Sustainable Electrodes for Advanced Flow Batteries

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Global warming, air quality, sustainability, energy security – an increase in installed renewable and clean sources of electricity are vital to solve our energy problems and battle climate change.
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Almost 75% of new electricity capacity was renewable in 2019

New capacity installed each year (gigawatts)

Renewables | Fossil fuel
---|---
2001 | 50 | 100
2002 | 100 | 200
2003 | 150 | 300
2004 | 200 | 400
2005 | 250 | 500
2006 | 300 | 600
2007 | 350 | 700
2008 | 400 | 800
2009 | 450 | 900
2010 | 500 | 1000
2011 | 550 | 1100
2012 | 600 | 1200
2013 | 650 | 1300
2014 | 700 | 1400
2015 | 750 | 1500
2016 | 800 | 1600
2017 | 850 | 1700
2018 | 900 | 1800
2019 | 950 | 1900

[Graphic: Renewables vs. Fossil fuel capacity installation 2001-2019]

Carbon Net Zero 2050

[Diagram: Storage, Redox membrane, Redox Flow Battery]
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National Grid: Live Status (4:15pm 20/10/2020)

The National Grid is Great Britain's electricity transmission network, distributing the electrical power generated in England, Scotland, and Wales, and transferring energy between Great Britain and Ireland, France, and the Netherlands.

<table>
<thead>
<tr>
<th>Generation</th>
<th>Demand (GW)</th>
<th>35.2% fossil fuels</th>
<th>30.5% fossil fuels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>0.000GW</td>
<td>0.0%</td>
<td></td>
</tr>
<tr>
<td>Oil</td>
<td>0.000GW</td>
<td>0.0%</td>
<td></td>
</tr>
<tr>
<td>Gas (open cycle)</td>
<td>0.000GW</td>
<td>0.0%</td>
<td></td>
</tr>
<tr>
<td>Gas (combined cycle)</td>
<td>10.72GW</td>
<td>30.5%</td>
<td></td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>Other energy</th>
<th>24.3% other energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pumped storage</td>
<td>0.000GW 0.0%</td>
</tr>
<tr>
<td>Nuclear</td>
<td>6.300GW 17.9%</td>
</tr>
<tr>
<td>Biomass</td>
<td>2.110GW 6.0%</td>
</tr>
<tr>
<td>Other</td>
<td>0.140GW 0.4%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Renewable energy</th>
<th>33.6% renewable energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar photovoltaic</td>
<td>1.56GW 4.4%</td>
</tr>
<tr>
<td>Wind</td>
<td>9.74GW 28.7%</td>
</tr>
<tr>
<td>Hydroelectric</td>
<td>0.54GW 1.5%</td>
</tr>
</tbody>
</table>

Note: this pie chart shows generation only, and excludes interconnectors.

11.6% interconnectors

- HVDC Moyle 0.08GW 0.2%
- HVDC Cross-Channel 1.83GW 5.2%
- BritNed 0.99GW 2.8%
- East-West interconnector 0.15GW 0.4%
- Nemo Link 1.03GW 2.9%
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Electricity storage is widely regarded to be the single most important technological breakthrough likely to happen over the period to 2030 and a complete ‘game changer’ in the way that the power system operates.

*Energy UK report 2016*
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Performance of RFBs

- Operating variables:
  - Temperature, flow rate, cell current or voltage, time, SOC.

- Reaction environment:
  - Current/potential distribution, mass transport, flow dispersion, pressure drop, etc.

- Cell and stack design:
  - Flow fields, manifolds, shunt currents, manufacture method, etc.

- Thermodynamics and kinetics:
  - Cell potential, electrode kinetics, parasitic reactions.

- Modes of operation:
  - Batch recirculation/single pass, fluid flow in stacks, constant current/potential, etc.

- Electrode material and structure:
  - Electrocatalysis, 2-D vs. 3-D, coated/uncoated, etc.

- Electrolyte properties:
  - SOC, concentration, viscosity, conductivity.

- Separator:
  - Permeability, ion selectivity, potential drop, ageing, etc.
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Increase sustainability and improve performance
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Increase sustainability and improve performance

Losses in efficiency

- 70%

- PAN-based electrodes
- Not optimised for flow battery applications

*Energies 2016, 9, 627.*
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Increase sustainability and improve performance
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Biomass-derived precursors and Electrospinning

Combined with in situ and operando techniques
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Biomass-derived precursors and Electrospinning
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Biomass-derived precursors and Electrospinning

- Carboxylic
- Lactone
- Phenol
- Anhydride
- Ether
- Quinone

Graph showing cell voltage (V) vs. current density (mA/cm²):
- Commercial CF
- CNF mat

Microscopy images of nanomaterials with labels highlighting different functional groups.
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Shaping the next generation of materials for grid-scale energy storage

<table>
<thead>
<tr>
<th></th>
<th>Redox Flow Battery</th>
<th>Li-ion battery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrolyte</td>
<td>• Non-toxic, non-flammable</td>
<td>• Flammable</td>
</tr>
<tr>
<td></td>
<td>• Completely recycle</td>
<td>• Non-recyclable</td>
</tr>
<tr>
<td></td>
<td>• Expensive</td>
<td>• Low-cost</td>
</tr>
<tr>
<td>Life Cycle</td>
<td>10,000 – 25,000</td>
<td>10,000</td>
</tr>
<tr>
<td>Round-trip efficiency</td>
<td>60-80%</td>
<td>&gt; 99%</td>
</tr>
<tr>
<td>Initial Capital Cost</td>
<td>1000 - 500 $/kWh *</td>
<td>400 $/kWh</td>
</tr>
<tr>
<td>LCOS</td>
<td>LOW</td>
<td>HIGH</td>
</tr>
</tbody>
</table>

- Key timing for innovation in grid-scale energy storage technologies
- Flow batteries *versus* Li-ion batteries
- Materials with targeted properties for flow batteries
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<table>
<thead>
<tr>
<th>Team-WP</th>
<th>Context</th>
<th>Challenge</th>
<th>Impact</th>
<th>Approach</th>
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<tbody>
<tr>
<td>06</td>
<td>04</td>
<td>02</td>
<td>05</td>
<td>03</td>
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</tbody>
</table>

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**FL Fellow**

**Context**

**Challenge**

**Impact**

**Approach**

**RFBs**

**WP1 – Biomass-derived Electrodes**
- **T1.1**: Electrospinning of mats
- **T1.2**: Nano-composites - Electro-catalysts

**WP2 – Electrochemical Characterisation and Optimisation**
- **T2.1**: Material testing
- **T2.2**: Further optimisation and testing

**WP3 – Structure–Composition–Property Relationship**
- **T3.1**: In-situ and operando spectroscopy studies

**WP4 – Modelling and Computational Studies**
- **T4.1**: Computational studies to understand reaction mechanisms at the electrode / electrolyte interface and electrolyte flow dynamics

**WP5 – Full Cell Testing and Optimisation**
- **T5.1**: Testing using redox aqueous / organic species

**WP6 – Hybrid Systems**
- **T6.1**: Solid Flow Batteries
- **T5.2**: Metal-Air Flow Batteries

**WP7 – Impact**
- **T6.1**: Engaging scientific / non-scientific community
Thanks!
Any questions?

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