A Flow Battery for Grid-Scale Energy Storage

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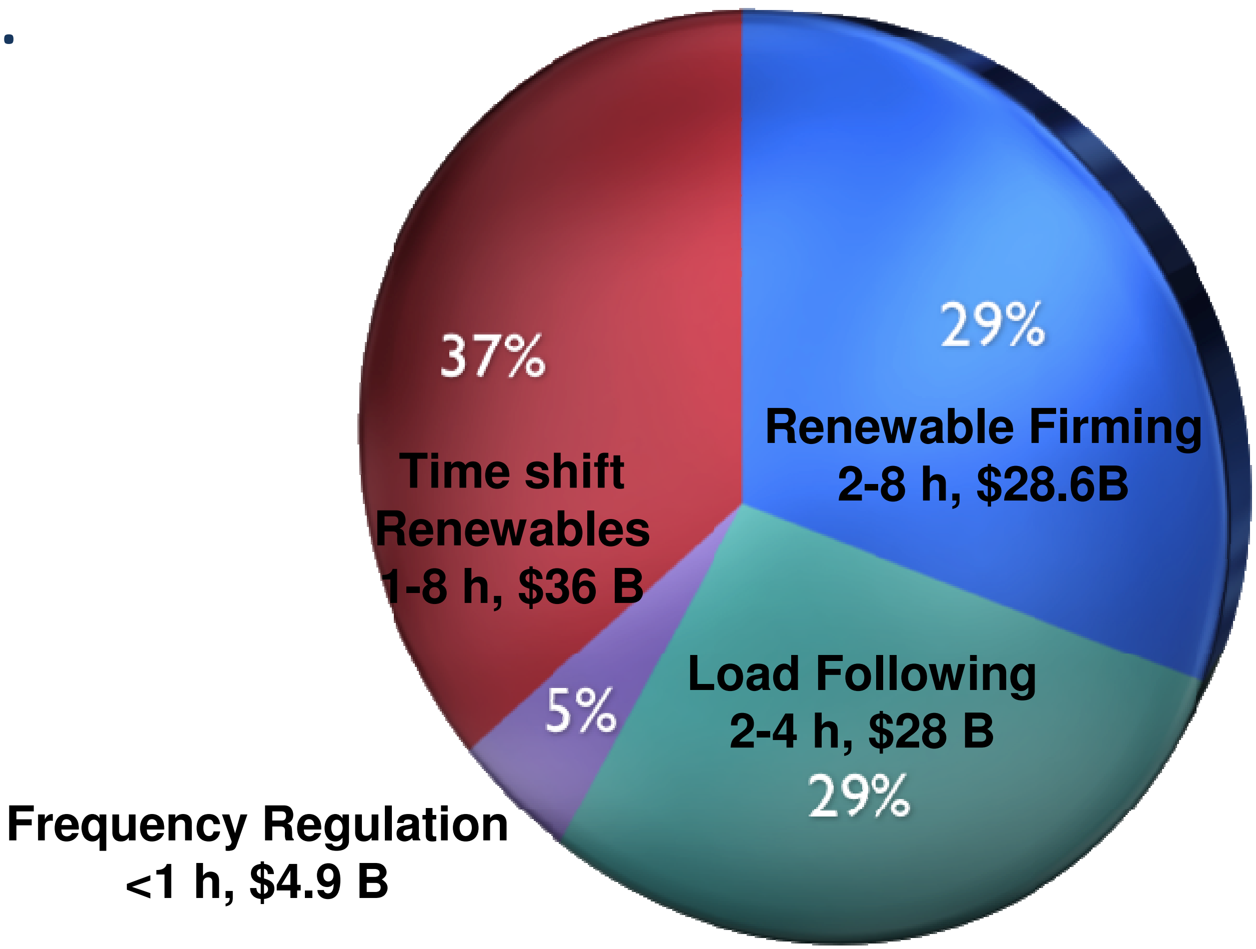
wable energy standards (e.g., 30% renewables by 2020 in California) will require of energy back-up

w CA state bills require CPUC to examine targets for procurement of energy storage syste

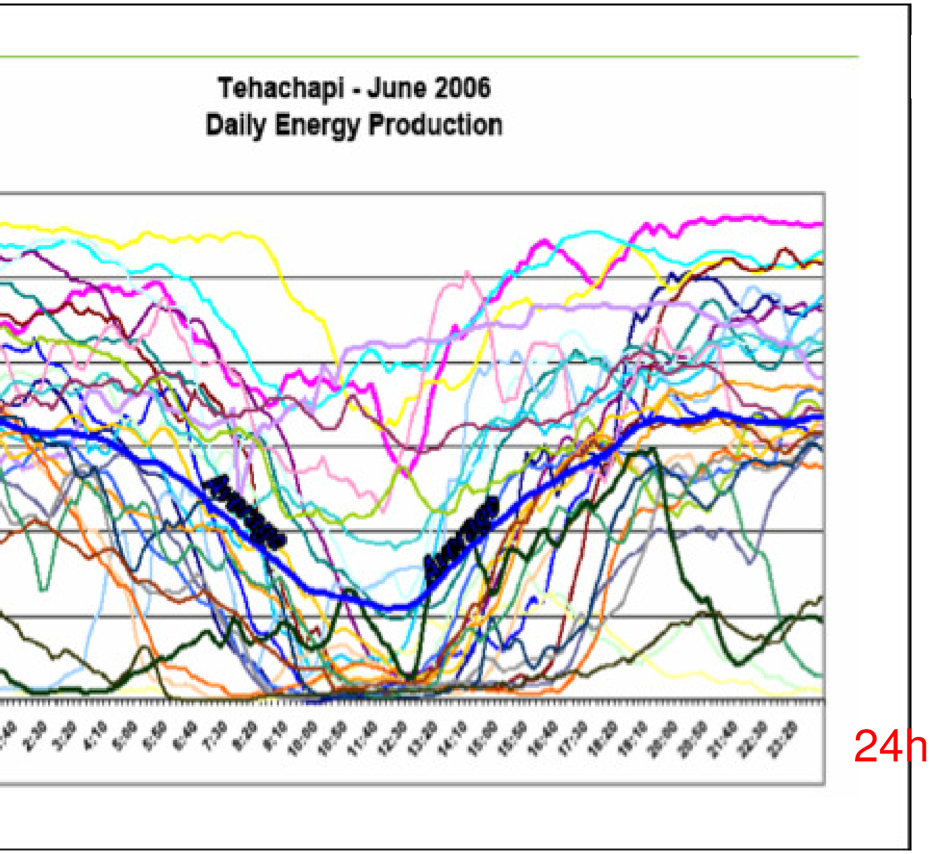
of storage needed in a decade

ntially a very large market ($100B); in contrast, vehicle market expected to be $1 by 2020.



