R&D In Private and Public Sector

A. Kaldor

Aspen Institute Energy Meeting

July 10, 2003

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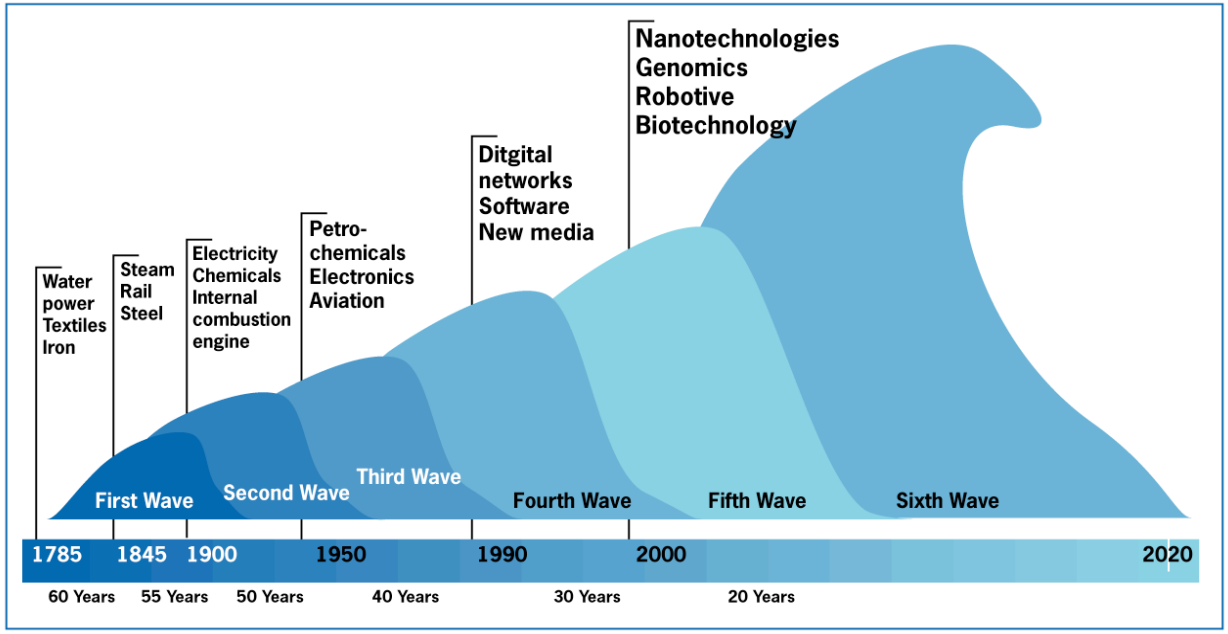
Today's Changing World: Exceptional challenges … and opportunities



Schumpeter's Accelerating Waves

Our world is

- **increasingly complex and chaotic**
- **dynamic, accelerating**
- **non-linear**
- **increasingly multidisciplinary**
- **growing exponentially**

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Specific Problems Posed by Technology for Transformation of Energy Sources

- **Major learning of past 30 years of R&D**
  - **basic science decoupled from practical focus has low probability of delivering impact**
  - **How to create that coupling when technology is far in future?**
  - **Risk management of (known x known) vs. (unknown x unknown) paradigm**
  - **Temptation to focus on niche near term applications to provide focus and feedback, and to return some $$s to investors**
  - **Potential for vicious cycle, niche product may eat R&D $$$s and push out support for higher risk, broader impact opportunity**
  - **Government R&D&E best when meeting government needs, often suffers from lack of the practical filter of the competitive market place; competitive technology research guidance and market place reality -checks**
  - **Need to find a way to include assessment of market/social interactions early, even when framing the questions that drive the research**
  - **Leveraged Venture Capital may be one of the most attractive options, portfolio venture managers create technology options from academic research discoveries. Many are promising but few survive to major impact**

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Probability of success for technology system based on multiple innovations

	known 1	known 2	known 3	unknown 1	unknown 2	unknown 3	unk1x2x3
known 1	1.00	0.90	0.50	0.10	0.20	0.30	0.03
known 2	0.90	0.81	0.45	0.09	0.18	0.27	0.027
known 3	0.50	0.45	0.25	0.05	0.10	0.15	0.015
unknown 3	0.30	0.27	0.15	0.03	0.06	0.09	0.009
unknown 2	0.20	0.18	0.25	0.02	0.04	0.06	0.006
unknown 1	0.10	0.09	0.05	0.01	0.02	0.03	0.003

(Known x Known) rule is a good way to recognize complexity of technology development which requires multiple new/novel concepts put together in new ways. Requires deliberate strategy to manage risk ! Early prototyping and model building, commercial test of components of system, risk assessment are some of the ways to manage risk

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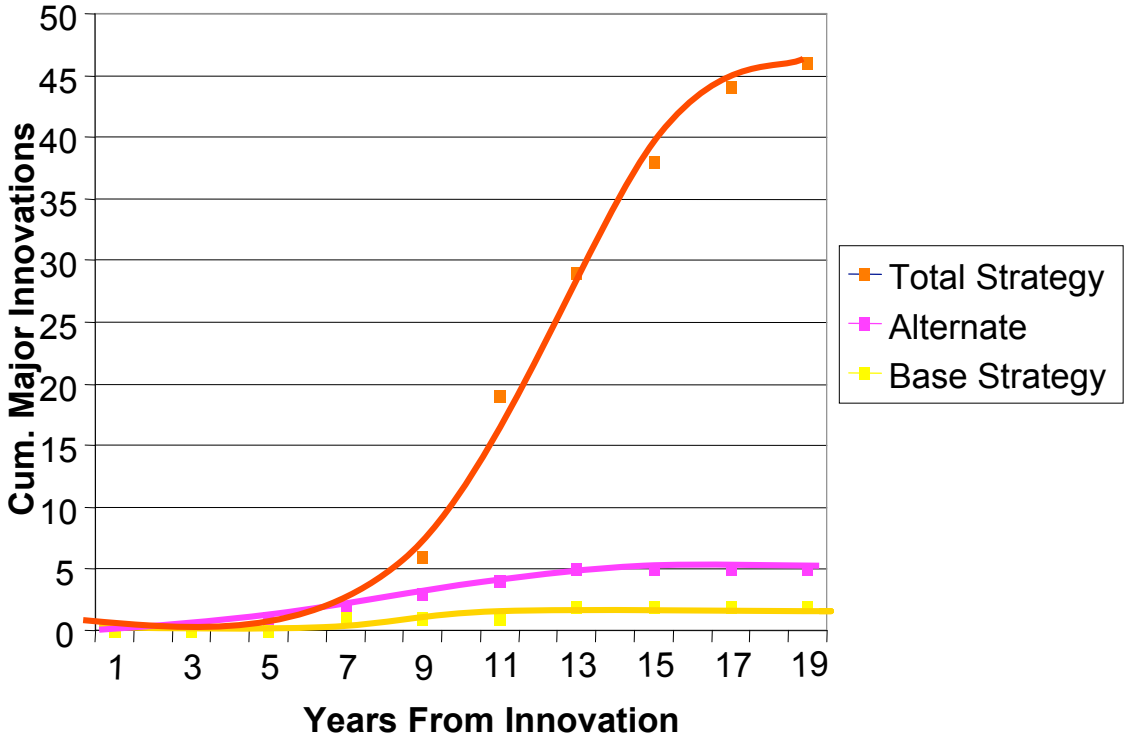
Model of System for Major Innovations

