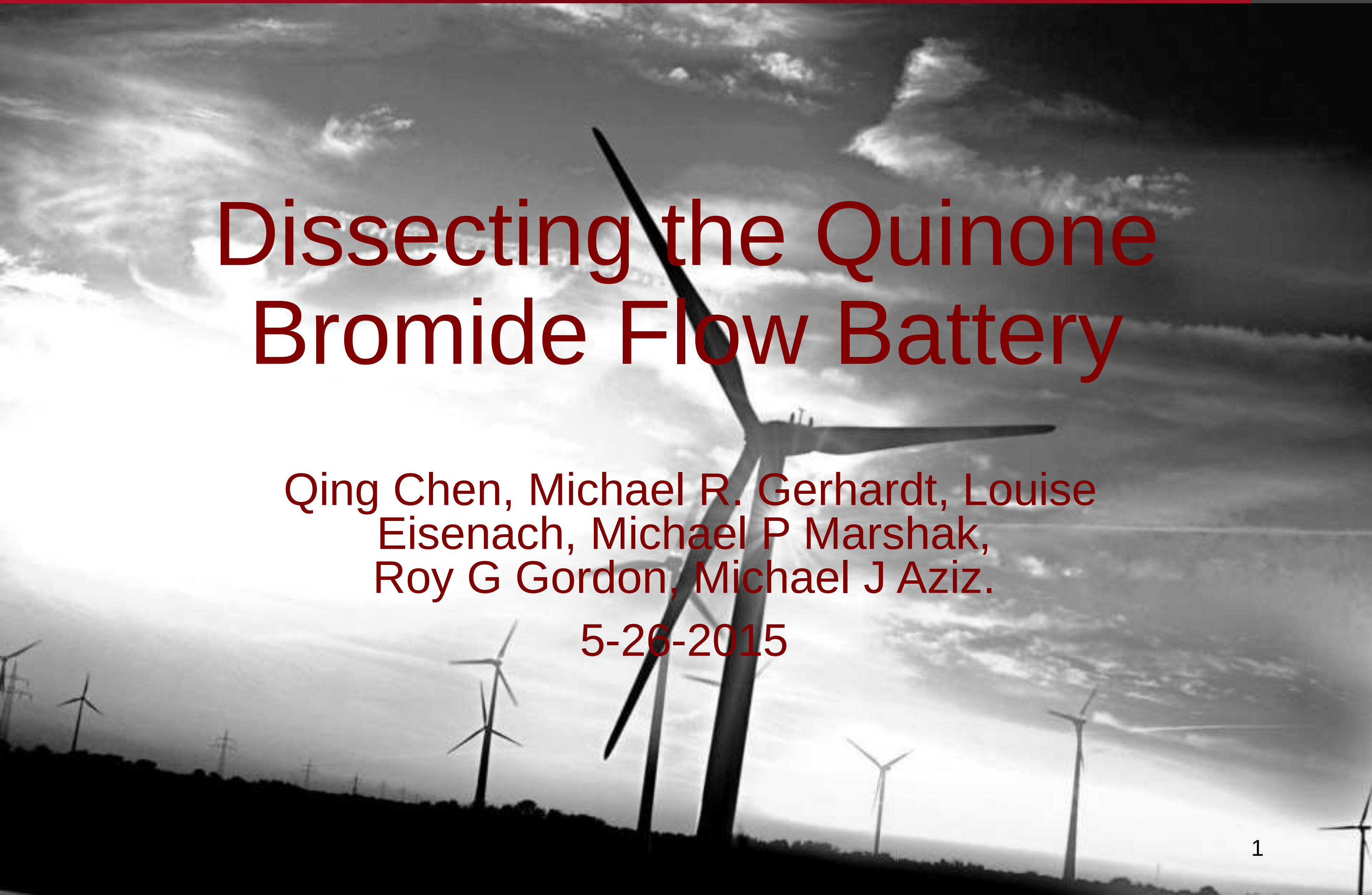
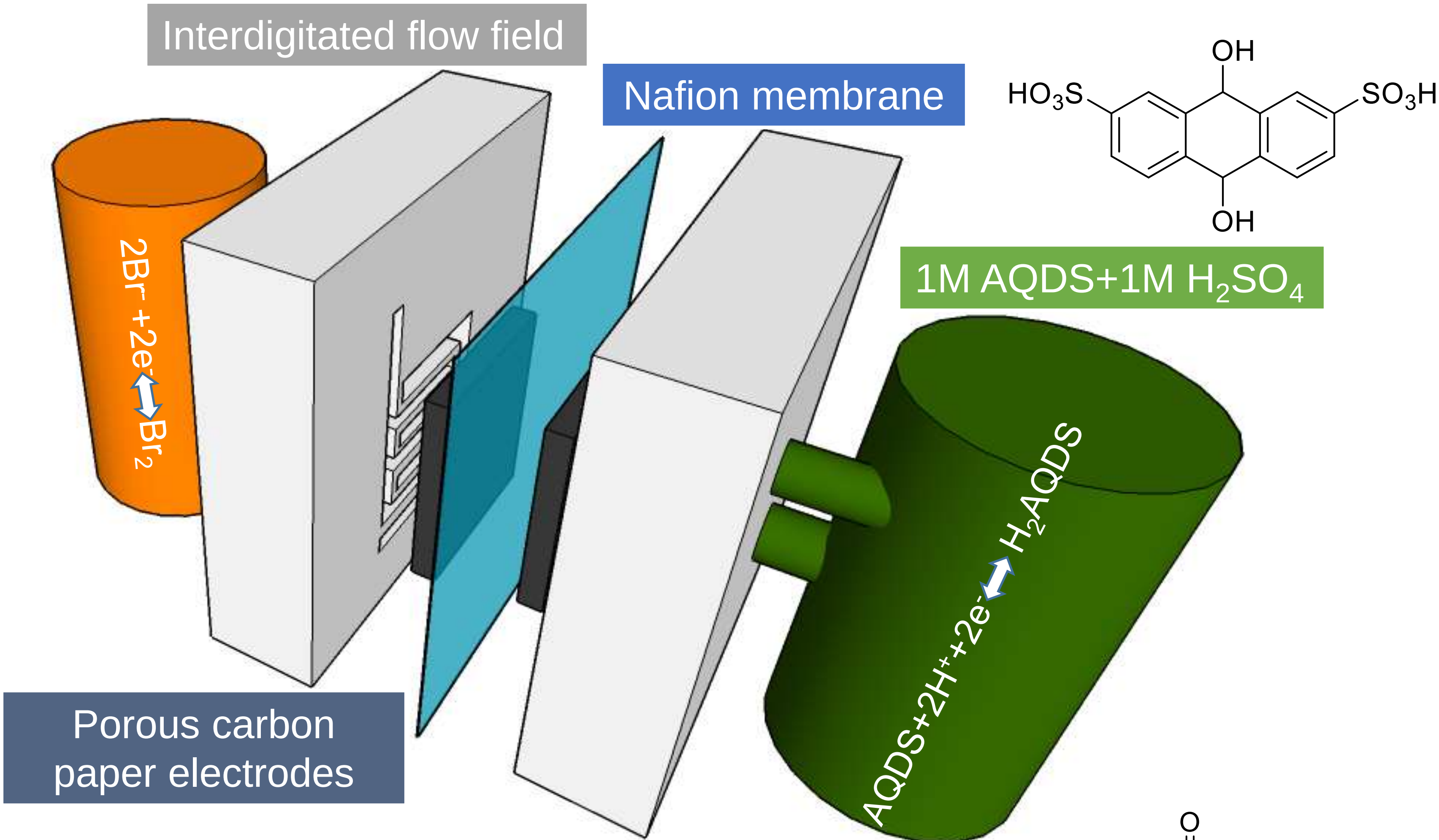


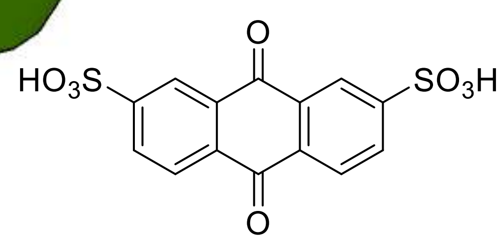
Dissecting the Quinone Bromide Flow Battery

Qing Chen, Michael R. Gerhardt, Louise Eisenach, Michael P Marshak,
Roy G Gordon, Michael J Aziz.

