Separating Nuclear Heat Island from Balance of Plant

Hasan Charkas, Ph.D.
Principal Technical Leader, Advanced Nuclear Technology
hcharkas@epri.com

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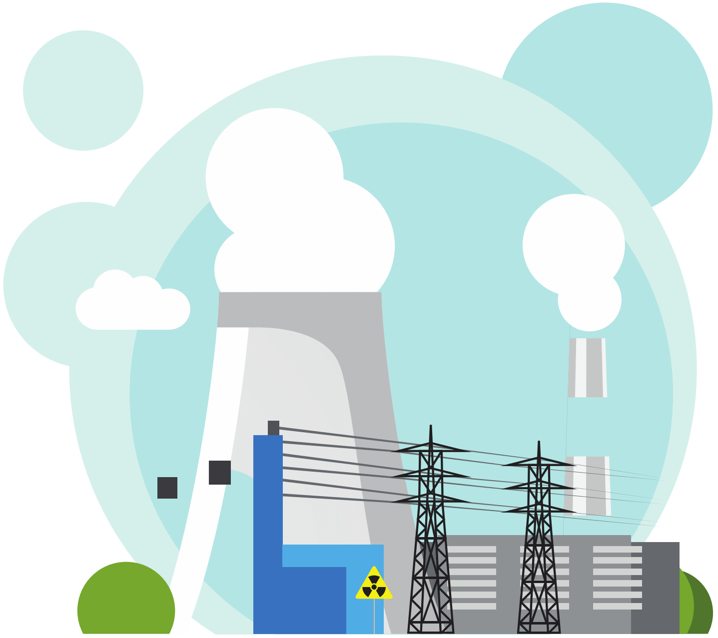
MOTIVATIONS

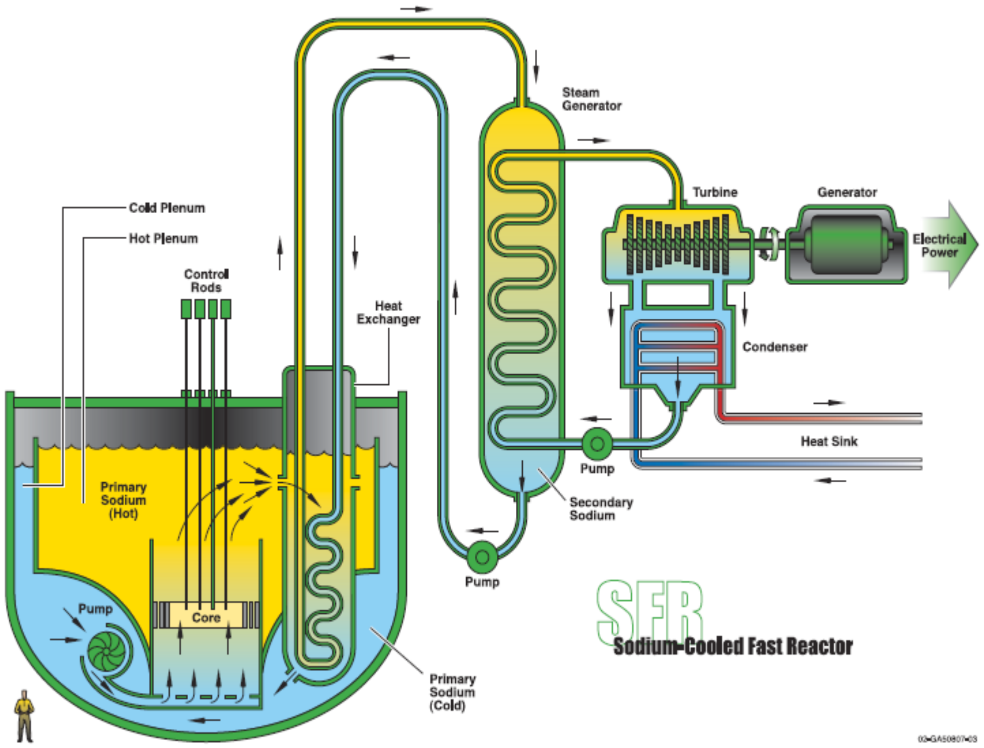
- Next-generation nuclear reactors, are currently under development, and are expected to be implemented on a broad scale over the next several decades.