- **Analysis of 30 Different Industrial Innovation Systems**
- **Dynamic Computational Model Constructed Using 6 Key Levers**
- **Model Predictions Depend on How Intensely Levers Applied**
- **First Five Years Show Little Impact**
- **Dramatically Different Results on Extensions of Existing Technology**

Integrated Innovation Strategy



Strategic Levers in Model

- **Constancy of Purpose in Technology Programs**
- **Aggressive Development Goals**
- **Broad/Multiple Approaches**
- **Increased focus vs. "spreading thin"**
- **Upgrading Science Base**
- **Business/Technology Interspersing**

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Technology Horizon 20-50 Years

- **Critical need to maintain continuous commitment and focus over several career generations, not to mention political cycles**

- **R&D best practices have been focusing on**
  - **Improve business and R&D guidance**
  - **Focus on asking the right question before focusing on science and technology solutions**
  - **Interspersing all elements of technology and business components**
  - **Risk management of high risk elements of novel systems**
  - **"Long range research" another word for high risk? Or discovery?**
  - **Reduce cycle time**
  - **Accelerate the pace of innovation**
  - **Modeling and computational tools**
  - **High throughput experimentation**
  - **Prototype early and often**
  - **Flexible, entrepreneurial science and R&D&E**
  - **Make hard decisions fast when needed**
  - **Breakthrough component of R&D $$$s growing**
  - **Partnering with ....academia, with other companies, with government labs...multiple and growing more complex, ventures**

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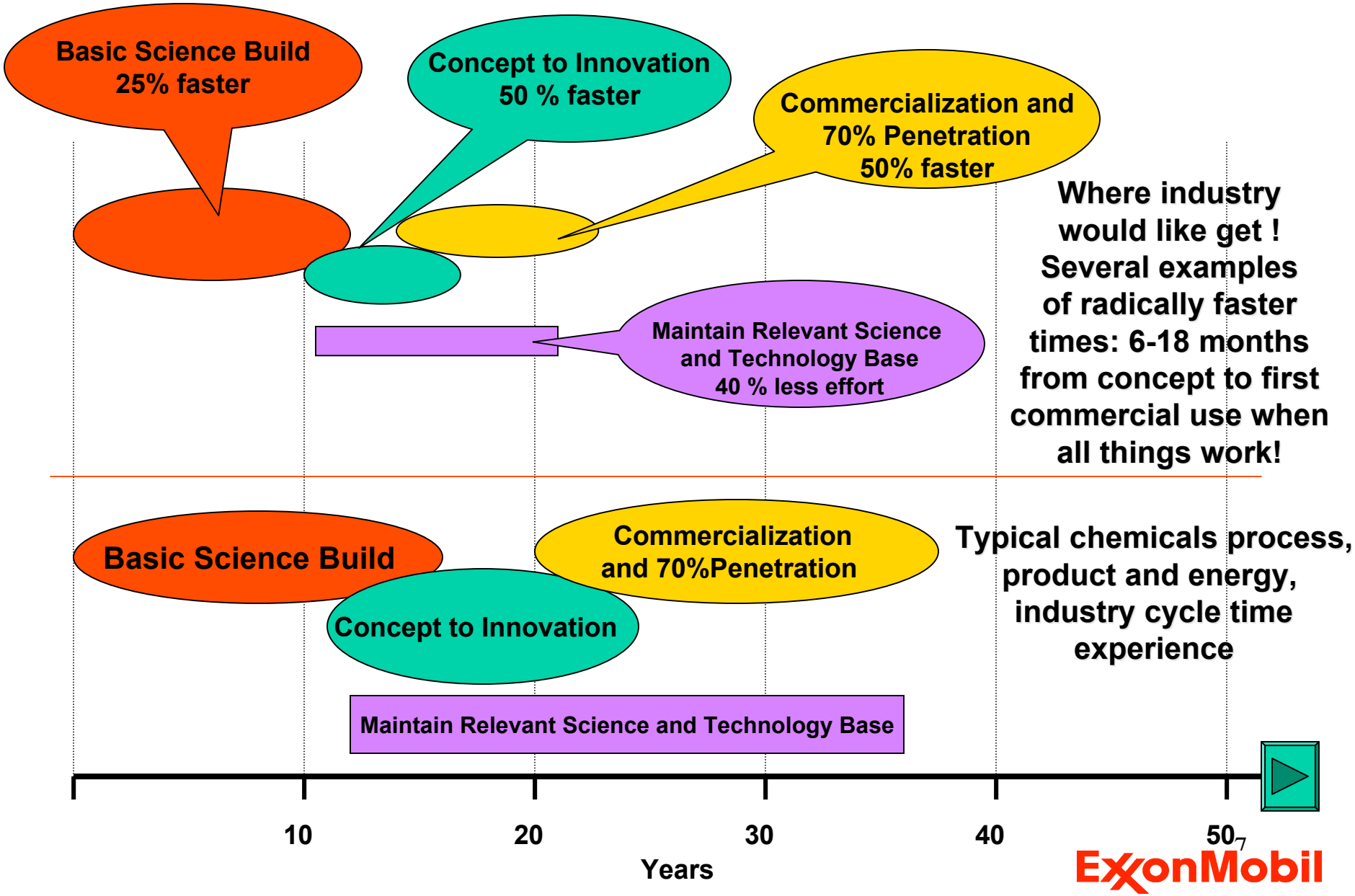
Significant R&D cycle time reduction



