U.S. Department of Energy
Energy Efficiency and Renewable Energy

Structurally Integrated Coatings for Wear and Corrosion

Materials Project Review
Chicago, IL
June 3, 2005

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Structrually Integrated Coatings for Wear and Corrosion (Award# DE-FC36-04GO14037)

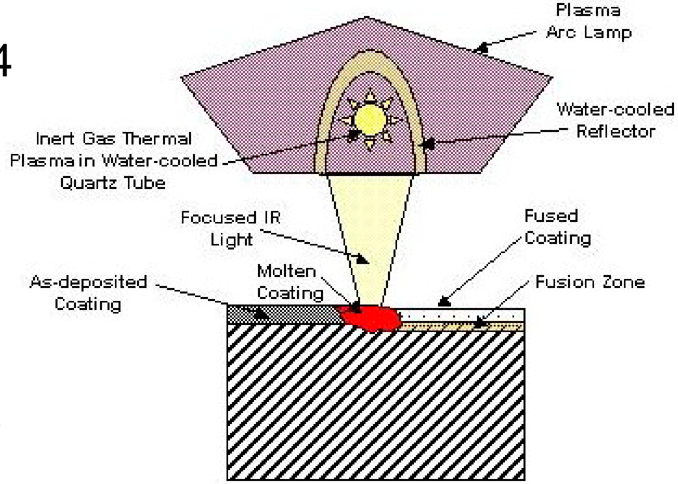
Goal: Develop cost effective surfacing materials and processes with wear and corrosion resistance with 4 to 8 improvement over heat treated steels.

Challenge: Cost effective materials that overcome the inherent low toughness of high hardness materials.

Benefits: Increase wear resistance allows reducing weight on earthmoving equipment resulting in direct energy savings by increased payload moved for same energy. Energy savings of 21.8 trillion Btu/year in 2020.

Potential End-User Applications: Buckets, cutting edges, truck bed liners, elevators, screens, and other wear applications

FY06 Activities: Arc lamp, laser assisted thermal spray and PTA processed materials to be lab bench and field tested to verify microstructural modeling which will aid in the design of the materials.



Schematic of arc lamp fusing

Participants: Caterpillar, Oak Ridge National Laboratory, Albany Research Center, QuesTek Innovations, Iowa State University, University of Illinois, University of Missouri-Rolla

Structurally Integrated Coatings for Wear and Corrosion
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Barrier-Pathway Approach

Barriers

- Low toughness of high hardness materials
- High alloy content (cost) of current hard facing materials
- Understanding of microstructural development and effect on wear

Pathways

- Graded claddings with high toughness matrix/hard particles
- Use of low cost raw materials and cost effective cladding processes
- Modeling to develop and design microstructures with high particle loading/tough matrix

Critical Metrics

- 4-8X wear improvements
- Applied coating cost less than $10 / lb

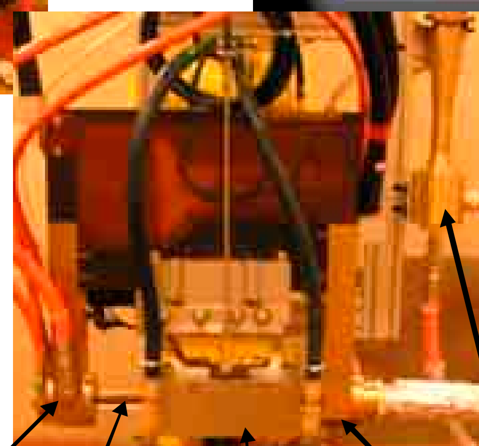
Benefits (est.)	2020
Energy Savings	135 trillion Btu
Cost Savings	$815 million
Carbon Reduction	2.68 MMTCe

Major Milestones Completed

- Economic and industrial feasibility analysis of each coating process and selection of candidate processes and materials
  - Hybrid welding process dropped from program due to material deficiency
  - Model alloys and selected processes projected to meet program targets
- Initial coating production with two of the three coating processes, using up to four material systems per process
  - PTA welding and Arc Lamp Fusing coatings produced with promising wear potentials
- Metallurgical analyses of coatings
  - Model coating microstructures have been analyzed in detail
  - Microstructural modeling has been verified as valuable tool for alloy/procss development

Caterpillar arc lamp installation

- Peak power: 500 kW
- Power density: ~20 kW/cm^2
- Robot mounted
- Sample chambers:
  - 1 ft^2 flat samples in air
  - 12 in^2 flats with N_2 purge
  - 6" dia. rods on lathe with N_2 purge