- The high capital costs for nuclear plants result from regulatory requirements, quality assurance measures, safety systems, unique fuel, and waste handling systems that are not required in other plant types.

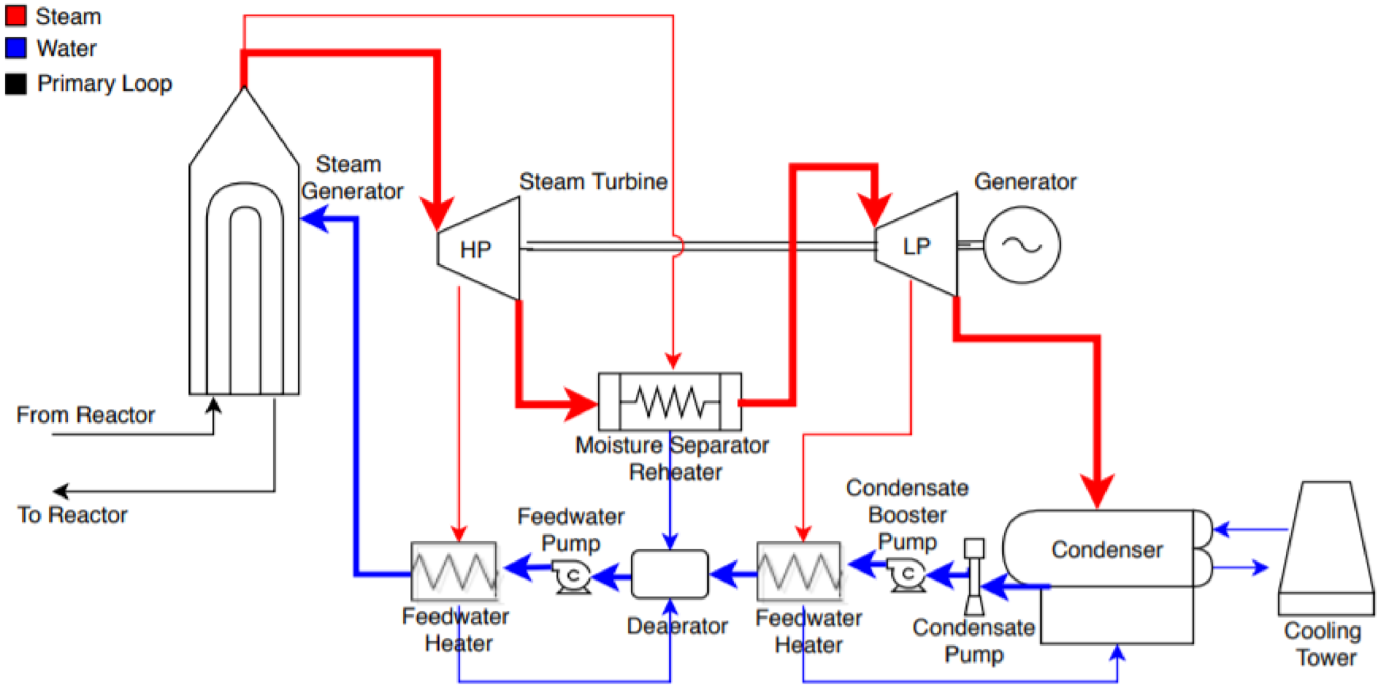
SCOPE

- Review of typical steam cycle designs for existing nuclear power plants and Combined Cycle Gas Turbine (CCGT) and Concentrated Solar Panel (CSP) power plants
- Comparison of the capital costs associated with the power cycle of each generating technology
- Collect insights on design and construction parameters that affect new power plant costs
- Identify approaches to reduce costs in the steam cycle for the next generation of plants



