

PPG Industries
Bringing innovation to the surface.™

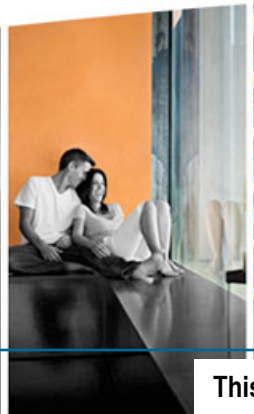
A Materials Approach to Fuel-Efficient Tires

Justin J. Martin, Ph.D.
Mark Bowman, Ph.D.
Peter L. Votruba-Drzal, Ph.D.

PPG Industries

Project ID #VSS084

June 19, 2014

Overview

Timeline

- **Start: 10/01/2011**
- **End: 09/30/2014**

- **% complete (4/2014)**
  - Phase I: 100%
  - Phase 2: 17%
    - Task 3: 79%
    - Task 4: 5%

Budget

- **Total project funding**
  - $2,046,503 (Total)
  - $1,485,851 (DOE)
- **Funding Obligated**
  - Fully funded

Barriers

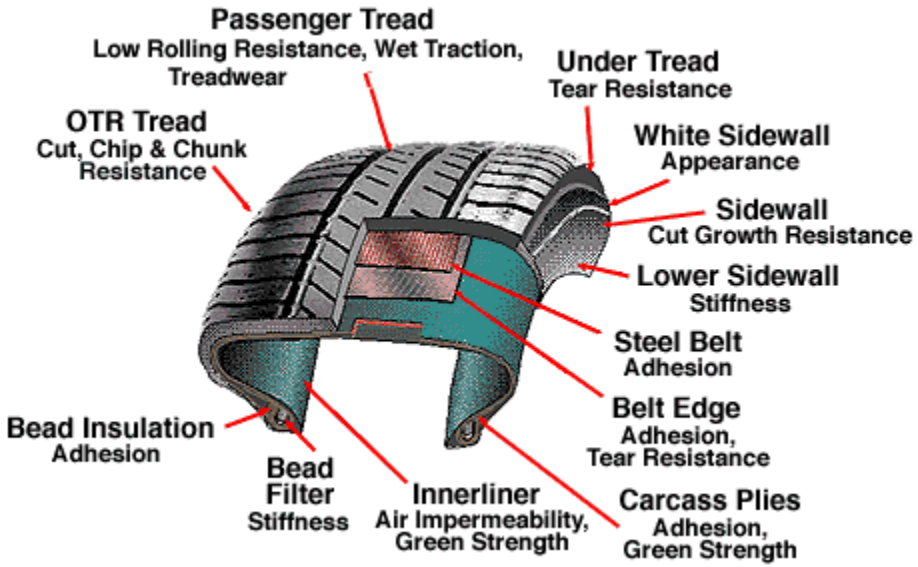
- **Barriers addressed**
- **Technical Target**
  - Tires for improved fuel efficiency to reduce fuel consumption by passenger vehicles
- **Technical Barriers**
  - Cost, tire manufacture adoption, and consumer adoption

Partners

- **Goodyear Tire & Rubber Co.**
- **North Dakota State University**

Relevance

- **The objective of this project is to design, develop, and demonstrate fuel efficient and safety regulation compliant tire filler and barrier coating technologies that will improve overall fuel efficiency by at least 2%.**
- **From the 2006 Transportation Research Board Report ***
  - A 10 percent reduction in rolling resistance can reduce consumer fuel expenditures by 1 to 2 percent for typical vehicles. This savings is equivalent to 6 to 12 gallons per year.
  - A 1 psi drop in inflation pressure increases the tire's rolling resistance by about 1.4 percent
- **The technologies to be researched, developed, and demonstrated under this project include:**
- **Tire Filler Technology**
  - (Modified Silica-based)
- **Tire Barrier Coating Technology**
  - (Reduced Air Transmission Rate)



