

## Carpet Identification using a Hand-held NIR Analyzer

*Bob Jenner, Walid Atia and Larry McDermott*  
Axsun Technologies

[LMCDERMOTT@AXSUN.COM](mailto:LMCDERMOTT@AXSUN.COM)

[www.axsun.com](http://www.axsun.com)

*Bryan Coppes*  
*Infiltrator Systems*

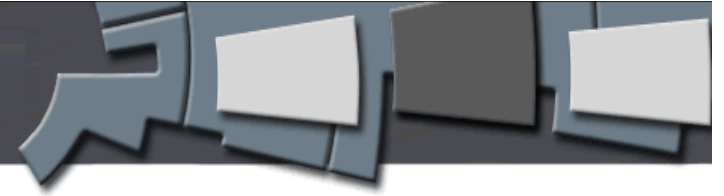


# Outline



- Introduction
- Company Information
- Core technology
- Analysis Model Capabilities
- System Development
- System Capabilities
- Conclusion

# INTRODUCTION



- A hand-held carpet identification analyzer has been developed for the rapid screening of carpet materials for a recycling application
- The system uses a high resolution, tunable laser source that allows for accurate analysis of carpet samples
  - Portable
  - Rugged solid state optical system
  - Rapid analysis (< 1 second)
  - Single button operation
  - Battery Operated
  - Light ( 9.5 Pounds)
  - On-board data processing allows stand-alone operation
  - Wireless operation allows for real-time data logging
- Feedback from initial field testing of several systems has been incorporated into improvements in analytical capabilities

# About AXSUN Technologies



***Axsun Technologies is a leader in  
the design and manufacture  
of products based on  
micro-scale optoelectronics***

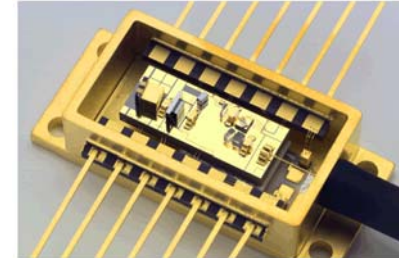
- Founded in 1998
- Locations
  - Billerica, MA
  - Livermore, CA
- More than 100 employees
- Privately funded - financially stable

# Axsun Technologies Business & Mission

*Axsun Technologies designs and manufactures “spectral engines” for a wide range of customers*



TRADITIONAL “SPECTRAL ENGINE”

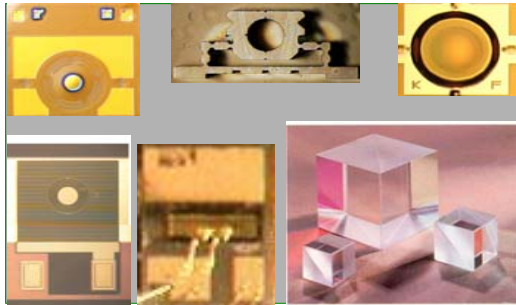


AXSUN'S SPECTRAL ENGINE

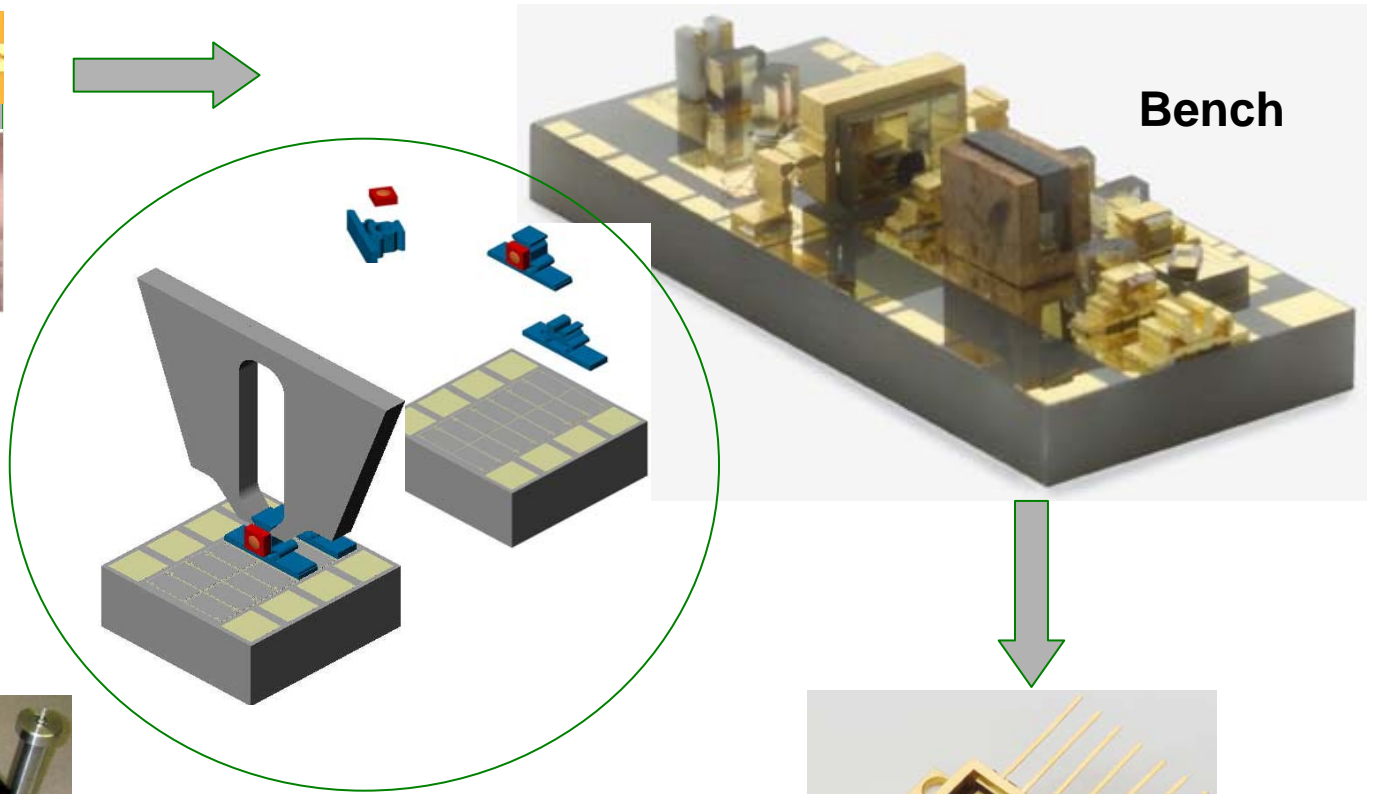


*These engines enable the transformation of sophisticated laboratory instruments to sensors for use outside of the lab  
...anytime, anywhere measurements*

# The Platform – Semiconductor Manufacturing Technologies



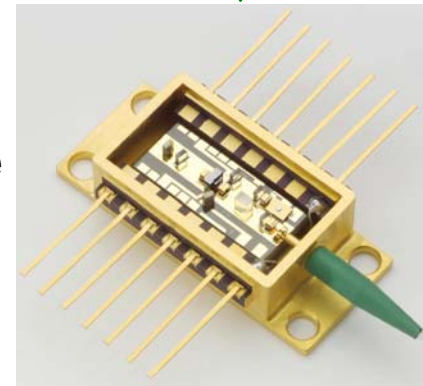
**Micro  
Optic  
Devices**



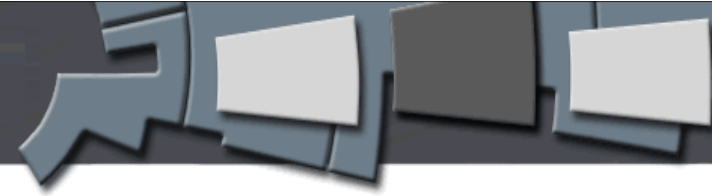
**Bench**



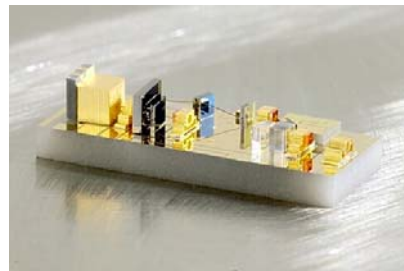
**Optical Module**



# Solid State Laser Source Technology

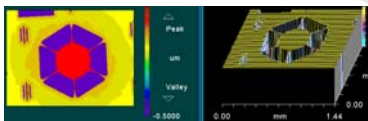
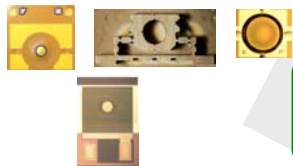


- Axsun's tunable, solid state laser source allows:
  - High resolution spectra (required for differentiation of similar compounds such as N6/N66)
  - High Optical power – allows for analysis of a wide array of sample types
    - Dark
    - Wet
  - High Speed – Spectrum for analysis collected in < 1 second
  - Low Maintenance – No need to change source bulb regularly
  - Ruggedness – Immune to vibration effects and normal handling

