NET Power

Truly Clean, Cheaper Energy

May 2016
The size of the prize

The only technology that will enable the world to meet the COP 21 climate targets *without* having to pay more for electricity.
NET Power is a truly novel approach

- **NET Power makes electricity from natural gas**
  - NET Power costs the *same as, or less than*, electricity from existing natural gas power plants
  - NET Power generates electricity at **high efficiency** (59% LHV)
- **NET Power will capture substantially all of the CO₂ and non-CO₂ atmospheric emissions without any additional cost**
  - The CO₂ is captured at **pipeline purity and pressure** ready for use in other industrial applications and EOR
  - NET Power increases *margins* per BOE extracted via EOR by reducing injectant, gas processing and re-injection energy costs.
- **NET Power does not need to use water (at a small reduction in efficiency)**
NET Power readiness

*Every single item of equipment is commercially available, except the turbine*

The turbine is in an advanced state of readiness

- It is being engineered, designed and manufactured by Toshiba.
- The blades, stages and pressure shells are not new.
- Only the combustor is new.
- A 5MWt test combustor has been operating since January 2013.
Technology Overview

The Supercritical CO₂ Allam Cycle
NET Power is based on the Allam Cycle platform

- 58.9% (LHV) net efficiency, with capture of >97% of carbon
- Oxy-fuel, closed-loop, CO₂ working fluid
- 200-400 bar; 6-12 pressure ratio
- CO₂ and water are the only byproducts

Fuel Combustion
CO₂ Turbine
Heat Rejection
Water Separation
Compression and Pumping
Additional Heat Input
Heat Recuperation
The NET Power advantage - the Allam Cycle
The supercritical CO₂ Allam Cycle is simple

- Historically, CO₂ capture has been expensive, whether using air to combust or oxy-combustion
  - Air combustion
    - \[8N₂ + 2O₂ + CH₄ → 8N₂ + CO₂ + 2H₂O\] expensive to separate
  - Oxy-combustion
    - \[2O₂ \rightarrow CO₂ + 2H₂O\] expensive to produce

- The Allam Cycle makes oxy-combustion economic by:
  - Relying on a more efficient core power cycle
  - Recycling heat within the system to reduce O₂ and CH₄ consumption, and associated costs of the ASU
NET Power is competitive without CO₂ sales

In climates with less O₂ per volume of air (higher altitudes and/or higher temperatures), Allam Cycle power output stays relatively stable, while output of traditional cycles falls sharply.

- LCOE calculated using EPRI methodology
- Assumes natural gas at $2.85/MMBTU and coal at $1.73/MMBTU
- Every move of $1 in natural gas moves LCOE $6
- Cost ranges represent range of data combined from: EIA (2013), Parsons Brinkerhoff (2013); Black & Veatch (2012); DOE NETL (2012)

Additional cost increase for CO₂ emissions tax @ $15/ton

Additional cost reduction for CO₂ sales @ $20/ton
NET Power’s Development Program

Performance and Economics Overview
Development pathway

- Thermodynamic modelling
- Costing
- Program development

- 295MWe commercial plant pre-FEED
- 50MWth demonstration plant FEED
- 5MWth combustor testing

- 50MWth demonstration construction and testing
- 295MWe commercial development

- 295MWe commercial construction and operation

Current Stage
Construction is underway on NET Power’s 50MW demonstration plant

- **50MWth natural gas demonstration plant**
  - Plant design scaled down from 500MWth pre-FEED design to ensure scalability
  - Site is in La Porte, TX

- **Plant includes all core components of the Allam Cycle**
  - Combustor/turbine, heat exchangers, pumps and compressors, control system, and ancillary equipment
  - Plant will undergo full performance evaluation (startup, shutdown, ramping, hot/warm/cold starts, emergency operations)
  - Oxygen will be pulled from a pipeline as opposed to a dedicated ASU
  - CO2 will be generated at high pressure and quality

- **$140 million program**
  - Includes first of a kind engineering, all construction, and testing period
Commercial plant characteristics

- **Large amount of operational flexibility**
  - Electrical turndown *not limited by air permit* constraints
  - Enables *rapid responsiveness* to load requirements
  - Ramp-rate
    - Cold (after being down for 36 hours): 3 to 4 hours
    - Warm/hot (being down less than 12 hours): 2-5% per minute from warm/hot start

