Concrete Thermal Energy Storage and Pumped Heat Variant

Bright Energy Storage Technologies

July, 2019

Thermal Energy Storage (TES)-Enabled New Options for Nuclear Power

- Reduce or delay reactor rebuild costs by running the existing steam turbines /generators with half of the existing reactors
- New, dispatchable capacity without building new reactors or same peak capacity with fewer reactors, with high flexibility
- Make non-GHG emitting nuclear plants a vital part of renewable power integration
- Enable the next generation of flexible nuclear energy to provide zero carbon firming of renewable assets

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Bright's TES Technology

- Patented high performance concrete and steel tube systems
- Designed to operate at up to 600^0 C
- Low cost, modular, factory built, stacked and configured on site
- Configurable for every thermal generation design
- Two TES designs
  - Thermally charged with steam
  - Thermally charged with CT exhaust / heated air

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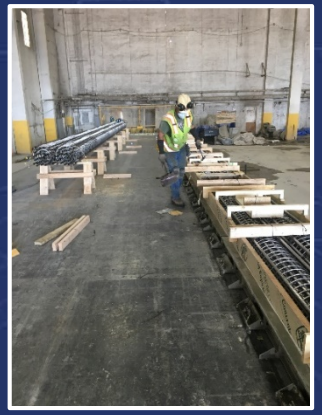
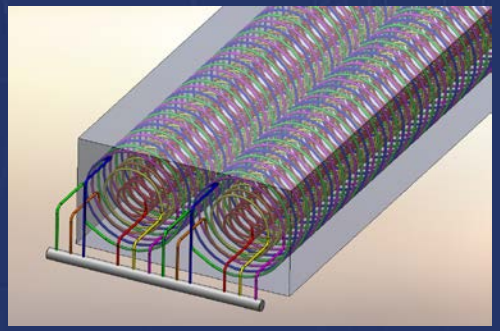
TES Module Details



Gas Charged TES block

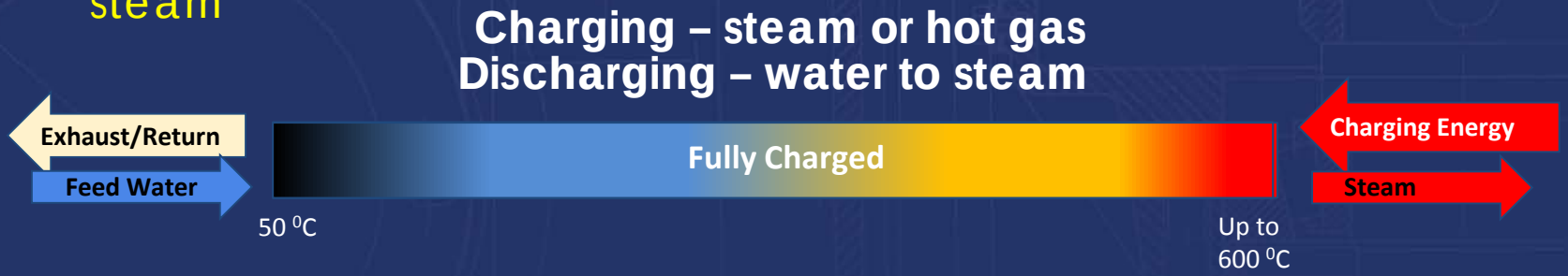


Steam Charged TES block

TES Block Placement

TES Charge and Discharge

- Boiler steam or hot gas, depending on application, flows in one direction through the TES, heating the concrete
- Charging process creates a thermocline, highest temperature at charging inlet
- Water pumped in opposite direction to discharge, resultant steam exits TES at ~hot end temperature, delivering consistent high quality steam



Industry and DOE Funded Bright TES Test Program

- **Electric Power Research Institute (EPRI)**
  - Currently funding Bright study of TES materials and assembly adequacy to application
  - Industry funders are Southern Company, Tri-State, and Salt River Project
- **$5 million DOE FOA Award June, 2019**
  - Awarded to Bright Energy, EPRI, Southern Company team
  - Grant to build and test 10 MWh_e Pilot at working generation plant
- **Bright seeking an additional pilot/test opportunity**
  - Nuclear, perhaps at INL?
  - Geothermal in CA, perhaps with California Energy Commission funding
  - Other TBD

