ThorCon: *Powering Up Our World*

Status Report

ThorCon, [http://thorconpower.com/](http://thorconpower.com/), info@thorconpower.com

Dane Wilson presenting

October 5, 2016

*Molten Salt Reactor Workshop 2016*
ThorCon is a block constructed, passively safe, molten-salt, fission power plant

- Based on MSR technology, proven in the 1960s
- Uses low-cost shipyard block construction

1 GWe fission island consisting of 4 paired Cans

Hellespont Fairfax

1 GW ThorCon size compared

Devanney Ultra Large Crude Carrier cost $89 million, built in 10 months
Low Cost, Rapid Construction Is Essential To Meeting Growing Electricity Consumption

- Power needs of 5,040 GW
- High-precision steel-fabrication builds ships for $2,000 per ton
- A small shipyard can build 10 1-GW ThorCon power plants a year
## Base Cost* Is Estimated To Be Less Than For Coal

<table>
<thead>
<tr>
<th>Electric Project</th>
<th>Westinghouse AP1000</th>
<th>ThorCon</th>
<th>Coal (high)</th>
<th>Coal (low)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest rate</td>
<td>8.00%</td>
<td>8.00%</td>
<td>8.00%</td>
<td>8.00%</td>
</tr>
<tr>
<td>Capital cost, $millions</td>
<td>16000</td>
<td>1200</td>
<td>2200</td>
<td>1800</td>
</tr>
<tr>
<td>Generating capacity, MW</td>
<td>2200</td>
<td>1000</td>
<td>800</td>
<td>1200</td>
</tr>
<tr>
<td>Lifetime, years</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Capacity factor</td>
<td>0.9</td>
<td>0.9</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td><strong>Capital cost per kWh</strong></td>
<td><strong>$0.077</strong></td>
<td><strong>$0.013</strong></td>
<td><strong>$0.033</strong></td>
<td><strong>$0.018</strong></td>
</tr>
<tr>
<td>Operating cost estimate</td>
<td>0.01</td>
<td>0.0056</td>
<td>0.0049</td>
<td>0.0049</td>
</tr>
<tr>
<td>Fuel cost</td>
<td>0.007</td>
<td>0.005</td>
<td>0.0145</td>
<td>0.0145</td>
</tr>
<tr>
<td><strong>Total cost per kWh</strong></td>
<td><strong>$0.094</strong></td>
<td><strong>$0.024</strong></td>
<td><strong>$0.052</strong></td>
<td><strong>$0.037</strong></td>
</tr>
</tbody>
</table>

* Base cost: power only; excludes fees, taxes, licenses, R&D, corporate management, investor return, ...

** Excel PMT function (interest rate, lifetime, cost) / capacity factor

“Can” Modularity (250 MWe) Is Integral To ThorCon And Allows Materiel Transport

- Shipyard builds new power plants (PP)  
- Barge to PP site (around 20 barge loads per GW)
- PP sites (1 GW site shown)  
  1,000-20,000 GW total
- Canship delivers new Cans and takes old Cans back for recycling. Also transports new fuel and returns spent fuel. One round trip every four years to each 1GWe site.

- Can recycling center cleans and inspects cans, replace graphite, stores offgas and graphite wastes. Similar to a shipyard.

- Secure site stores spent fuel (dry cast) for possible future processing.
ThorCon’s Heart Is The Can Which Contains:

- **Pot**
  - Pressure: 3.5 bar
  - Temperature: inlet of 564°C and outlet of 704°C
  - Graphite moderator
  - Some Th converts to U-233, U-238 to Pu-239

- **Pump**
  - Fuelsalt pumped at ~ 3000 kg/s
    - 14 sec loop time

- **Primary Heat Exchanger (PHX)**
ThorCon Employs Three Salt Loops

44% thermal efficiency
## ThorCon Is Fuel And Salt Flexible

<table>
<thead>
<tr>
<th>Mission</th>
<th>Salt 12% HM</th>
<th>Startup</th>
<th>Makeup Th plus</th>
<th>Self generated fuel (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Heavy metal (%)</td>
<td>U distribution (%)</td>
<td>U distribution (%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Th</td>
<td>U</td>
<td>U233</td>
</tr>
<tr>
<td>1) Initial tests</td>
<td>NaBe</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>2) Economic baseline</td>
<td>NaBe</td>
<td>82</td>
<td>18</td>
<td>0</td>
</tr>
<tr>
<td>3) Better fuel utilization</td>
<td>FLiBe</td>
<td>82</td>
<td>18</td>
<td>0</td>
</tr>
<tr>
<td>4) Best fuel utilization *</td>
<td>FLiBe</td>
<td>82</td>
<td>18</td>
<td>12</td>
</tr>
</tbody>
</table>

* Possible future: Separate of seeker fission products + Pu, Am, Cm. Plutonium goes to a fast reactor and LEU U233 returns. Makeup is almost all thorium.
Neutronics Modeling Is In A State Of Flux

