Drive one.

New Soy-lutions for Sustainability in Automotive Applications

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U-Mass Amherst, IGERT Lecture Series
February 26, 2009

Roadmap

- **Why biomaterials?**
- **Historical perspective**
- Soy foam research and development
- Soy foam implementation
- Soy meal applications
- Looking ahead

Photo by Scott Bauer, courtesy of USDA

Ford N.A. Plastics Research

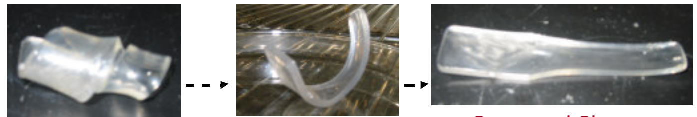
Objective: Develop novel materials and processing techniques supporting lightweight, sustainable, high performance automotive plastics

Novel Materials

Exfoliated PP/clay nanocomposite

Develop materials that are lighter in weight, cost effective, greater performance, and provide a competitive advantage

•Nanocomposites
•Shape Memory Polymer



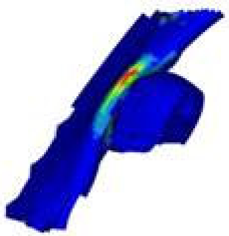
Deformed Shape

Recovered Shape

High Strain Rate Performance

Optimize materials selection and materials-based design for impact applications

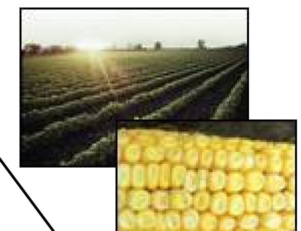
•Flex
•Tensile
•Impact



Biomaterials

Develop materials from renewable crops that can replace petroleum-based plastics and will also reduce weight and cost

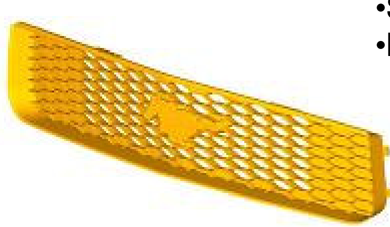
•Soy Based Polyurethane Foams
•Natural Fiber Composites
•PLA

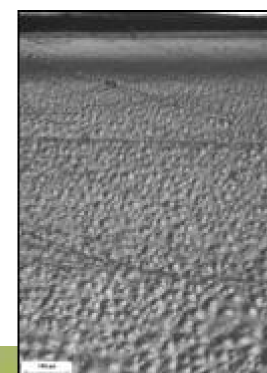


Polymer Processing Optimization

Optimize polymer processing through the use of effective models and novel processing methods. Understand the relationships between processing, microstructure, and performance.

•Virtual Plastics Processing
•Aluminum Tooling for Injection Molding
•Super Critical Fluid Processing
•Mucell





Why Biomaterials? Why Now?

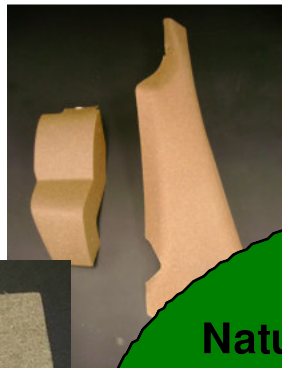
- Increased use of renewable feedstocks and agricultural products
- Reduce dependence on foreign petroleum ($150 barrel ?)
- Reduce the negative effects on human health and the environment
  - respiratory illnesses
  - carbon sequestration
- Improved performance in select functions
- Increased consumer awareness

Ford's Commitment

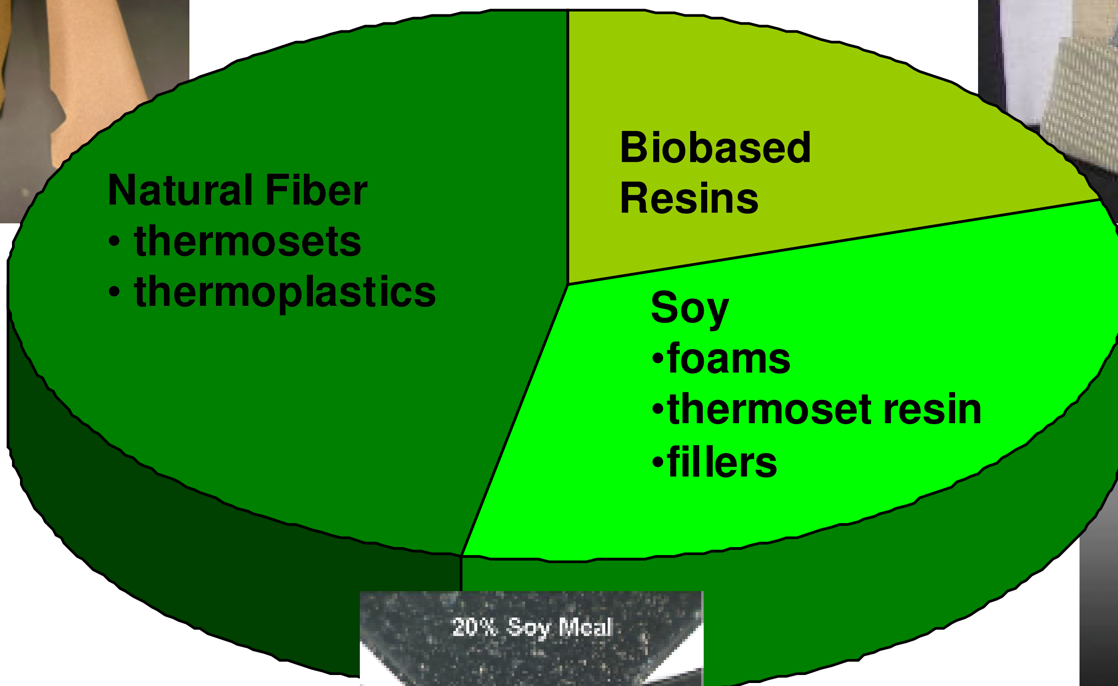
"Ford is committed to offering customers affordable, ***environmentally friendly technologies*** *in vehicles they really want. We are focused on providing solutions that can be used not for hundreds or thousands of cars, but for millions of cars because that is how Ford can truly make a difference."*

-Alan Mulally
President & CEO
Ford Motor Company

Ford Biomaterials Overview



PLA (fabric, resin, carpet)



hemp
switch grass
flax

soybeans

Soybeans have been part of Ford Motor Company's history…

Henry Ford testing the impact strength of a soy flour composite decklid, 1940.

- Henry Ford's "cars growing from the ground" project

- Investigated crops for fuels, plastics and textiles

Henry Ford's Interest in Soybeans

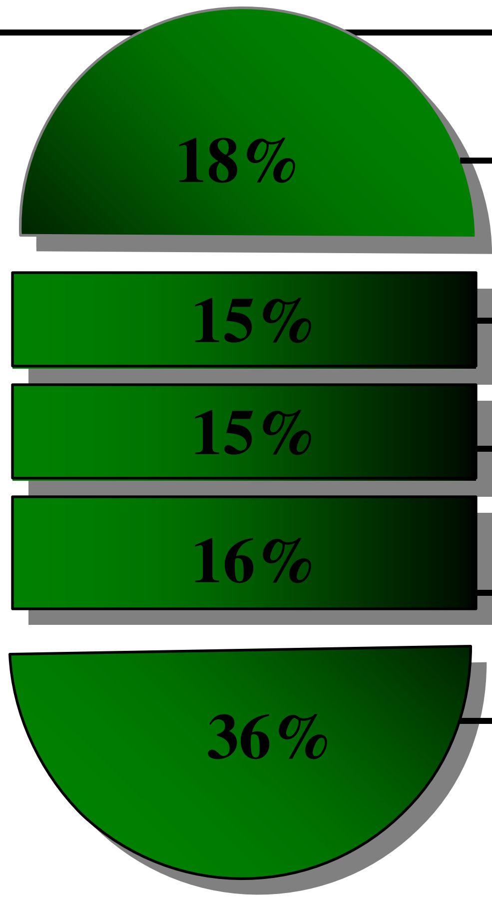
- Henry Ford spent $1.25 Million from 1932-1933 to research soy crops
- 7,400 acres of Ford soybeans farms in Southeastern Michigan
- Ford established soy processing plant at the Rouge

Current Interest in Bio-materials

- Reduced environmental footprint
- Increased use of renewable feedstocks and agricultural products
- Reduce dependence on foreign petroleum
- Competitive pricing of soy products versus petroleum products
- Marketing differentiation

Soybean Statistics

(Source: USDA from 2006 soybean crop)



- Oil
- Soluble Carbohydrates (sucrose, raffinose, etc.)
- Insoluble Carbohydrates (dietary fiber)
- Other
- Protein

U.S. Soy Oil production

20.2 billion lbs.

28.5¢ lb.

U.S. Soy meal production

84.8 billion lbs.

8 – 10 ¢ lb.

Increase in bio-diesel demand has resulted in excess in soy meal availability.

* Reference www.soystats.com

Using Soybeans in Plastics

SOYBEANS

- **Soy Resin**
  - Sheet Molding Compound
- **Soy Polyol**
  - Polyurethane Foam
- **Soy Meal**
  - Reinforced Rubber

Roadmap

- Why biomaterials?
- Historical perspective
- **Soy foam research and development**
- Soy foam implementation
- Soy meal applications
- Looking ahead

Photo by Scott Bauer, courtesy of USDA

Soy-Based Foam Technology

- Can we use oil from soybeans to make seats?
- Technology Overview: Use of soy polyol in formulating flexible polyurethane foam for seating applications.

