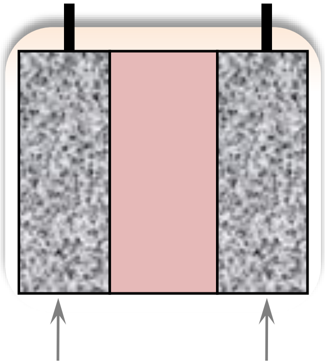
Novel Carbon Materials for Supercapacitors

Vinod Nair

FaradPower, Inc.

The Problem With Energy Storage Devices



Electrode #1 Electrode #2

Supercapacitors

Electrode #1 & Electrode #2 = Carbon
Fast Recharge, Low Energy Stored

Lithium Ion batteries

Electrode #2 = Carbon
Slow Recharge, High Energy Stored

Desired

Fast Recharge
Higher Energy Stored

Mazda i-ELOOP system

New, fast-charging, higher energy-storage devices will find applications in consumer and industrial segments

This can only be enabled by the development of

NEW, HIGHER-PERFORMANCE MATERIALS

- Power tools
- Cell phones
- Tablets
- Hybrid Cars
- Transportation
- Military
- Grid storage
- Industrial

New Sources of Carbon for Energy Storage

NEW SOURCES

Natural sources

- Other nuts
- Shrimp shell
- Hard woods
- Bamboo

Low gravimetric capacitance

Structured carbons

- Nano tubes
- Nano fibers
- Graphene

Low volumetric capacitance

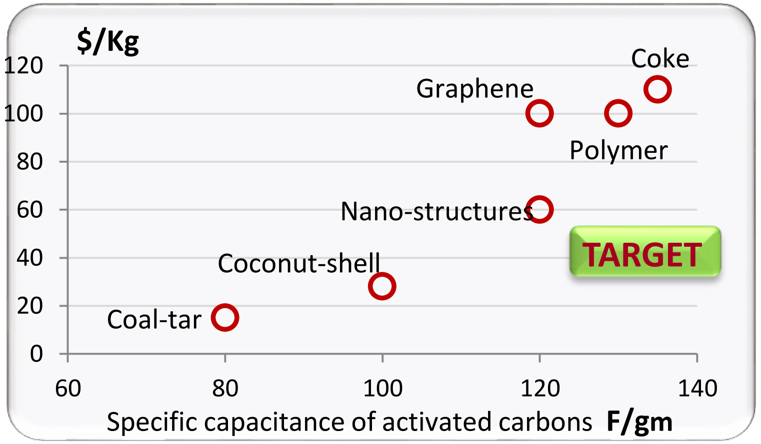
Synthetic sources

- Carbide templating
- Polymer templating
- Polymer/Sol-gel

Most promising

Characteristics desired in the activated carbons for supercapacitors

- Low impurities (<10ppm)
- Hetero-atom doping
- Capacitance (Area/Pore size)
- Low cost



FaradPower, Inc.
Efficient Energy Storage

Next-gen Carbon Requirements

	Porosity (size & distribution)	Impurity levels	Cost of carbon	Physical form = Powder
	Electrode specific capacitance	Electrode resistance; cell voltage	Cost of device	Make use of existing manufacturing
Coconut-shell Carbon	❖ Less than 10 Angstrom pore sizes ❖ Electrode capacitance ~ 100 F/gm	❖ At least 20 impurities @ 10 – 100ppm levels ❖ Limits cell voltage; resistance is high	❖ Coconut-shell carbon impurity removal ❖ Overall cost remains reasonably low	❖ Incumbent technology
Next-gen Carbon	❖ Need to increase capacitance ❖ Need more pore-size options	❖ No impurities → increased cell voltage ❖ Resistance will also drop	❖ Initially pure materials, no impurity removal ❖ Low-cost starting materials	❖ Must also be nano-porous powder

FaradPower Carbon Technology

Polymerization Technologies

Liquid Carbon Source (+ Catalyst, Other Additives) → Polymerization (+ Time, Temp.) → Solid