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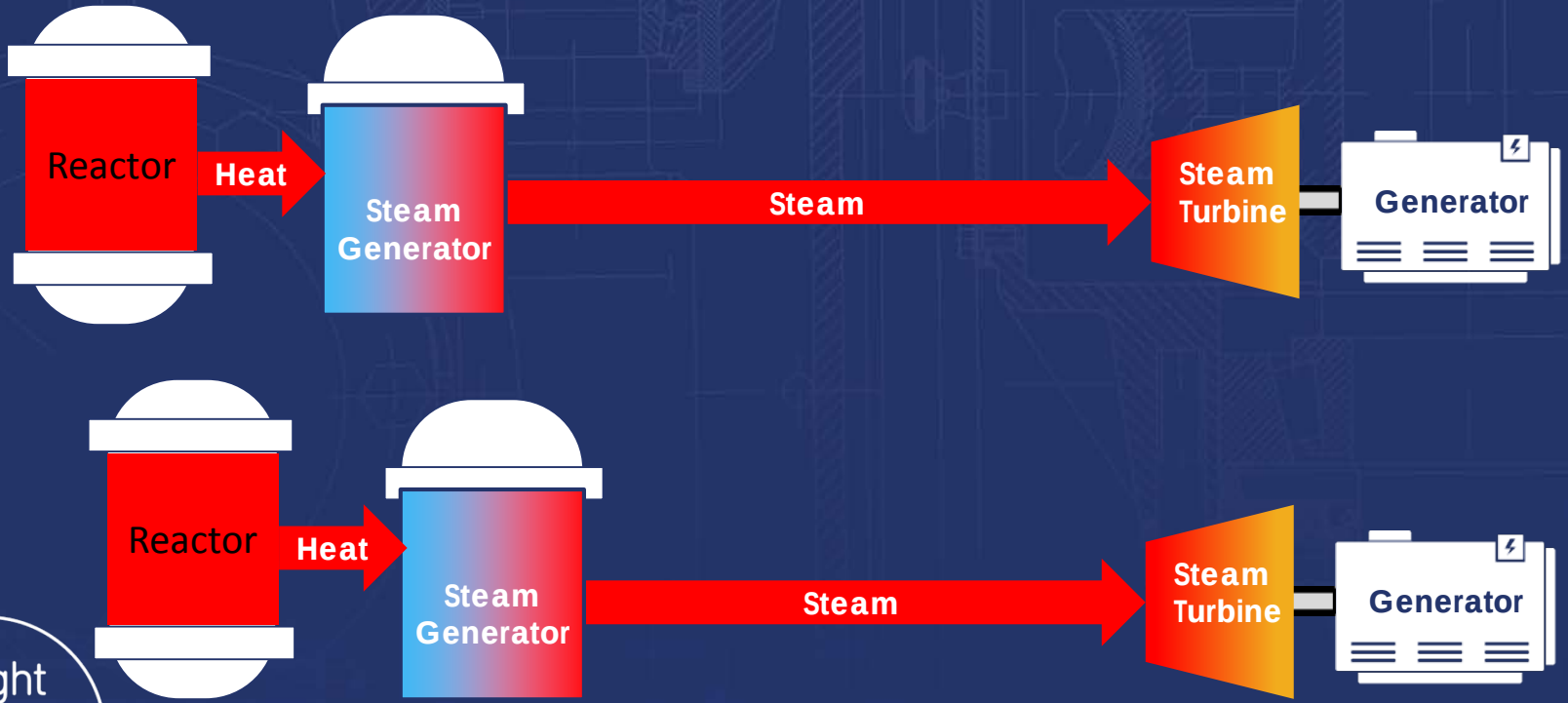
FlexNuke - Same Peak Output with Fewer Reactors