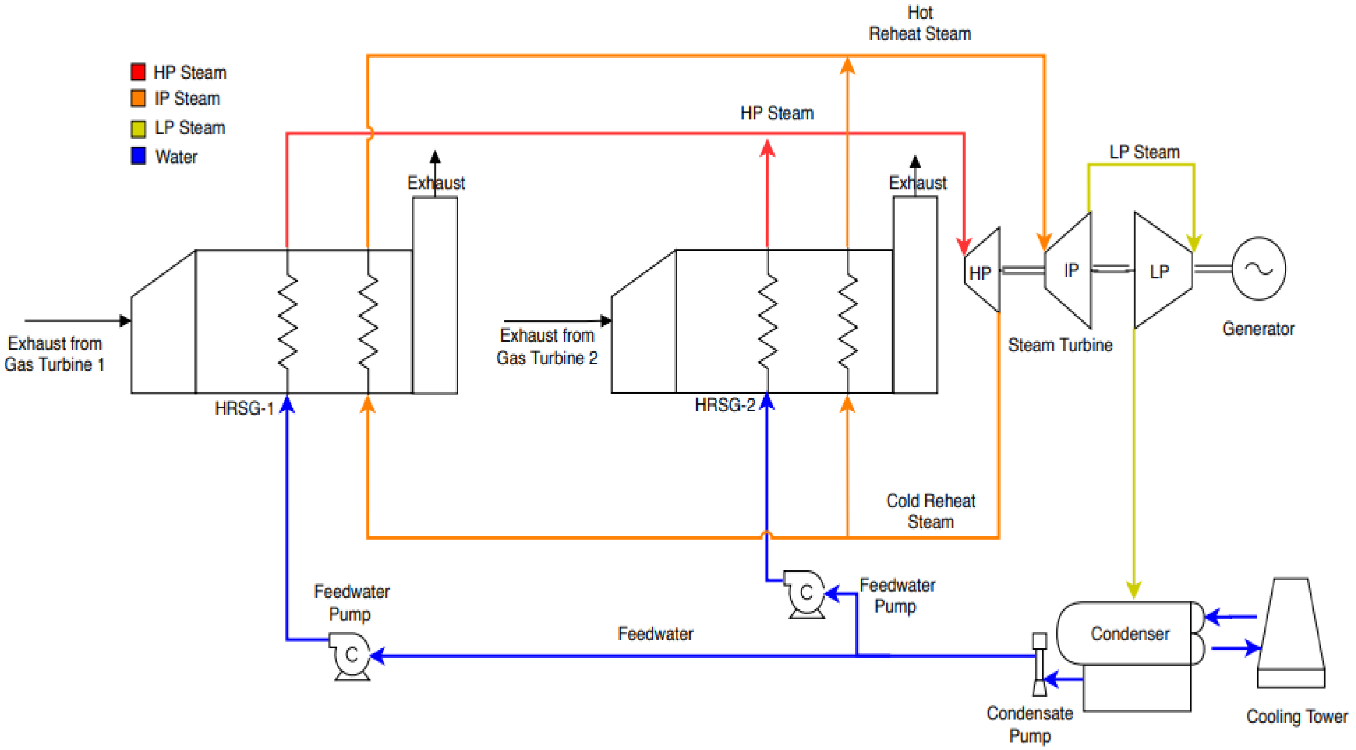
Typical Light Water PWRs

- Reactor Primary System produces saturated steam in Steam Generators
- Large steam turbines specific to nuclear industry
- Large Moisture Separator Reheaters to increase steam quality to LP Turbine
- Feedwater heaters using extraction steam



