Green Synthesized Banana peel Carbon-CoO Composite Electrodes for Supercapacitor

Objectives

1. To synthesize and incorporate cobalt oxide into the banana peel carbon matrix to form a BPC/CoO composite electrode material.
2. To fabricate the BPC/CoO composite electrode on nickel foam using a binder-assisted coating method.
3. To evaluate the electrochemical performance of the electrode using CV, GCD, and EIS in alkaline electrolyte.

Literature Review

Why Supercapacitor?

Supercapacitor:

A supercapacitor is a high-capacity energy storage device that bridges the gap between conventional capacitors and rechargeable batteries, offering much higher capacitance through electrostatic charge storage in an electric double layer.

TYPES

- **Electrostatic Double-Layer Capacitors (EDLC's)**
- **Electrochemical Pseudocapacitors**
- **Hybrid Supercapacitors**

Cont’d

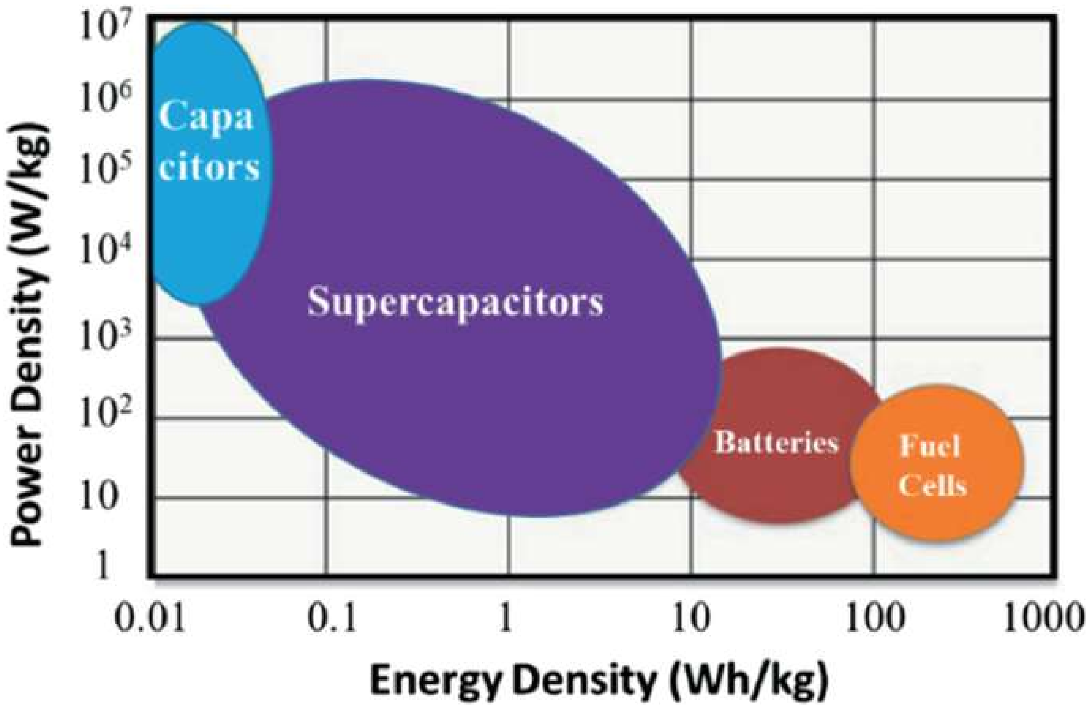
Supercapacitors bridge the gap between conventional capacitors and batteries, offering much higher power density than batteries while maintaining moderate energy density.

Applications:

✓Electric & Hybrid Vehicles (EVs/HEVs)

✓Aerospace & Defense

✓Public Transport & Industrial Equipment

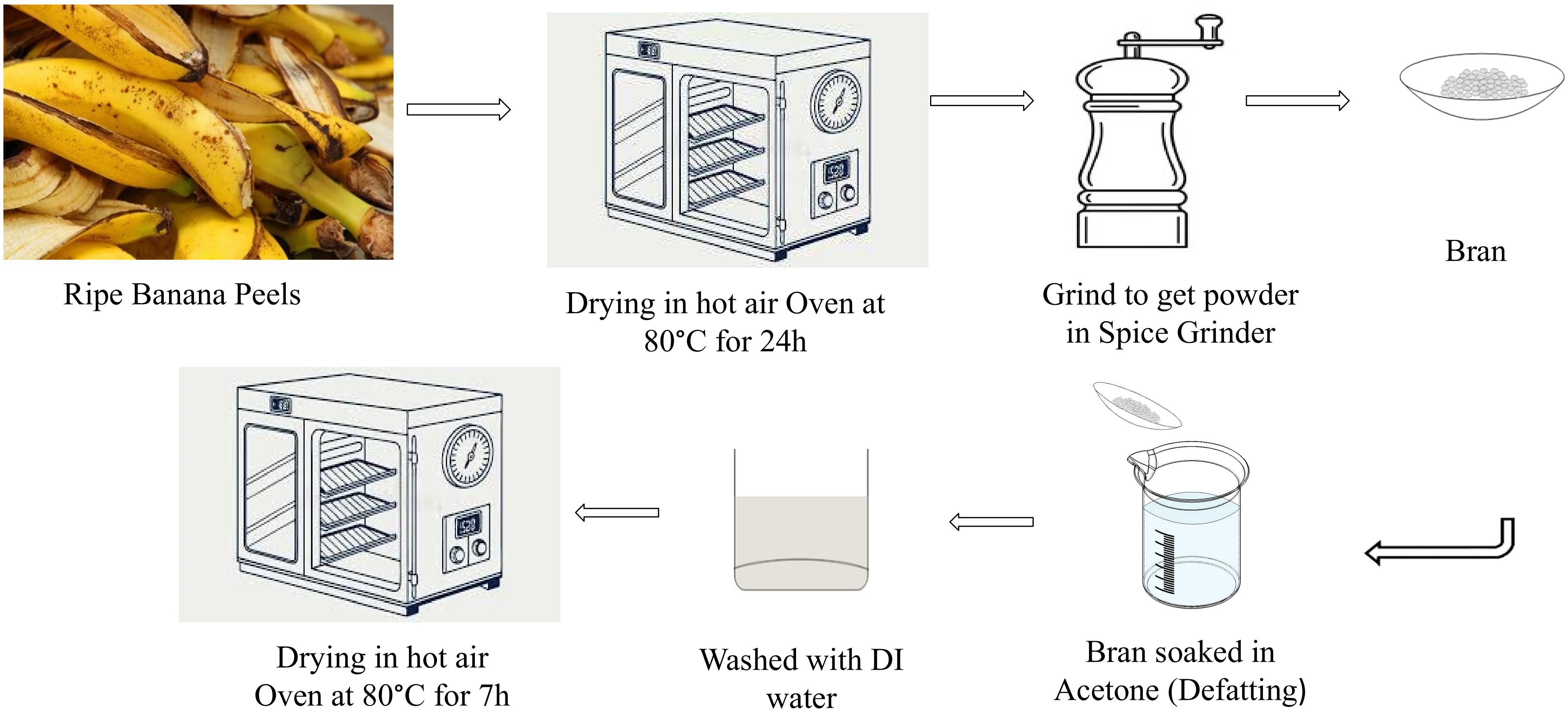


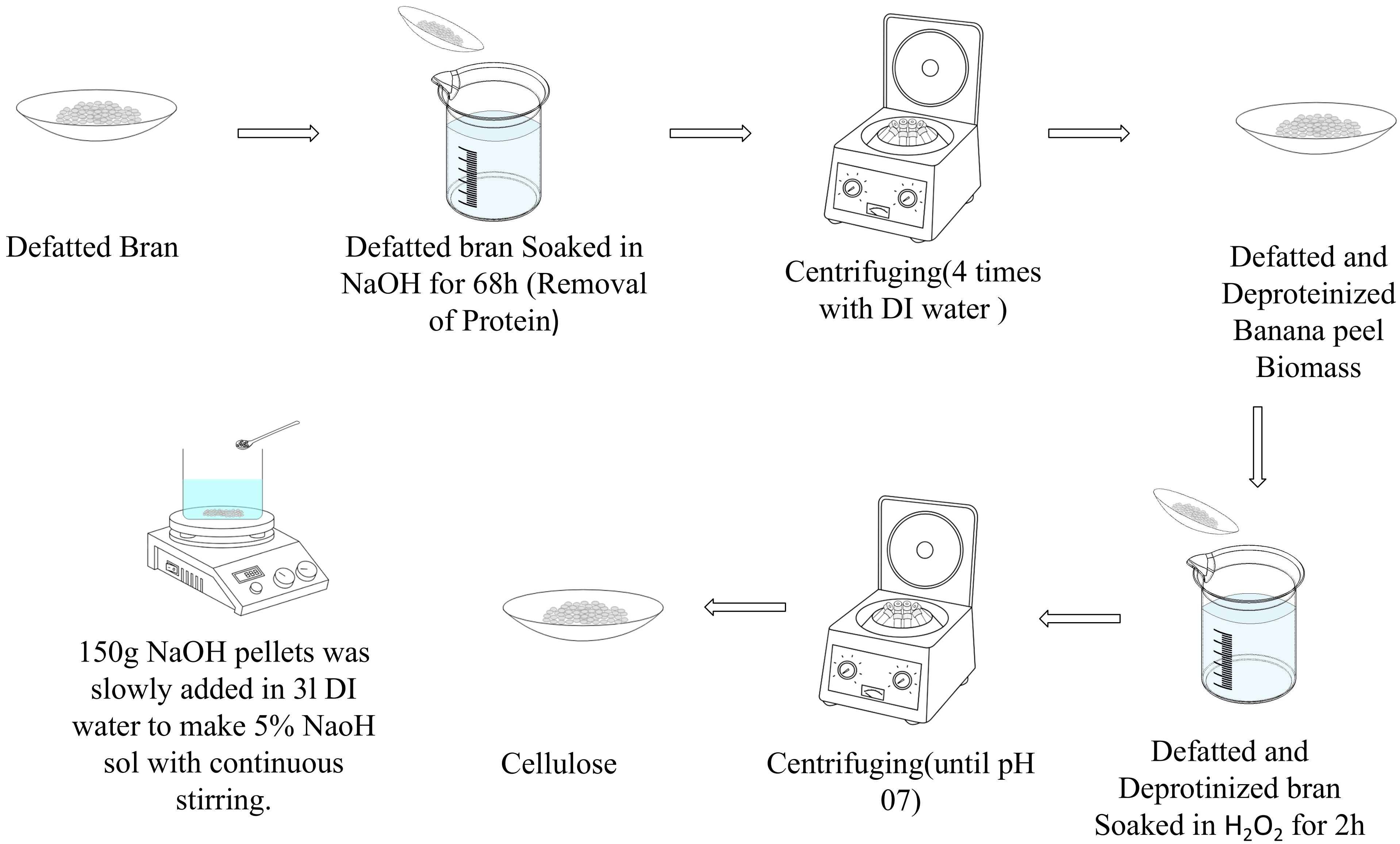
Active Material	Major Findings	Key Performance	Reference
Banana Peel NCC	Extracted from banana peel by chemical treatment.	High crystallinity	Shreedhana et al., 2020
Banana Peel CNFs	Homogenization improved morphology and stability.	5.1% yield	Pelissari et al., 2014
Cellulose Aerogels	Renewable porous materials for functional applications.	High porosity	Long et al., 2018
Biomass Carbon	Sustainable carbon electrodes for SCs.	High conductivity	Zhu et al., 2025

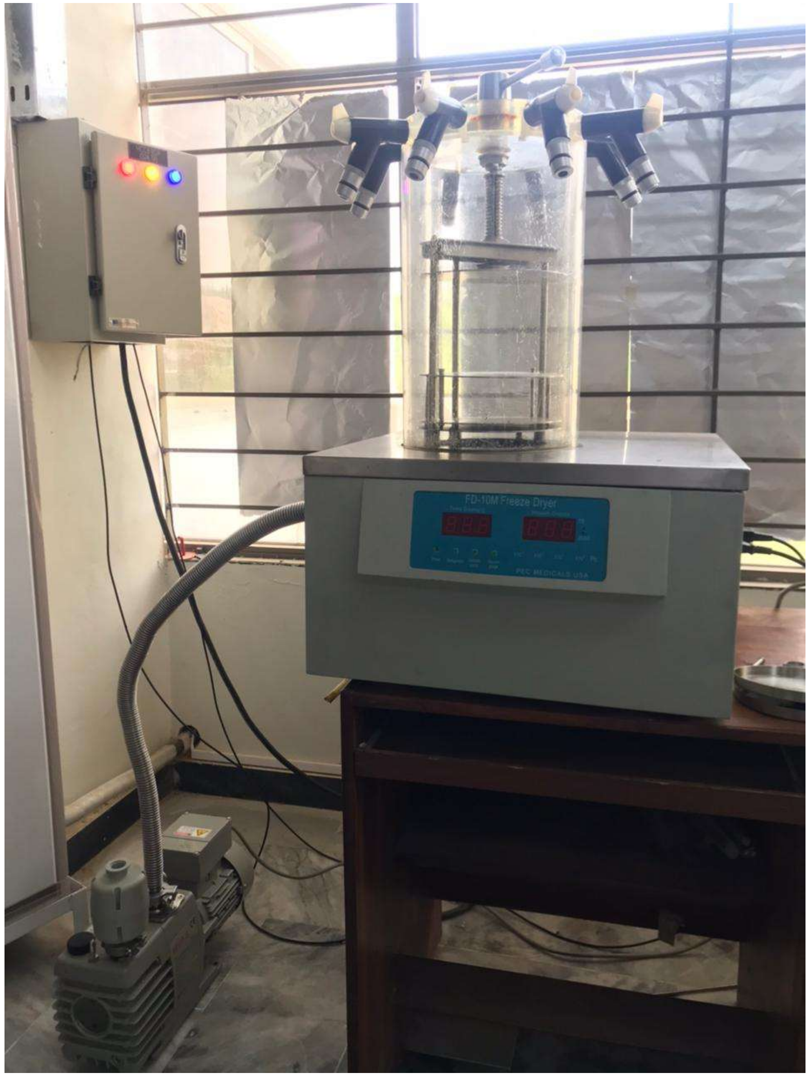
Active Material	Major Findings	Key Performance	Reference
Banana Peel Carbon	Porous conductive biomass carbon.	High surface area	Zhu et al., 2025
Coconut Shell AC	Hierarchical porous carbon for SCs.	367 F g-1	Wang et al., 2023
N,P Co-doped Carbon	Doping improved conductivity.	375 F g-1	Yan et al., 2019

Synthesis of Carbon from Banana peels

Synthesis of Biomass from Banana peels




Defatted Bran
Defatted bran Soaked in NaOH for 68h (Removal of Protein)
Centrifuging(4 times with DI water)
Defatted and Deproteinized Banana peel Biomass
Defatted and Deprotinized bran Soaked in H_2O_2 for 2h
Centrifuging(until pH 07)
Cellulose
150g NaOH pellets was slowly added in 3l DI water to make 5% NaoH sol with continuous stirring.



- Made 0.21 M $CoCl_2.6H2O$ solution in DI water and stirr for 30 mins.
- Made 12.5 mg/ml of cellulose solution in DI water and sonicate for 30 mins.
- Added cellulose sol. Into salt solution while stirring and stir it for 2 hrs.
- **Freeze treatment:** Samples were frozen for **9 hours** at **-48°C**.
- **Vacuum drying:** Frozen samples were subsequently vacuum-dried for **63 hours**.

