# Advanced Bus and Truck Radial Materials for Fuel Efficiency

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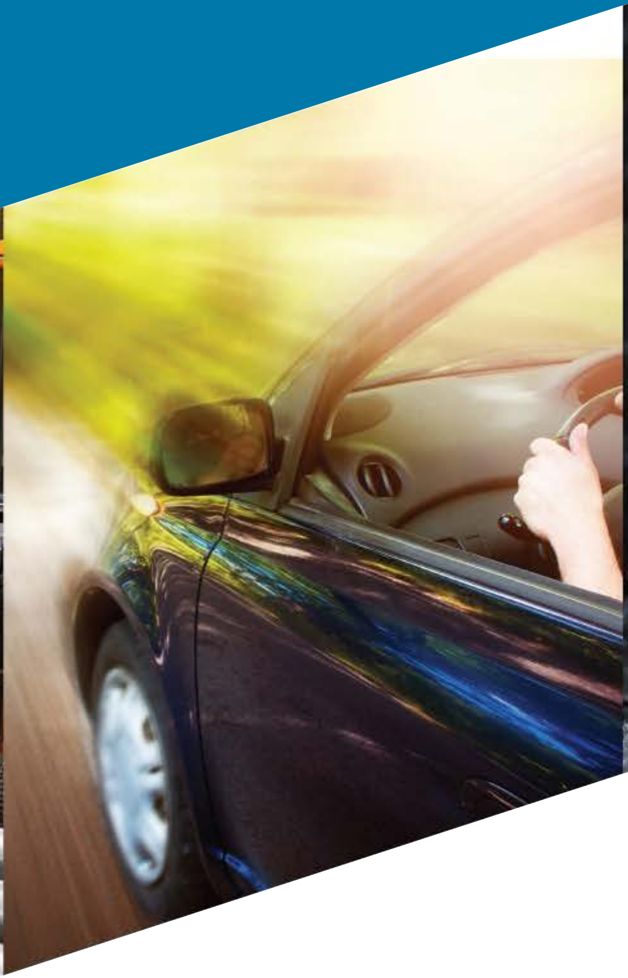


Project ID: ACS115

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# Overview

## Timeline

**Start: 10/01/2014**

**End: 03/31/2018**

**BP2 completed**

- On March 31st, 2017

## Barriers

**Technical Target**

- 4-6% improved fuel efficiency of truck and bus radial tires

**Technical Barriers**

- Tire Efficiency
- Reduce petroleum consumption and greenhouse gas emissions

## Budget

**Total project funding**

- $1,253,269 (Total), $939,950 (DOE)
- $679,159 (Spent), $526.220 (DOE spent)

**BP3 Funding**

- $451,681 (Total), $338,760 (DOE)

## Partners

**Bridgestone Americas Tire Operations (BATO)**

# Relevance

## Overall objective: develop a novel surface-modified silica technology and demonstrate 4-6% improved fuel efficiency of truck and bus radial (TBR) tires built from the technology

- Maintaining or improving tear strength and treadwear over the state of the art carbon black-filled natural rubber-based TBR tread compound

## Past year goal (BP 2)

- Identify at least one tread compound formula meeting a >40% reduction in tan δ with no more than a 20% reduction in hardness, tear strength, or tread wear as compared to a carbon-black-filled NR compound at the lab scale
- Produce 36 trailer tires for two experimental formulas and a control formula according to specification
- TBR tread compound formula with a >20% decrease in RR and +/-10% hardness, tear strength, and tread wear compared to a CB-filled NR-based control when measured on-tire
- Identify any gaps in performance between laboratory and on-tire testing. Adjust laboratory performance targets as needed to direct BP 3 formula optimization activities

## BP 3

- Optimize the TBR compound performance and select the final rubber compound formulations for the tire builds that will be delivered to DOE for independent testing

# Milestones

| Milestone | Date | Status |
|---|---|---|
| 3.1 Tread Compound Determined | 9/13/2016 | Completed |
| 3.2 Tread Compound Formulas Selected | 9/30/2016 | Completed |
| 4.2.1 Experimental Trailer Tires Produced | 12/02/2016 | Completed |
| 5.1 Performance Gaps Identified | 3/30/2017 | Completed |
| 6.1 Tread Compound Formula Identified | 7/03/2017 | |
| 6.2 Exp. Tread Compound Formula Selected | 10/02/2017 | |
| 7.2.1 Experimental Tires Produced | 10/20/2017 | |
| 8.1 Selection of Tire Technology for Testing | 03/30/2018 | |
| Final Report | 6/30/2018 | |

