Highly porous willow-derived activated carbon for high performance supercapacitor electrodes

AUTHORS:
Josphat Phiri, Jinze Dou, Tapani Vuorinen, Patrick Gane, Thad Maloney

PRESENTED BY:
Josphat Phiri
Doctoral Candidate
Aalto University

Aalto University
School of Chemical Engineering

TAPPI

Energy situation

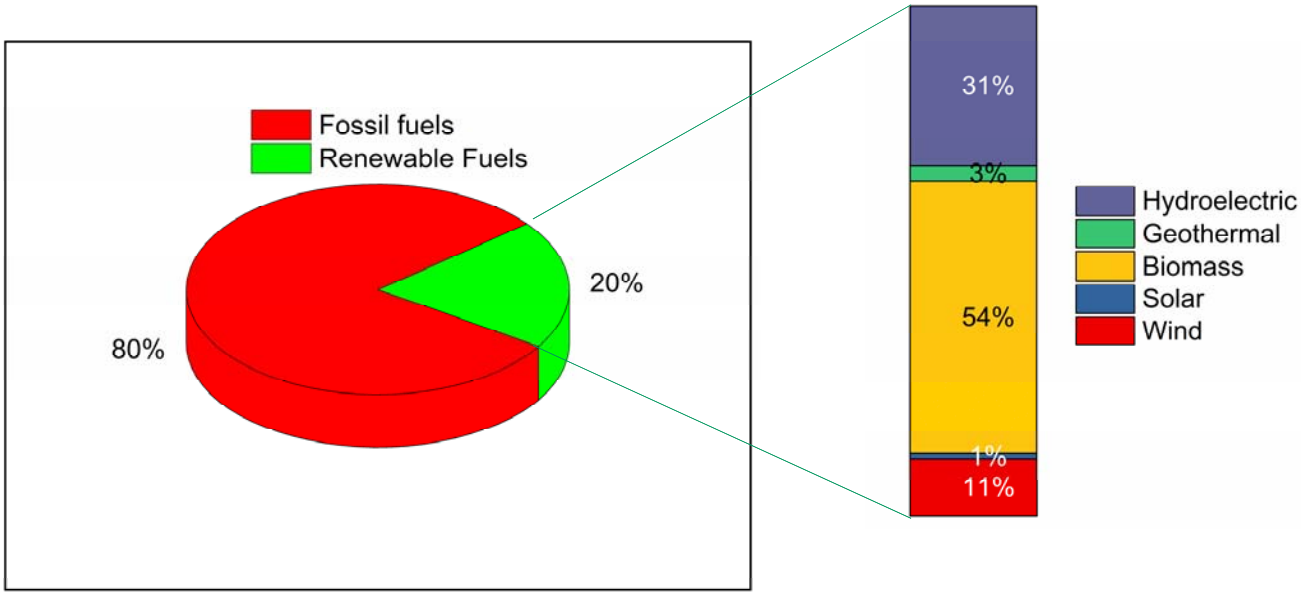
- Fossil fuel account for about 80% world's primary energy use.
- Fossil fuel resources are diminishing.
- Fossil fuel contribute to the negative climate change/greenhouse gas emissions.
- The use of renewable energy sources can lead to the reduction of carbon dioxide emissions.

Share of EU energy sources

Fossil fuels

- natural gas
- crude oil and other
- hydrocarbons
- solid fossil fuels, nuclear
- non-renewable wastes