- Neutronics and burnup modeled with both MCNP and Serpent
- ThorCon DNA design control system allows changes to flow to documentation and model preprocessors, facilitating design experimentation
- Moderator mounting system allows graphite changes with temperature and fluence
- Strongly negative temperature coefficient throughout fuel cycle, even on NaBe
- Load response via pump speed confirmed
Fission Product Removed Via Off-gas System

- Recovery involves He sweep, hold-up tanks, charcoal delay
  - Low turbulence flows
- Gases (Kr, Xe)
  - Removed by spray bubbling
  - 216 kg/GWe-yr
- Noble metals (Nb-Te)
  - Plate out into OGR and PHX
  - 234 kg/GWe-yr
- Solubles (Rb, Sr, Y, Zr, Cs-Gd, Pu-Cm)
  - Stay in the salts
  - 409 kg/GWe-yr
- Trifluorides approach saturation in fuel salt after 8 years
ThorCon Design Allows For Tritium Control

- Beryllium is the tritium source: $^9\text{Be}(n,\alpha) \rightarrow ^6\text{Li}(n,\alpha) \rightarrow ^3\text{H} + \alpha$

- Tritium migrates through hot metal surfaces such as the PHX

- Tritium is gettered in each sealed gas space

- Solar salt (NaNO$_3$, KNO$_3$) third loop will capture the last of the tritium
ThorCon Is Walk-away Safe

- Safety is **intrinsic** from physics, not add-on safety systems
  - Overheating stops chain reaction
- Any break will **drain** reactor fuel to cold shutdown Fuelsalt Drain Tank (FDT)
- Decay heat is removed by silo cooling wall continuous **passive** water circulation
  - Even in power blackout
- Radioactive fuel salt at **low** pressure
  - No energy for significant dispersion
- Fluoride salt chemically **locks up** hazardous fission products Cs-137, Sr-90
Layered, Passive Decay Heat Cooling Is Employed

- On station black-out
  - Sentry turbine handles decay heat
    - Avoids drain
- On Sentry turbine failure
  - Loop overheats, fuse valve thaws, primary loop drains to FDT
- On drain at full power to FDT
  - Always-on membrane wall cools
    - After ~3h, temperature peaks at 975°C – 450°C below boiling point
- **Nothing the operator can do to prevent the drain and cooling**
Additionally, The Silo Wall Is Continuously Passively Cooled

- Silo wall can cool 30 MWt
  - Max decay heat is 5 MWt
- Pond has 72 days worth of water
  - 180 days with wet towers
- Basement water adds over a year of walkaway safety

![Diagram of silo wall cooling system]

- Pond volume (m³): 14134
- Condenser surf. area (m²/Can): 1435.2
- Downcomer head (m): 19.976
- Exp. Tank H₂O volume (m³): 462
- Exp. Tank gas volume (m³): 50

If level in expansion tank falls below level in pond, pond check valve automatically drains portion of pond water into membrane wall loop.
ThorCon Has 3 To 4 Radioactivity Transport Barriers

1. Primary Loop Piping
2. Can/Drain Tank
3. Silo Cavity
4. Silo Hall

1’ Primary HX
2’ SHX Loop
3’ SHX Cell
Likely Demonstration Site Is Indonesia

- ThorCon discussing test-then-license with regulator
- Site selection initiated by Indonesia
- ThorConIsle prototype will be built on a hull, pretested, towed to Indonesia, settled near shore, and powered up
  - Water depth 5-10 m
  - Allows for changes to prototype at shipyard and siting flexibility
  - Lower-cost land-based version will be available

Related Map: [Bangka ThorCon site?](http://endcoal.org/tracker/)

SKN 2016: Bapeten Hadirkan keynote speaker Wade Allison
The ThorCon Indonesia Project Has 6 Phases

<table>
<thead>
<tr>
<th>Phase</th>
<th>Task</th>
<th>Milestone</th>
<th>Investments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bid</td>
<td>Complete engineering</td>
<td>Bids in hand</td>
<td>$10 million</td>
</tr>
<tr>
<td>Pre-fission</td>
<td>Build, test unfueled prototype on hull in shipyard</td>
<td>Tests complete</td>
<td>$120 million</td>
</tr>
<tr>
<td>Construction</td>
<td>Add turbine-generator, switchgear, Cans; contract fuel</td>
<td>Ready to tow hull</td>
<td>$520 million</td>
</tr>
<tr>
<td>Prototype</td>
<td>Tow to Indonesia, fuel, test</td>
<td>Power to grid</td>
<td>$65 million</td>
</tr>
<tr>
<td>Power-up</td>
<td>Increase power to 250+ MW</td>
<td>License for +3 GW</td>
<td>$65 million</td>
</tr>
<tr>
<td>Production</td>
<td>Build 3 GW more plants</td>
<td>Revenue from +3 GW</td>
<td>borrowing</td>
</tr>
</tbody>
</table>

Month 0 6 12 18 24 30 36 42 48 54 60 66 72 78 84 90
Summarizing as two 500 MW ThorConIsles are serviced by a CanShip.