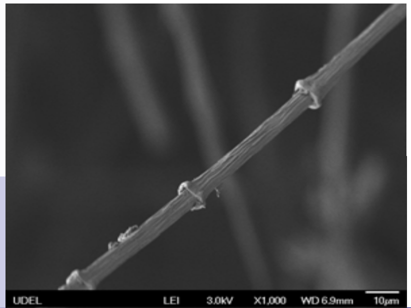

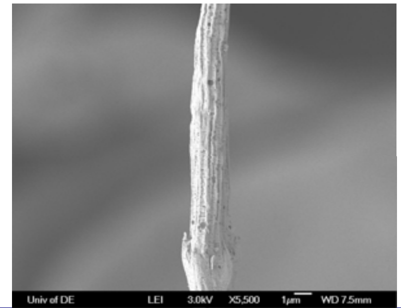

HYDROGEN STORAGE ON CARBONIZED CHICKEN FEATHER FIBERS

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13th Annual Green Chemistry & Engineering Conference, June 23, 2009

OUTLINE

- Introduction
  - Storage Problem Overview
  - Structure of Chicken Feather Fibers (CFF)
- Experimental Results
  - Thermal Analysis (DSC and TGA with Mass Spec.)
  - Hydrogen Storage Results
- Conclusions
- Acknowledgements

Hydrogen Facts

Hydrogen Powered UD Bus[3]

- Energy density → ~3 times larger than gasoline[1]
- Fuel cells are at least 2 times more efficient than combustion engines[2]
- Gasoline density: 0.75 kg/L
  - H_2 density at STD: 8.98×10^{-5} kg/L → 8000 times lighter
  - H_2 density at 350 bars: 0.025 kg/L → 30 times lighter
  - Liquid H_2: 0.07 kg/L → 11 times lighter
- If a material fulfills the DOE H_2 storage targets for 300 miles range:

~75 kg/vehicle is required

$5.5 million/vehicle is required for SWCNT
$22, 000/vehicle is required for MWCNT

1 Louis Schlapbach, MRS Bull., 2002
2 Jesse L. C. Rowsell and Omar M. Yaghi, Angew. Chem. Int. 2005,44, 4670-4679
3 UDaily Archive April 9, 2007

OBJECTIVES

- To find the best process to obtain H_2 storage material from waste materials, chicken feather fibers (CFF)

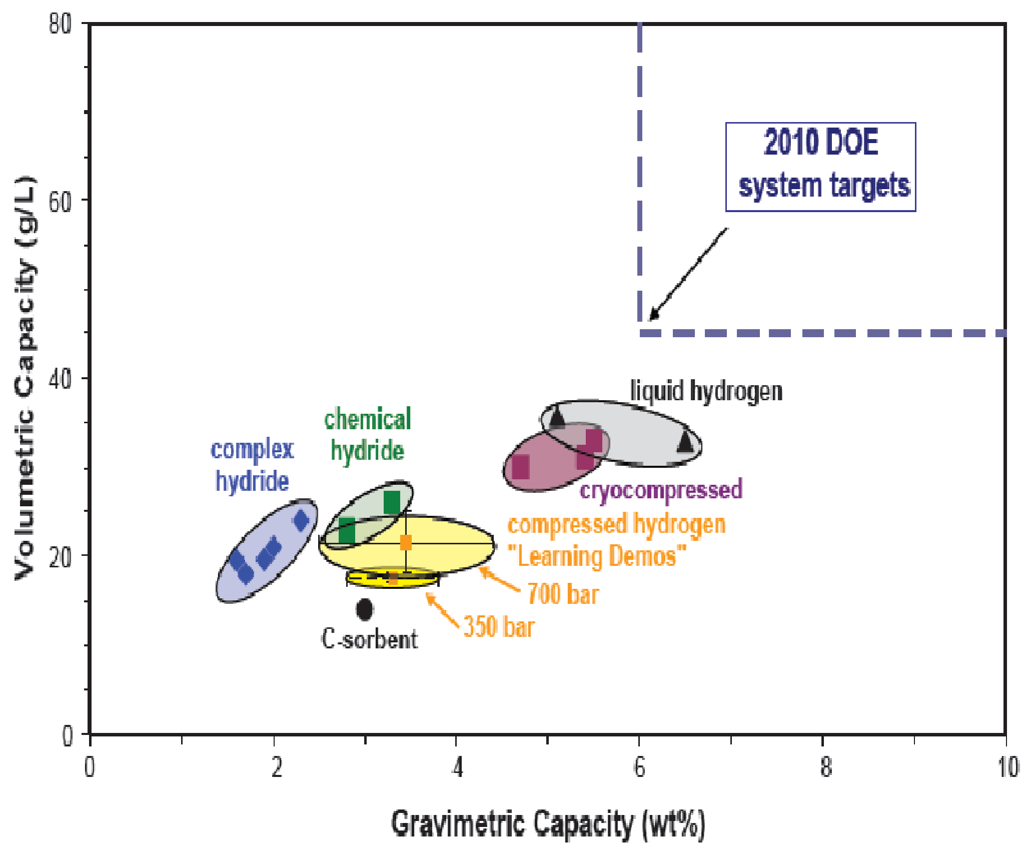
- To fulfill Department of Energy's (DOE) 2010 H_2 storage targets which are
  - Gravimetric Capacity= 6 wt% H_2 (light)
  - Volumetric Capacity= 45 g H_2/l (compact)
  - System Storage Cost= $4 /kWh (cheap to store)
  - System Cost= $666 (cheap)

  for future H_2 powered technologies.

Background

- **Physisorption (ΔH_{ads}= ~4 kJ/mol)**
  - *Graphite*
  - *Carbon Nanofibers*
  - *Carbon Nanotubes*
  - *Metal Organic Frameworks (MOF)*
  - *Activated Carbon*
- **Chemisorption**

  (ΔH_{ads} = ~50-100 kJ/mol)
  - *Metal Hydrides*
  - *Complex Hydrides*

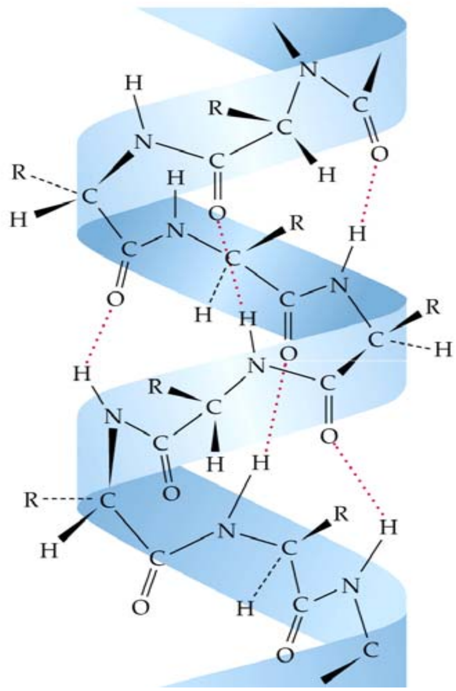


Status of hydrogen storage vs. system targets as of 2008[1]