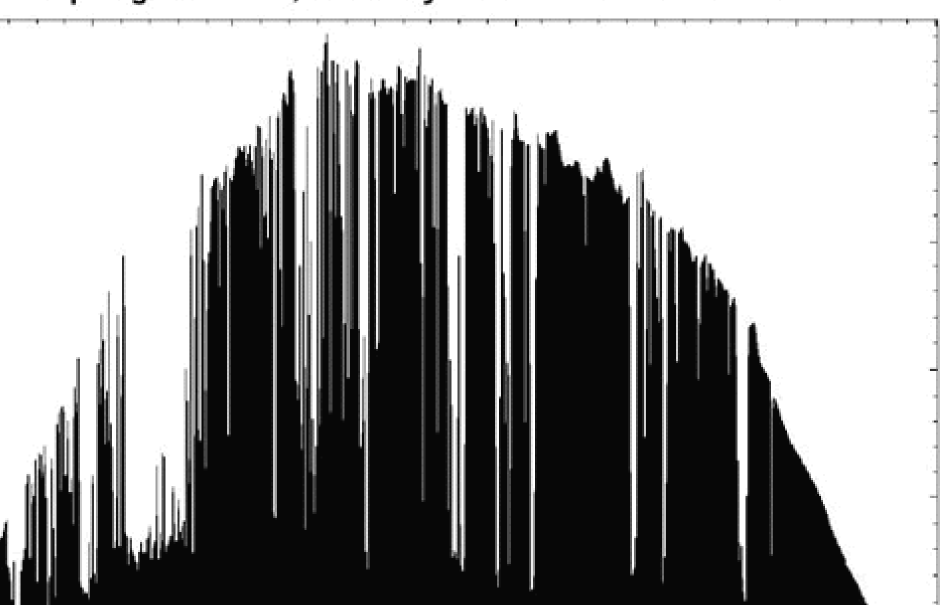
Source: Extracted from E

Need a source of back-up electricity in the range of 1 to 8 h



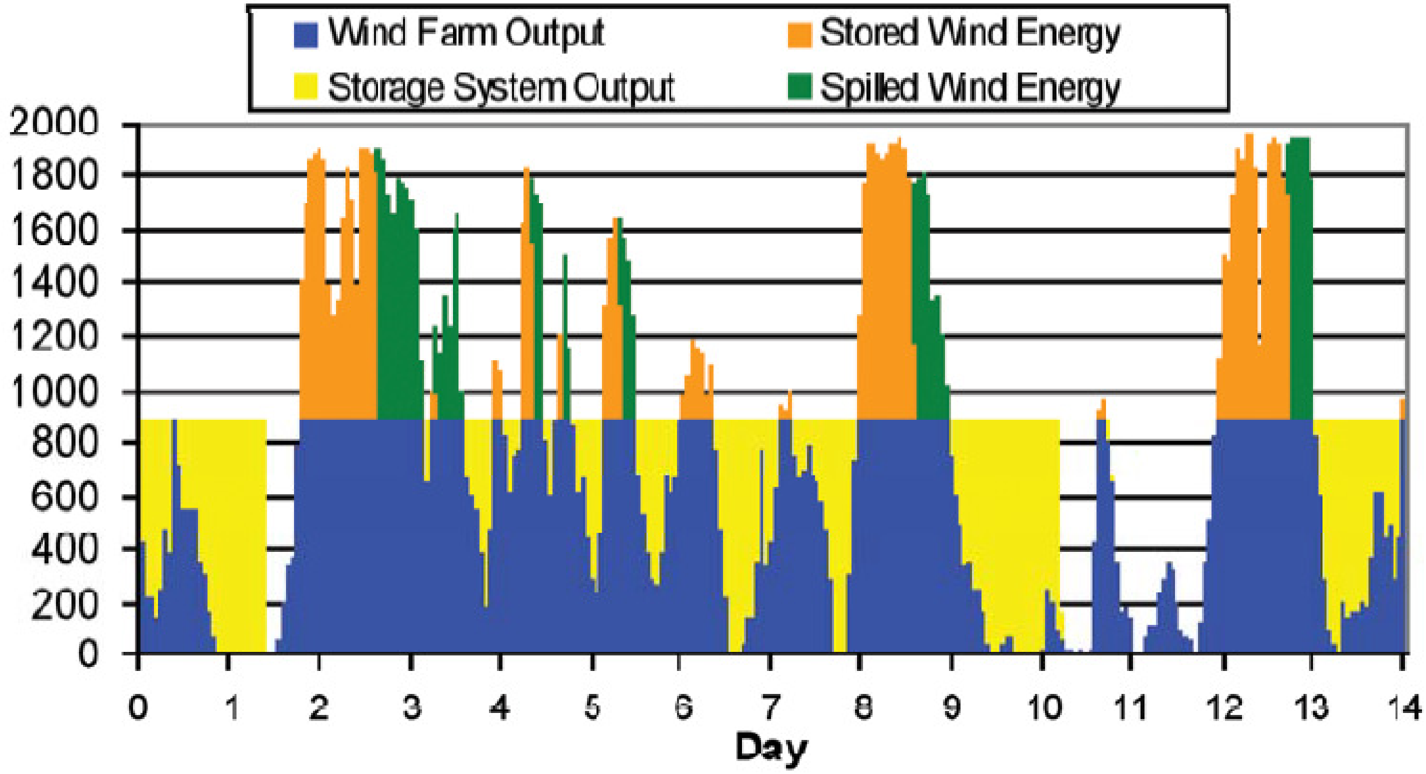
California ISO – Integration of Renewable Resources Nov 2007

Wind



- **Stabilize grid power at 60Hz given intermittent generation assets (in solar, wind)**
- **Requirements**
  - High power (MW)
  - Fast ramp rate (seconds)
  - High efficiency (70-90%)
  - Short discharge times (< 1 hour)

Solar

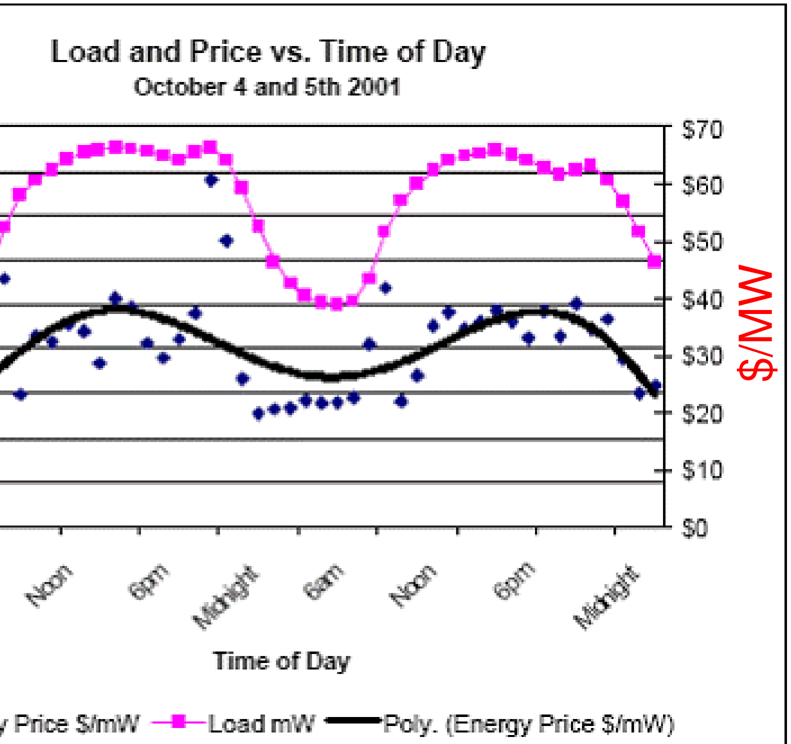


Source: Denholm, Paul. (October 2006). "Creating Baseload Wind Power Systems Using Advanced Compressed Air Energy Storage Concepts." Poster presented at the University of Colorado Energy Initiative/NREL Symposium. http://www.nrel.gov/docs/fy07osti/40674.pdf

shifting of intermittent assets to high-value periods

ar requirements to Grid Reliability, but longer discharge time

3 day



ectric Plan (2005)

- **Capture low-cost electricity for peak us**
- **Replace spinning reserves**
- **Provide backup for "Never-Off" system**
- **Industrial, commercial, institutional customers**
- **Siting near point-of-use**
  - Perceived safety is critical – may hinder adopt

atteries can be designed to meet all of thes requirements, and in some cases, simultaneously.

Simply design to the largest energy and power requirements, then verify overall cost reduction

onal Battery

energy density

CoO$_2$; concentration of Li = 46 mol Li/l of oxide =
Ah/l

e = 3.6

er power density

ance ~ 30 ohm cm^2 due to solid state diffusion

function of E/P

Total Cost (\$/kWh) ~ 600x$(P/E)^{1/2}$

~ 600x$(1/t_d)^{1/2}$

ost of constructing the battery with the
r energy and power are coupled.

elated to high cost of active materials.

- ## Flow Battery

  - Low energy density
    - Ex. 1 M Br2 solutions = 54 Ah/l (factor of 23 t
    - V = 1 V
  - High power density
    - Resistance ~ 0.3 ohm cm^2 (a factor of 100 tim
  - Cost
    - The power and energy are literally separate e

Power unit Tanks

Total Cost (\$/kWh) = (\$/kW)/t_d + \$/kWh

= \$/m^2*ASR/[$\eta^{1/2}(1-\eta^{1/2})U^2$)]/$t_d$

These batteries are preferred if you can c
inexpensive materials with a high-rate po

•Low resistance

•High voltage but within electrolyte stabi

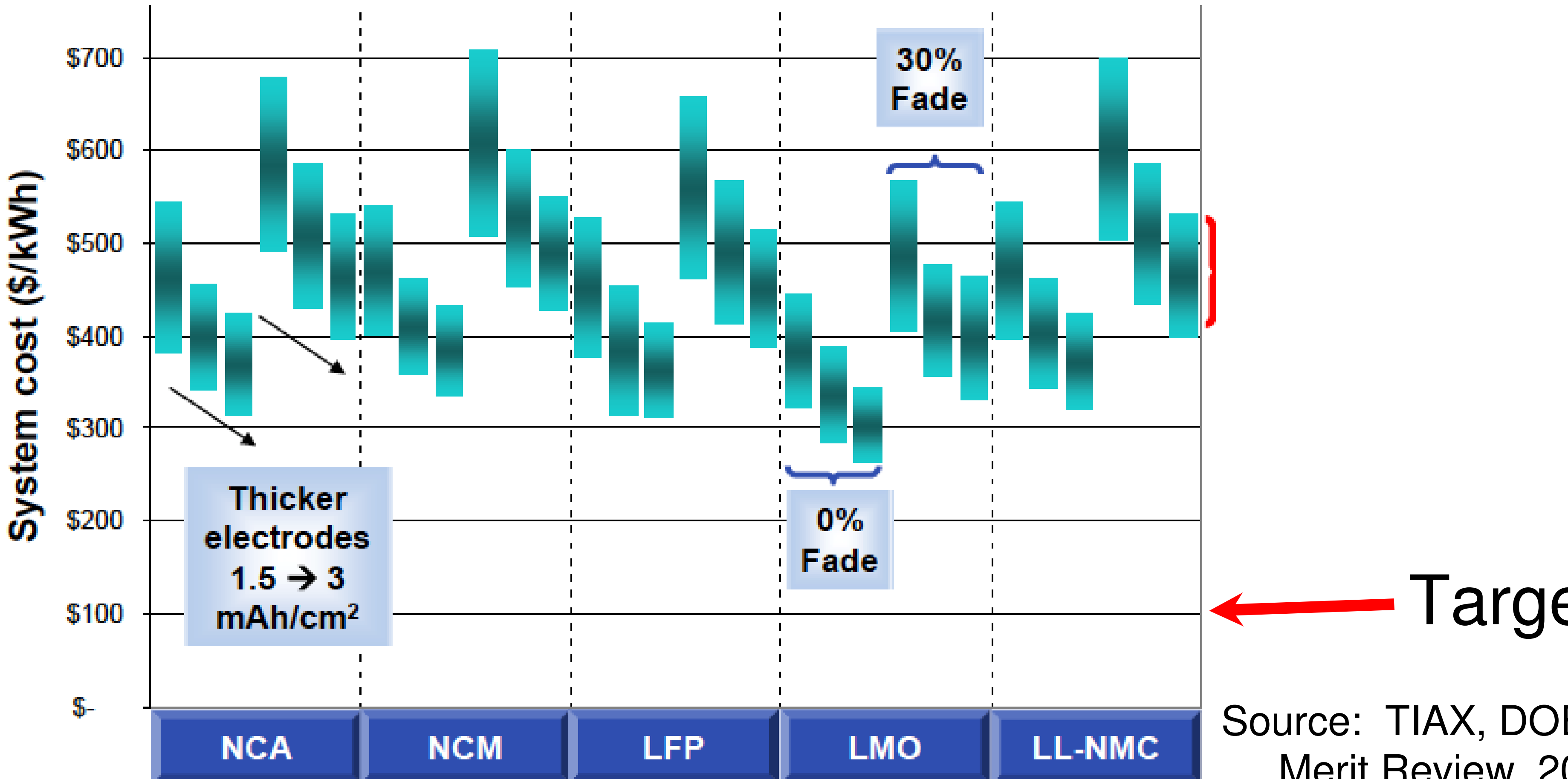
Both can be designed to meet the power and energy

mportant metrics: Performance (energy efficiency rather than energy y), cost, life, and safety