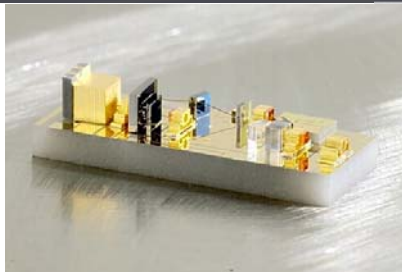


# Automated Volume Manufacturing Processes

## Micro Optics



Characterize

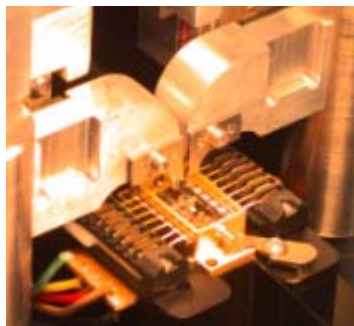


Pick & Place



Solder Attach

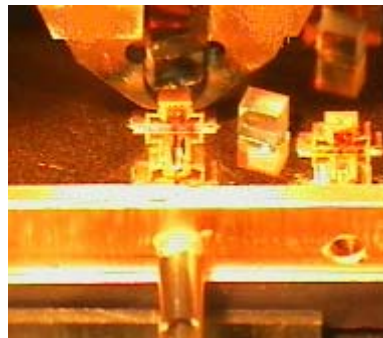
Micro-robotic alignment  
Final alignment capability is  
< 0.1 micron



Align

Seal

Test & Sort



Pick and place



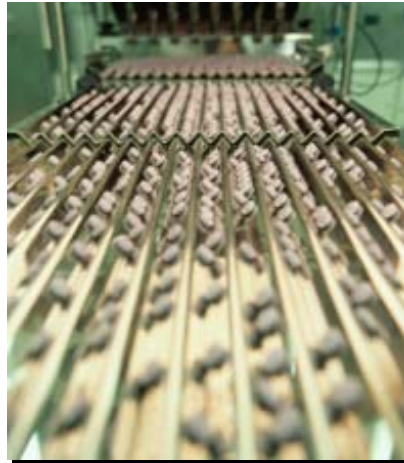
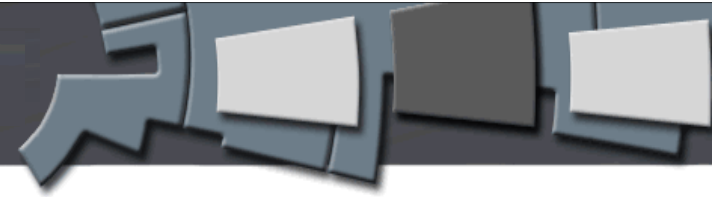
# High Reliability, Scalability



- Components, modules and subsystems undergo rigorous qualification
  - Similar Axsun products are qualified to Telcordia and MIL standards to ensure long term reliability
- Axsun currently builds and delivers thousands of NIR “spectrometers” a year to other industries
- Actual field failure rates for our performance monitors is one failure in 15 million device hours of operation!

Robustness far beyond today’s typical analytical instruments!

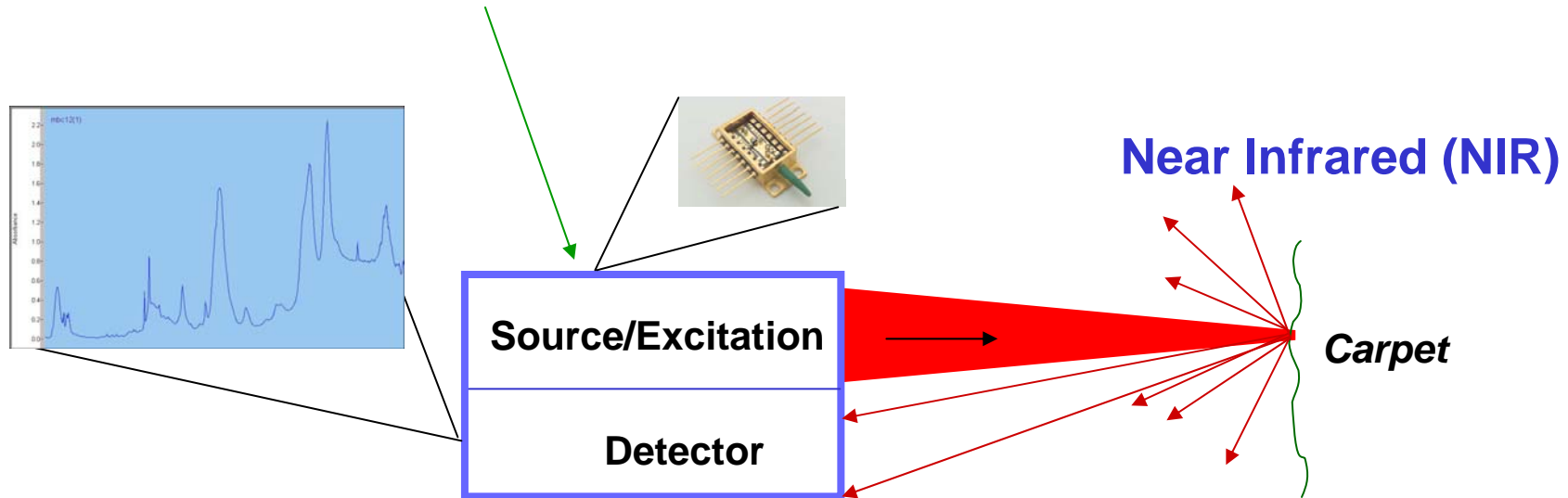
# NIR Spectroscopy



- Near IR (NIR) spectroscopy has been used to improve many processes
  - Meet Specifications
  - Raw material Identification
  - Higher quality
  - Reduced waste

# Near Infrared Technology

High Power, High resolution tunable laser



Near Infrared (NIR) covers the spectral range of 1000-2500 nm

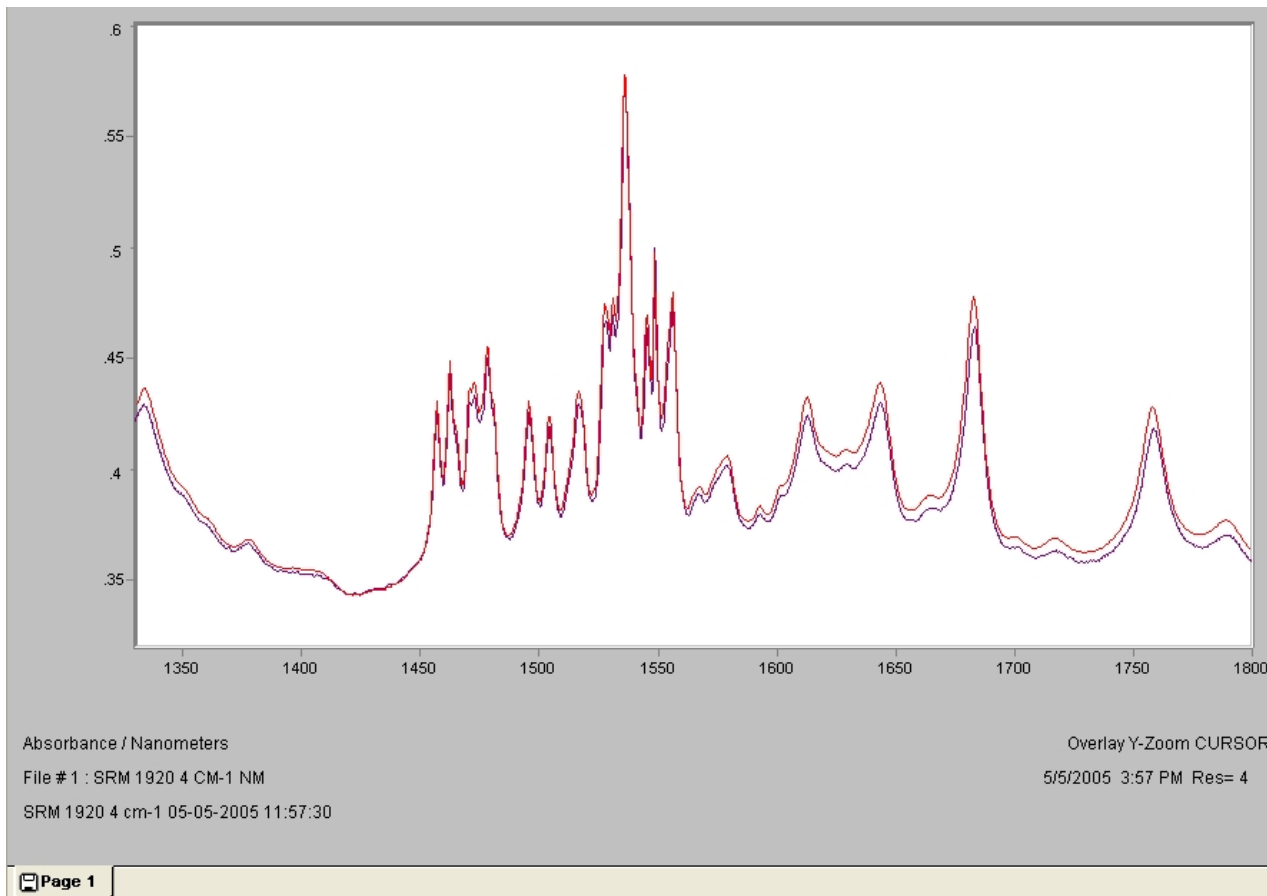
Absorptions measured are the result of molecular vibrations due to incoming excitation