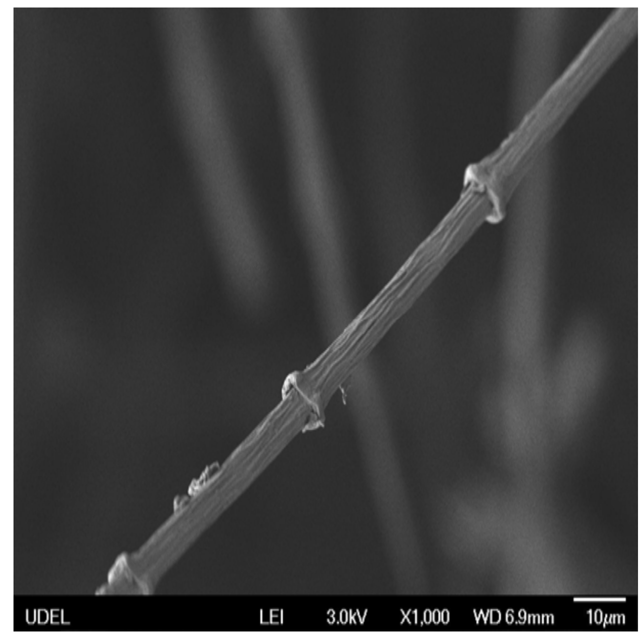
1 Annual Progress Report, DOE Hydrogen Program, 2008

Chicken Feather Fiber (CFF) Properties

- Bio-renewable
- Agricultural waste
- Very cheap!
- 6 μm diameter[1]
- Above 92% Keratin[2]
- Hollow tubes[1]
- Low density



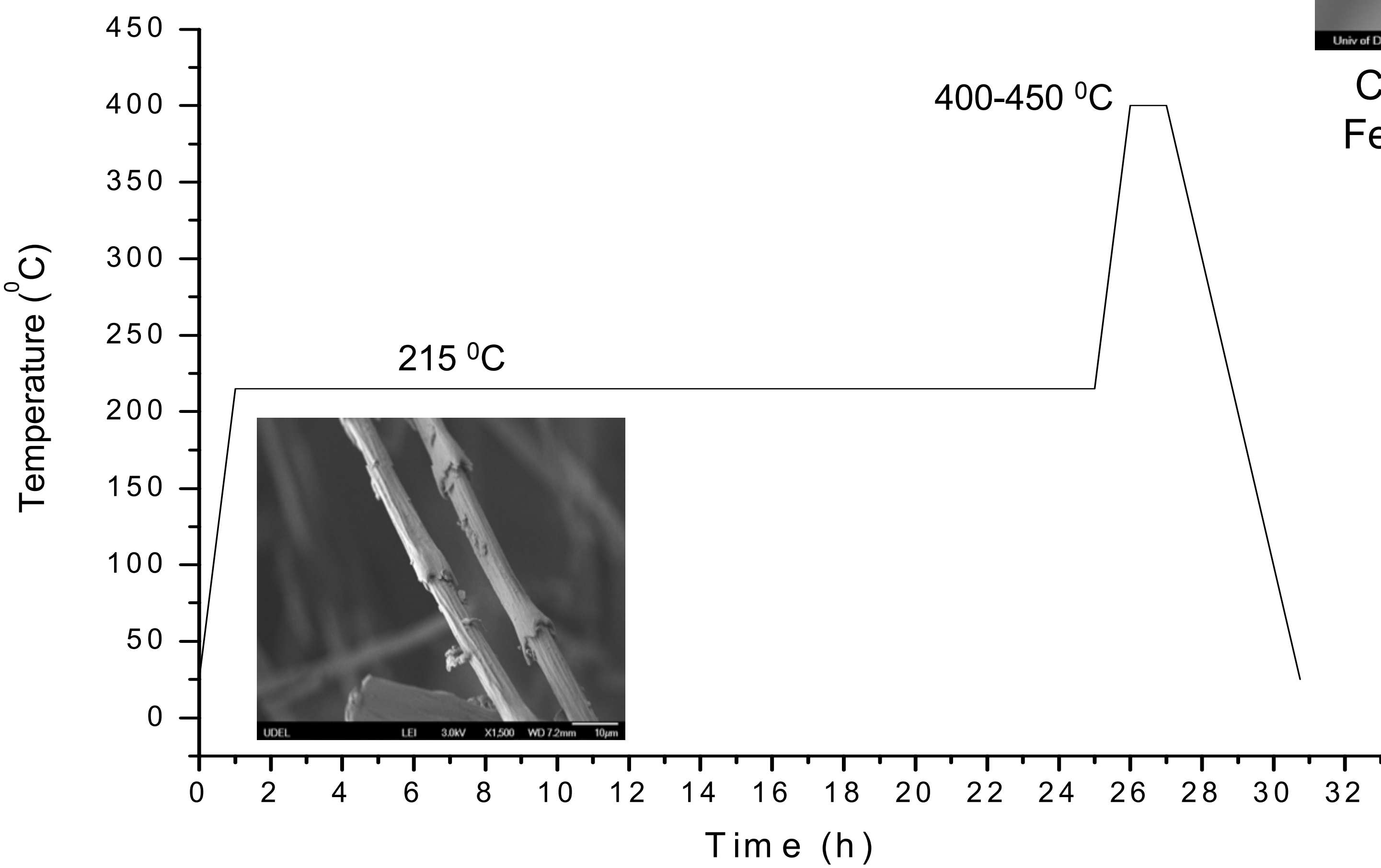
α-helix Keratin Structure

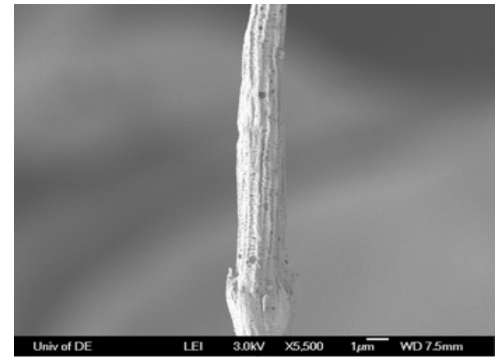


SEM image of CFF, X1000 magnification

1 Hong, Chang K and Richard P. Wool "Development of a Bio-based Composite Material from Soybean Oil and Keratin Fibers" 2005
2 Farner, Donald S. et al. Avian Biology. vol 6. Academic Press, New York: 1982.