Existing Nuclear steam plant



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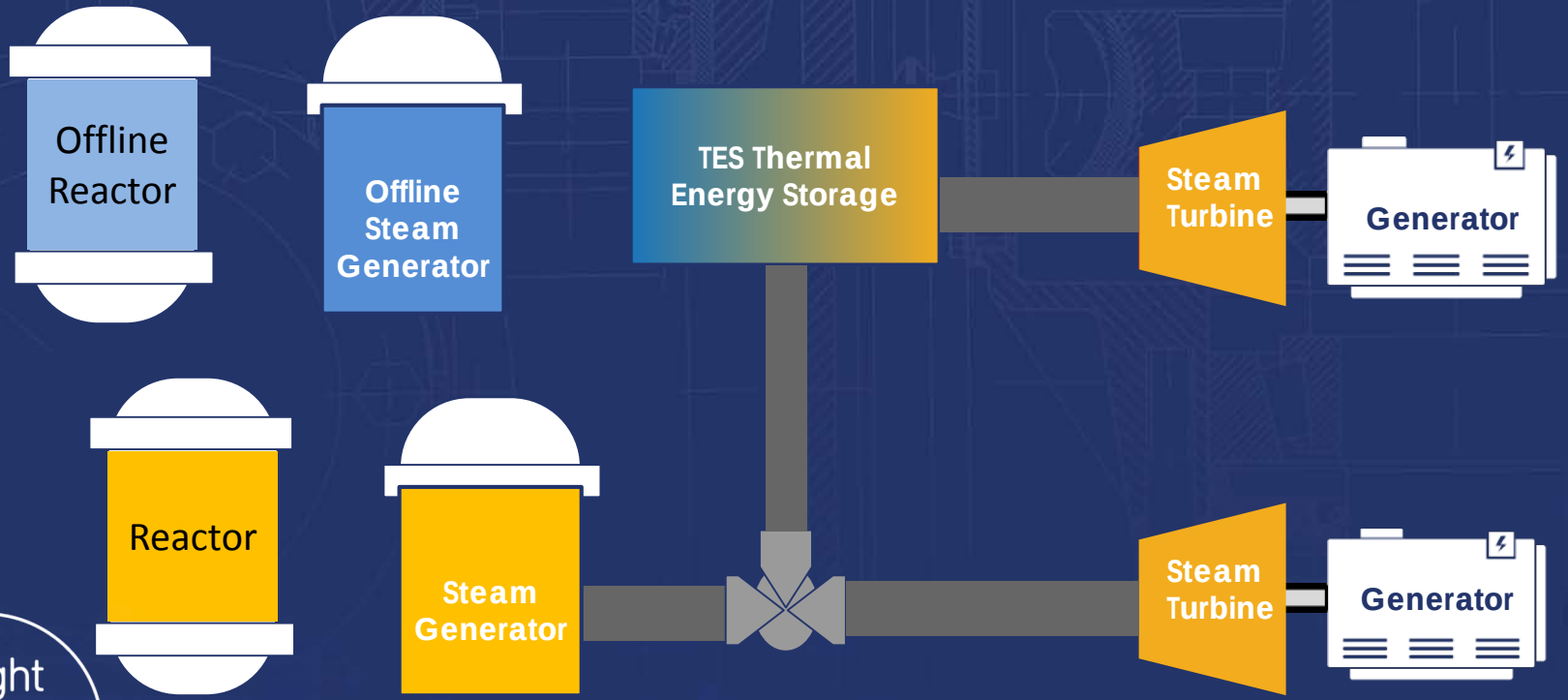
FlexNuke – Same Peak Output with Fewer Reactors