Carbonization

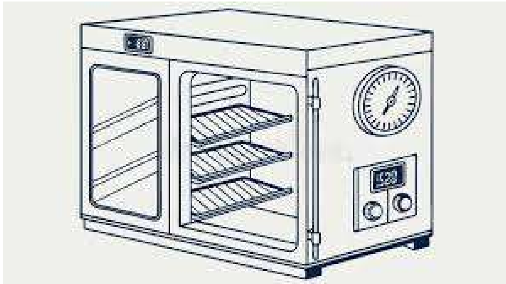
Ramp rate 2°C /min Holding time 2 hr Temperature 850°C

Synthesis of CoO (NPs and NWs)

Molten Salt Synthesis []

Mix and ground $CoCl_2.6H_2O$ + Na_2CO_3 for 15 min

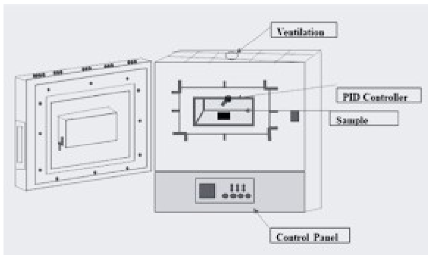
Washing (4-5 at 4000 rpm)



Drying (80 °C for 5h)

$CoCO_3$+NaCl+NP-9

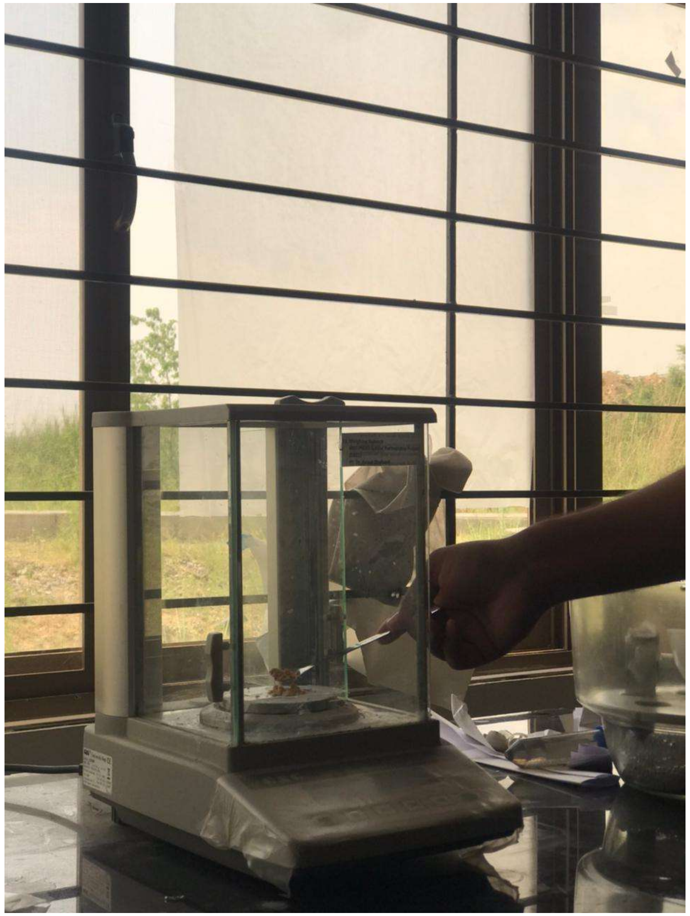
$CoCO_3$+NaCl



Reaction (850 °C for 2h)

CoO(NPs and NWs)

Synthesis of Composite



Weighing samples

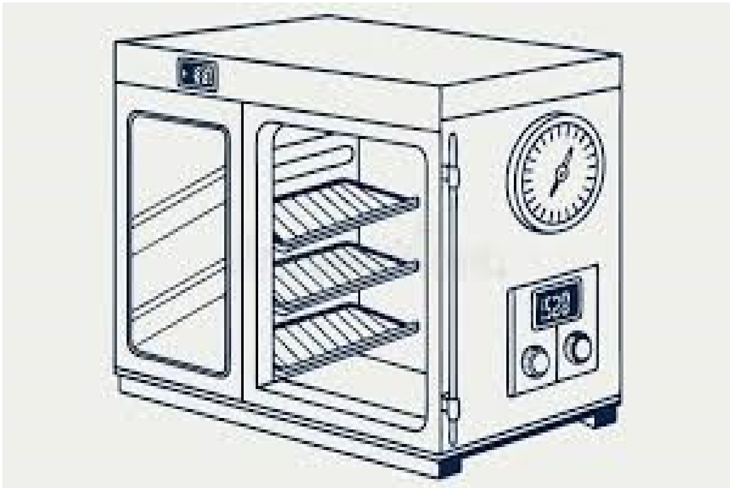
Composite Synthesis

C to CoO ratio by weight is 2:1wt%. **[13]**

Pure Carbon | Carbon + CoO nanoparticles | Carbon + CoO nanowires | Carbon+ $CoCl_2$.6H2O

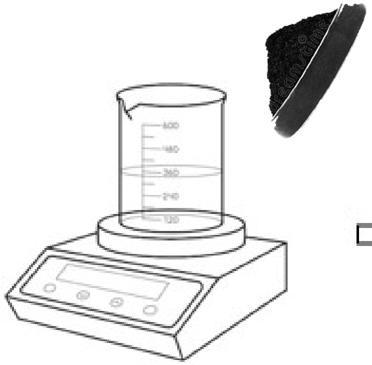
Synthesis of Carbon-CoOxide composite

Drying

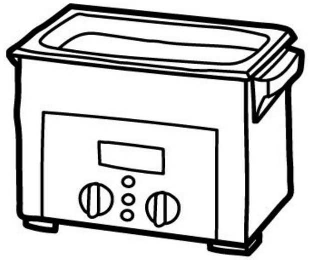


Finally, **dry the composite sample at 80°C for 24 hours** to obtain the desired material.

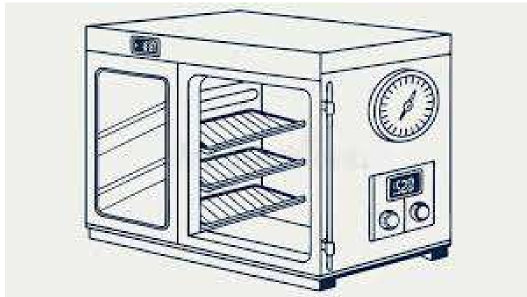
Composite Activation



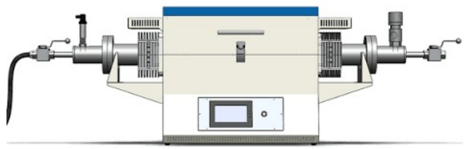
Add dry composite into
6M KOH
KOH:Composite 2:1



Sonicate for 2 hr

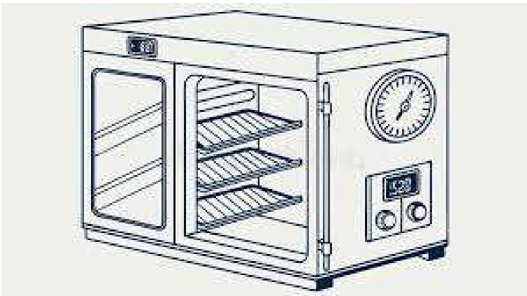


Drying for 12 hrs at 80°C



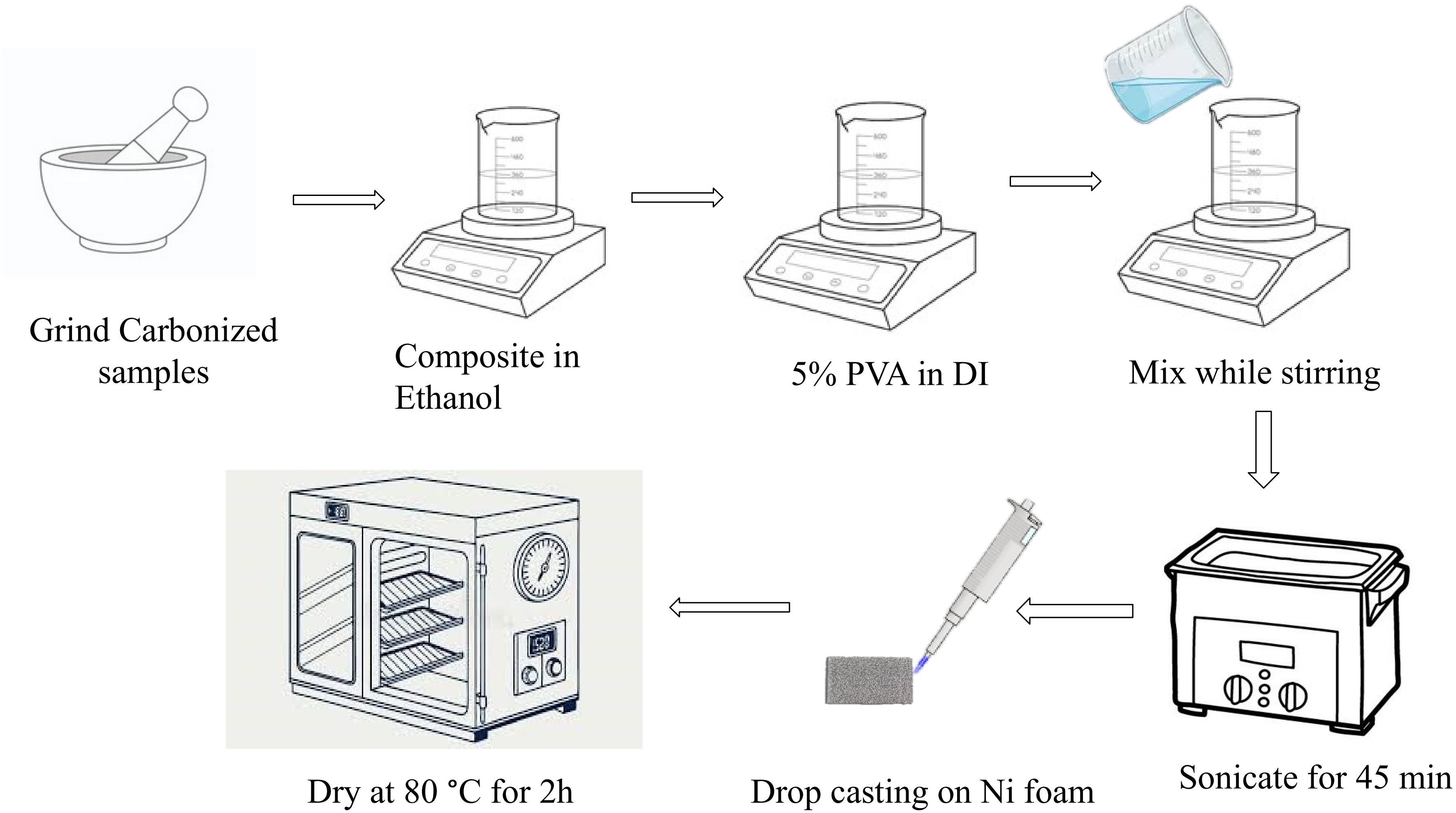
Ramp rate 5°C /min, Holding time 1 hr, T 750 °C

Washing (3 times at 4000 rpm)



12 hours at 100 °C

Electrode Fabrication


Grind Carbonized samples
Composite in Ethanol
5% PVA in DI
Mix while stirring
Sonicate for 45 min
Drop casting on Ni foam
Dry at 80 °C for 2h

Mass Loading

Our target mass loading is 1 mg/cm^2

Sample 1(Pure Carbon)

we achieved 0.366mg/cm^2

Sample 2(Pure Carbon + NWs)

we achieved 0.523mg/cm^2

Sample 3(Pure Carbon + NPs)

we achieved 0.971mg/cm^2

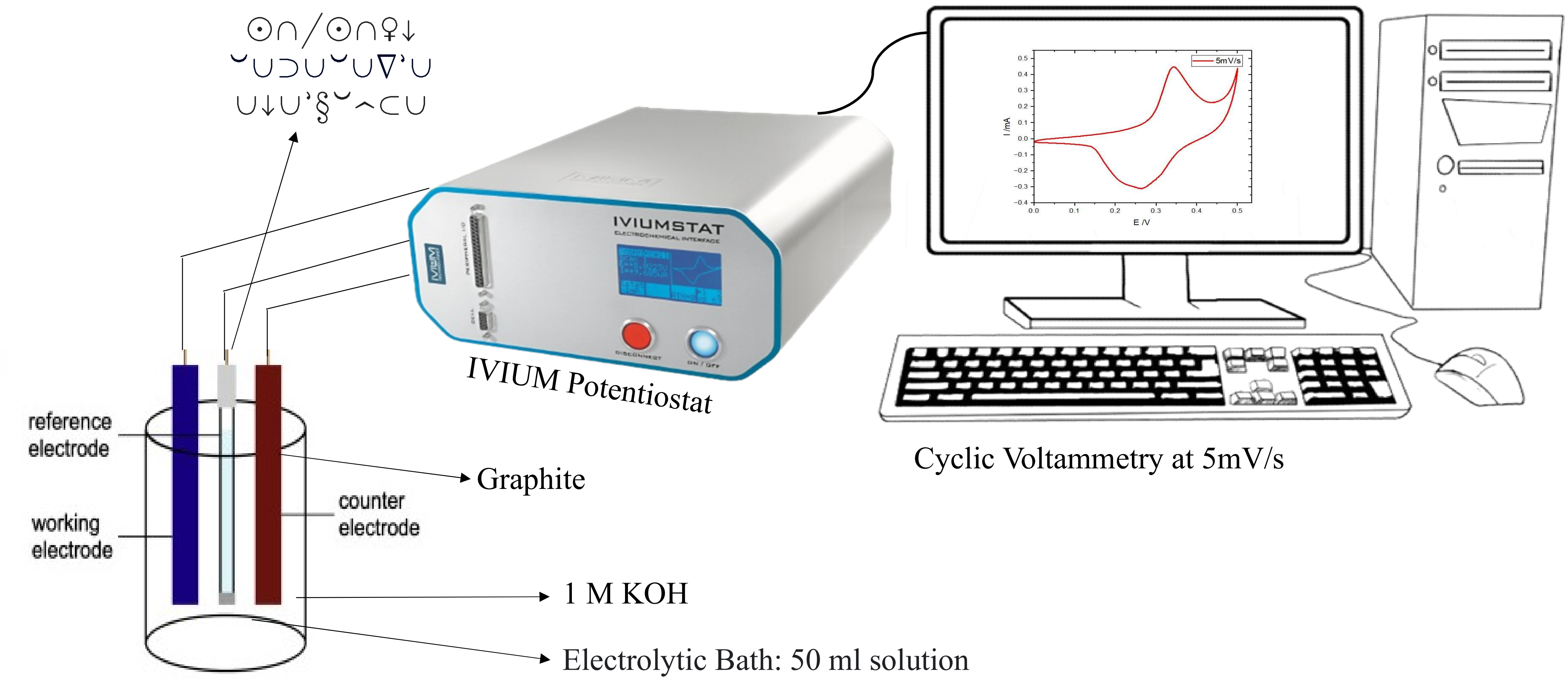
Sample 4(Pure Carbon + Co salt)