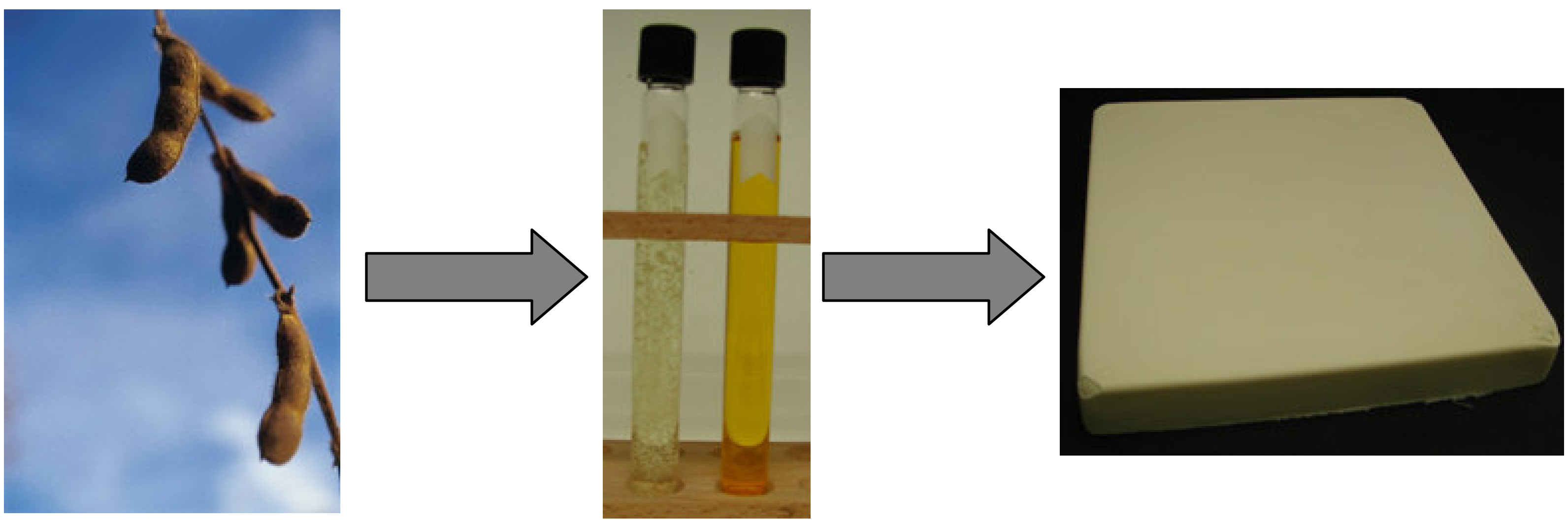


Photo by Lynn Betts, USDA Natural Resources Conservation Service.

Soy-Based Foam Benefits

- Reduction of environmental footprint (CO_2 improvement)
  - For 1kg polyol produced: soy removes 2kg CO_2, petro increases 3.5kg CO_2
- Use of renewable resource (soy) to decrease U.S. dependency on petroleum
- Competitive pricing of soy products versus petroleum products
- Ability to migrate technology across all vehicle lines
- Marketing differentiation of products

Life Cycle Analysis: Soy vs. Petroleum

Source: "Soy vs. Petro Polyols: A Life Cycle Comparison"

James Pollack, USB TAP Meeting April 2006

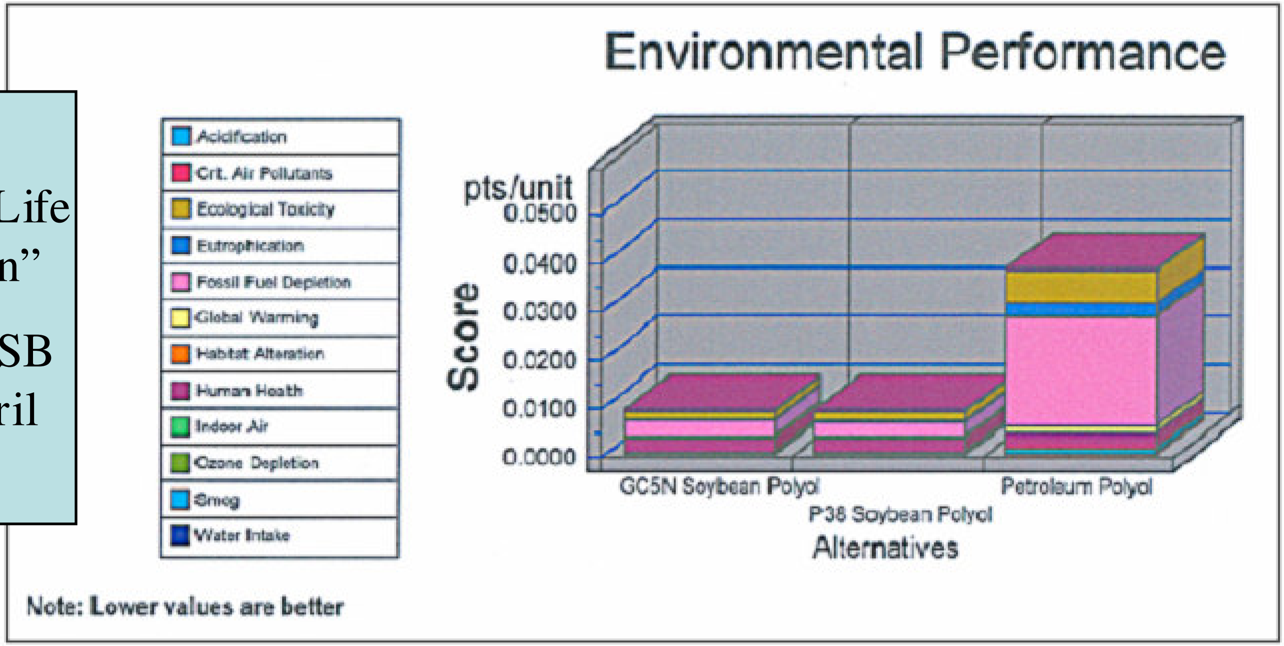
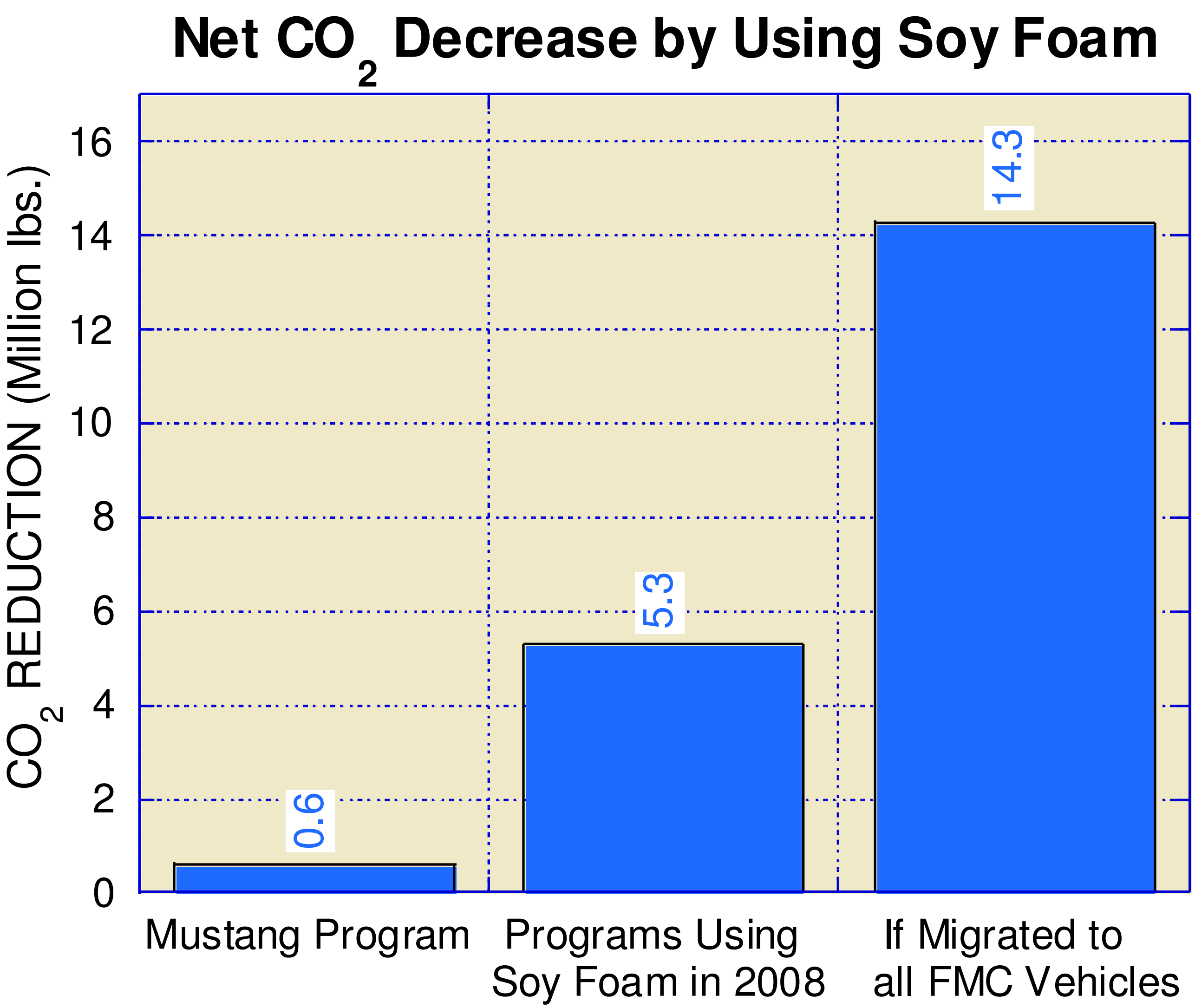


Figure 3

The difference in global warming potential is due to the CO^2 being taken up (sequestered) during the soybean agriculture phase. Excerpts from the soy and petro polyol LCI spreadsheets (Figure 4) show over 2 kg of CO^2 being taken out of the atmosphere per kg of soy polyol produced. In contrast, the LCI shows over 3.5 kg of CO^2 added to the atmosphere per kg of petro polyol produced.

Soy-Based PU Foam: Environmental Benefit



- Chart shows seat back and cushion applications only; potential for greater impact with all foam applications
- Reduction of carbon dioxide emissions (life cycle analysis)
- Use of sustainable, agricultural materials

What are Soy Polyols?