XPS ANALYSIS OF PYROLYSIS OF CFF





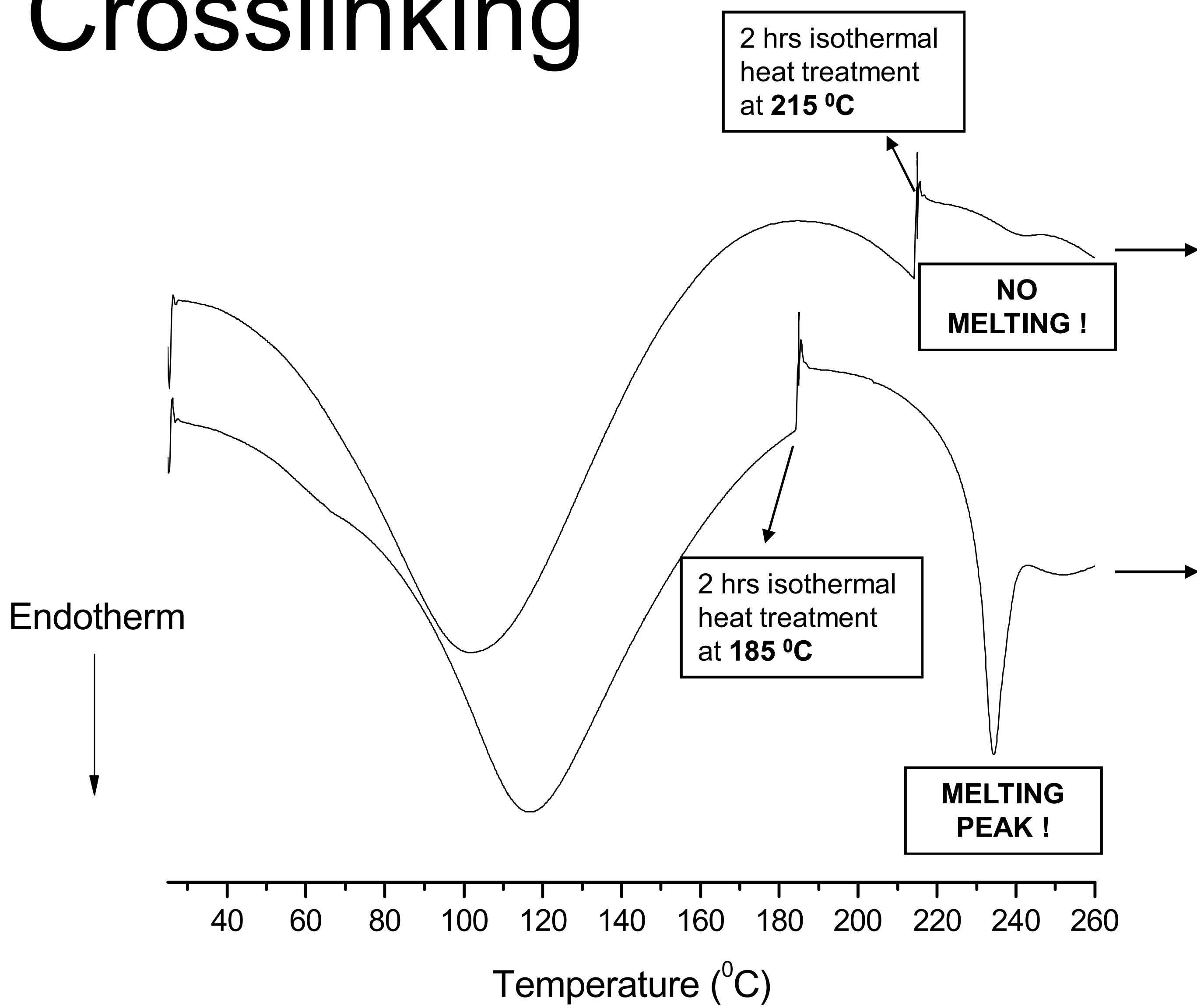
Carbonized Chicken Feather Fiber (CCFF)