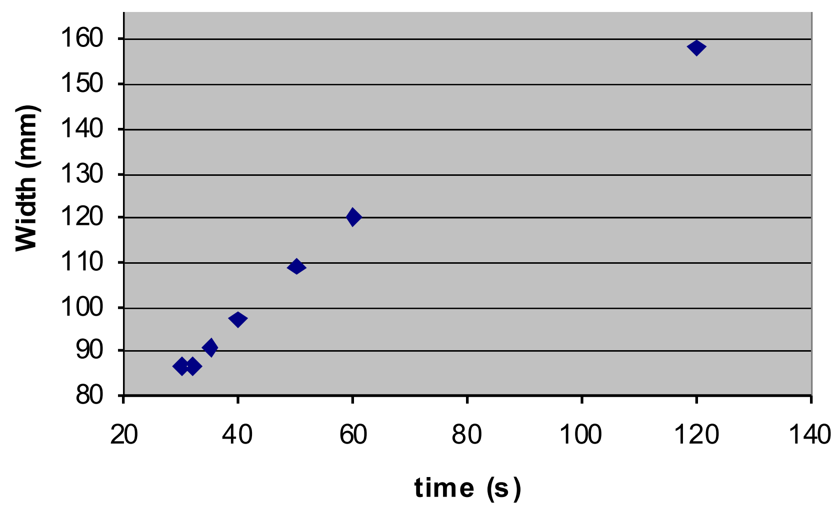


Arc lamp processing

Coating: WOKA8020
Substrate: 1045 steel
Coating thickness: ~ 500 µm

Power level: 330 kW
Distance to focal plane: 42 mm

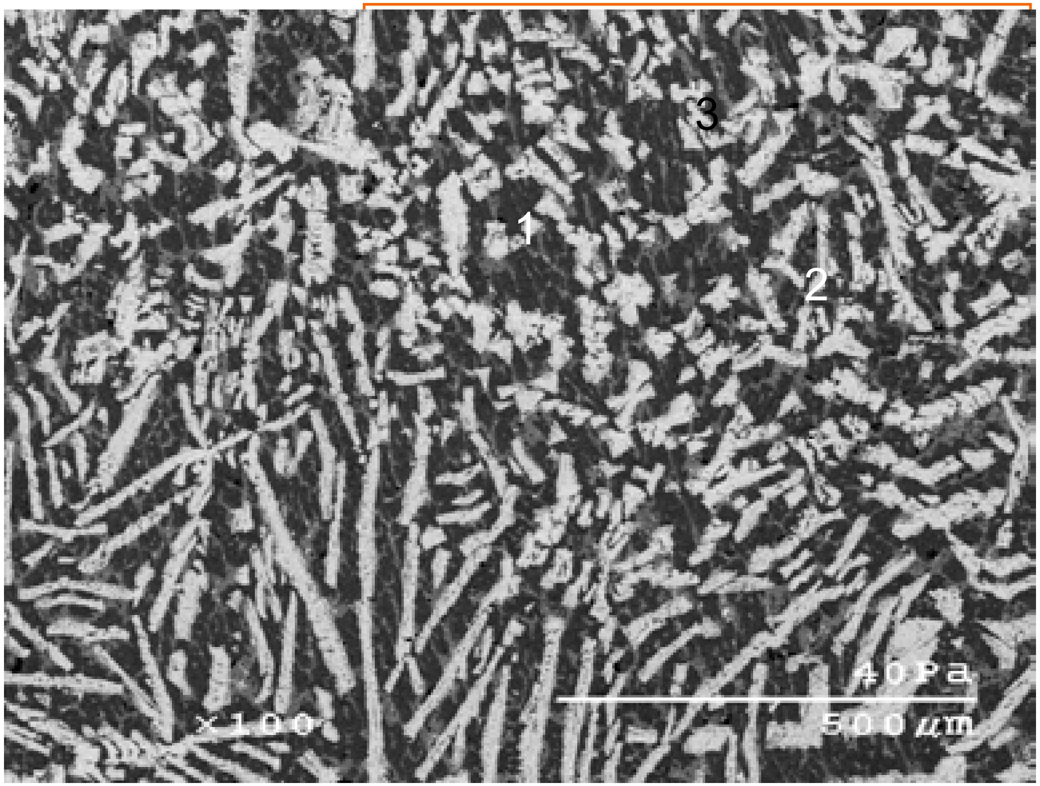
time (s):
30 32 35 40 50 60 120



Microstructural Modeling

Comparison of calculated and experimental phase fractions – Questek and ISU

BSE Images of Alloy G3-1 after annealing for 4 weeks at 1000 °C



Phase proportions:
Fe-fcc(1) ≈ 16%
Fe_2B(2) ≈ 48%
$FeMo_2B_2$(3) ≈ 36%

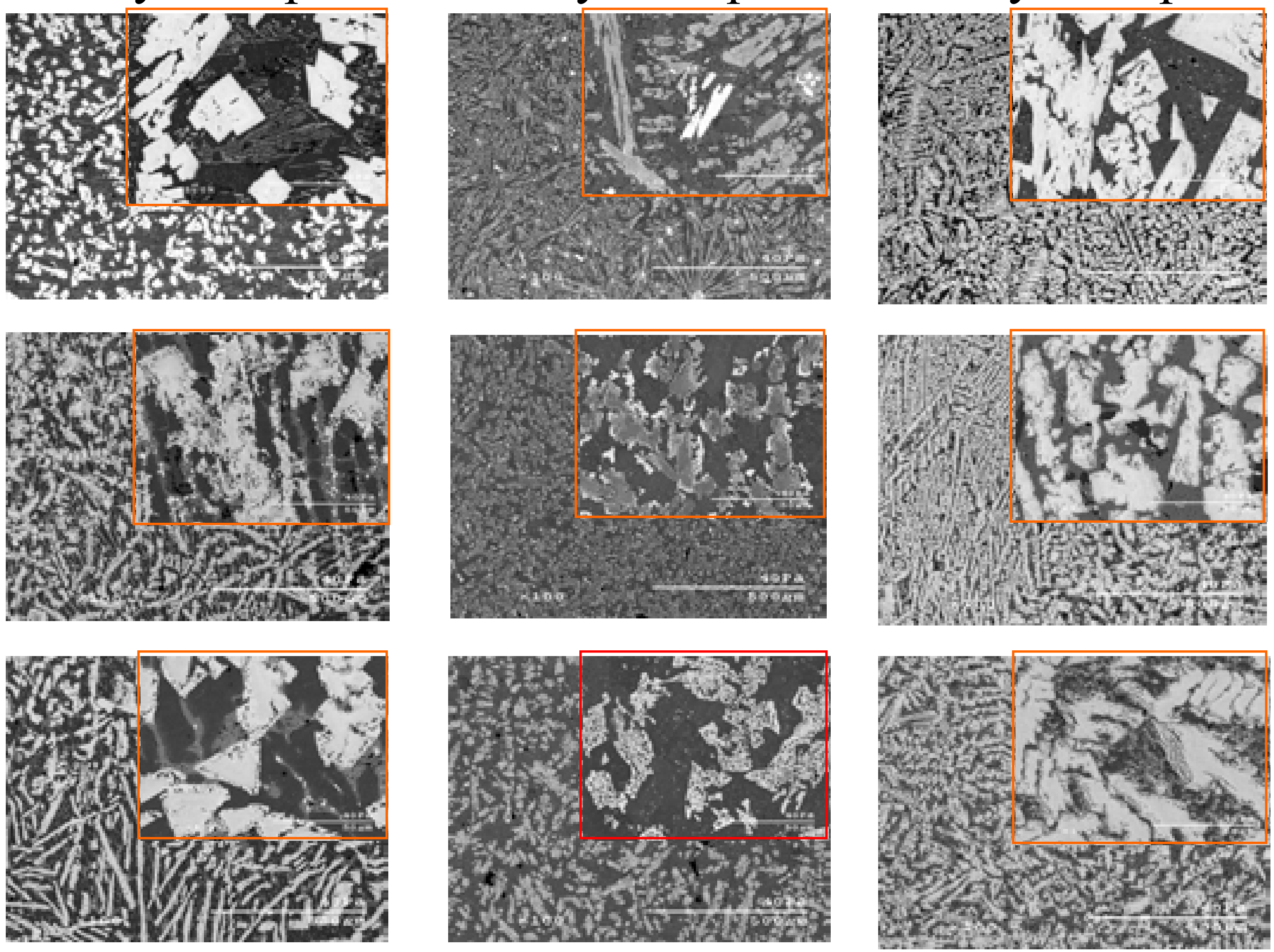
Phases by QuesTek:
Fe-fcc~14%
M_2B~56%
$FeMo_2B_2$~30%