## Go/No-Go Budget Period 2

✓ Identify one TBR tread compound formula with a >20% decrease in rolling resistance coefficient, and +/- 10% hardness, tear strength, and tread wear compared to a carbon black-filled NR-based control when measured on-tire

# Approach

## In passenger tires silica provides fuel-efficiency gains over CB

## TBR tires predominantly comprised of natural rubber (NR)

- NR provides the chip and tear resistance essential for TBR applications
- NR contaminants (proteins, metal ions, etc.) are believed to interfere with the in situ coupling reaction required to effectively disperse silica in NR, yielding poor filler dispersion, tire performance, and processing

## Silicas traditionally used in passenger tires do not provide the same benefits in TBR compounds

## PPG has shown the ability of surface treated silica to overcome the NR contaminant problem and observed good dispersion in NR and provided RR improvements over carbon black


"Innovating the silica surface for Improved NR truck tire vulcanisates" *Tire Technology International* 2/2014.

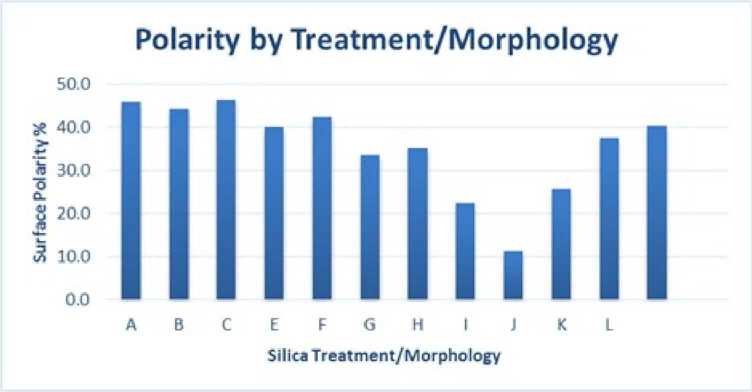
"Functionalized silicas for improved NR truck tire vulcanizates" *Rubber World* (2014) 249(2), 19-24.

"Bringing Innovation to the Surface: Functionalized Silicas for Improved Natural Rubber Truck Tire Vulcanizates," 184th Technical Meeting of the ACS Rubber Division, October 2013, #33.

"Agilon Performance Silicas in Natural Rubber Truck Tire Tread Compounds" 180th Technical Meeting of the ACS Rubber Division, October 2011, #70.

