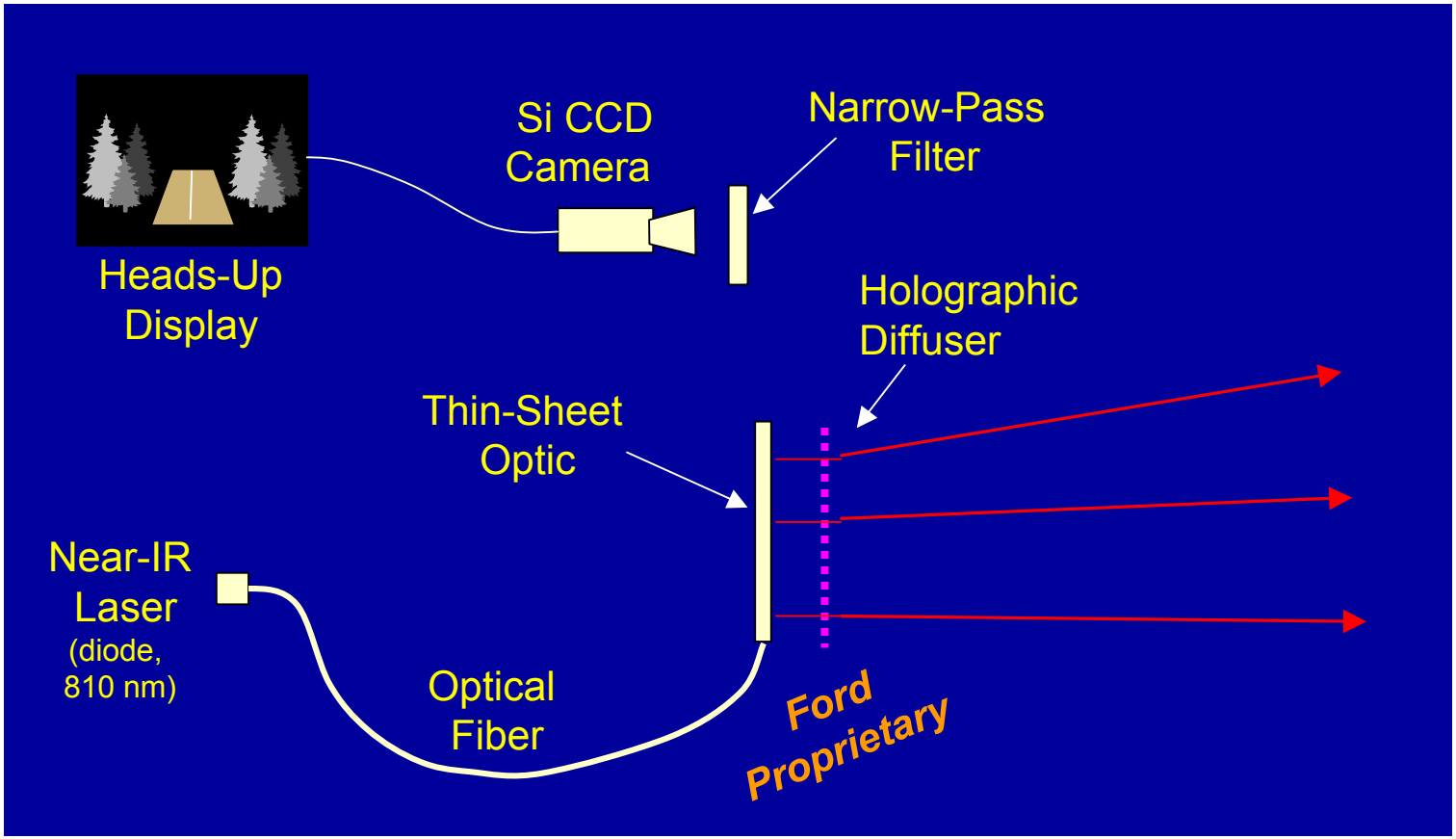
Tech Transfer and Commercialization



- Focus on most promising market opportunities very challenging
- Simple mental models (linear path, “over the wall”) inadequate
- Biological analogies (e. g., adaptive networks) may be helpful
  - Complete paths matter, not sequence in which they develop
  - Most promising pathways need to be reinforced at expense of others

Ford Active Night Vision System

(W. H. Weber, J. T. Remillard, et. al)