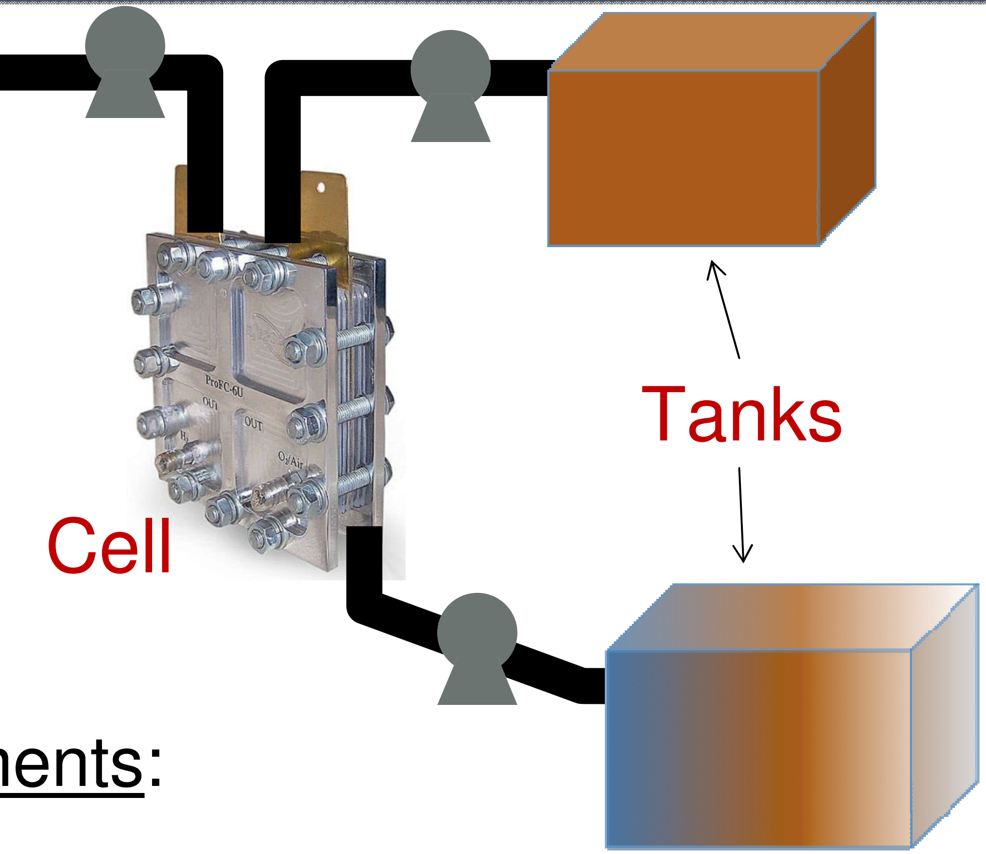
rically, choice of battery is a compromise

rid storage, main challenge is cost. Target: $100/kWh (gas turbine)

High-volume cost projections for Li-ion batteries



Source: TIAX, DOE Merit Review, 20



- Separation of energy and power
- Energy dictated by size of tanks
- Power depends on size of cell
- Cell is typically expensive

ents:

good reversibility

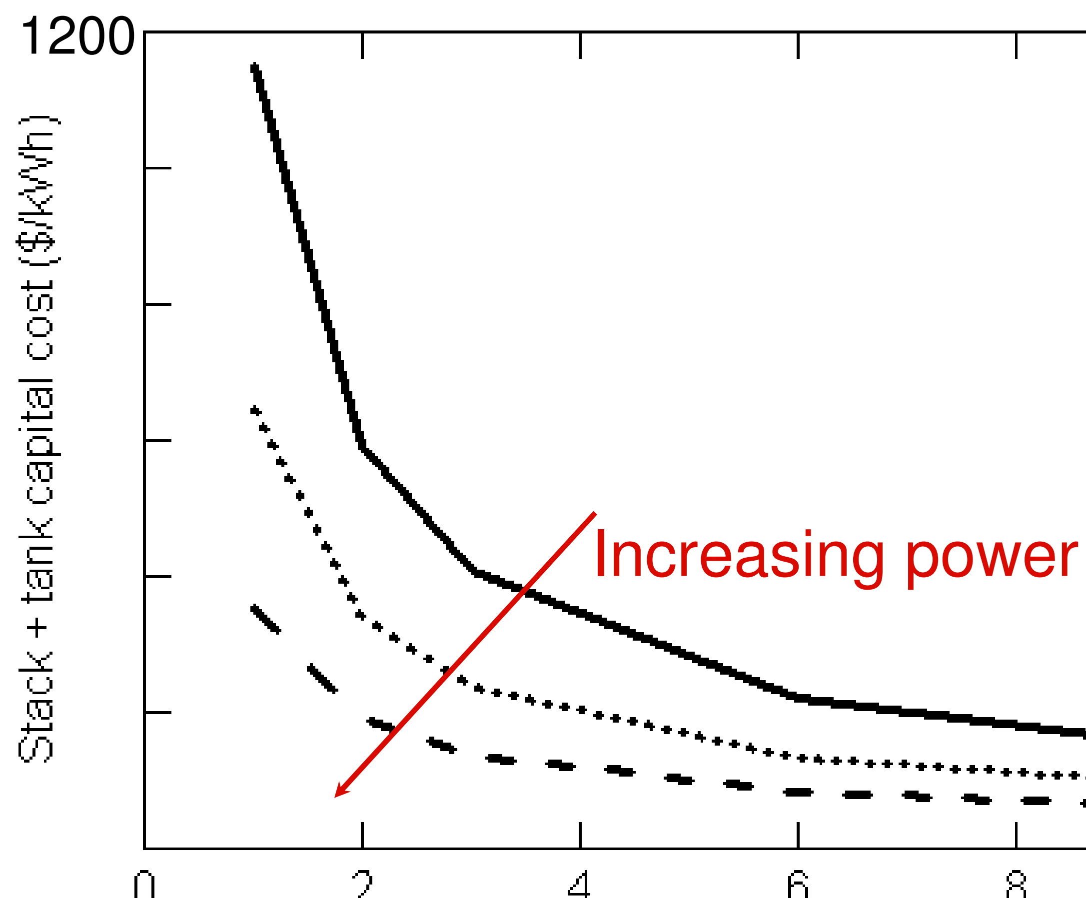
chemicals that are inexpensive

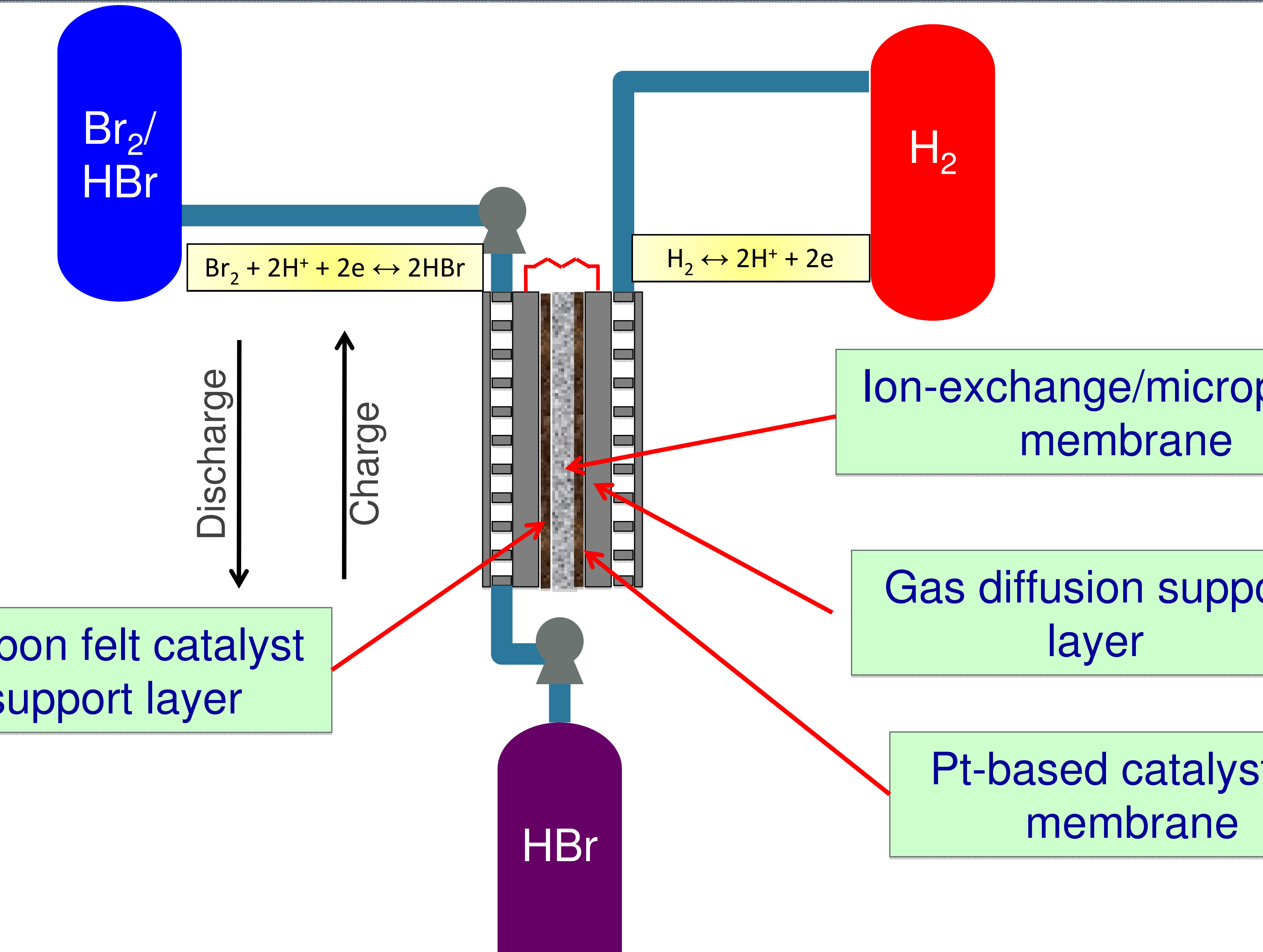
nexpensive cell components

a high power device

r the power, lower the number of cells

uctural changes (e.g., plating)