5-26-2015

Quinone-bromide flow battery



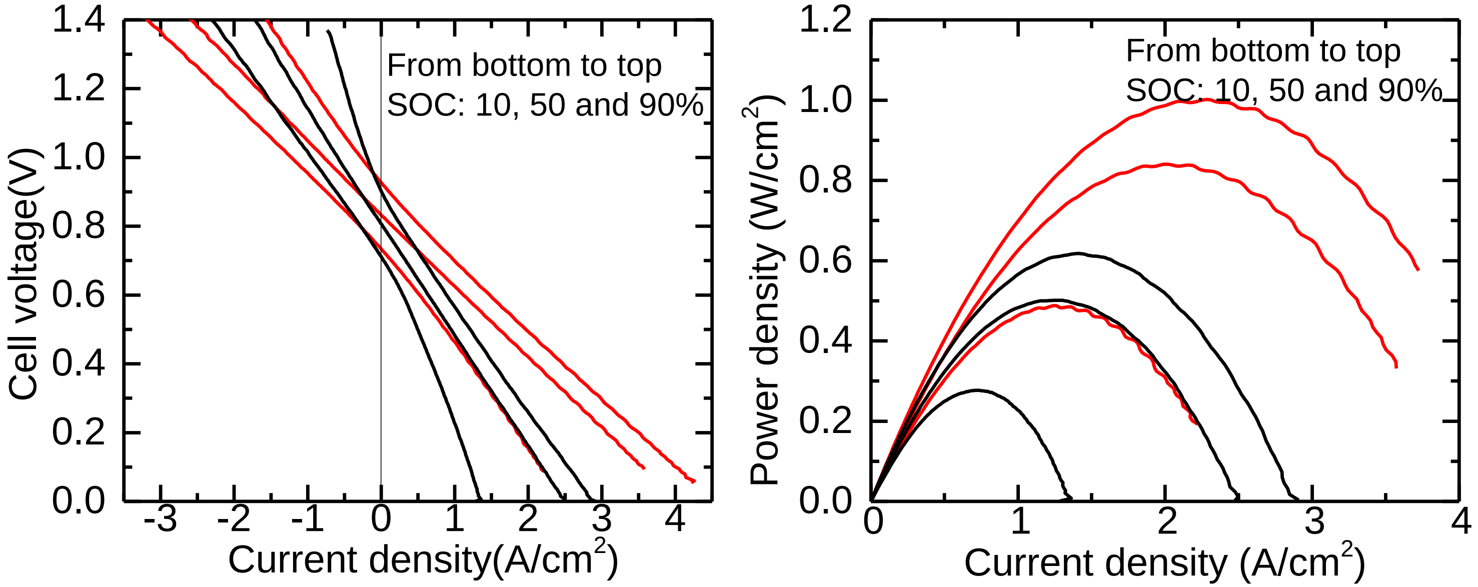


References:
Huskinson, Brian, et al. *Nature* 505.7482 (2014): 195-198.
Huskinson, Brian, et al. *ECS Transactions* 61.37 (2014): 27-30.

QBFB reaches 1.0 W/cm^2

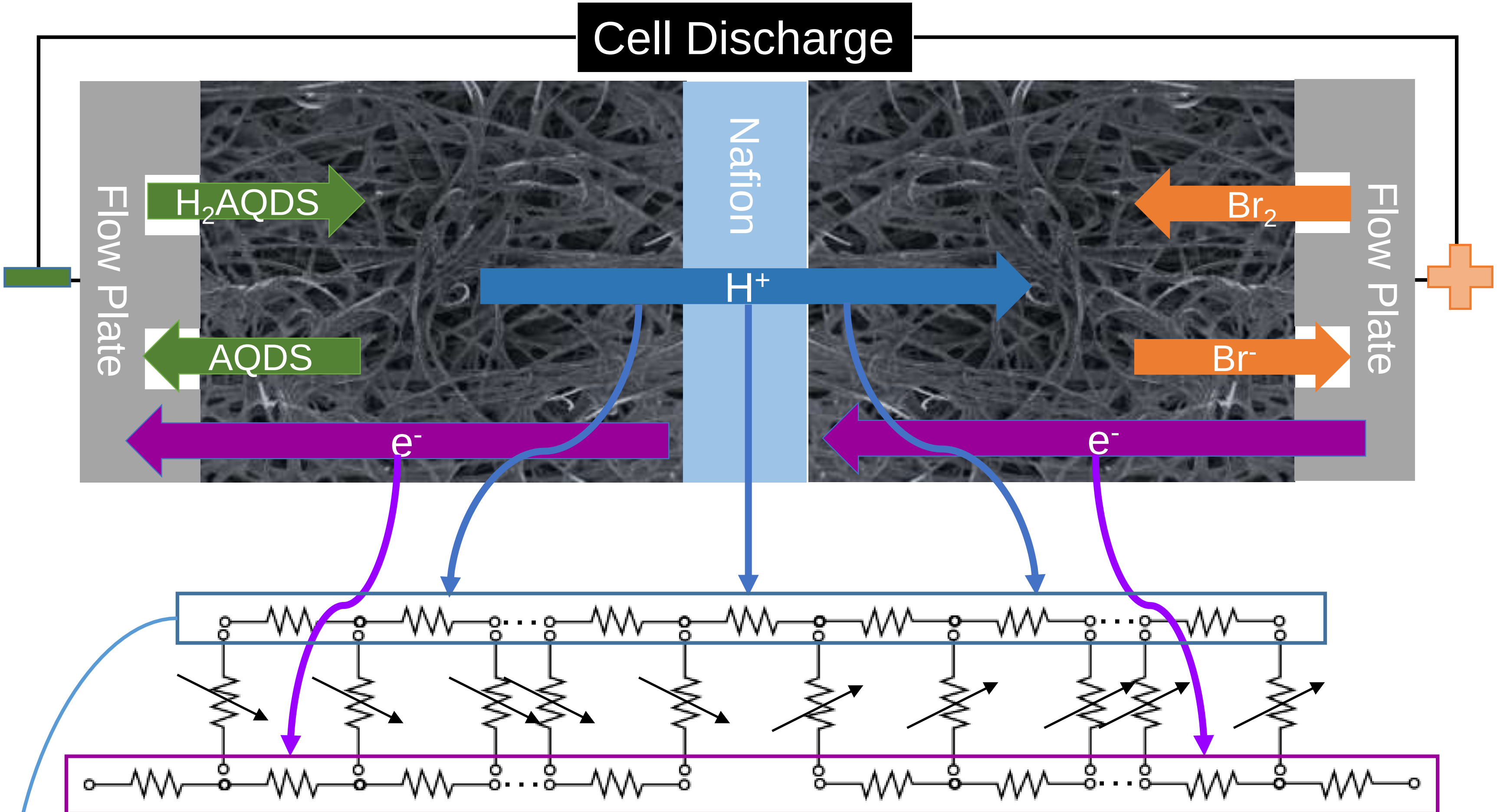
Black: base case ***Red: high power build***

Electrode	Membrane	Flow rate	Temperature	Posolyte
Baked SGL 10AA	Pretreated 212	200 mL/min	20 °C	3 M HBr, 0.5 M Br_2
SGL 10AA	212	100 mL/min	30 °C	3.5 M HBr, 0.5 M Br_2
Etched Toray 060	115	50 mL/min	40 °C	2.5 M HBr, 0.5 M Br_2
•	•	•	•	•
•	•	•	•	•
Baked SGL 10AA	Pretreated 212	400 mL/min	45 °C	3 M HBr, 2 M Br_2