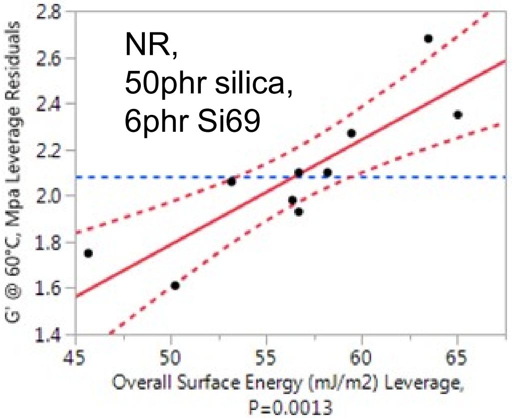
# Strategy & Summary of Past Work

### Identify Silica Chemistries for Improved Wetting

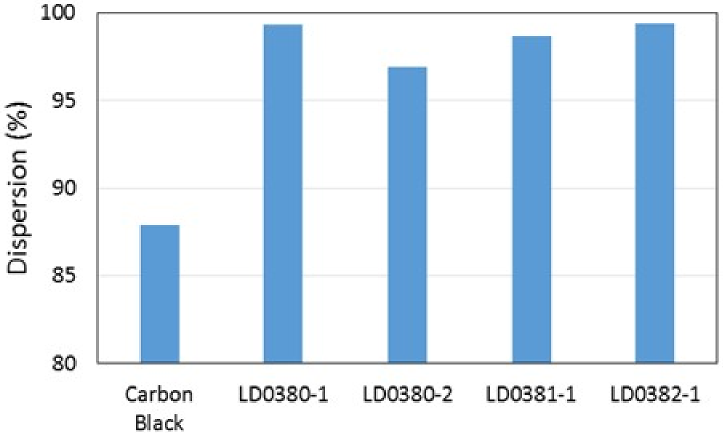


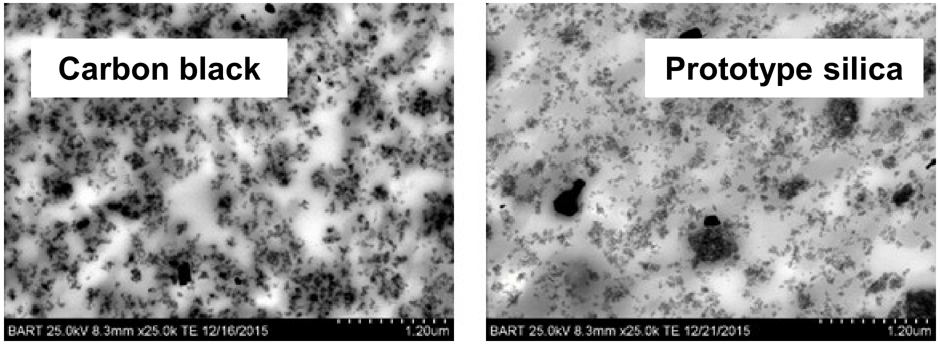

### Reduced Payne Effect by Reducing Surface Energy

Lower G' at low strain, lower filler-filler interaction




### Improved Dispersion over CB in NR and in Polymer Blends



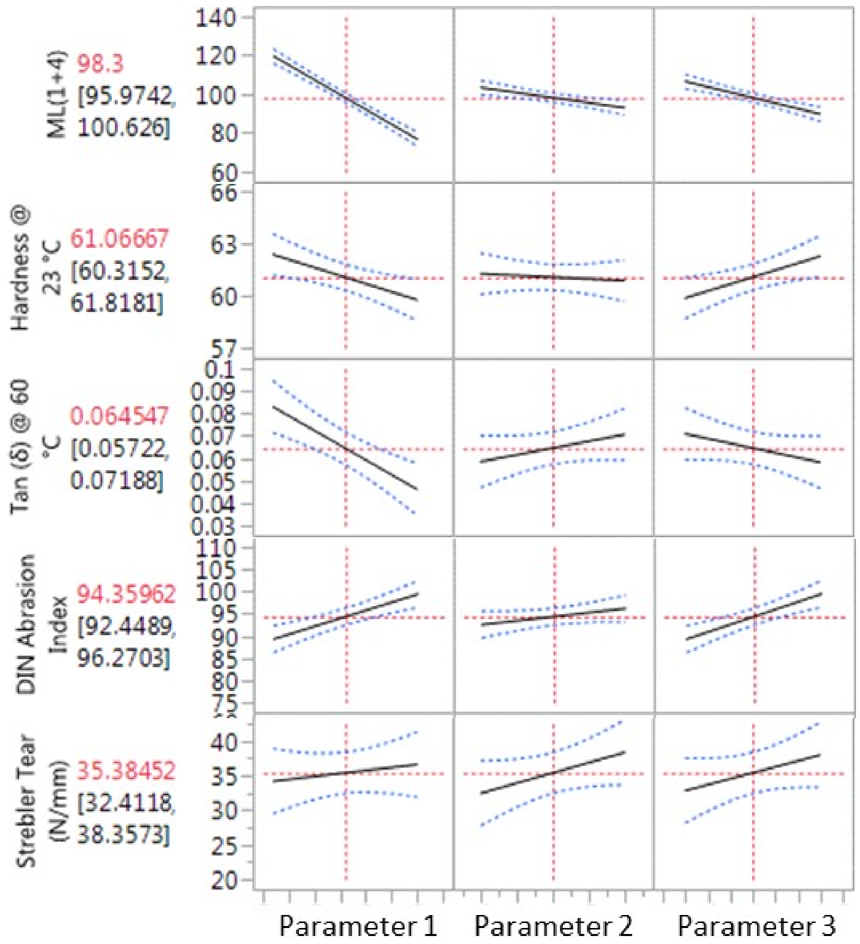

SBR: dark phase; NR: white phase

- Silica prototypes showed reduced Payne effect and improved dispersion
- Best modifiers/morphologies selected to move forward

# Technical Accomplishments and Progress

## Silica Optimization

- Three silica parameters evaluated on Bridgestone TBR tread formulation
- Final values selected based on optimum performance:
  - Similar hardness than CB control
  - Lowest rolling resistance
  - Acceptable processing
  - Tolerable compromise on DIN abrasion and tear strength