Specific Surface Area = **100-450 m^2/g**

Pore Volume = **0.06 - 0.2 cm^3/g**

Pore Size= **< 1 nm**

Crosslinking

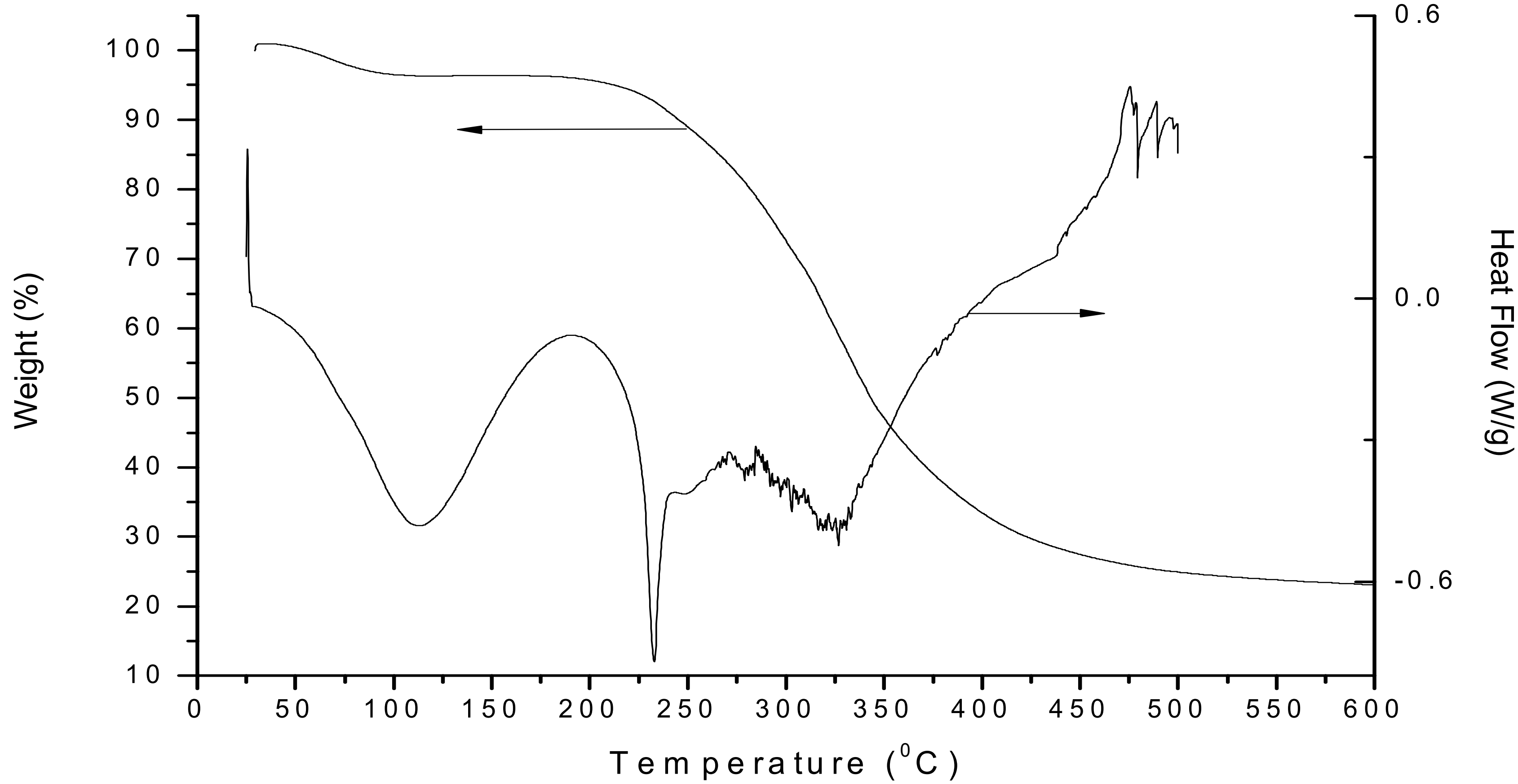


With isotherm at 215 ^{0}C

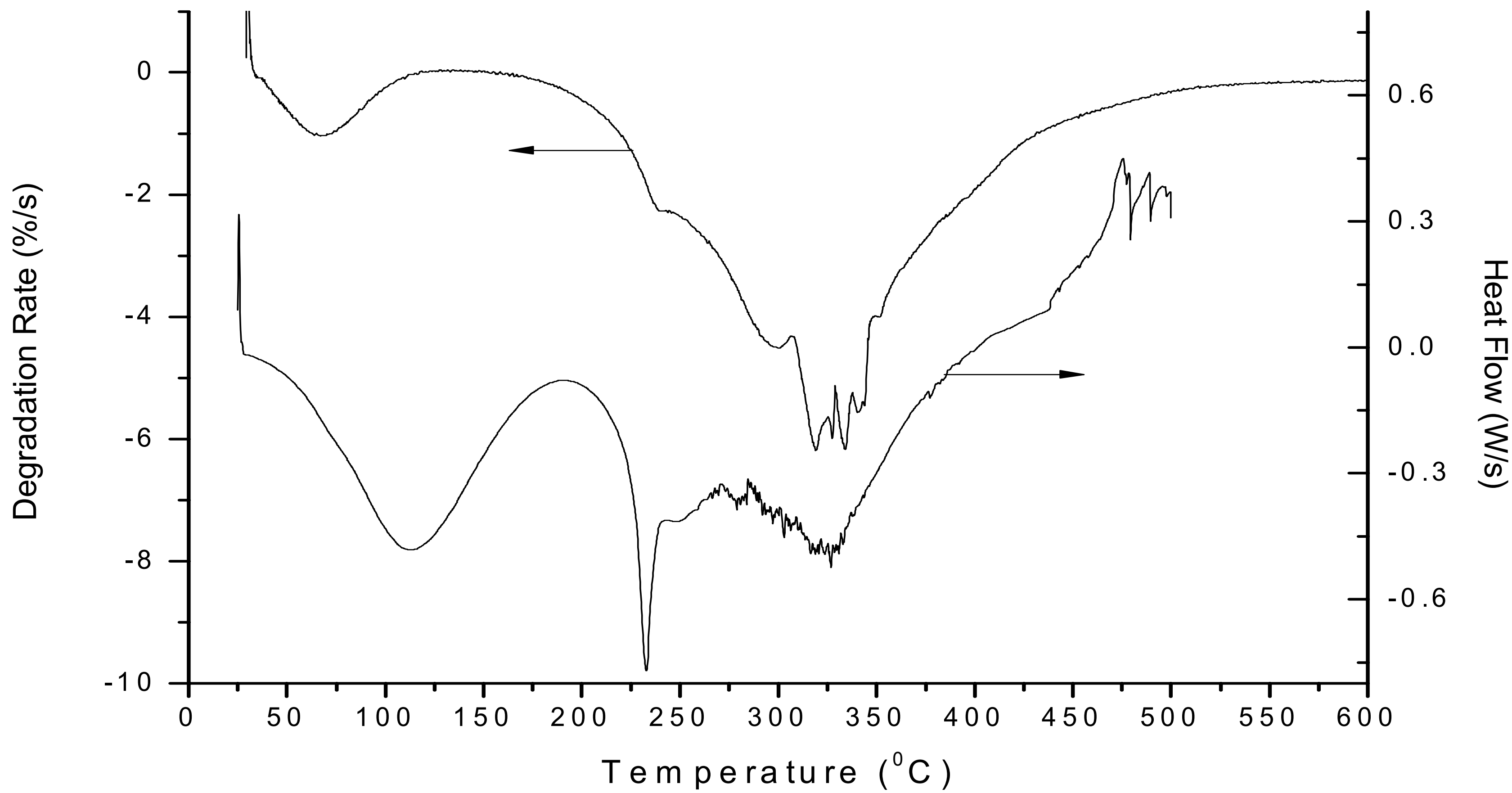
With isotherm at 185 ^{0}C

Thermal Analysis of CFF (TGA and DSC)

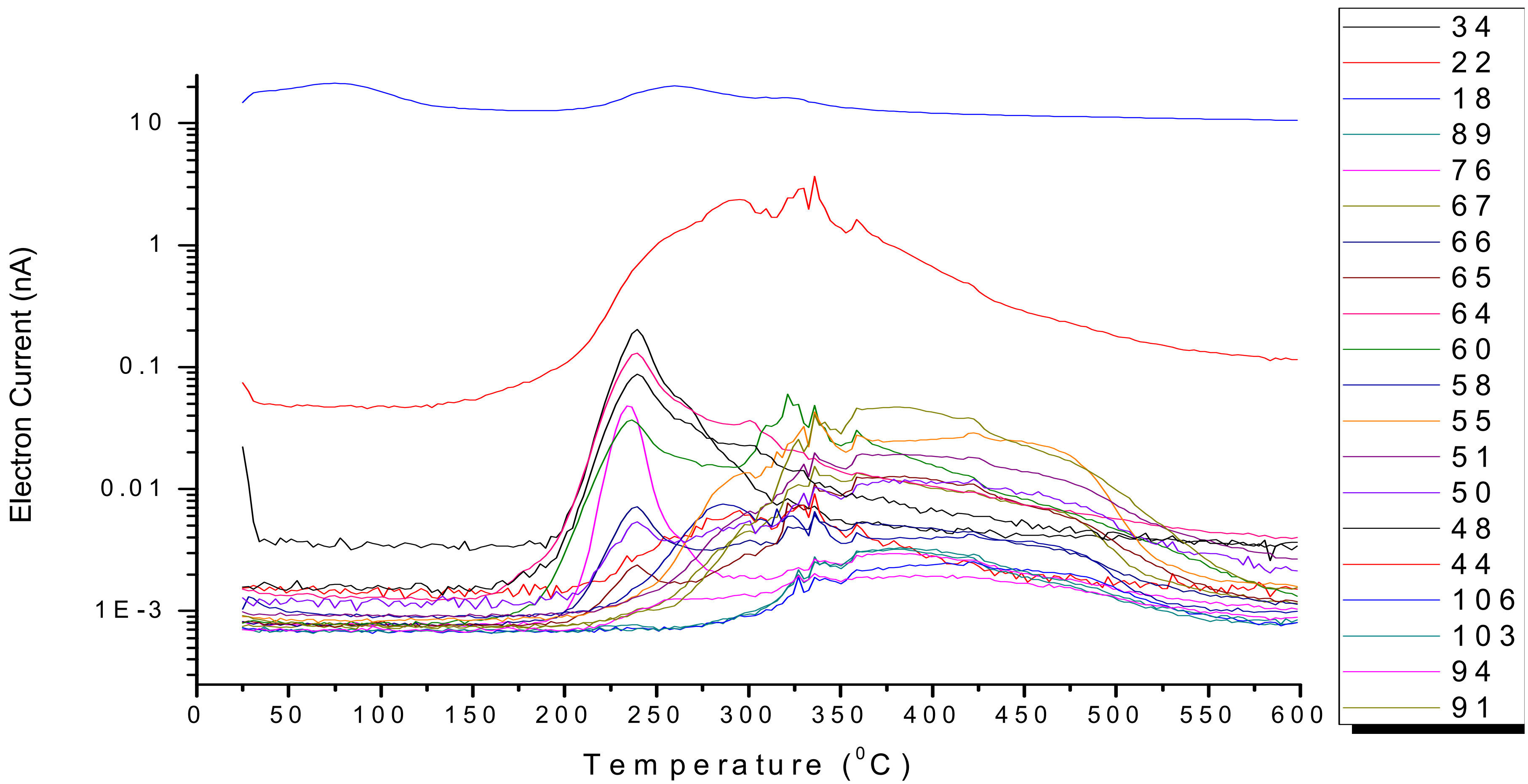
Melting transition is at ~230 ^{0}C



Thermal Analysis of CFF (TGA and DSC)



Thermal Analysis (TGA+Mass Spec.)