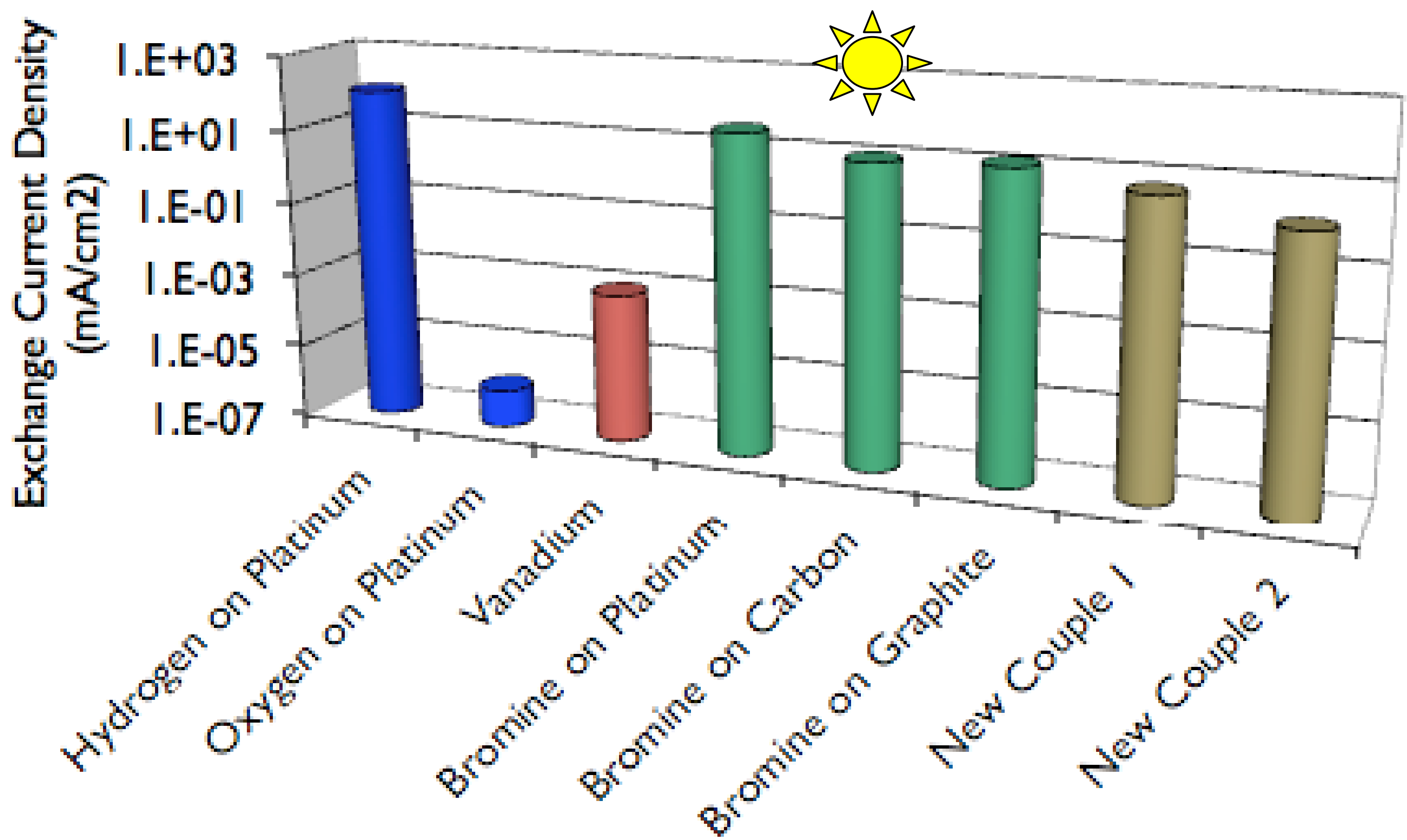
Br2/
HBr
$Br_2 + 2H^+ + 2e \leftrightarrow 2HBr$
H2
$H_2 \leftrightarrow 2H^+ + 2e$
Discharge
Charge
Ion-exchange/microp
membrane
Gas diffusion suppo
layer
oon felt catalyst
support layer
Pt-based catalyst
membrane
HBr

al cell resistance = Ohmic+charge transfer+mass transfer

Membranes and contact

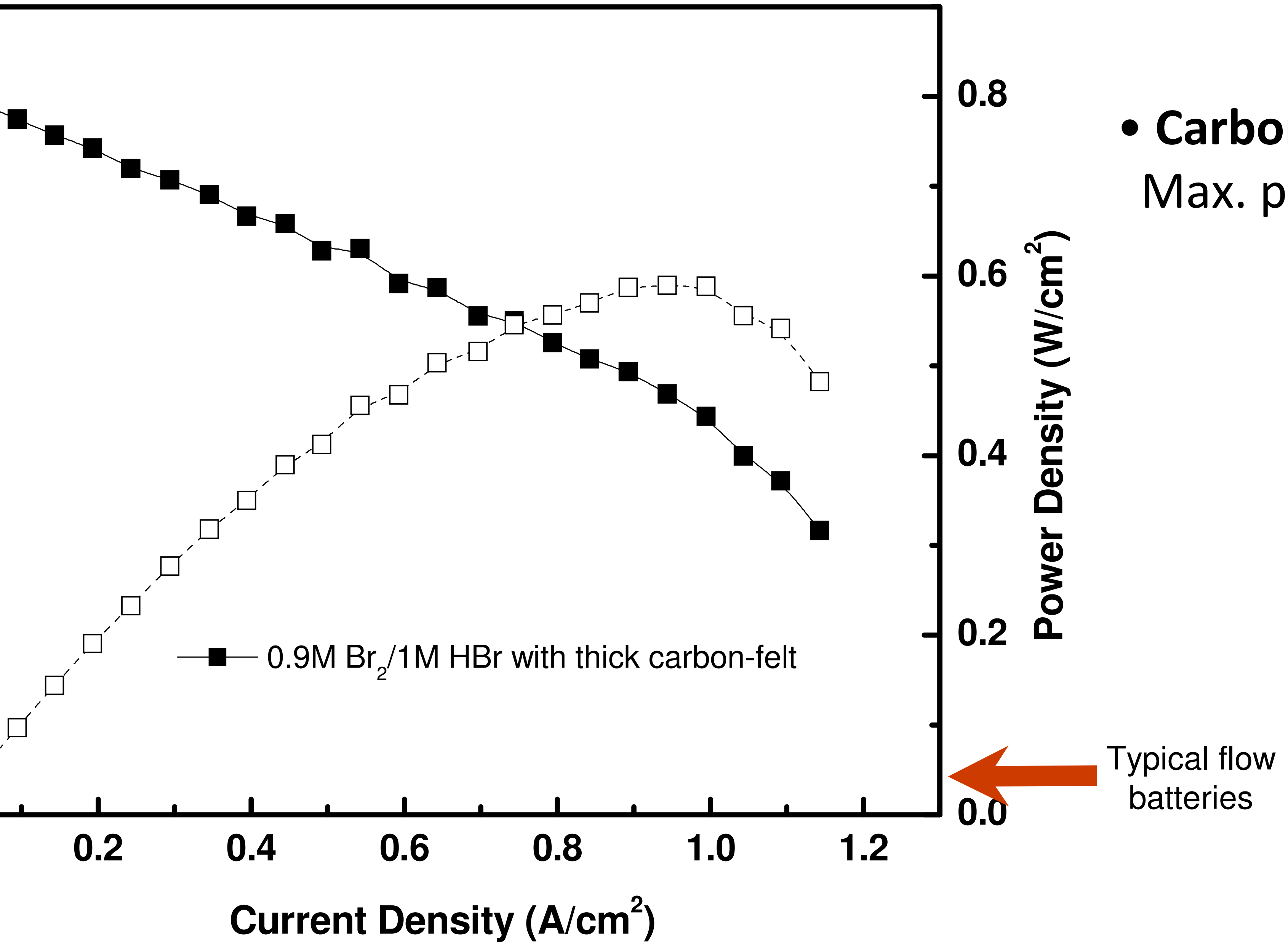
Kinetically fast reactions

Better cell design



Rotating disc studies

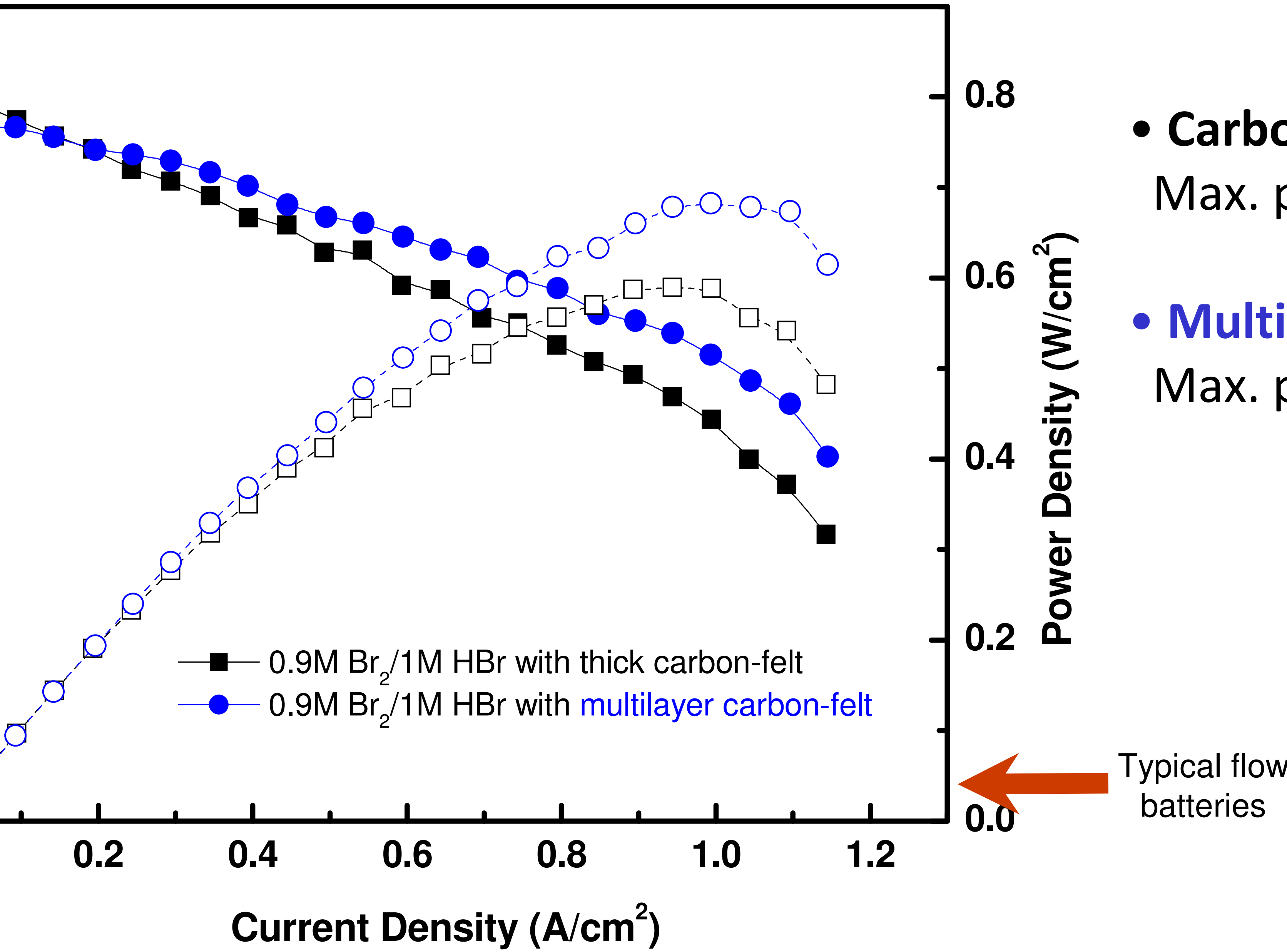
Temperature: RT; flowrate: 200 ml/min



- **Carbon-felt electrode**

  Max. performance: 0.