# TBR Tread Compound Optimization at Bench Scale

## Performed several compound studies to optimize performance

- Polymers ratio
- Silica loading
- Silica/CB ratio
- Additives addition study
- Tear and abrasion improvement
- Cure studies
- Mixing conditions (drop temp., mixing temp., addition sequence)
- Plant trial

## Main Conclusions:

- Need to maintain 100% NR to maintain tear resistance
- Selected silica and curatives loadings for ideal balance of performance
- Optimum mixing conditions for lab mixer

# Experimental Tire Build

- Produced 2,000lbs of silica (2 prototypes) at PPG Silicas Pilot Plant
- Tire build performed at Warren County’s Bridgestone tire plant
- Minimum changes from CB control formulation

## Simplified formulations

| | Control | Spec 1 | Spec 2 |
|---|---|---|---|
| NR | 100 | 100 | 100 |
| CB | 46 | 15 | 15 |
| Prototype 1 | 0 | 37 | 0 |
| Prototype 2 | 0 | 0 | 37 |

- Similar energy consumption and mixing times for all compounds
- No problems during mixing or tire building
- Tire testing performed at Bridgestone R&D Center in Akron, OH

# Testing

## Tread Compound Data

| | Parameter | CB control | BXR-990 | BXR-991 |
|---|---|---|---|---|
| **Viscosity** | ML1+4 | 100 | 112 | 114 |
| **Scorch** | T50 | 100 | 82 | 82 |
| | T90 | 100 | 96 | 91 |
| **Tensile at 25°C** | Mod300 | 100 | 102 | 90 |
| | Elongation | 100 | 101 | 105 |
| | Tensile | 100 | 102 | 103 |
| **Temp. sweep** | Tan δ @ 0°C | 100 | 84 | 78 |
| | E' @ 30°C | 100 | 104 | 119 |
| | Tan δ @ 60°C | **100** | **53** | **60** |
| **Wear** | Index | **100** | **90** | **93** |
| **Hardness** | Index | **100** | **108** | **109** |
| **Tear at 25°C** | Load | **100** | **95** | **108** |

- Lower tan δ for silica compounds
- Lab wear target encouraging
- Hardness and tear targets achieved

Tires:

Ecopia R197 carcass used

Tire Size: 295/75R22.5


Image courtesy of Bridgestone

| Test | # Tires |
|---|---|
| Rolling Resistance | 3 |
| Indoor Wear | 1 |
| Endurance | 2 |
| Section Analysis / Footprint | 1 |
| High Speed | 1 |
| Service Growth / Wear Energy | 1 |
| Spares | 3 |

# Tire Testing Results

| Test | CB Control | BXR-990 | BXR-991 | 990 Index | 991 Index |
|---|---|---|---|---|---|
| **RRC** | | | | | |
| Average | 4.62 | 3.90 | 3.99 | **84** | **86** |
| St. dev. | 0.052 | 0.031 | 0.037 | - | - |
| **Endurance** | | | | | |
| Mileage | 4219 | 4752 | 4600 | + | + |
| Removal | Tread Area | Tread Area | Tread Area | | |

## Section analysis

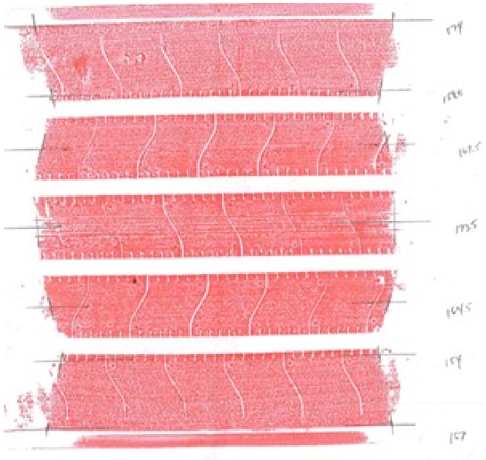
## BP2 Goal

| Test | Target | BXR-990 | BXR-991 |
|---|---|---|---|
| Hardness | ± 10 % | 108 | 109 |
| Tear strength | ± 10 % | 95 | 108 |
| RR | ≤ 80 % | 84 | 86 |
| Lab wear | ± 10 % | 90* | 93* |

* Preliminary abrasion test

- RR close to target
- Indication of better tire endurance
- Wear test not completed at time of slides production

## Footprint



# Responses to Reviewer Comments

## No clear link between lab rolling resistance indicator, tire rolling resistance coefficient and vehicle fuel economy

- We have shown that a 47% reduction in tan $\delta$ at 60°C produced a 16% improvement in rolling resistance
- Two largest tire manufacturers published that this should give a 5% improvement in fuel efficiency in trucks[a,b]