Renewable energy

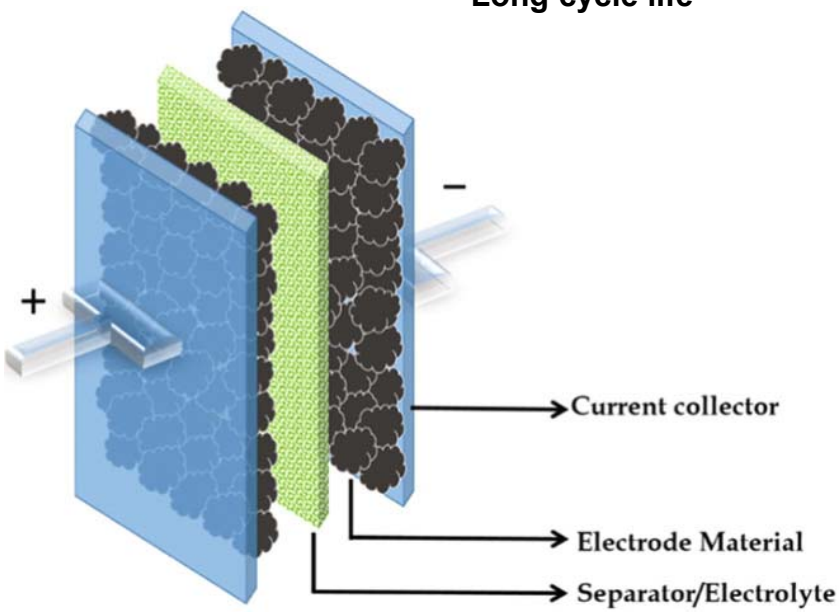


http://www.europeanbioenergyday.eu/about/european-bioenergy-day-concept/

Supercapacitors as energy storage devices

Advantages

- Fast charge/discharge rate
- High power density
- Long cycle life



Samantara, A. K., & Ratha, S. (2017). *Components of Supercapacitor. SpringerBriefs in Materials, 11–39.* doi:10.1007/978-981-10-7263-5_3

Electrode properties

- High porosity
- High surface area
- Excellent electrical conductivity
- High thermal and chemical stability
- Corrosion resistance

Electrode materials

- Activated carbon
- Graphene
- Carbon nanotubes
- Conductive polymers
- Metal oxides

Why willow?

- Homogenous material ⇨ controlled end product synthesis
- 2-3 year circulation cycle (20-30 years cultivation)
- Negative life cycle assessment
- High density plantation 13000 plants/hectare
- Very high productivity
- Ability to grow on marginal lands
- Water purification

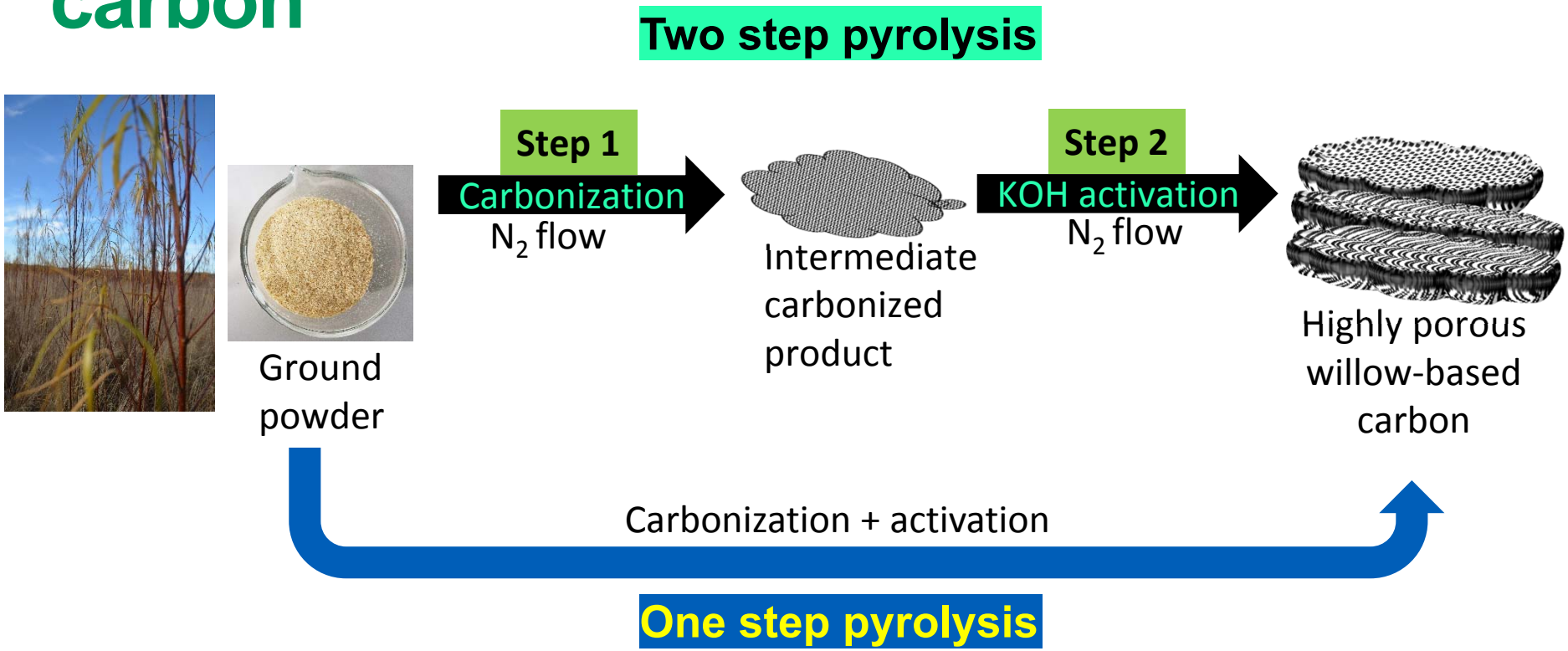
Potential yields of biofuels per ha p.a.