When kinetics and mass transport limits are insignificant, polarization curves are linear

Ohmic resistors in the cell



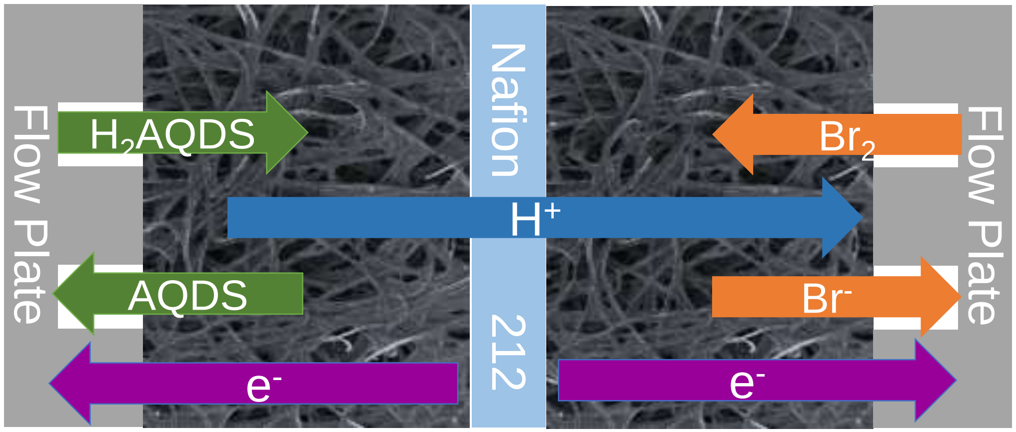
Ionic resistance
- Electrolyte +
- Electrolyte –
- Membrane

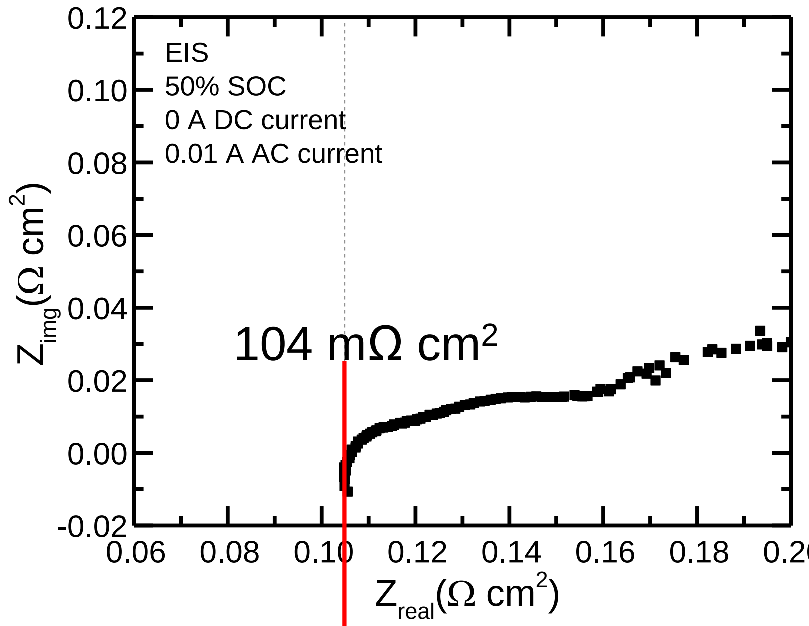
Faradaic resistance
- +
- –

Electronic resistance
- +
- –

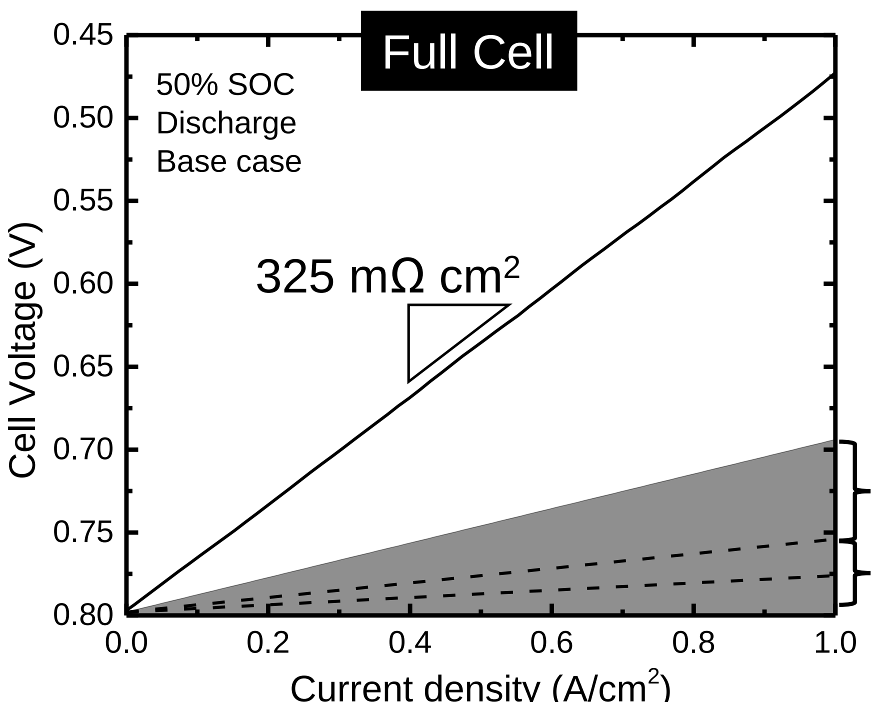
We may use linearized Butler-Volmer

Separating voltage losses





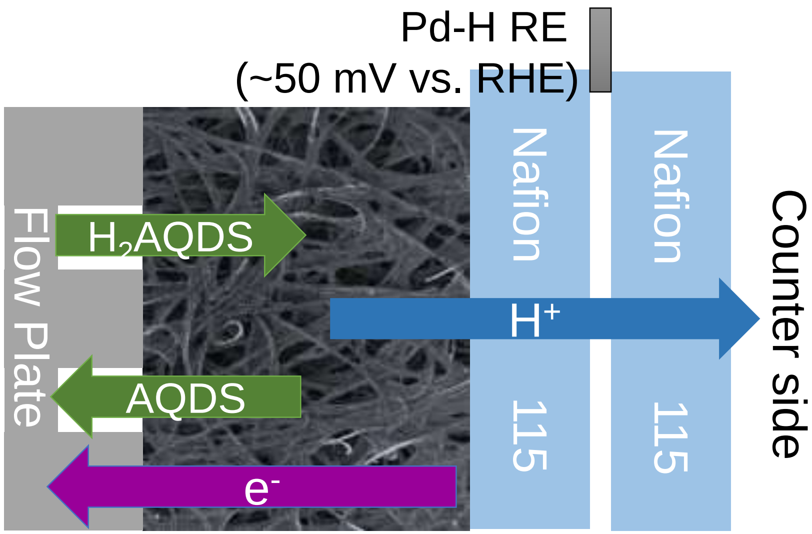
Membrane ionic + electronic (+ & -)
104 mΩ cm^2