Temperature: RT; flowrate: 200 ml/min

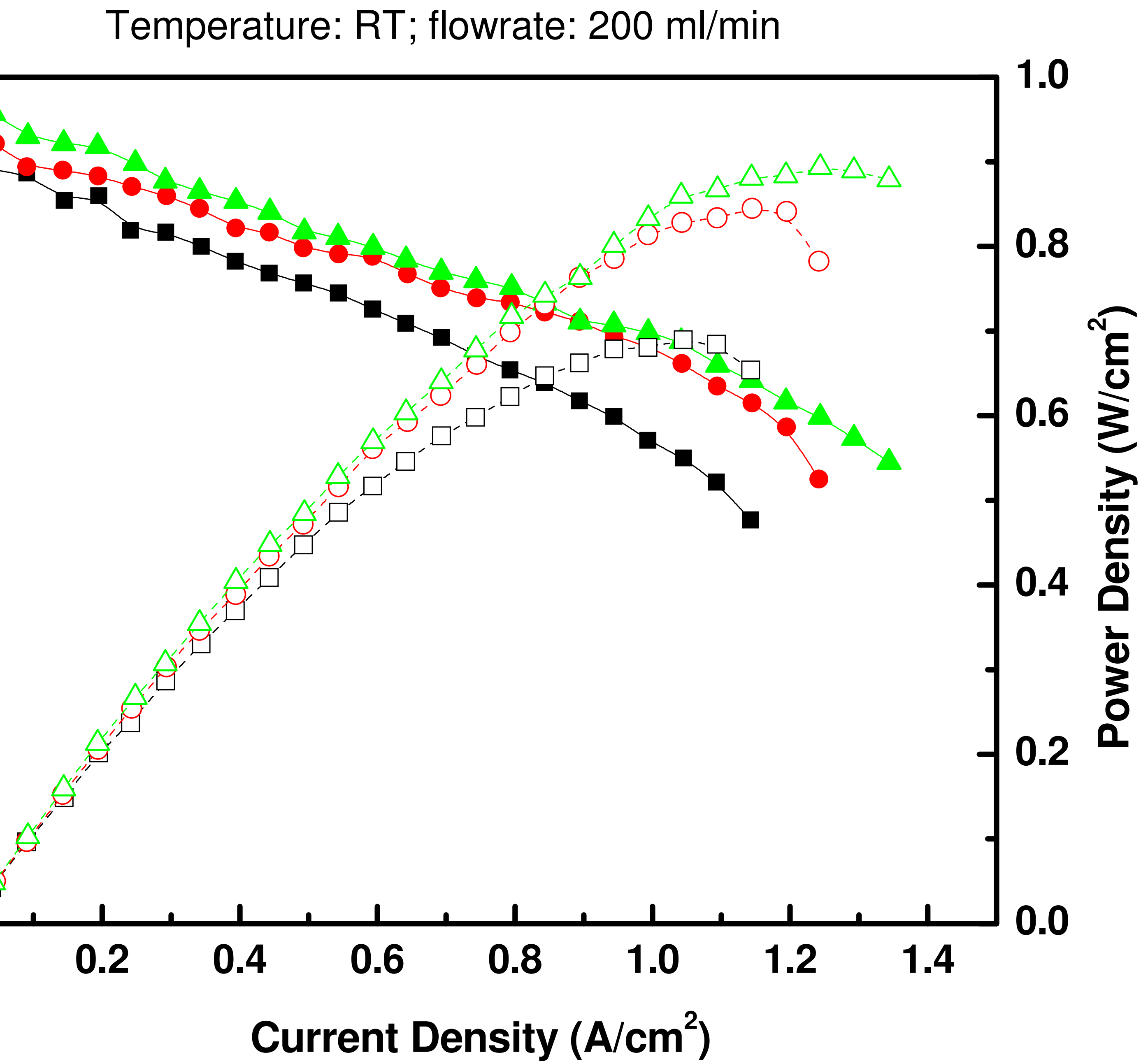


- **Carbon-felt electrode**

  Max. performance: 0.

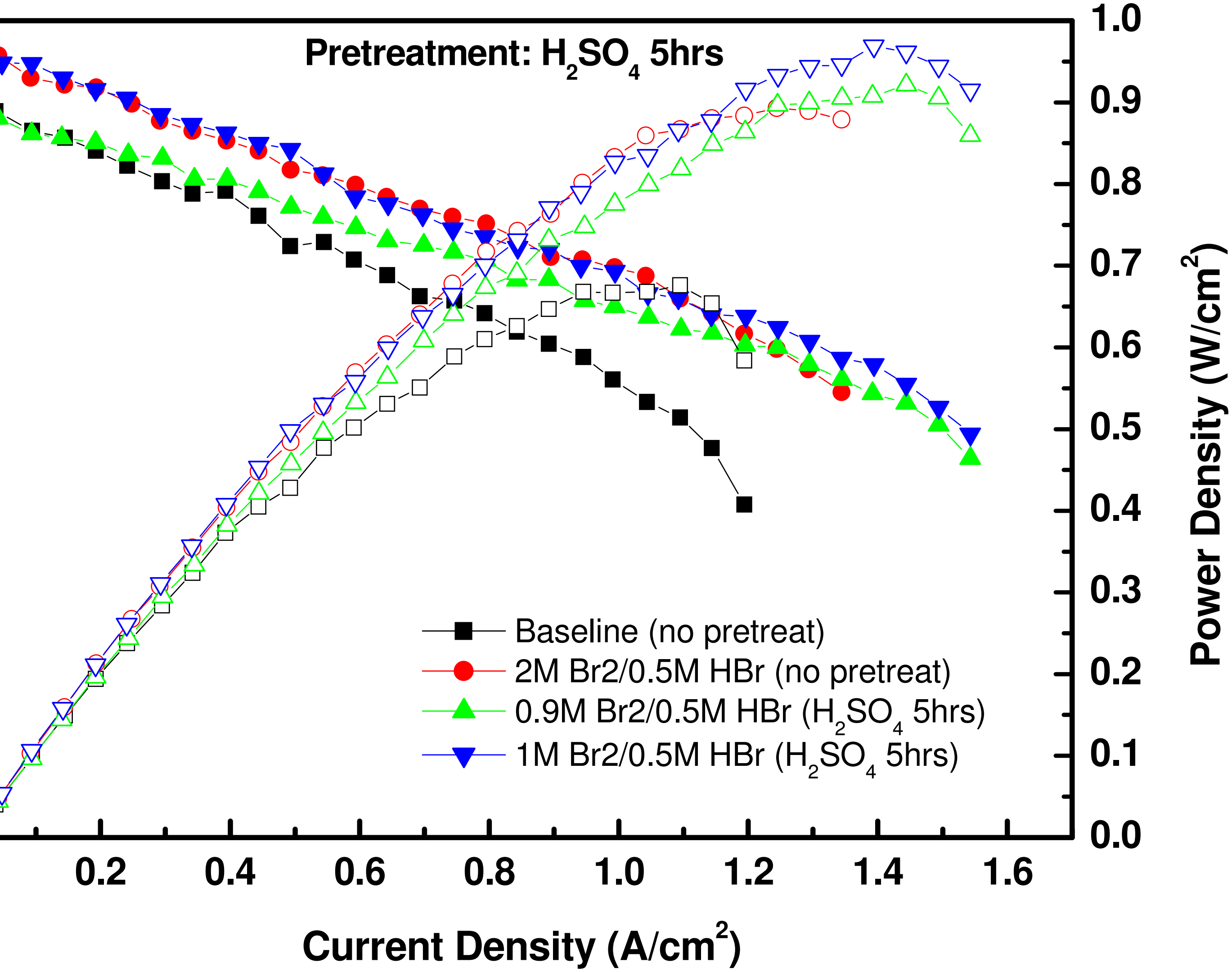
- **Multi-layered C-felt e**

  Max. performance: 0.



- **Multi-layered C-felt e**
  Max. performance: 0.

- **Optimized electrolyte**
  Max. performance: 0.