All substances (gases, liquids, solids) have unique characteristics resulting in “fingerprint” spectra

Monitoring reflected/transmitted NIR radiation provides qualitative and quantitative information about the target sample

# FT-NIR and Axsun Spectrometer

- Axsun's spectral response is comparable to conventional analyzers
- This FTNIR performance is now possible in a small, rugged, fast analyzer system



- Spectrum of NIST reference material on an Axsun spectrometer and a conventional FTNIR system
- Measurements made using FTNIR systems can be made using Axsun MEMS based analyzers

# Modeling (Chemometrics)

- Building a mathematical equation that relates a spectrum collected from a sample to some information of interest
  - Concentration (Quantitative)
  - Identification (Qualitative)

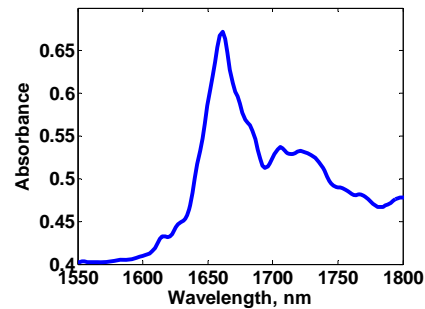
Carpet



Analyzer



Spectrum



Analysis

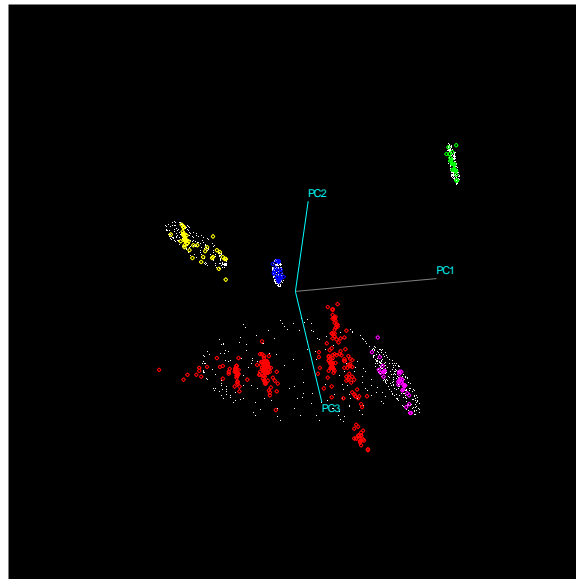


Information

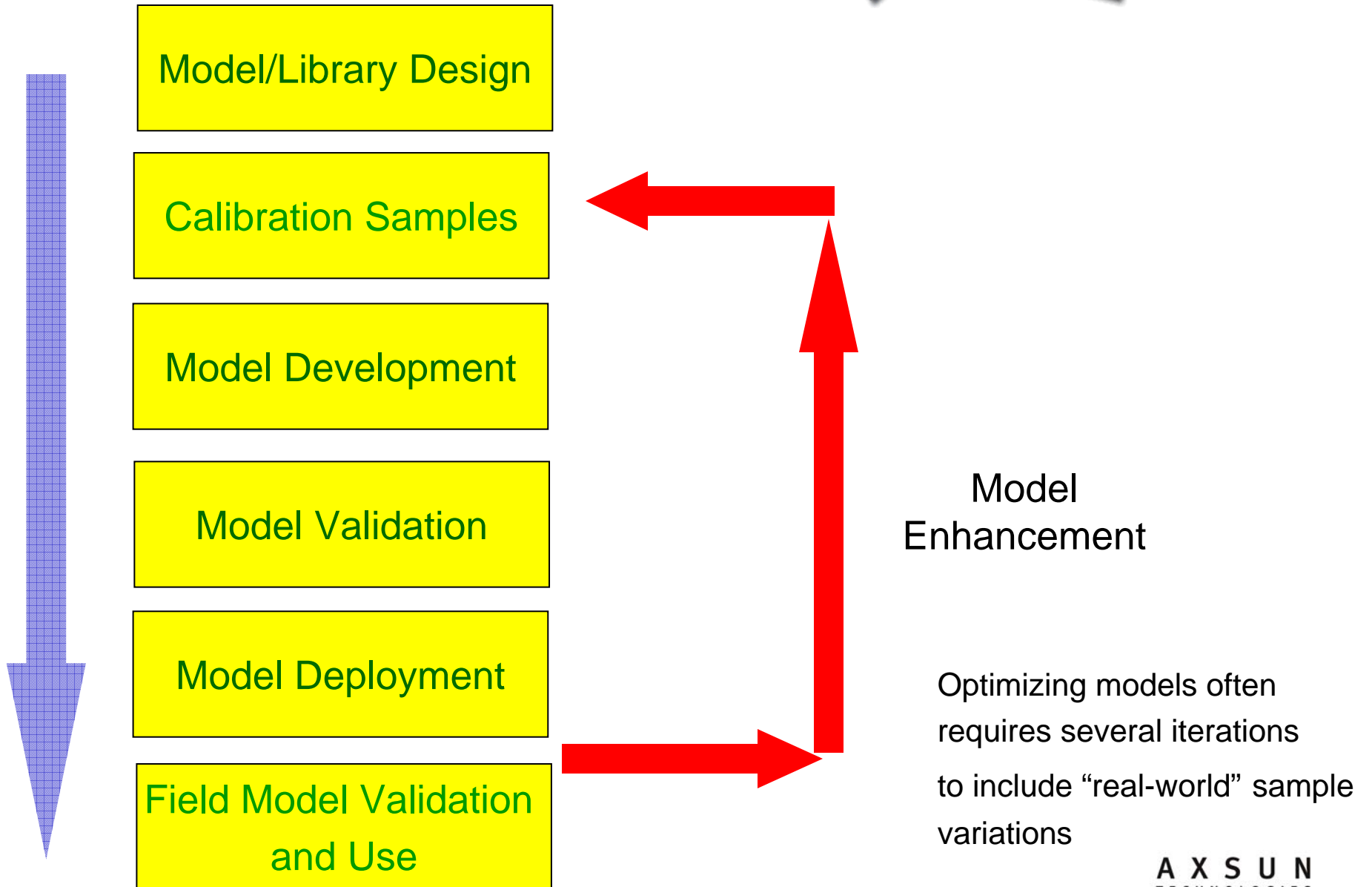
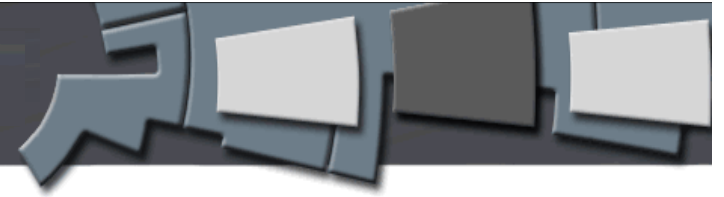


