Low Carbon Fuels for Power Generation

Robert Steele
EPRI - Technical Executive
Need Low-Carbon Fuels Beyond 2030
LCRI Core Technical Scope

ENERGY CARRIERS
Hydrogen, Ammonia, Bio-fuels, Synthetic/Derivative Fuels

PRODUCTION
Electrolysis through Low Carbon Sources, CCS, Innovative Production Methods

TRANSPORTATION & STORAGE
Pipeline Blending, Safety and Protocols, Storage, Alternate transportation approaches

USE
Transportation, Heating, Commercial, Residential, Industrial, Power Generation

FOUNDATIONAL TOPICS
State of Technology
Integrated Energy Systems Analysis
Safety & Environmental Aspects
Techno-Economic Studies & Technical Risk Quantification
Demonstration & Assessment Insights

POTENTIAL FIRST PROJECT
ARPA-E REFUEL
Integration Of Ammonia Synthesis Technologies At Scale
Renewable Green Ammonia Pilot Plant
Strong Team Is Already Formed
Welcome New Collaborators
Use of Ammonia will be addressed by all subcommittees

<table>
<thead>
<tr>
<th>Group</th>
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<tbody>
<tr>
<td>Executive Council</td>
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<td>Technical Advisory Group</td>
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<tr>
<td>Electrolysis</td>
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<tr>
<td>Hydrocarbons</td>
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<tr>
<td>Renewable Fuels</td>
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<tr>
<td>Storage and Delivery</td>
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<tr>
<td>End Use: Transportation, Industrial and Residential</td>
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<td><strong>Power Generation – R Steele (EPRI lead)</strong></td>
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<td>Integrated Energy Analysis</td>
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<td>Safety and Environmental Aspects</td>
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Objective: Confirm the viability of alternative energy carriers as fuels for power generation – both in pure or blended forms

Current Approach: Review and assess power generation technologies as related to burning low-carbon fuels with emphasis on Ammonia and Hydrogen

- Include summary of key worldwide players and projects
- Identify R&D gaps and collaboration opportunities

2021 Deliverables:
- Short Technology Insight Reports (in progress):
  - Gas Turbines, HRSG Duct Burners, Electric Generation and Industrial Applications Boilers, Reciprocating Engines, Fuel Cells
  - Establish collaboration with worldwide universities and research organizations
  - Finalize multi-year roadmap .... WILL INCLUDE AMMONIA FUEL STANDARD
Comparison of Fuel Characteristics

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Lower Heating Value (LHV)</th>
<th>Mass</th>
<th>Volume</th>
<th>Flame Speed ($S_f$)</th>
<th>Flame Temperature ($T_{ad}$)</th>
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<tbody>
<tr>
<td>Methane</td>
<td>50 MJ/kg (21,500 BTU/lb)</td>
<td>120 MJ/kg (51,600 BTU/lb)</td>
<td>915 BTU/scf</td>
<td>37 cm/s (1.2 ft/s)</td>
<td>1950°C (3542°F)</td>
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<tr>
<td>Hydrogen</td>
<td>120 MJ/kg (51,600 BTU/lb)</td>
<td>275 BTU/scf</td>
<td>291 cm/s (9.5 ft/s)</td>
<td>2110°C (3830°F)</td>
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<tr>
<td>Ammonia</td>
<td>18.6 MJ/kg (8,000 BTU/lb)</td>
<td>365 BTU/scf</td>
<td>7 cm/s (0.23 ft/s)</td>
<td>1800°C (3272°F)</td>
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Ammonia will require extensive R&D before widespread use as a fuel source for Power Generation
Ammonia as a Fuel has Potential in Many Industries

Introduction of Ammonia will start as an additive with natural gas
Together...Shaping the Future of Electricity