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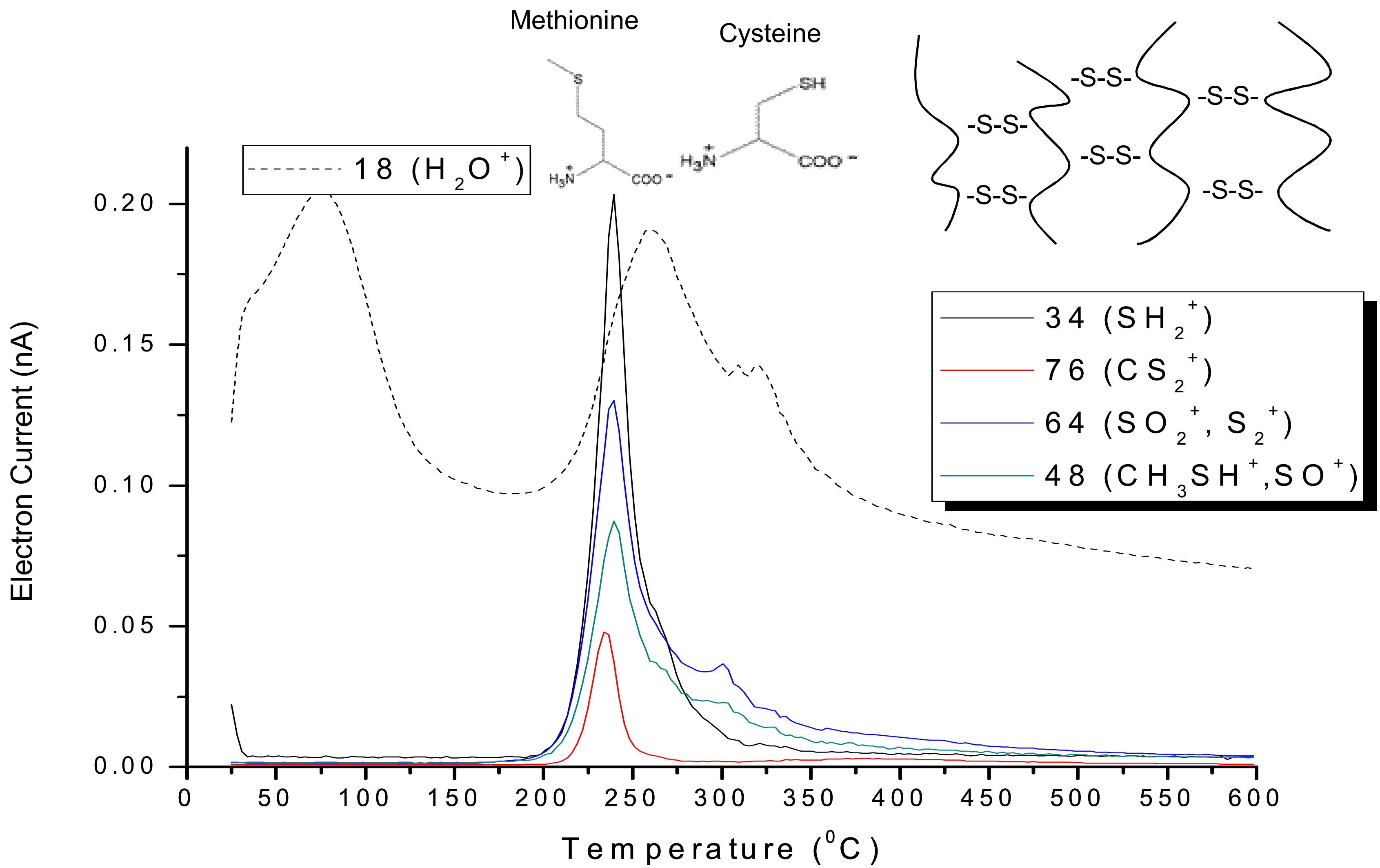

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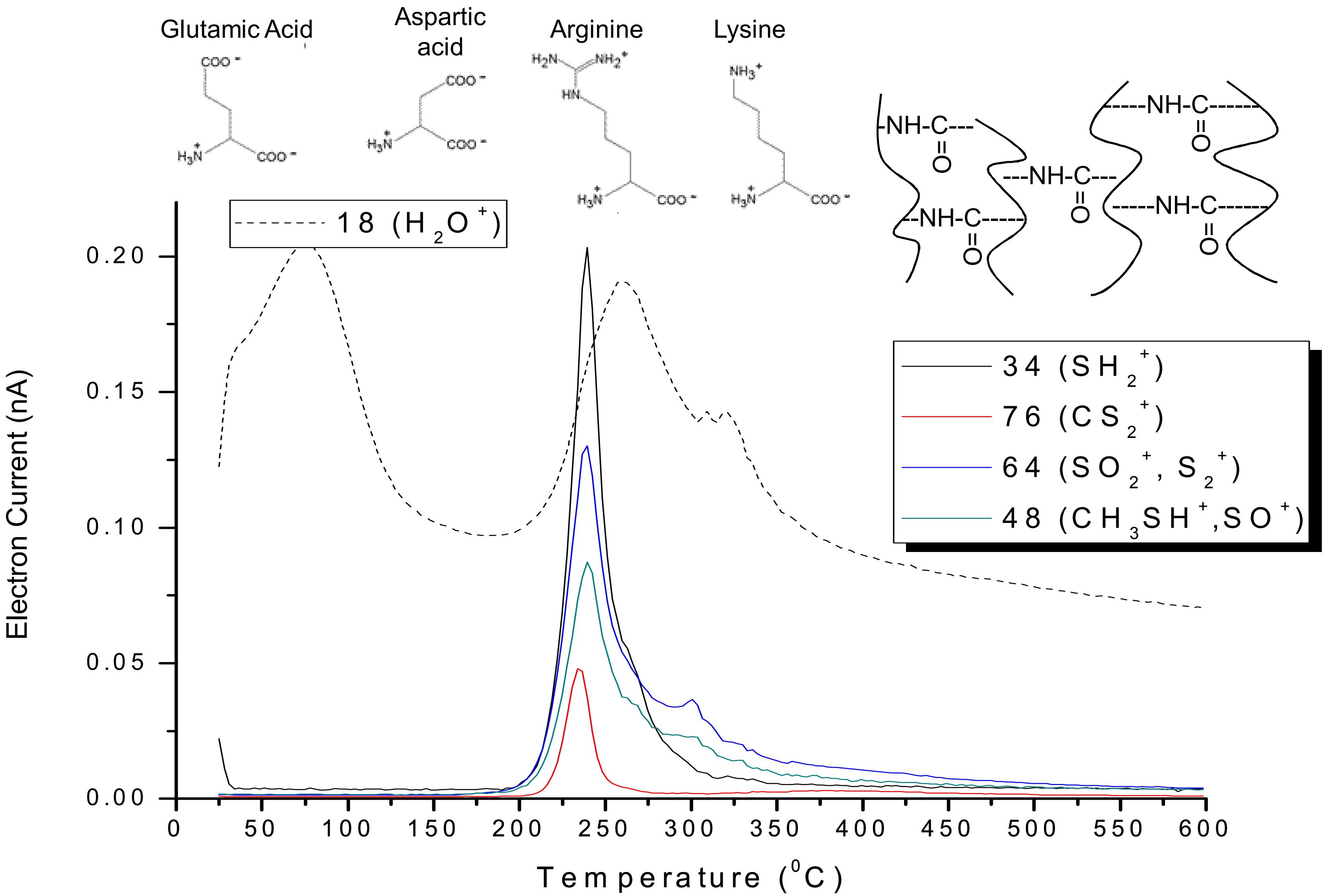