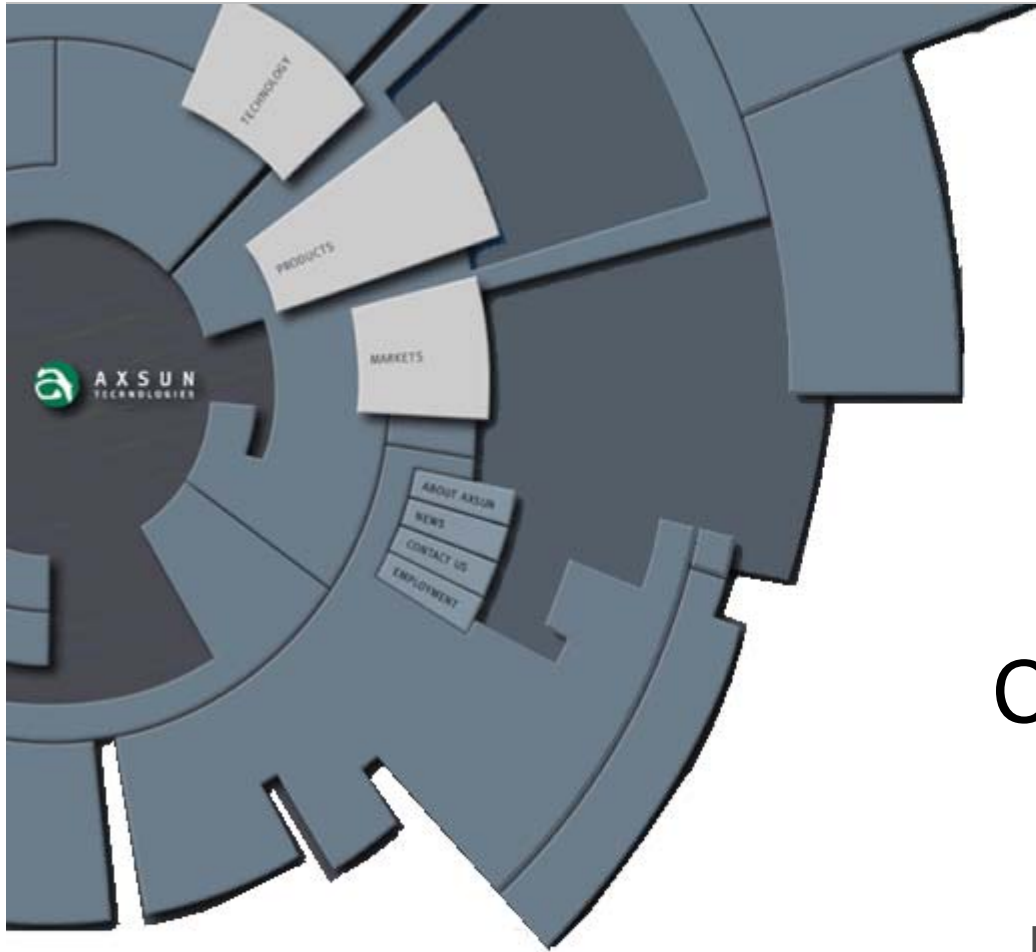
# Modeling (Chemometrics)

- Different methods are routinely used for NIR testing for qualitative analysis
  - Correlation Fit (simple and more complex)
  - SIMCA
  - KNN
  - PLS-DA
  - Etc.
- Once a model is built, it can be coded into the firmware and future samples will automatically be analyzed using the model.



# Model Development

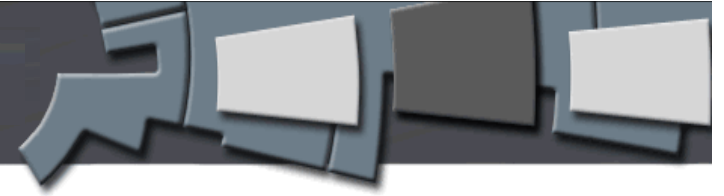




# Carpet Analysis

Product Development

# Axsun System Development



- Initial request was to identify polypropylene in mixed product incoming material stream
  - Measurement was polypropylene or other.
  - Axsun system using core analyzer technology showed feasibility
- Project was initiated to develop a carpet analyzer system based on Axsun's core spectrometer
  - Design review with customer at Axsun resulted in several system improvements
- System was upgraded to add the capability to identify Nylon 6, Nylon 6-6, PET and Wool
- Improvements in model performance attained by updating library to include field samples
  - Improvements done remotely over the internet

# Raw Material Sorting



Volume of incoming materials requires rapid, accurate analyzers to sort carpets based on material of construction

# Raw Material Sorting

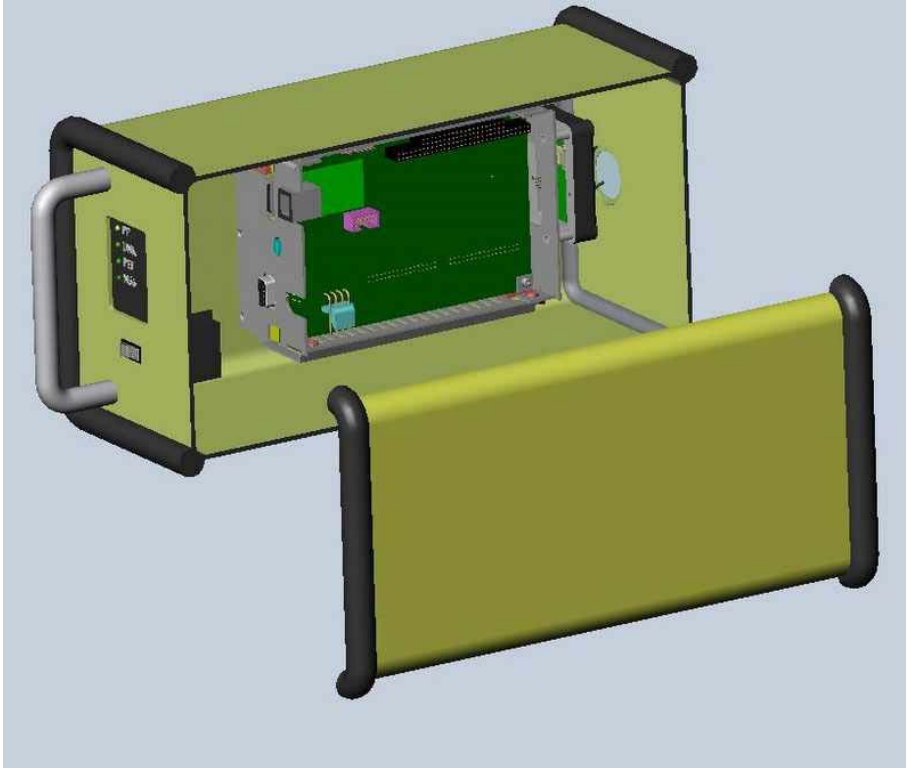


Existing test system  
being used



Field Demonstration –  
Late December, 2005

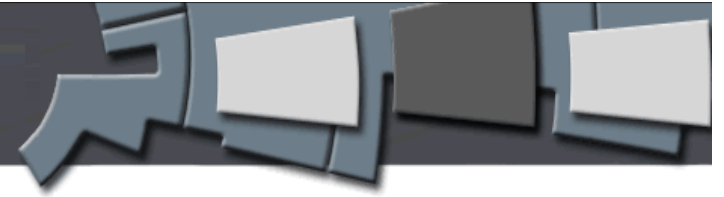
# System Concept



“Stock” Axsun spectrometer integrated into applications specific enclosure

Capability added to trigger analysis, on-board processing, sampling optics, battery operation etc.

# Axsun Carpet Analyzer



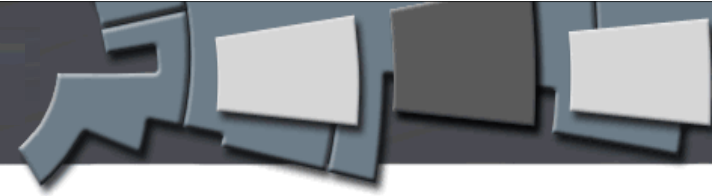
Sample interface (window)



Dual Handles (with triggers) allows for vertical and horizontal operation

Commercially available battery pack

# Axsun Carpet Analyzer



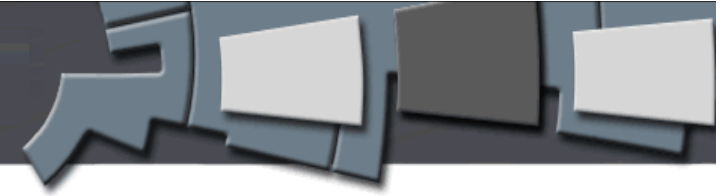
- Technology
  - Near Infrared Diffuse Reflectance - 1550:1800 nm
- Data Analysis
  - Custom Sample Correlation Algorithm (performed automatically on-board).
- Measurements
  - Polypropylene, Nylon 6, Nylon 66, Wool, PET, Unknown
- Cycle Time (Scan + Analysis)
  - < 1 Second
- Background Frequency
  - On Startup or every 4 hours.
- Weight
  - 9.5 pounds
- Dimensions
  - 12" x 6" x 5"
- Power
  - Battery Operated, commercially available battery pack
- Battery Life
  - Minimum 3 hours operation, 4 hours common.
- User Interface
  - Intuitive LED based product identification

# Display Panel



- On/Off Switch
- Calibrate Lever (automatically takes background scan)
- Low Battery Indicator
- Analysis Results / Carpet Identification

