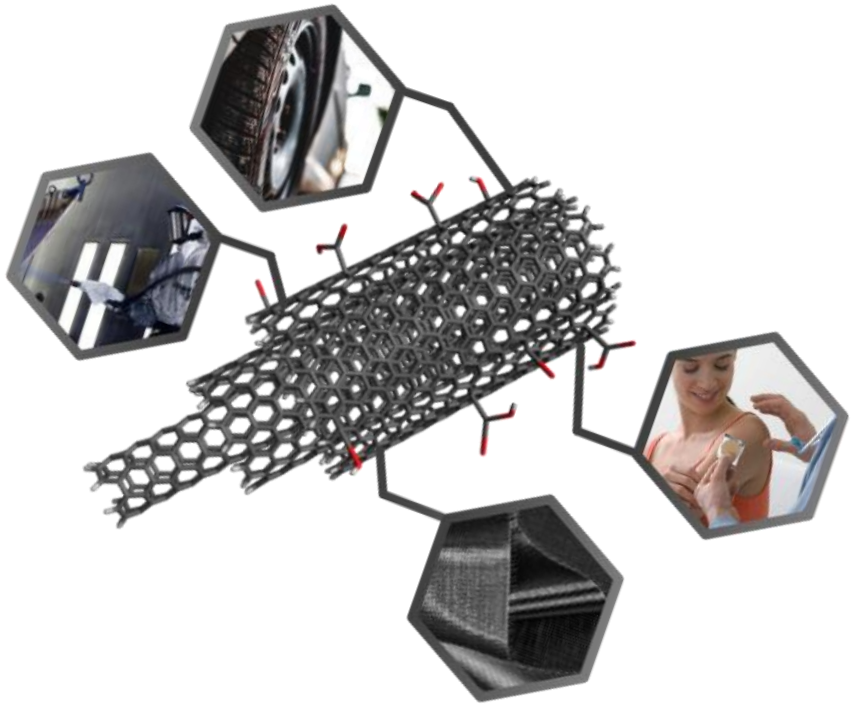
Introduction to MOLECULAR REBAR®

Nanotechnology for longer-life, sustainable rubber goods



MOLECULAR REBAR® DESIGN

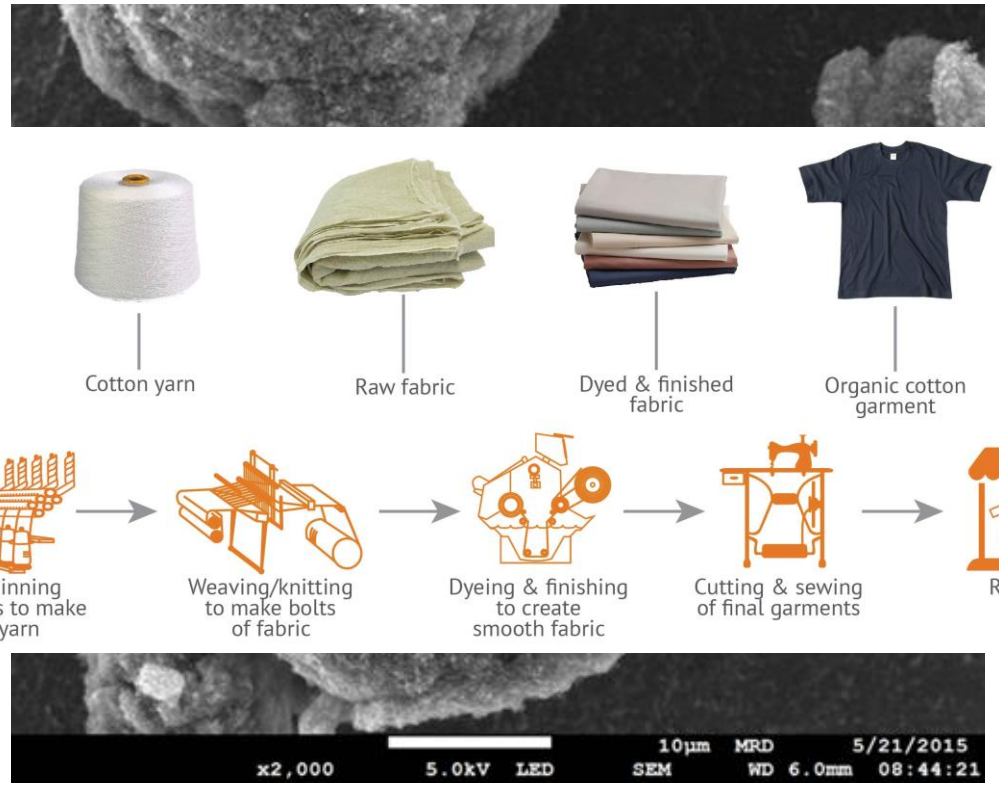
Transforming Businesses with Nanotechnology

Molecular Rebar Design Company Profile

- Established in 2009, to develop and commercialize a breakthrough form of discrete, surface modified multiwall carbon nanotubes (MWCNT's), called MOLECULAR REBAR® (MR)
- R&D and Manufacturing based in Austin, TX including 100 tonne capacity, ISO 9001:2015 certified plant
- 77 Granted/Allowed Patents
- Fast-growth thru commercial partnerships for targeted markets for MOLECULAR REBAR®
  - **Black Diamond Structures**: JV with SABIC. Energy storage, commercial globally in LIB and Pb Acid batteries
  - **Biopact Ventures**: Targeted biomolecule delivery into cells
  - **MECHnano**: Additive manufacturing (3D printing)

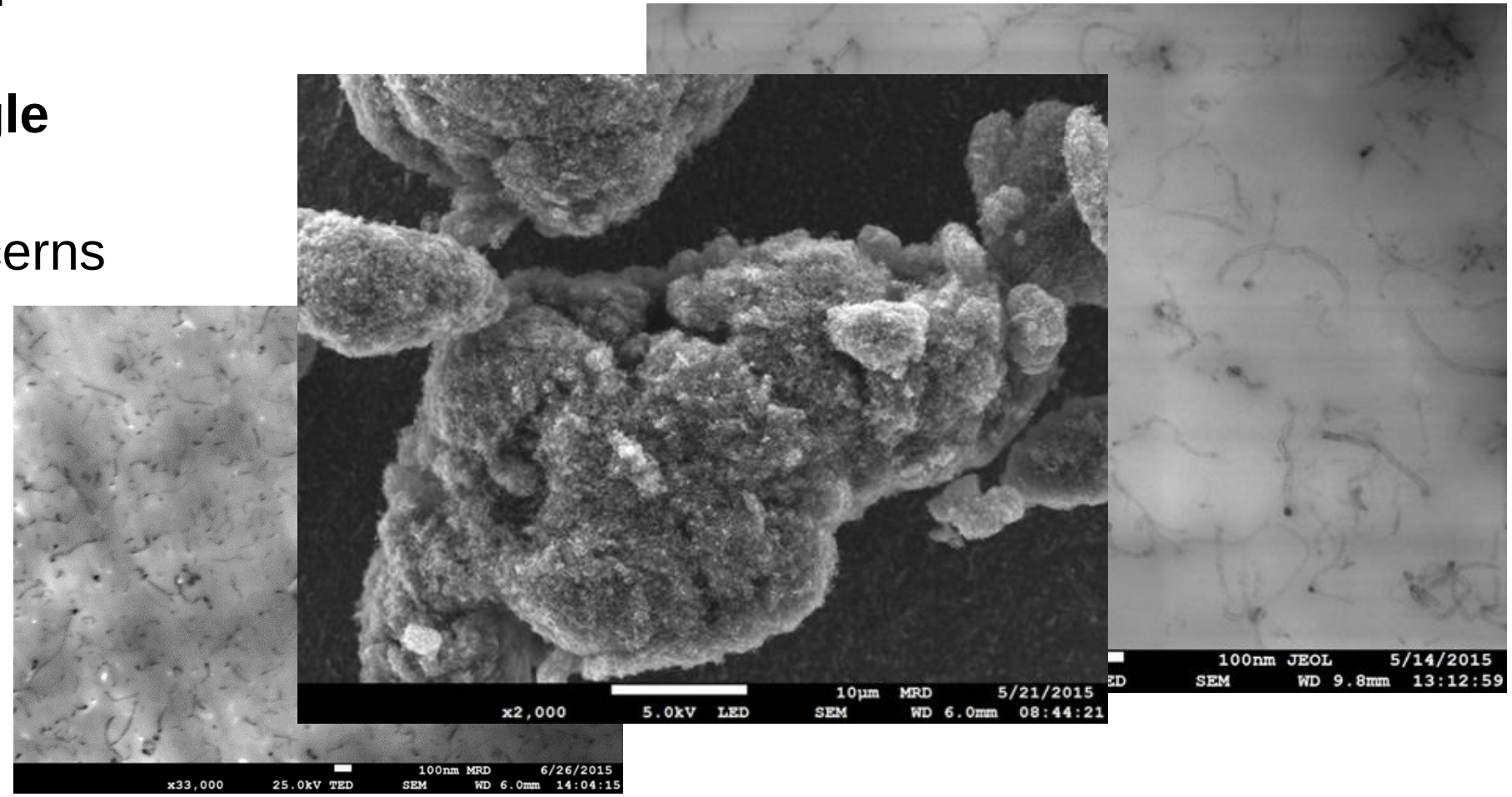
“Deceptive” Phase of Adoption

- CNTs measured in lab are not CNTs used or produced commercially
- Commercial tubes are…
  - Dirty
  - Bundled/Tangled
  - Imperfect
- Also…
  - Expensive
  - Possibly toxic
- **In short… Useless!**

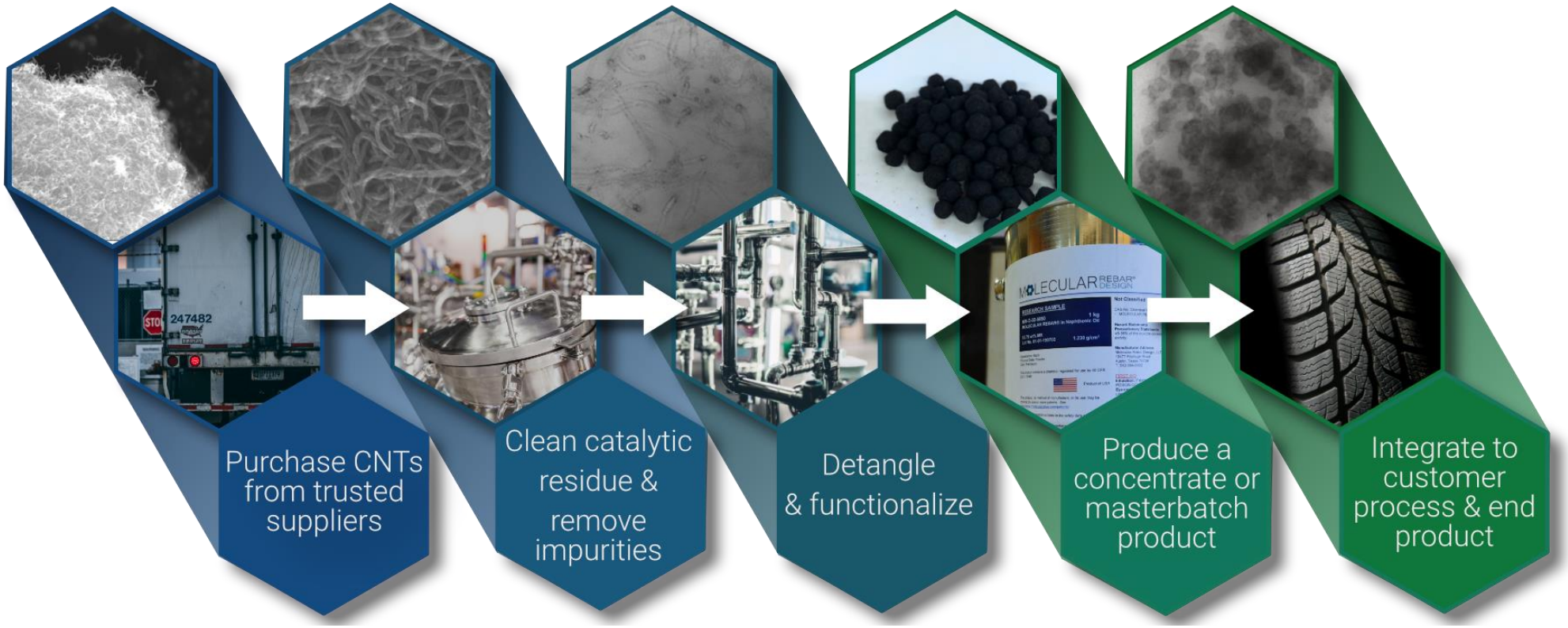


How to become disruptive

- Make commercially produced CNTs useful
  - Clean
  - **Separate or detangle**
  - Scale
  - Resolve EH&S concerns



MRO Technology Advantage



- MR is dispersible in a range of elastomeric systems unlike standard CNTs, leading to effective reinforcement of the part

MRO Gen II Product- Qualities & Dispersion

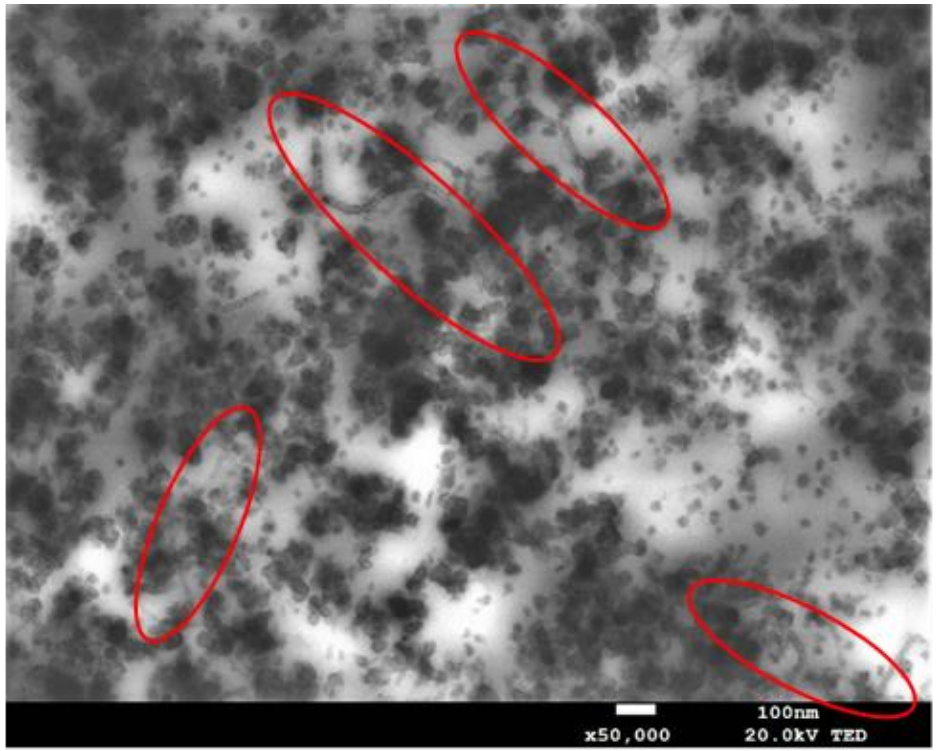
- 50wt% MWCNTs & 50wt% naphthenic oil
- Tailored oxidation level to promote adhesion/physisorption to less polar elastomers
- High dispersion quality resulting in aspect ratio of ~65
- Oil content prevents dusting; less EH&S concerns
- Capital-free drop-in ingredient
  - No change to mixing process
  - No extra mixing equipment
- Product can be in a powder or pelletized form
  - Same property improvements w/ either

Typical Property Improvements

- **30%+** cut & chip resistance
- **15%+** tear resistance
- **10%+** abrasion resistance
- No change in tan delta °C/rolling resistance

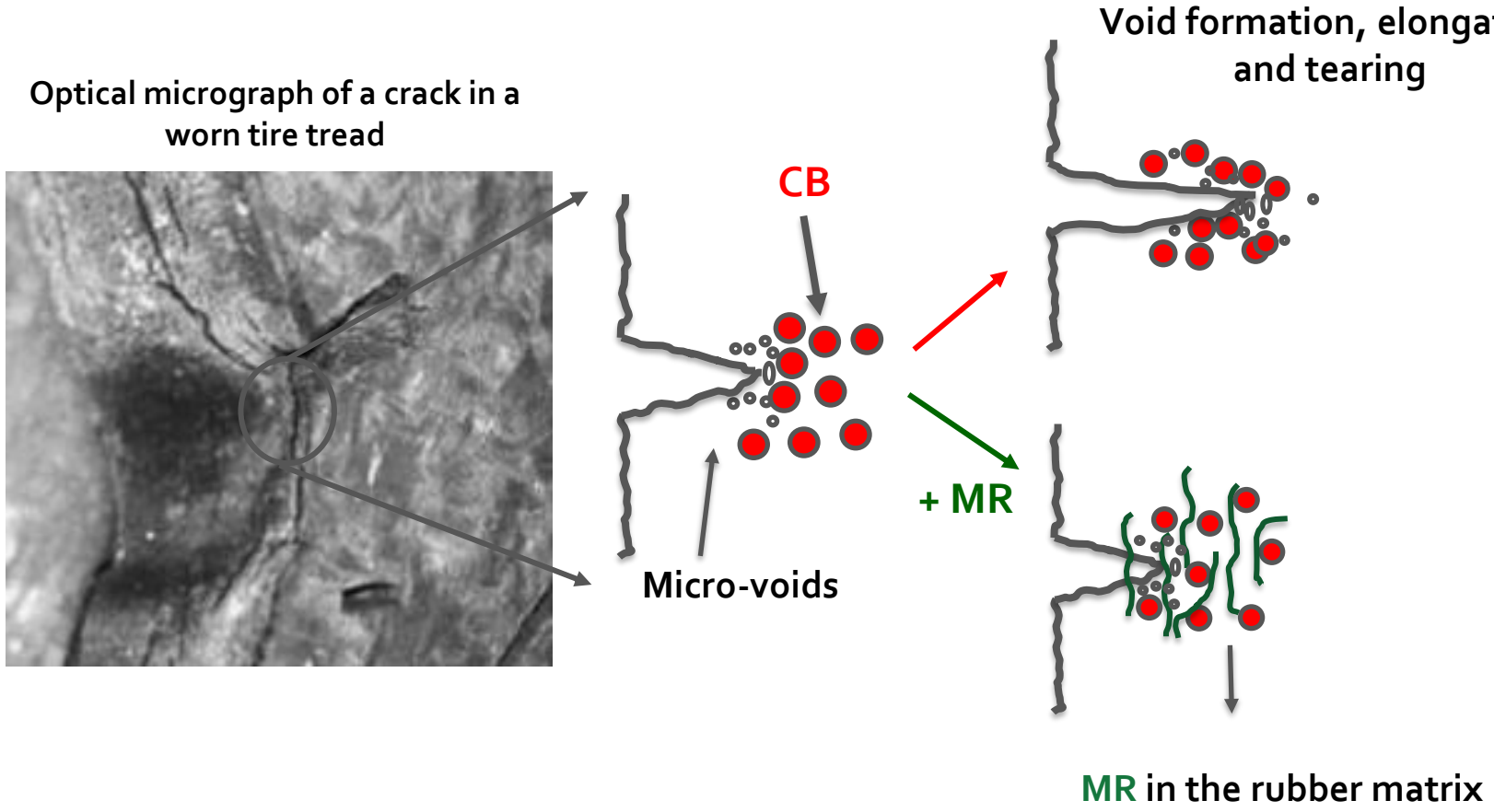
Product Characteristics

	Typical Value	Method
Density	1.208 g/cm^3	Compositional Calculations
Appearance	Crumb/Pellets	Visual Inspection
Color	Black	Visual Inspection
MR %	50%	Thermogravimetric Analysis
Oil %	50%	Thermogravimetric Analysis



TEM image of dispersed MR in a formulated tire tread compound.

Superior Properties via Crack Bridging with MR

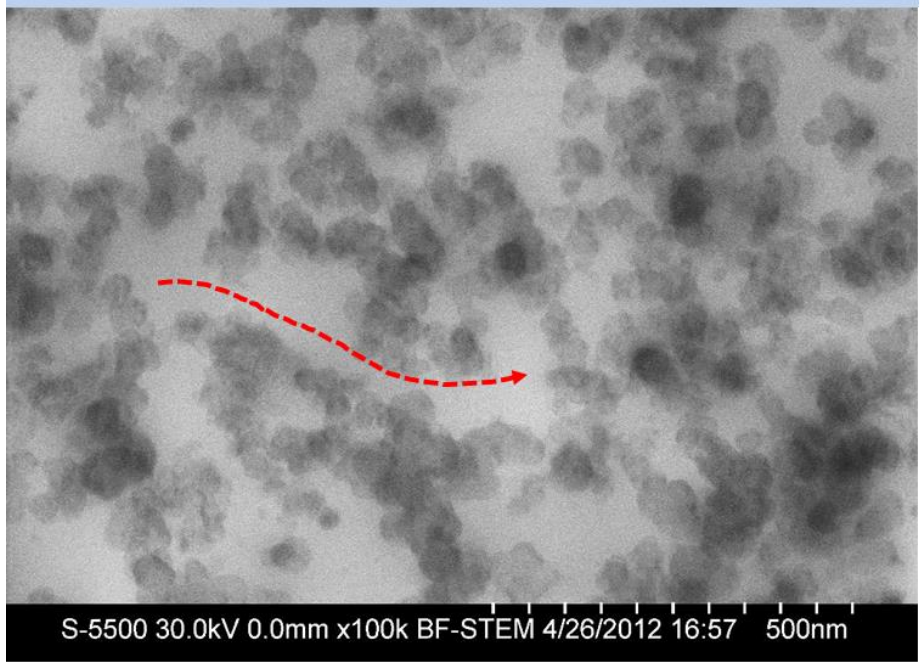


- MR provides an effective Crack Bridging Mechanism
- Better toughness and tear strength in field applications

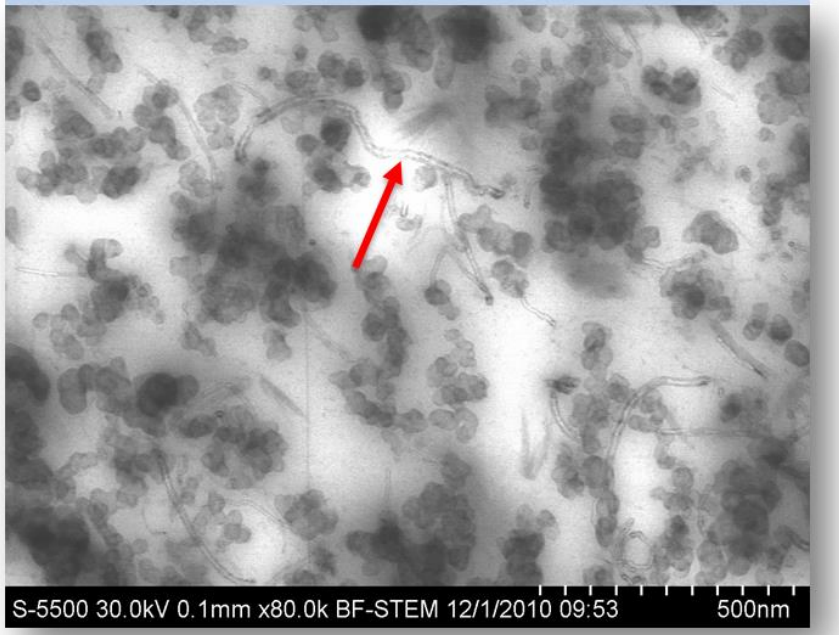
MRO Toughness Mechanism

In filled systems, the weakest phase are the unfilled spaces, "white spaces".

Crack propagation can occur in unreinforced 'White Spaces'



MR in the 'White Spaces'

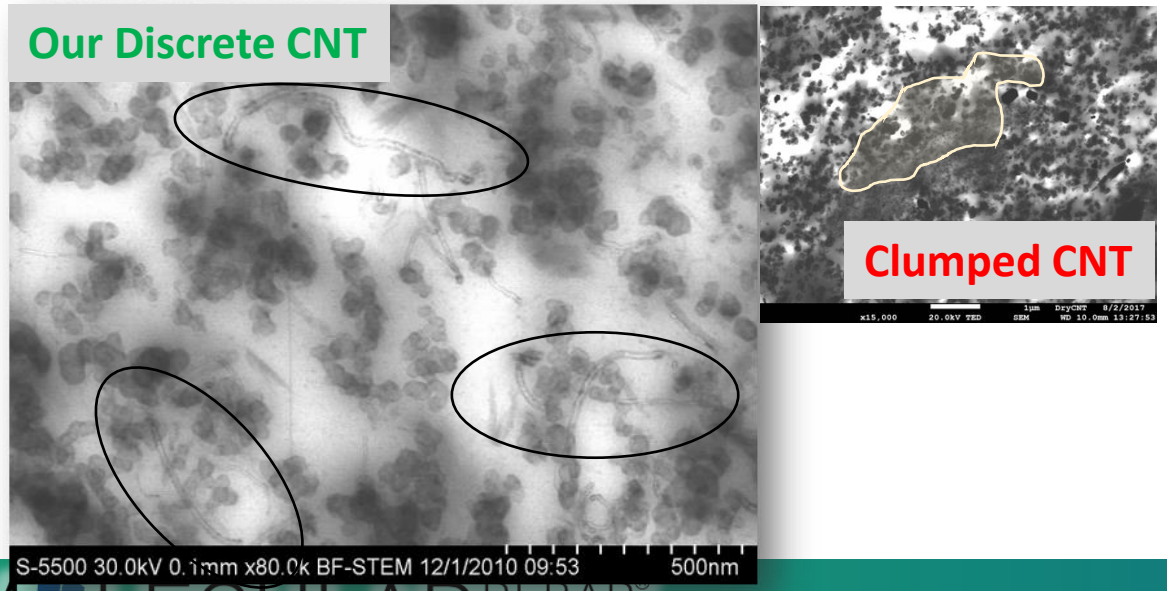


MR strengthens the white spaces and act as "molecular rebar" to prevent crack propagation.

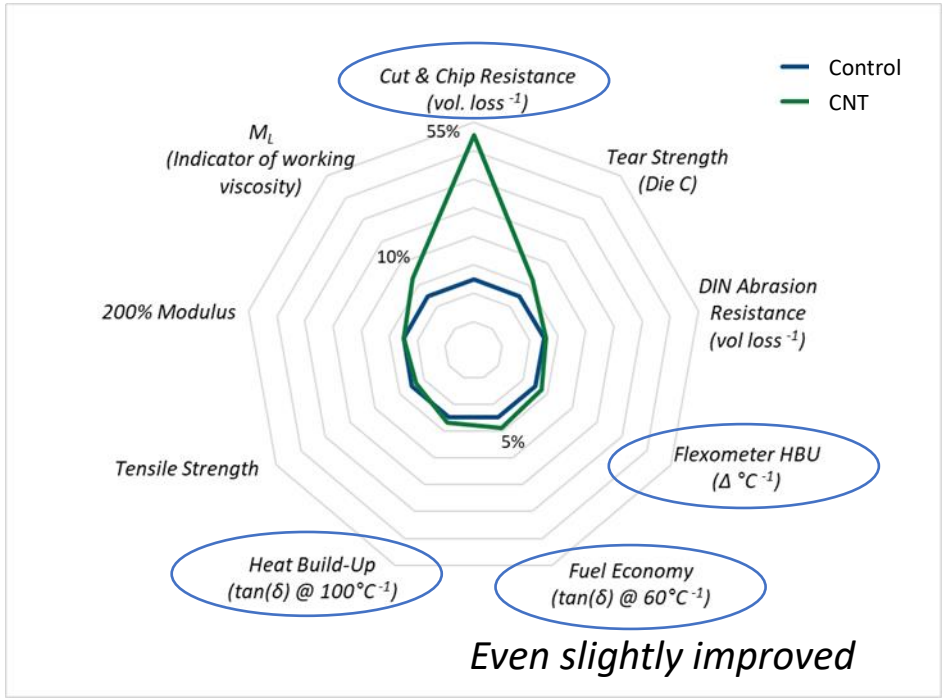
MRO Gen II Product - Performance in Tires

New CNT product that <u>works</u> – our MR in Oil

- Dispersible – no clumps or entanglements
- Capital-free drop-in to customer process
- Few EH&S concerns – oil prevents dusting
- Gives 30%+ cut, chip, & chunk resistance
  - No tradeoffs on RR and Heat Build-Up
- Produced with propriety process
  - Cost effective: +10% cost on tire for +30% life



OTR Tire: 55% Wear Improvement, No tradeoffs



- Drop-in nanotechnology for a commodity market
- Issue with cost effectiveness is scale – solved.
- Issue with dispersion – solved.
- Issue with formulation – solved.
- **Result: longer-lasting parts & tires for a better future**
  - **Less waste, better efficiency, more profits, less downtin**

Partner to Optimize

- 'Instructions for Use' document helps design a set of experiments at various MRO loading levels. Probably ~5 samples with CNTs.
- Loading of MR & reduction of carbon black depends on overall filler level & compound.

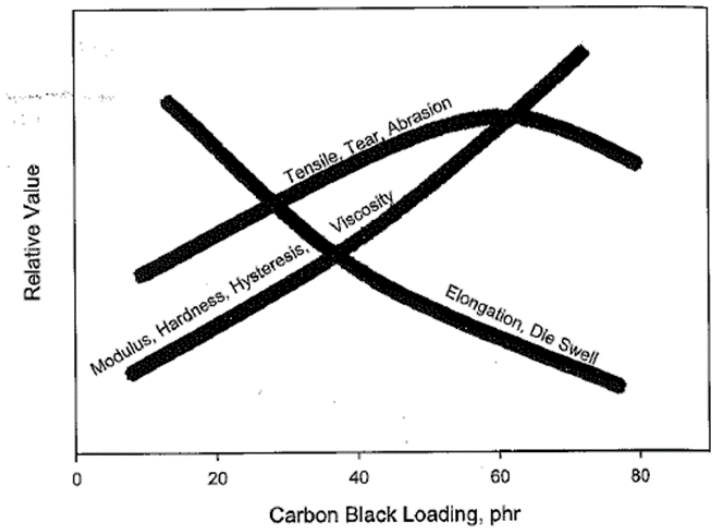


Figure 6 Generalized relationships between carbon black loading and selected rubber properties.

	Add 1 phr MR	Add 2 phr MR	Add 3 phr MR
Carbon Black Grade	**Carbon Black Reduction**		
N220	-2 phr CB	-4 phr CB	-7 phr CB
N234	-2 phr CB	-4 phr CB	-8 phr CB
N330	-2 phr CB	-5 phr CB	-8 phr CB
N550	-2 phr CB	-5 phr CB	-8 phr CB
N774	-3 phr CB	-5 phr CB	-8 phr CB
N990	-3 phr CB	-5 phr CB	-8 phr CB

Market adoption strategy validated; 1 successful field trial, more underway

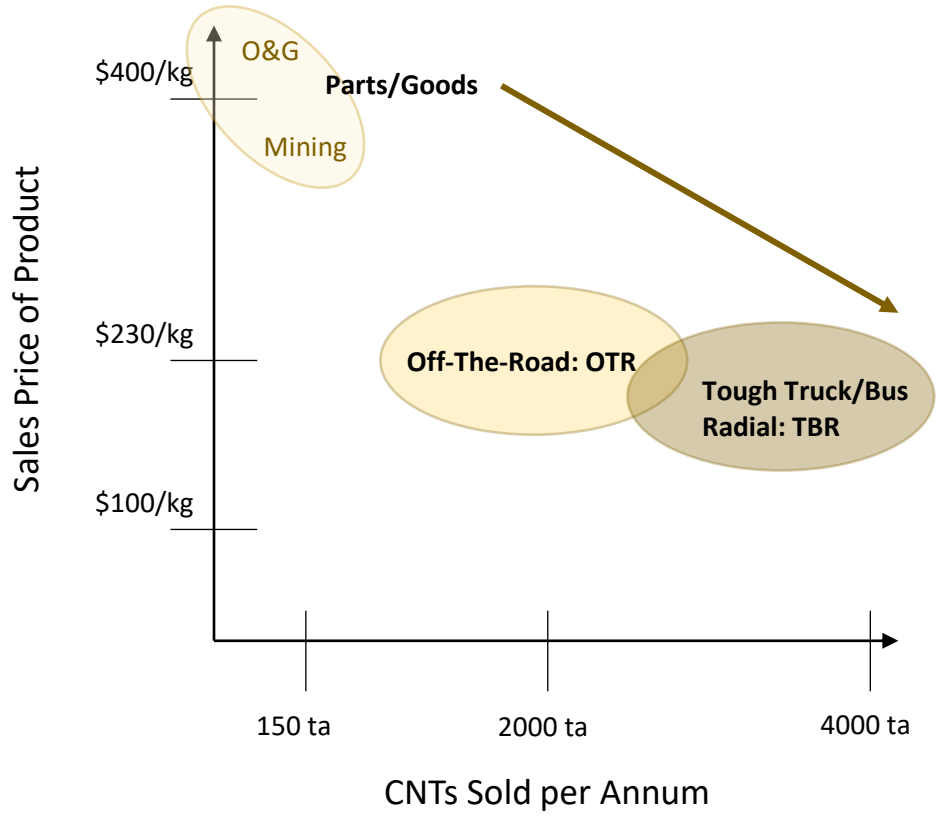
Overall

- Direct sales
- Focus on macro-abrasive environments with high costs of down-time -> mining parts, transport truck tires, etc.
- Typical failure is cut, chip, & chunking of tread compound

Multiphase approach

1. Target small-volume specialty parts/goods
   - Higher margins, less scale, $$ downtime
2. Target small-medium players in large markets
   - Quicker to trial & adopt
   - Use to garner attention of Big Tire, keep them informed

- Even a few customers leads to a profitable business
  - Multi-ton purchases can be $MMs
  - Even 'small' quantities for field trials are $10k+ orders



Segment	Customers- Discussion	Customers- Lab Trials	Customers- Field Trials
Parts/Goods	13	5	3
OTR Tire	15	5	1
Tough TBR	6	4	0
Big Tire	9: 4 out of top 5	6: 4 out of top 5	0 (3-4 years out)

Oil & gas – likely 1st recurring sale, revenue while capturing other markets

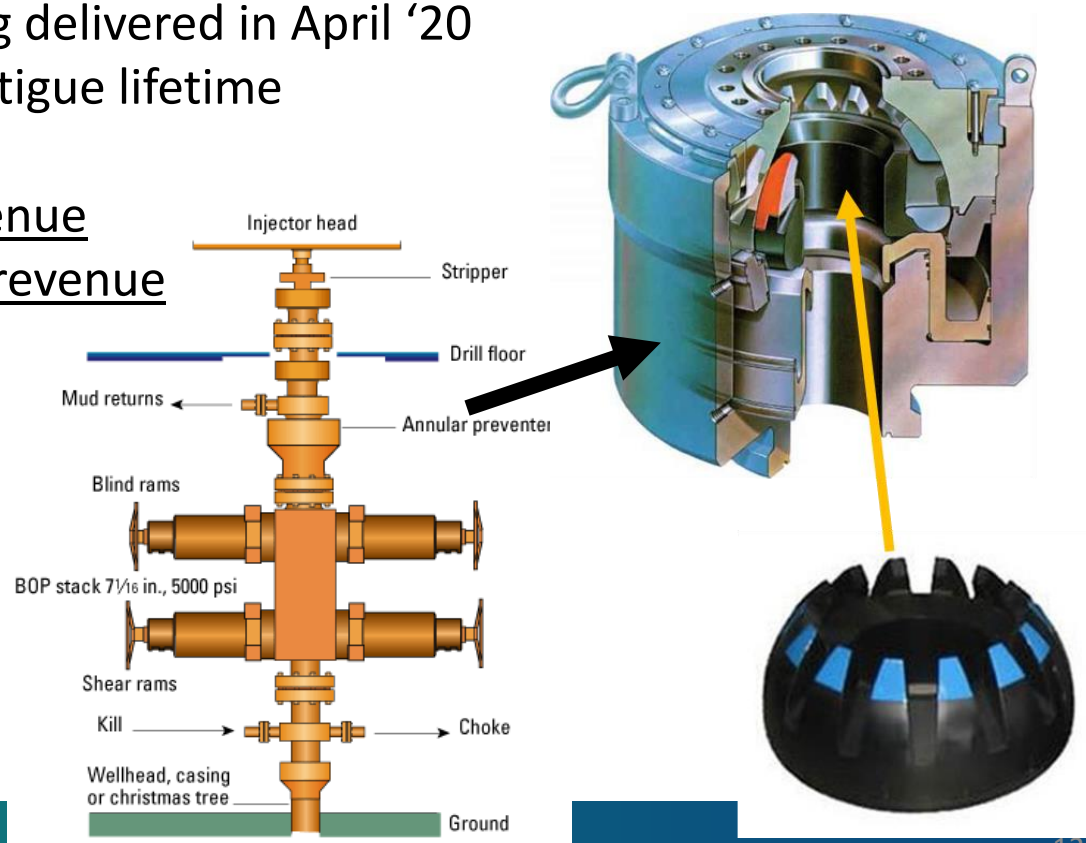
- First successful field trial complete
- Not majority of sales, but strong revenue while building traction in other markets

- Customer produces blowout preventers (BOPs) and the rubber packing elements
- Have purchased 2 field trial quantity orders (85 lbs ea.), with another planned in Q1 ‘20
- Customer sees “huge improvements” on a new part being delivered in April ‘20
- Solving issues with manufacturing reject rate & cyclical fatigue lifetime

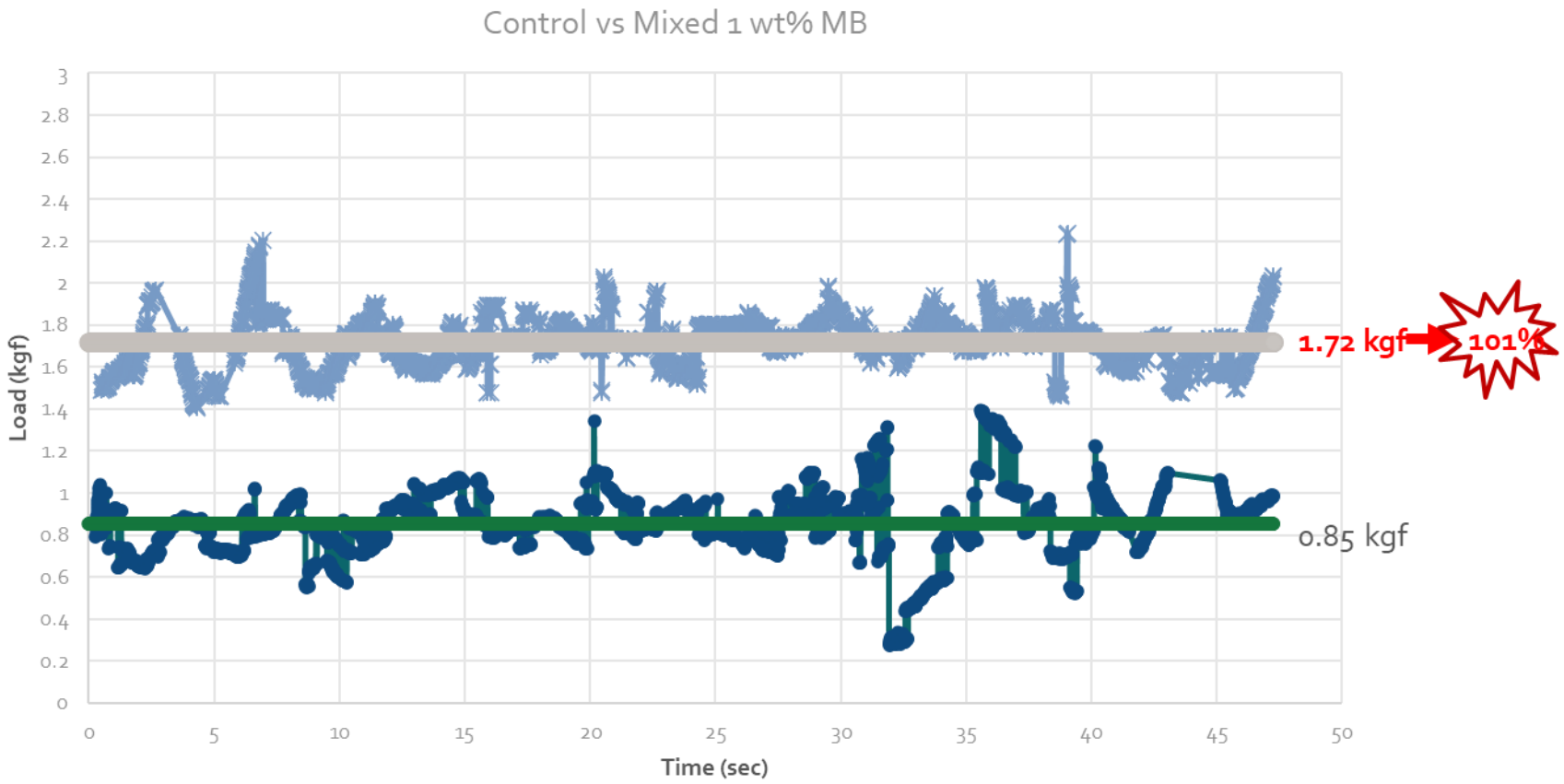
- Expect >0.5 t in 2020 sales on 1 product line = $200K revenue
- 1% of the packing element market is 7.65 ta CNTs = $3M revenue
  - This customer has ~10% market share

- Targeting other customers in this space
  - Quick validation times (4 mo.)
  - Hope to rapidly achieve ~10% total market

- **Great play to achieve short-term cash neutrality**
  - **High margin, small scale**



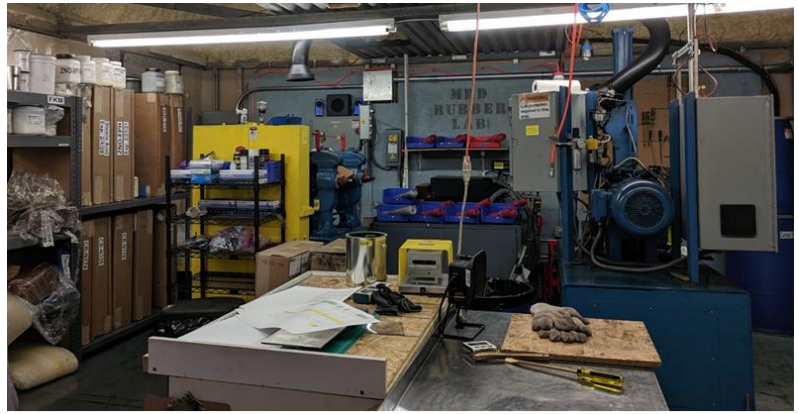
1 wt% MR increases adhesion up to 100%



MR in SBR MB- created thru WC MB process.

Laboratory Capabilities- Partnering to Optimize

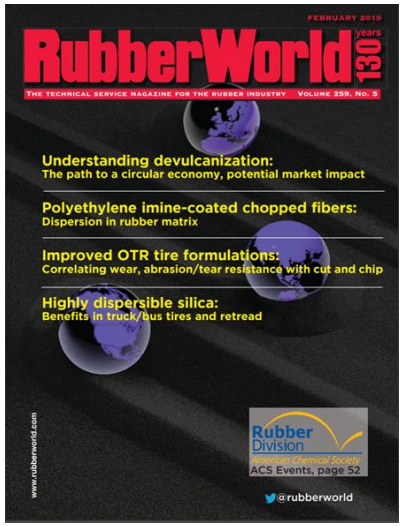
- R&D Facilities
  - Analytical equipment
  - DMA, DSC, TGA, Tensile Testing
  - Cut & chip, Taber abrader



- TS&D Facilities
  - Rubber lab
  - 1.6L Banbury
  - 18” roll mill
  - ODR & curing press

Data Packages

- RubberWorld 2019



- RubberWorld 2020

- Other technical papers/presentations:
  - Polymer(1), Polymer(2), ACS(1), ACS(2), ACS(3)