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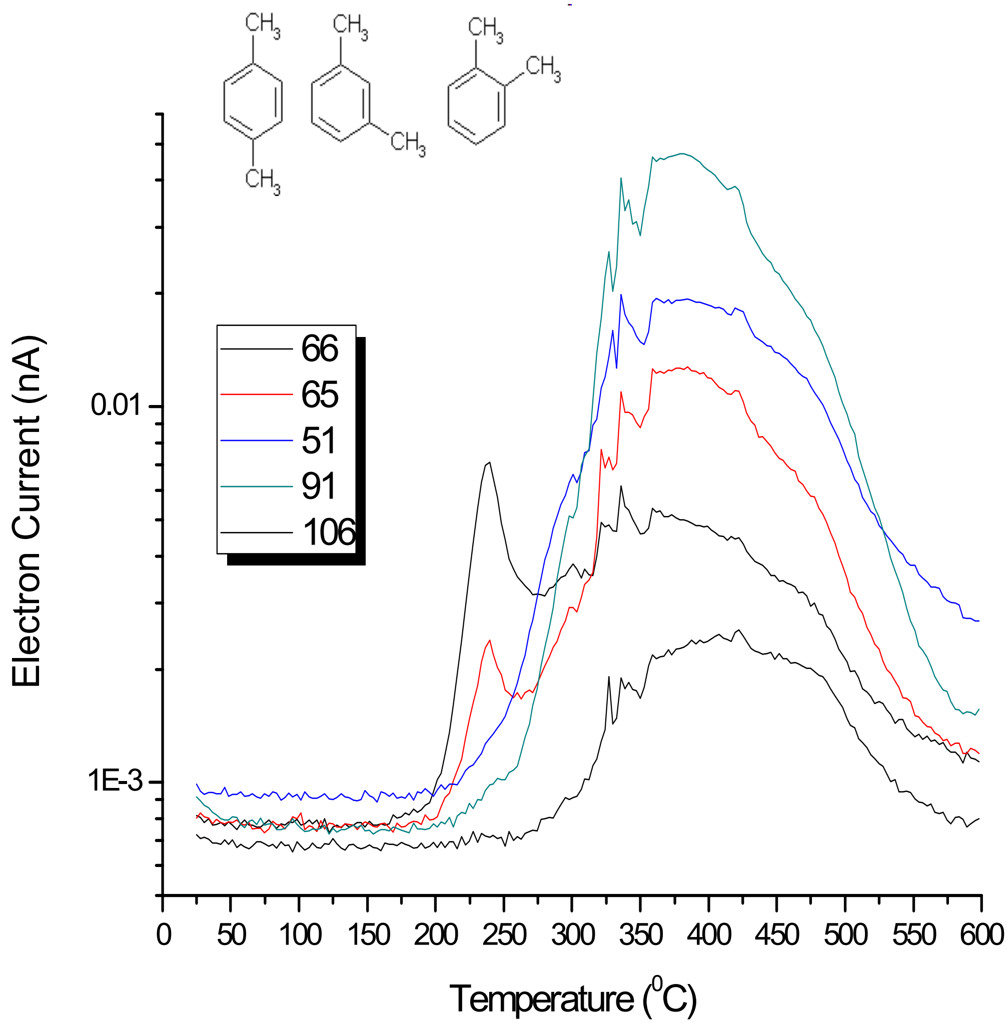
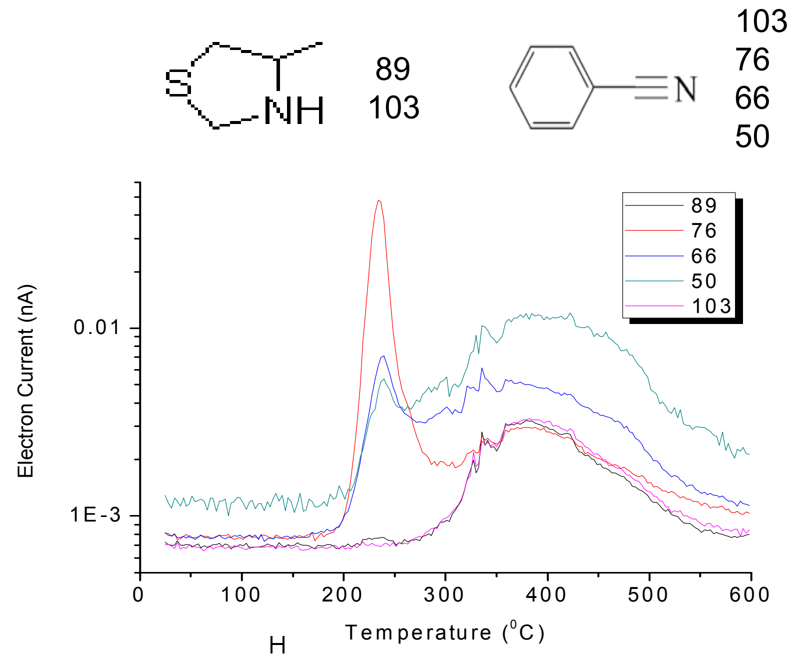
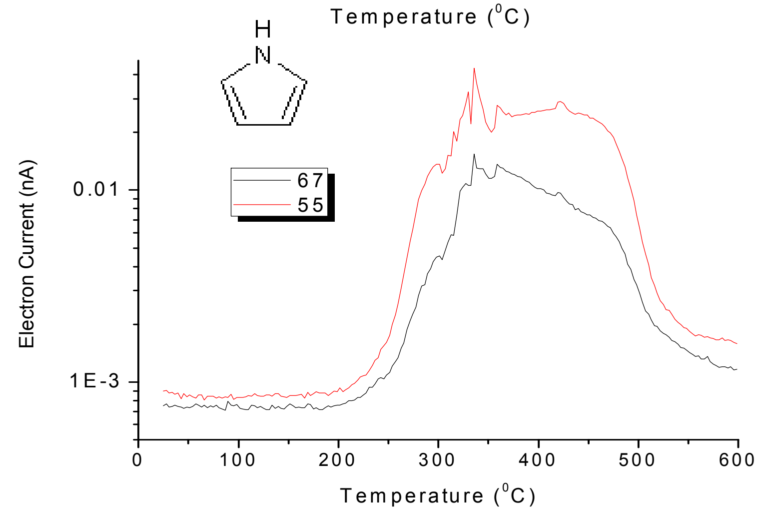
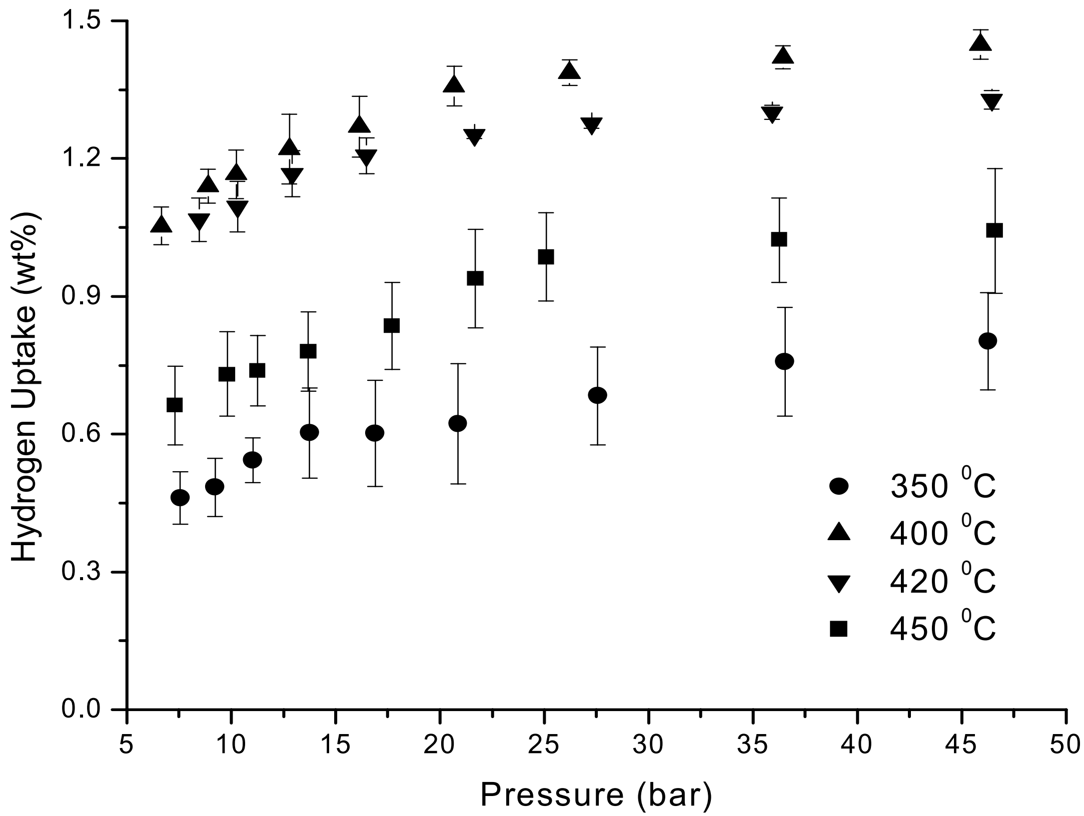
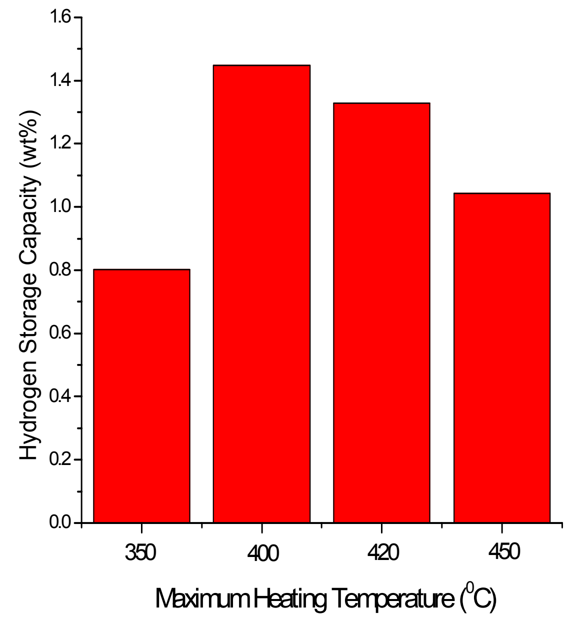