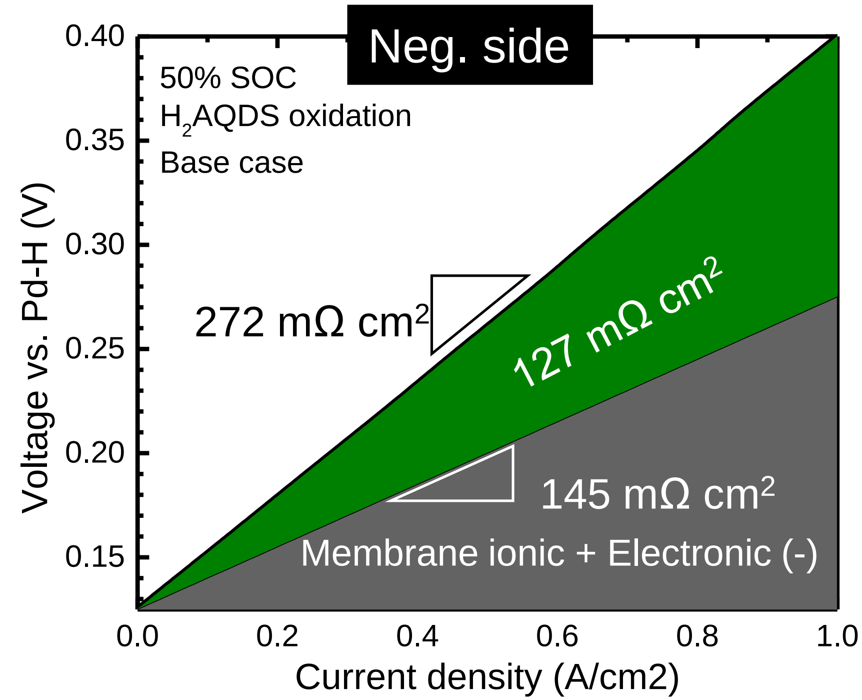


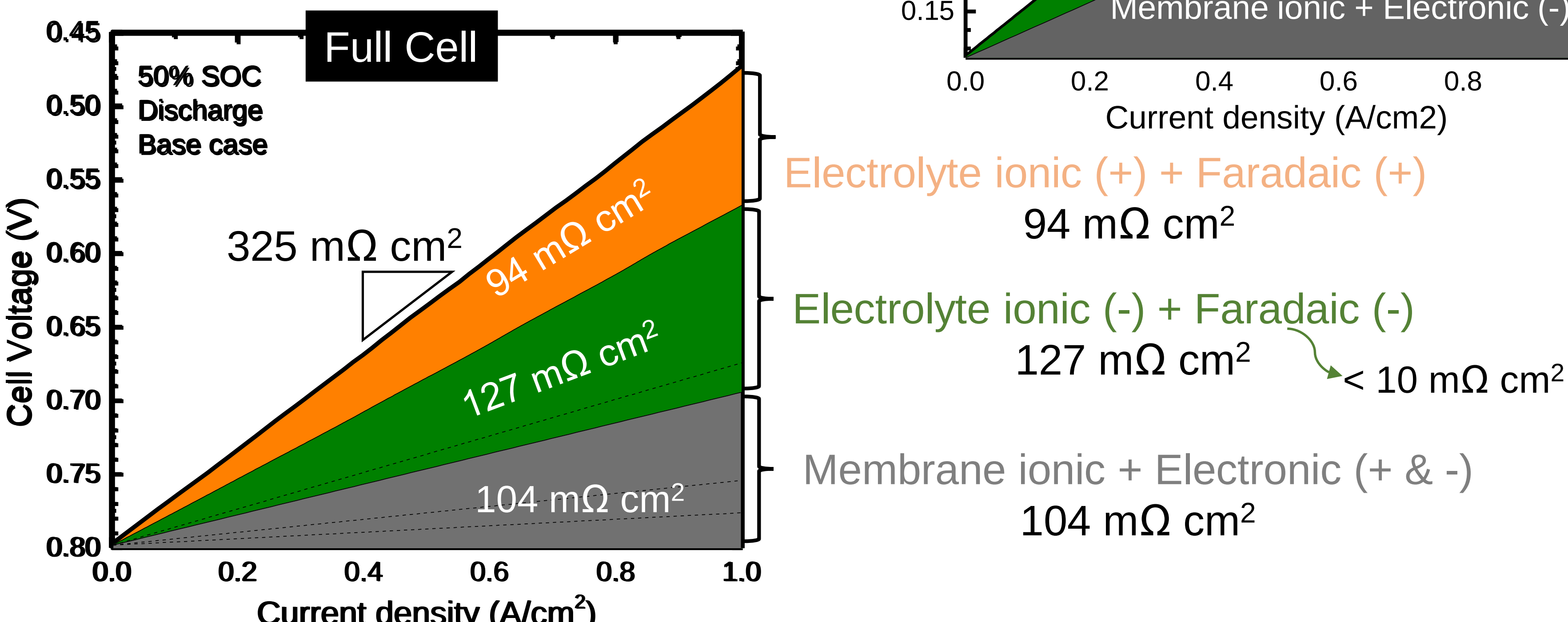
Membrane ionic: 60 mΩ cm^2

Electronic: 22 mΩ cm^2 (each)

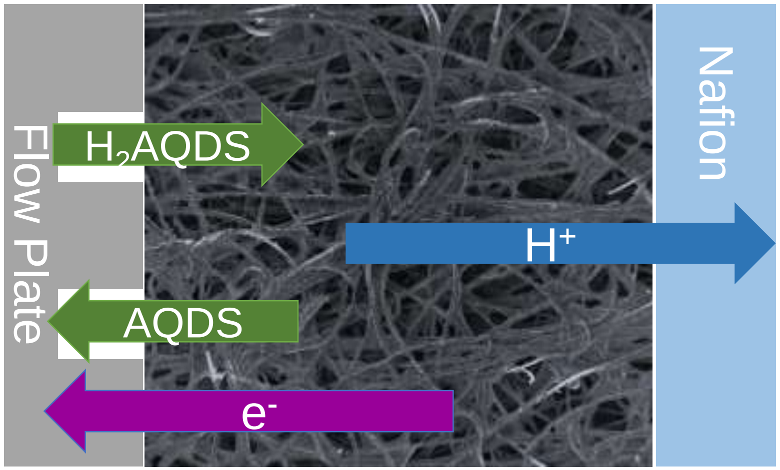
Separating voltage losses



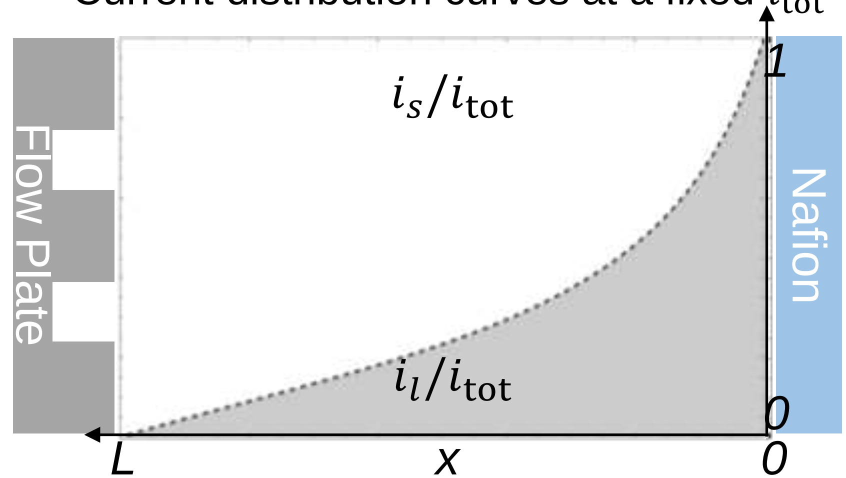




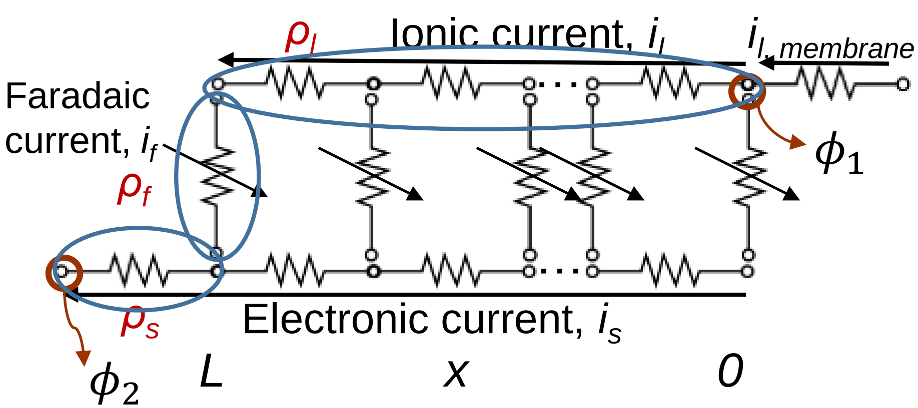
Two phase conducting and Current distribution