Fuel	Net CV	Annual yield per ha	Energy per ha p.a.	
	MJ/kg	tonne/ha.a (odt/ha.a)	GJ/ha.a	MWh/ha.a
Wood (forestry residues, SRW, thinnings, etc.) @ 30% MC	13	2.9 (2 odt)	37	10.3
Wood (SRC Willow) @ 30% MC	**13**	**12.9 (9 odt)**	**167**	**46**
Miscanthus @ 25% MC	13	17.3 (13 odt)	225	63
Wheat straw @ 20% MC	13.5	3.5 (2.8 odt)	47	13
Biodiesel (from rapeseed oil)	37	1.1	41	11.3
Bioethanol (from sugar beet)	27	4.4	119	33
Bioethanol (from wheat)	27	2.3	62	17
Biogas @60% CH4 (from cattle slurry)	30	0.88	26	7.3
Biogas @60% CH4 (from sugar beet)	30	5.3	159	44

In Sweden values of >30 odt/ha have been reported

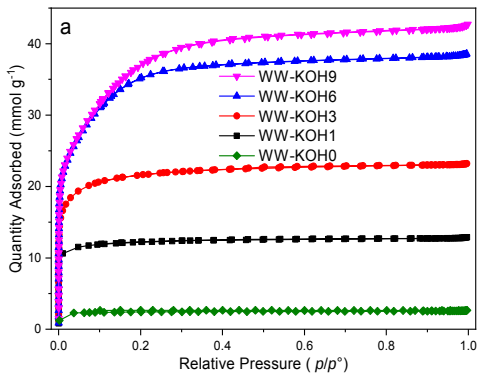
https://www.forestresearch.gov.uk/tools-and-resources/biomass-energy-resources/reference-biomass/facts-figures/potential-yields-of-biofuels-per-ha-pa/

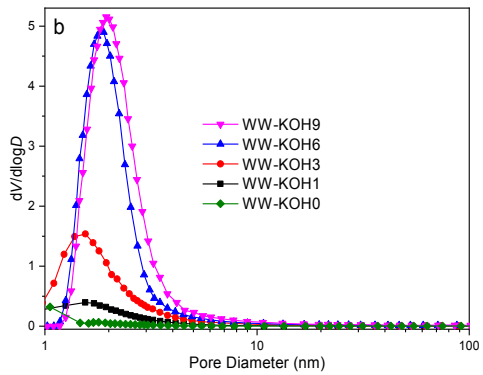
Synthesis of willow derived activated carbon