Alloy Group 1 | Alloy Group 2 | Alloy Group 3

Base alloys

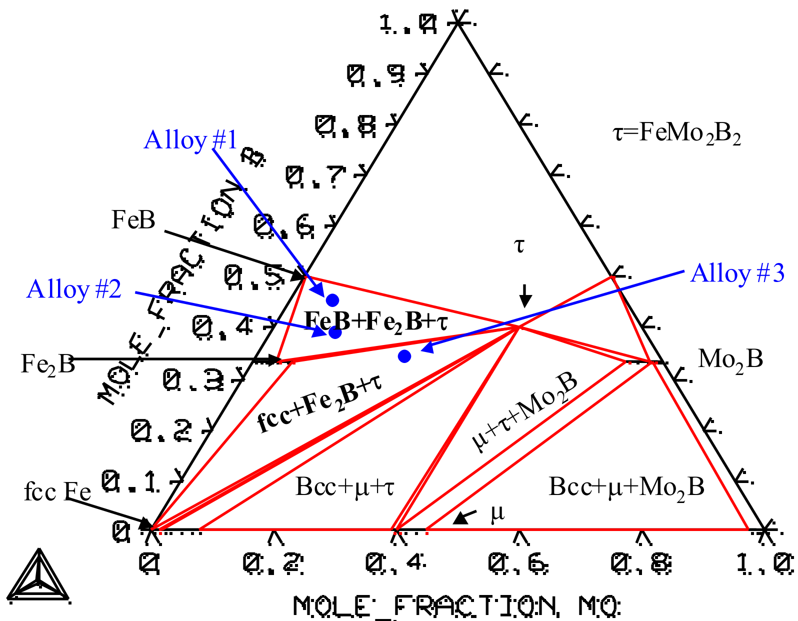
Base alloys + 20wt% Cr

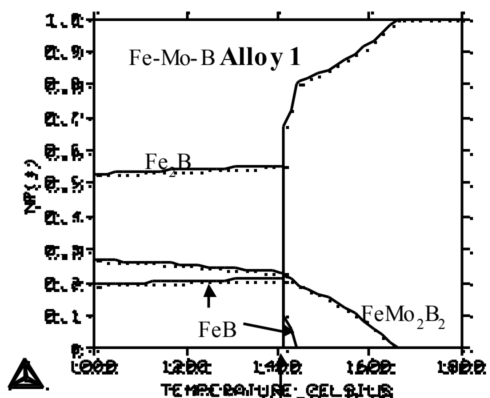
Base alloys + 10wt% Cr + 10wt% Ni



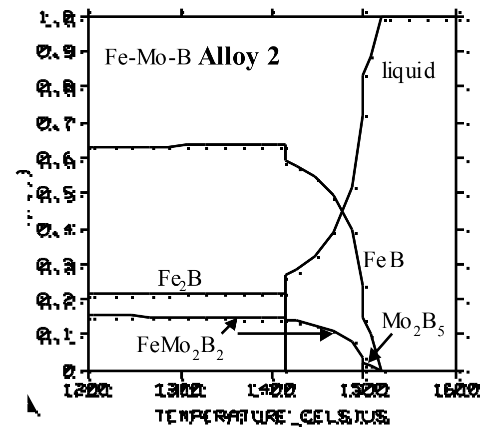
Phase diagram calculations - QuesTek

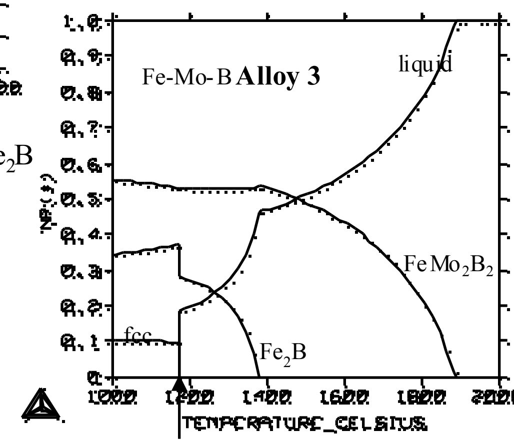
1000 °C isothermal section of Fe-Mo-B system