Current distribution curves at a fixed i_{tot}



1D homogeneous porous electrode model neglecting mass transport



$$i_{tot} = i_s + i_l$$
$$i_s = \nabla\phi_s/\rho_s \qquad i_l = \nabla\phi_l/\rho_l$$
$$i_f \propto \nabla \cdot i_s = f[\phi_s - \phi_l]$$

Overvoltage $\eta_{nego} = \phi_1 - \phi_2 \approx \int_0^L i_l(x)\rho_l \, dx$

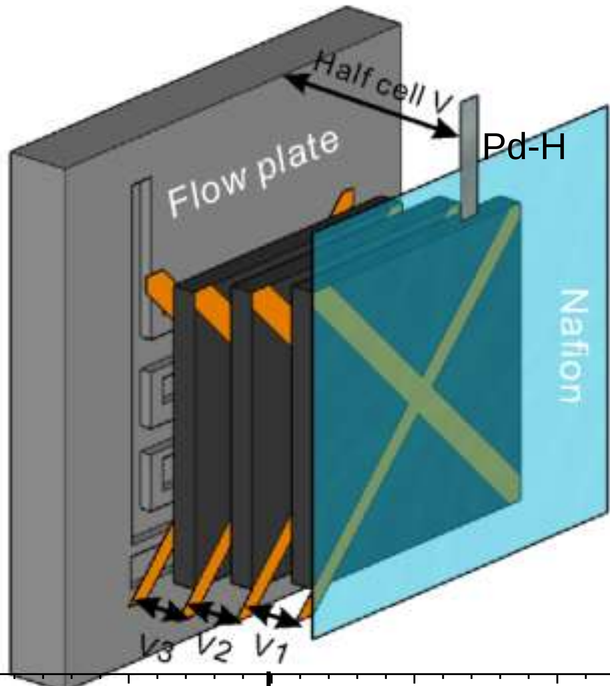
Resistance $r_{nego} = \frac{\eta_{nego}}{i_{tot}} = \rho_l \int_0^L \frac{i_l(x)}{i_{tot}} \, dx$

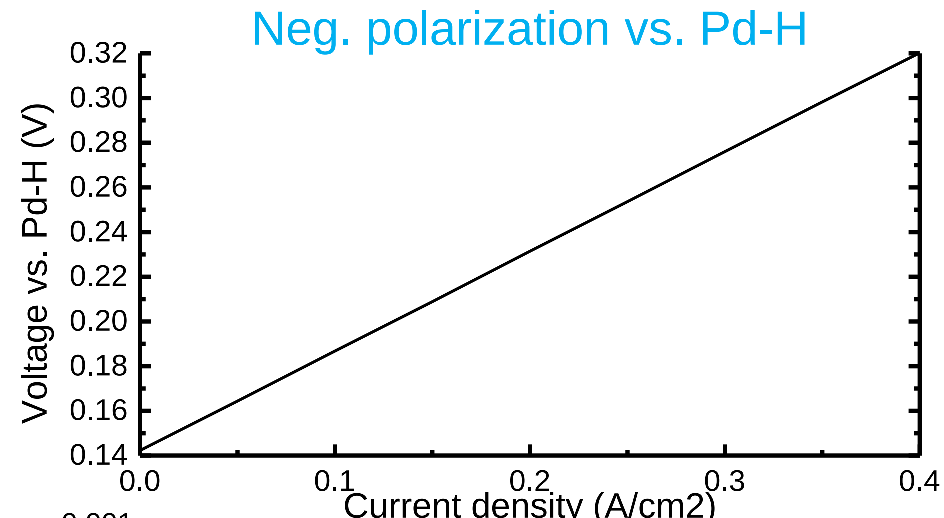
s: solid electrode phase; *l*: liquid electrolyte phase; *f*: Faradaic
ρ: resistivity; *Φ*: potential; *i*: current density; *Φ*: voltage;
η: overvoltage; *L*: electrode thickness

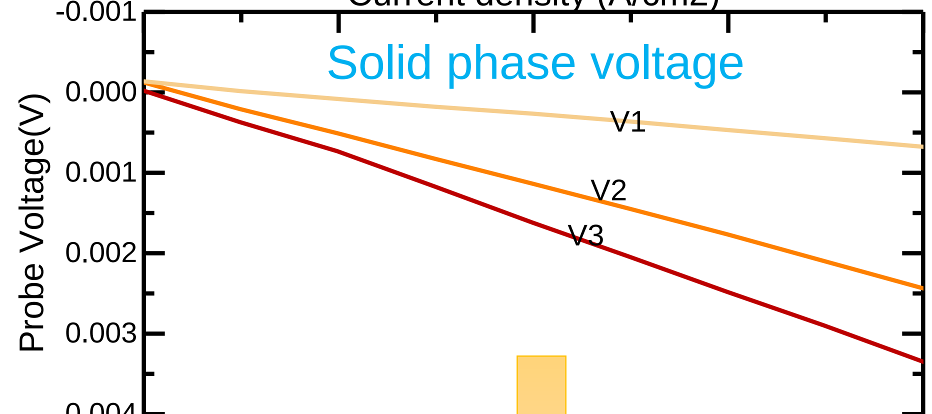
Reference

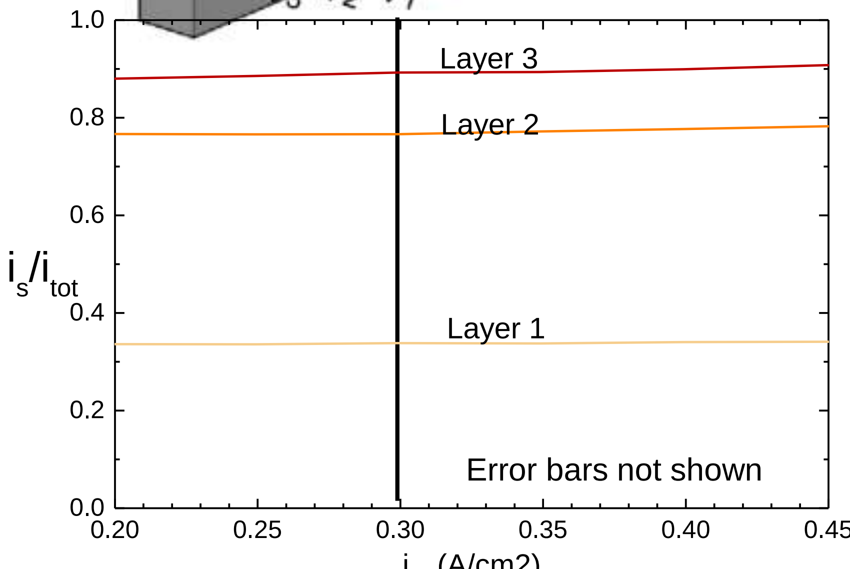
Newman, John and Thomas-Alyea, Karen. *Electrochemical Systems,* 3rd edition, Wiley