we achieved 0.647mg/cm^2

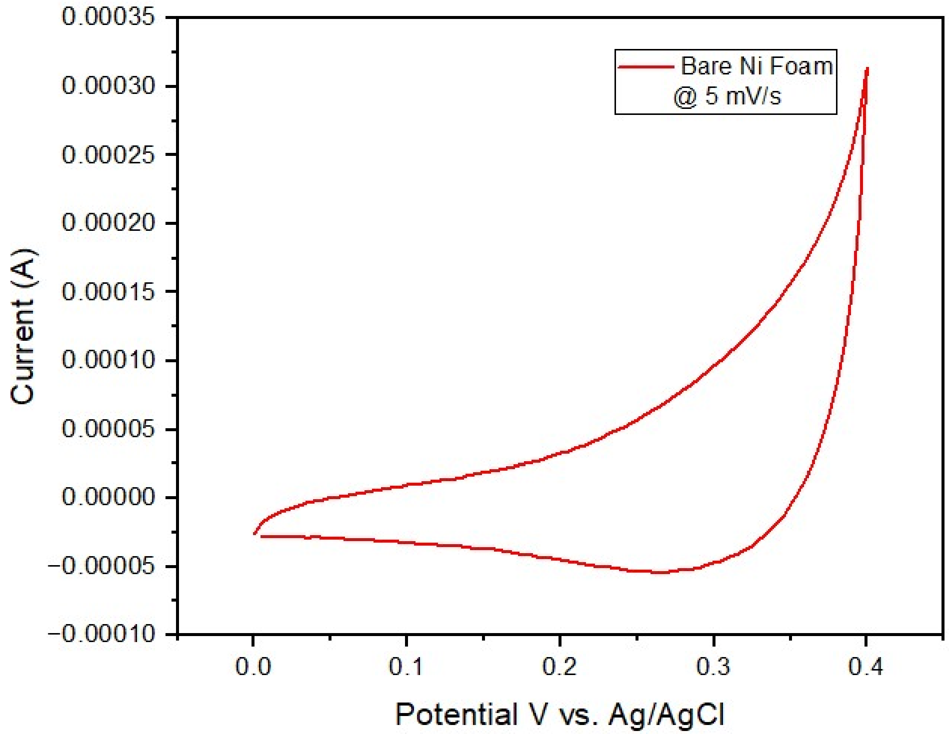
Results

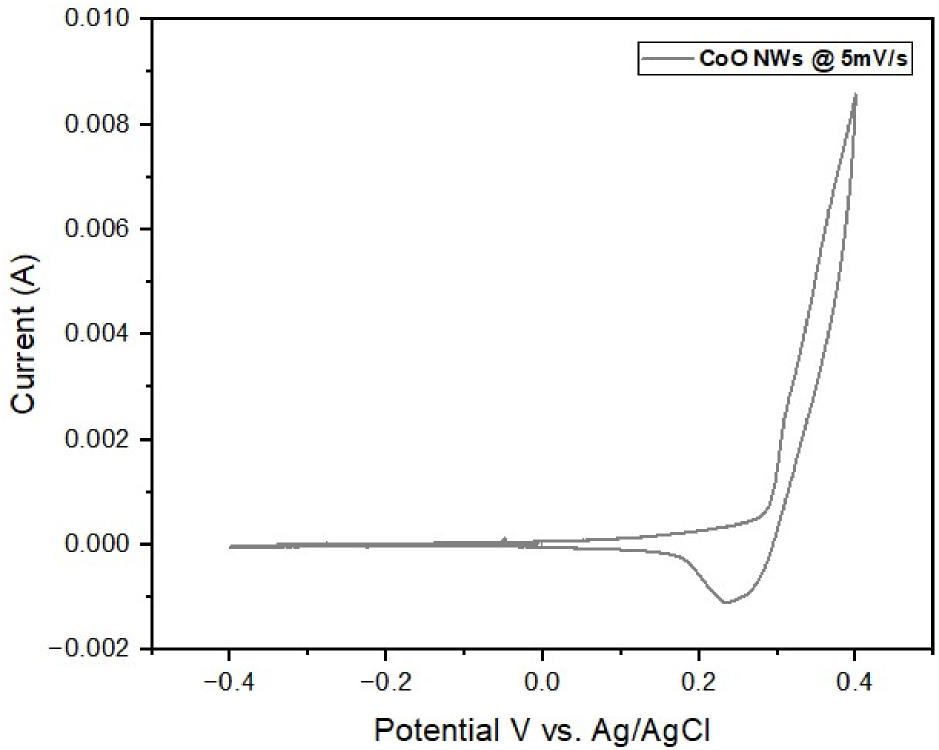
Electrochemical Testing

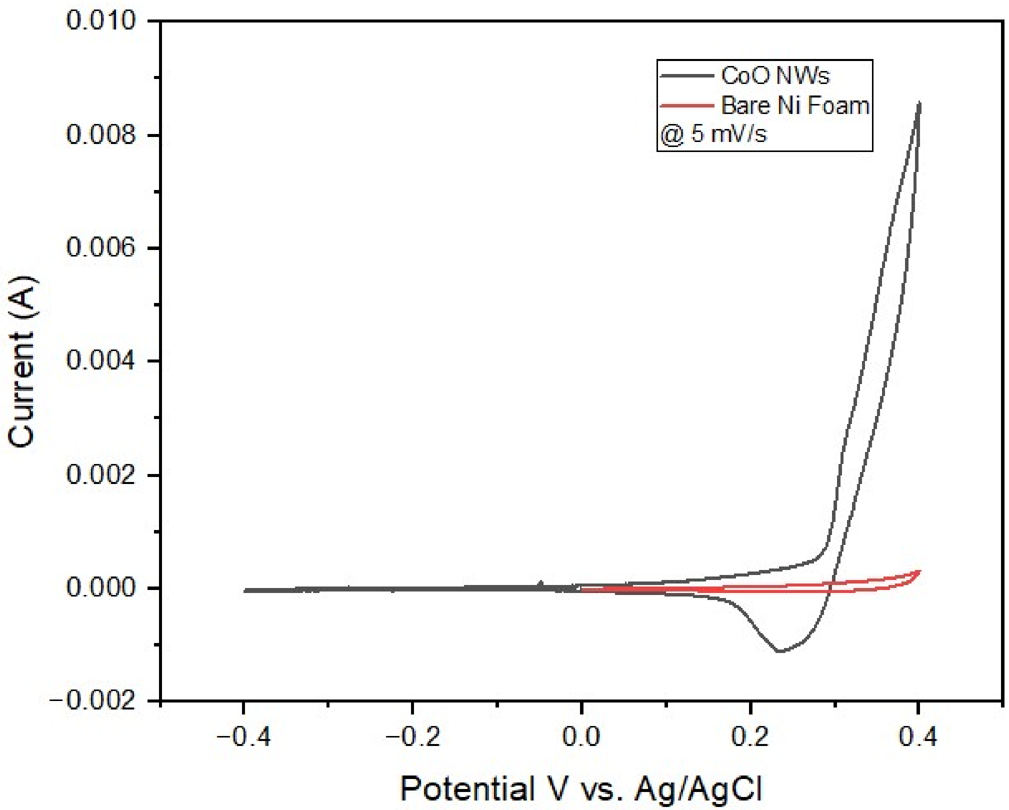
Graphical representation of Electrochemical Setup

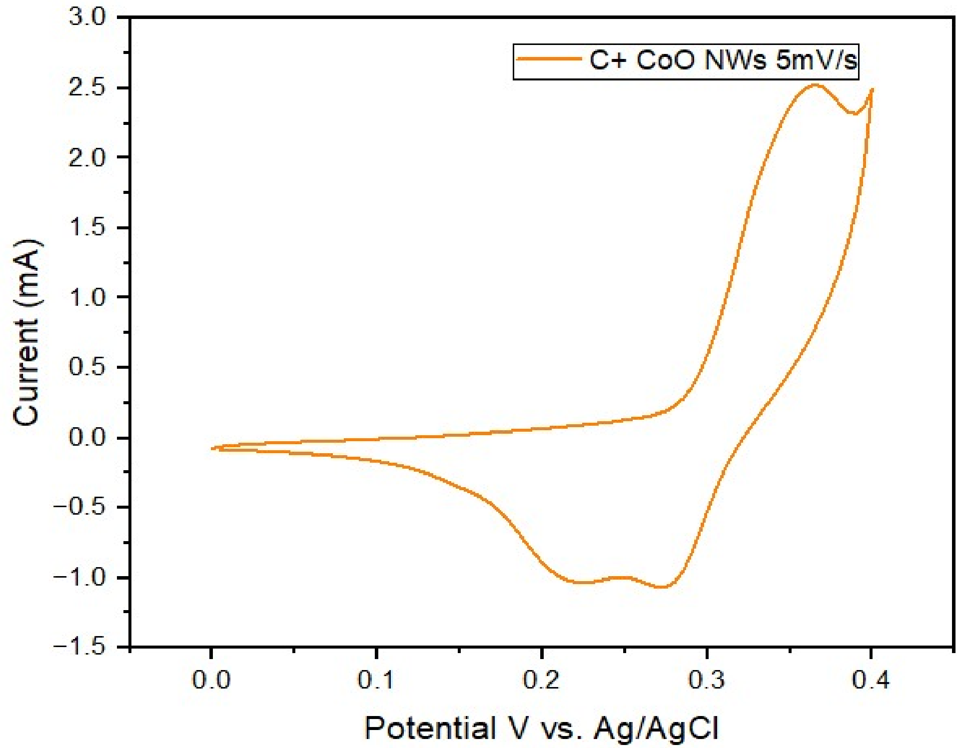


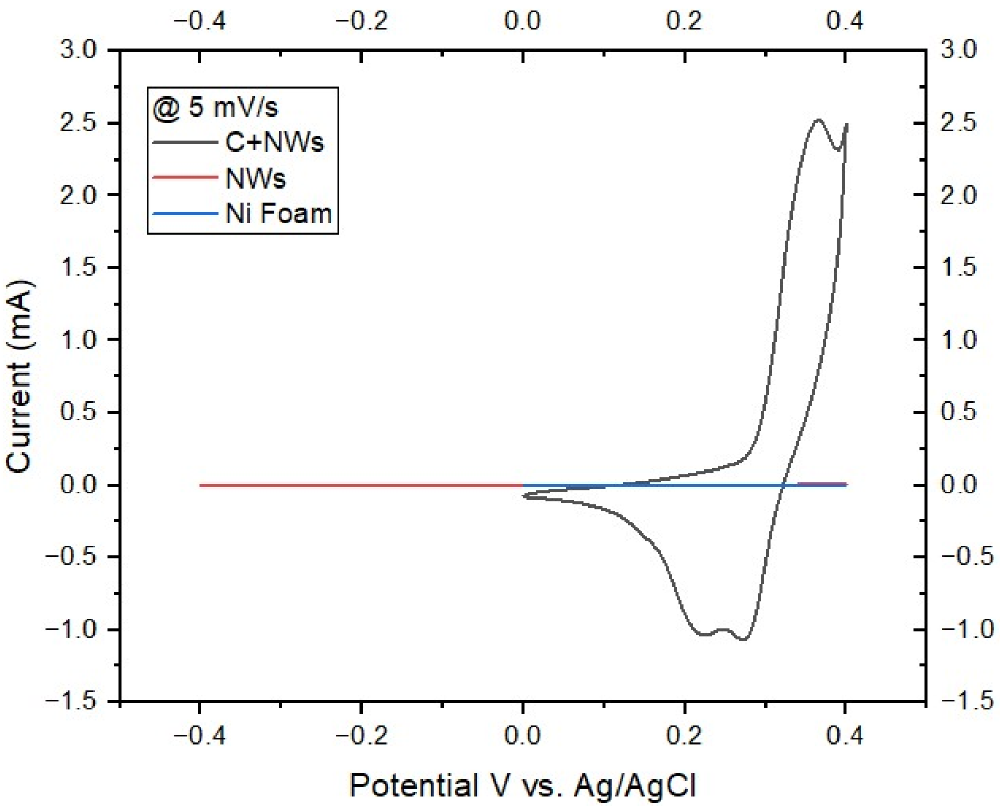
Electrochemical Testing (Cyclic Voltametry)