Add TES, diverter valve and take one reactor offline



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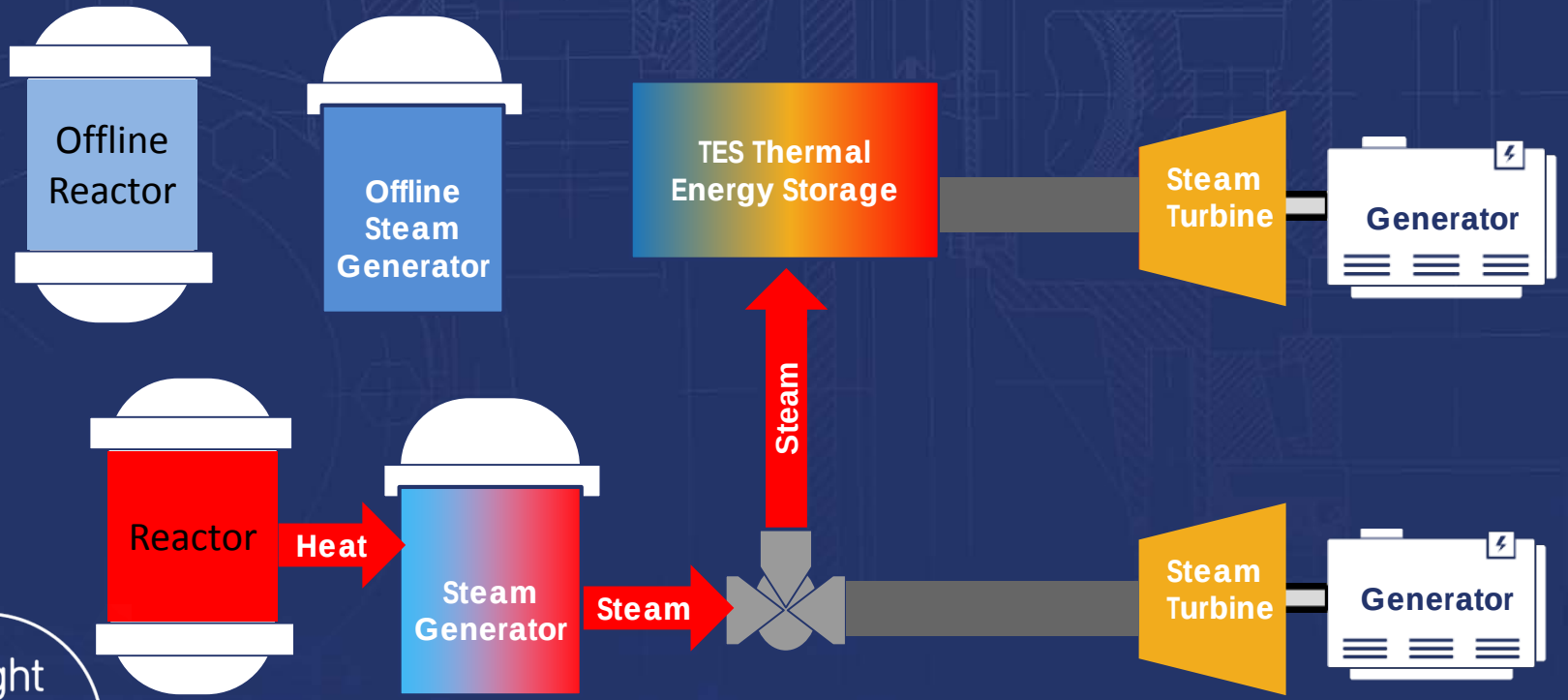
FlexNuke – Same Peak Output with Fewer Reactors