Manufacturing Infrastructure

Solid →

COCONUT SHELL → Char →

Carbonization → Washing → Activation → Jet Milling →

Activated Carbon

Existing Manufacturing Infrastructure

Cost

- Low-cost starting materials
- Simple processes that do not need fancy equipment
- Utilize existing manufacturing infrastructure
- Non-hazardous materials, no special handling equipment

US Patent # 9458021

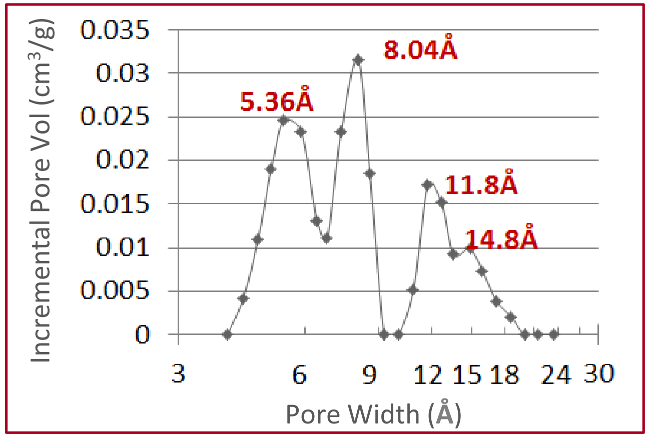
- Synthesizing nano-porous carbon using polymer approach

C-containing organic liquids
+
Liquid polymerization catalysts

→ Solid polymer → Carbonized → Activate

- Starting materials Furfuryl alcohol, Furfural, Acetylfuran

BET Pore size	Pore size (Å)	Pore Size (Å)	Pore Size (Å)
Kuraray (YP50/ standard)	-	8.2	11.6 - 15.0
FaradPower Furfuryl Alcohol	5.36	8.04	11.8 - 14.8
FaradPower Acetylfuran	5.9	8.04	12.7



Other US Patent Applications (CIP)

- Variations on the polymerizing systems
- Same starting materials
- Chemical activation method that is involves soaking in dilute aqueous solutions & heating
- Combining chemical + CO_2/steam activation for pore size control
- ‘Hetero-atom’ doping of polymerized solid before activation

Pure Carbon polymerization		High burn-off CO_2 activation	→
Pure Carbon polymerization	Low temperature chemical activation	High burn-off CO_2 activation	→
Pure Carbon polymerization	High temperature chemical activation		→
Pure Carbon polymerization	High temperature chemical activation	Low burn-off CO_2 activation	→
Doped Carbon polymerization	Low temperature chemical activation	High burn-off CO_2 activation	→

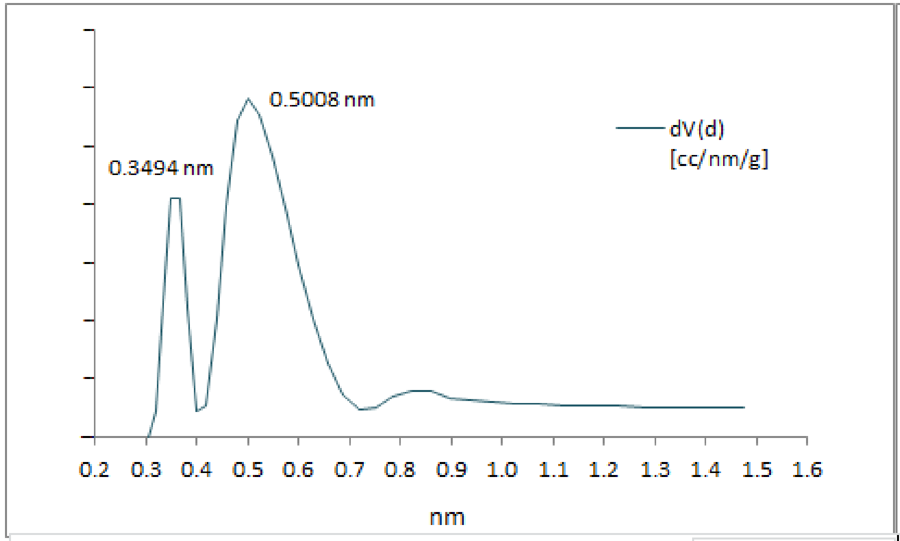
Different pore-size and surface-area profiles