http://www.ppg.com/specialty/silicas/productsegments/Pages/tire.aspx

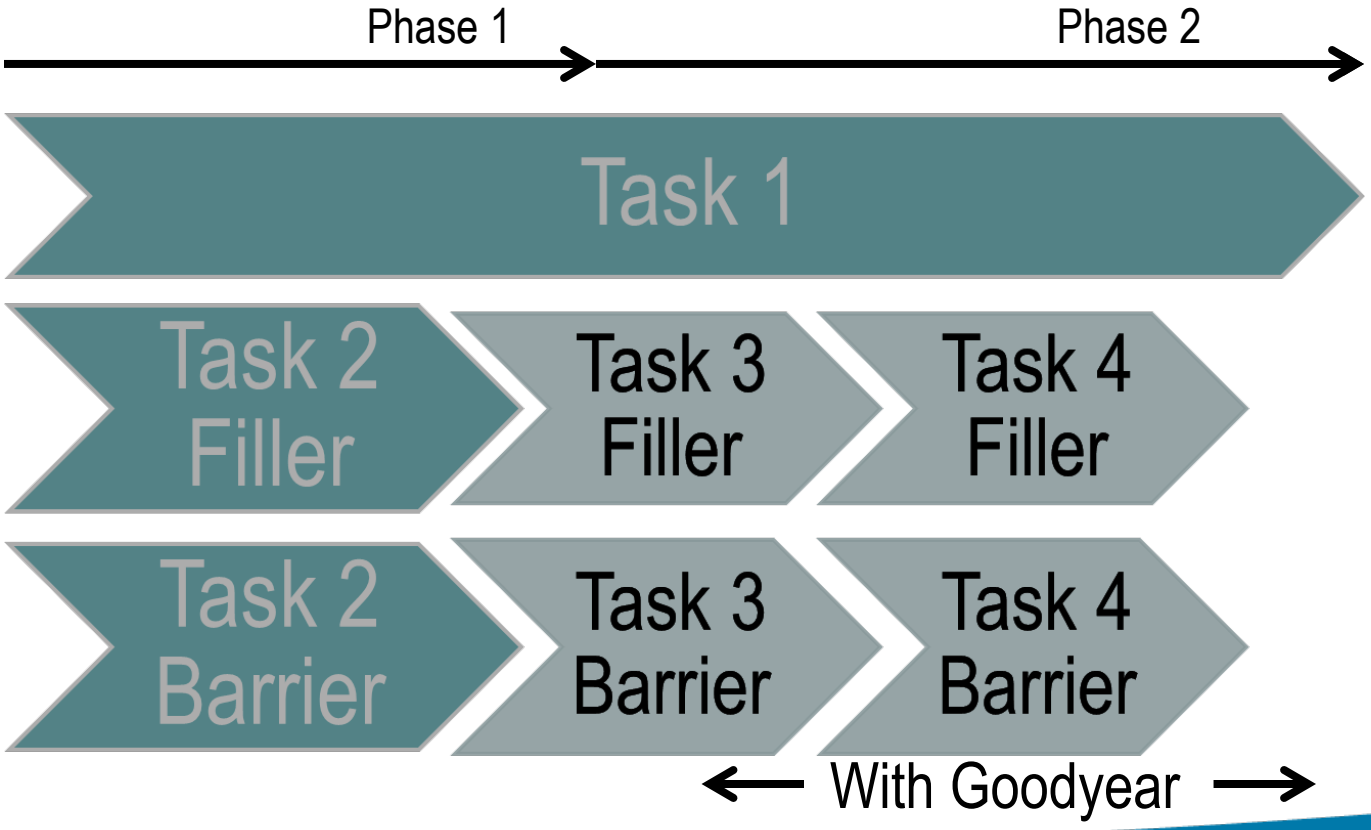
*Transportation Research Board Special Report 286, "Tires and Passenger Vehicle Fuel Economy Informing Consumers, Improving Performance", NATIONAL RESEARCH COUNCIL OF THE NATIONAL ACADEMIES,2006

Milestones

Milestone	Plan (Est. Date)	Status
Update PMP	1/10/12	Submitted
Coatings Benchmark	12/31/11 (5/31/12)	Completed
Identify Coatings Design Principles	8/31/12	Completed
Select Silica Surface Treatments (original)	12/31/12	Completed
Silica Surface Treatments (Phase 2)	12/31/2013	Completed
Select New Silica Materials	12/31/13	Completed
Select New Coatings Materials	12/31/13	Completed
Pilot Batch of Silicas	1/31/14	Completed
Attain Coating Compatibility with Tires	3/31/14	Tentative
Select silica and coatings for tire build	4/1/14 (5/2/2014)	Awaiting Results
Test Tires Built and Coated	6/4/14	
Testing and Analysis Complete	9/30/14	
Final Report	12/29/14	