Potential probes for current distribution









$i_s = V_{1,\ 2\ or\ 3} / r_{1,\ 2\ or\ 3}$ → Measured by EIS

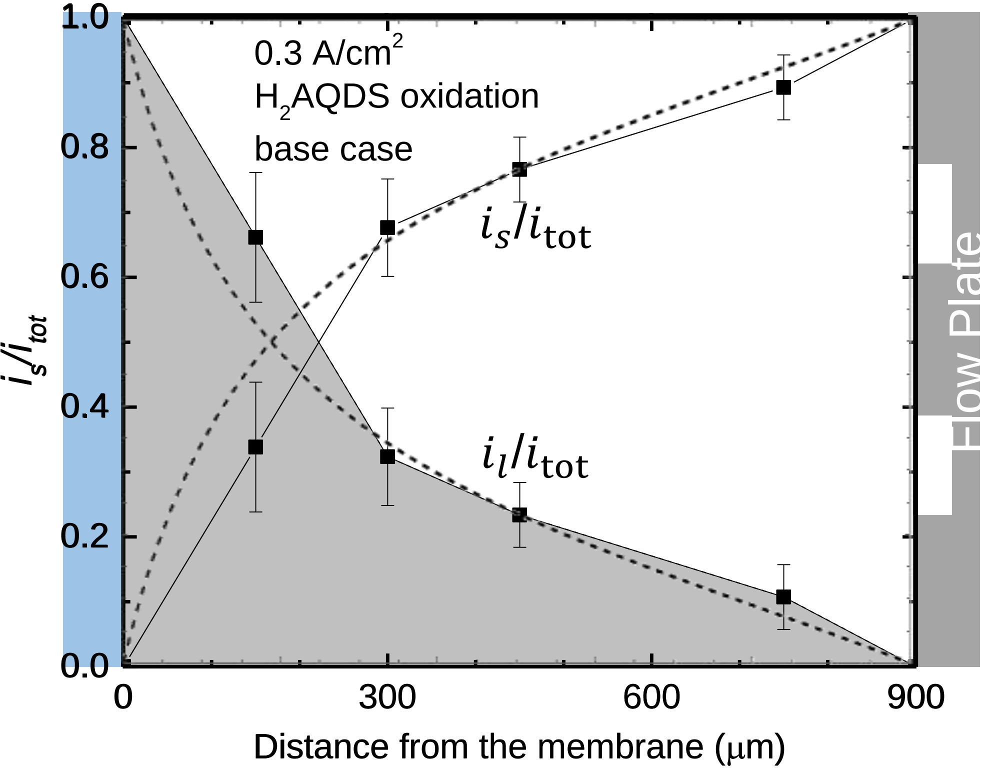
All i_s / i_{tot} appear independent of i_{tot}

Overvoltage from the negative side

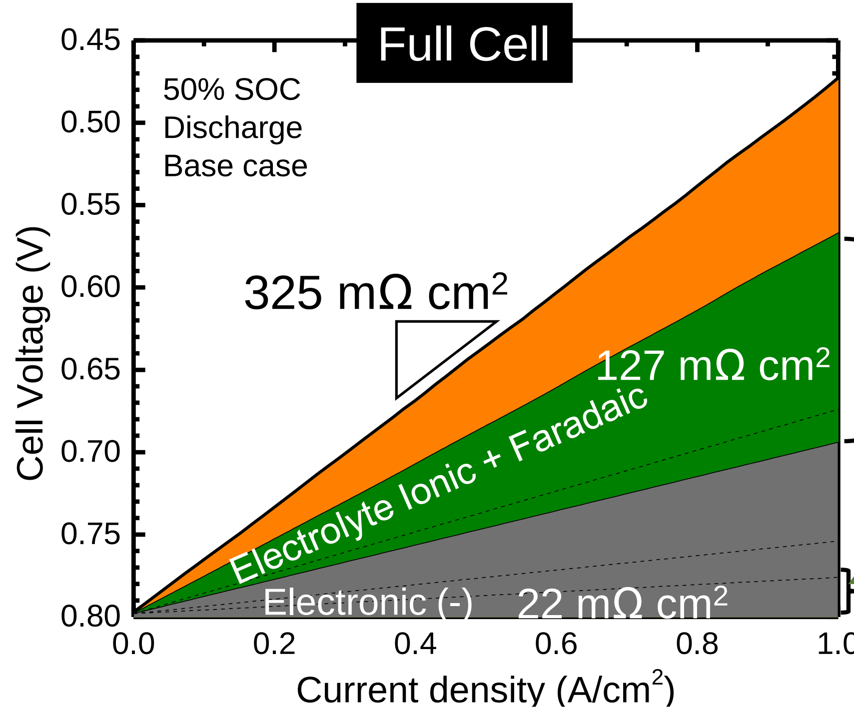
$$r_{nego} = \frac{\eta_{nego}}{i_{tot}} = \rho_l \int_0^L \frac{i_l(x)}{i_{tot}}\, dx$$

Neg. ρ_l ~2.2 Ω cm
(~ 5.4 Ω cm after Bruggerman correction using 55% porosity)

Line & scatters: experimental values
Dashed lines: 1D porous electrode model



161 mΩ cm^2
Electronic + Electrolyte Ionic + Faradaic



All i_s/i_{tot} appear independent of i_{tot}

Conclusions

- Highest QBFB peak power density to date: 1.0 W/cm^2
- Linear polarization for QBFB
- Contributions to overvoltage have been quantified
- Negative Faradaic reaction occurs primarily in the first 300 µm of the electrode
- Enables future engineering improvements

Acknowledgements

We thank the Alán Aspuru-Guzik research group for molecule property theoretical calculation, Sustainable Innovations, LLC. for Product-to-Market insights and ARPA-E for funding the research.

Thank you!