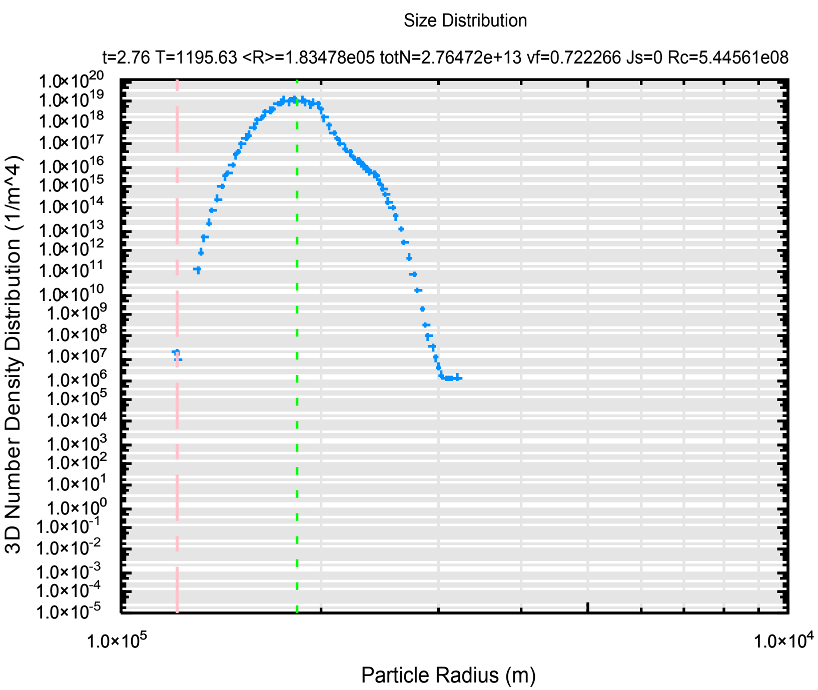


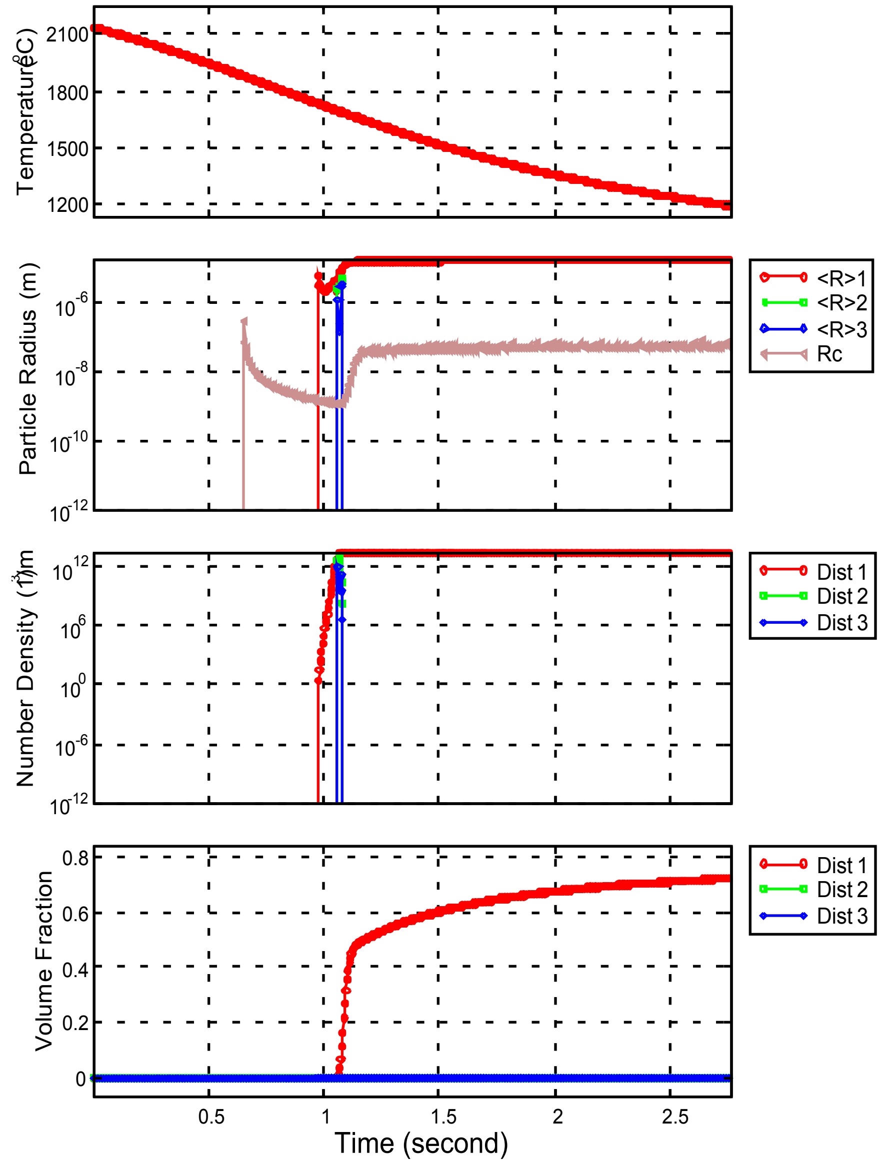
eutectic reaction with FeB & Fe_2B





Calculations of precipitation kinetics - QuesTek





Screening Wear tests – Albany Research Center

- Baseline for comparison: D2 tool steel
- Initial results for SICWC alloys:
  - Dry sand rubber wheel: mass losses of Fe-Mo-B TiC-based alloys and are similar to baseline
  - Pin on disk: TiC-based alloys show superior grinding resistance to baseline (up to 10x improvement).
  - Impeller tests: Fe-Mo-B and TiC-based alloys show similar impact abrasion resistance as baseline tool steel

Screening Wear tests – Albany Research Center

Material Designation	Average Hardness, RKW C	Wear Rank DSRW	Wear Rank Pin Abrasion	Wear Rank Impact Abrasion
Fe-Mo-B-20Cr	62.0	2	1	NA
Fe-Mo-B	64.2	6	6	NA
WOKA 8020	51.9	4	2	11
Del 60	60.6	5	5	10
Fe-TiC15	48.3	1	3	1
Fe-TiC3	44.3	3	4	4

Future work

- Produce and evaluate coatings with compositions calculated by Questek (3Q05 – 2Q06)
  - Model verification and initial alloy refinement
  - Initial laser assisted thermal spray coatings to be produced
- Development of finite element process models (3Q05 – 1Q06)
  - Couple microstrucuturally modeling of alloys with process modeling
- Residual stress measurements (3Q05 – 1Q06)
  - Aid in verification of process modeling
- Thermophysical and mechanical property measurements (3Q05 – 4Q05)
  - Input to the microstructural modeling
  - Go/No for properties to proceed with field wear test
- Refinement of alloy compositions to achieve desired microstructures (3Q05 – 3Q06)
- Wear testing of refined alloy compositions (3Q05 – 2Q06)
  - Completion of lab wear test and initial laboratory component wear testing
  - Go/No for proceeding with field wear test
- Produce coated components for field test (3Q05 – 1Q06)
  - Opportunity to verify lab wear testing results of initial alloys
  - Early determination of coating toughness, longer to evaluate wear