- Functionalized soybean oil used in reaction with isocyanate to form urethane linkage

- Soybean oil is a triglyceride with fatty acid distribution including:
  - 23.4% Oleic Acid (18 C: 1 double bond)
  - 53.2% Linoleic Acid (18 C: 2 double bonds)

- Various methods have been used to functionalize soy oil:
  - Blown with air and heat and/or catalyst
  - Ozonolysis
  - Epoxidation
  - Hydroformylation

Potential Applications

- Soft, Flexible PU Foam
  - Seating Foam
    - Seat Back
    - Seat Cushion
    - Head Rest
  - Instrument Panel Foam
  - Headliner Foam
  - Arm Rest Foam
- Rigid PU Foam
  - Package Tray

Potential Agricultural Usage

×

→ ~90 Million lbs. foam

2.9 Million Vehicles

~30 lbs. foam/ vehicle

→

54 Million lbs. polyol

→

Assume: 20% soy polyol in blend

Photo courtesy of USDA

11 Million lbs. soy polyol

Soy Polyurethane Chemistry

Polyols (Soy, Petroleum)

Blowing Agent

Surfactants

Chain Extenders

Catalysts

Soy Polyol Blend

OH-R-OH

Replacing up to 40% of Petroleum Polyol with Soy Polyol

SOY / PETRO	PETRO standard foam

\+

diisocyanate

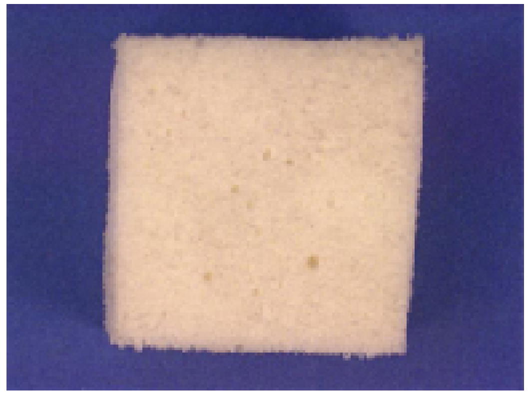
OCN-R′ -NCO

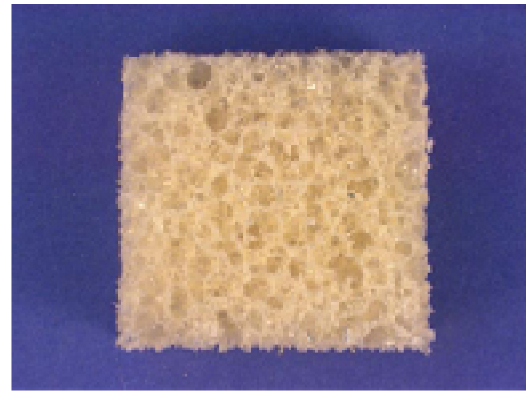
Soy-Based Polyurethane Foam

$$\left[\,\underset{\displaystyle \mathrm{O}}{\overset{}{\underset{\|}{\mathrm{C}}}}\mathrm{-}\underset{\displaystyle \mathrm{H}}{\underset{|}{\mathrm{N}}}\mathrm{-R'-}\underset{\displaystyle \mathrm{H}}{\underset{|}{\mathrm{N}}}\mathrm{-}\underset{\displaystyle \mathrm{O}}{\underset{\|}{\mathrm{C}}}\mathrm{-O-R-O}\,\right]_n$$

Microstructure of Soy Foams Prior to Formulation Optimization

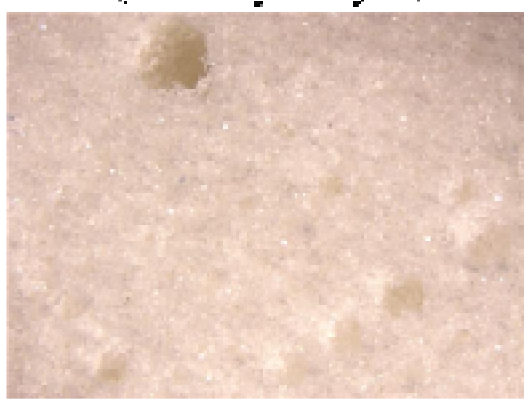
YIKES !!!

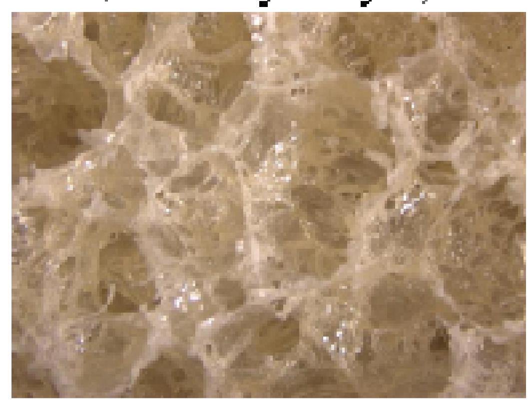




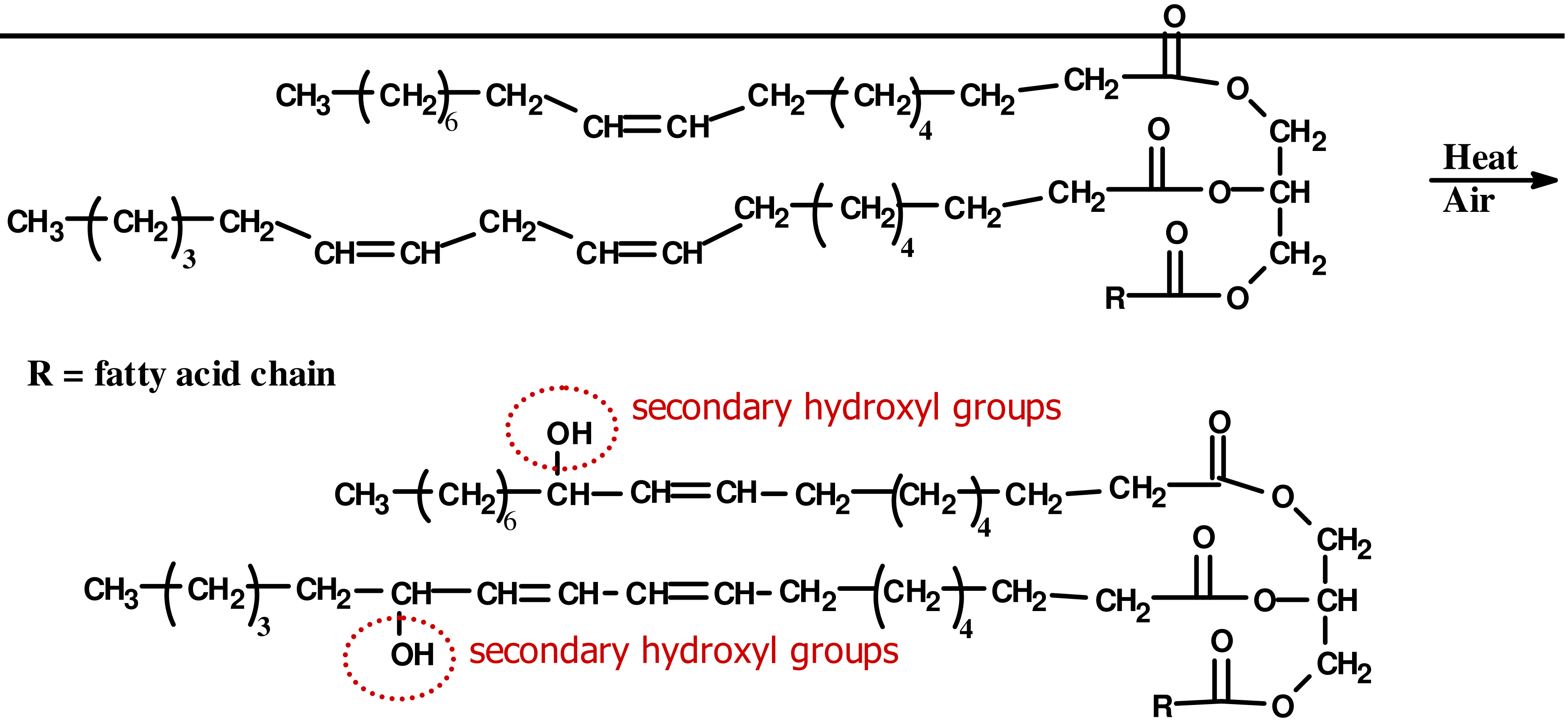
Petroleum Foam
(0% Soy Polyol)

Soy Foam
(25% Soy Polyol)





What's Happening?



R = fatty acid chain

+

Aldehydes, Ketones, Epoxides, Acids, etc.

* From Ann R. Fornof and Timothy E. Long "Synthesis and Characterization of Polyols via Air Oxidation of Triglycerides"

Key Technical Challenges

- Formulations:
  - Optimizing formulation for levels of soy used
  - Balancing gel/blow reactions for soy formulation
  - Blend stability between bio-polyol and petroleum-polyol
- Odor:
  - Odor of blown soy oil and resulting foam
- Properties:
  - Passing material specifications
  - Meeting performance and plant requirements

Formulation Development Process

1. Polyol and additives are mixed together

2. Add iso to polyol blend and pour in mold

3. Evaluate "foaming" characteristics

Balancing Gel and Blow Reactions

Reaction 1: Gel Reaction

Isocyanate + Polyol → Polymer w/ high MW

Reaction 2: Blow Reaction

Isocyanate + Water → Carbon dioxide Gas (promotes foaming)

If R2>> R1, CO_2 evolution too rapid compared to gel reaction, **foam collapses.**

If R1>> R2, gel extension reaction too rapid compared with CO_2 generation, foam rise is restricted and will **form high density foam**.

How can we improve the foam?