## A trucking fleet could add perspective and the project could benefit from the interaction.

- Bridgestone largest tire manufacturer in the world. They are responsive to market trends and have unmatched testing capabilities.
- Discussions took place with trucking companies and letters of support obtained from several companies including UPS, Oak Harbor Freight Lines, Frozen Food Express and others
- PPG Silicas team continuously attend conferences, participate in forums and discuss with workforces of other TBR-related companies regarding trends in TBR and future needs

[a] The Tyre. Rolling resistance and fuel savings. Michelin 2003. https://community.michelinchallengebibendum.com/docs/DOC-3212
[b] Tires & Truck fuel economy. A new Perspective. Bridgestone. https://commercial.bridgestone.com/en-us/solutions#/?tbr

# Collaboration and Coordination with Other Institutions

## Bridgestone Americas Tire Operations

- Working as advisor for the duration of the program
- Provides truck tire tread compound formulations
- Performed mixing optimization of silica in NR-based compounds
- Performing tire builds at end of BP2 and BP 3
- Performing tires testing including fuel efficiency test at end of BP3

## TARDEC

- Interagency observer
- Advisor for tire demands and tire testing

# Remaining Challenges and Barriers

## Further decrease rolling resistance to match target

- Perform further compound adjustments based on tire performance achieved on BP2
- Redesign silica prototype to adjust to newly developed formulation

## Awaiting final data to confirm achievement of wear target

- Evaluation of wear indicators. Compound adjustment
- Reformulate for improved wear

## Current TBR formulations are optimized for carbon black and further tuning might be needed for silica

- Evaluate additional modifications for the silica formulations

## Tire build and test lessons learned from BP2

- Readjust schedule and perform tire build earlier in the project

# Proposed Future Work

## Within Project

- Silica Materials
  - Re-evaluate if silica modifications are necessary to achieve targets
  - DOE study on silica morphology – filler loading – cure level
  - Goal: Maximize tread wear, rolling resistance and tear strength at same hardness than CB control

- Rubber Compounds
  - Develop optimized compound and mixing parameters.
  - Perform tire build and testing by the end of March 2018
  - Perform fuel efficiency testing

## Beyond Project

- Market development for truck retread market segment
- Expand to other types of tires with similar requirements such as off-road and aircraft tires

Any proposed future work is subject to change based on funding levels

# Summary

## Objective

- Develop a novel surface-modified silica technology and demonstrate 4-6% improved fuel efficiency of TBR tires built from the technology

## BP2 Goals: Improved Tire Compound Performance

- Identify at least one TBR tread compound formula with:
  - ≥ 20% decrease in rolling resistance
  - +/- 10% hardness, tear strength, and tread wear - compared to a CB-filled NR-based control when measured on-tire

## Accomplishments

- Manufactured a TBR tire with 16% better rolling resistance than carbon black control. Achieved other targets.
- Lab abrasion resistance is slightly lower, but within target
- Processing of the tread compound similar to carbon black control

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# Advanced Bus and Truck Radial Materials for Fuel Efficiency

## Technical Backup Slides




# Approach

## Budget Period 1: CONTROLLING DISPERSION:

- Understand how different silica surface chemistries and surface areas are linked to dispersion performance in different rubber phases including both natural and synthetic rubbers
- Selection of silica chemistries and surface areas that deliver the most consistent dispersions in various rubbers

## Budget Period 2: DEVELOP NEW TREAD COMPOUND:

- Use the design principles identified in BP 1 to reduce the rolling resistance of a TBR compound by at least 60% compared to carbon black with no decrease in hardness and equal or better tear strength and tread wear
- Select no more than two combinations of silica and rubber formulations to make an experimental tire build and conduct on-tire testing to identify any performance gaps

## Budget Period 3: OPTIMIZING FORMULA FOR ON-TIRE PERFORMANCE:

- Optimize the TBR compound performance and select the final rubber compound formulations for the tire builds that will be delivered to DOE for independent testing

# Budget Period 2

## Task 3 - Developing an Improved TBR Compound at Bench Scale

- Develop TBR tread compounds containing up to three of the silicas and polymer blends to deliver a >40% reduction in rolling resistance as measured by tan $\delta$ at 60°C compared to an all carbon black-filled natural rubber-based compound
- Hardness, tear strength, and tread wear will be evaluated at bench scale