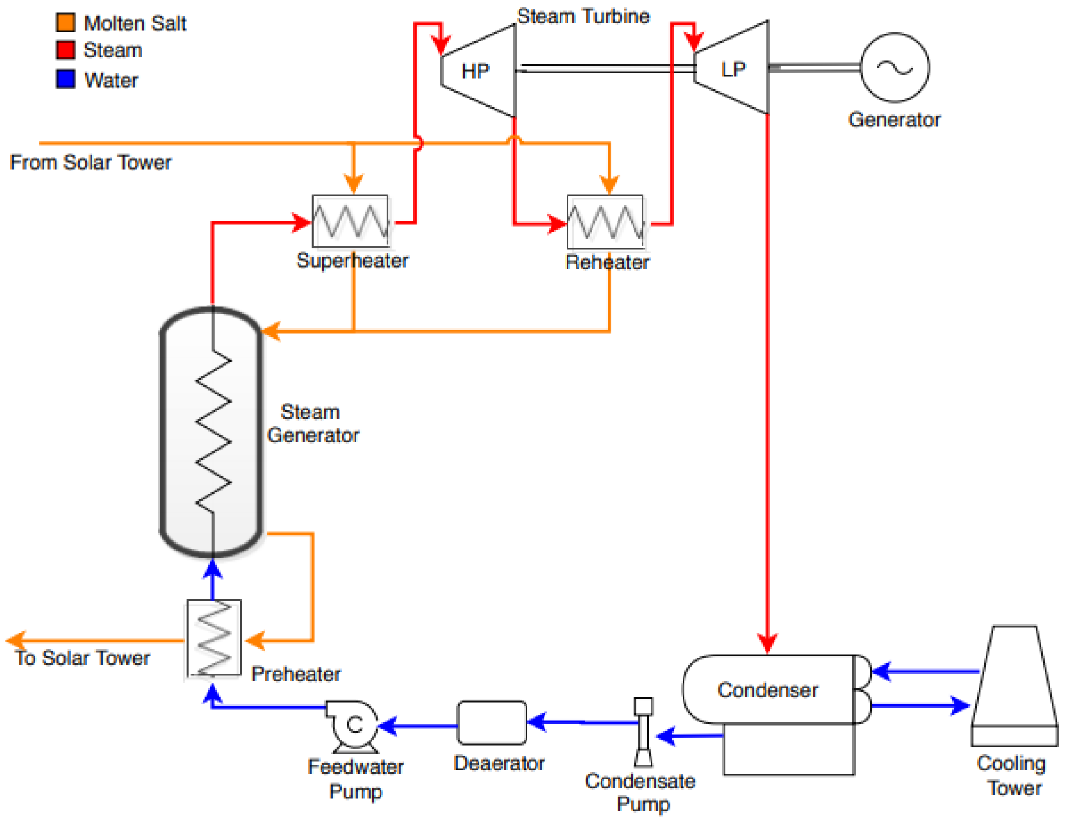
Typical CCGT

- Gas turbine exhaust produces superheated steam in heat recovery steam generators (HRSG)
- Relatively compact turbine, “off-the-shelf”
- Reheat occurs in HRSG
- Feedwater heating occurs in HRSG
- CCGT compared to current nuclear:
  - Smaller, more commercial turbines
  - No moisture separator reheaters
  - No feedwater heaters / drains system



Typical CSP

- Heat transfer fluid (e.g., molten salt) produces superheated steam in steam generating heat exchangers
  - Preheater
  - evaporator
  - Superheater/Reheater
- Compact turbine, “off-the-shelf”
- Reheat in steam generator reheater stage
- Feedwater heating in steam generator preheater stage
- CSP compared to current nuclear:
  - Smaller, more commercial turbines
  - No moisture separator reheaters
  - No feedwater heaters / drains system



Comparison of Generating Technologies

Plant Type	PWRs	CCGT	CSP
Steam Generator Primary Inlet Temperature (°F)	625	1100	1022-1202
Steam Generator Primary Outlet Temperature (°F)	553	200	550
Main Steam Conditions	Saturated Steam 532 °F / 900 psia	Superheated Steam 1050 °F / 2400 psia	Superheated Steam 1004 °F / 2321 psia
Steam Turbine-Generator	~1150 MWe Specific to nuclear	~350 MWe Standard Designs, Compact	~130 MWe Standard Designs, Compact
Feedwater Heating	Five to eight stages heated by turbine extraction steam	Within HRSG	Within one stage of steam generating heat exchangers
Reheat	Moisture Separator Reheaters	Within HRSG	Within one stage of steam generating heat exchangers