Characterization

N_2 adsorption-desorption isotherms and pore size distribution

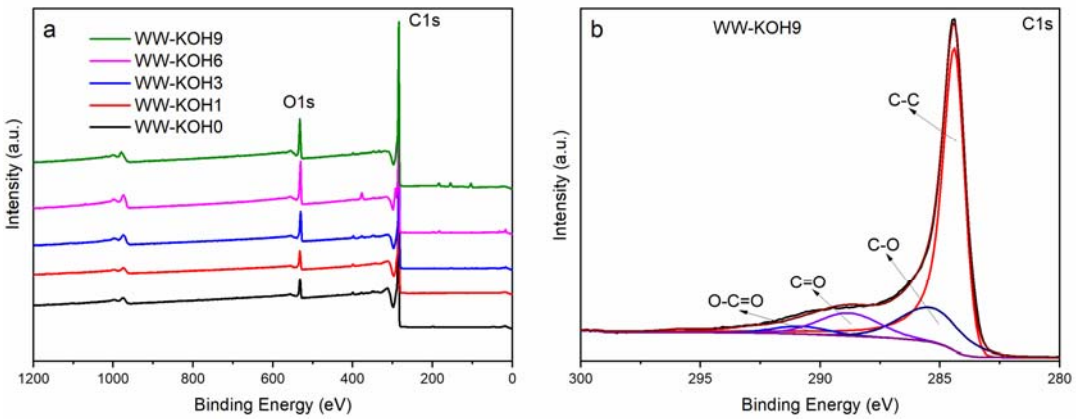




Samples	S_{BET}, $m^2\ g^{-1}$	V_{total}, $m^3\ g^{-1}$	V_{micro}, %
WW-KOH0	171	0.08	-
WW-KOH1	899	0.22	75
WW-KOH3	1591	0.58	75
WW-KOH6	2596	1.25	66
WW-KOH9	2793	1.45	57