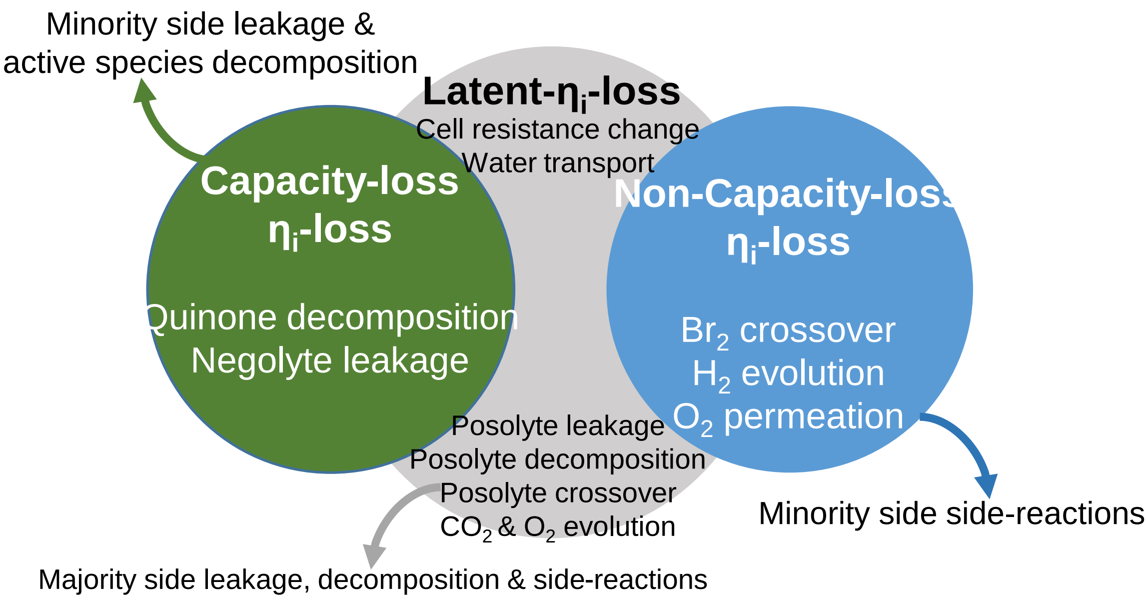
arpa·e

Harvard Department of Chemistry & Chemical Biology

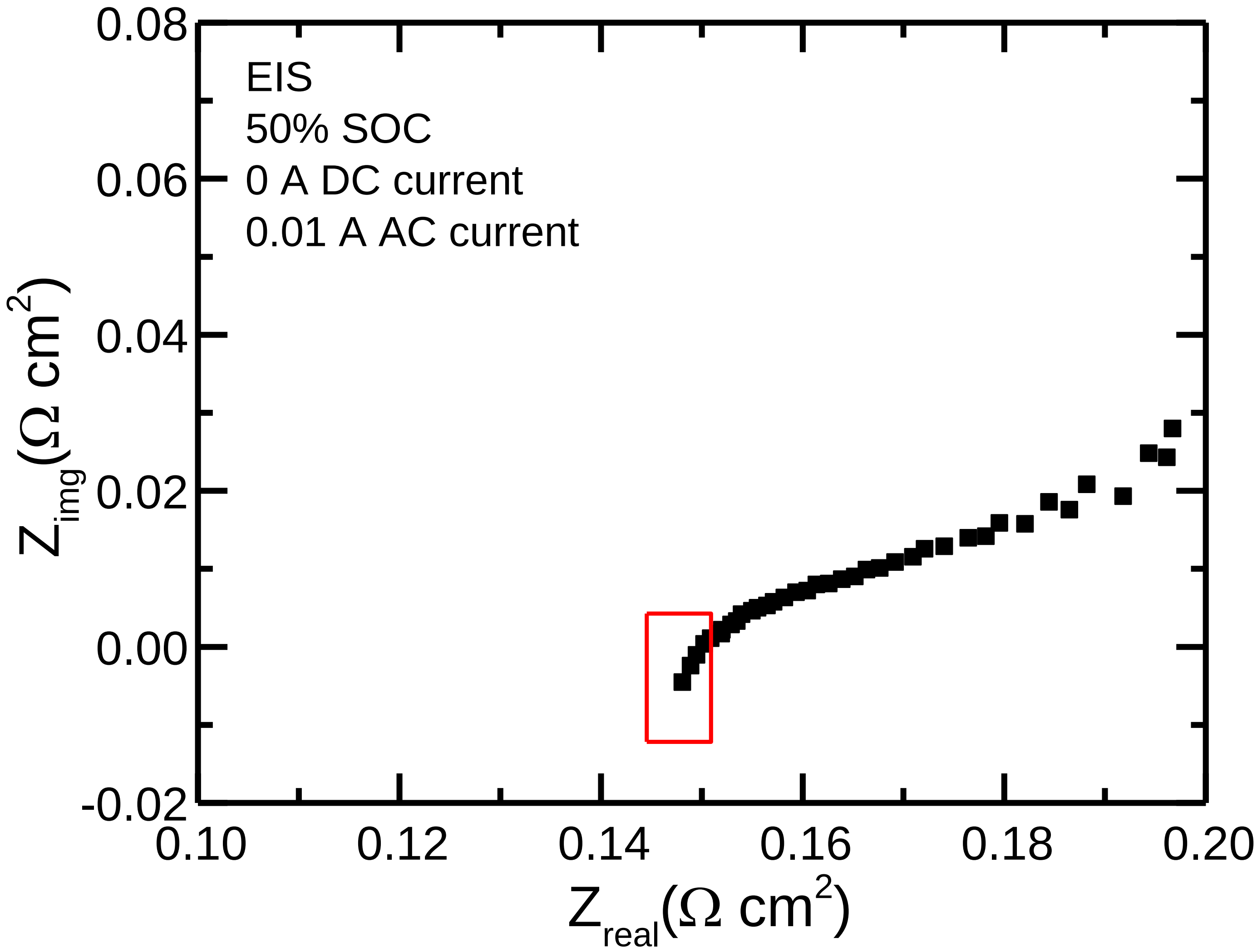
HARVARD Kennedy School
JOHN F. KENNEDY SCHOOL OF GOVERNMENT

HARVARD School of Engineering and Applied Sciences

Sustainable Innovations



Minority side leakage &
active species decomposition
Latent-η_i-loss
Cell resistance change
Water transport
Capacity-loss
η_i-loss
Quinone decomposition
Negolyte leakage
Non-Capacity-loss
η_i-loss
Br_2 crossover
H_2 evolution
O_2 permeation
Posolyte leakage
Posolyte decomposition
Posolyte crossover
CO_2 & O_2 evolution
Minority side side-reactions
Majority side leakage, decomposition & side-reactions


EIS
50% SOC
0 A DC current
0.01 A AC current
0.08
0.06
0.04
0.02
0.00
-0.02
0.10
0.12
0.14
0.16
0.18
0.20
$Z_{img}(\Omega\ cm^2)$
$Z_{real}(\Omega\ cm^2)$