Changing Index, 50% Soy Polyol

60 Index | 70 Index | 80 Index | 90 Index | 100 Index | 110 Index

Changing Percent Soy Polyol, 70 Index

Optimizing Properties Through DOEs

	StdOrder	RunOrder	Blocks	Index	S8715 (g)	S5943 (g)
Control				100	1.0	0.10
1	1	1	1	80	0.5	0.05
2	2	2	1	80	0.5	0.10
3	3	3	1	80	0.5	0.50
4	4	4	1	80	1.0	0.05
5	5	5	1	80	1.0	0.10
6	6	6	1	80	1.0	0.50
7	7	7	1	80	1.5	0.05
8	8	8	1	80	1.5	0.10
9	9	9	1	80	1.5	0.50
10	10	10	1	90	0.5	0.05
11	11	11	1	90	0.5	0.10
12	12	12	1	90	0.5	0.50
13	13	13	1	90	1.0	0.05
14	14	14	1	90	1.0	0.10
15	15	15	1	90	1.0	0.50
16	16	16	1	90	1.5	0.05
17	17	17	1	90	1.5	0.10
18	18	18	1	90	1.5	0.50
19	19	19	1	100	0.5	0.05
20	20	20	1	100	0.5	0.10
21	21	21	1	100	0.5	0.50
22	22	22	1	100	1.0	0.05
23	23	23	1	100	1.0	0.10
24	24	24	1	100	1.0	0.50
25	25	25	1	100	1.5	0.05
26	26	26	1	100	1.5	0.10
27	27	27	1	100	1.5	0.50

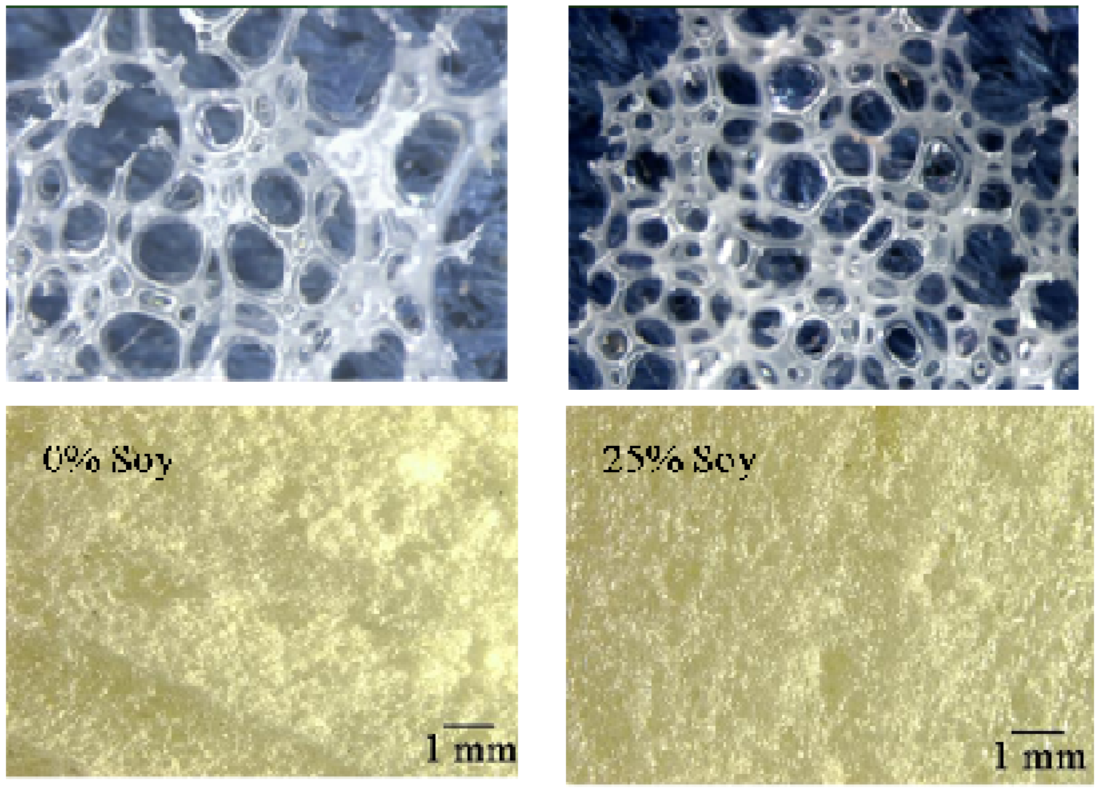
Index – ratio of polyol to isocyanate (100=one-to-one ratio, below 100=excess polyol, etc.)

S8715 – surfactant; controls/stabilizes size of gas bubbles; lowers surface tension of iso/polyol

S5943 – surfactant; enables fine, consistent cells in foam; provides consistent air flow through foam

Optimized Polyurethane Foam: Optical Micrographs

Petroleum Foam



Soy-Based Foam

- Similar appearance in microstructure
- Open celled foams, as desired for seating foam

Microstructure looks good … now what?

Odor, fogging and staining are 3 key issues!

- **Concern**: "rancid" odor detected in soy foam by foam odor panelists; cause for material rejection
- **Cause**: low molecular weight side products in polyol produce odor
- **Technical accomplishments**:
  - Masking of odor through addition of volatile fragrances and neutralizing agents
  - Encapsulation of foam with gas impermeable layers
  - Ultraviolet light synthesis method
  - Stripping of polyol with thin film evaporation method

Industry Standard for Evaluating Odors: SAE J1351

Ford R&A Odor Test Panel

Testing Process:

- Foams cut to 1" x 0.5" x 5"
- Samples placed in sealed jar
- Conditioned 1hr. at 70 °C
- Odor evaluated by 5 panelists

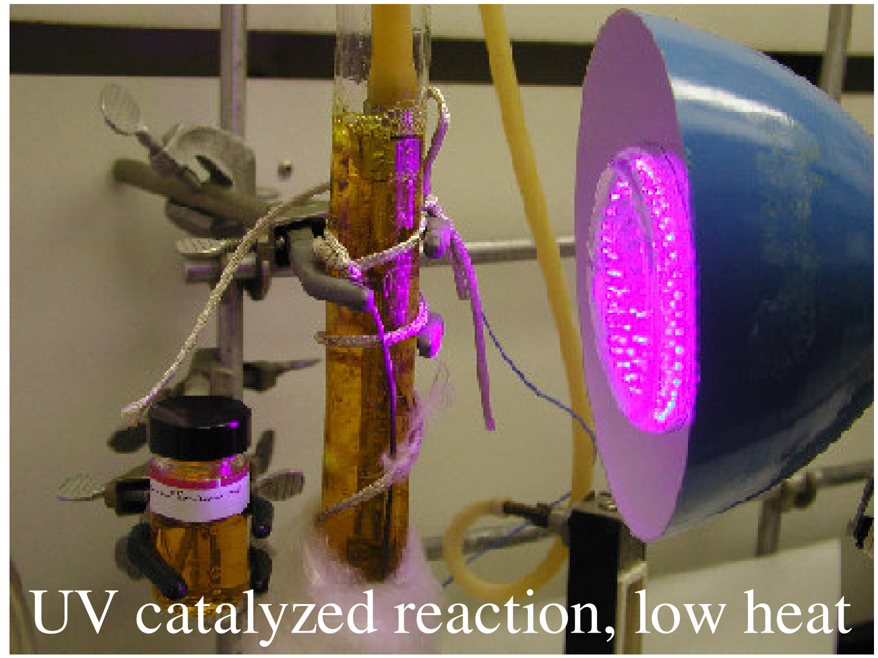
Odor Ratings

1= No Noticeable Odor
2= Slight, but Noticeable Odor
3= Definite Odor, but Not Strong Enough to be Offensive
4= Strong Offensive Odor
5= Very Strong Offensive Odor

New Synthetic Route for Soy Polyol

- Reaction Set Up:
  - Degummed soy oil placed in quartz long glass column
  - Column heated to 100F
  - Air bubbled through column
  - UV light applied to column in range 290-350nm
- Process:
  - Initiation of reaction as hydroperoxides form
  - Increase in hydroxyl number, visually seen with color change from amber to pale yellow
  - Termination of reaction at hydroxyl number ~50 by removing heat and switching from air to nitrogen gas flow.