Test Results – Pore size

Quantachrome INSTRUMENTS

Pure Carbon polymerization	Low temperature chemical activation

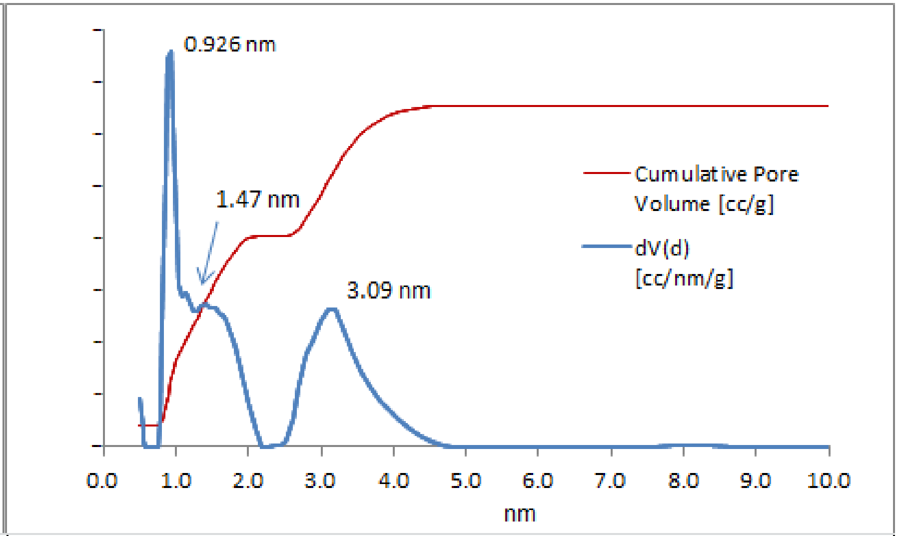
Pure Carbon polymerization	Low temperature chemical activation	High burn-off CO2 activation



DFT : dV(d)

Thermal Transpiration: on
Eff. mol. diameter (D): 3.54 Å
Eff. cell stem diam. (d): 4.0000 mm
DFT method
Calc. Model: CO2 at 273 K on carbon (NLDFT model)
Rel. press. range: 0.0000 - 1.0000 **Moving pt. avg:** 3
Adsorbate model : Carbon-dioxide **Temperature** 273.150K
Molec. Wt.:44.010; Cross Section:21.000 Å²; Liquid Density:0.927 g/cc

606 m²/g



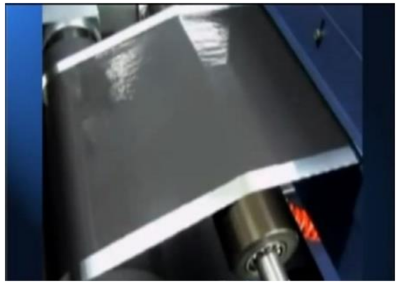
DFT : dV(d)

Thermal Transpiration: on
Eff. mol. diameter (D): 3.54 Å
Eff. cell stem diam. (d): 4.0000 mm
DFT method
Calc. Model: N2 at 77 K on carbon (slit/cylindr. pores, QSDFT adsorption branch)
Rel. press. range: 0.0000 - 1.0000 **Moving pt. avg:** 3
Adsorbate model : Nitrogen **Temperature** 77.350K
Molec. Wt.: 28.013 Cross Section: 16.200 Å² Liquid Density: 0.806 g/cc