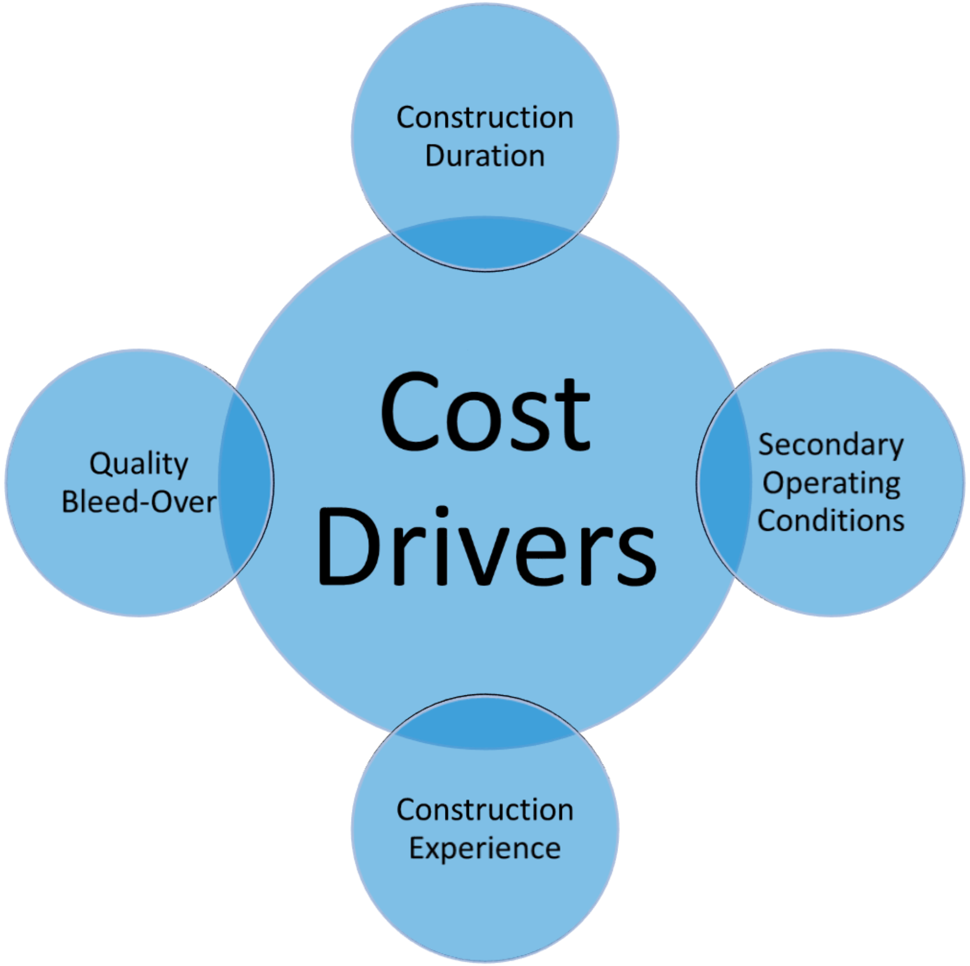
Key Cost Drivers Impacting Nuclear Steam Cycles

- **Construction Duration**
  - Avg construction time for nuclear power plant more than 7.25 years
  - CSP construction time is 3 years and CCGT takes about 2 years

- **Quality bleed-over**
  - Nuclear plants (Higher Quality on Steam Cycle components)
  - Proximity to safety related SSCs also lead to higher quality
  - Storage of materials for safety related structures adds the cost
  - Security and access protocols