Charge TES with zero electricity output



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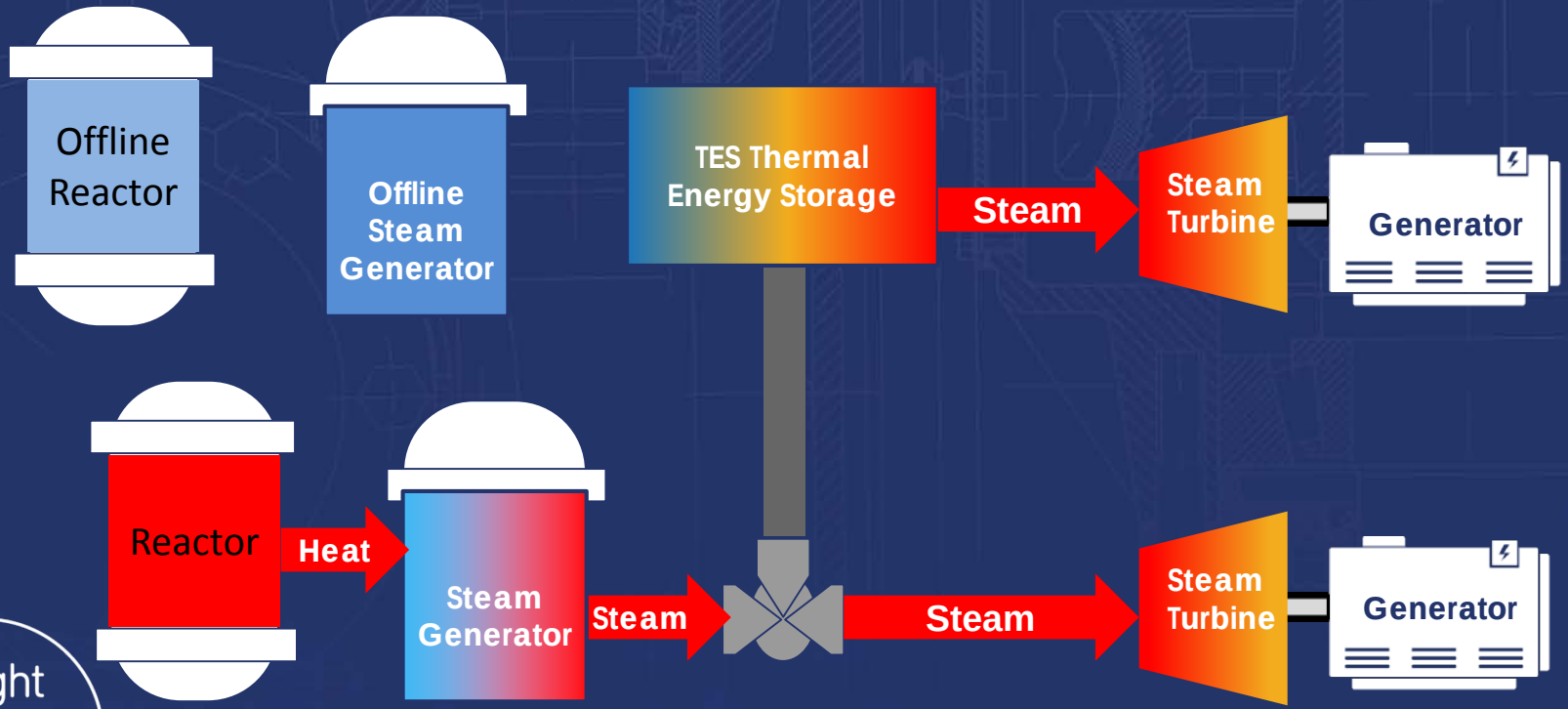
FlexNuke - Same Peak Output with Fewer Reactors