2827 m²/g

Test Results- C, ESR & SD

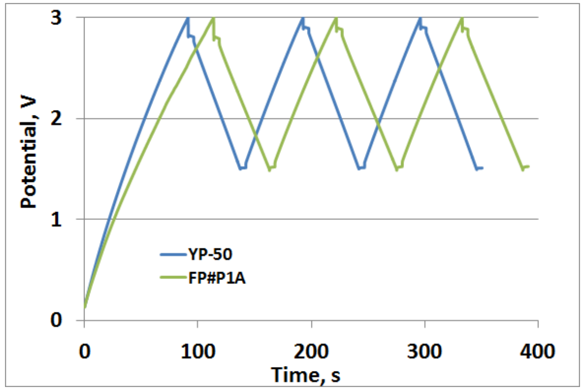
Activated Carbon Powder



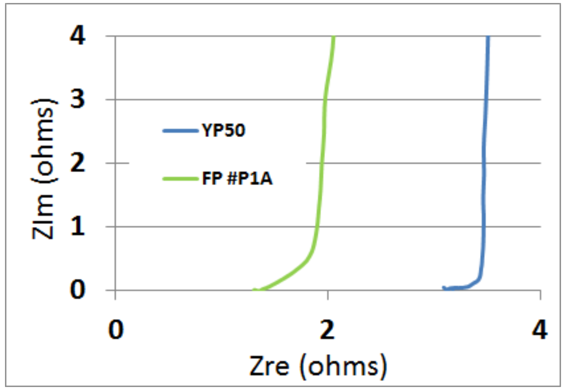
Electrodes:
NOT JET-MILLED

Coin-cell electrode punched out

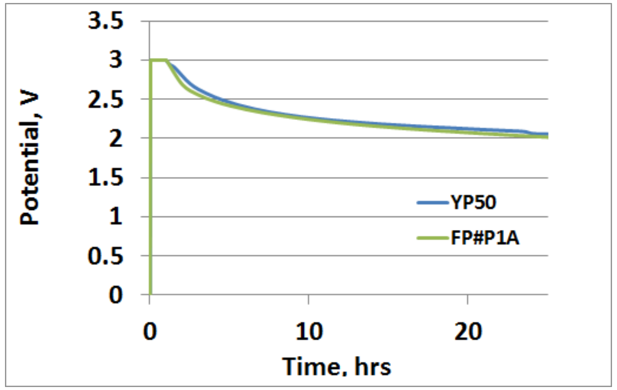
Coin-cells fabricated



- Linear charge-discharge curves
- No pseudo-capacitance
- 20mA current source



- ESR of synthetic carbon based cells is lower than obtained with industry standard YP50



- Self discharge rates are equivalent

Capacitance

	Description	Activation	Electrode Density (of C) (gm/cc)	Avg. F/g
1	Pure Carbon Polymerization + CO2 activation	Increasing Activation ↓	0.854	65.0
			0.681	79.6
			0.632	84.2
2	Pure Carbon Polymerization + Low temperature chemical + CO2 activation	Increasing Activation ↓	0.669	96.6
			0.554	106.2
			0.526	126.5
3	Doped Carbon/Polymerization + Low temperature chemical + CO2 activation	Moderate Activation	0.497	121.2
4	Kuraray YP-50	commercial sample	0.688	109.9

- Electrode density depends on:
  1. Inherent density of the carbon precursor
  2. Level of activation
  3. Particle size (jet-milling)
- At comparable levels of activation (with YP-50), our electrode density remains lower (difference due to jet milling)

Role of Impurities

- Typical coconut-shell carbons contain several impurities that impair their performance
- FaradPower's carbons use very pure starting materials
  - = The final activated carbon is thus also very pure

Proton Induced X-ray Emission (PIXE) Analysis by:

EAI Elemental Analysis, Inc.

Elemental Analysis, Inc
2101 Capstone Drive 110
Lexington, KY 40511

Element	Det. Limit (ppm)	Concentration (ppm)	
Name	95% Conf.	FaradPower	YP-50
Na	81.64		
Al	16.57		33.3
Si	10.58		325.9
S	8.53		108.6
K	3.059		32.2
Ca	4.451		7.2
Iron	0.864	3	10
Cu	0.436		12.4

Summary

- We have developed a technique to synthesize activated carbons suitable for high-end applications like energy storage (EDLCs)
- The technique allows different combinations of pore-sizes and surface areas by adjusting different aspects like chemical activation, physical activation and doping
- Very high surface areas and high capacitance values were obtained
- A US patent for the original platform technology has already been granted
- FaradPower is now working on expanding manufacturing capabilities