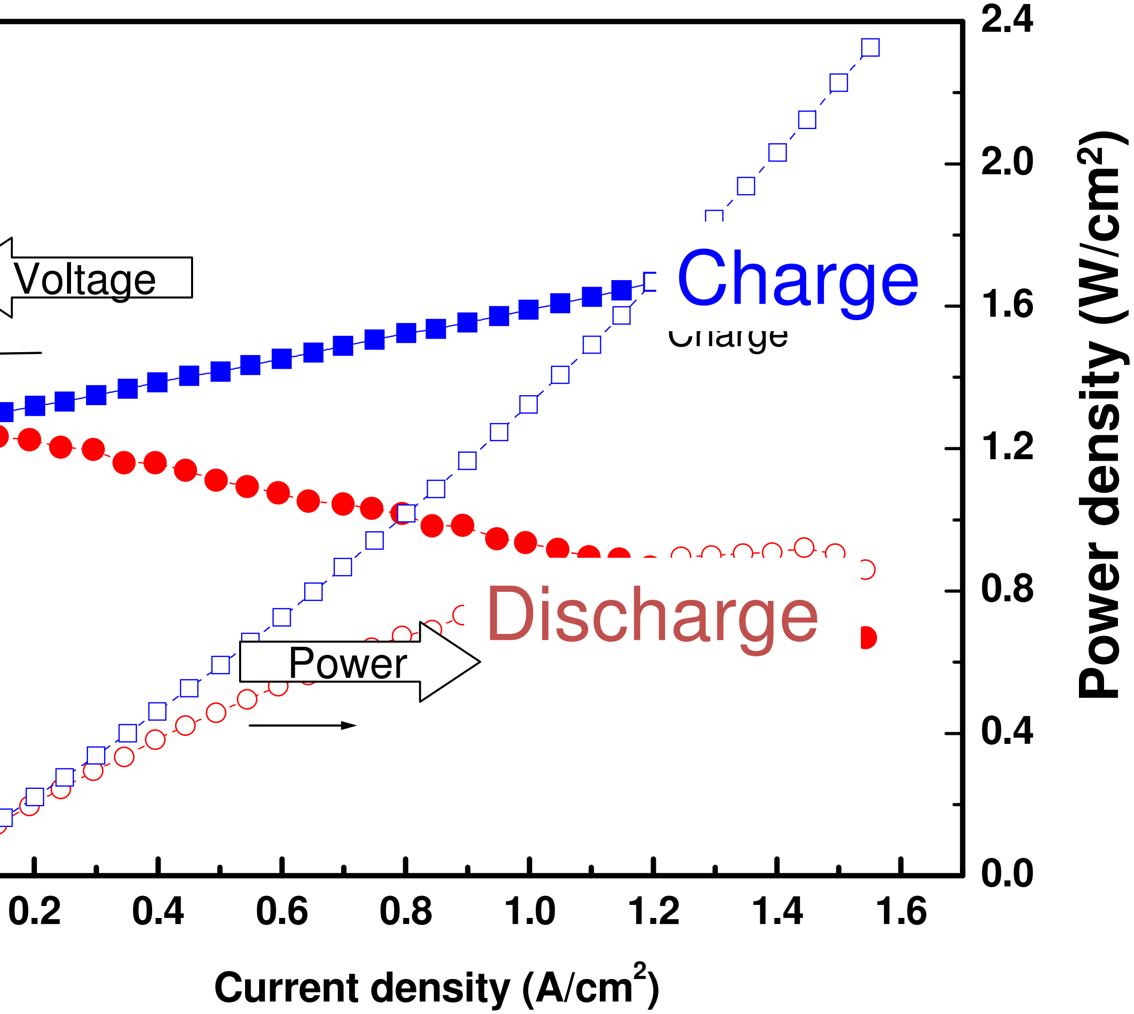
	Max PD (W/cm2)	%	M (A
Baseline	0.68	0.0	
2M Br2/0.5M HBr (No pretreat)	0.89	31.7	
0.9M Br2/1M HBr (H_2SO_4 pretreated)	0.92	36.2	
1M Br2/0.5M HBr (H_2SO_4 pretreated)	0.97	43.5	

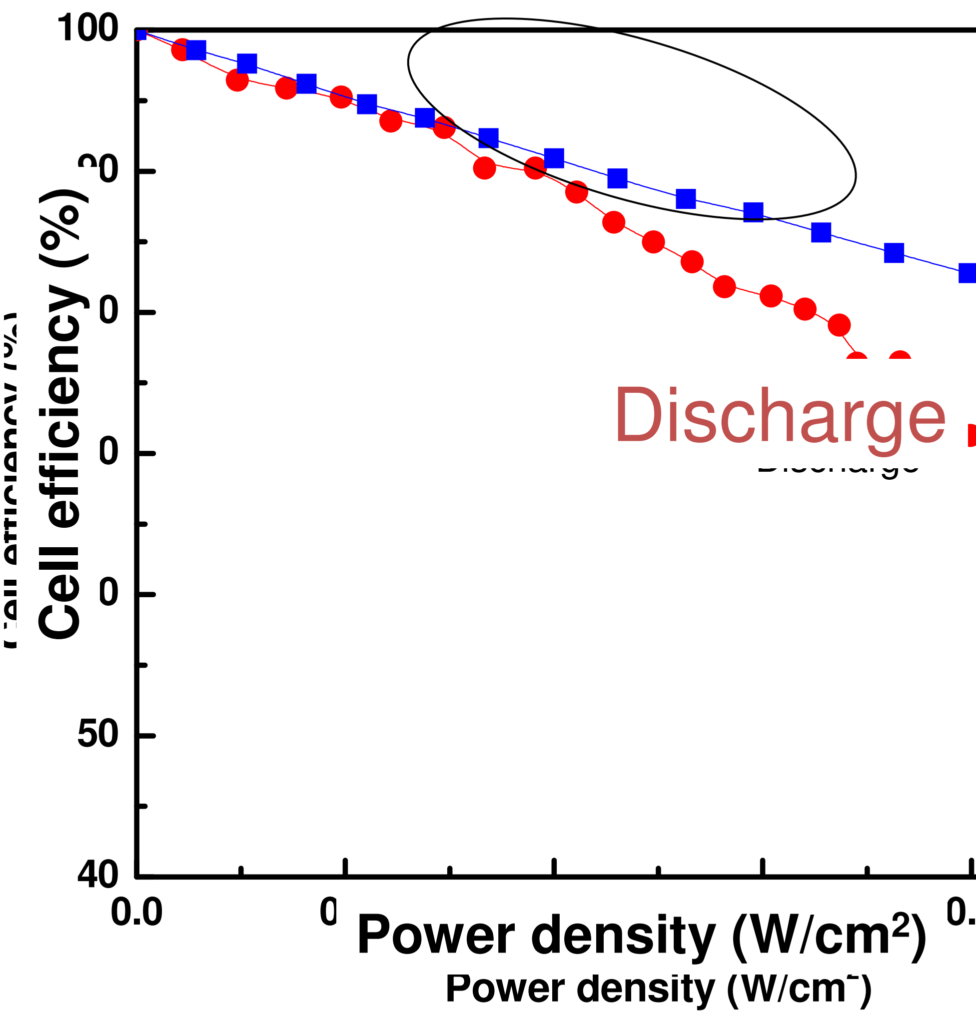
ormance from <u>pretreated</u> PM with H_2SO_4 was very reliable

ax power : 0.92 (0.9M Br2/1M HBr) and **<u>0.97</u>** (1M Br2/0.5M HBr)