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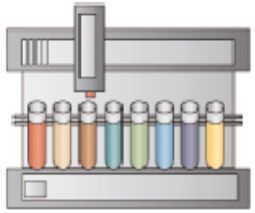
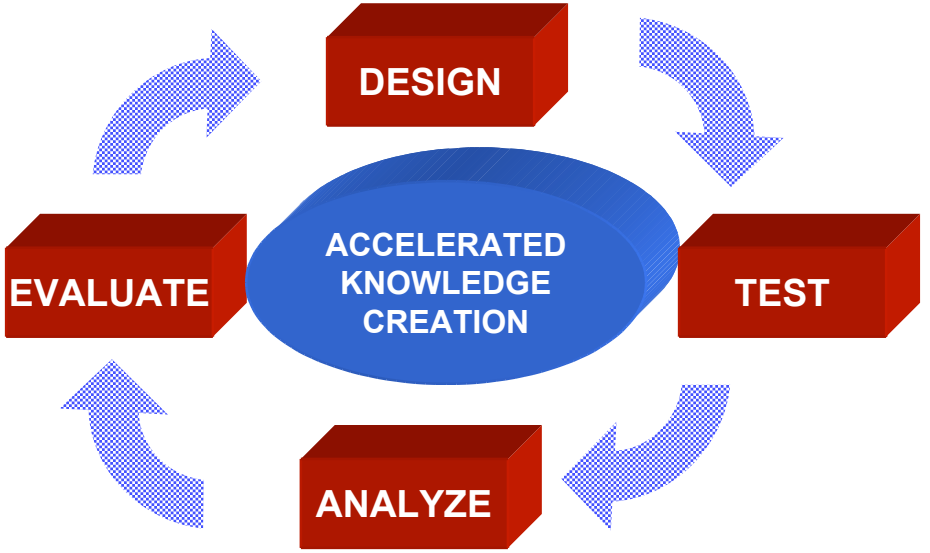
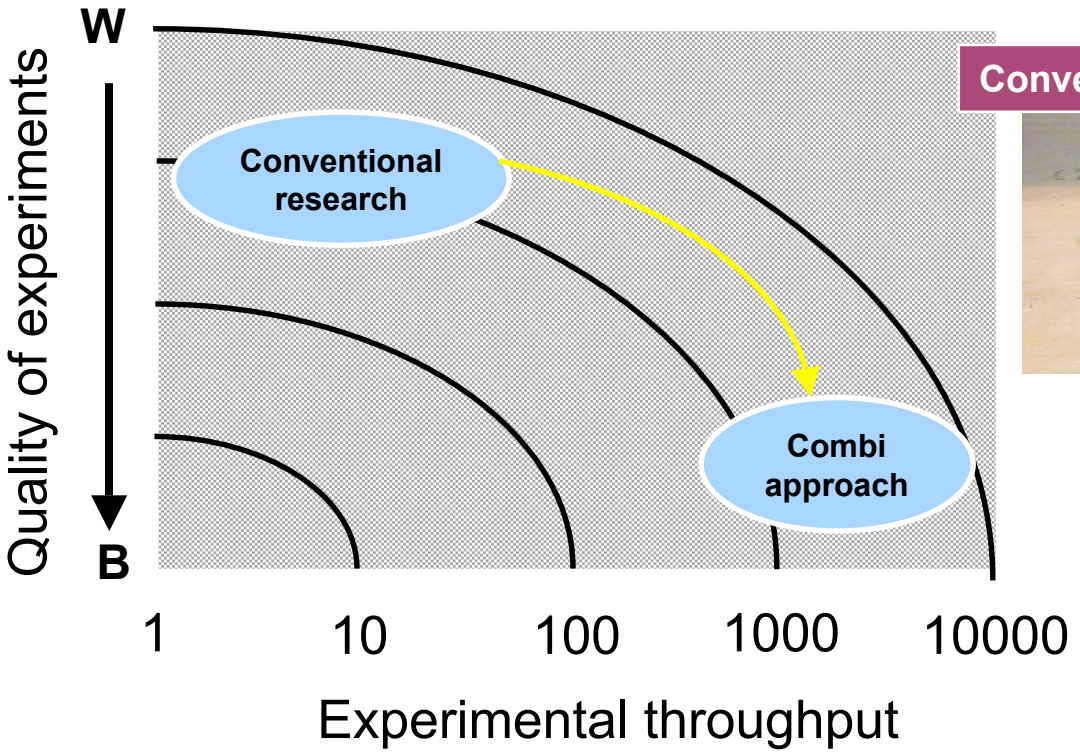
High-throughput R&D accelerates technology



HT Synthesis

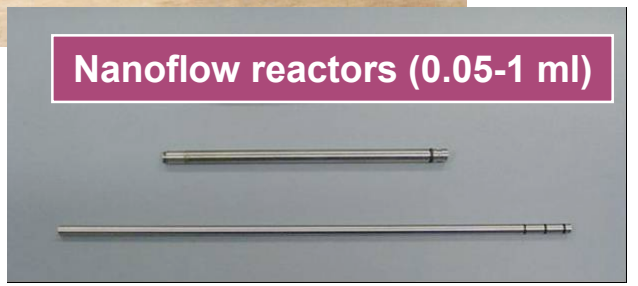
HT Screening & Analytics





Conventional microflow reactors (5-30 ml)

Nanoflow reactors (0.05-1 ml)



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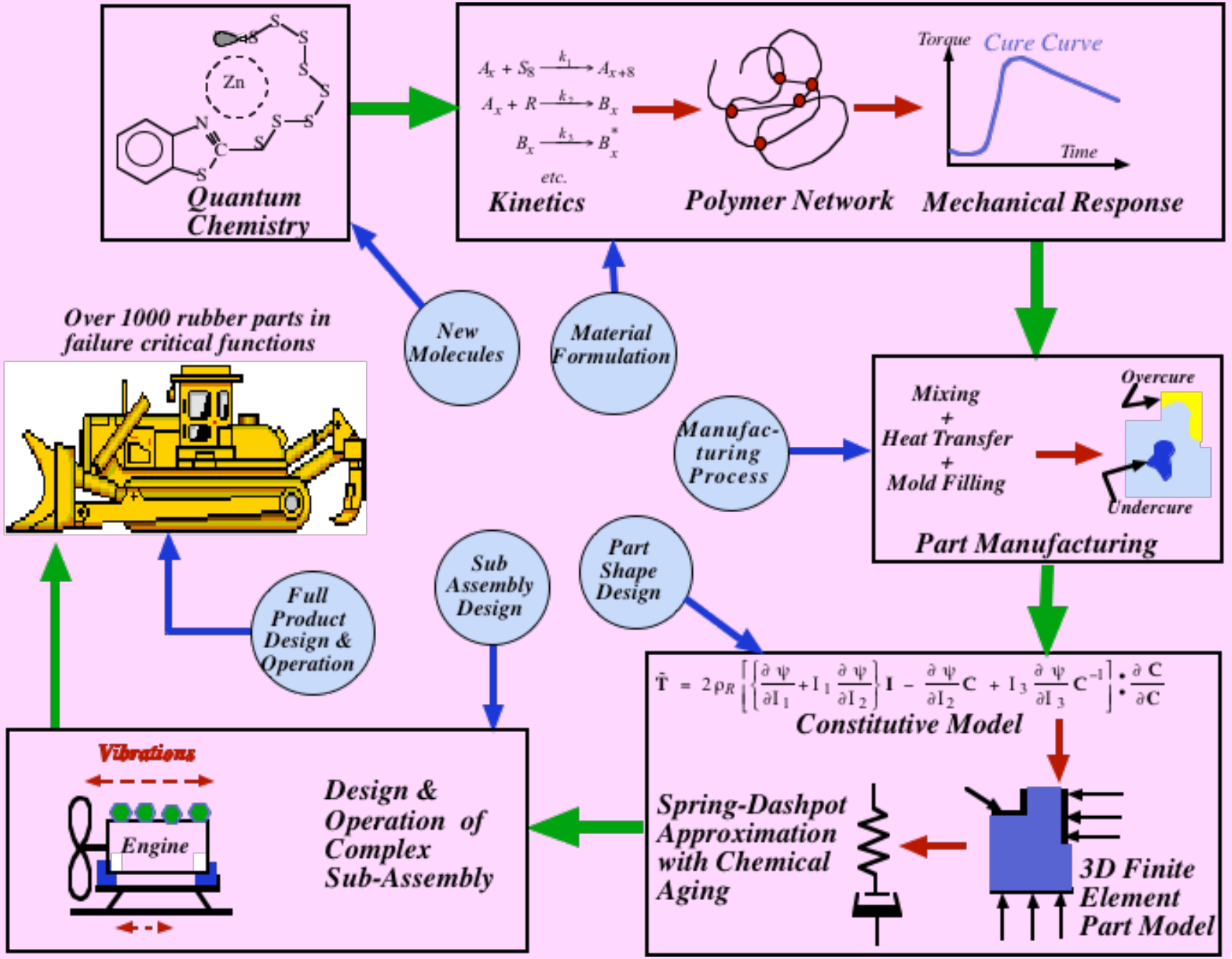
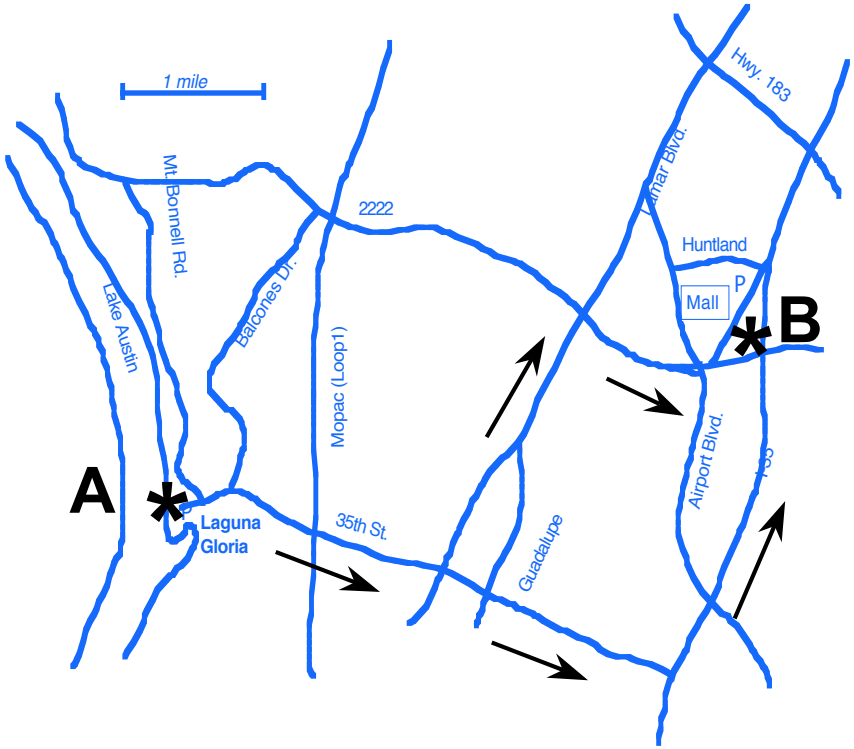
Caterpillar: Grand Challenge Problem