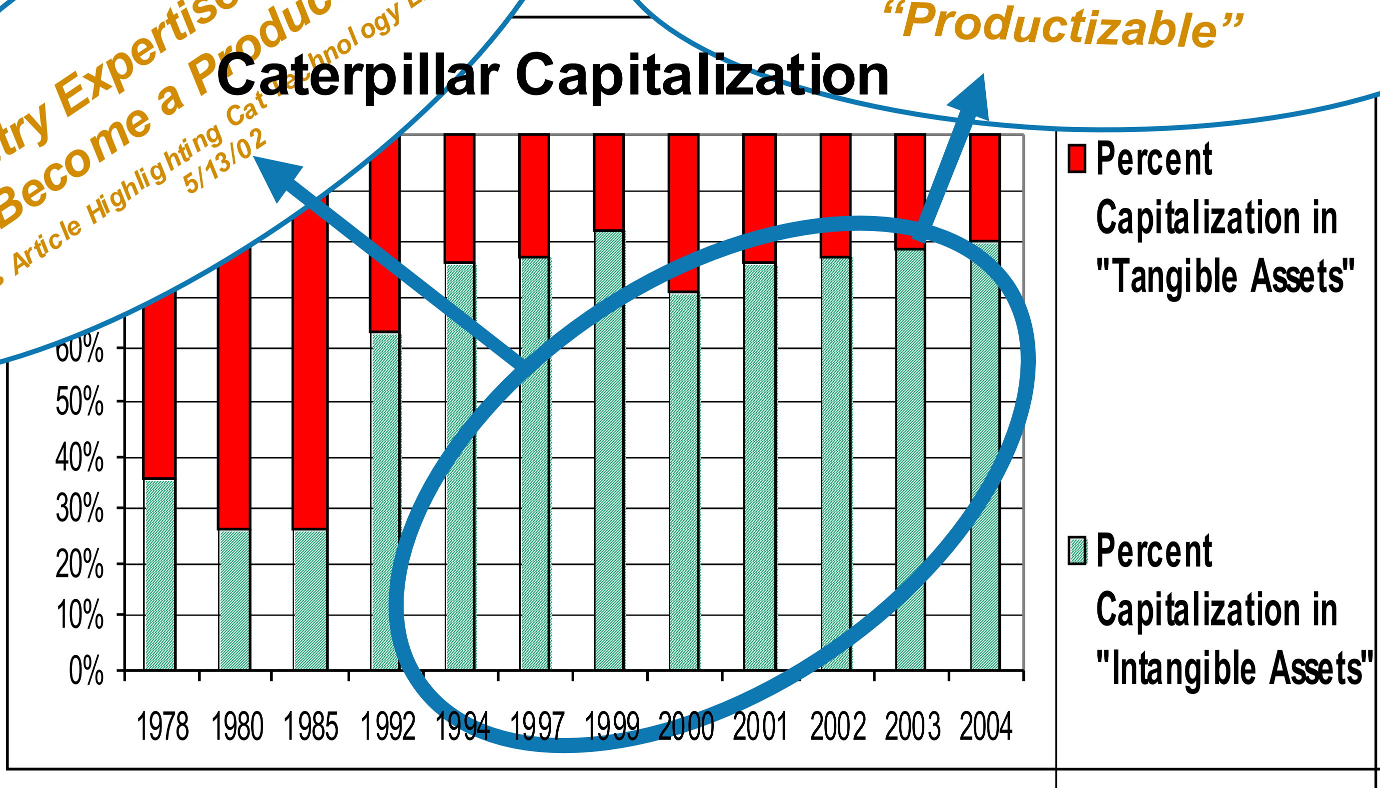
Commercialization Plans

What "Intangibles" Do We Measure?

"Industry Expertise Has Itself Become a Product"

NY Times Article Highlighting Cat Technology Licensing 5/13/02

Measure, Track & Pursue Deals with those Assets that are "Productizable"



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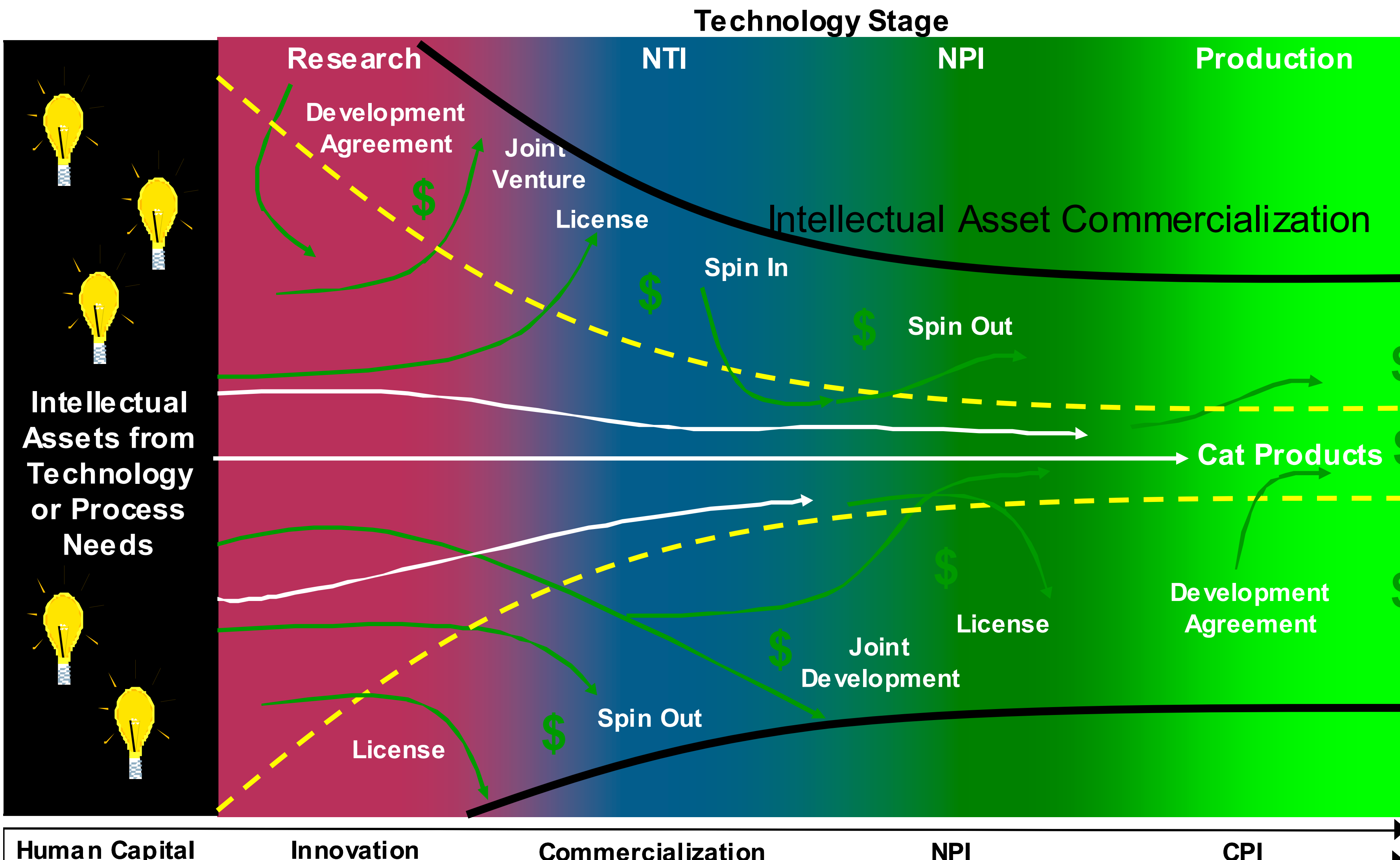
What is the process for Caterpillar to turn its Intellectual Assets into revenue?