ax current density: 1.54 A/cm2

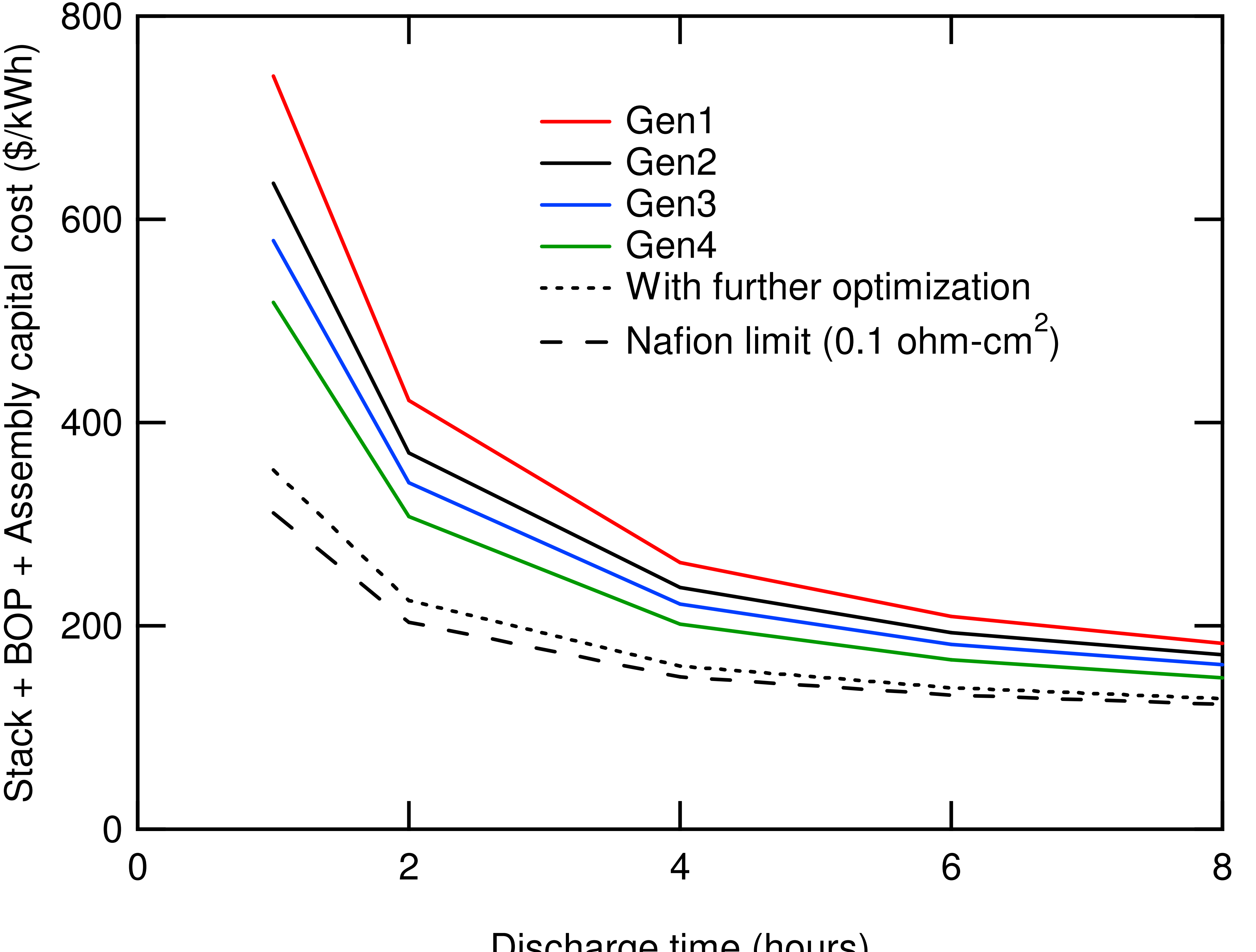
@ Room Temperature





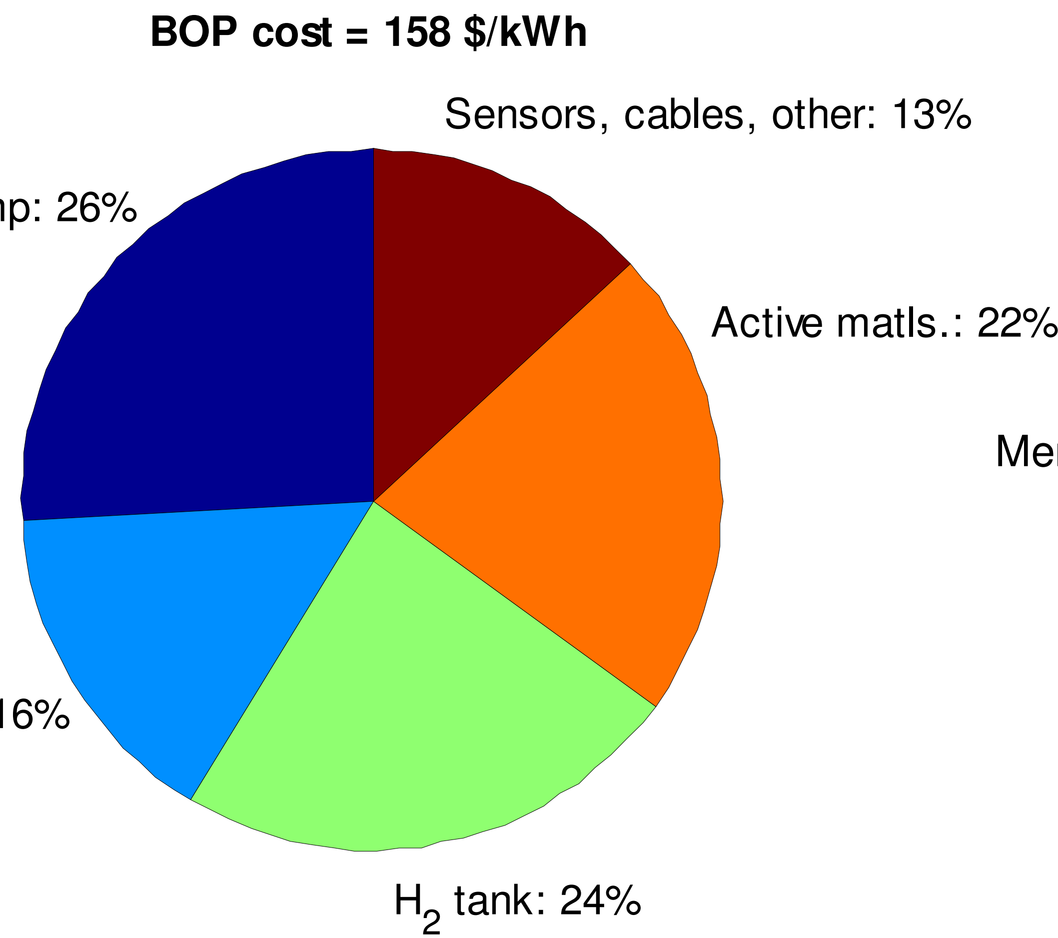
Highly reversible;
no side reactions

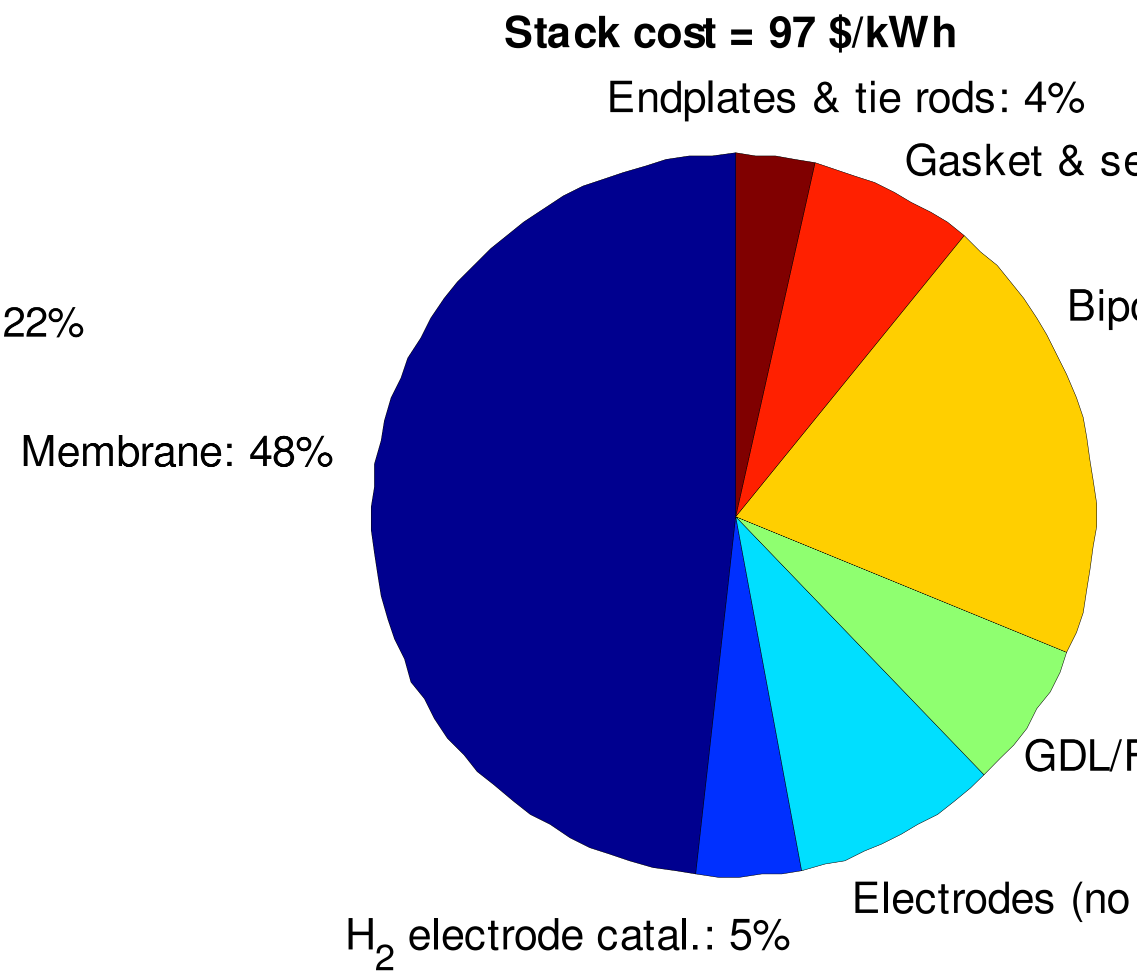
High power at hig
efficiencies


Gen1
Gen2
Gen3
Gen4
With further optimization
Nafion limit (0.1 ohm-cm2)
Stack + BOP + Assembly capital cost ($/kWh)
0
200
400
600
800
0
2
4
6
8
Discharge time (hours)