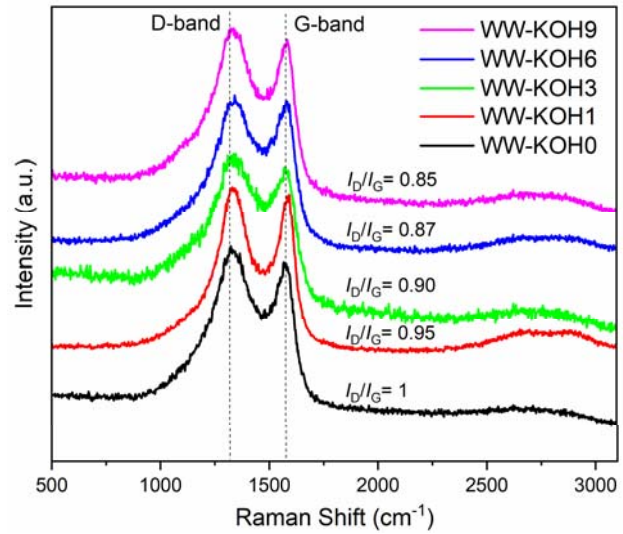
Surface properties

XPS analysis



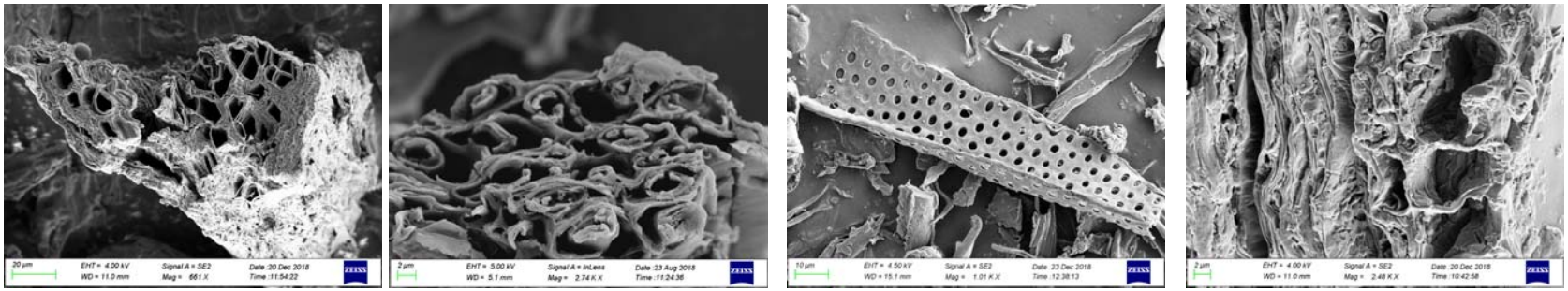
Samples	Atomic concentration, at%		
	C	O	C/O
WW-KOH0	93.15	5.15	18.09
WW-KOH1	93.38	5.58	16.74
WW-KOH3	88.57	8.87	10.00
WW- KOH6	82.42	12.40	6.65
WW-KOH9	85.50	11.27	7.59

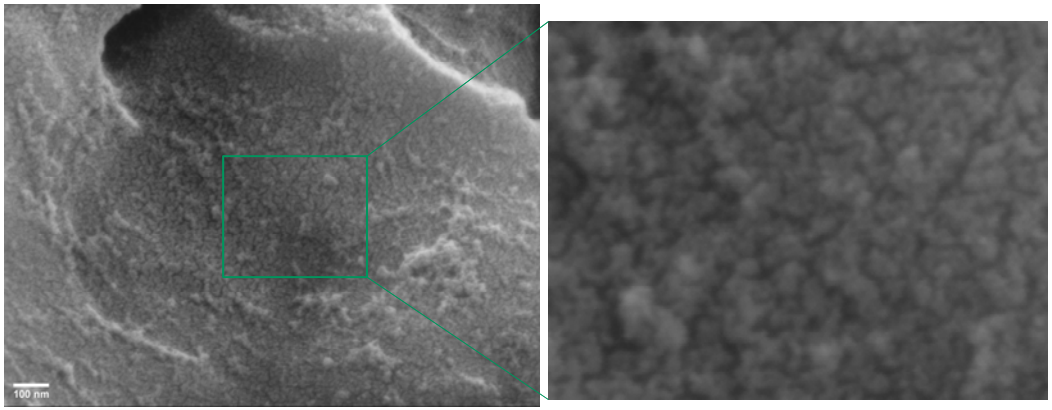
Raman analysis



SEM analysis

Hierarchical willow structure retained

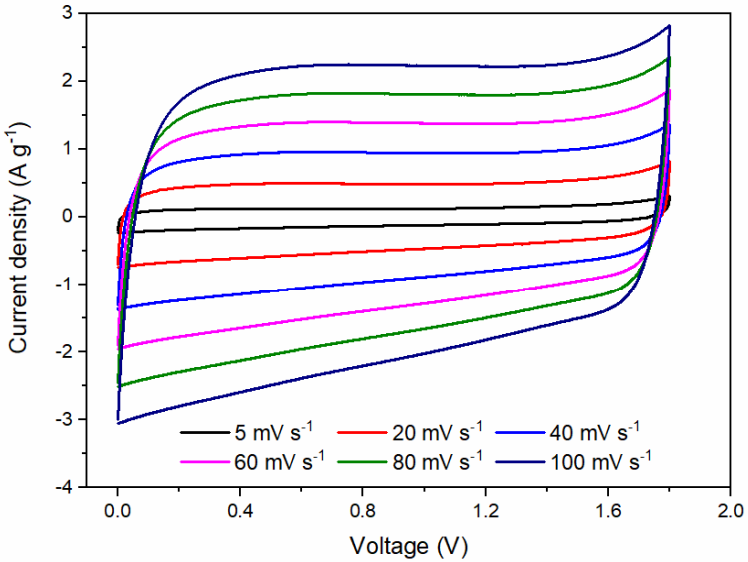


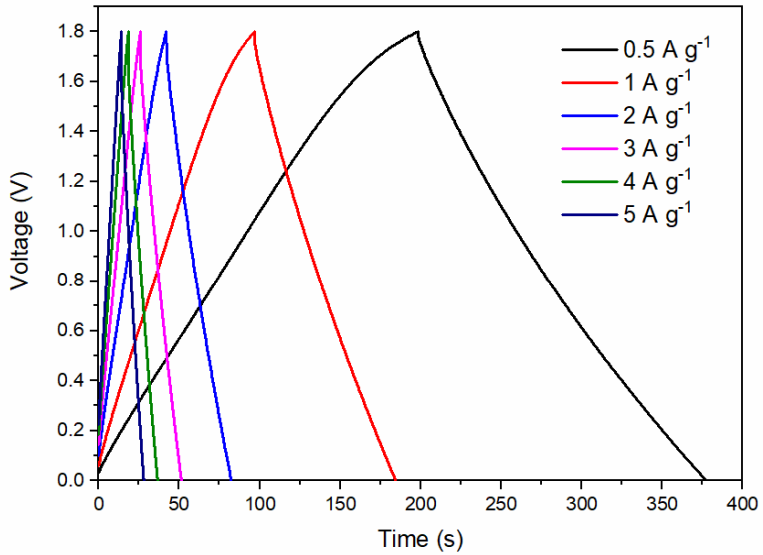


Surface covered in nanopores

Electrochemical properties

Symmetrical supercapacitor. Electrolyte: 1 M Na_2SO_4

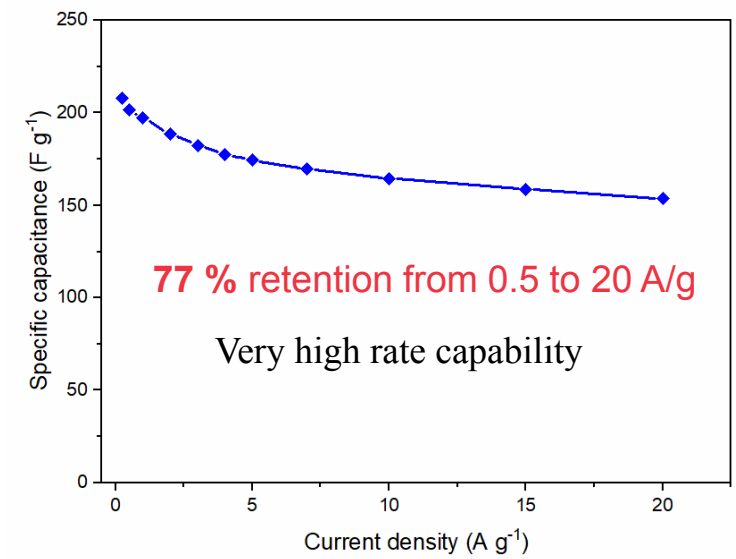




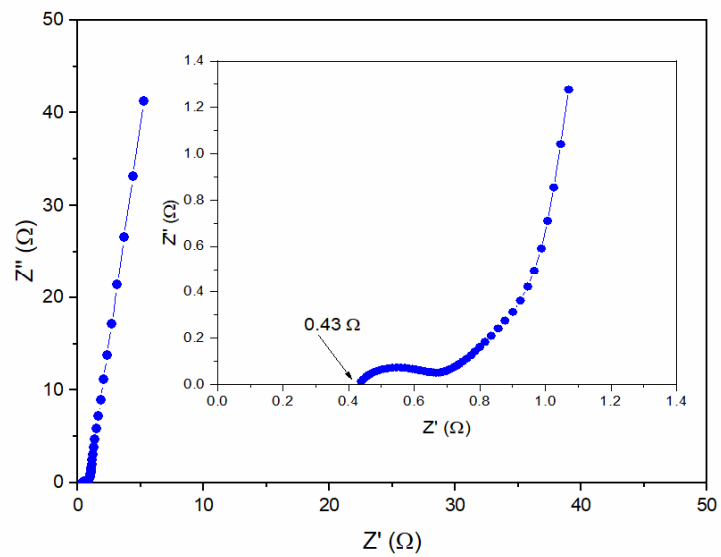