- **Large amount of siting flexibility**
  - Ability to cool with hybrid or air cooling configurations, *eliminating water needs* (no make-up water required), with minimal (2-3%) efficiency impact
  - Simplified configuration capable of using *alternative water resources* (non-potable and/or brackish)
  - Elimination of air emissions enables siting in *non-attainment zones* without requiring purchase of offsets
  - Maintains *performance* (no major de-rating) in low air density locations (hot ambient temps/high altitudes)
  - Flexible with small contaminants in *fuel gas chemistry*

<table>
<thead>
<tr>
<th>NET Power Commercial Natural Gas Plant</th>
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<tr>
<td><strong>Electric Output</strong></td>
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<tr>
<td><strong>CO₂ Output</strong></td>
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<tr>
<td><strong>N₂ Output</strong></td>
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<td><strong>ASU Output Demand</strong></td>
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<td><strong>Site Area</strong></td>
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Commercial marketing

- Commercial power customers are already engaged
  - In commercial discussions with many of the largest power generators in US and internationally.
  - Planned natural gas capacity additions by this group of customers is equal to, conservatively, 50 NET Power 2-train power stations.

- Commercial-scale pre-FEED completed
  - Moving into plant FEED stage.

- Major and minor oil and gas EOR companies interested in CO₂ off-take
  - NET Power enhances their economics and provides much needed CO₂ supply.

- Potential regulatory opportunity in US
  - New CO₂ regulations enhance NET Power’s market position.
  - NET Power provides customers with certainty in the face of changing and increasingly stringent regulations.
NET Power’s Benefits

Performance and Economics Overview
NET Power plants are highly efficient

- Competes with or exceeds combined cycle efficiency, while eliminating air emissions.

<table>
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<tr>
<th>NET Power and Combined Cycle: Efficiency Comparison</th>
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<tr>
<td><strong>HHV</strong></td>
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<tr>
<td>Energy Components</td>
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<tr>
<td>Gross Turbine Output</td>
</tr>
<tr>
<td>CO₂ Compressor Power</td>
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<tr>
<td>Plant Parasitic Auxiliary Power</td>
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<tr>
<td>Net Efficiency</td>
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NET Power’s low cost-of-capture solves the CO$_2$ utilization and storage problem

- **CO$_2$ capture**
  - at no extra cost
  - already at pressure (available from 30 bar/450 psi to 300 bar/4500 psi)
  - already at high purity

- **Scalable CO$_2$ uses**
  - Enhanced oil recovery (EOR)
    - Cheaper than geologic CO$_2$ (no associated lifting costs, mineral lease costs or pressurization costs)
    - Current CO$_2$ use in US would by matched by the CO$_2$ output from over 110 Allam Cycle turbines (500 MWth)
    - Industry is drastically under-supplied with affordable CO$_2$
  - Additional CO$_2$ utilization opportunities
    - Building materials
    - Chemical processes
    - Artificial photosynthesis
NET Power can build upon the large CO₂-EOR infrastructure already in place
NET Power can deliver significant economic and geographic growth in lower oil prices via EOR

- Shutdown of tight oil/high cost plays highlights EOR as a low-cost opportunity for growth from existing fields.
- NET Power further improves the economics of EOR and will significantly expand CO₂ supplies for producers.
NET Power provides growth opportunities to industries outside of electricity generation

- **Key gases**
  - Synergistic with chemicals and oil & gas industries
  - For each turbine train (operating at an estimated 85% capacity factor for power, 98% for ASU)
    - 13.9 million MMBTU per year NG use
    - 800,000 tons per year CO\(_2\) production
    - 4.8 MM tons per year N\(_2\) production
    - 166,000 tons per year O\(_2\) production (during planned outages for electricity part of plant)
  - Capability of delivering syngas (H\(_2\) and CO)

- **Significant flexibility to site where resources exist**
  - Option for zero water usage
  - Insensitive to changes in ambient conditions (altitude, temperature, etc.)