A Roadmap to Research is NOT the Answer



Good Points

- Plan from A to B
- Path around obstacles
- Provides direction
- Defines distance

But ...

- Assumes everyone starts from the same place
- Assumes the destination remains fixed
- Assumes no new roads will be built (or that an airplane will be invented)
- No time information

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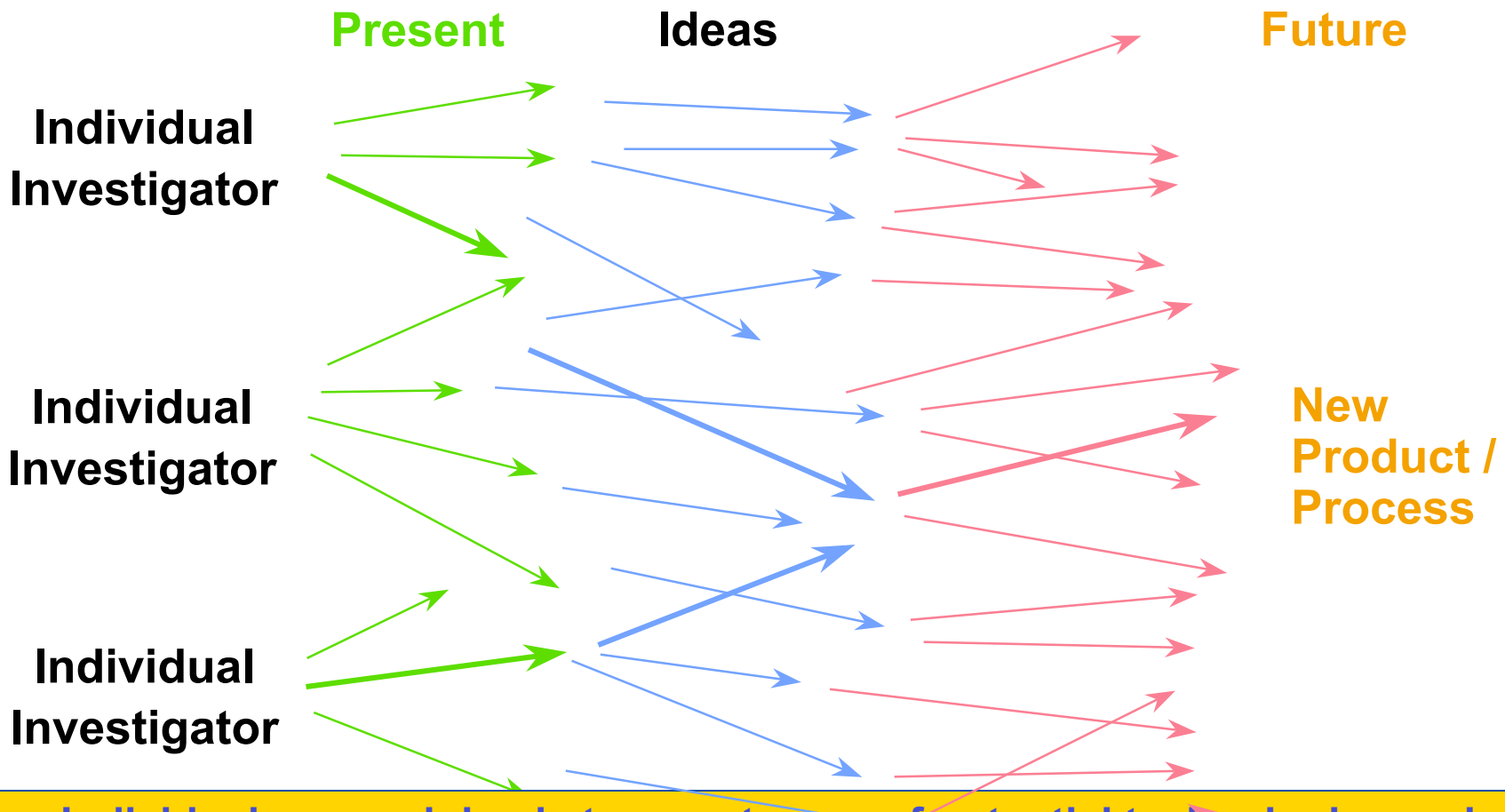
Technology Development: Typical Approach