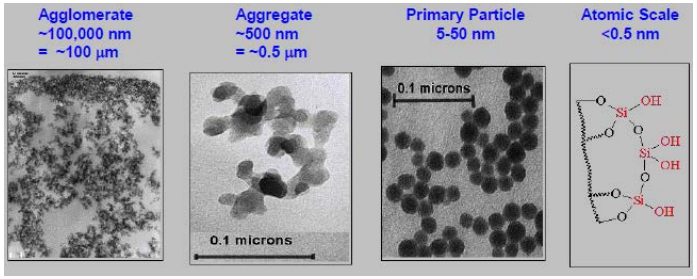
Programmatic Approach

- ***Phase I:*** This phase will systematically evaluate the feasibility of the two technology approaches and down select candidates for Phase II development.
- ***Phase II:*** This phase will combine the prototypes down selected from Phase I and includes a tire build and testing scheme to validate the developed technologies.

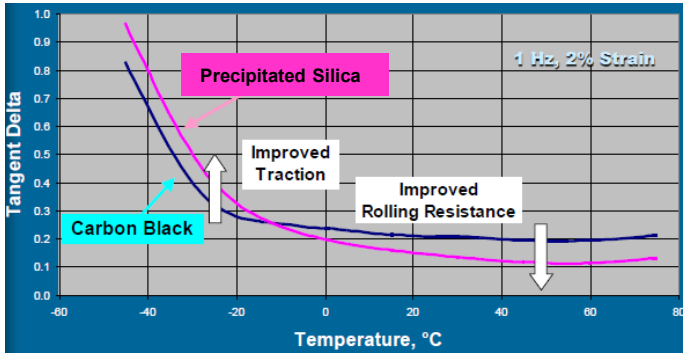


Approach/Strategy: Fillers

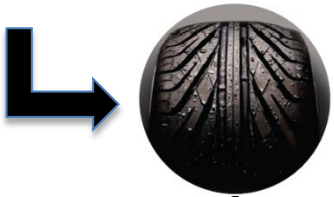
Structure-Property Relationships



Silica Structure, Morphology, and Surface Functionality



Material Properties (Industry Standards)



Tire Performance

Lab Scale – 200g silica

- Surface Characterization
- Brabender Mixing
- Rubber Characterization

Pilot Scale – 12 lbs

- Surface Characterization
- Banberry mixing
- Rubber Characterization

Manufacturing Lab Evaluations

Pilot Scale – 200 lbs

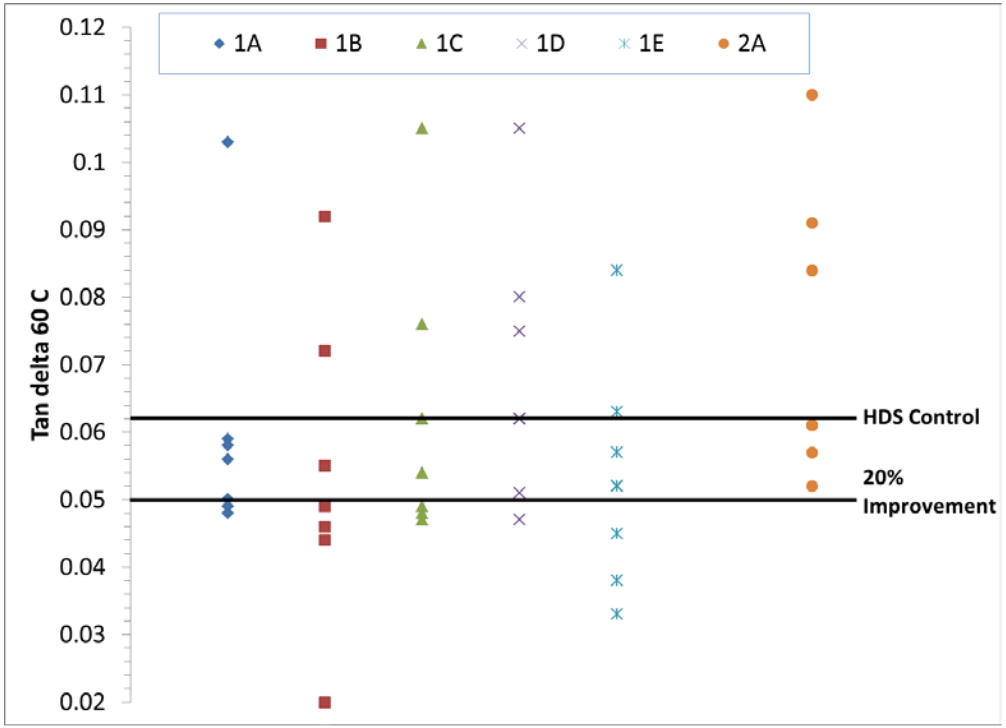
Select 3 combinations of surface modifiers/morphology silicas for tire builds:

- 10% improvement in tread wear
- Rolling resistance equal to or greater than HDS silicas

*HDS = Highly Dispersible Silica

Fillers: Technical Accomplishments and Progress:

- **13 samples selected based on Goodyear processing requirements.**



*Each data point represents a single rubber compound

(HDS) Highly Dispersible Silica

Selected examples

- **Selection from Goodyear pending, 3 selections will be scaled-up for tire tread evaluations**

Approach/Strategy: Elastic Barrier Coating

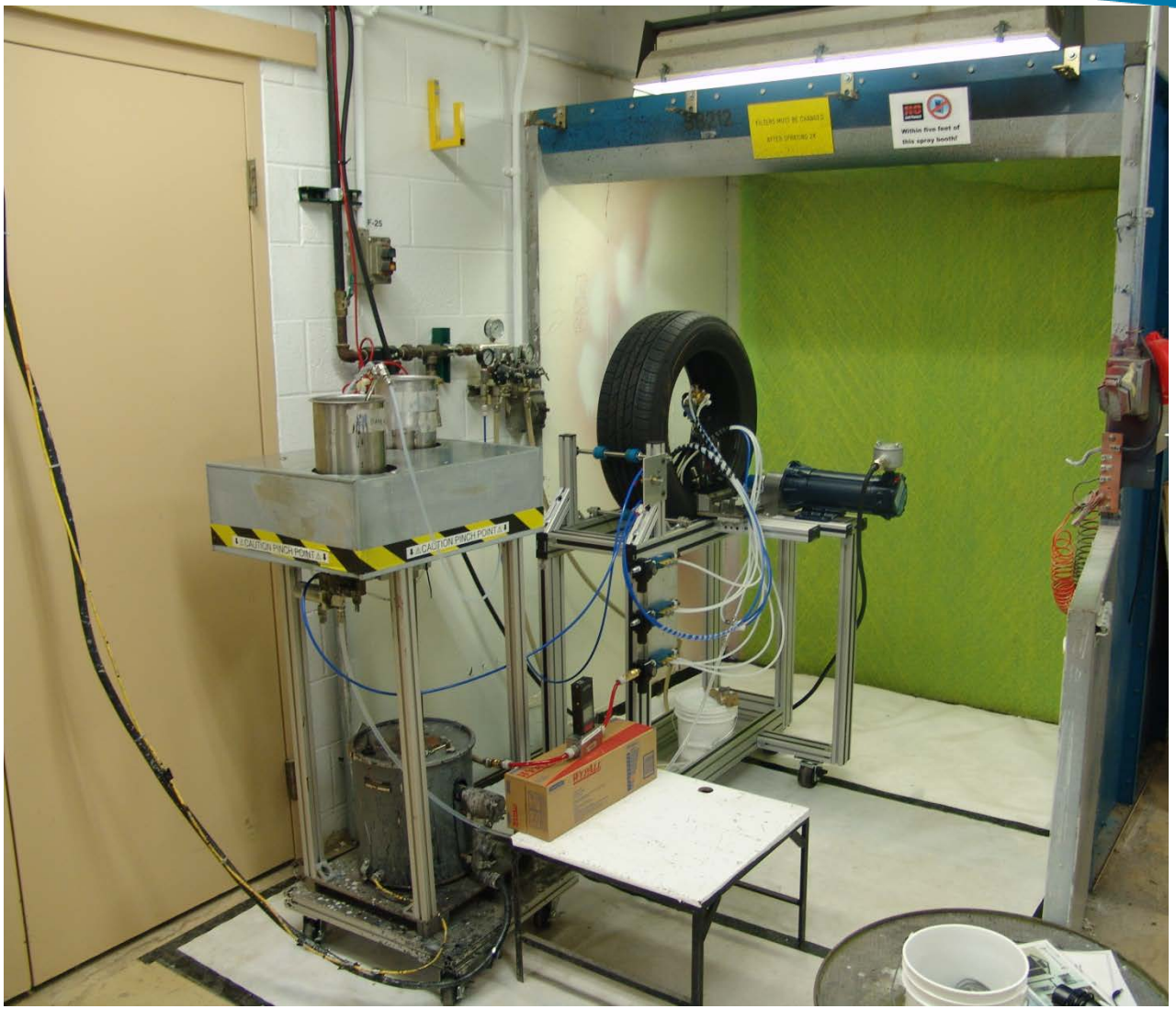
- **Tire Innerlayer:**
  - The raw material cost of the barrier coating is projected to be equal to or less than the rubber that it is replacing
  - Formulate inelastic polyurethanes which are excellent gas barriers together with elastomers that are poor gas barriers
  - Spray apply the elastic, gas barrier coating to the interior of a cured tire