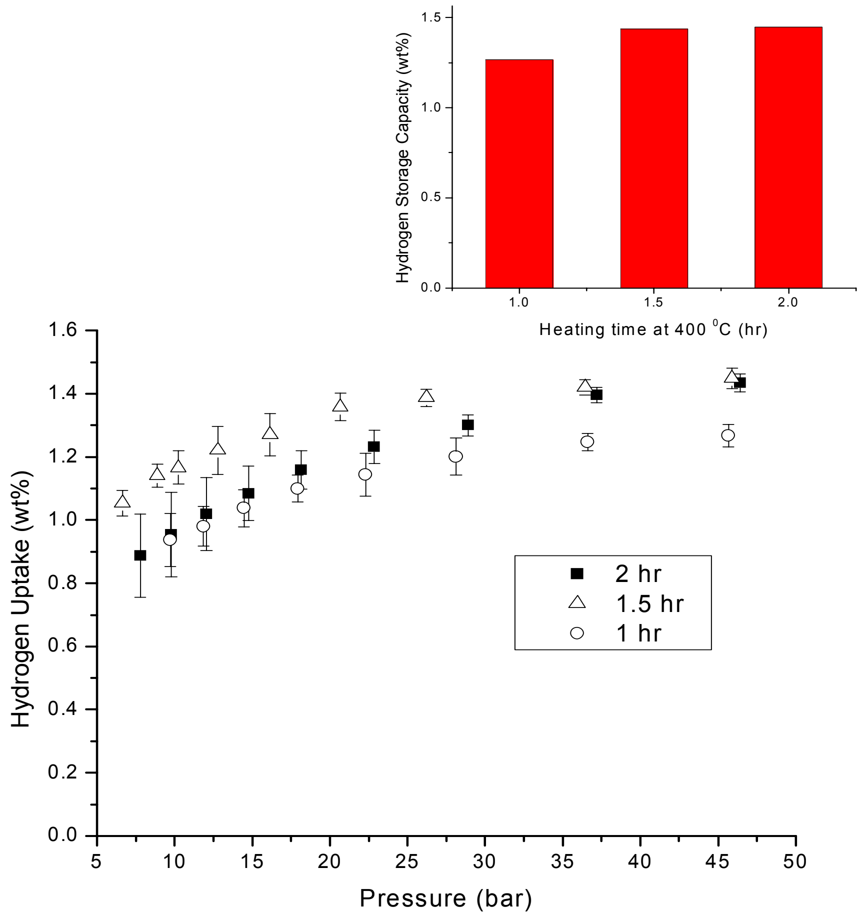
Hydrogen Uptake Capacities



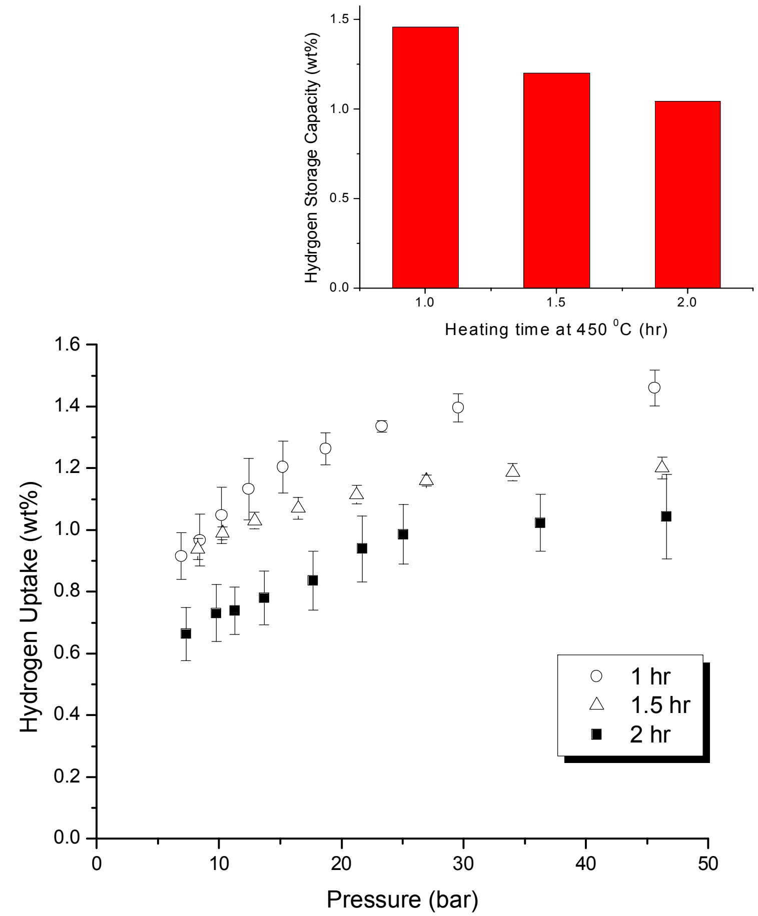


Hydrogen storage capacities of CCFF heated up to 350, 400, 420, 450 ^{0}C for 2 hrs

Hydrogen Uptake Capacities



Hydrogen storage capacities of CCFF heated up to 400 ⁰C for 1, 1.5 and 2 hrs performed at 77K



Hydrogen storage capacities of CCFF heated up to 450 ⁰C for 1, 1.5 and 2 hrs performed at 77K