Marketing Initiatives

www.yet2.com
- 70+ TechPac's … worldwide exposure

- Nat'l Mfg Week (Chicago – Y2003)
- SAE (Chicago – 2004, Detroit – 2005)

www.catlic.com

Benchmarking & Technology transfer

News Media
- Provides Cat immediate recognition in licensing & technology transfer
- Trade & business press
- Articles in Chicago Tribune & New York Times

Marketing Companies

Technology Transfer Conference & Exhibit

March 3-6, 2003 McCormick Place

Websites

Caterpillar Corporate Site

(www.cat.com)

Caterpillar Technology Licensing

(www.catlic.com)

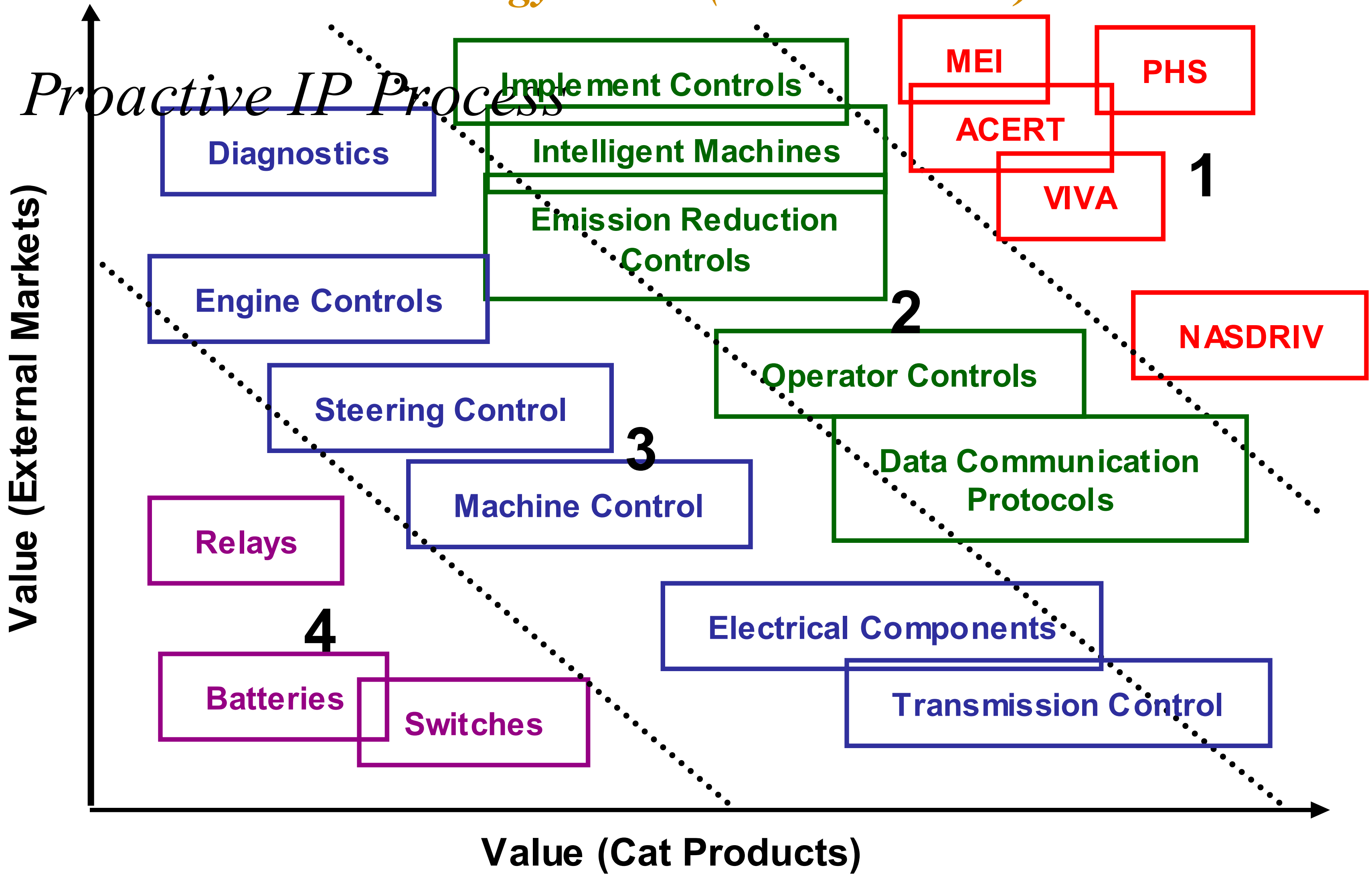
Yet2.Com Internet Marketplace

(Type Caterpillar in Search String)