Developing Elastic Barrier Coatings

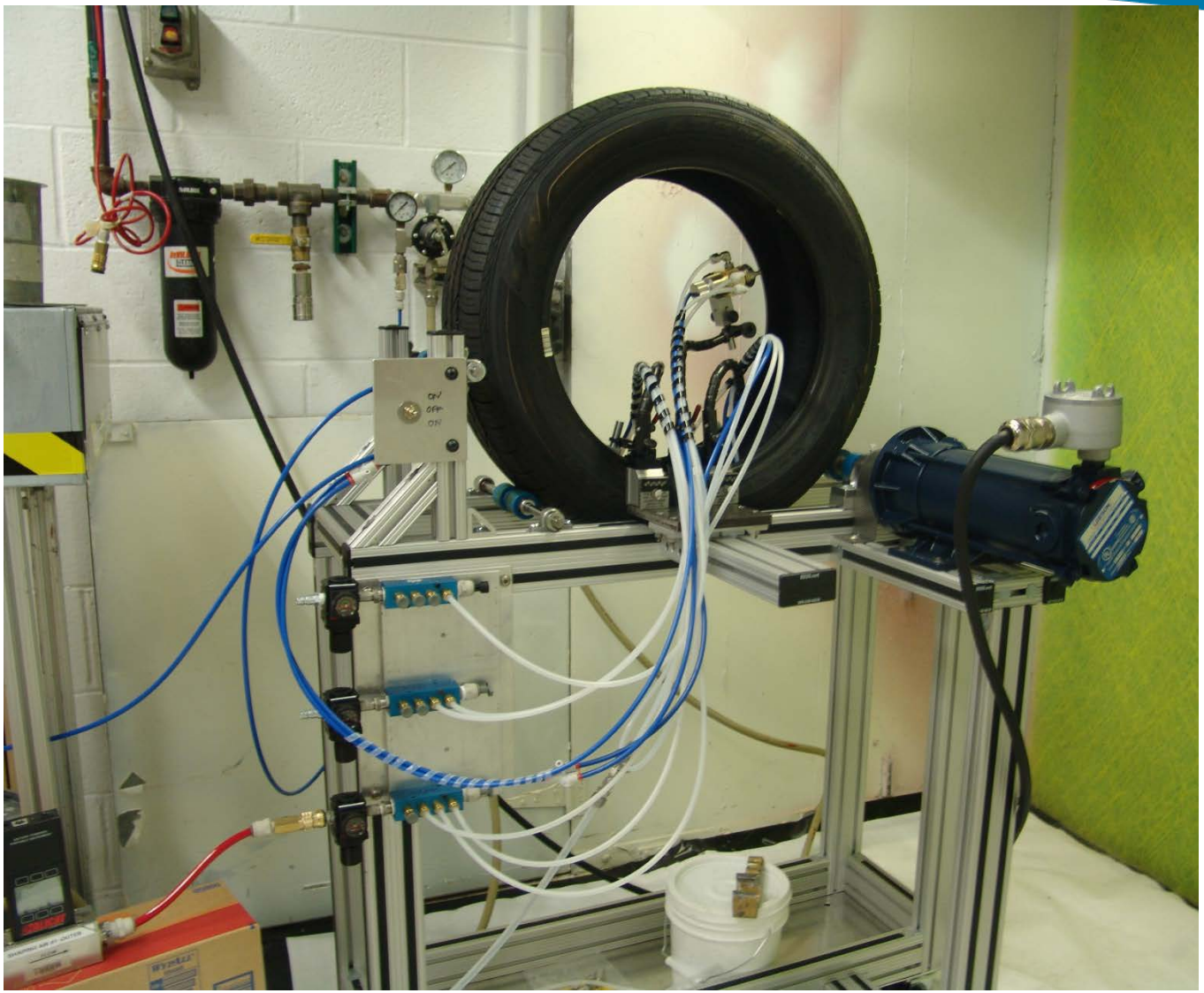
1. Formulate coatings – Measure elasticity and oxygen barrier performance **PASS**
2. Apply coating to rubber – Industry tape adhesion test **PASS**
3. Evaluate durability - barrier performance after DeMattia flex testing **PASS**
4. Resistance to fatigue – Rubber cylinder coated with barrier coating and subjected to Goodyear cyclic fatigue test **PASS**
5. Tire testing - Goodyear passenger tires fabricated without an innerliner have a PPG barrier coating spray applied. Tires are tested for air retention and durability. **In test as of April 2014**
6. Full battery of tire tests - Custom Durability, DOT High Speed, Cold Box, Rolling Resistance, Tire Weight, Inflation Pressure Retention **3Q CY 2014**
7. Joint development project by PPG and tire company to commercialize a tire barrier coating