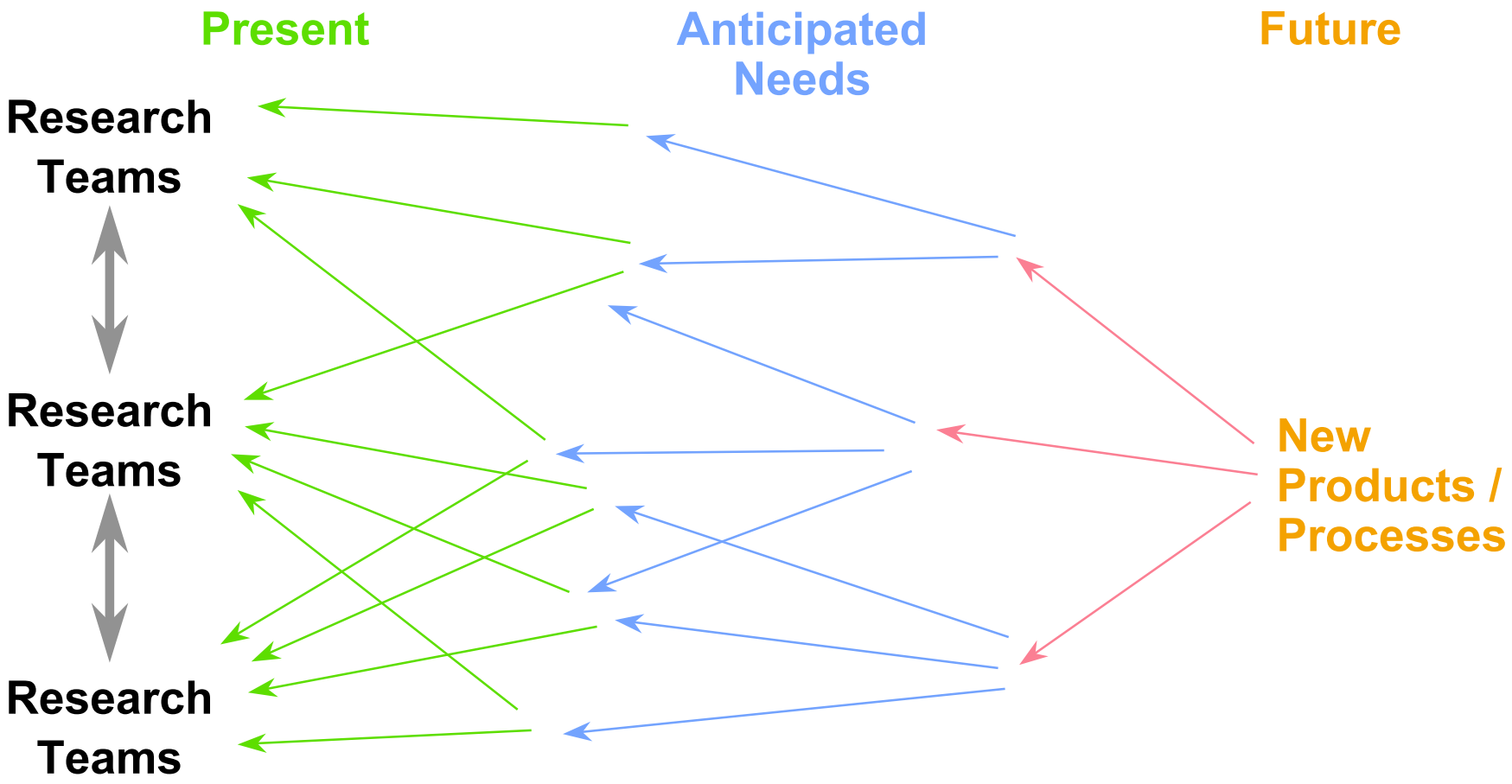


Individual research leads to a vast array of potential technologies and discoveries, only a fraction of which are combined to form useful new products / processes.

Curiosity driven, opportunistic - *needed, discovery oriented basic research*

Classical model of Corporate Basic R&D labs-endangered species

Technology Development: End-game Approach

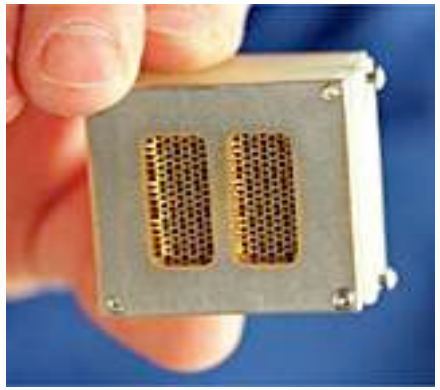


By first defining the target properties of desired product / process and the anticipated technology barriers, research teams have a higher rate of return on research/technology development. Defining the right targets, and continuous assessment and refinement is paramount, rigidity is deadly !

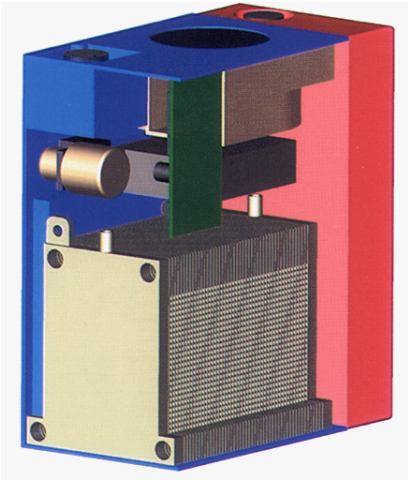
DARPA and advanced Corporate Research model with high level of success!

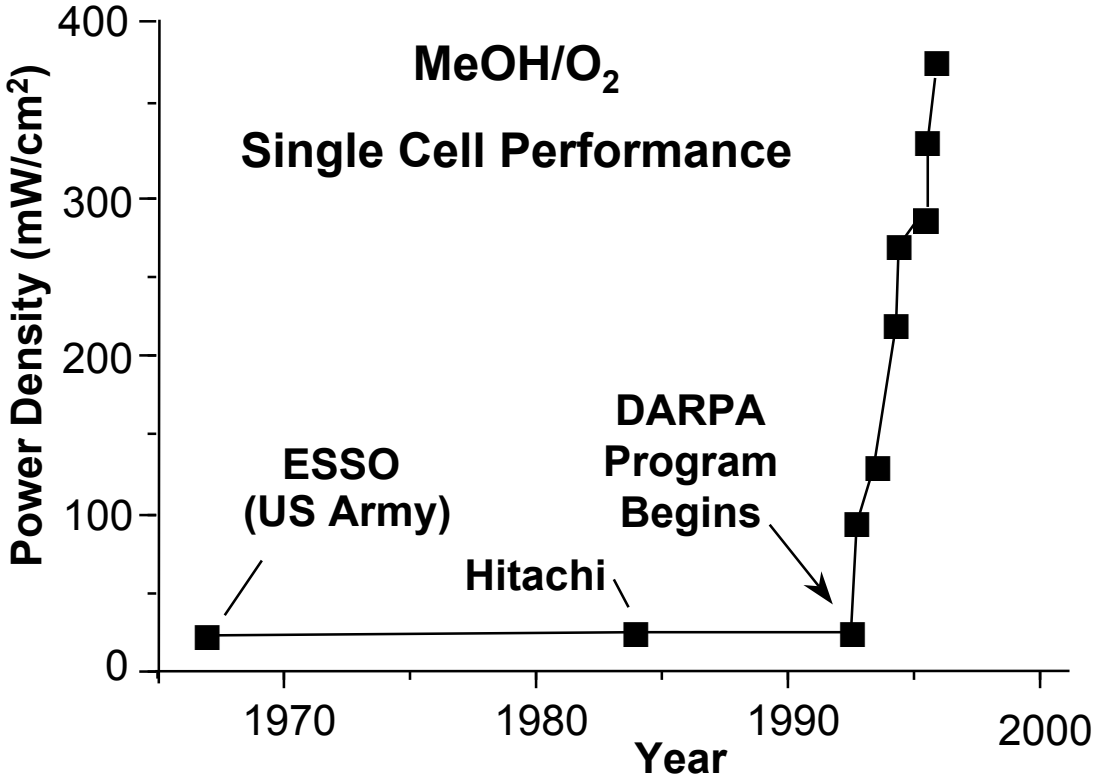
Progress in Direct Methanol Oxidation PEM Fuel Cells

LANL Direct Methanol Oxidation Fuel Cell



BA-5590 *Equivalent*





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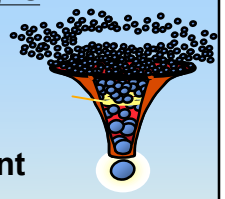
Breakthrough Technology Is Inherently Episodic

- **There Are Few Breakthroughs to Be Had**

Petrochemical Industry Breakthroughs



- Rotary Drilling
- Seismic
- Deepwater Development
- Fluid Catalytic Cracking
- Catalytic Reforming
- Paraffin Alkylation
- Butyl Rubber
- Zeigler-Natta Polymerization
- Metallocene Catalysts
- Sterically-hindered Gas Treating

Many notable examples of targeted breakthroughs

- Transistor
- Semiconductor technology
- Fiberoptics
- NMR imaging
- Drug discoveries