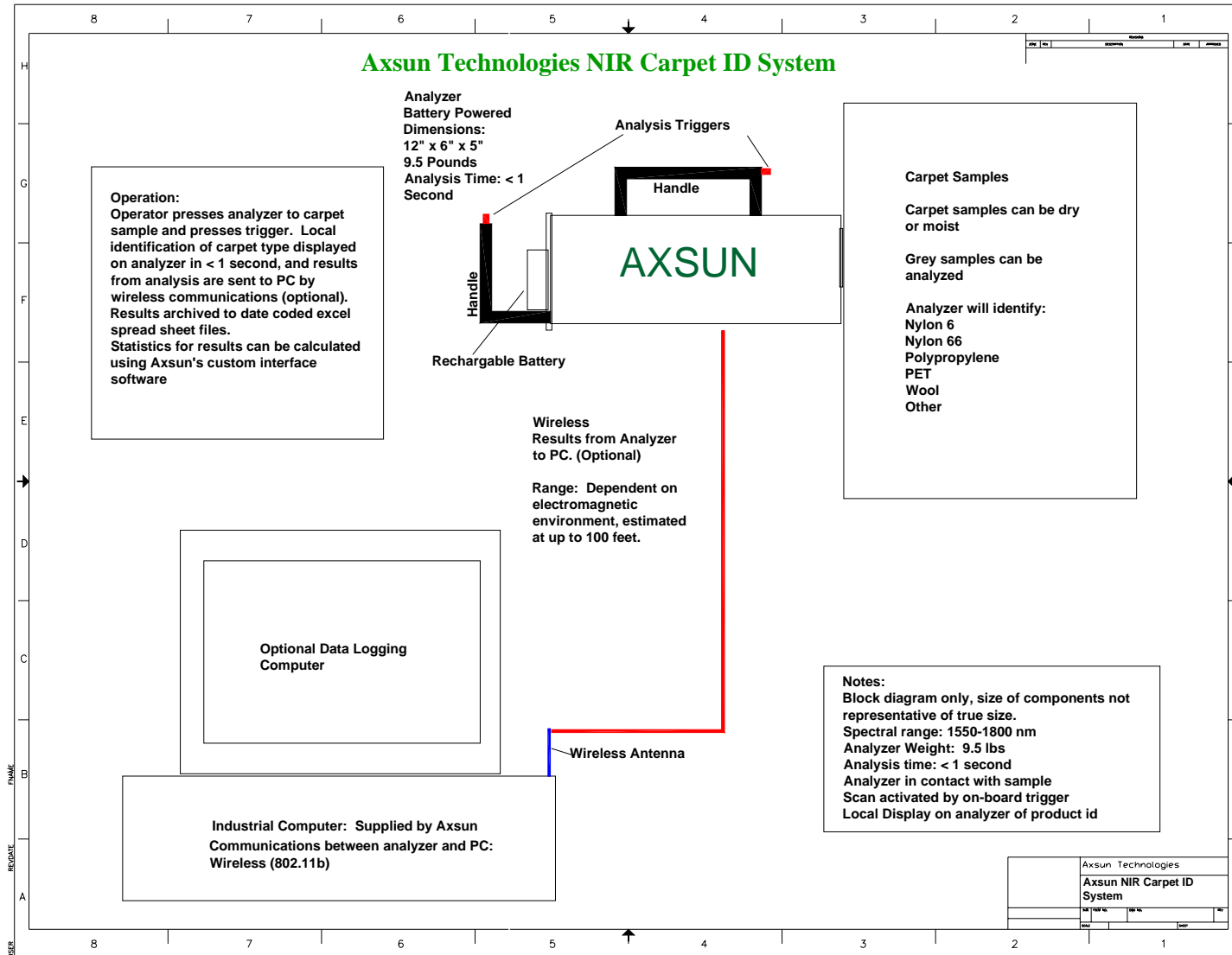
# System Referencing



To “calibrate” the system (collect a reference/background scan the operator simply pulls the reference bar

- A reference material slides into the optical path
- A reference scan is automatically collected and stored
- Takes < 1 second

# Optional wireless (or wired) data logging



# Data Entry/Logging software

**Axsun Carpet Identification System**

Test ID: 
 Supplier Name: 
 City: 
 State:

PO Number: 
 Carrier: 
 # of Bales: 
 Scale Weight: 
 Run Analyzer:

Date:

**Current Sample: Nylon 66**

Analysis	Test ID	Supplier	City	State	P.O.	Carrier	# Bales	Weight	Date	QC Da	
10	PP	Test 1223	Carpet Again Recycling	Mobile	Alabama	PO 8121	Davis Transfer	75	75000	04/11/2006	04/14/2
11	Nylon 6	Test 1223	Carpet Again Recycling	Mobile	Alabama	PO 8121	Davis Transfer	75	75000	04/11/2006	04/14/2
12	Nylon 6	Test 1223	Carpet Again Recycling	Mobile	Alabama	PO 8121	Davis Transfer	75	75000	04/11/2006	04/14/2
13	Unknown	Test 1223	Carpet Again Recycling	Mobile	Alabama	PO 8121	Davis Transfer	75	75000	04/11/2006	04/14/2
14	PP	Test 1223	Carpet Again Recycling	Mobile	Alabama	PO 8121	Davis Transfer	75	75000	04/11/2006	04/14/2
15	Nylon 6	Test 1223	Carpet Again Recycling	Mobile	Alabama	PO 8121	Davis Transfer	75	75000	04/11/2006	04/14/2
16	Wool	Test 1223	Carpet Again Recycling	Mobile	Alabama	PO 8121	Davis Transfer	75	75000	04/11/2006	04/14/2
17	Unknown	Test 1223	Carpet Again Recycling	Mobile	Alabama	PO 8121	Davis Transfer	75	75000	04/11/2006	04/14/2
18	Nylon 6	Test 1223	Carpet Again Recycling	Mobile	Alabama	PO 8121	Davis Transfer	75	75000	04/11/2006	04/14/2
19	Wool	Test 1223	Carpet Again Recycling	Mobile	Alabama	PO 8121	Davis Transfer	75	75000	04/11/2006	04/14/2
20	Nylon 6	Test 1223	Carpet Again Recycling	Mobile	Alabama	PO 8121	Davis Transfer	75	75000	04/11/2006	04/14/2
21	Nylon 66	Test 1223	Carpet Again Recycling	Mobile	Alabama	PO 8121	Davis Transfer	75	75000	04/11/2006	04/14/2
22	PP	Test 1223	Carpet Again Recycling	Mobile	Alabama	PO 8121	Davis Transfer	75	75000	04/11/2006	04/14/2
23	Nylon 6	Test 1223	Carpet Again Recycling	Mobile	Alabama	PO 8121	Davis Transfer	75	75000	04/11/2006	04/14/2
24	Nylon 66	Test 1223	Carpet Again Recycling	Mobile	Alabama	PO 8121	Davis Transfer	75	75000	04/11/2006	04/14/2
25											
26											

Simulate: 
 Delay:

Show ActiveX

**Daily Summary**

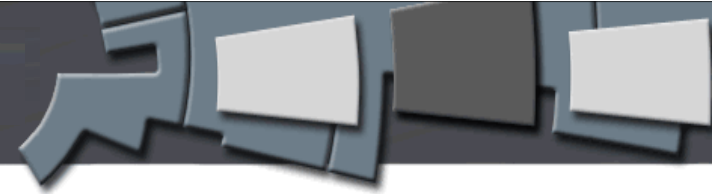
Type	Count	Percent
1 Nylon 6	549	51.74 %
2 Nylon 66	217	20.45 %
3 PolyProp (PP)	155	14.61 %
4 PET	0	0 %
5 Wool	97	9.14 %
6 Unknown	43	4.05 %
7 Total	1061	
8		

# System Calibration Test Samples

## Test Samples Supplied by customer



# Pre-shipment testing

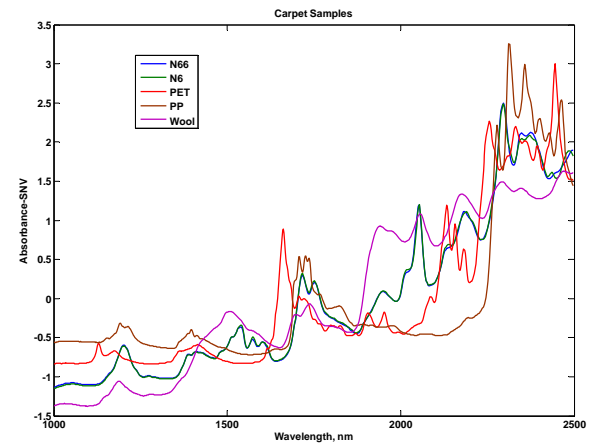


<b>Carpet #</b>	<b>Sample Type</b>	<b>Measured</b>
1	Nylon_6	Nylon_6
2	Nylon_6	Nylon_6
3	Nylon_6	Nylon_6
4	Nylon_6	Nylon_6
5	Nylon_6	Nylon_6
30	Nylon_66	Nylon_66
31	Nylon_66	Unknown_Nylon
32	Nylon_66	Nylon_66
33	Nylon_66	Nylon_66
34	Nylon_66	Nylon_66
35	PET	PET
36	PET	PET
37	PET	PET
38	PET	PET
57	Polypropylene	Polypropylene
58	Polypropylene	Polypropylene
59	Polypropylene	Polypropylene
60	Polypropylene	Polypropylene
61	Polypropylene	Polypropylene
66	Wool	Wool
67	Wool	Wool
68	Wool	Wool
69	Wool	Wool
70	Wool	Wool