Energy

Power



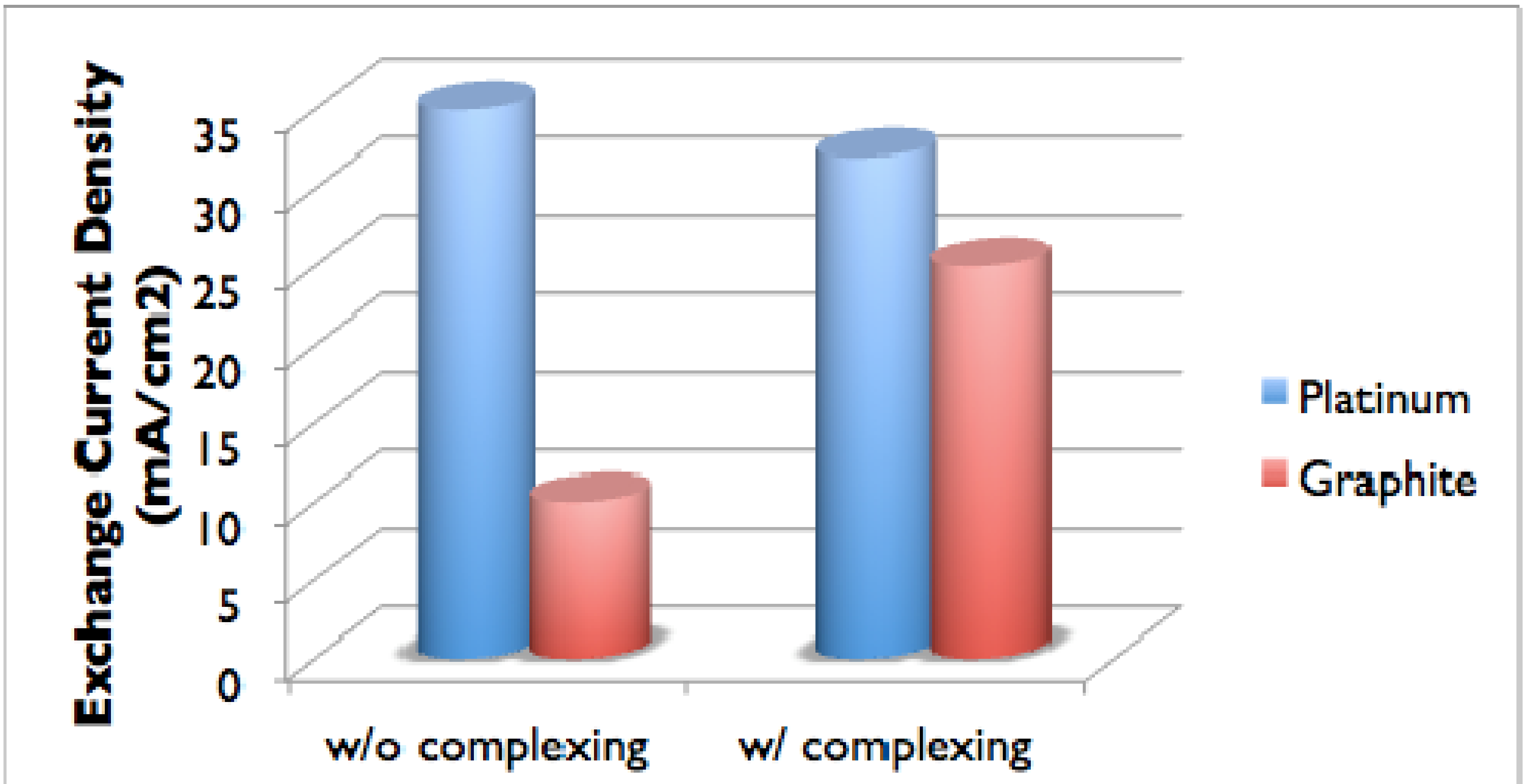


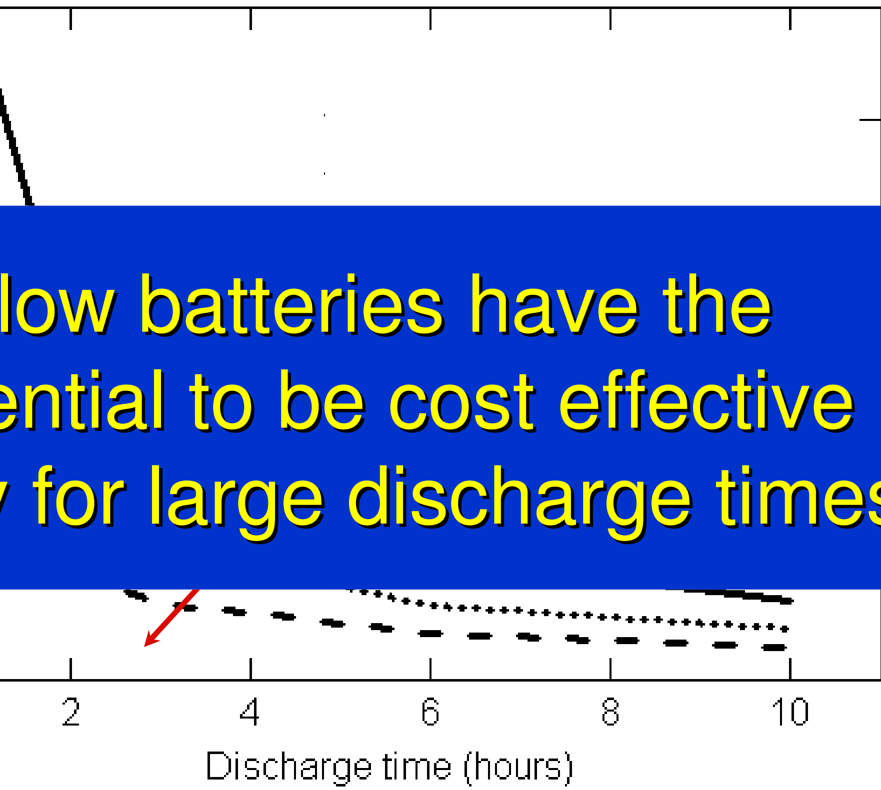
er pay for the H_2 tanks and
plates or pay for the pumps.

Focus on reducing membra
and bipolar plate costs.

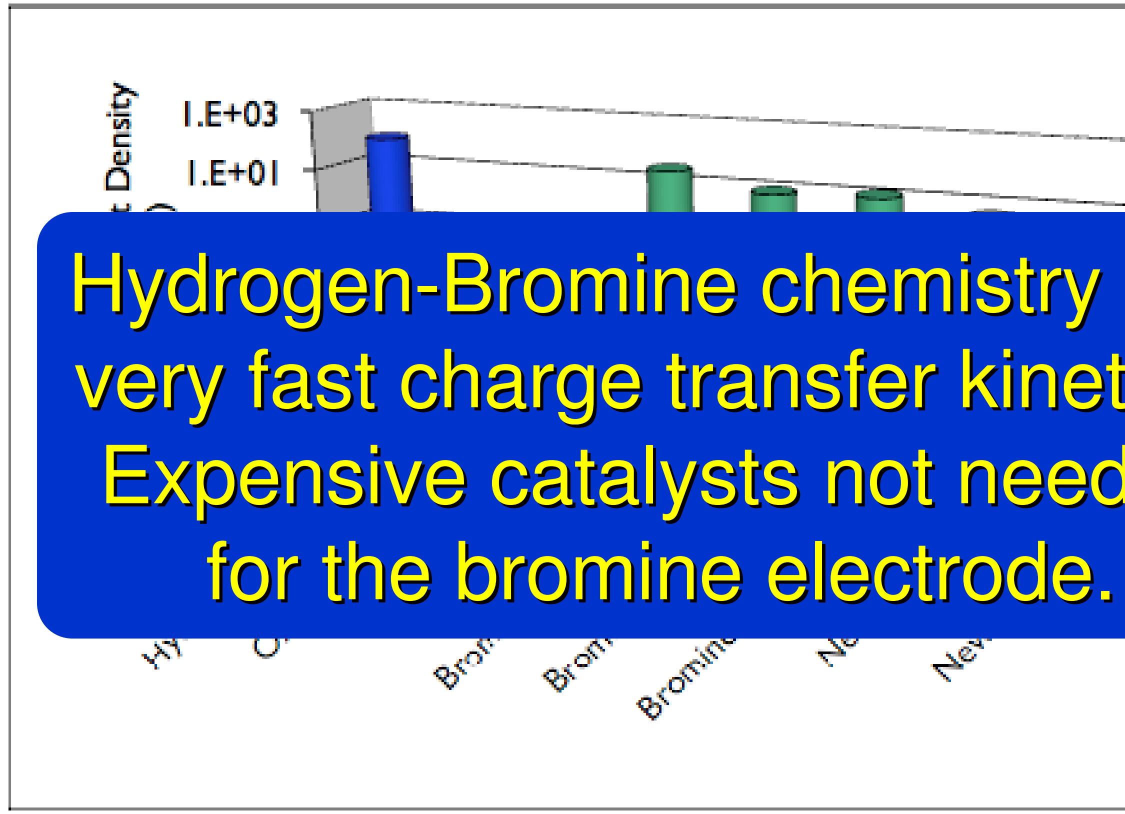
Br_2 is a problem as it's toxic with a low vapor press
(boils at 58.8°C)

But perhaps we can find a complexing agent that keeps it in solution while maintaining its performar

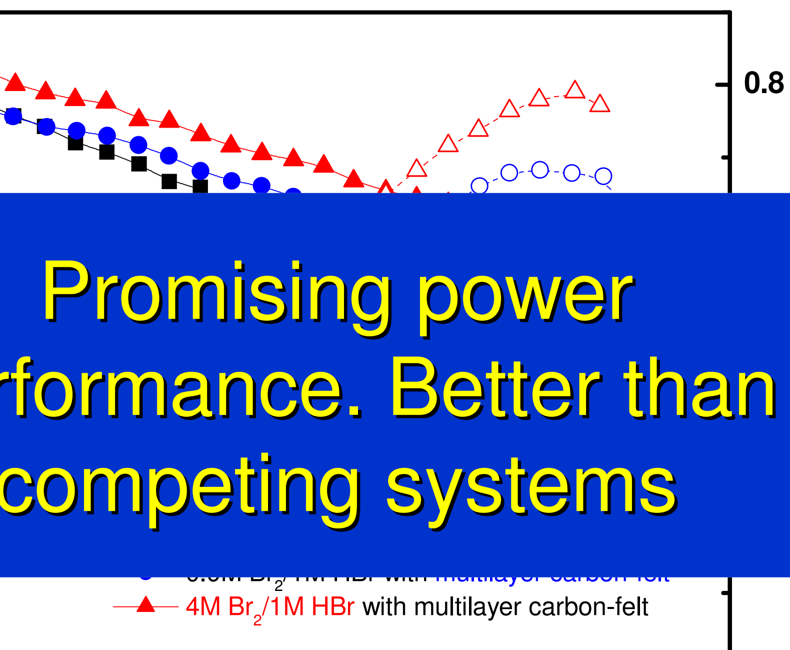




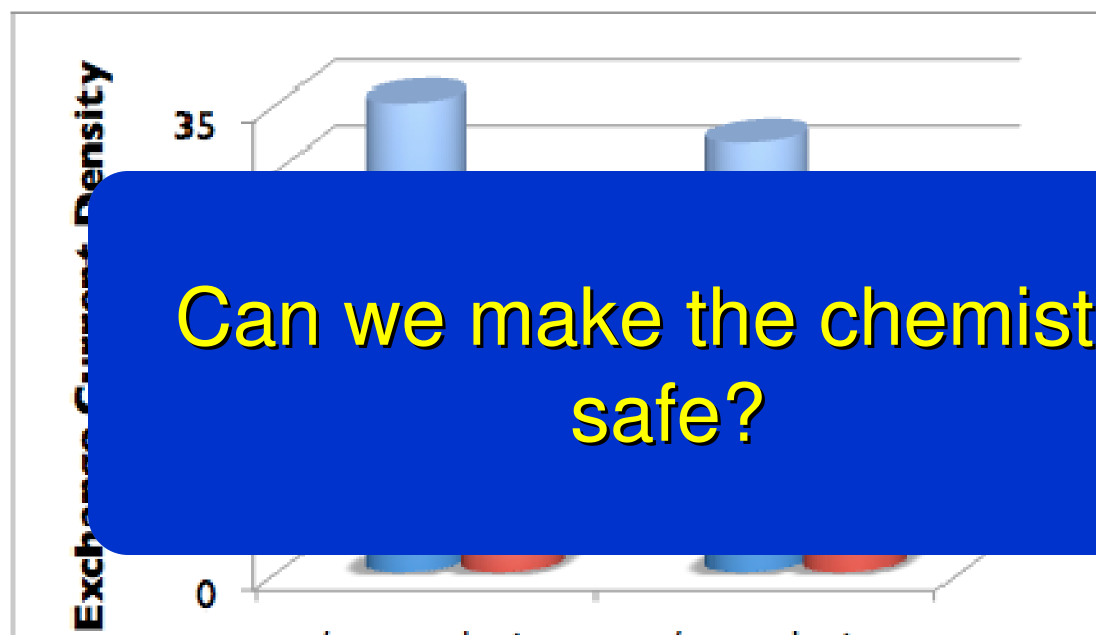
low batteries have the
ential to be cost effective
for large discharge times



Hydrogen-Bromine chemistry
very fast charge transfer kinet
Expensive catalysts not need
for the bromine electrode.



Promising power
rformance. Better than
competing systems



Can we make the chemist
safe?

ding from ARPA-E

ek Cho (Cell studies)
dgeway (Catalysis studies)
Haussener (Transport modeling)

pertus (Cost Modeling)
anchez-Carrera and Boris Kozinsky (Catalyst theory)

Choudhury (New membranes)

ebe (Catalyst structures)

nSite: