Indonesia seeks to supplement its coal power with cheap nuclear power.
Coal power plant costs derive from handling massive amounts of fuel.

1 GW ThorCon: 280 tons fuelsalt every 8 years
<0.1 tonnes/day

1 GW coal plant: 10,000 tons coal every day
ThorCon capital and fuel costs are less than for coal.

500 MWe scale comparison; both use same 550°C steam to power conversion.

<table>
<thead>
<tr>
<th>Economics</th>
<th>Coal generate steam</th>
<th>ThorCon generate steam</th>
<th>Steam to kilowatts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital, $/kW</td>
<td>500-1500</td>
<td>400-500</td>
<td>500</td>
</tr>
<tr>
<td>Fuel, cents/kWh</td>
<td>2.5</td>
<td>0.5</td>
<td></td>
</tr>
</tbody>
</table>
ThorCon designers are experienced in shipyard construction technology.

- Built eight of the world’s largest supertankers
- $600 million program
- Responsible for all specifications, financing, yard negotiations and supervision
- World-class shipyards will fabricate blocks quickly, reliably, at low cost.
- Built on firm, fixed price, fixed schedule project.
ThorCon Molten Salt Reactor (TMSR-500) Technology for Indonesia

Two 500 MW ThorCon liquid fission power plants

October, 2019
ICENES Bali

Lars Jorgensen
CEO ThorCon US
ThorCon prototype will be built in a hull, pretested, towed to Indonesia, settled shoreside, and powered up.
ThorCon is a complete power plant.
Each 557 MWt power module has an Active and a Cooldown Can.
Power conversion occupies most of the plant.
47.7% thermal efficiency @ 20°C

46.4% thermal efficiency @ 30°C
The reactor Pot contains the graphite moderator with channels for molten salt flow.

Freeze valve melt drains salt to drain tank.

Cold wall absorbs heat radiated from drain tank.

Cold wall is cooled by natural water circulation.

Replaceable Can unit in Cold Wall
ORNL designed freeze valves, quadrupled
Cold wall is cooled by natural convection to condenser in Cooling Pond.

Ten times the water per MW compared to AP1000.

Enough water to cool for many months.

Likely air cooling is sufficient after that.
Basement water provides backup passive decay heat cooling.
Primary loop is within Can.

- Can thermal output: 557 MW
- Can electrical output: 258 MW
- Plant efficiency: 46.3%
- NaF-BeF2-ThF4-UF4 fuelsalt
- 76/12/10.2/1.8 mol pct
- Vapor Pressure@704°C: ≤3 Pa
- Fuelsalt flow kg/s: 2934
- Pot inlet C: 565
- Pot outlet C: 704
- Loop transit time: 11.6 sec
- Pot outlet press: 2.9 barg
- Can diameter: 7.775 m
- Can height: 10.250 m
- Pot diameter: 4.916 m
- Pot height: 5.590 m
- Can weight (no salt): 343 tons
- Fuelsalt weight: 43 tons
- Fast $\alpha_K$: pcm/K: -2/-3
- Slow $\alpha_K$: pcm/K: -5/-7
Prototype ThorCon TMSR-500 has 3 Y-shaped neutron-absorbing shutdown rods.

Three ways to stop fission:

1. Increase temperature to reduce reactivity to nil, reaching elevated temperature idle mode.

2. Drop any one of 3 shutdown rods.

3. Drain fuelsalt to drain tank.
Radioactive off-gases cool in Can, decay in hold-up tanks, then delay 2 years in charcoal bed; Xe and Kr bottled; He reused.
Graphite life is 4 years.

Cans are exchanged to CanShip at 4 year intervals.
ThorCon CanShip exchanges Cans and Fuel Casks.
ThorCon is passively safe.

- Safety is intrinsic; heating stops fission.
- Over-temperature or loss of electricity causes a drain. Operators can not stop flow to drain tank.
- Decay heat is removed by silo cold wall continuous passive water convection, even in power blackout.
- Radioactive fuel salt at low, garden-hose pressure and 700C below boiling so no dispersal mechanism.
- Fluoride salt chemically locks up hazardous fission products I-131, Cs-137, Sr-90.
Multiple Barriers to Fission Particle Release

First Barrier is the Can+FDT
- Can 25mm stainless steel
- No pressure
- 350°C, helium or argon gas
- => No stress
- FDT 10mm stainless steel,
  <0.5m diameter
  Short exposure to >700°C
  < 1 barg pressure
  Helium or argon gas

Second barrier (red outline) is the Silo
- 25mm stainless steel
- 140°C
- A few bar pressure
Final Barrier is the Hull

- 25mm Steel
- 3m Concrete
- 25mm Steel
How would ThorCon survive a Fukushima-like failure?