Barrier Coating Performance

	Oxygen Transmission Rate [cc/100 in²/day at 50% humidity]
1 mm thick body ply rubber	61.7
Barrier coating [5.4 mil DFT] sprayed applied to 1 mm thick body ply rubber	Before 20.7
	After 100,000 cycles on DeMattia Flexing Fatigue Testing, 18.6
Current Passenger Tire	12.77
9.8 mil [0.25 mm]	9.89
22.7 mil [0.58 mm]	4.61



Spray Application into Tires



Tire Rotated, Stationary Spray Heads

Proposed Future Work

- **Fillers**
  - Goal: Improved tread wear with equal rolling resistance
  - Scale up and deliver Goodyear selected silicas for tire tread evaluations
  - Evaluation of selected silicas in other rubber compounds
    - Key metrics: processing, cure, dispersion, stress-strain, abrasion, and dynamic properties
    - Milestones: Silica selection by Goodyear (5/2/14)
- **Coatings**
  - Goal: Improved fuel efficiency by maintaining tire pressure
  - Evaluate performance of barrier coating in tires
    - Key metrics: Rolling resistance, inflation pressure retention, durability and cold box tests
    - Milestones: Completion of coated tires tests by Goodyear
- **Risk Management**
  - Silica materials may not process well with Goodyear formulations
    - Modify silicas based on processing feedback from Goodyear
  - Barrier materials that pass screening tests may not pass testing in tires
    - Modify barrier coating formulation to meet adhesion and durability requirements

Responses to Previous Year Reviewers' Comments

- **What are the cost of the filler materials**
  - The price of the filler materials has not been set, however, it would be expected to be consistent with PPG's Agilon™ performance silicas.
- **What is the cost of the barrier materials and what are the issues in the "manufacturability" of the barrier materials?**
  - The raw material cost of the barrier coating is projected to be equal to or less than the rubber that it is replacing
  - The manufacturability of the barrier materials has not yet been addressed and would be the subject of future work outside of the DOE project.

Collaboration and Coordination with Other Institutions

- **The Goodyear Tire & Rubber Company (Sub-contractor)**
  - Working in an advisory role during much of the program
  - Will build filler and barrier tires for testing and evaluation

Filler Technology

- Ongoing discussions, model elastomer formulation reviewed and validated
- Provided minimum specifications for important properties
- Laboratory evaluations of selected silicas will begin in 3rd quarter

Barrier Coatings

- Provided model ply formulations
- Periodic consulting and material evaluation
- Provided processing information and mechanical property requirements

- **North Dakota State University**
  - Center for Nanoscale Science and Engineering
  - Synthesis of novel soybean oil-based materials for evaluation in rubber compounds

Summary Slide

- **Objective**
  - Design, develop, and demonstrate fuel efficient and safety regulation compliant tire filler and barrier coating technologies
- **Expected Outcome**
  - A tire with improved overall fuel efficiency by at least 2%
    - 15% reduction in manufacturing cost, or
    - 10% improvement in tread wear, while
    - Maintaining the fuel efficiency improvements
    - Maintaining tire pressure with barrier coating
- **Fillers**
  - Candidate silicas are under evaluation by Goodyear. Selected silicas will be scaled up for tread testing scheduled for late May
  - Three invention disclosures produced during the program and PPG will fund additional development work of selected silicas.
- **Barrier**
  - Barrier coating that is both elastic and an excellent air barrier has been spray applied to tires
  - PPG will fund future development and commercialization work after DOE project completion.