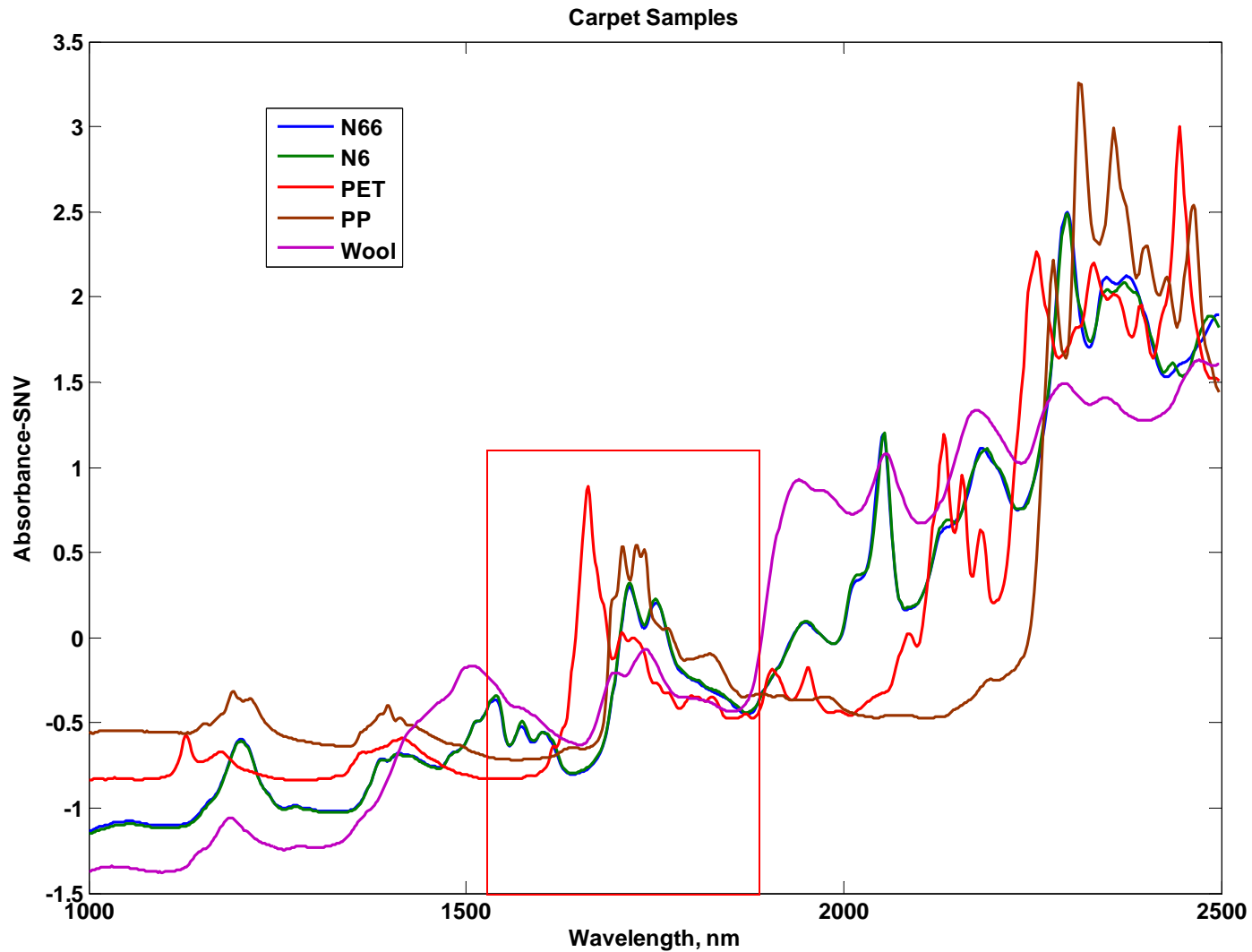
## Summary:

- 70 Carpet samples tested
- 69 properly identified (98.6%)
- None misidentified
- 1 identified as “Unknown Nylon”

# Full Range FTNIR Spectra

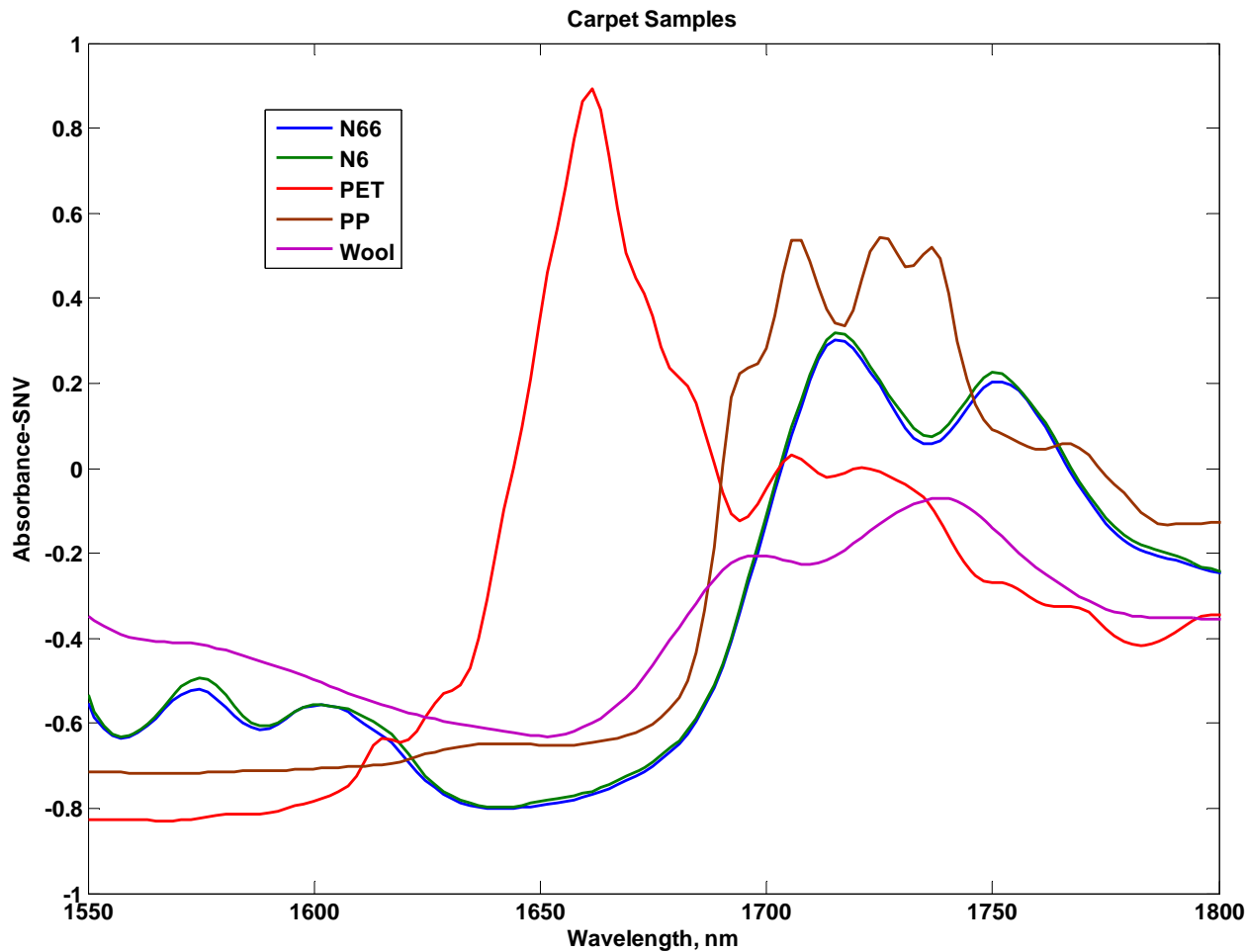
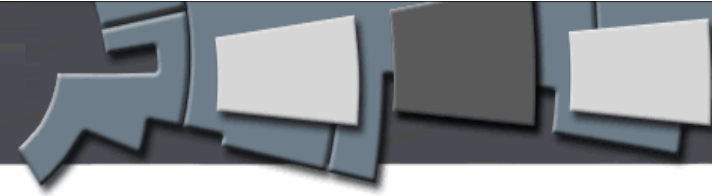