Fukushima power plant

1. Earthquake sensor caused successful SCRAM shutdown.
2. Then, tsunami caused all power and cooling to be lost.
3. Decay heat overheated fuel rod zirconium cladding, generating hydrogen, causing building explosion.
4. Fuel rods melted.
ThorCon Fukushima response:

1. Earthquake sensors
   - initiate fuelsalt drain
   - drop shutdown rods (SCRAM)
   - fission stops

2. Then, all power and primary cooling path lost

3. Reactor in safe state with fuelsalt in passively cooled drain tank.

4. Fuelsalt temperature max 750°C.
Worse, instant station blackout

1. Loss of power
   - initiates fuelsalt drain
   - drops shutdown rods
   - fission stops

2. As freeze valve melts, core cooled by natural circulation.

3. Reactor in safe state with fuelsalt in passively cooled drain tank.

4. Fuelsalt temperature max 850°C.
Worse yet, instant station blackout, shutdown rods stick

1. Loss of power
   - fuelsalt drain initiated
   - fission continues
   - primary cooling path lost

2. Rising temperature shuts fission down from natural feedbacks.

3. As freeze valve melts, core cooled by natural circulation.

4. Reactor in safe state with fuelsalt in passively cooled drain tank.

5. Temperature max 1000°C; 0.5% creep.
ThorCon hull towed through North Atlantic storm seas accepts 1 g forces.

### Draught at Tow Condition

<table>
<thead>
<tr>
<th>Length</th>
<th>Width</th>
<th>Depth</th>
<th>Draught</th>
<th>Hull Weight</th>
<th>Total Equipment Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>174 m</td>
<td>65 m</td>
<td>33 m</td>
<td>13.3 m (Stern)</td>
<td>12.1 m (midship)</td>
<td>11.0 m (Bow)</td>
</tr>
</tbody>
</table>

### Material Properties (Nominal Values)

<table>
<thead>
<tr>
<th>Material</th>
<th>Yield Strength</th>
<th>Elastic Modulus</th>
<th>Poisson’s Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild Steel</td>
<td>235 MPa</td>
<td>205.8 GPa</td>
<td>0.3</td>
</tr>
<tr>
<td>AH36</td>
<td>355 MPa</td>
<td>205.8 GPa</td>
<td>0.3</td>
</tr>
</tbody>
</table>
Scenario: 8 t aircraft engine strikes sand-filled sandwich wall at 200 m/sec.

- Max penetration 200 mm
- Max inner wall deflection 300 mm
- No effect on
  - Silo surrounding
  - Cold wall around
  - Can containing
  - Primary loop containing
  - Radioactive fuelsalt
Horizontal seismic wave shear limited to 0.6 g in sand. Sand to hull slip limits acceleration to 0.3 g. Analysis to continue.
Can is seismically isolated from hull.

- Elastomeric bearings
- Dashpots
Tsunami surge up to 15 meters will not float ThorCon hull. Tsunami waves broken by breakwater.
ThorCon design uses high-quality, low-cost shipyard block construction technology.

A large shipyard can build 20 1-GW ThorCon power plants per year.

High-precision steel-fabrication builds ships for $2000 per ton.
**Indonesia 3.5 GW ThorCon power plant project**

- **$ tranche 1**
  - Design

- **$ tranche 2**
  - Pre-fission construction
  - Pre-fission testing

- **$ tranche 3**
  - ThorConIsle construction
  - Power up
  - Stress tests

- **$ PPA guaranteed loans**

**Month**: 0 6 12 18 24 30 36 42 48 54 60 66 72 78 84 90

**Milestones**
- Bids in hand
- Pre-fission tests complete
- Power plant delivered to site
- Power to grid
- Type license approval
- 27.6 billion kWh/year
Next step: pre-fission test plant
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Technology for Indonesia

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Thank you.
Questions?