- Many notable examples where basic research and discovery lead to breakthroughs
- The significant difference is the time is takes to recognize the discovery and connect it to practical applications

- **Breakthroughs Explore the Unexplored**
- **Practical, Out-of-the-Box Thinking Is Not a Routine Activity**
- **Innovation Techniques Exist but Are Still Much More an Art Than a Science**

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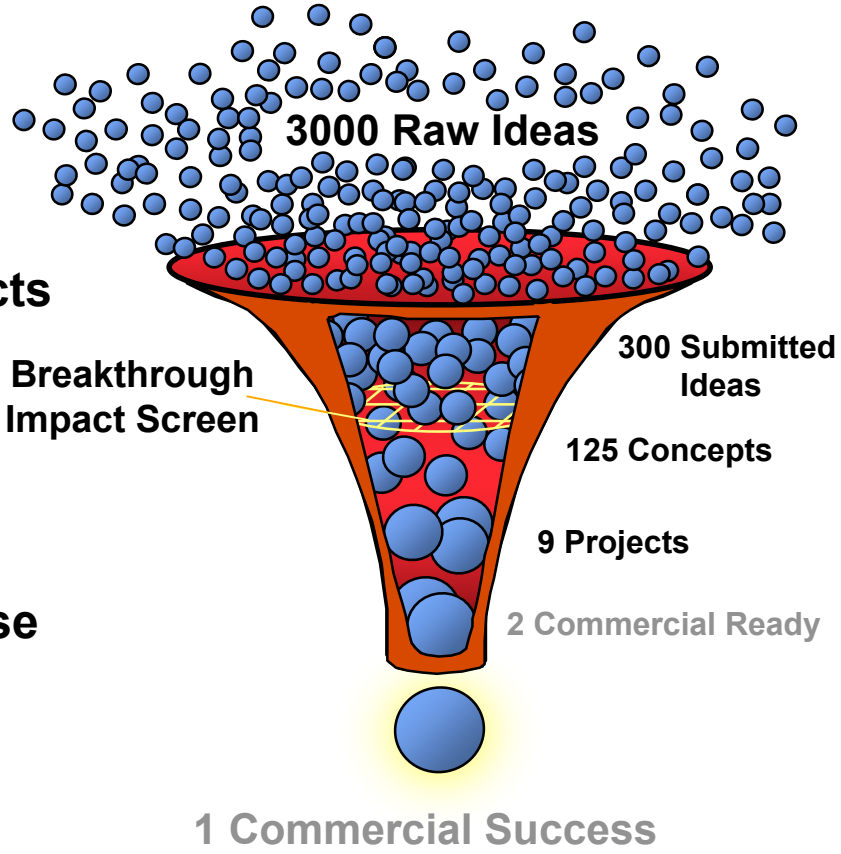
Breakthrough--High Risk-High Reward Research

- **Create New Business Opportunities**

- **Breakthrough Technology That Can:**
  - **Create step-out value**
  - **Change the game**

- **Qualifying Criteria For Potential Projects**
  - **Large economic prize**
  - **Proprietary advantage**
  - **Technical novelty**

- **Unlikely to Identify in Planning the Base R&D Program**



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Shell "Game-Changer" Process Includes Structured Intelligence Function

- GameChanger is Shell's Process for Getting Best Ideas to Market Quickly
  - **Encourage new technologies and ensure that Shell maintains a high level of innovation**
  - **Any Shell employee can be an "innovator" and can submit an idea to gamechanger**
  - **Program level several M$/yr in each major segment**
  - **Chemicals process includes manager plus global team of six+**
- Four Systems Within GameChanger
  - **Externalization Program - monitor emerging and developing technologies and trends**
  - **Advanced Technology Program - Assessment of specific threats and opportunities**
  - **Strategic Innovation Program - Breakthrough innovation chain (shown below)**
  - **Innovation Lab Program - Broaden awareness and use of innovation tools**

- **Innovator submits idea**
- **Approximately three game-changer representatives select ideas**
- **Selected projects are provided with ca. $250,000 for initial R&D and economic assessment**

- **Innovator presents micro-business plan to approximately six game-changer and business representatives**
- **If approved, additional funding of $250,000 to $2MM is awarded to progress proof of concept**

- **Project is handed over to a stream technology group where it is either:**
  - **Commercialized**
  - **Further developed and demonstrated**

BP Emphasizing Universities In Breakthrough Lead Generation

Major Programs

Univ. Colorado
Visualization
10 M$/? yr

Cambridge
Multiphase Flow
40 M$/? yr

Princeton
Carbon Mitigation Initiative
15 M$/10 yr

UC Berkeley
Methane Conversion
10 M$/10 yr

Caltech
Methane Conversion
10 M$/10 yr

Dalian Institute
Methane/H_2
10 M$/10 yr

Imperial College
Polyolefin Catalyst Alliance
? M$/15 yr

- Major Programs Aligned with Key Business Strategies
  - **Reduce drilling costs**
  - **Reduce cost of moving gas to market**
  - **Reduce CO_2 emissions in safe, reliable way**
- Refining Process/Catalysis Absent
- Multiyear, Multimillion Dollar Commitments Enable More Favorable Agreement Rights vs Those Available to Others
  - **95 M$ announced since 2000 - approx. 10 M$/yr**

- Berkeley/Caltech Work Involves Small Number Senior Faculty--Iglesia, Bell, Bercaw, Grubbs
  - Methane to aromatics, methanol, hydrogen, and derivatives
- Management Process Integrates Alaska and BP Staff in Virtual Team
  - BP manager plus group (10-12) of researchers
  - Rapidly progress ideas to pilot testing
  - Semi-annual meetings rotate between BP sites and universities

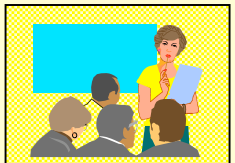
- **Favorable Impact on Recruiting Expected**
- **Generally No Clear Process to Capture and Build on Academic Discoveries**