## Task 4 - Experimental Tire Build

- Generate on-tire data to identify performance gaps
- Subtask 4.1: Produce Novel Silica at Pilot Scale
  - Produce approximately 500 lbs. each of up to three silica compositions
- Subtask 4.2: Produce Novel Tread Compounds and Tires
  - The silicas will be compounded in up to two TBR tread formulations
  - Up to two novel formulations and one control formulation will be used to tread approximately 30 test tires

## Task 5: On-Tire Testing

- Generate on-tire data to identify any performance gaps

# Budget Period 3

## Task 6: Optimize TBR Compound at Bench Scale

- Close the gaps in rolling resistance, hardness, tear strength, or tread wear through further formulation and silica modifications as needed

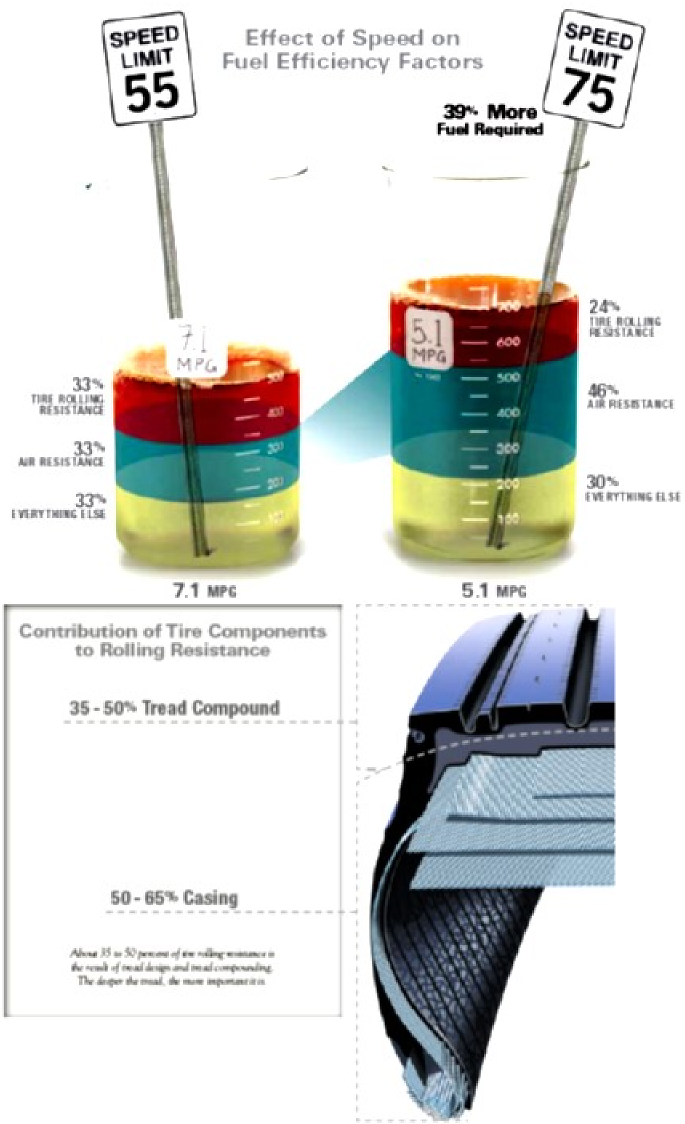
## Task 7: Final Experimental Tire Build

- Confirm the improvements and supply baseline and experimental tires to the DOE for independent testing
- Subtask 7.1: Produce Novel Silica at Pilot Scale
  - Produce the volumes needed to support tire builds and on-tire testing
- Subtask 7.2: Produce Novel Tread Compounds and Tires
  - Up to two novel formulations and one control formulation will be used to tread approximately 30 test tires

## Task 8: On-Tire Testing

- The objective of this task is to generate on-tire data to confirm performance against project goals

# Fuel efficiency




- Tire rolling resistance contributes to 24-33% of the total fuel consumption
- 20% reduction in RR would reduce fuel consumption 4.8-6.6%
- Other factors: underinflated tires, worn tires, and tire pattern

- 35-50% of the total tire RR comes from the tread energy loss
- To reduce tire energy loss as rolling resistance by 20%, tread hysteresis needs to be reduced by 40-60%

$$\tan\delta = \frac{G''}{G'} = \frac{loss\ energy}{stored\ energy}$$

Tires & Truck fuel economy. A new Perspective. Bridgestone. https://commercial.bridgestone.com/en-us/solutions#/?tbr