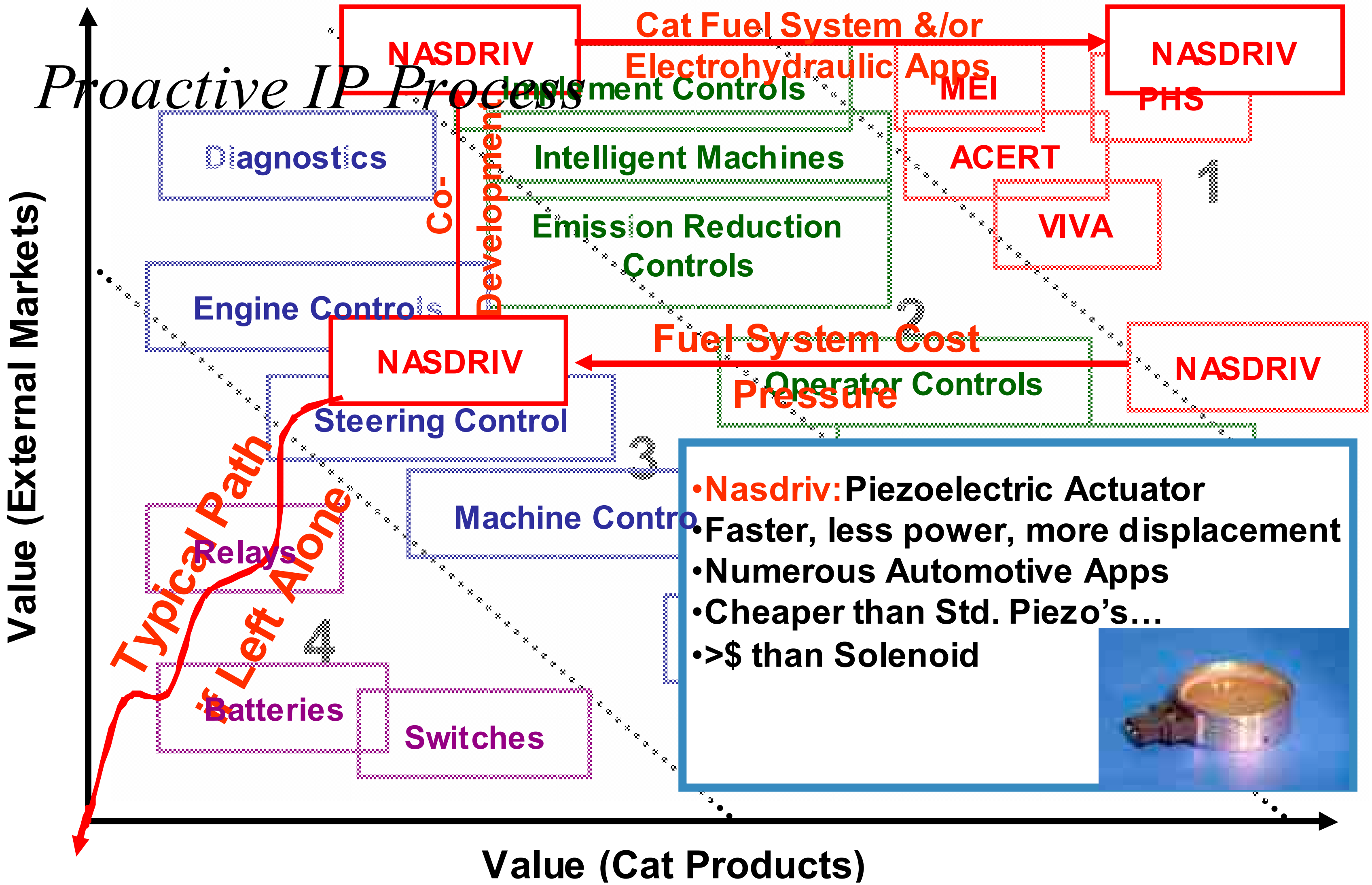
Examples

Strategy Charts (Cat Electronics)

Proactive IP Process



Strategy Charts (Cat Electronics)