Discharge at nearly original power of two reactors



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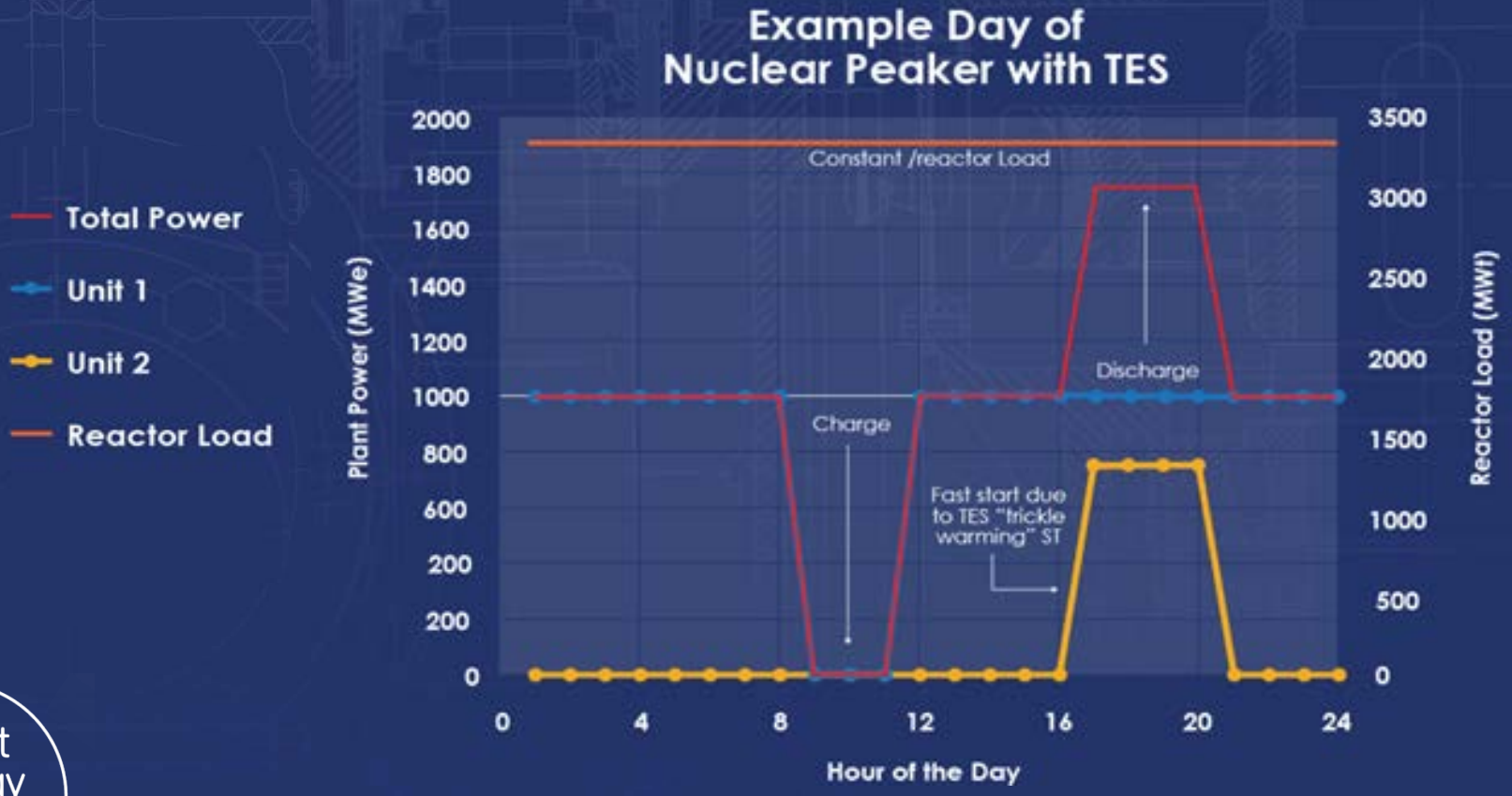
FlexNuke - Convert Baseload to Load Following Peaker



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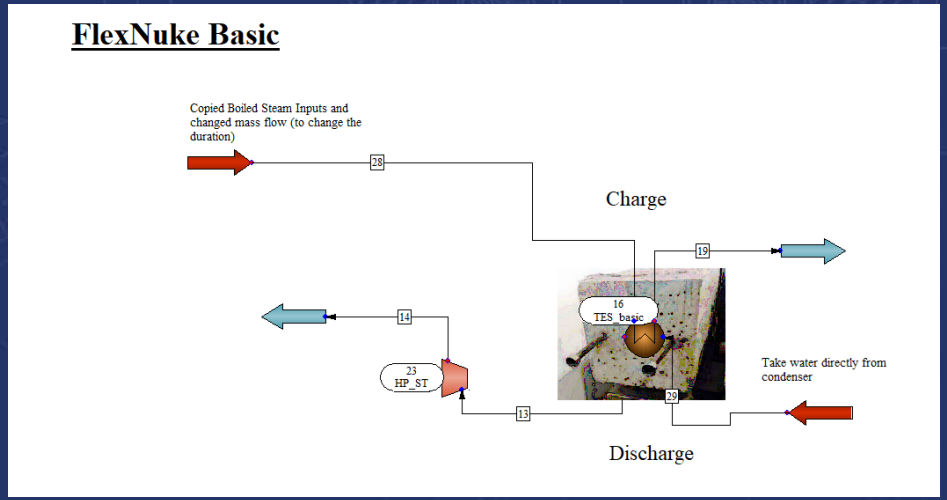
Baseline TES Configuration, $278/kW and $62/kWh