EM Breakthrough Research Process

Holy Grails

Set By Senior Business Executives

Idea Generation



Business / Technology Innovation Sessions

Scouting

Volunteered Ideas

Maturation / Enhancement

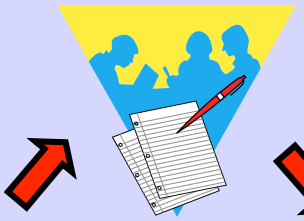
Green House

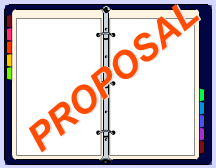
Mentored Scoping Team

Venture Team

Evaluation / Approval

Peer Review

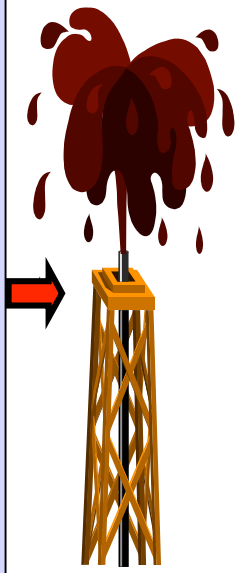




Sr. Mgmt Team

- Testable Hypothesis
- Critical Show Stoppers
- Phased Execution Plan

Project



Critical: A committed champion and a sponsor with clout

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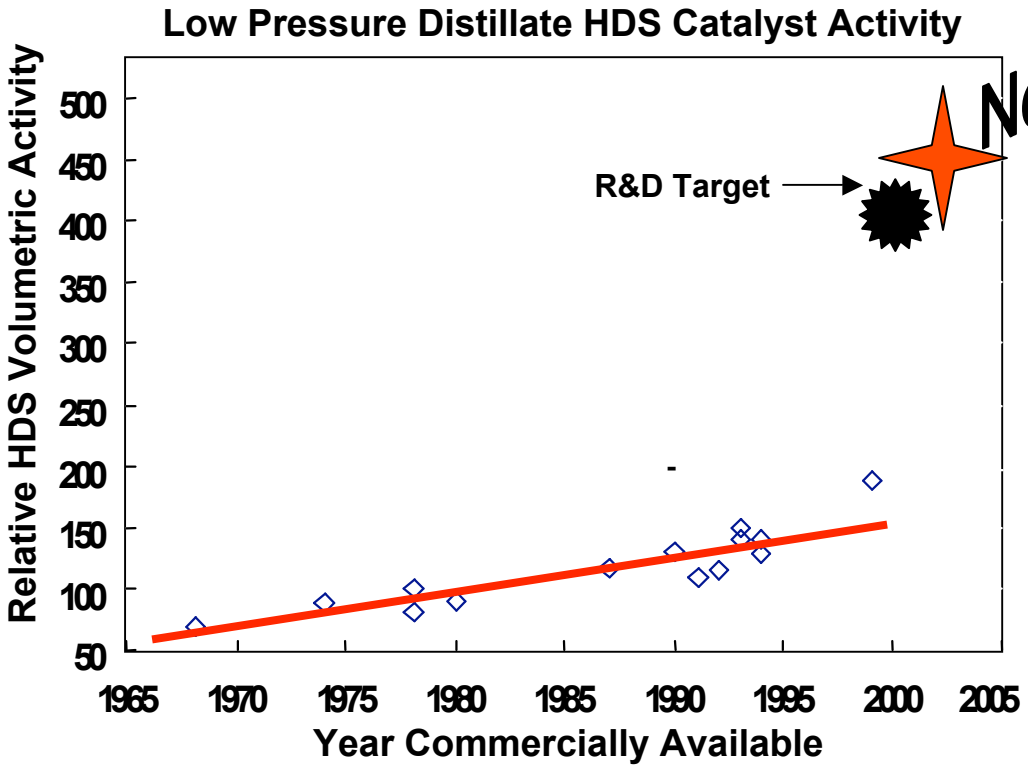
Example of an Aggressive Goal



- Industry Can Define R&D Target
- Science Knowledge Critical
- Reframe Problem to Find Ideas
- Brainstorming/Innovate
- Convert Science to Technology
- Time Window for Opportunity
- Fast, Fast, Fast

Target achieved/exceeded in joint R&D with Akzo-Nobel - *NEBULA created!!*

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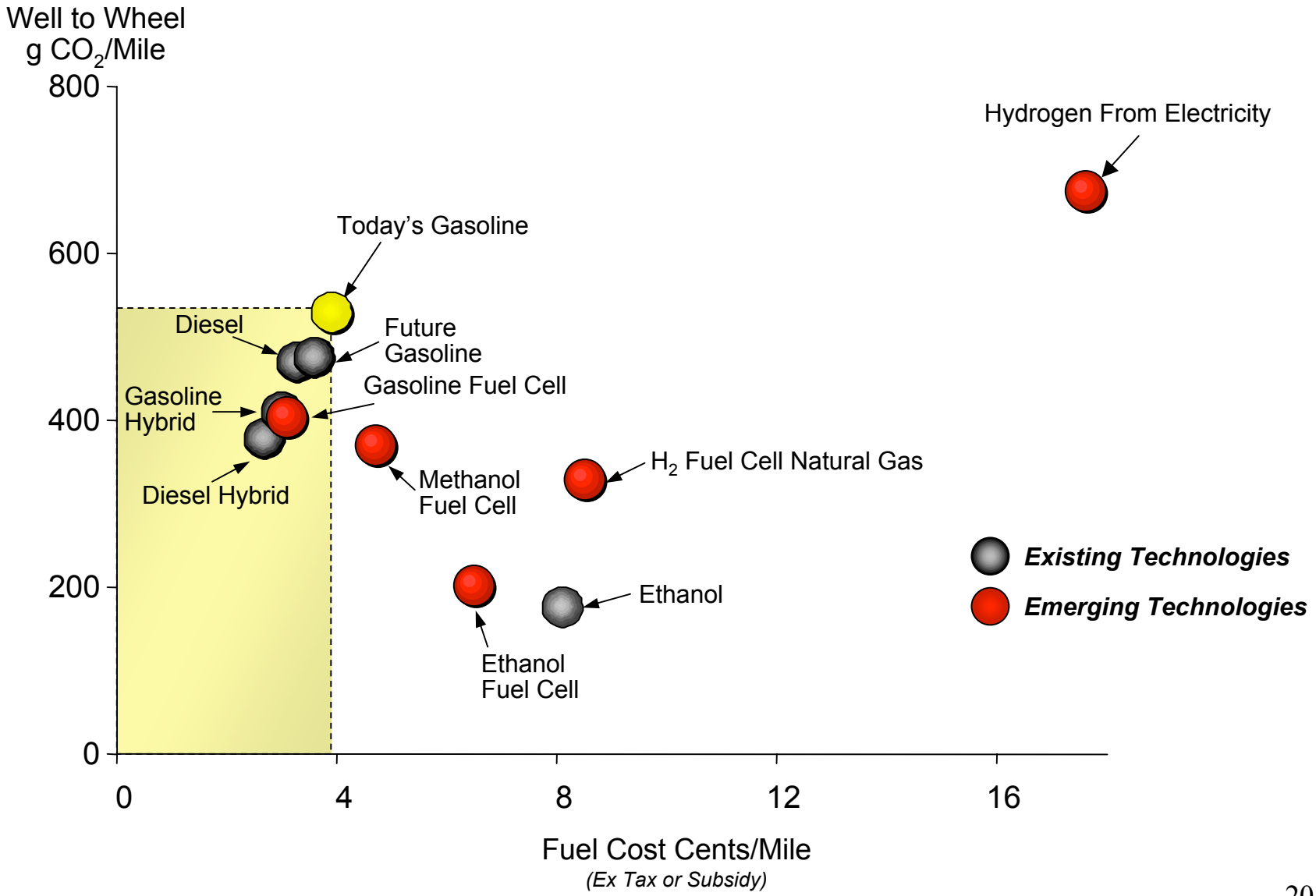
Well-to-Wheel Performance of Technology Options



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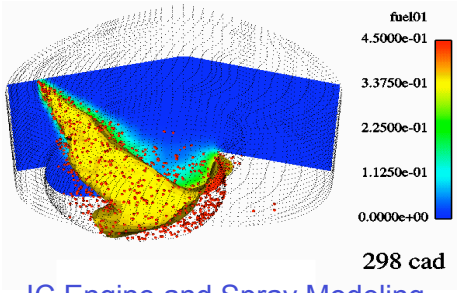
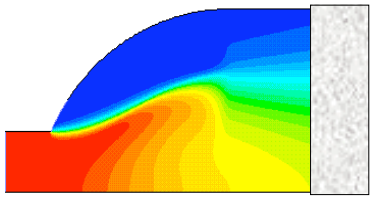
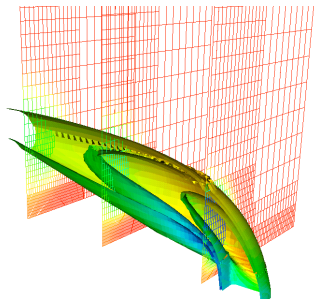
Modeling Research an Integral Design Tool