Normal View

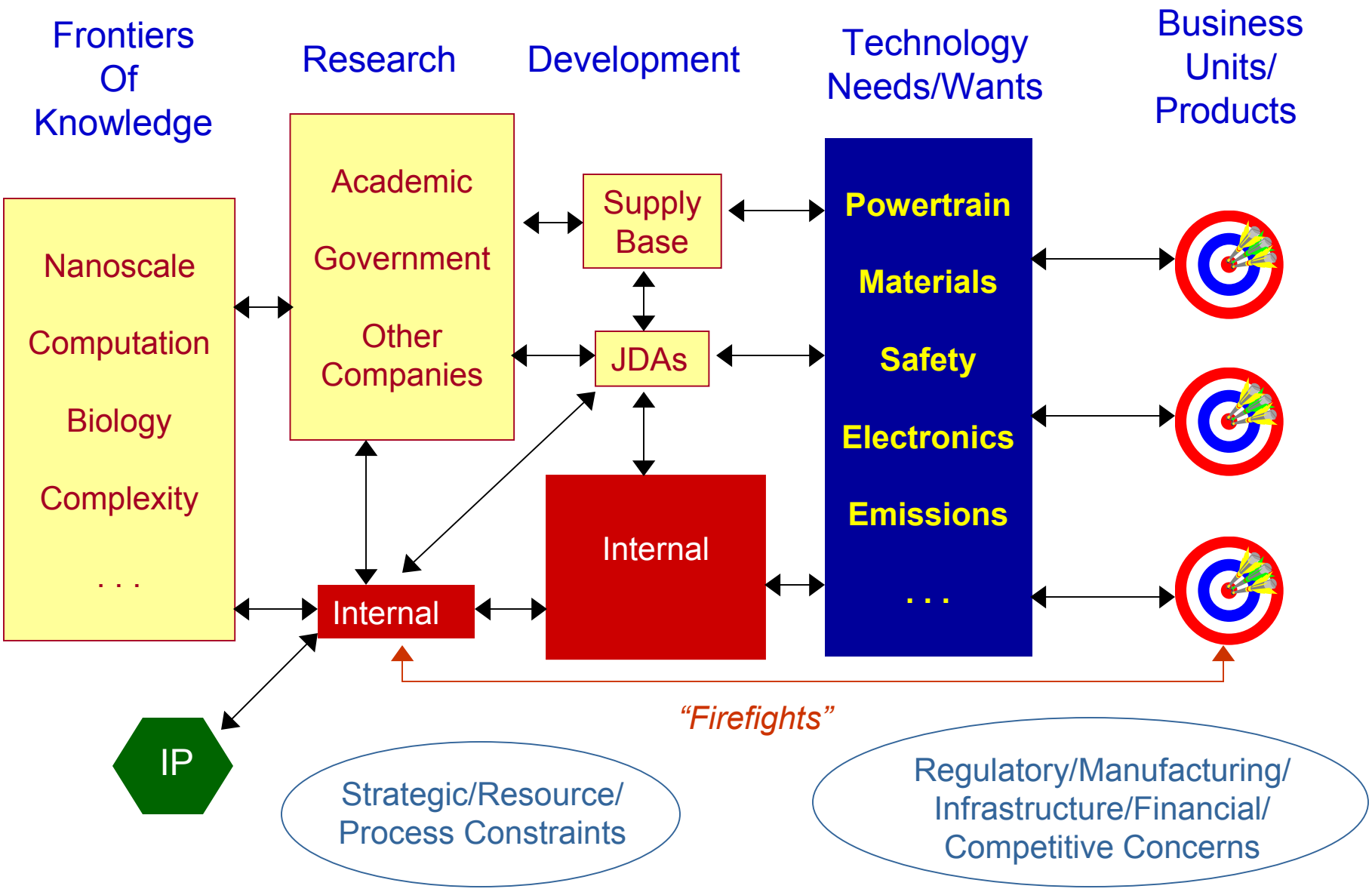
Ford-Tier I Jointly-Developed Active System

Passive Thermal Vision

Once the technology is close to implementation, the hard work begins!

Marketing
Cost Reduction
Integration with Other Systems
Packaging
Regulatory Compliance
. . .

Automotive OEM View of R&D Enterprise



General Comments on Industrial Research

- Generalizations are dangerous!
  - Most important thing is for R&D organization to be aligned with overall business strategy
  - Innovation and R&D may be more important than ever in providing competitive advantage → approaches to industrial research are becoming increasingly diverse (not just big company vs. small, mature vs. start-up))
- Physicists face particularly strong challenges & opportunities
  - No entitlements, but always a need for talented, flexible, creative, and persistent people who can solve known problems and/or lead the way through technological uncertainty and change
  - Value of “pure” physics research likely to be increasingly questioned, but physicists who understand and can cope with the two cultures of physics and business and can interact/collaborate effectively with experts in other fields have tremendous opportunities

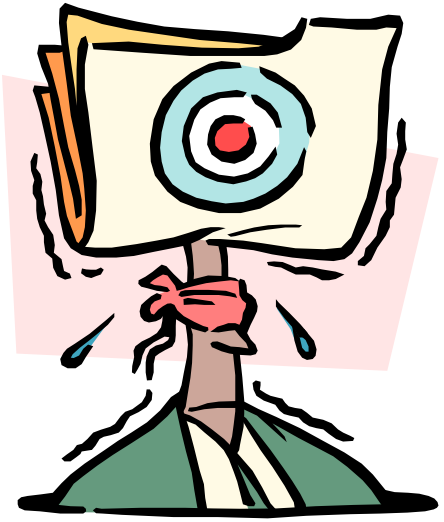
Academic Perspective

"Basic research is like shooting an arrow into the air, and where it lands, painting a target" - H. Stine

University physics departments produce master archers!

Industrial Perspective

Business Plan, Technological Needs



Moving Targets

Greatest need is for people who can steer and catch arrows!

Requires breadth, flexibility, persistence, teamwork, communication, discipline, …

Challenges for the Broader Physics Community

- Are industrial physicists valued by the community if they do not engage in “pure” physics research nor attend APS meetings?
- Will/can the mainstream culture adapt rapidly enough to the changing needs of industrial physicists and retain them as part of the community? How?
- Will the broader physics community also begin to experience creative destruction if industrial involvement declines?

FIAP welcomes your thoughts and suggestions!

Send to fiap-exec@aps.org