- **Good capacitor behavior even at high scan rates**
- **Good rate capability → rapid ion diffusion**

Electrochemical properties

Capacitance vs current density

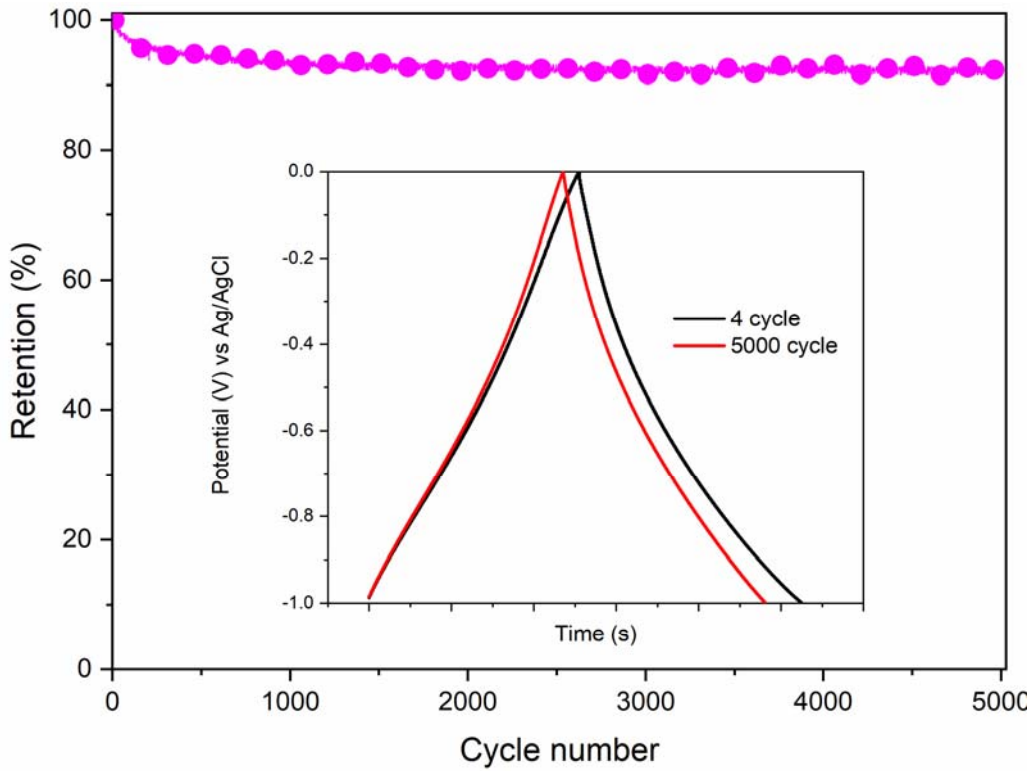


Electrochemical impedance spectroscopy



Very low internal resistance ➡ good electron conduction and fast ion exchange between the electrode and electrolyte