- $278/kW + $62/kWh Total Project Cost
- 71% estimated RTE
- 4 hour discharge
- 2.9 hour charge
  - We can vary this ratio of charge/discharge to just about whatever we want by varying the ST we purchase for discharge.
- 62 bar charge pressure
- 20 bar discharge pressure
- Assumed $200/kW ST designed for 20 bar discharge

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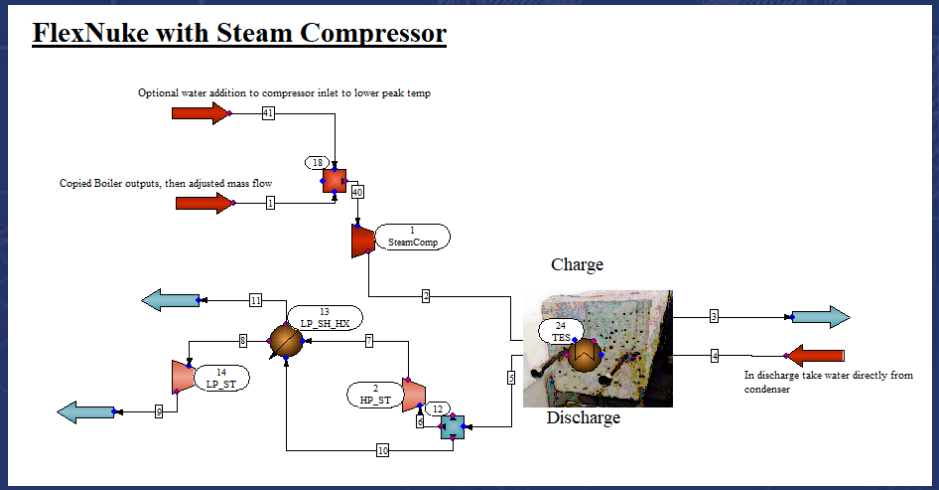
Pumped Steam Variant - $375/kW + $62/kWh



- $375/kW + $62/kWh Total Project Cost
- 58% estimated RTE
- 4 hour discharge
- 5.3 hour charge
  - We could change the charge/discharge time/power ratio be changing the discharge ST we buy. Going with a higher power ST will require more charge time, but will lower the cost of the compressor in terms of $/kW
- 155 bar charge pressure
- 62 bar discharge pressure
- Assumed $200/kW ST designed for 62 bar discharge

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TES Performance

- **Thermal energy losses**
  - Less than 1% energy loss per day
  - Estimated heat-to-heat efficiency >92%, fuel to electric efficiency depends on steam turbine
- **Ramping and Steam Quality**
  - TES can ramp steam output in less than minute - “hot end” of TES blocks always delivers high quality steam after feedwater fed into cold end
  - “Discharged” defined by when hot end of TES no longer at adequate temperature to deliver requisite steam quality
- **Maintenance - ruptured steam tube embedded in concrete**
  - ID tube(s) during routine maintenance, cut, crimp/weld and abandon in place
  - 75,000 steam tubes, loss of a small number has marginal impact on system performance

Bright Energy Background

- **Angel-backed startup based in Arvada, CO, founded in 2010, 15 employees**
- **Several themes common in development concepts**
  - Low capital costs per kW/kWh, high efficiency, low cost heat exchangers and heat storage media, re-use of existing capital equipment
  - Must be competitive against operating costs of incumbent generation equipment, not just better than competing storage systems
- **Sustainable advantages**
  - Lowest cost solutions with 25+ year lifetime
  - Proprietary technology
  - Strategic relationships with the industry, EPCs and Concrete Fabricators

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