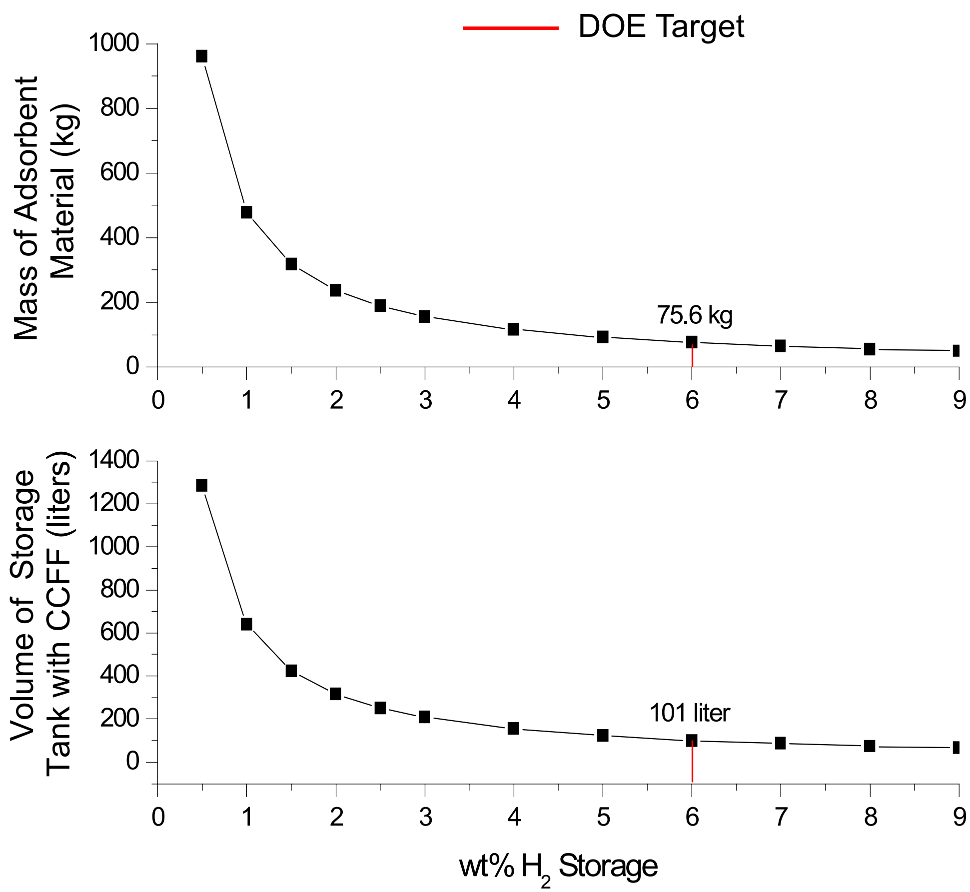
Conclusions

- CFF structure can be retained even at high temperatures by crosslinking during heat treatment. Sulfur and Amide crosslinks play an important role.
- Above 260 ^{0}C systematic aromatization and cyclization reactions take place accompanying the degradation.
- Optimized heating time and temperature values were determined:
  - 400 ^{0}C for 1.5-2 hrs or 450 ^{0}C for 1hr
- Pore size distribution is quite suitable for H_2 storage.
- Seeking other applications for the CCFF?
  - Gas separation and purification
  - Mechanical properties of non-porous CCFF samples
  - Separation of pyrolysis products

ACKNOWLEDGEMENTS

- This project was supported by the National Research Initiative of the USDA Cooperative State Research, Education and Extension Service, grant number 2005-35504-16137.
- Anne Dillon - National Renewable Energy Laboratory
- The Wool Research Group
- The Lobo Group
- George Whitmyre - Colburn Lab Manager
- Steve Sauerbrunn - METTLER TOLEDO

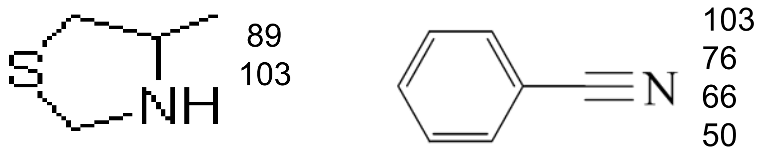
How to reach 300 miles range?

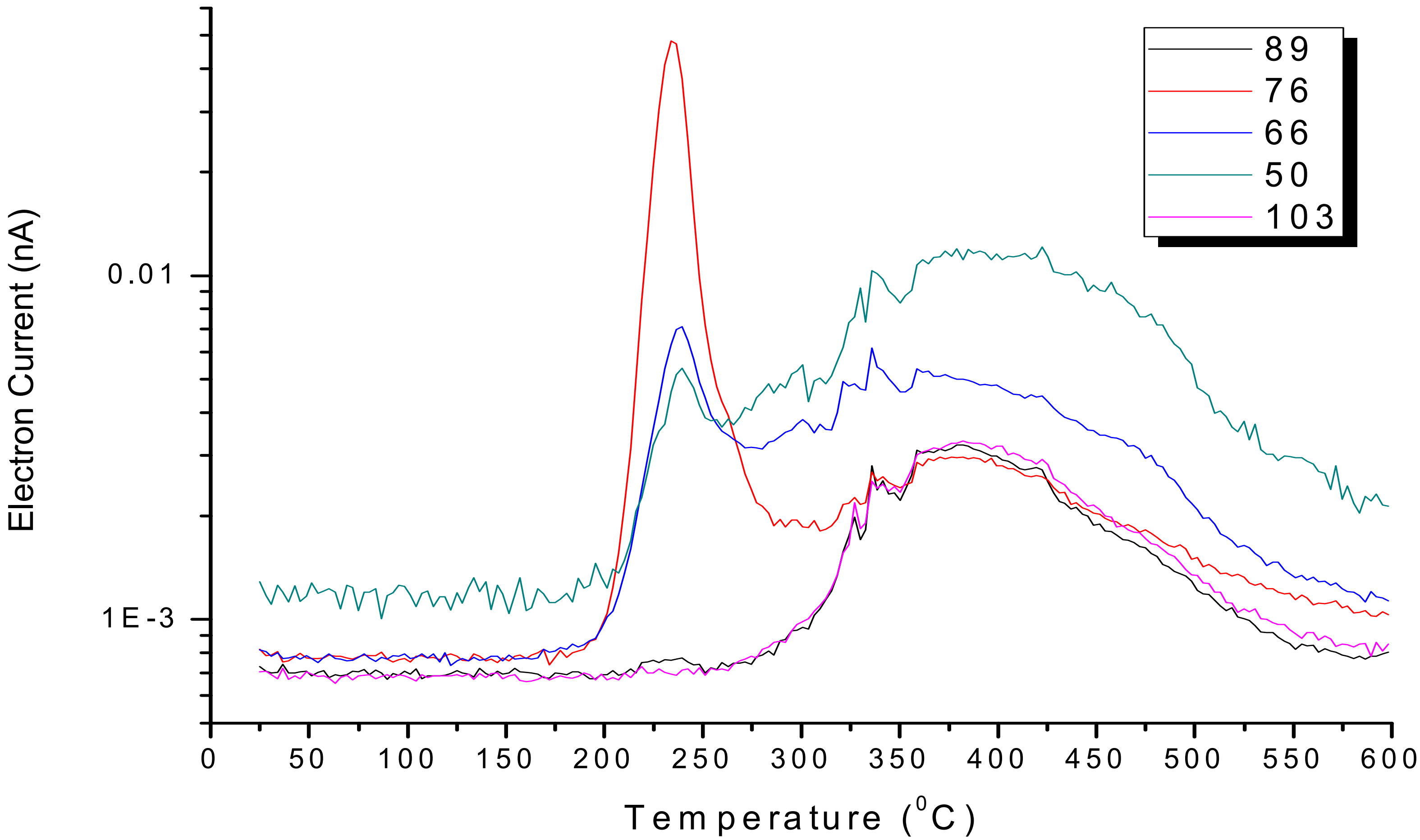


Required adsorbent mass and CCFF tank volume to build a car with 300 miles range

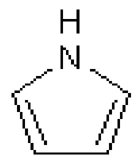
- Hydrogen's extreme low density requires huge tanks!
- Relatively high wt% H_2 storage values has to be achieved!
- Material has to be as cheap as possible!

Thermal Analysis (TGA+Mass Spec.)





Thermal Analysis (TGA+Mass Spec.)



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