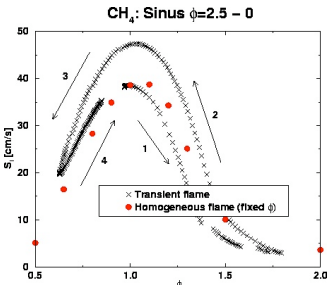
IC Engine and Spray Modeling



Fuel Inlet Performace Evaluation



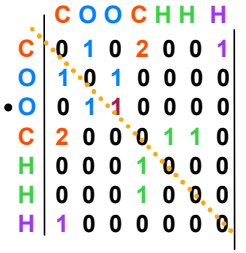
Cold Flow Mixing Studies

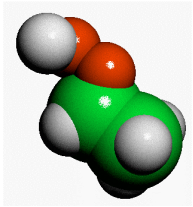


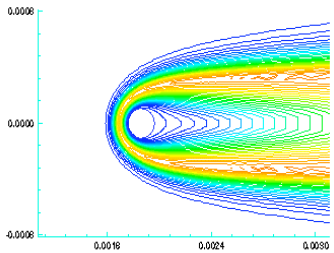
Stratified Flame Propagation

Modeling research directed at fundamental coupling of transport and chemical kinetics

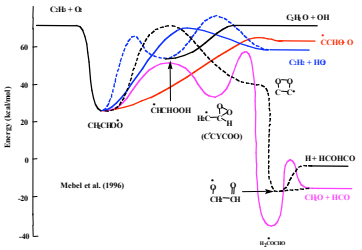
- CFD mixing/combustion
- computer model building
- spray physics and dynamics
- reaction rate estimation
- porous media flows



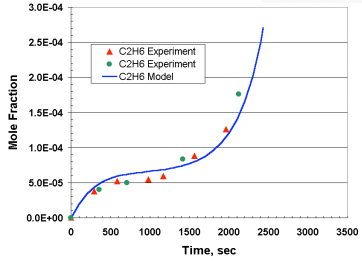




Droplet Vaporization and Combustion



Kinetic Analyses and Reaction Rate Estimation



Computational Mechanism Generation and Thermo Property Estimation

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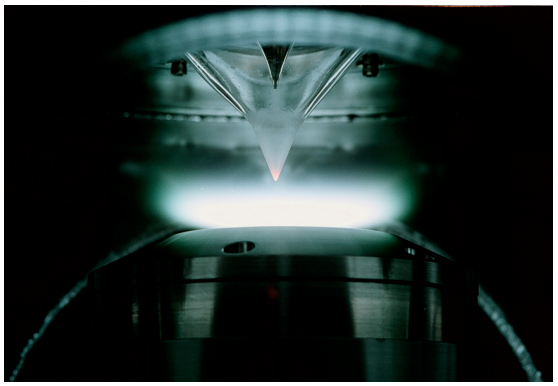
Experiment - Modeling Identify Strategy to Minimize PM and NO_x Formation in Diesel Systems



ExxonMobil Flame Studies

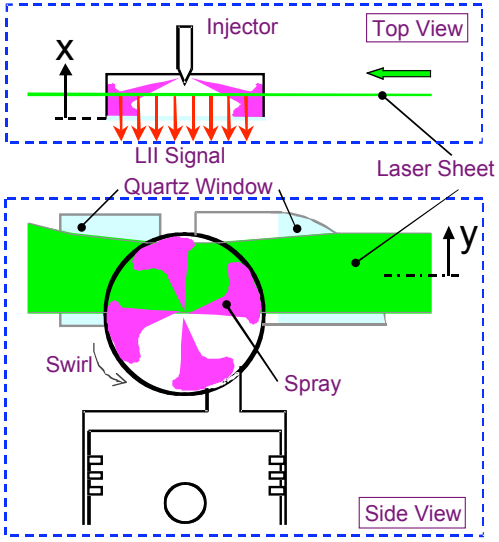
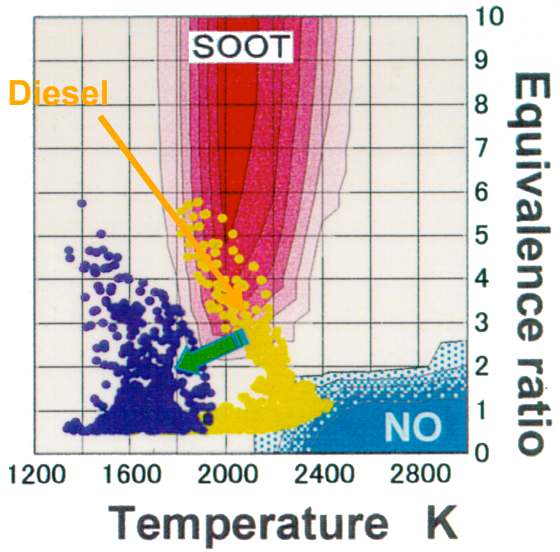


Fig. 1 Optically accessible diesel engine and LII optical setup

- CFD Simulations
- Heat Release Simple Kinetics
- Soot Kinetic Model
- Overlay Detailed Chemistry



K. Akihama, et. al., SAE2001-01-1655

- Key discovery that "flame speed" of specific molecules and blends is more important combustion parameter than CN
- Designing engine and control system around "flame speed" at different part of driving cycle enables higher efficiency, more complete combustion and lower engine-out NOx

K. Nakakita, H. Ban, S. Takasu, Y. Hotta, K. Inagaju, W. Weissman and J, Farrell, SAE 2003-01-1914

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Technology Horizon 20-50 Years

- **Critical need to maintain continuous commitment and focus over several career generations, not to mention political cycles**

- **R&D best practices have been focusing on**
  - **Improve business and R&D guidance**
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  - **Modeling and computational tools**
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  - **Prototype early and often**
  - **Flexible, entrepreneurial science and R&D&E**
  - **Make hard decisions fast when needed**
  - **Breakthrough component of R&D $$$s growing**
  - **Partnering with ....academia, with other companies, with government labs...multiple and growing more complex, ventures**

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Back-up

Recurring Themes on Breakthrough Hurdles

- **Extensive Experimentation and Modeling Required**
  - **A technical idea is seldom recognizable as "*the* solution" until extensive scoping work is performed**
  - **Any idea with a low acceptance-barrier would almost certainly already been implemented**
  - **Thinking exercises inherently limited to identifying promising pathways rather than solutions**
    - **"Genius is 1% inspiration and 99% perspiration" – Thomas Edison**
- **Risk Aversion**
  - **Individual: Why work on high-visibility projects with low chance of success, when important lower risk projects are options?**
  - **Corporate: Why fund high-risk projects with poor tracking metrics, when there are more than enough incremental efforts to do?**
- **Disruption**
  - **Competes with incremental research programs**
  - **Takes resources (*e.g.* funds and staffing) from established programs**
  - **Typically requires some support from naysayers (vocal and private)**
- **Episodic**
  - **Discoveries unevenly distributed in time**
    - **The higher the bar for "Breakthrough", the more unevenly distributed in time the discoveries**
  - **"Nonlinear" project progress**
- **Not Fitting The Mold**
  - **Much higher uncertainty than traditional projects**
    - **Timetables and costs cannot be estimated at the outset as accurately as incremental projects**
    - **Approval required without endless justification exercises**
  - **Projects often cross business divisions**
    - **Cross-disciplinary research by its nature is much well-tread than research focused on single disciplines**
  - **May require new business models to profit from the Breakthrough technology**
  - **"Success" of the project and team cannot be measured solely by the project's ultimate profitability**

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