- **Reduces the CO\(_2\) intensity of the oil & gas industry**
  - Can utilize flare and waste gases (associated, acid, sour) that are otherwise environmentally harmful
    - Can integrate directly with operations of oil and gas producers
    - Simplifies operations and reduces costs
  - Integration with LNG-regasification terminals provides high efficiency power generation (67% LHV) and eliminates the need for gas-fired regasification
The NET Power advantage summarized

**Low-Cost**
- Utilizes abundant, low-cost natural gas
- Produces electricity that is equal to, or less than, NGCC’s cost of electricity
- No additional cost for CO₂ capture

**De-risk fleet**
- Near-100% capture of all carbon emissions (>97%)
- No other air emissions, including NOₓ
- Water usage can be eliminated

**Reliable**
- Less sensitive to changes in siting conditions (high altitude and temp)
- Reactive power and maintaining voltage, frequency, & stability
- Capable of full electrical turndown without emissions issues, enabling fast response

May 2016
The Allam Cycle provides a flexible platform with broad applications.

- **Water Desal** (50,000 m³/day)
- **LNG Regas** (67% Efficient)
- **Direct EOR** (65% Efficient)
NET Power’s commercial plant is much smaller and simpler than previous carbon capture projects.
NET Power transforms U.S. EOR and CO₂ storage potential

CO₂ demand far outstrips supply

- As current geologic supply drops, the gap will grow wider.

NET Power produces the lowest-cost CO₂

- The Allam Cycle can produce pipeline CO₂ at a cost lower than any existing source, including geologic, which is currently the lowest cost, and by far the most common, source of CO₂ for EOR.

NET Power will have a major supply impact

- 57 commercial NET Power Allam Cycle plants would match the entire combined geologic CO₂ supply of the 3 largest US EOR operators (OXY, Kinder, Denbury).

NET Power untethers EOR from the current geologic CO₂ supply network

- NET Power-based CO₂ hubs enable utilization of EOR assets isolated from the geologic CO₂ network and justify a major expansion of CO₂ supply network.

NET Power Allows the CO₂ Pipeline Network to Grow Rapidly

Low-Cost CO₂ production would support a massive network expansion

Approximately 7 NET Power 590 MWe stations would produce enough low-cost CO₂ to justify the development of an 800 mile CO₂ pipeline.
**CO2 sequestration can generate revenue with EOR and ECBMR**

**ECBMR:** Enhanced Coal Bed Methane Recovery. Injection of CO\(_2\) into coal seams that cannot be mined. CO\(_2\) is sequestered and CH\(_4\) is produced.

**EOR:** Enhanced Oil Recovery. CO\(_2\) is injected into mature oil wells to stimulate additional oil production.

<table>
<thead>
<tr>
<th>Region</th>
<th>Gross Fossil Capacity Builds to 2035 (IEA)</th>
<th>Fraction of Gross Build That Would Be Justified by EOR Demand*</th>
<th>Fraction of Gross Build That Would Be Justified by ECBM Demand*</th>
<th>500MWt/295MWe Trains justified by EOR and ECBM demand for CO(_2)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total</strong></td>
<td>2,403 GW</td>
<td>254%</td>
<td>603%</td>
<td>8,146</td>
</tr>
<tr>
<td><strong>Europe</strong></td>
<td>213 GW</td>
<td>67%</td>
<td>72%</td>
<td>722</td>
</tr>
<tr>
<td><strong>Former Soviet Union</strong></td>
<td>262 GW</td>
<td>299%</td>
<td>313%</td>
<td>888</td>
</tr>
<tr>
<td><strong>Asia Pacific/Oceana</strong></td>
<td>1408 GW</td>
<td>9%</td>
<td>226%</td>
<td>4,773</td>
</tr>
<tr>
<td><strong>Middle East</strong></td>
<td>185 GW</td>
<td>1091%</td>
<td>197%</td>
<td>627</td>
</tr>
<tr>
<td><strong>Latin America</strong></td>
<td>96 GW</td>
<td>334%</td>
<td>123%</td>
<td>325</td>
</tr>
<tr>
<td><strong>United States and Canada</strong></td>
<td>239 GW</td>
<td>254%</td>
<td>603%</td>
<td>810</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>2,403 GW</td>
<td></td>
<td></td>
<td>815</td>
</tr>
</tbody>
</table>

*A value greater than 100% indicates that EOR/ECBM demands exceed CO\(_2\) supply from gross capacity builds between now and 2035. Sources: Godec et al. Potential global implications of gas production from shales and coal for geological CO\(_2\) storage. Energy Procedia. GHGT-11 (2013)