Patent Filed 2005

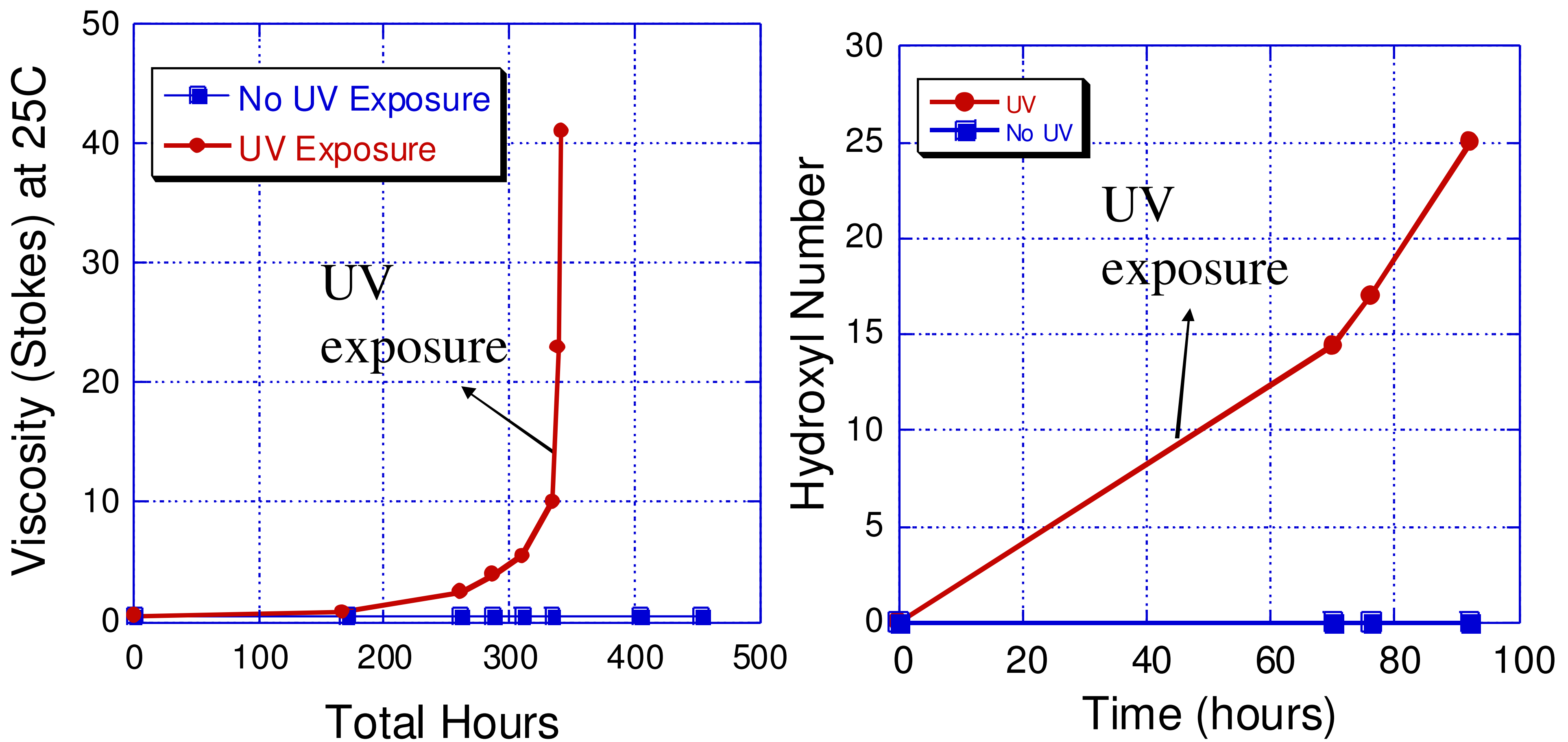


Low odor

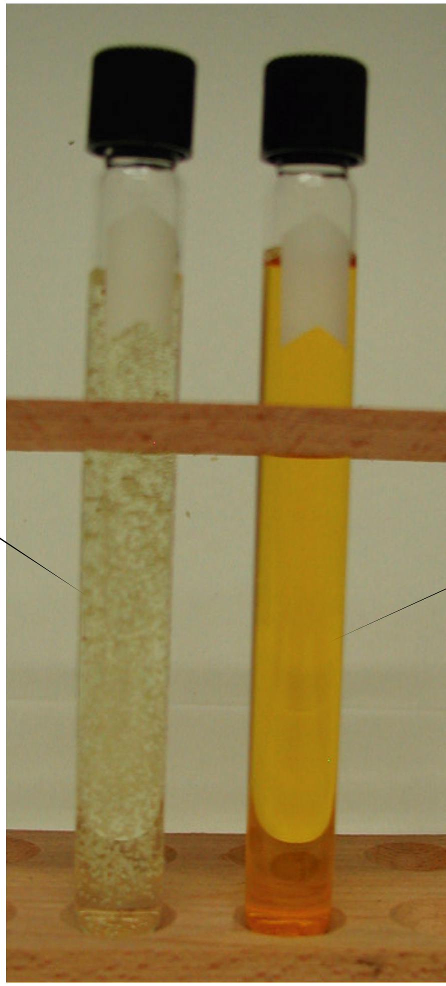
Simple Method

Inexpensive

Synthesis of Soy Polyol



UV Catalyzed Soy Polyol

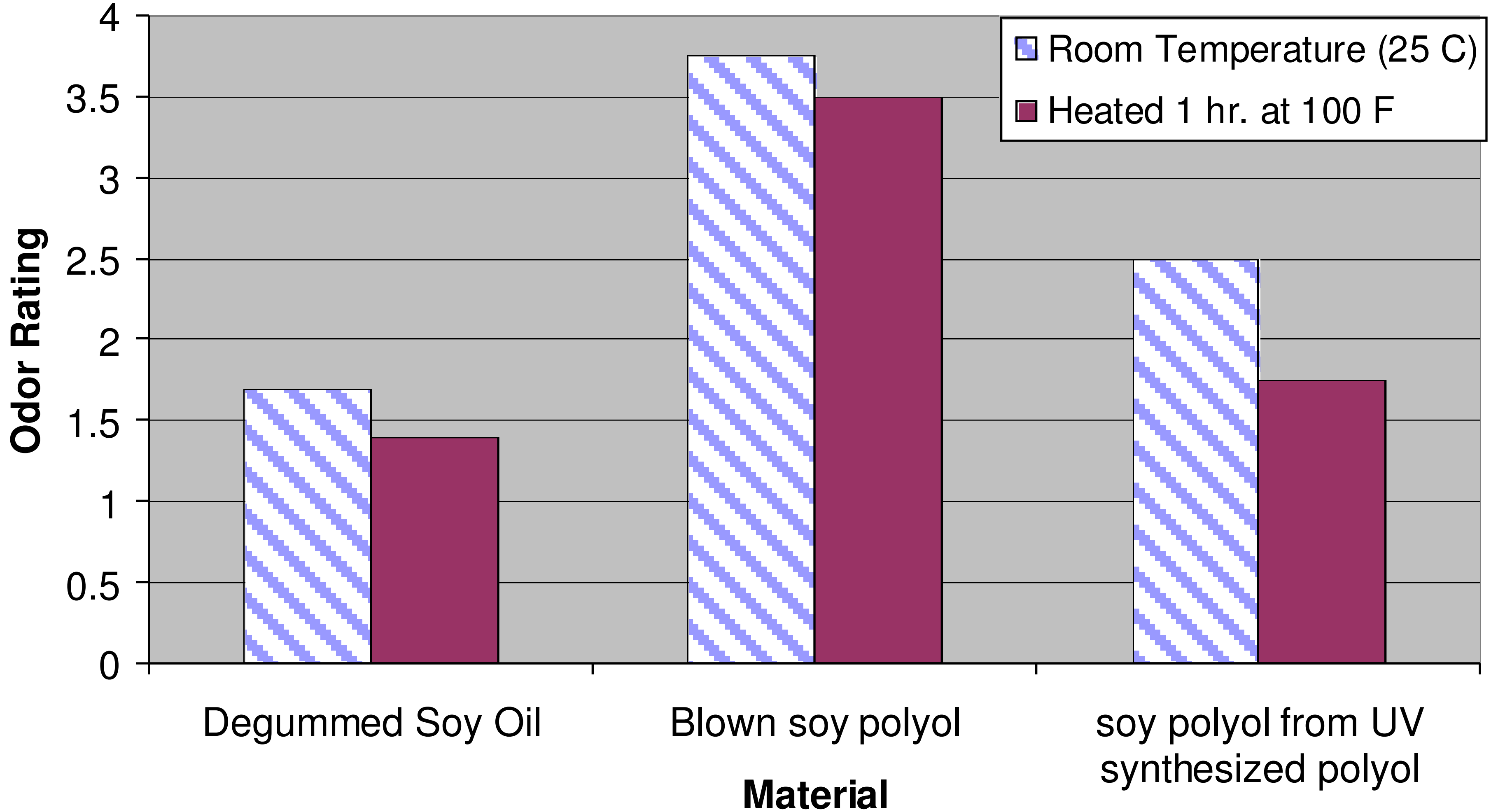


soy polyol

degummed soy oil

Analysis	“UV” Crude Polyol
Hydroxyl Number (mgKOH/g)	**47**
Color (Gardner)	1
Viscosity (cps)	2700
Acid Value (mgKOH/g)	**5.4**
Karl Fischer Water (%)	0.064

