Ammonia Production From Wind Power

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Vice President, Ideation and Partnering
RE has beaten coal – Next frontier: **Beat Oil and Gas**

Direct electrification in some sectors. **Electro-fuels in other.**
Why ammonia looks to be the most promising e-fuel candidate?

Ammonia is a transportable, scalable, carbon-free fossil fuel replacement which can be created with RE

<table>
<thead>
<tr>
<th></th>
<th>Gasoline</th>
<th>Hydrogen (H₂)</th>
<th>Ammonia (NH₃)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Global Market</strong></td>
<td>✅</td>
<td>❌</td>
<td>✅</td>
</tr>
<tr>
<td>Limited market, typically produced on-site</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Transport ability</strong></td>
<td>✅</td>
<td>✅</td>
<td>✅</td>
</tr>
<tr>
<td>Problematic long distance transport, but possible through pipelines</td>
<td></td>
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<tr>
<td><strong>Energy density</strong></td>
<td>8,8 kWh/l</td>
<td>0,6 kWh/l</td>
<td>4,3 kWh/l</td>
</tr>
<tr>
<td><strong>EHS</strong></td>
<td>❌</td>
<td>✅</td>
<td>✅</td>
</tr>
<tr>
<td>Unavoidable emissions</td>
<td>No emission &amp; manageable flammability</td>
<td>No emission &amp; manageable toxicity</td>
<td></td>
</tr>
</tbody>
</table>

**Fundamental properties indicate:**

- NH₃: Superior product for large scale production from power
- H₂: Pipelines to off-taker or small amounts of energy only
Commercial feasibility → Continuous cost reduction is expected

Cost gap to fossil ammonia and fuel is expected to be closed towards year 2030

### E-fuel plant lifetime costs

- 20 year lifetime
- Plant size: 100 MW
- Plant utilization rate/CF: 80%

### Expected development in e-fuel ammonia price

1) Current low bid auction level
2) Development is based on expected electrolysis development (source: Haldor Topsøe, NEL) and plant costs and RE electricity cost are assumed to decrease 3% per year

### Comments

- CAPEX to decrease significantly
- E-fuel to be competitive towards 2030
- Conventional ammonia market is a promising stepping stone towards e-fuel
- Renewable energy based e-fuel is expected to be sold at a premium compared to fossil fuel
- Fuel and ammonia prices are highly fluctuating & varies geographically
Case: Marine e-fuel market projection through 2050
Scale comfortably within reach

Scenario: Cover all marine shipping fuel

Global Fuel Demand

- Road
- Aviation
- Marine
- Other
- Direct & Indirect electrification potential

~10 TW

Marine Fuel Demand

~1 TW

Perspective case

- With current technology the energy need from a local shipping company: ~42 GW Wind
- Danish EFKM has conservatively pointed out areas to install 50 GW offshore wind
- Good synergy with hydropower resources in Nordic region to balance wind

Installing 1 TW e-fuel production capacity

Wind installation [GW/y] Electrolysis installation [GW/y]
Main take aways

If nothing else, this is what to remember

Hydrogen is a stepping stone to something else that can store bulk amounts of energy. Ammonia is such a chemical that can be used in shipping and other large industry sectors transferring away from fossil fuels.

Making ammonia from renewable energy in general is not new and the task at hand is to scale and deploy to get prices down. Despite of what you may be told it is not R&D efforts or small scale demos that are needed.

Do not forget the offtaker and the end user.

Cost of ammonia as a fuel will come at premium cost to start with, but we do have line of site to get on par with fossil fuels in forseeable future.

This is not scaling to an extend we cannot manage, the wind industry alone has magnitude to make this happen.
Thank you for your attention