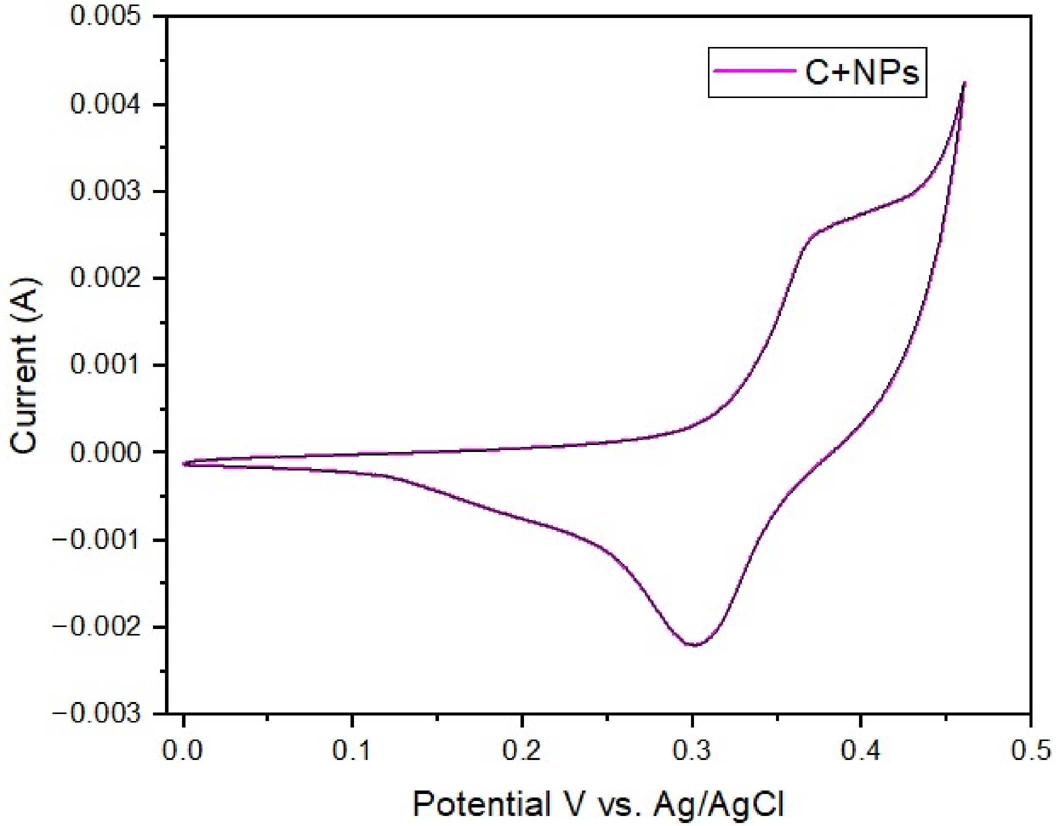


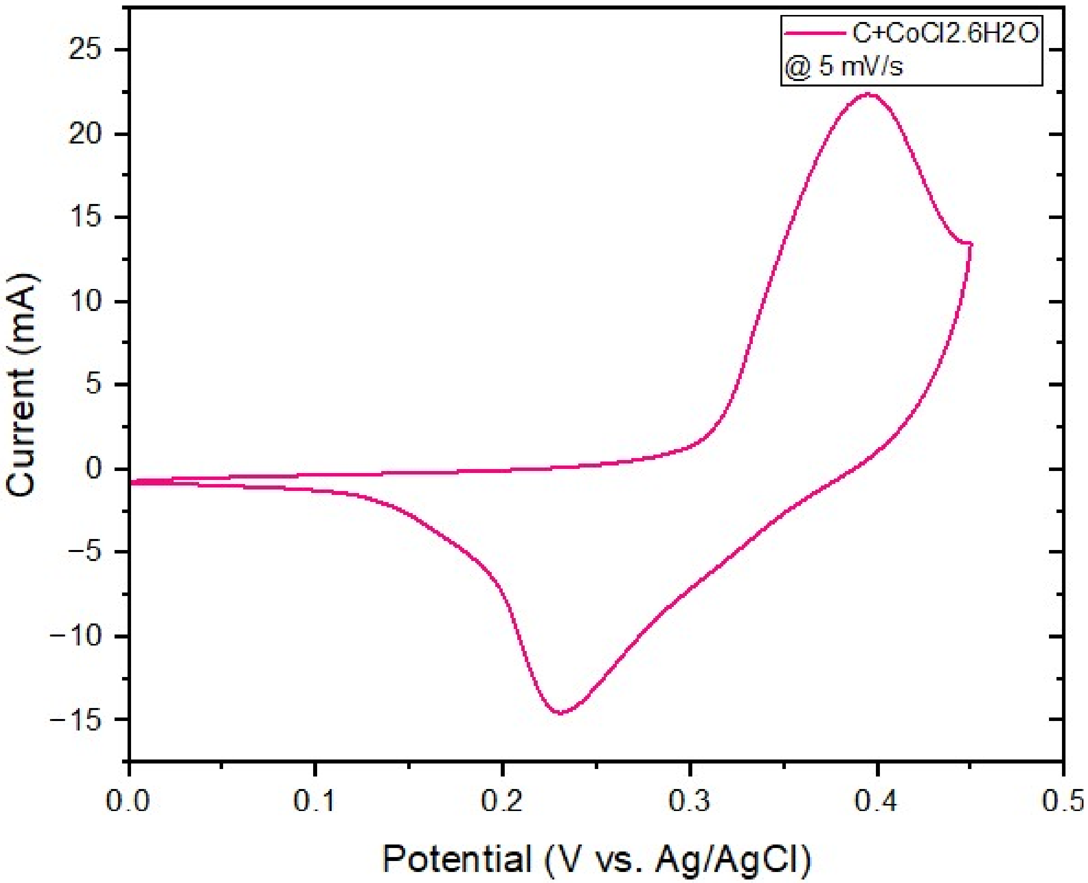



CoO NWs
Bare Ni Foam
@ 5 mV/s
Current (A)
Potential V vs. Ag/AgCl
0.010
0.008
0.006
0.004
0.002
0.000
−0.002
−0.4
−0.2
0.0
0.2
0.4

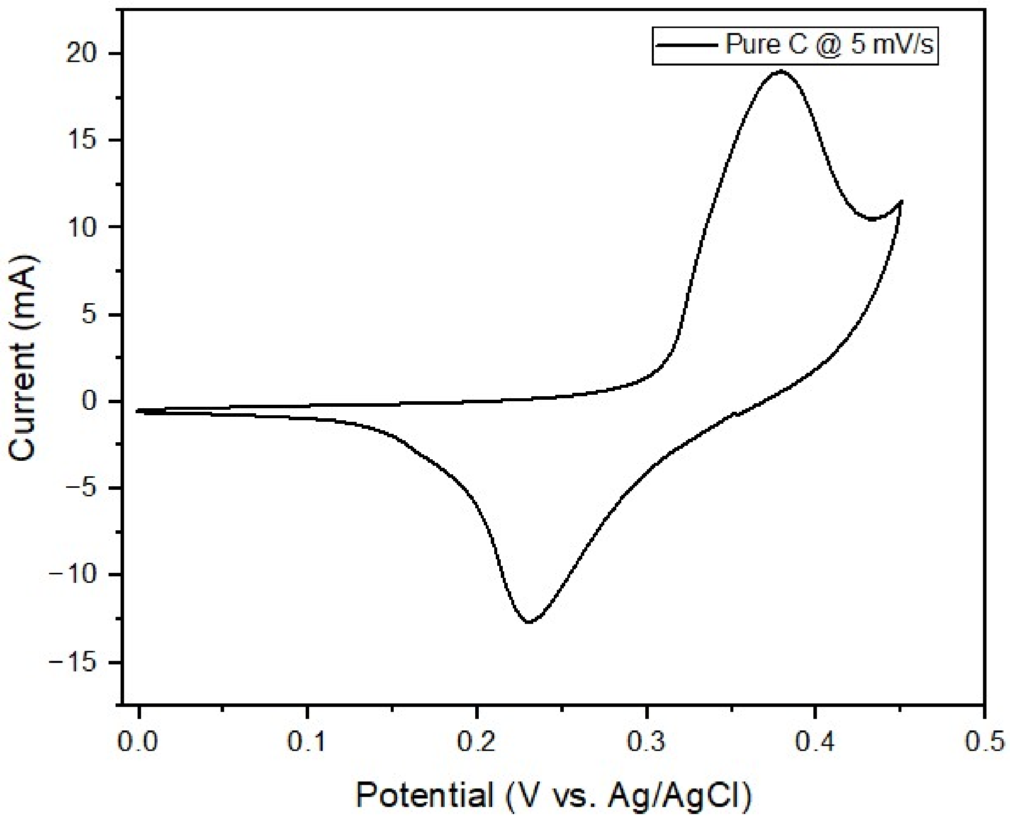

C+ CoO NWs 5mV/s
Current (mA)
Potential V vs. Ag/AgCl
3.0
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
0.0
0.1
0.2
0.3
0.4


@ 5 mV/s
C+NWs
NWs
Ni Foam
Current (mA)
Potential V vs. Ag/AgCl


C+NPs
Current (A)
Potential V vs. Ag/AgCl

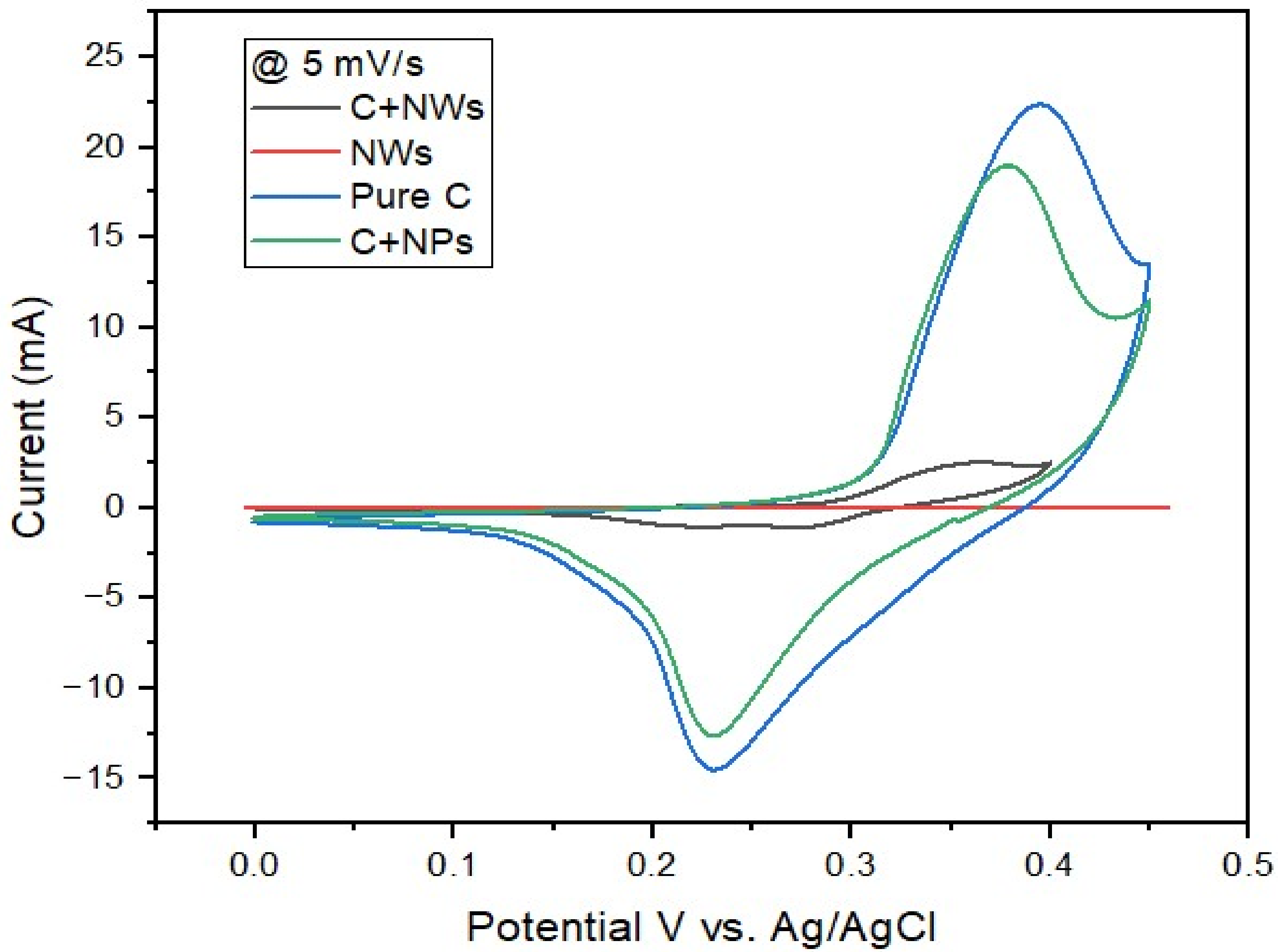


C+CoCl2.6H2O @ 5 mV/s
Current (mA)
Potential (V vs. Ag/AgCl)

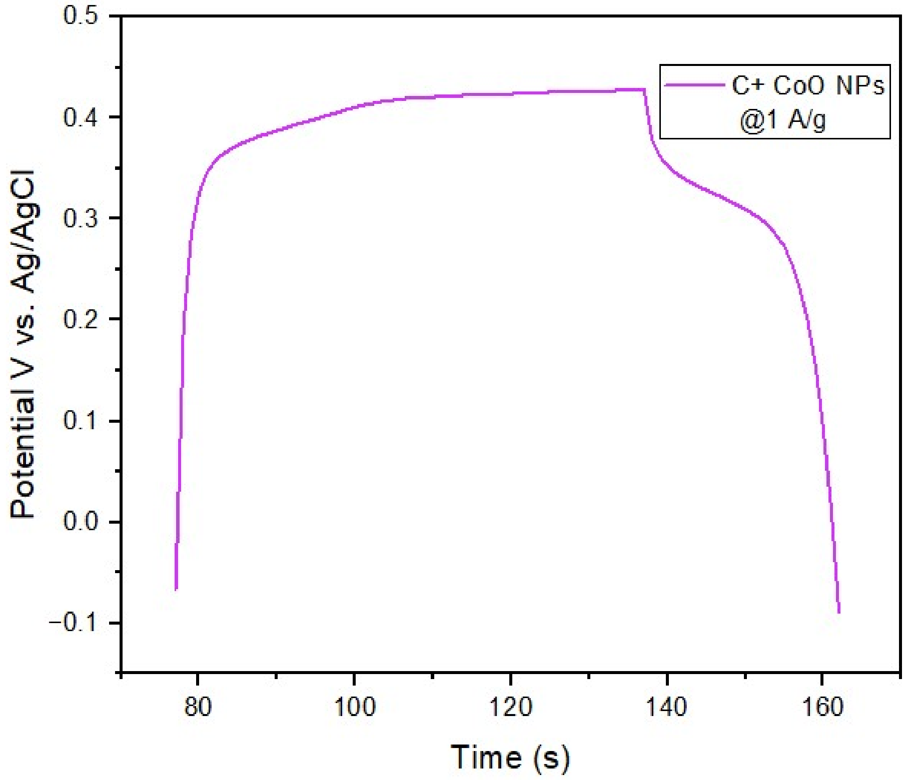


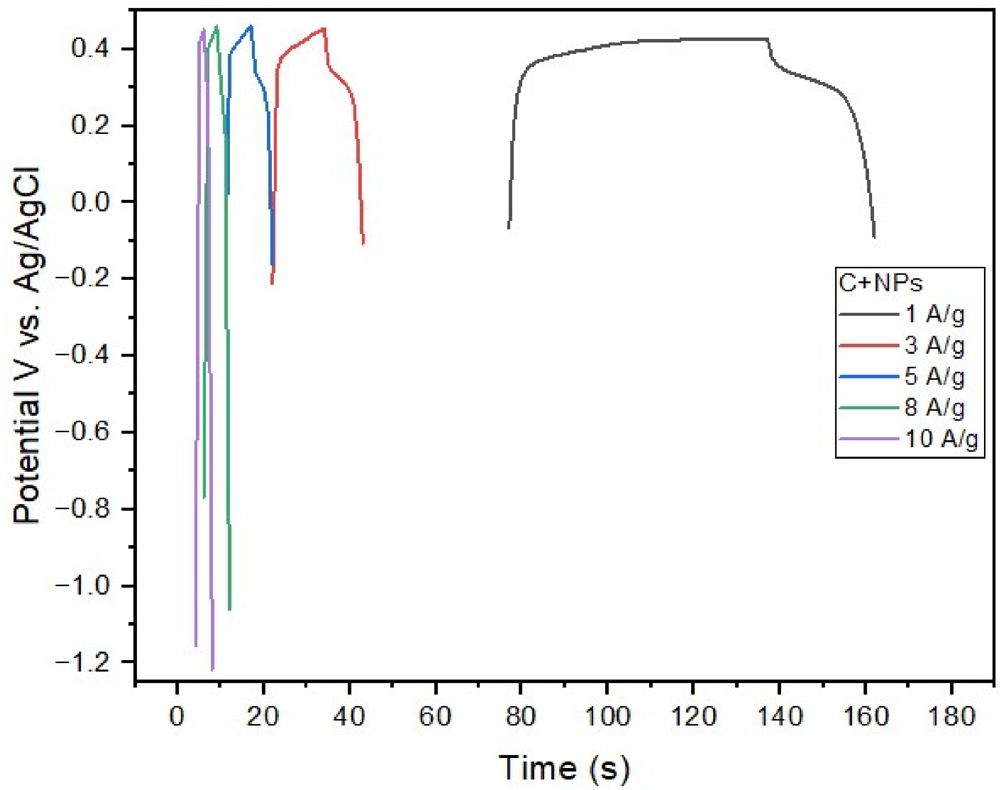
Pure C @ 5 mV/s
Current (mA)
Potential (V vs. Ag/AgCl)

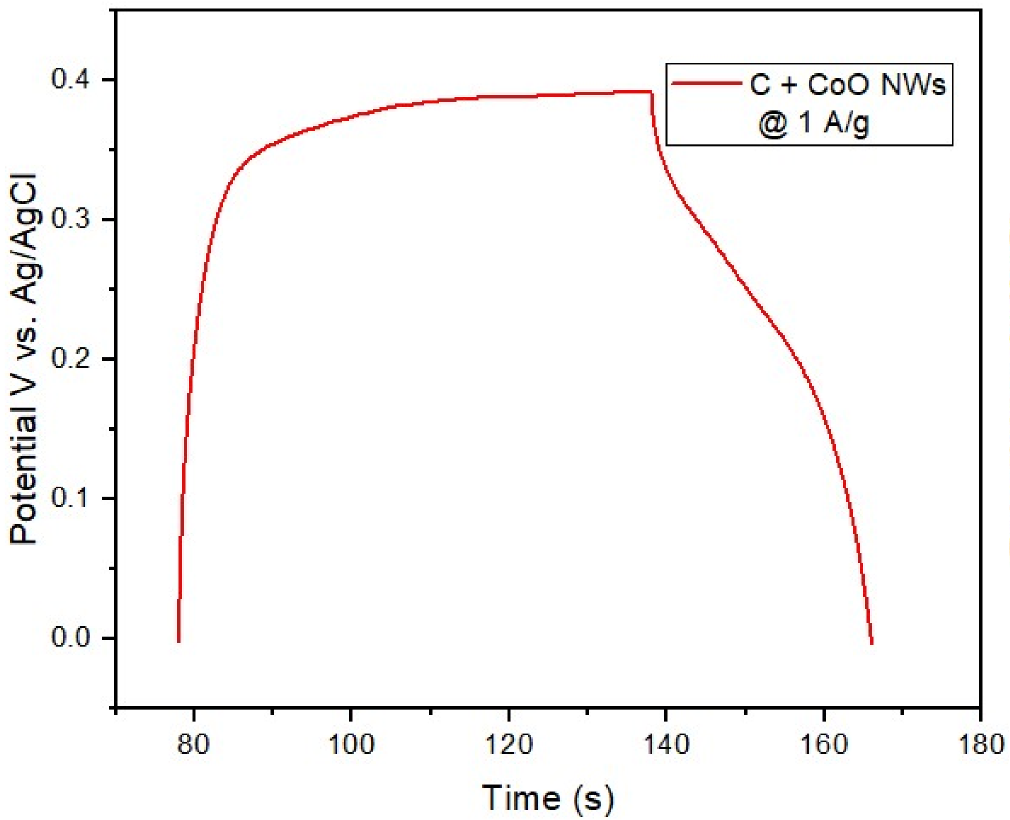
CV Comparison All Samples

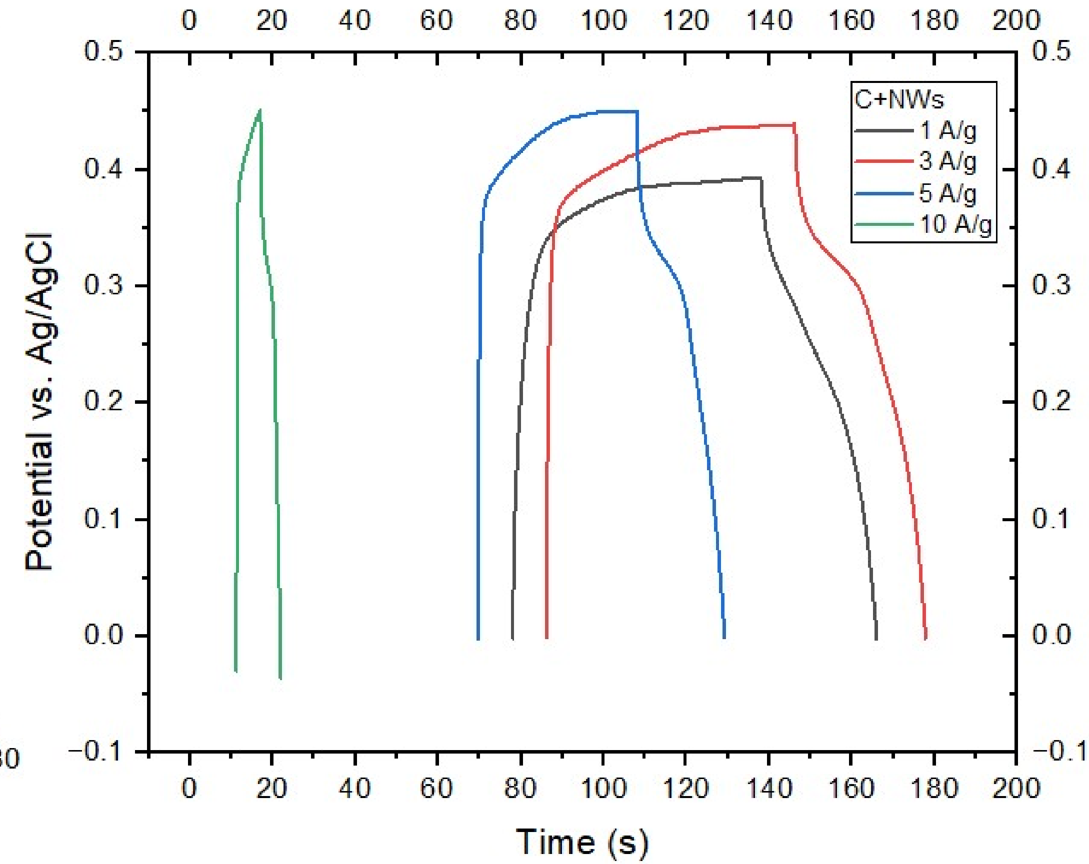


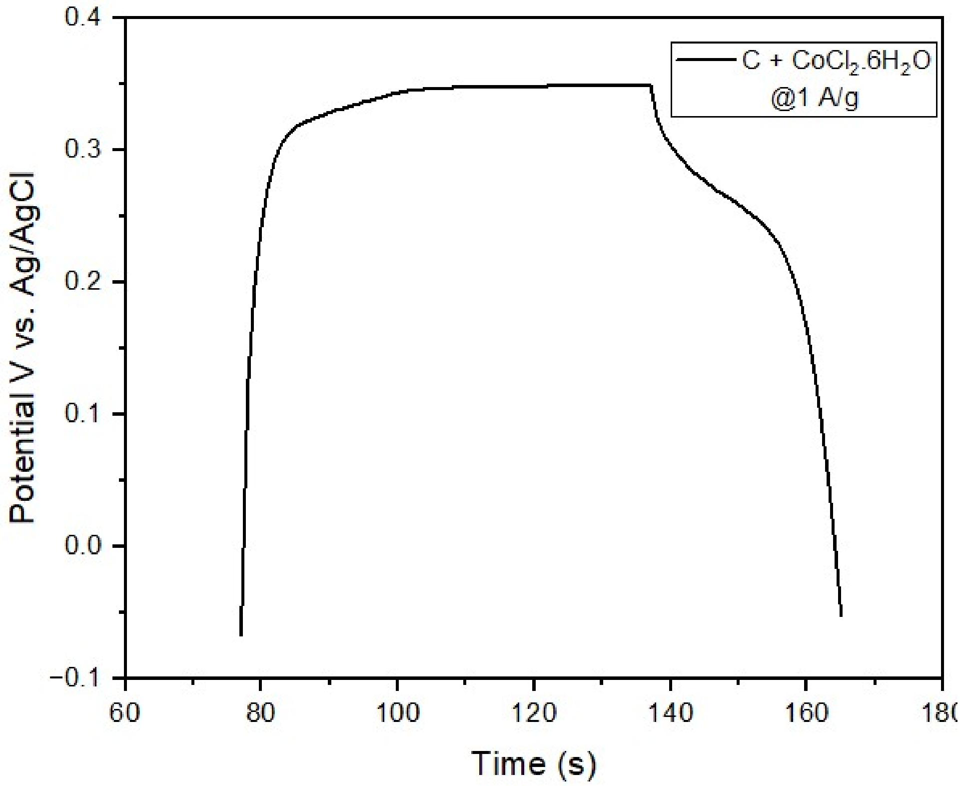
Electrochemical Testing (GCD)

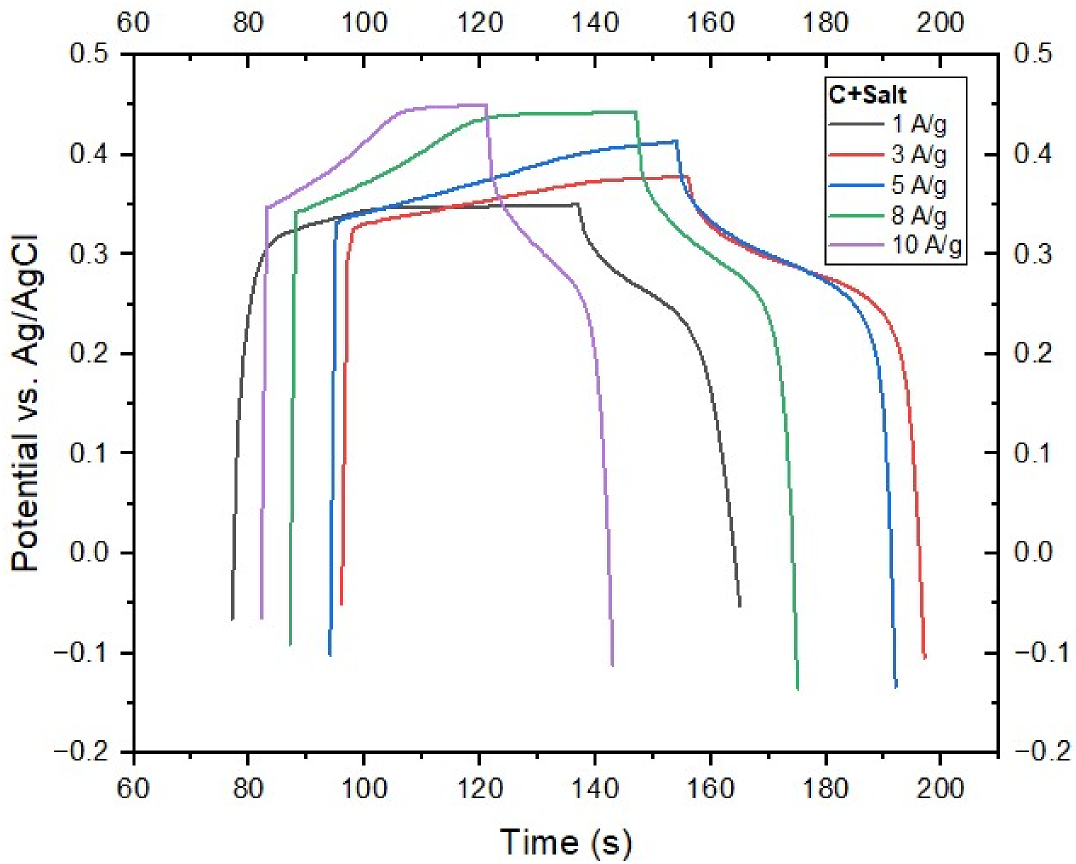


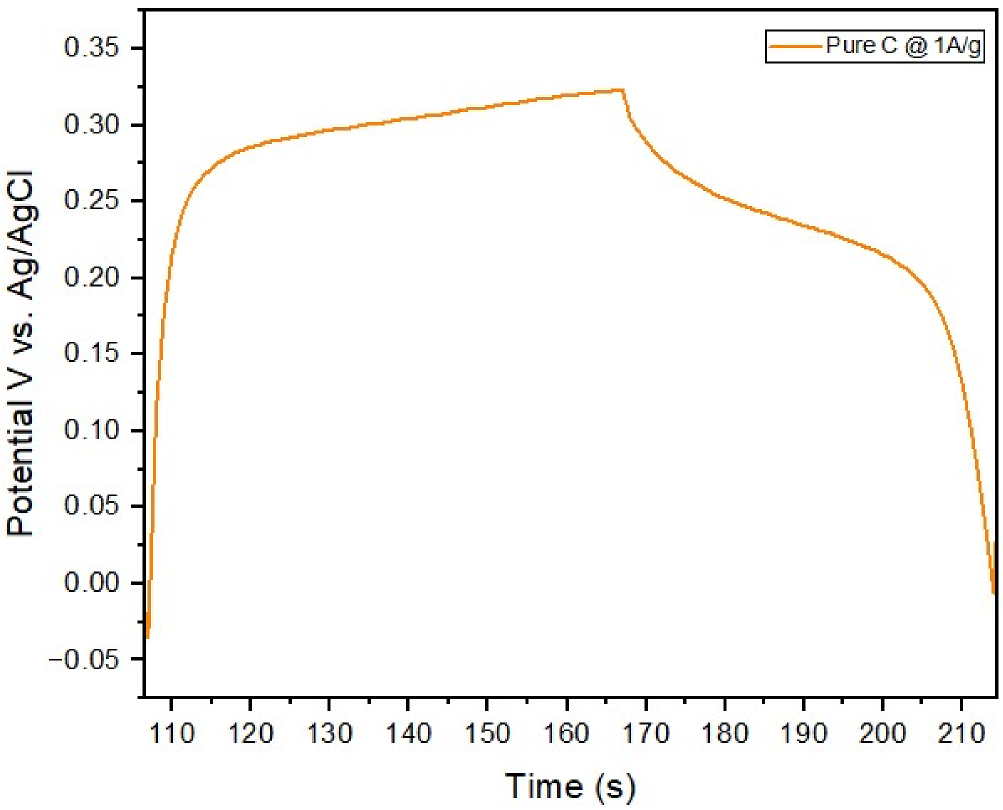


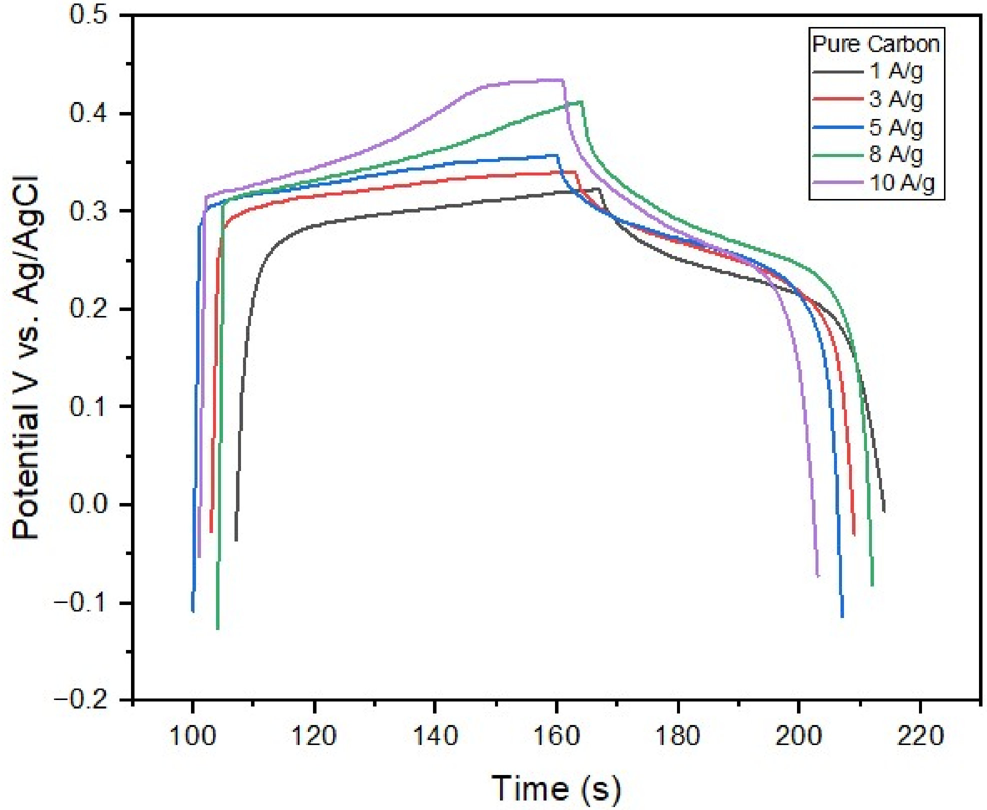

C + CoO NWs
@ 1 A/g
Potential V vs. Ag/AgCl
Time (s)


C+NWs
1 A/g
3 A/g
5 A/g
10 A/g
Potential vs. Ag/AgCl
Time (s)

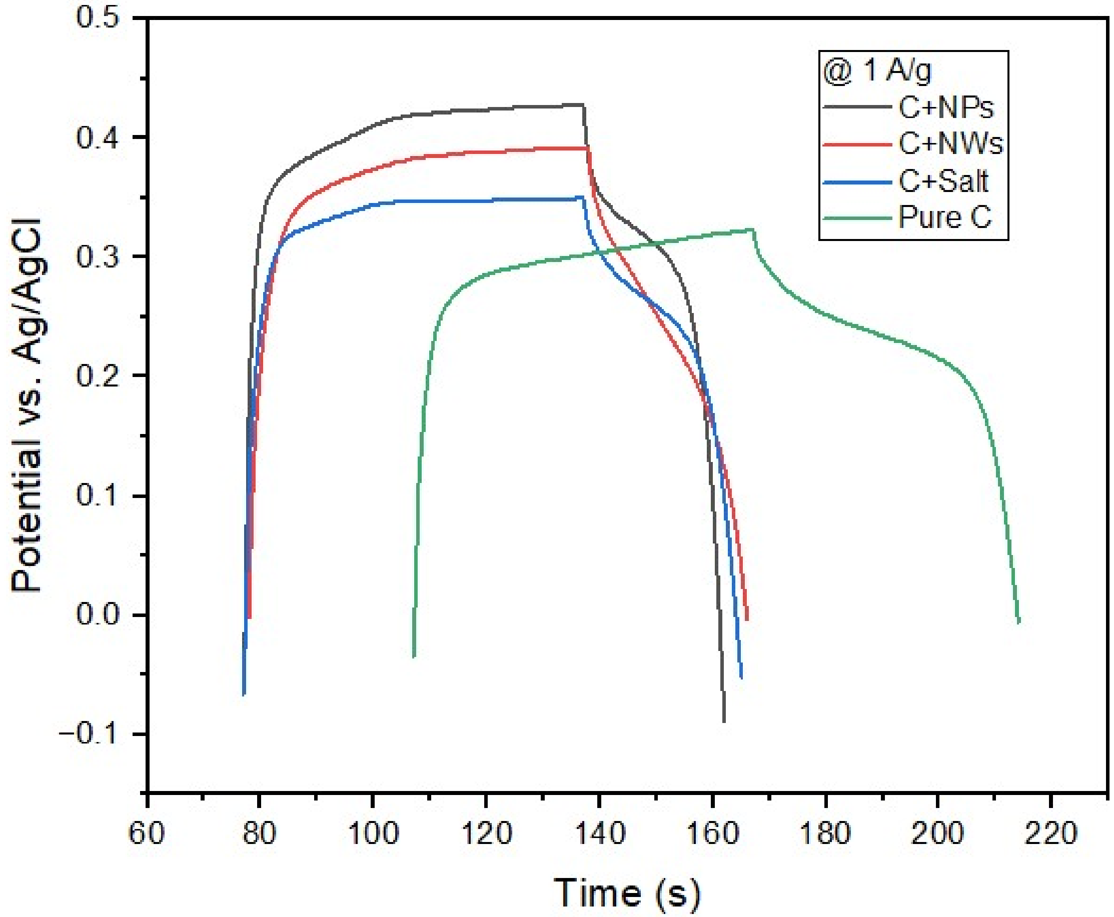

C + CoCl2.6H2O
@1 A/g
Potential V vs. Ag/AgCl
Time (s)


C+Salt
1 A/g
3 A/g
5 A/g
8 A/g
10 A/g
Potential vs. Ag/AgCl
Time (s)

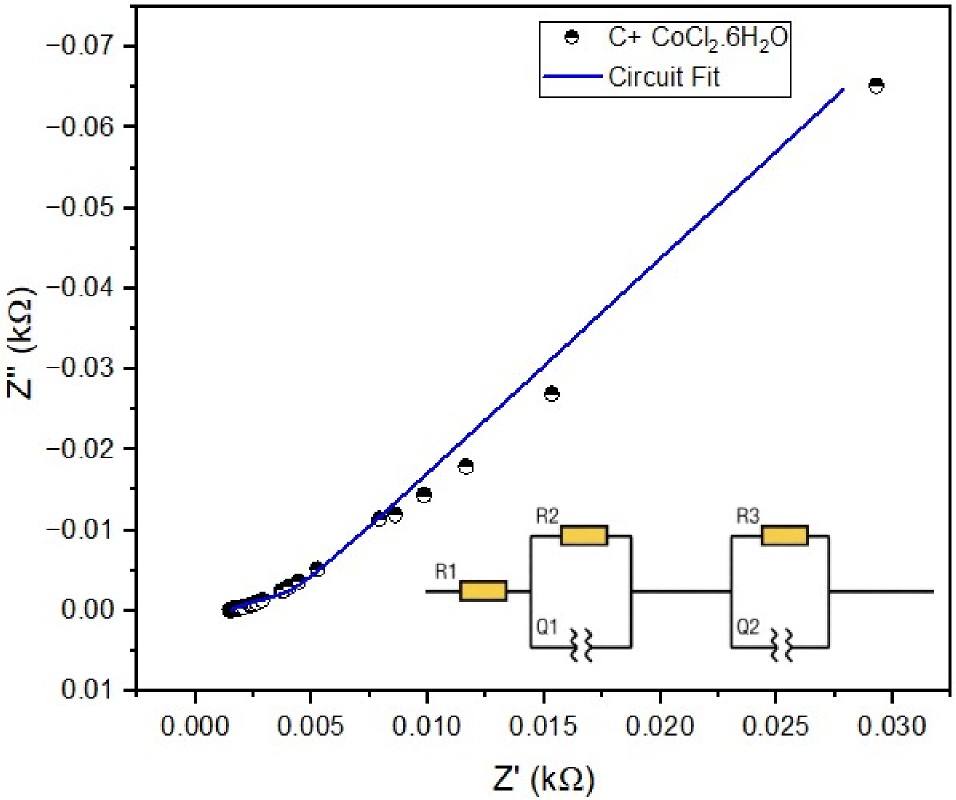

Pure C @ 1A/g
Potential V vs. Ag/AgCl
Time (s)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
−0.05
110
120
130
140
150
160
170
180
190
200
210

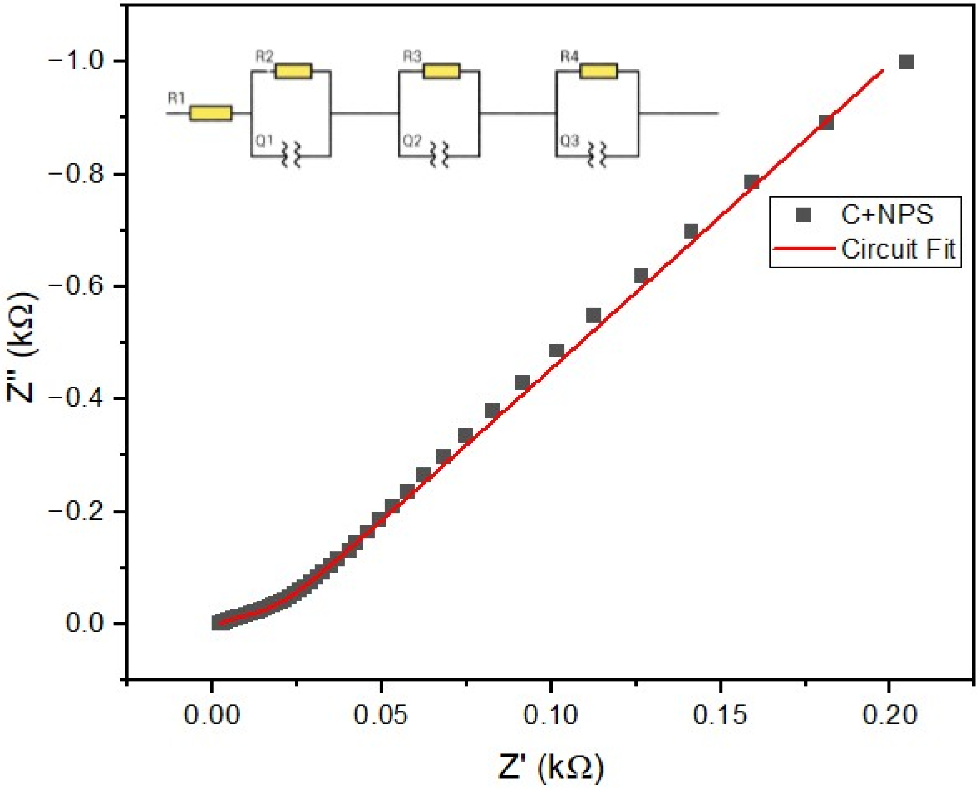

Pure Carbon
1 A/g
3 A/g
5 A/g
8 A/g
10 A/g
Potential V vs. Ag/AgCl
Time (s)
0.5
0.4
0.3
0.2
0.1
0.0
−0.1
−0.2
100
120
140
160
180
200
220

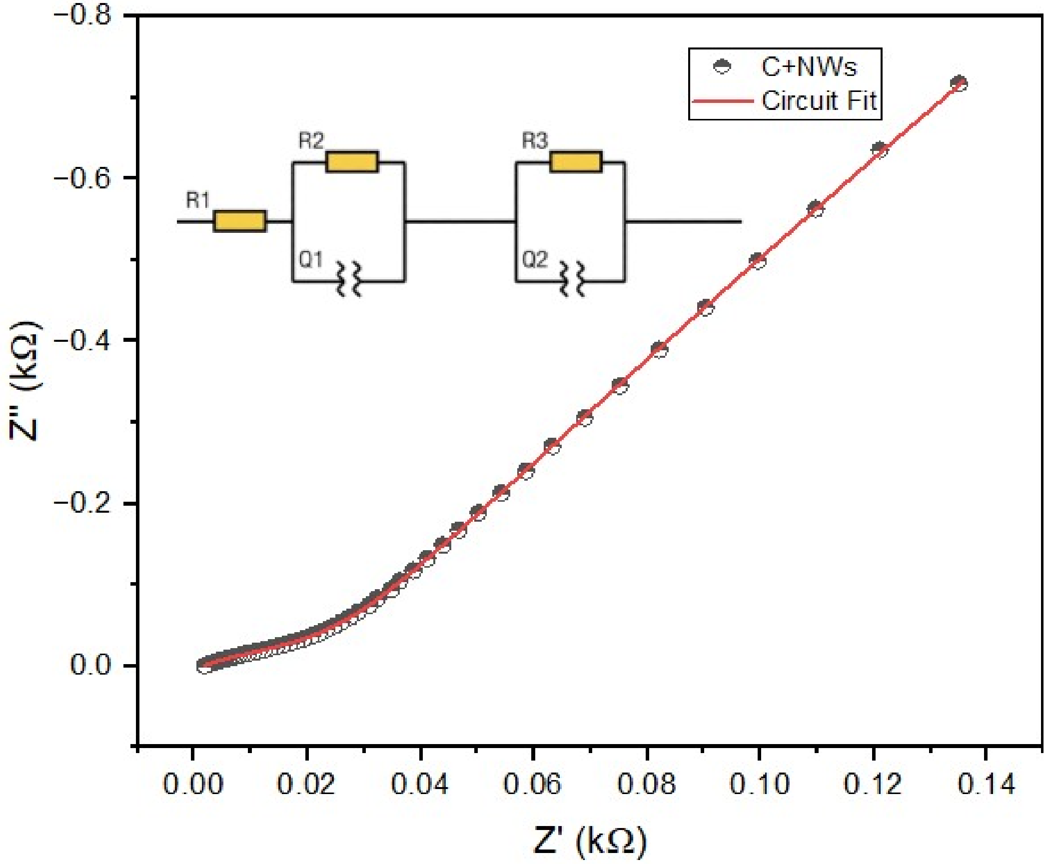
GCD Comparison of All Samples

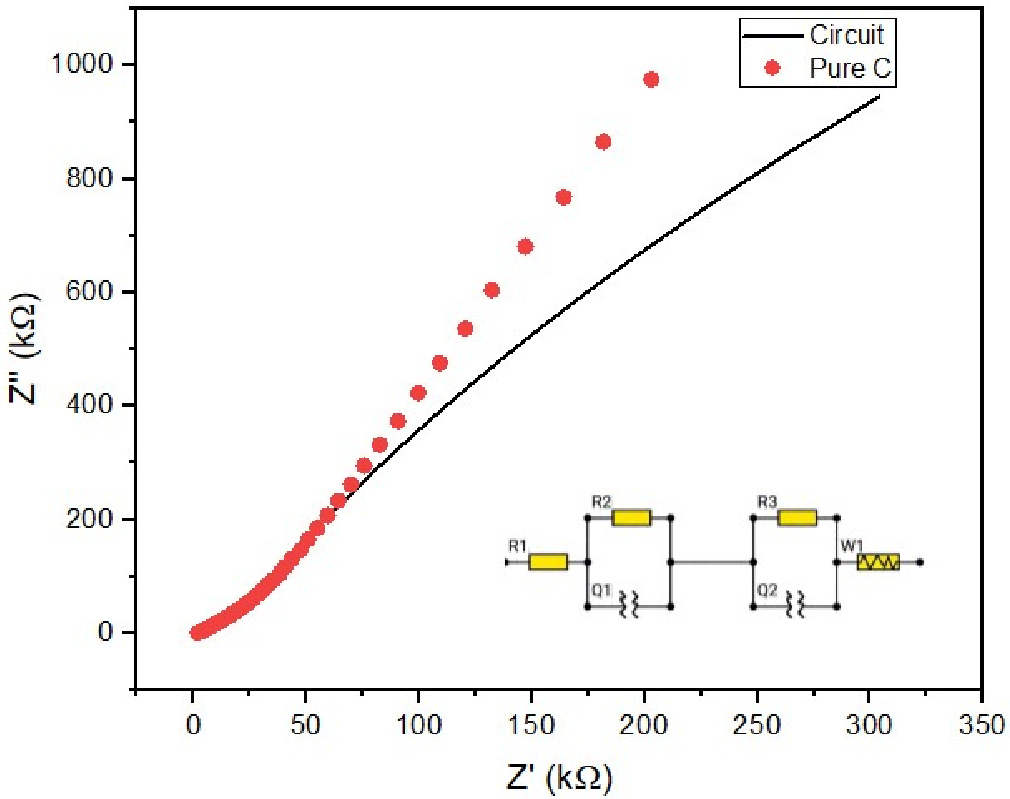


Electrochemical Testing (EIS)

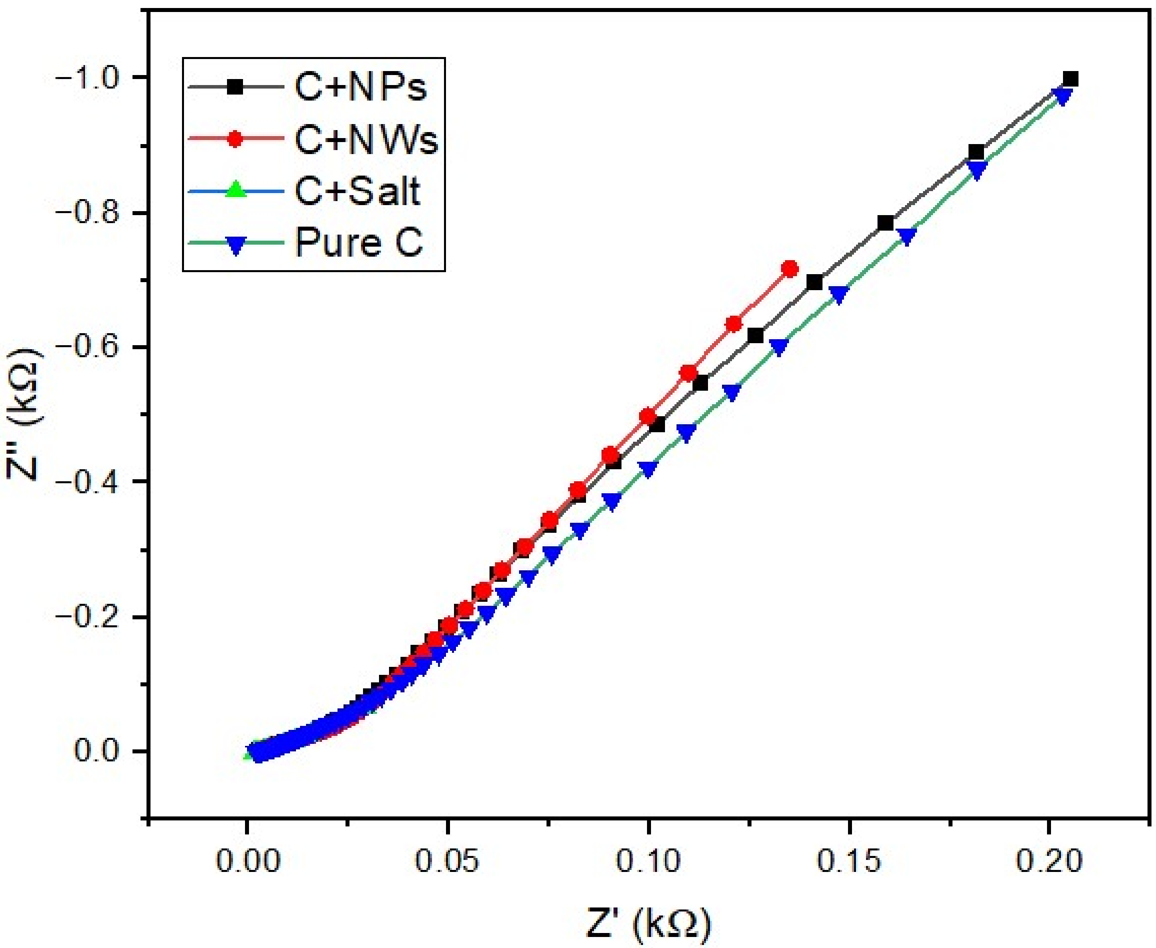





C+NWs
Circuit Fit
R1
R2
R3
Q1
Q2
−0.8
−0.6
−0.4
−0.2
0.0
Z'' (kΩ)
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
Z' (kΩ)


Circuit
Pure C
R1
R2
R3
W1
Q1
Q2
1000
800
600
400
200
0
Z'' (kΩ)
0
50
100
150
200
250
300
350
Z' (kΩ)

EIS Comparison All Samples



Capacitance, Power Density and Energy Density

Sample	Specific Capacitance (F/g)	Power Density (W/kg)	Energy Density (Wh/kg)
C + CoO Nanowires	83.78	3672	5.1
C + CoO Nanoparticles	51.069	244.8	1.70
C + CoCl2.6H2O	79	204.4	1.59
Pure C	202.36	209	2.73

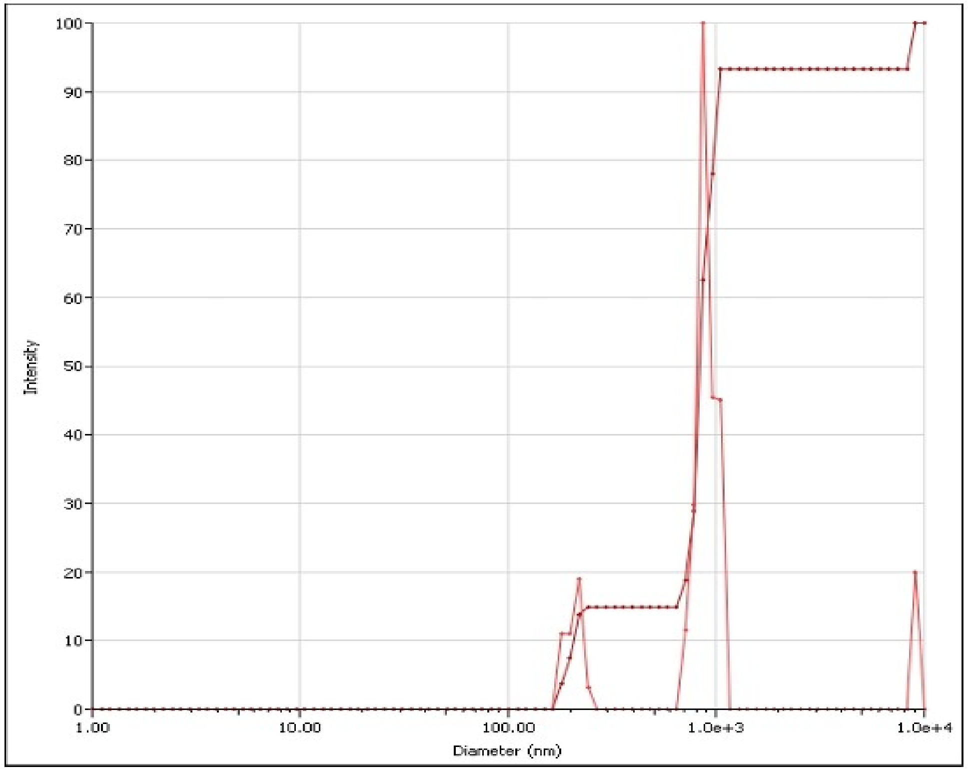
Characterization

Particle Size DLS(C+NPs) and (C+NWs)

Sample		Results	
Type:	DLS	Eff. Diam. (nm):	1,409.16
Sample ID:	C +NPs	Polydispersity:	0.194
Operator ID:	Ayesha	Diffusion Coeff. (cm^2/s):	3.483e-09
SOP ID:	Default		
Start Date/Time:	11/4/2025 12:35:17 AM		

Notes:

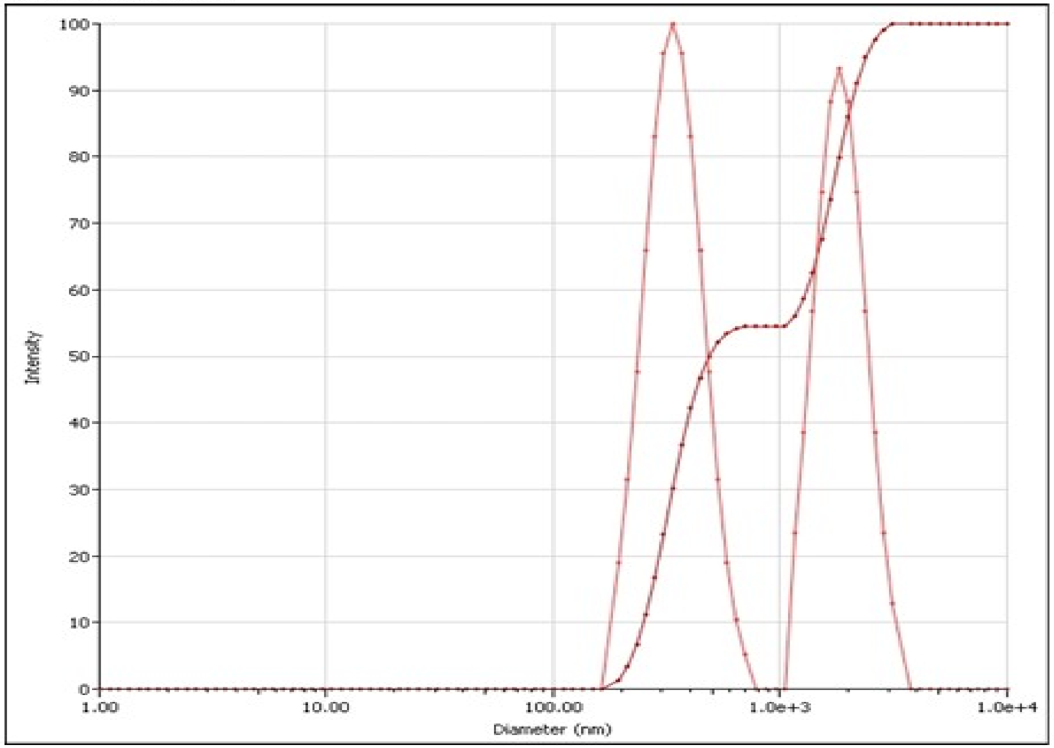
Multimodal Size Distribution:



Sample		Results	
Type:	DLS	Eff. Diam. (nm):	610.77
Sample ID:	C+ NWs	Polydispersity:	0.306
Operator ID:	Ayesha	Diffusion Coeff. (cm^2/s):	8.035e-09
SOP ID:	Default		
Start Date/Time:	11/4/2025 12:47:50 AM		

Notes:

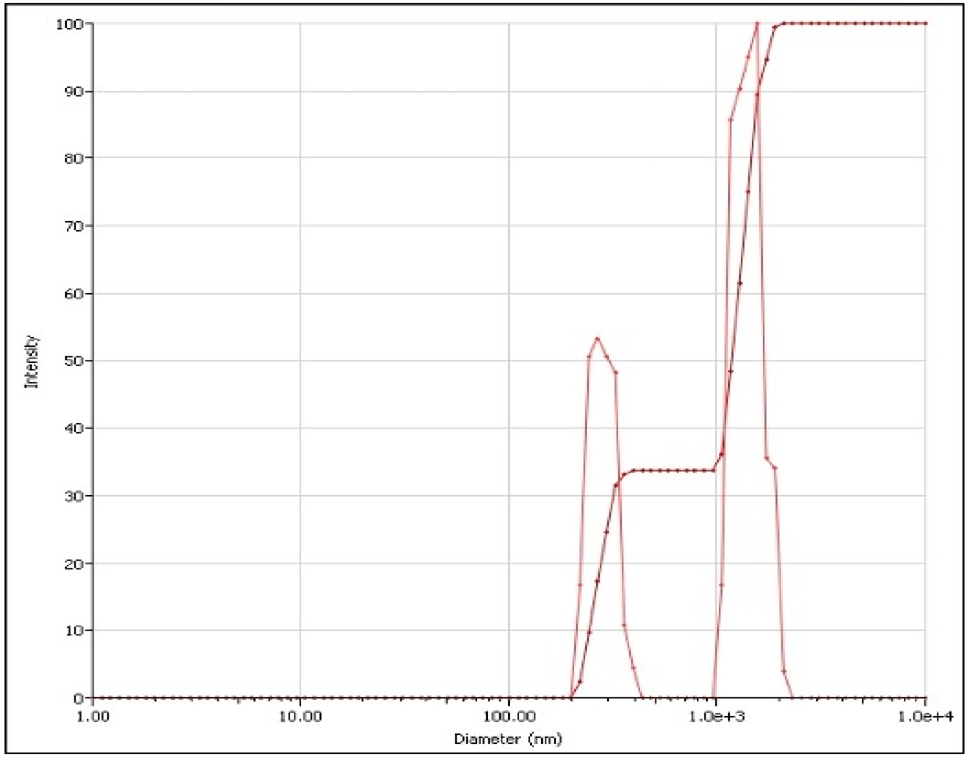
Multimodal Size Distribution:



DLS(C and C + salt)

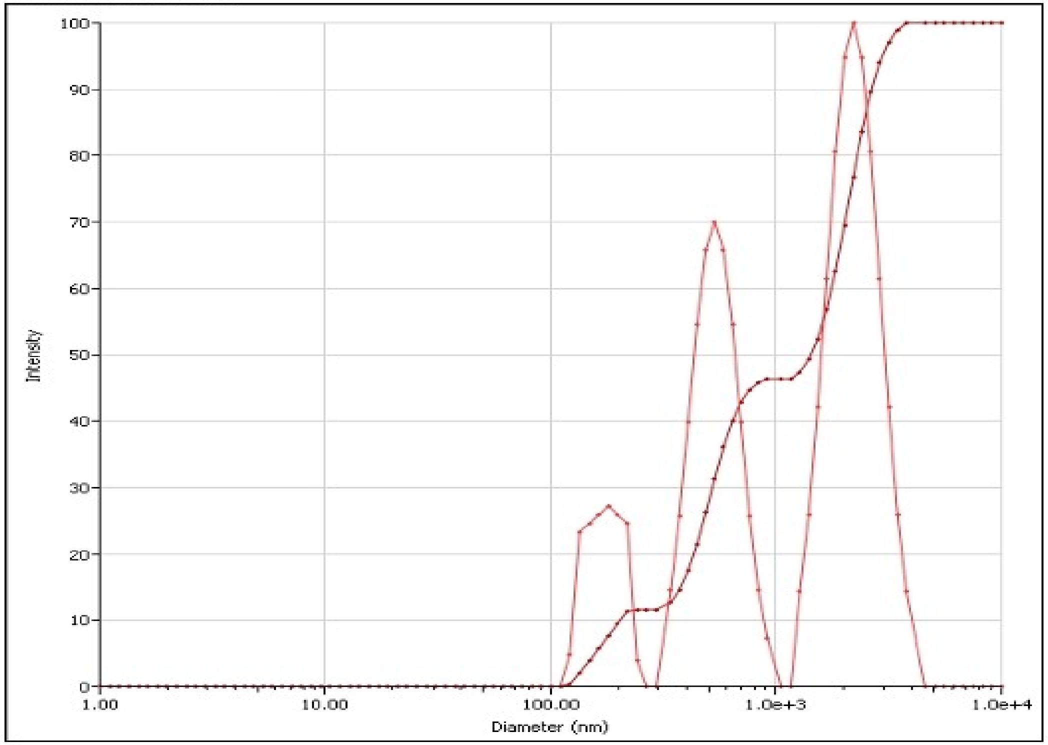
Sample		Results	
Type:	DLS	Eff. Diam. (nm):	676.26
Sample ID:	Pure carbon	Polydispersity:	0.331
Operator ID:	Ayesha	Diffusion Coeff. (cm²/s):	7.257e-09
SOP ID:	Default		
Start Date/Time:	11/4/2025 12:53:01 AM		
Notes:			

Multimodal Size Distribution:



Sample		Results	
Type:	DLS	Eff. Diam. (nm):	841.48
Sample ID:	C +salt	Polydispersity:	0.350
Operator ID:	Ayesha	Diffusion Coeff. (cm²/s):	5.832e-09
SOP ID:	Default		
Start Date/Time:	11/4/2025 12:42:17 AM		
Notes:			

Multimodal Size Distribution:



DLS Cont'd

Sample	Effective Dia (nm)
Pure Carbon	676.26 nm
C + Nanoparticles	1409.16 nm
C + Nanowire	610.77 nm
C + Co salt	841.48 nm