Odor of Oils: Commercial vs. UV Polyols

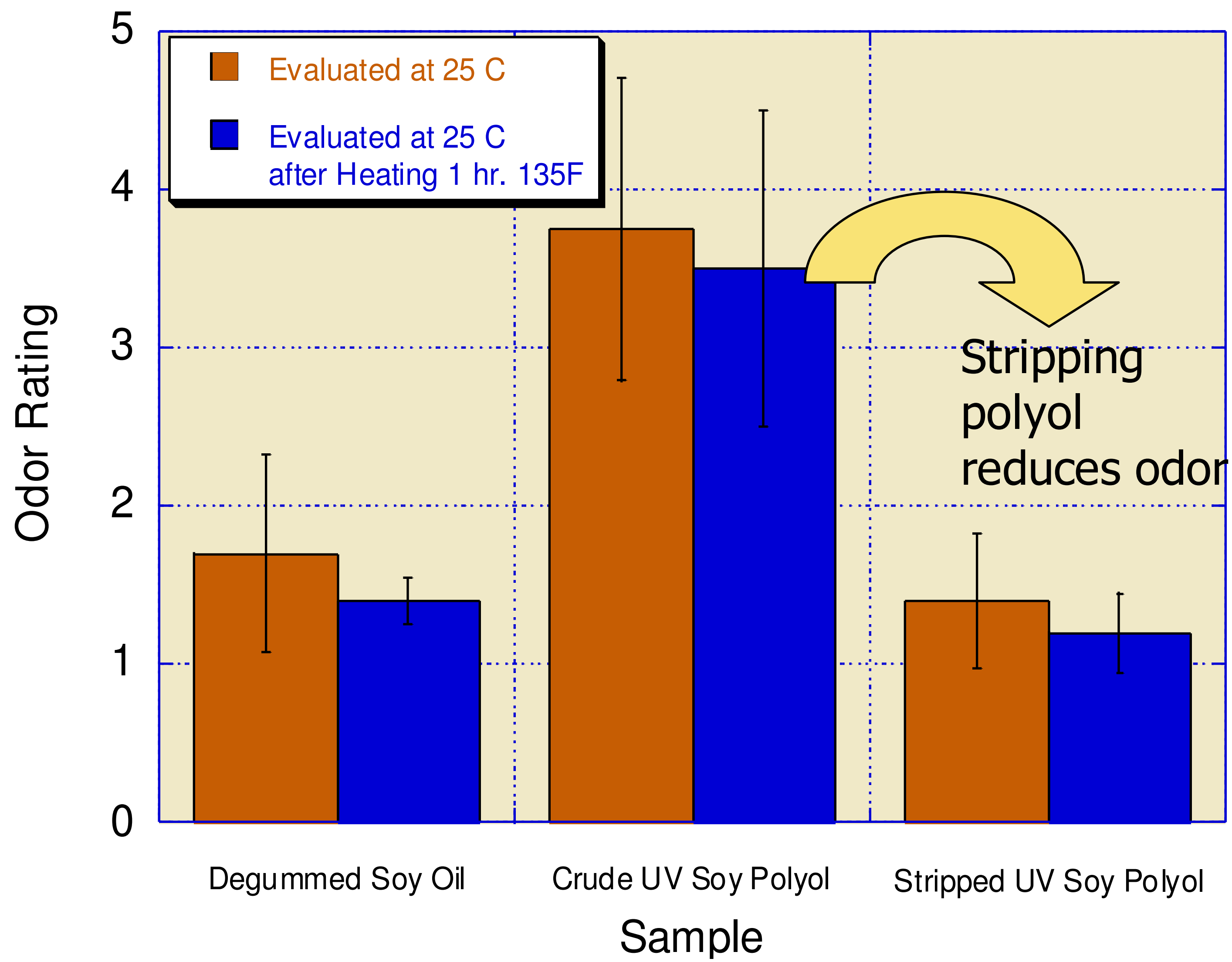


Wiped Film Evaporator Process

- Completed trial using WFE to "clean up" the soy polyols
- Determined optimized processing temperature for odor reduction (double pass through equipment at 190C)
- Conducted odor tests on Ford's polyols

Using WFE to Improve Odor

Polyol sample was stripped of low molecular weight volatiles using a Wiped Film Evaporator Technique

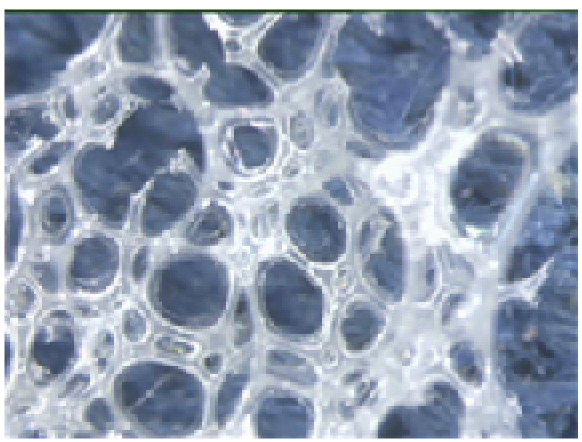


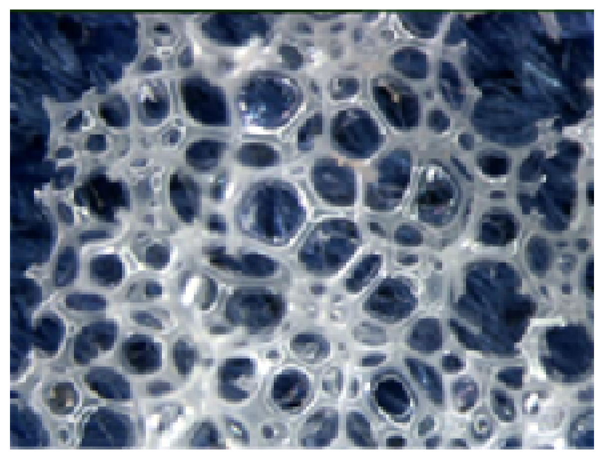
Formulation Development: Typical Soy Foam Formulation

Components with Parts by Weight	
Soybean Oil Polyol	40
Petroleum Polyol	60
Water	3-4
Multiple Silicone Surfactants	1-1.5
Multiple Amine Catalysts	0.5-1.0
Cross-Linker	0.25-0.35
Isocyanate	100 Index

Design of Experiments for Optimization

Petroleum





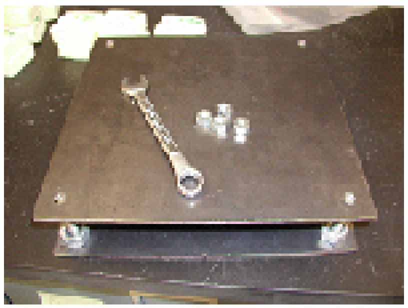
40% Soy

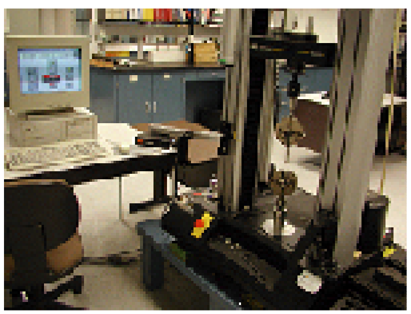
Isocyanate Comparison

Property	**MDI**	**TDI**
Name	Methylene diphenyl diisocyanate	Toluene diisocyanate
Component*	European seats, N.A. headrests and armrests	North American seats
Foam Attribute	Thin, firm seats (favorable hardness/density)	Cushioning, plush seat (high tensile strength)
Maximum % of soy	40%	5%
Health/ Environment Assessment (MSDS)	Moderate	Serious

*Asia Pacific uses TDI/MDI blend for seats

Required Property Tests of New Foam Formulations





- Density
- Optical Microscopy
- Tensile Strength, Elongation
- Compressive Modulus
- Tear Resistance
- Compression Set
  (50% deflection at 70^{o}C, 22hrs.)
- Fogging
- Odor

Ford R&A Lab Scale Soy Foam Properties

40% soy polyol in polyol blend in MDI formulation

Ford Spec. Test	Density (kg/m^3)	Compression Set at 50% Deflection	Tensile Strength (kPa)	Elongation (%)	Tear Resistance (N/m)
Benchmark	40	< 14%	> 110	> 100	> 170
40% Soy Foam	37 ✔	11 ✔	113 ✔	100 ✔	190 ✔

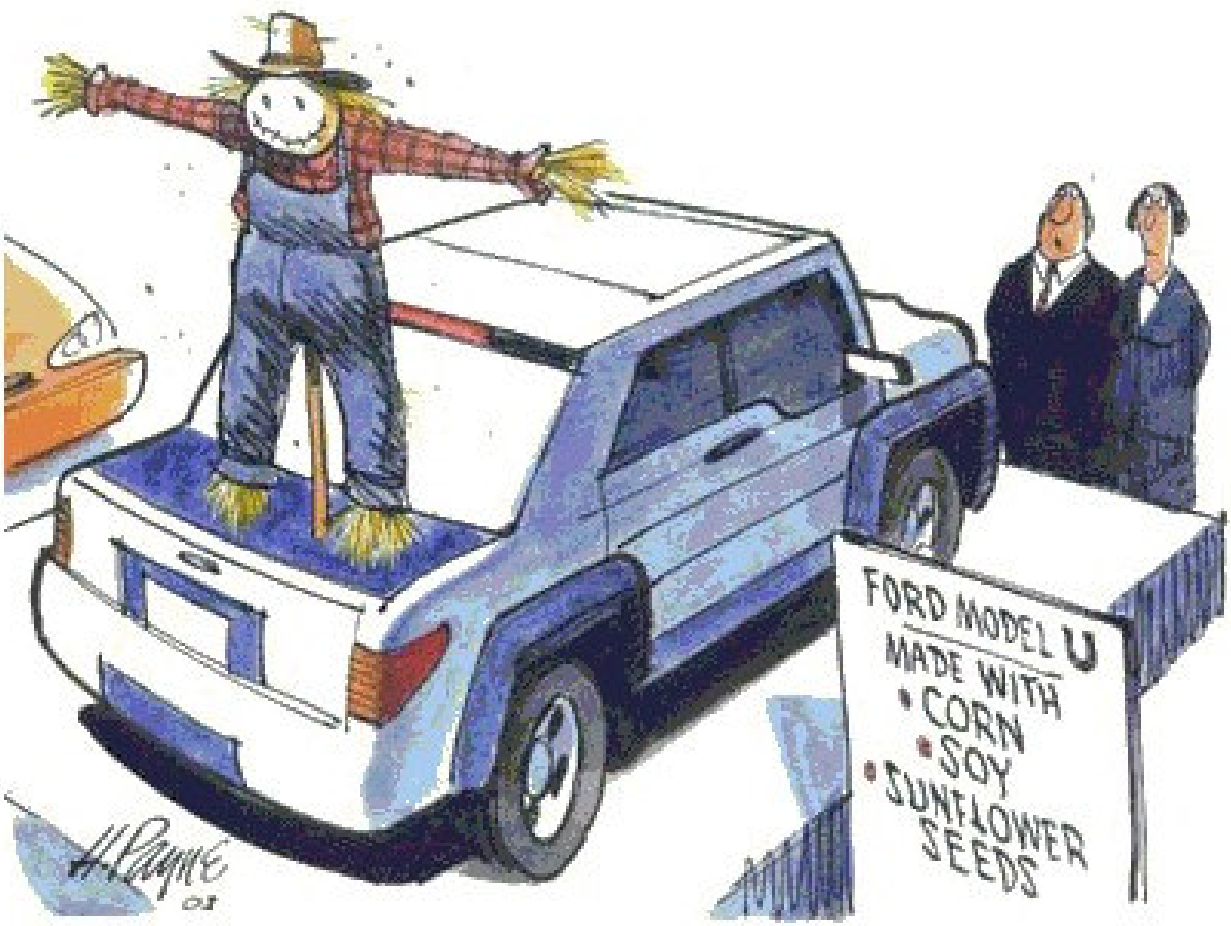
Formulation Patent Application Filed 2005

Demonstrating Soy Foam Seats on Model U Concept Vehicle

A Model for Change

Model U

Future of Biomaterials



"With all the crop-based materials, we added a scarecrow option to keep the crows away."