# Full Range FTNIR Spectra



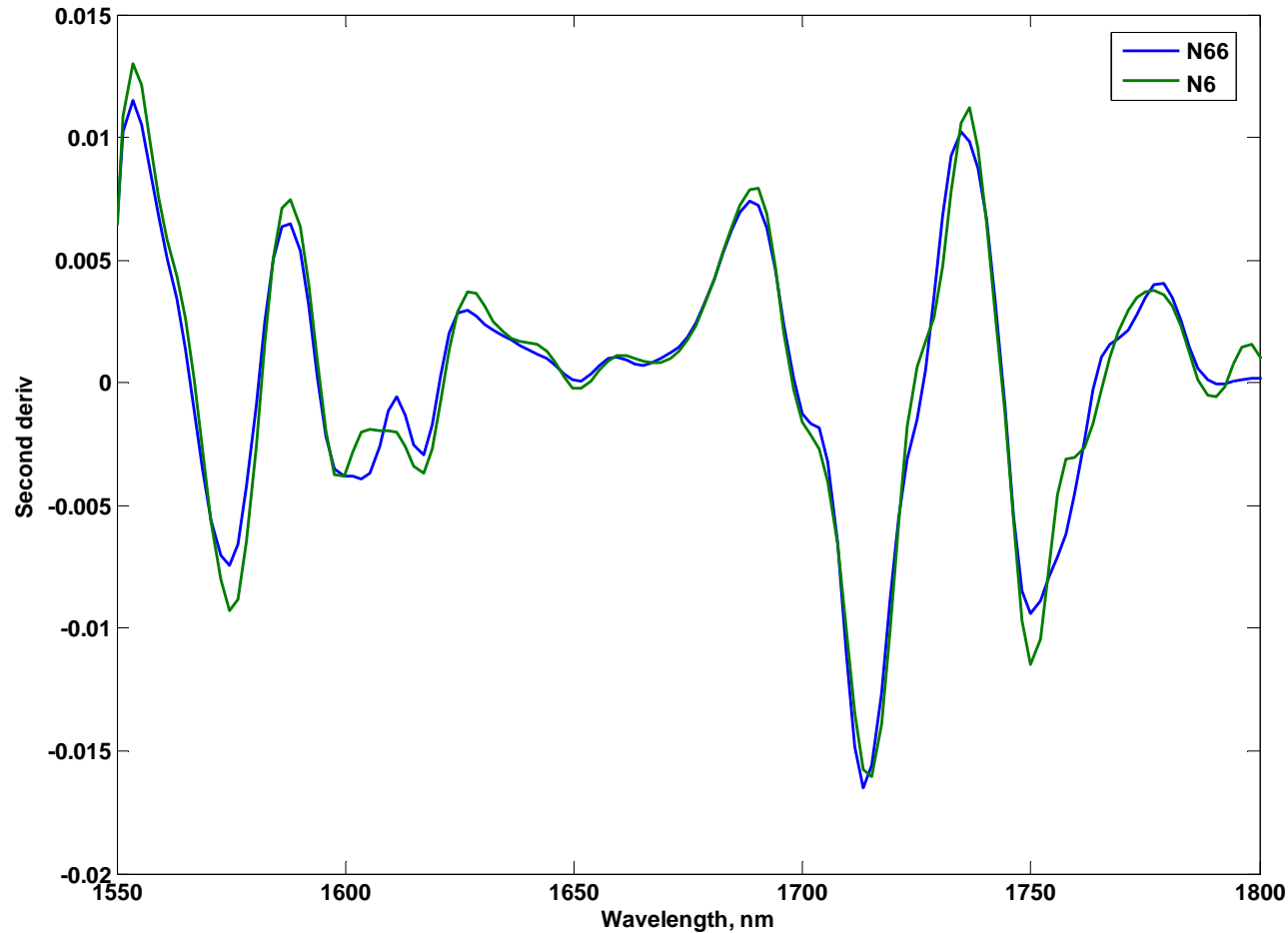
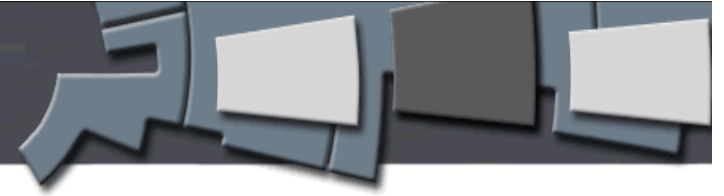
The wavelength range covered by Axsun's system is ideal for carpet analysis

# Axsun Analyzer Spectra



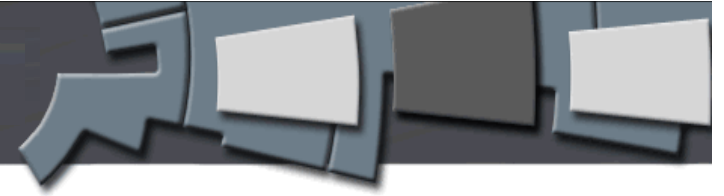
- PET, PP and Wool can be seen to be dramatically different from each other and Nylons.
- Small observed differences in Nylons can be used to develop highly reliable analysis methods

# Axsun Analyzer Spectra



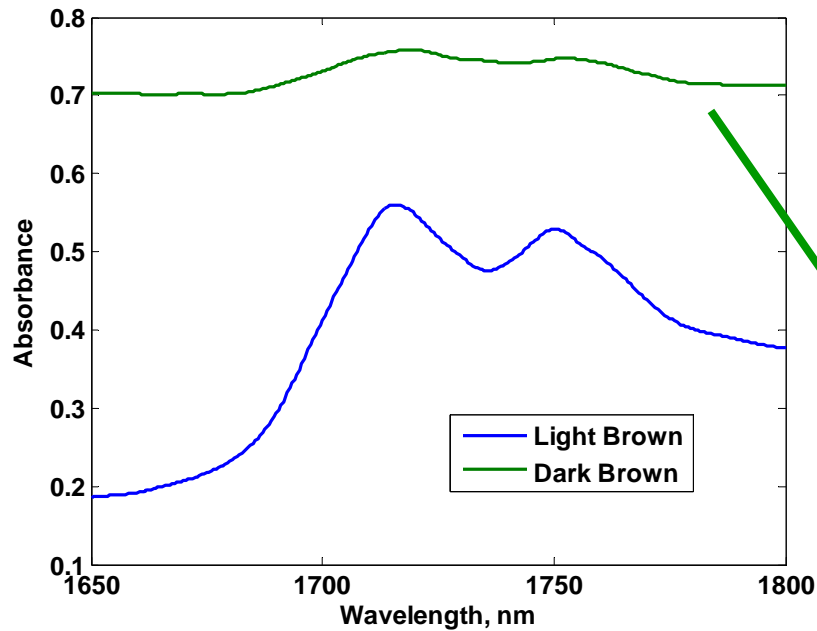
Analyzer's very high "Signal to noise ratio" allows for differentiation based on relatively small spectral differences

# “Dirty” Samples



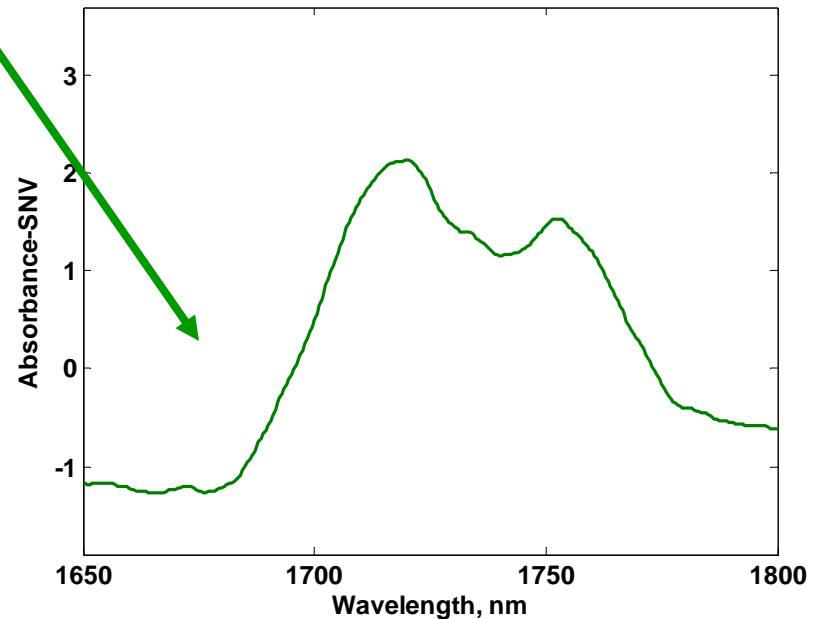
- Extensive testing has been successfully performed on “real-world” used carpet samples
- Operators are trained to perform the analysis on a piece of the carpet sample that doesn’t have obviously large grease/oil contamination

# Dark Carpets

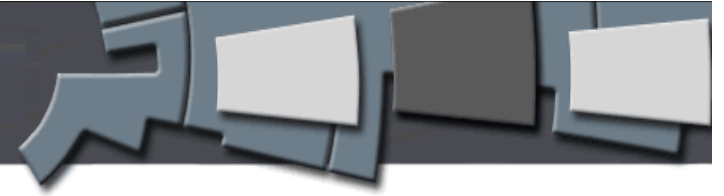


- Very dark samples “Absorb” much more light than lighter samples
- Data processing normalizes this intensity effect for most samples

- Samples that are too absorbing will be classified as “Unknown”
- This is a very small percentage of carpet materials