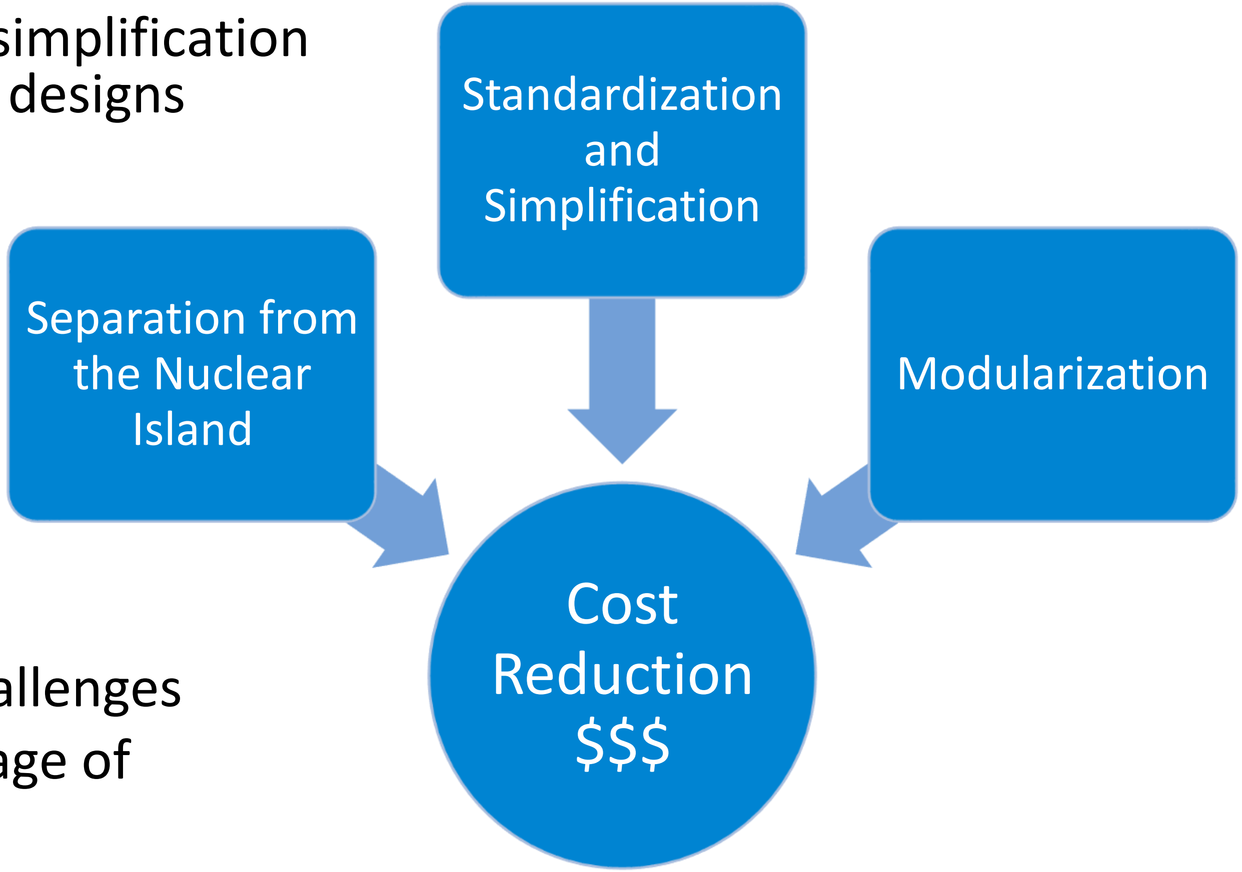
- **Secondary Operating conditions**
  - CSP and CCGT plants have significantly higher primary side temperatures
  - Superheated steam results in lower feedwater and steam flow rates

- **Construction experience**
  - Lack of recent nuclear construction experience will significantly increase costs of new nuclear construction
  - CCGT and CSP are much simpler to build