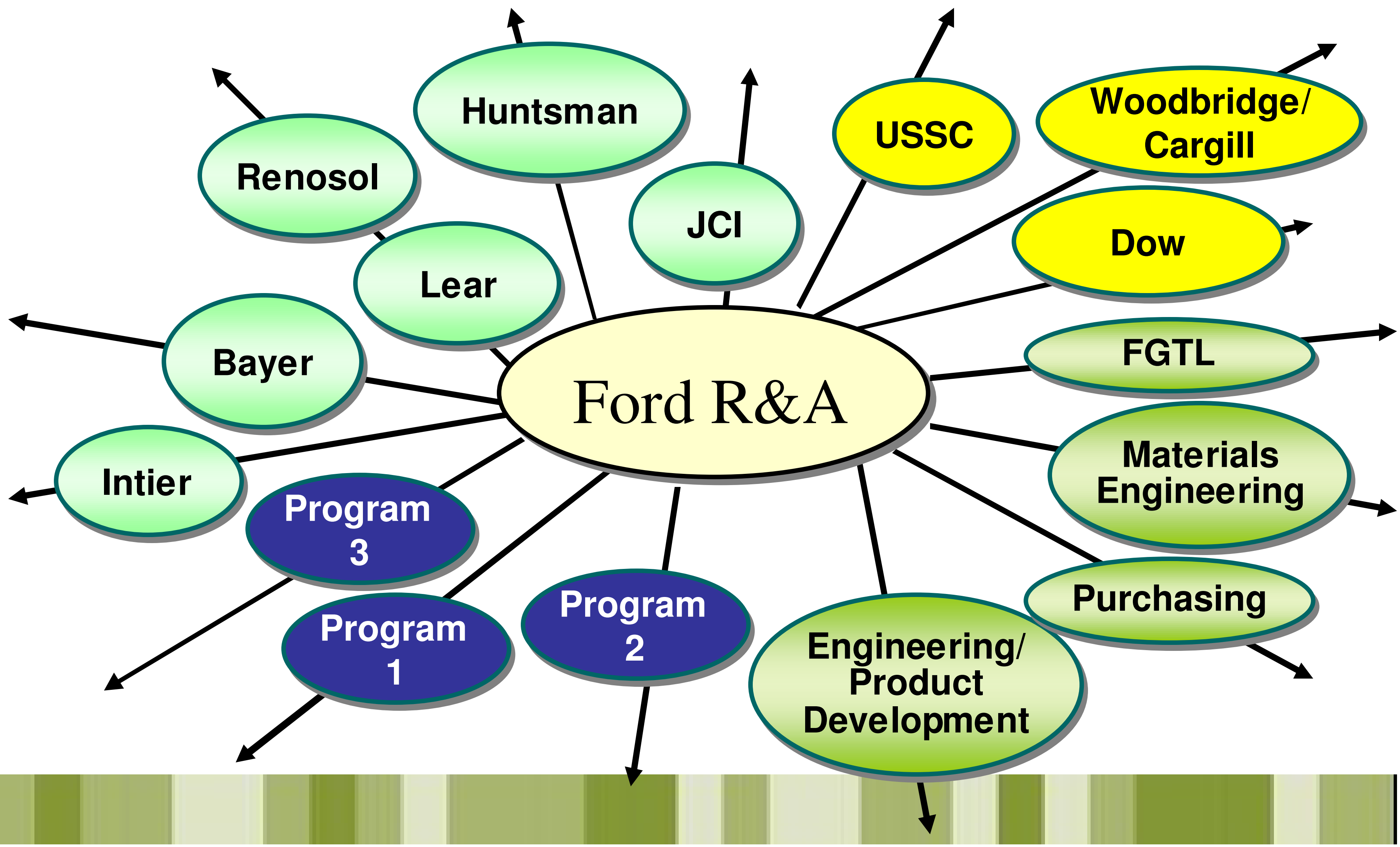
Henry Payne,
Detroit Free Press

Roadmap

- Why biomaterials?
- Historical perspective
- Soy foam research and development
- **Soy foam implementation**
- Soy meal applications
- Looking ahead

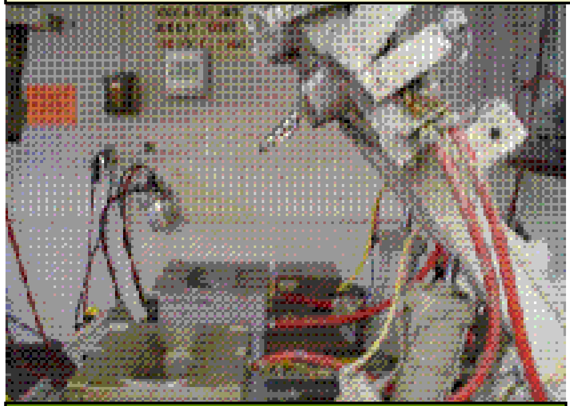
Photo by Scott Bauer, courtesy of USDA

Teamwork to Move Forward



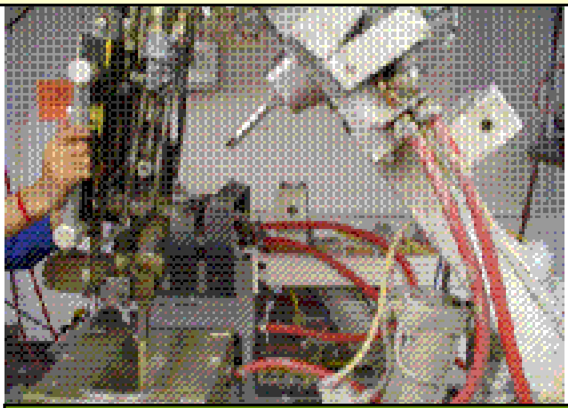
Processing Optimization for Soy Foam Headrests

- Optimized formulations and processing conditions
  - Cycle Time: meets production requirement
  - Reactivity profile meets manufacturing setup
  - Molded HR meets production level quality
- Issues identified: blend separation, surface skinning, tear resistance

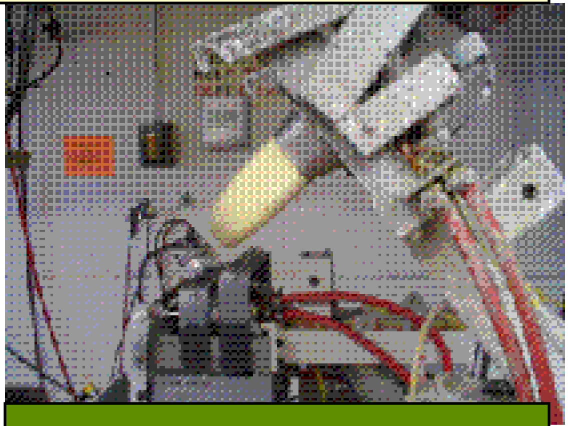


Impingement mixing

Temperature controlled tool



Polyol/iso mixture is poured into tool



Molded polyurethane using 20% soy in foam (40% b-side)

Headrest Trimming Process

- "Foam on stick" placed on fixture

- Vacuum compresses foam
- Plastic covering placed on foam

- Final trim piece inserted over foam
- Vacuum released

Foam Tests from Each Trial

- Density
- Tensile Strength
- Elongation
- Heat Aged Tensile
- Heat Aged Elongation
- Tear Resistance
- Compression Set (as received -50%)
- Compression Set (steam autoclave aged -50%)
- Compression Set (as received -75%)
- Compression Set (steam aged -75%)
- Sag Factor
- Recovery
- Staining
- Fogging
- Odor
- Load Indentation
- Aged Loss
- Flammability

Material Performance of MDI Soy Foam Headrests

Property Description	Units	Target	Soy Foam	Comments
1. Core Density	Kg/m^3	As per drawing	37	Pass
2. Tensile Strength	kPa	82 min	174	Pass
3. Elongation	%	80 min	112	Pass
4. Compression Set	%	10 max (cushions)	2.8	Pass
5. IFD @ 50% Deflection	N	As Per Drawing	280	Pass
6. Staining	Visual	No Stain	No Staining	Pass
7. Fogging	%	70 min.	98 (dried droplets)	Pass
8. Odor	Rating	2 max	2	Pass
9. Aged Flexibility	Visual	No Splitting or Crumbling after Aging	OK	Pass

TDI Based Soy Foam Seat:
Process Optimization

- Completed 2 trials at Renosol Seating Plant with Mustang Front Seat Cushion and Back Foam
- Molded TDI formulation with 5% Soy contents
- Adjusted minor process parameters
- Parts molded met current production quality appearance

Material Performance of TDI Soy Foam Seats

Properties	Target	Soy Foam
1. Density (kg/m^3)	50	50
2. Hardness (N)	280	285
3. Tensile: (kPa)	82 min	172
4. Elongation: (%)	80 min	150
5. Tear Strength: (N/m)	450 min	664
6. Compression Set 75%:	10% max	10%
7. Compression Set HA 75%:	25%	9%
8. Flammability: (mm/min.)	100 max	SE

TDI Based Soy Foam Seat: **Process Optimization**

- Completed prototype molding trials with Lear using front seat cushion tooling
- Molded TDI formulation with 5% soy contents
- Parts molded met current production quality standards
- Passed property requirements including flammability and tensile strength

Key Steps Towards Implementation

Formulation development

Technical issues

Cost and supply analysis

Vehicle component level testing

Vehicle level testing

Physical and mechanical properties

Challenges of Soy Foam: Business Considerations

- 1st implementer paving the way
  - Materials specifications
  - Program support
- Cost evaluation of final product
  - Quantity of material needed
- Plant complexity
  - Additional chemical line or tank
  - Multiple products
- Supply chain availability

Ford Motor Company Soy Foam Progression

2002 — R&A initiates research project on soy foam

2003 — Model U concept vehicle

2004 — Completed MDI trials & testing with Lear & Bayer

2004 — United Soybean Board awards R&A 3yr. $230k grant

2005

2006 — Completed TDI trials & testing with Lear & Renesol

2006 — Materials Engineering approval TDI

2007 — Component approval; Processing Evaluation completed

2007 — Press release on Mustang soy foam seats

Implementation of Soy Foam on 2008 Mustang

- Seat supplier: Lear Corporation
- Applications: seat cushion, seat back
- Soy content: 5% by pad weight
- Implemented August, 2007

Times Square, New York, July 2007

Positive Media Attention

Ford puts the green under your seat

Written October 14, 2006 by Via Ford Motor Co.