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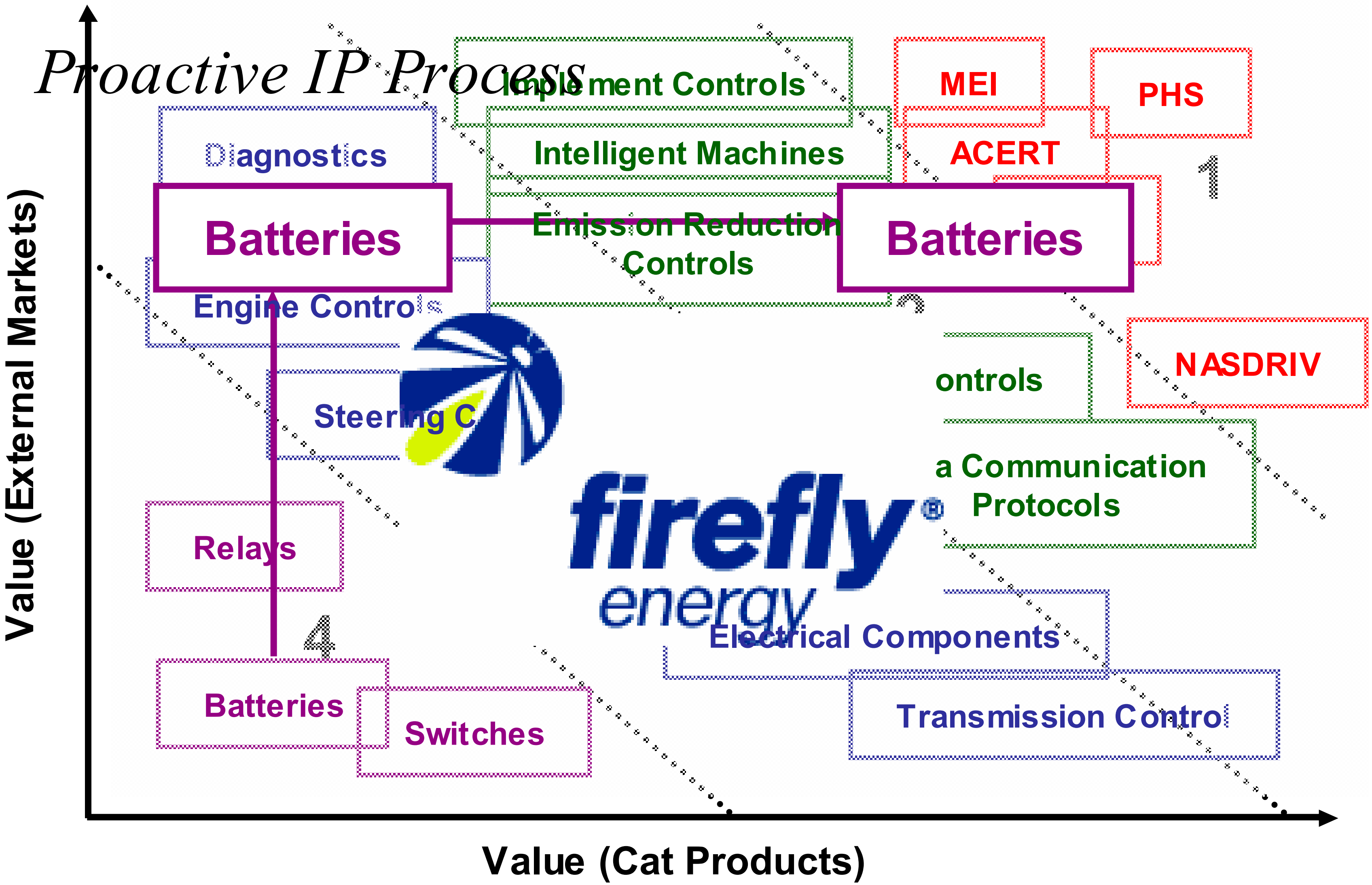
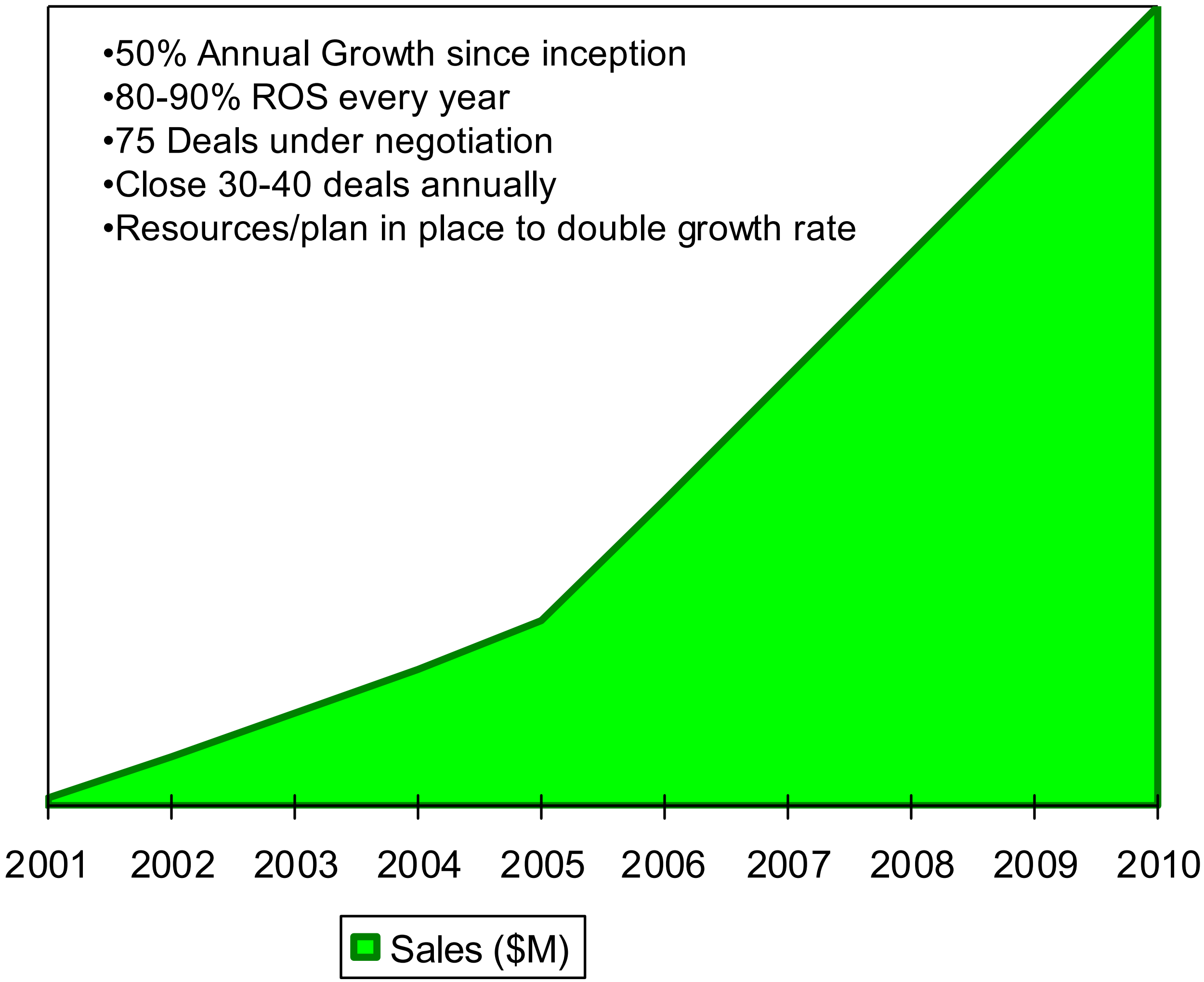


A Growing Business



Questions?