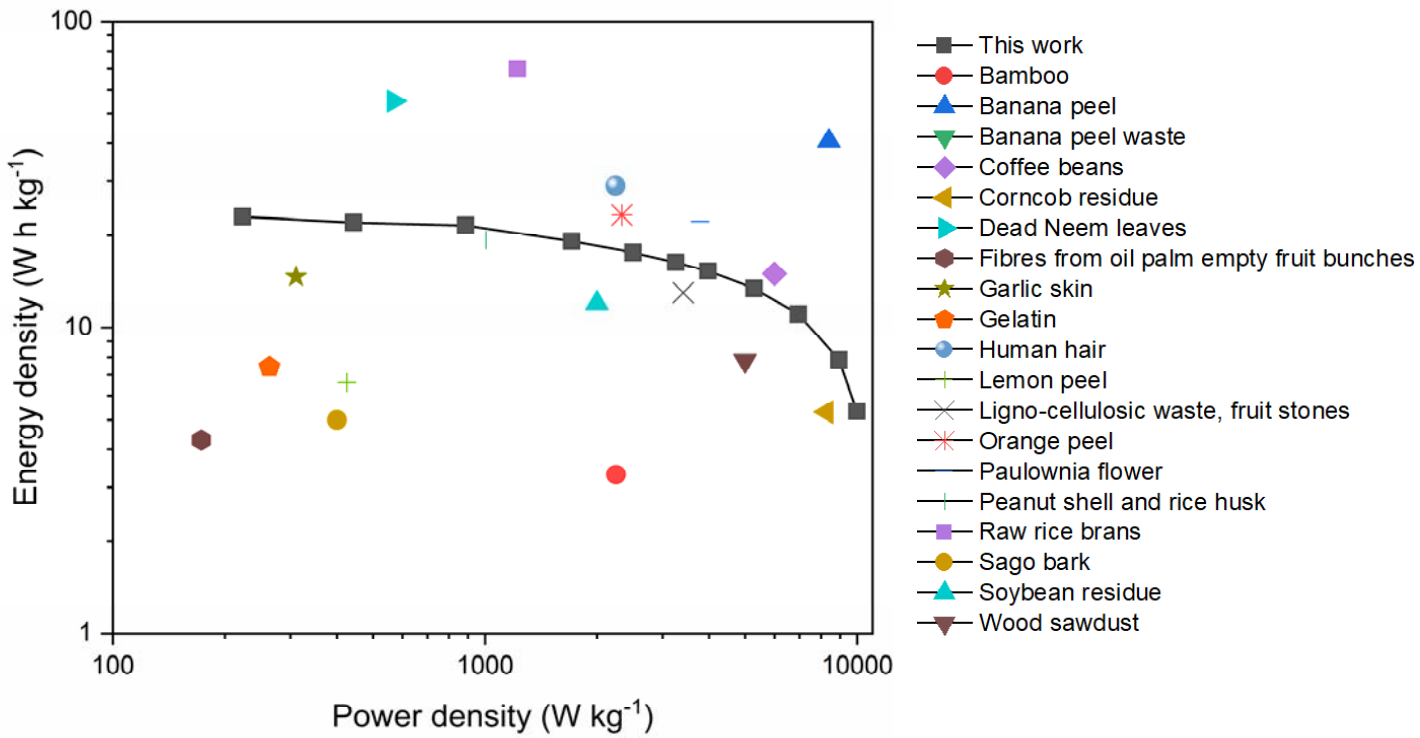
Cycle stability



- **Capacitance retention over 93 % after 5000 cycles at 5 A/g**
- **Excellent cycle performance**

Electrochemical properties

Ragone plot



Thank you

PRESENTED BY

Josphat Phiri

Doctoral candidate

Aalto University

josphat.phiri@aalto.fi

JENNY AND ANTTI WIHURI FOUNDATION

ONYA

KAUTEsäätiö

PUUNJALOSTUS-INSINÖÖRIT
Träförädlingsingenjörerna
Forest Products Engineers

Aalto University
School of Chemical Engineering

TAPPI