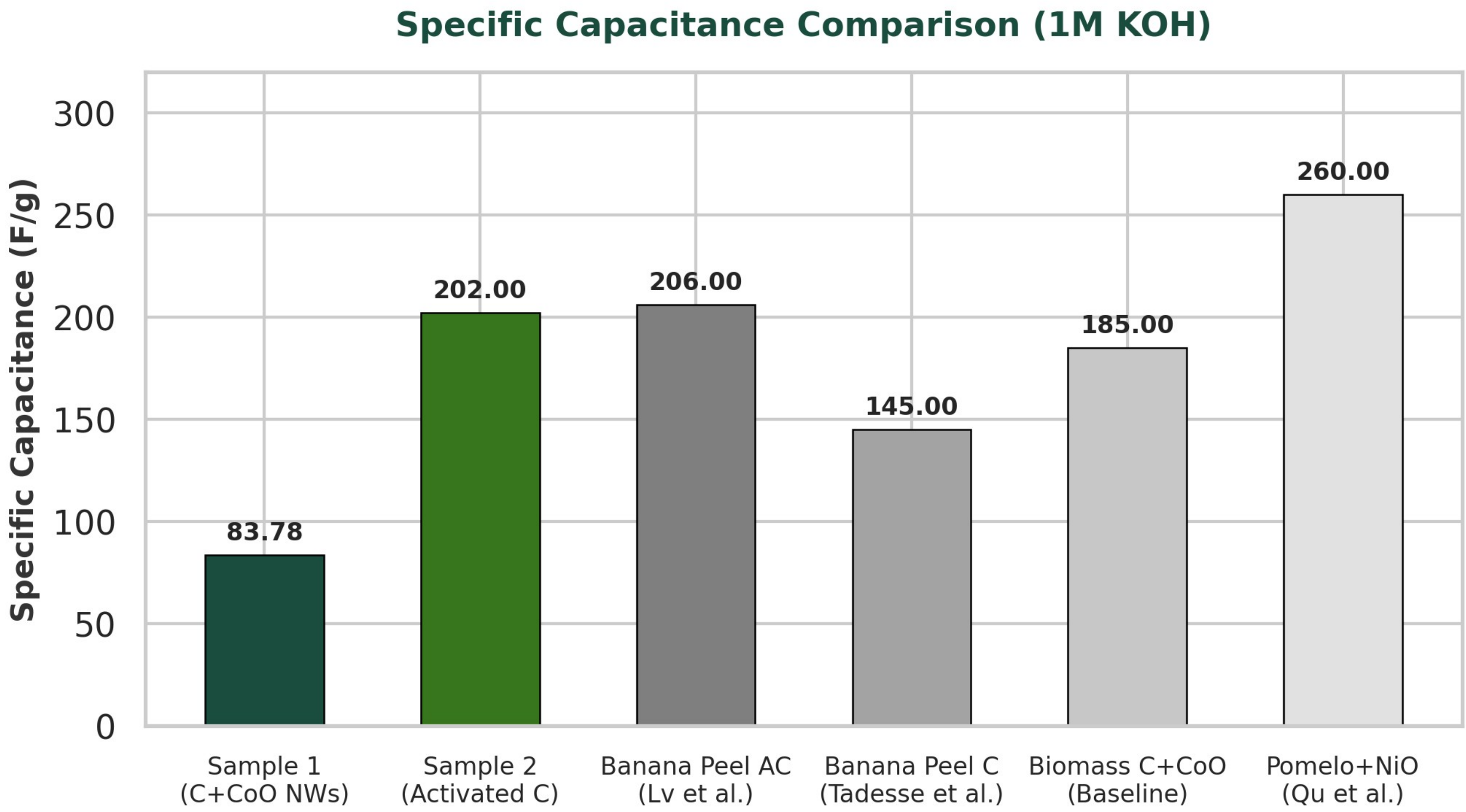
Comparison With Literature

Performance Data Matrix

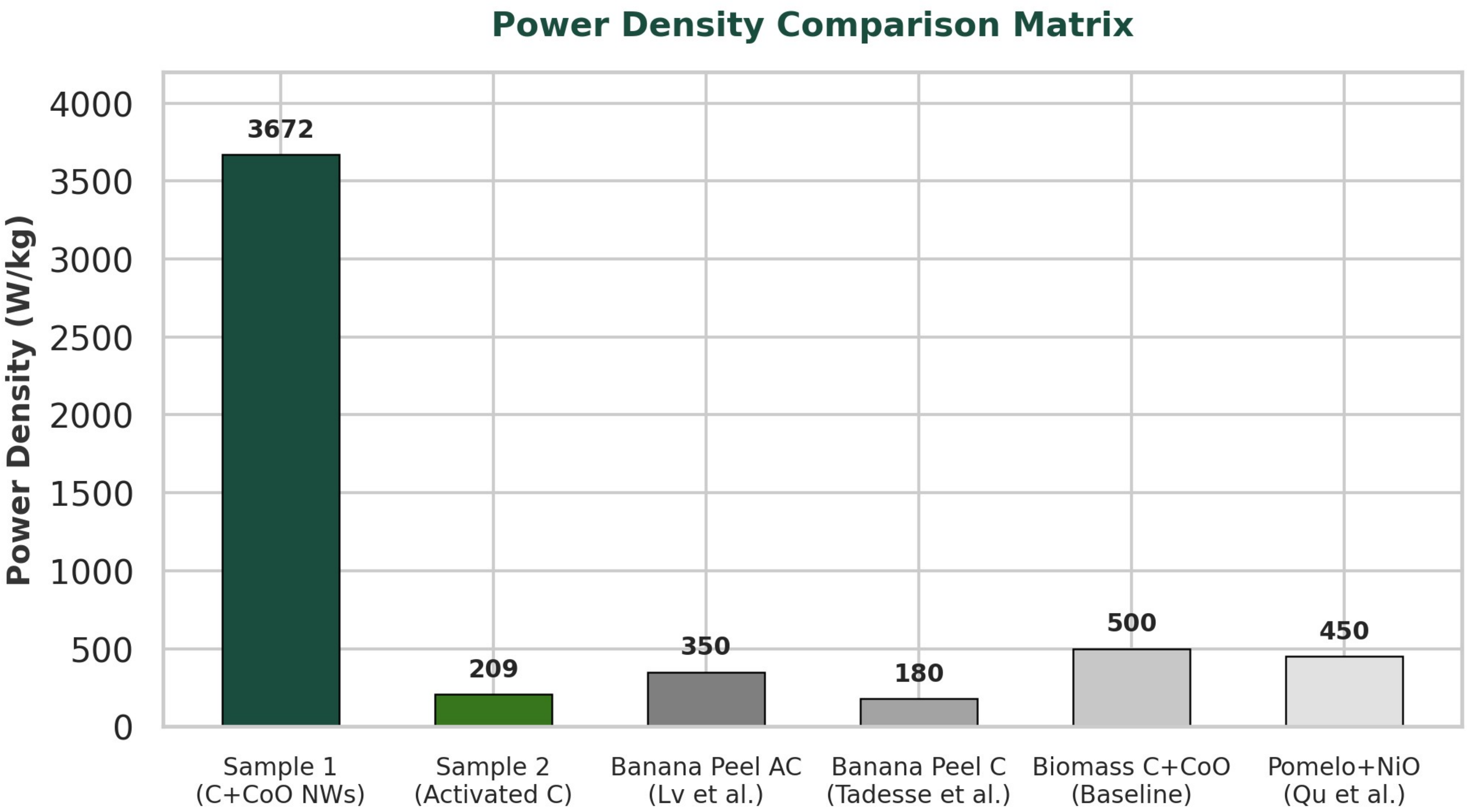
Electrode Material	Capacitance (F/g)	Energy Density (Wh/kg)	Power Density (W/kg)	Electrolyte	Reference Source
Sample 1 (C + CoO NWs)	83.78	5.10	3672	1M KOH	Our Work
Sample 2 (Activated C)	202.00	2.73	209	1M KOH	Our Work
Banana Peel AC	206.00	4.50	350	1M KOH	Lv et al.
Banana Peel Carbon	145.00	2.10	180	1M KOH	Tadesse et al. (2023)
Biomass C + CoO Base	185.00	6.20	550	1M KOH	Literature Baseline
Pomelo Peel + NiO Array	260.00	8.50	450	1M KOH	Qu et al. (2016)

Graphical Implementations & Benchmarks

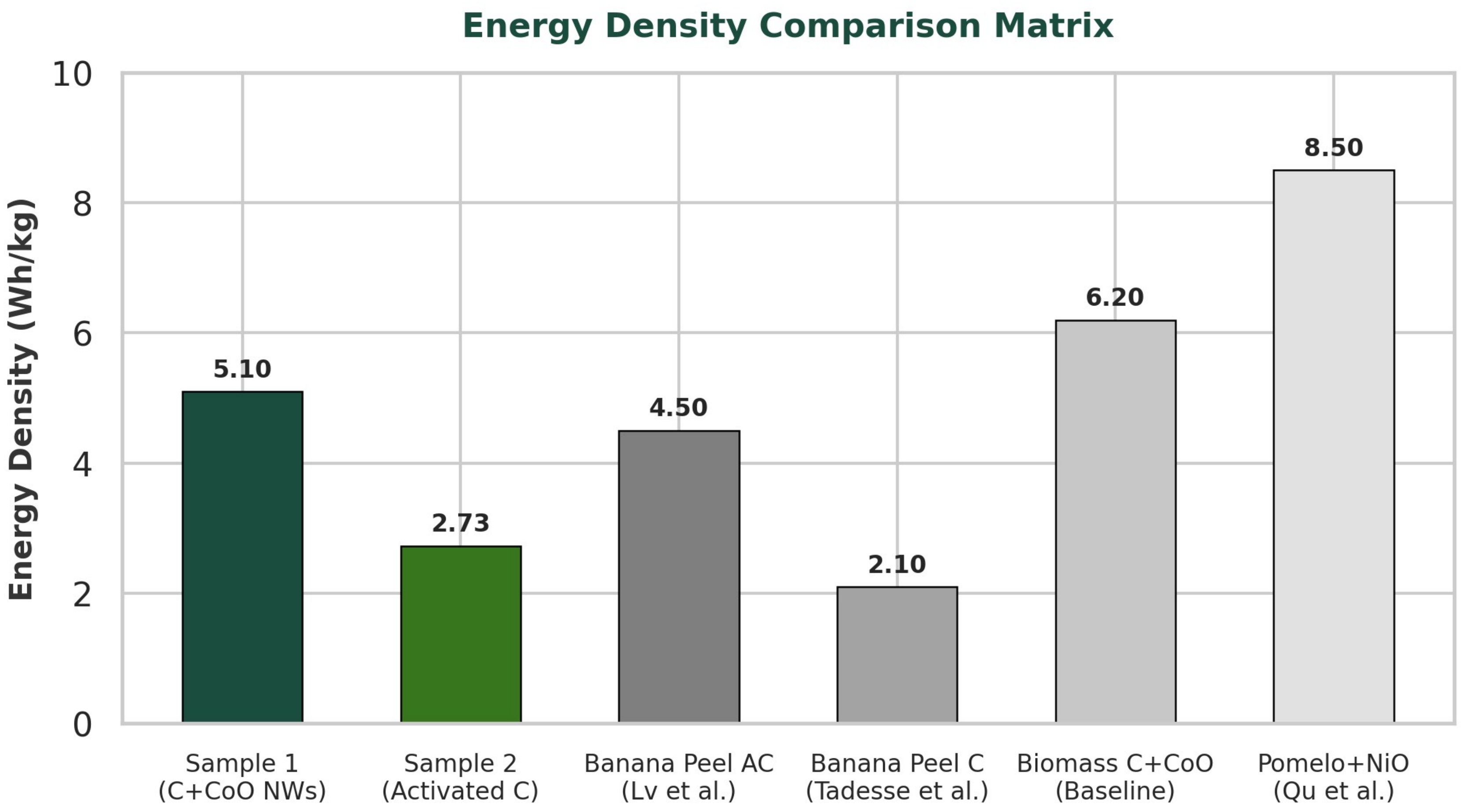
Isolated Comparison: Specific Capacitance Profile



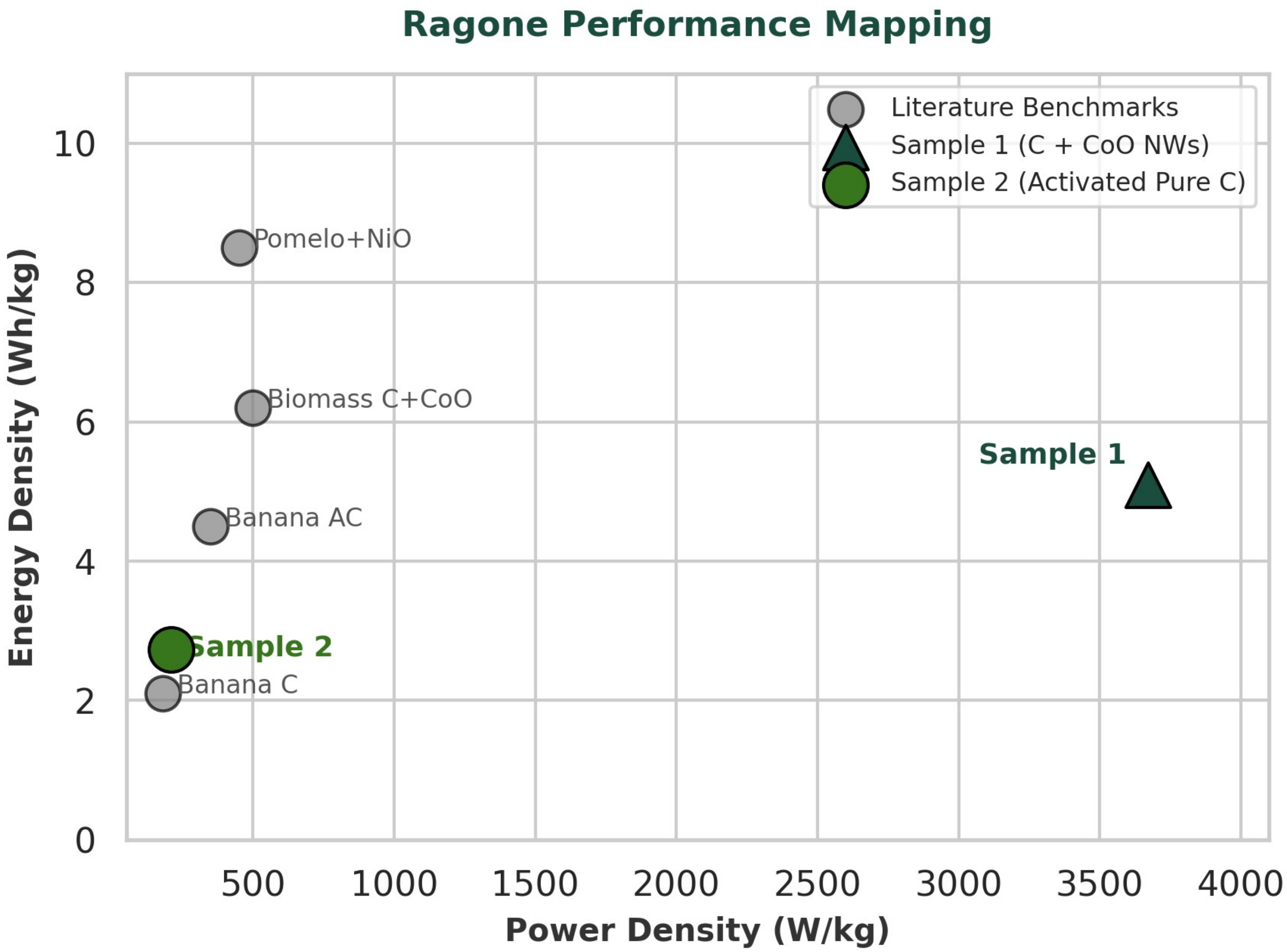
Isolated Comparison: Power Density Profile



Isolated Comparison: Energy Density Profile



- **Comprehensive Mapping: Ragone Plot Coordinates**



Steps to Increase Specific Capacitance

- Increase CoO to Carbon Ratio **[15]**
- Reduce PVA binder content **[16]**
- Optimize electrode mass loading **[18]**

References

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Thank You