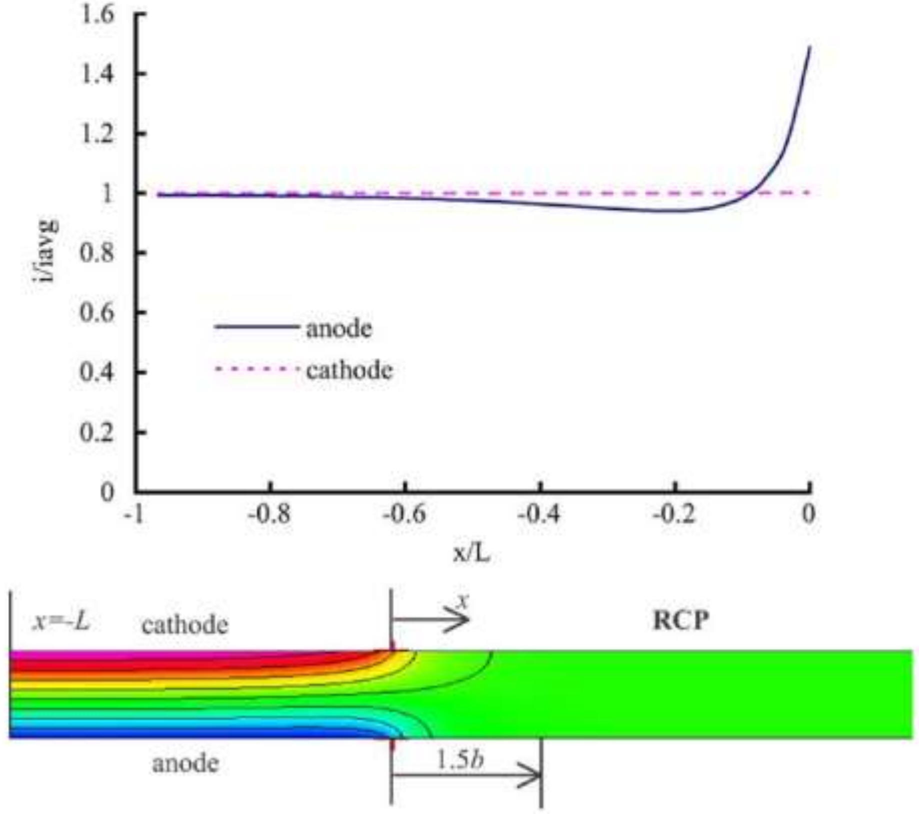
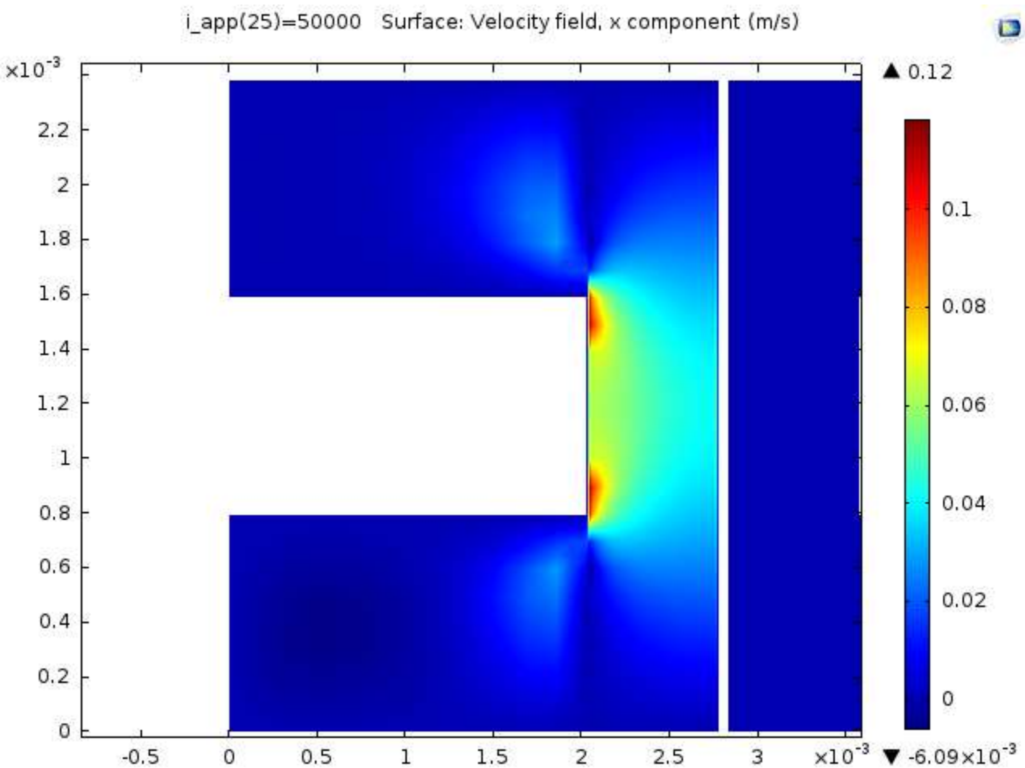
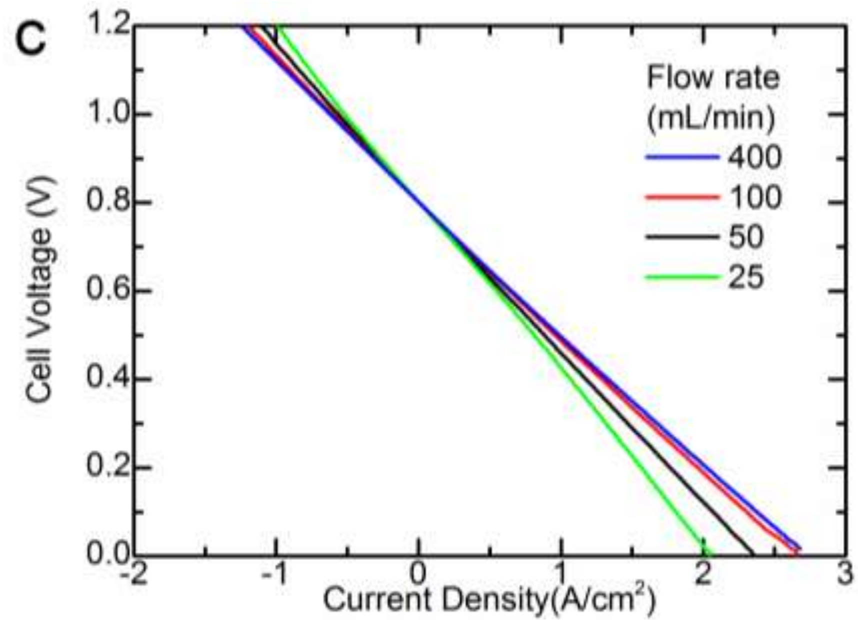
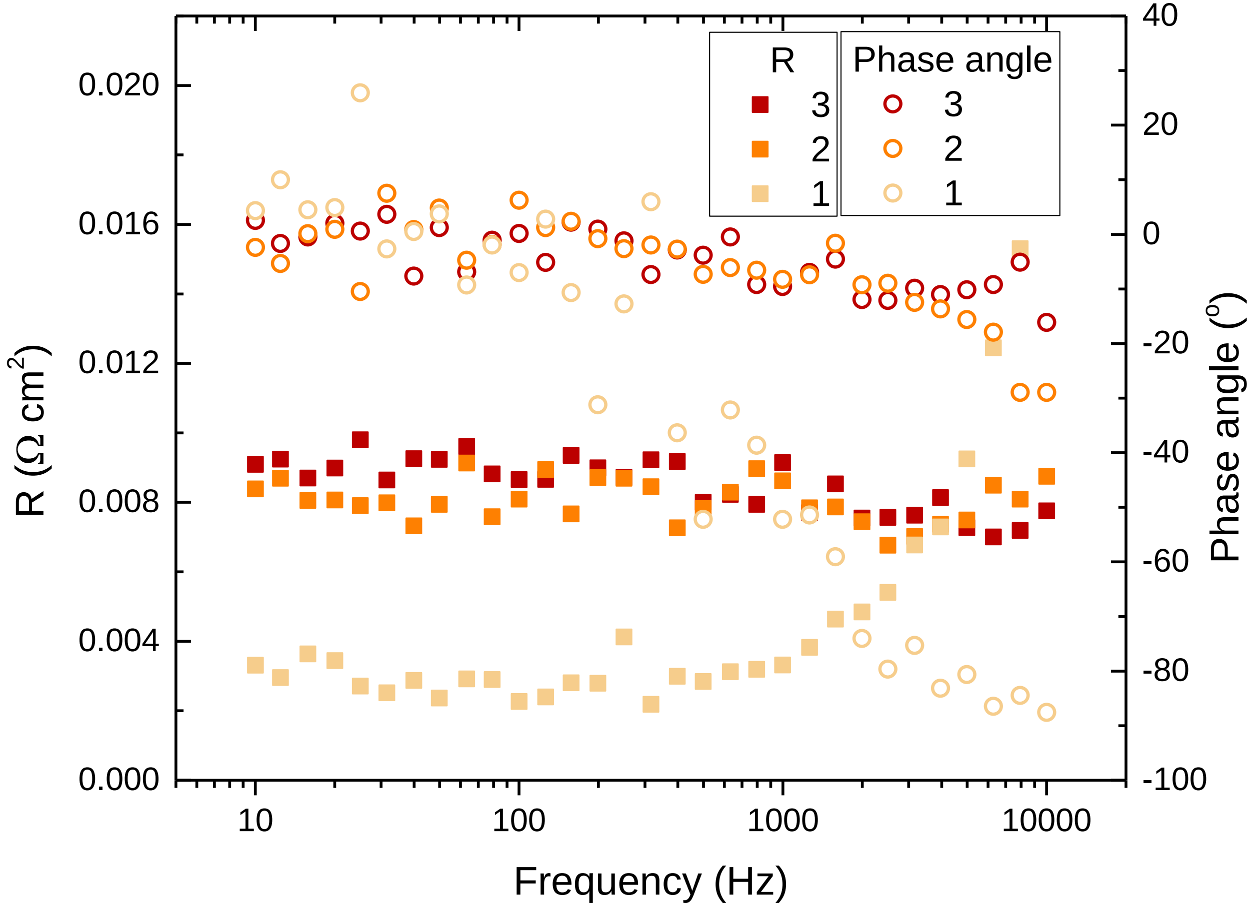


Fig. 5. The potential profile and current distribution for symmetric electrodes geometry under secondary current distribution (Wa (anode) = 0.1, Wa (cathode) = 100).


i_app(25)=50000 Surface: Velocity field, x component (m/s)
×10^-3
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.5
0
0.5
1
1.5
2
2.5
3
×10^-3
▲ 0.12
0.1
0.08
0.06
0.04
0.02
0
▼ -6.09×10^-3


C
Cell Voltage (V)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-2
-1
0
1
2
3
Current Density(A/cm²)
Flow rate
(mL/min)
400
100
50
25


R
3
2
1
Phase angle
3
2
1
0.000
0.004
0.008
0.012
0.016
0.020
R (Ω cm^2)
40
20
0
-20
-40
-60
-80
-100
Phase angle (°)
10
100
1000
10000
Frequency (Hz)