# Blended Carpets

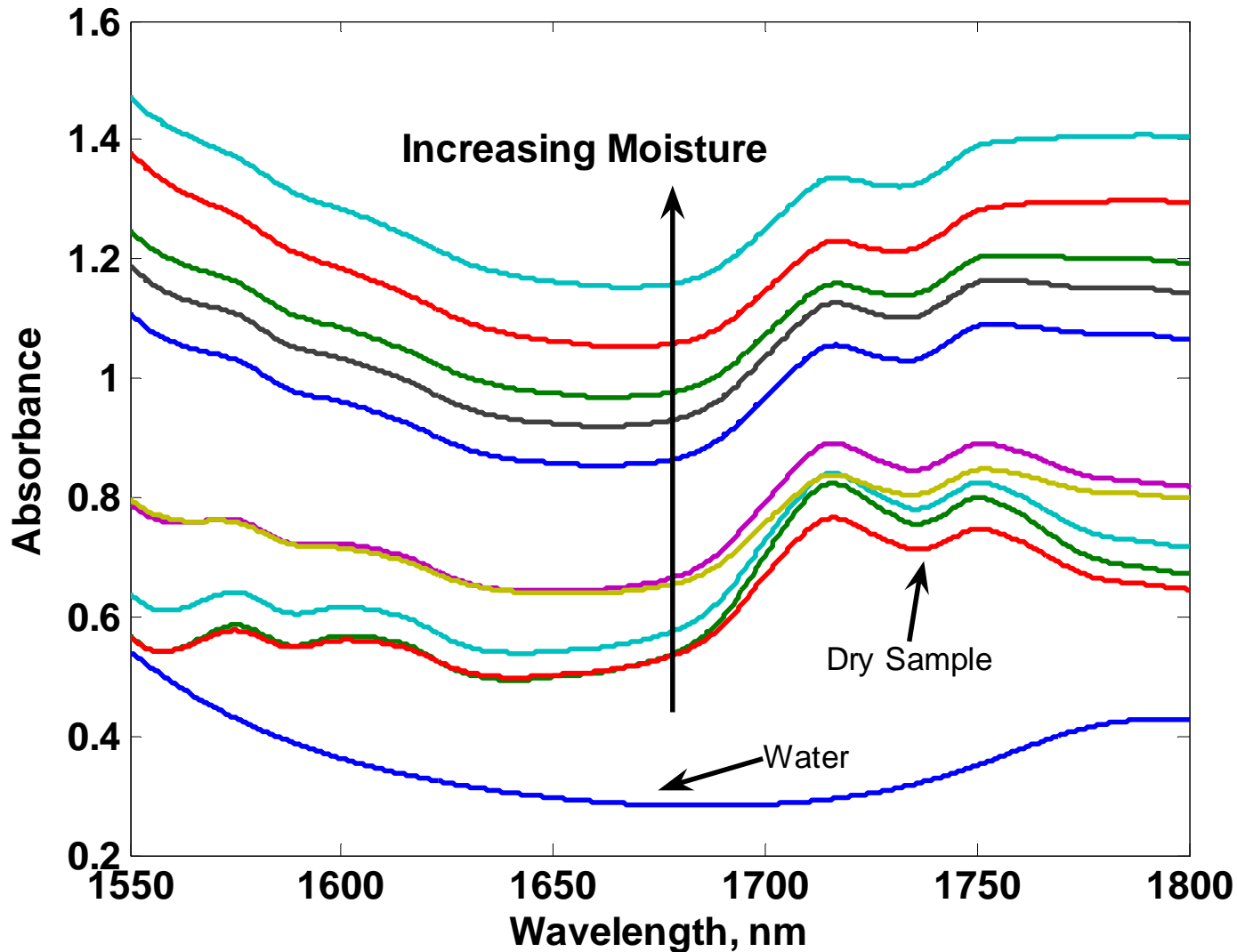


- Blended Carpets contain more than one material
  - Example: Nylon 6 / Polypropylene Blends
- The spectra for the blended samples will contain features of both blended materials
- Blended carpets that aren't predominantly one material will be classified as "Unknown"

# Axsun's system can accurately identify wet samples



## Nylon 6 - Wet sample



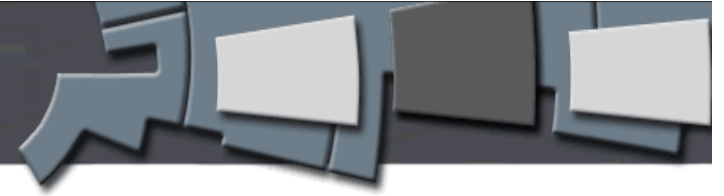
Mathematical correction applied to minimize distortions due to water in samples

# System Status



- Several systems currently being evaluated in the field.
- Currently optimizing system performance
  - Evaluating existing models
  - Evaluating model pass/fail limits
  - Evaluating alternate algorithms
- Upon completion of trials, Axsun's carpet analyzer will be offered to the market

# Conclusion



- A hand-held carpet identification analyzer has been developed for the rapid screening of carpet materials for a recycling application
- The system uses a high resolution, tunable laser source that allows for accurate analysis of carpet samples
- Performance of a benchtop conventional spectrometer is available in a portable analyzer
  - Portable
  - Rugged solid state optical system
  - Rapid analysis (< 1 second)
  - Single button operation
  - Battery Operated
  - Light ( 9.5 Pounds)
  - On-board data processing allows stand-alone operation
  - Wireless operation allows for real-time data logging
  - Common analyzer platform for:
    - Bench-top
    - Portable stand-alone version
    - Portable data-logging version
- Feedback from initial field testing of several systems has been incorporated into improvements in analytical capabilities

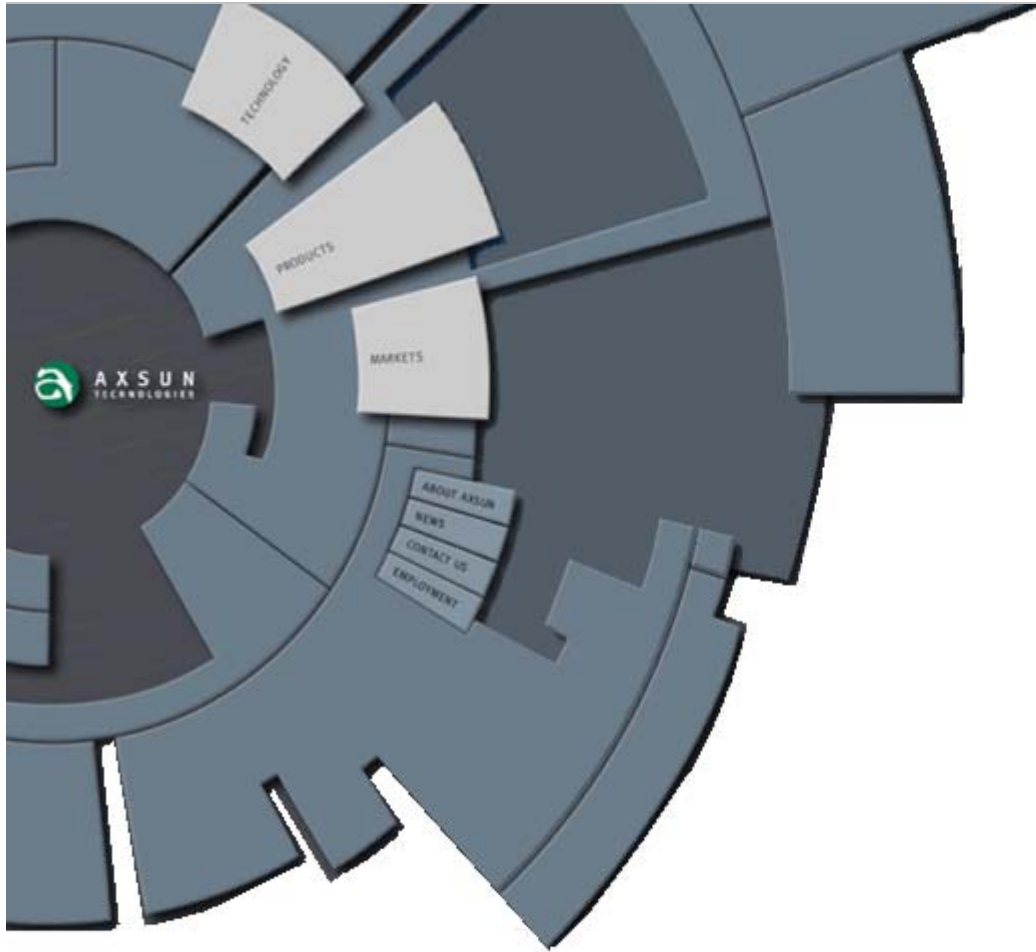
# Acknowledgements

- Bob Jenner – Lead Project Engineer
- Walid Atia - Co-lead Project Engineer

- Customers

- Infiltrator Systems team
- Infiltrator Systems field evaluation partners





Thank you!