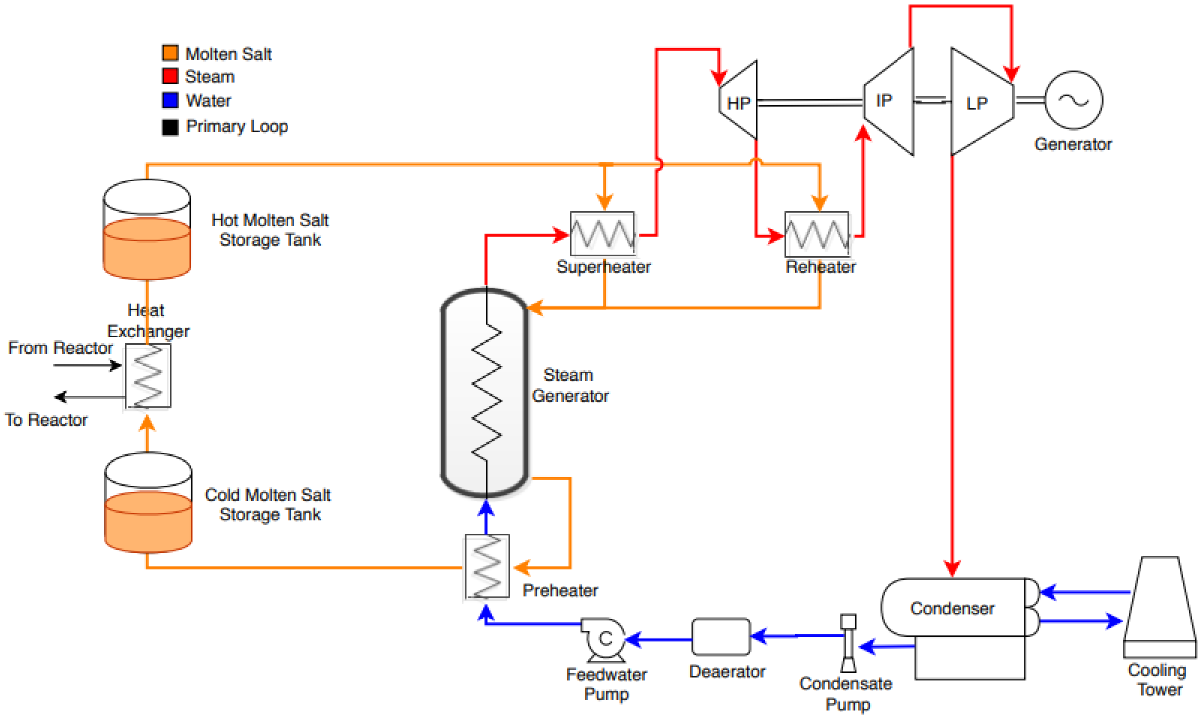
Cost Reduction Strategies

- Standardization and Simplification
  - BOP designs should stay relatively constant across reactors
  - CCGT an CSP designs offer a degree of cycle simplification over currently-deployed nuclear steam cycle designs
- Separation from the Nuclear Island
  - Intermediate loop
  - Lowered construction costs
  - Lowered licensing and regulatory risks
- Modularization
  - Importance of addressing modularization challenges
  - Simplified BOP design offers increased leverage of modularization



Proposed Standardized Power Cycle Design

- A steam cycle design based on that for CCGT and CSP plants appears to be implementable for future plants
- Intermediate loop
  - Allows standardization of design between GenIV types
  - Provides more physical separation of the steam cycle SSCs from safety-related SSCs
  - Permits easier integration of renewables and multiple thermal energy customers
- Primary side thermal conditions allow plants to produce superheated steam and reheat steam to boost the steam cycle efficiency and simplify steam cycle design.



Conclusions

- Primary side operating conditions for GenIV reactors closely aligned with those present in CCGT and CSP permitting the use of superheated steam in the turbine-generator

- Standardization and physical separation of steam cycle from the nuclear island have been identified as impactful cost reduction strategies

- Construction timelines should be evaluated to see when the BOP construction activities can be performed to ensure reasonable separation and optimal duration