While many in the auto industry are experimenting with a 5% soy-based polyol – one of the many ingredients used to create the foam used in vehicles – Ford researchers have formulated the chemistry to replace a staggering 40% of the standard petroleum-based polyol with a soy-derived material

Ford Mustang Press on Soy Foam

- **CNN, Forbes, Wall St. Journal**
- **Finance, Farming, Auto Articles**
- **Over 200 media outlets covered soy foam story**

ecology center

Ford and Honda Join Toyota as Leaders in Using Environmentally-Friendly, Safe Plastics for Car Interiors

Second Annual Ecology Center Report Grades Auto Manufacturers On Use of Sustainable, Non-Toxic Materials for Indoor Parts Leaders Applauded for Use of Bio-Based Materials

Press Release

Lear Corp.

Release date: December 14, 2006

Lear Introduces SoyFoam(TM) Technology for Automotive Seating Applications

SOUTHFIELD, Mich., Dec. 14 -- Lear Corporation (NYSE:LEA), one of the world's leading automotive interior suppliers, today announced it has developed SoyFoam(TM), a soybean oil-based flexible foam material for automotive interior applications.

Technology Migration: Programs Using Soy Foam

-Ford Mustang

-Ford Expedition

-Lincoln Navigator

-Ford F-150

-Ford Escape

-Mercury Mariner

-Mazda Tribute

-Ford Focus

Soy-Based Foam Awards

- "The Excellence in New Uses Award" by the New Uses Committee, United Soybean Board, Tampa, Florida, February 2007.
- "Plastic Materials from Renewable Resources Award" by the SPE Global Plastics Environmental Conference, March 2008 to Ford Motor Company and Lear Corporation.
- "Environmental Excellence in Transportation, E2T, Award" by SAE International, May 2008, to Ford Motor Company and Lear Corporation.
- "SPE Innovation Award in Environmental Category" by SPE Automotive, November 2008 to Ford Motor Company and Lear Corporation.

Opportunities for Soybeans

- Increased levels of soy polyol in foam applications
- Use of soy oil in other flexible foam applications
- Use of soy meal and soy flour as filler in thermoplastics, rubber and thermosets
- Rigid polyurethane foams using soy polyols

Roadmap

- Why biomaterials?
- Historical perspective
- Soy foam research and development
- Soy foam implementation
- **Soy meal applications**
- **Looking ahead**

Photo by Scott Bauer, courtesy of USDA

Can we use the other part of the bean?

- Technology Overview: Use of soy meal in formulation and processing of automotive plastics.

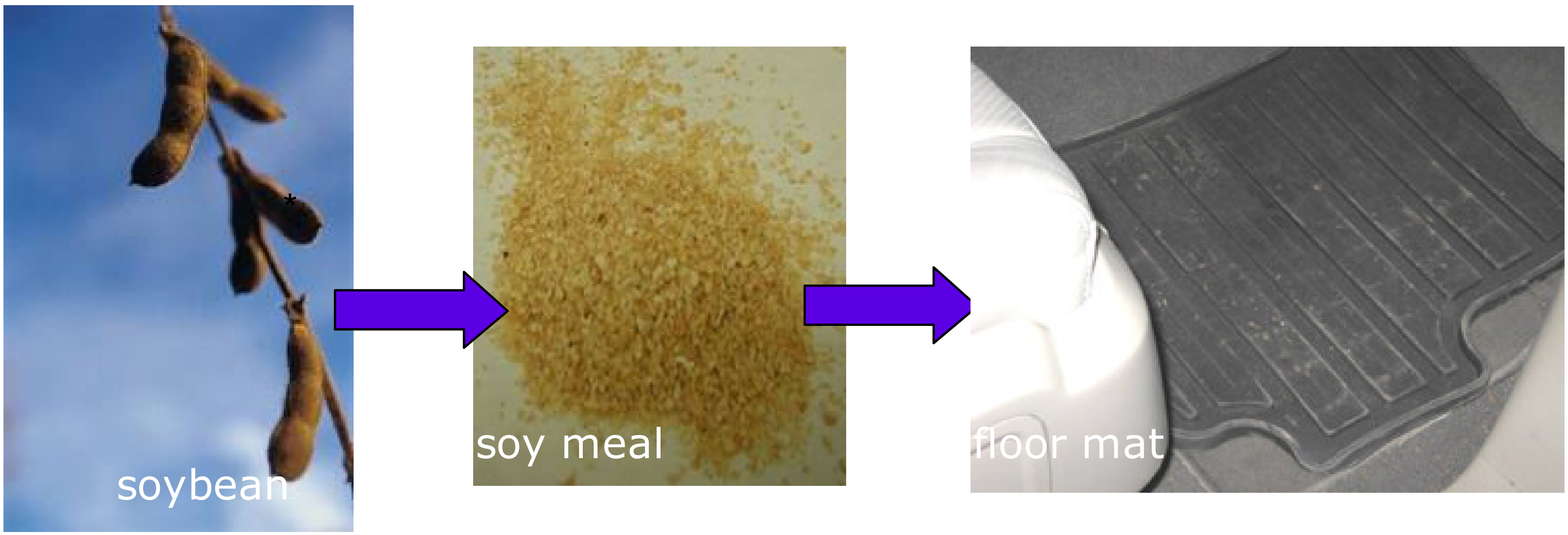


Photo by Lynn Betts, USDA Natural Resources Conservation Services

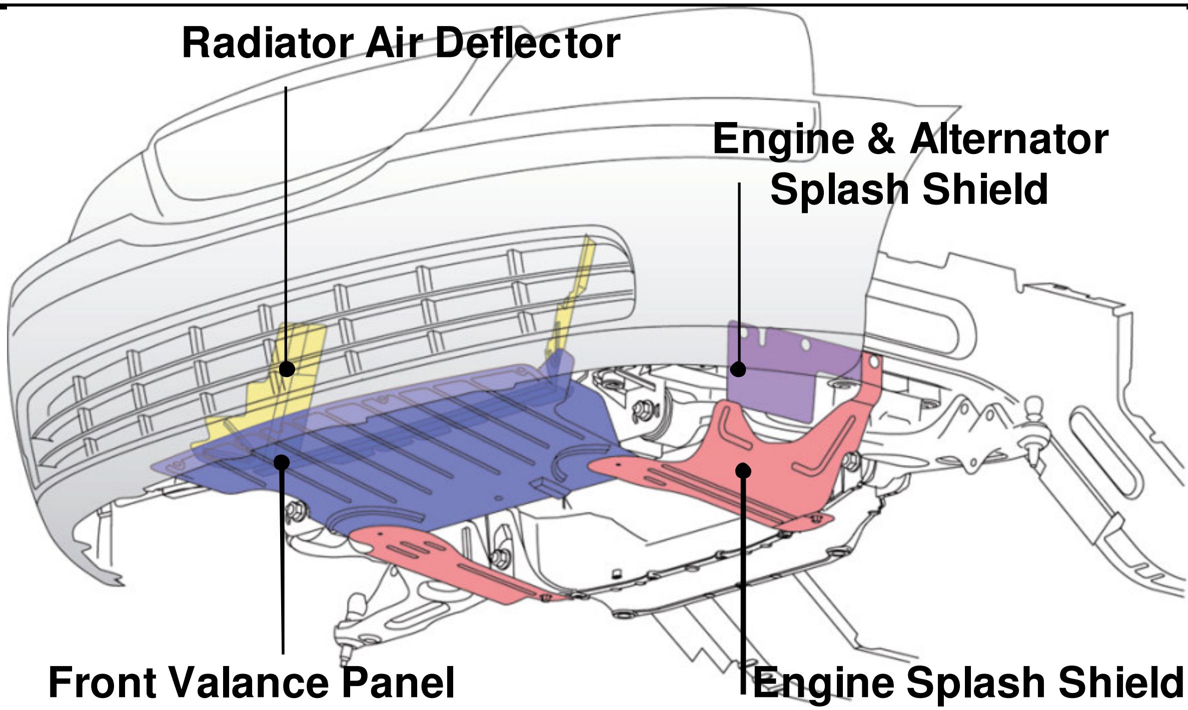
Soy Protein Filler for Plastics

- **Technology Overview:** Use of soy meal in formulation and processing of automotive plastics.

- **Benefits:**
  - Low cost alternative filler
  - Use of agricultural byproduct

- **Goals:**
  - Determine properties of automotive components using soy protein fillers
  - Assess mechanical properties and overcome processing challenges
  - Identify specific automotive components for soy protein filler
  - Mold components in collaboration with automotive Tier 1 suppliers

Molding Soy Meal- EPDM Parts



Schematic courtesy of Hematite mfg.

Next Steps For Biomaterials

- Continued Research support for three main thrust areas in biomaterials projects
- Leverage biomaterial development with material suppliers and non-competing partners
- Work jointly with our Product Development partners to further develop the internal market at Ford for biomaterials
- Complete Ford material and component level testing to obtain material approvals
- Communicate our work and progress to our customers!

Supplier Acknowledgments

Soy Reinforced Rubber

- Hematite Manufacturing
- USB New Uses Committee
- Zeeland Farm Soya
- Lion Copolymer
- CHS Oilseed Processing
- Michigan Soybean Board
- Prof. Amar Mohanty (MSU)

Soy Based Polyurethane Foam

- Ford R&A
  - Christine Perry
  - Matt Schwalm
  - Brian Witkowski
- Bayer Corporation
- Lear Corporation
- Renosol Corporation
- Urethane Soy Systems Co.
- United Soybean Board
- Omni Tech International

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Ford Soy Foam Team Acknowledgements

Drive one.

Questions?