Optimization for the Nuclear Heat Storage and Recovery Rankine Cycle

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Overall objective

The Goals

- To **maximize round-trip efficiency** of Nuclear Heat Storage and Recovery (NHS&R) system integrated with APR1400
- To **minimize impact** of the NHS&R system on plant configuration
- To **simplify the NHS&R system design**

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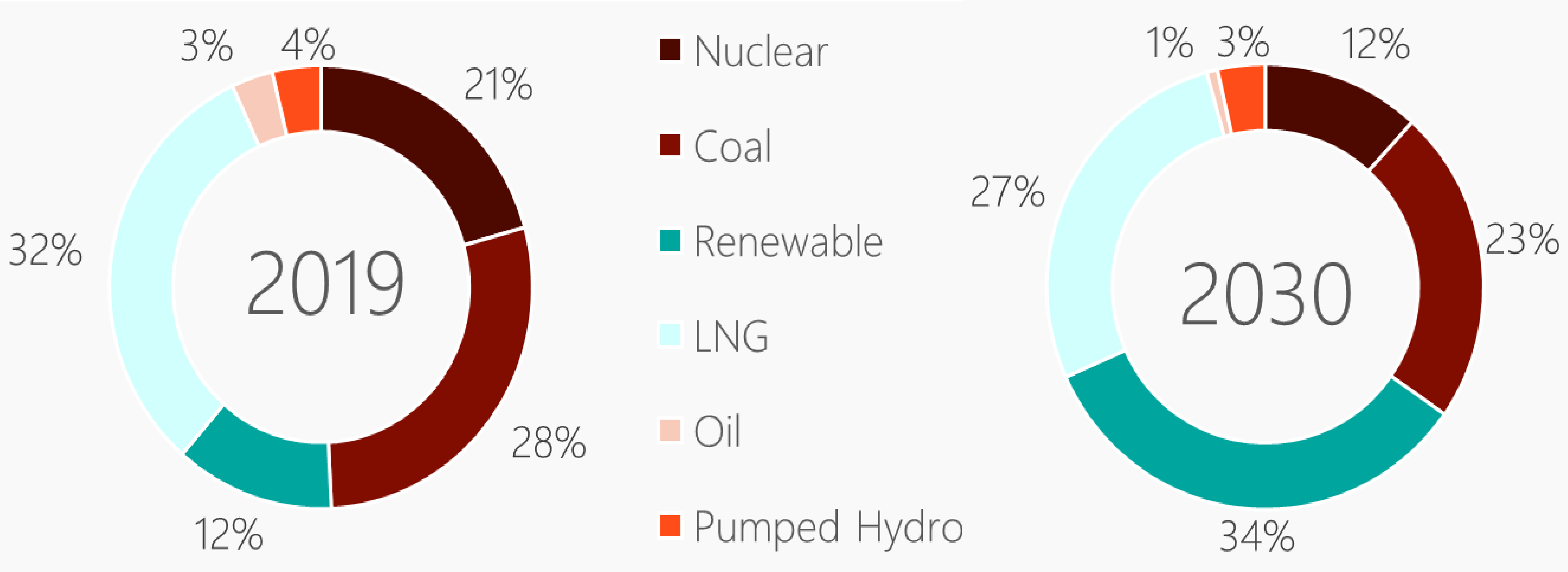
Motivation for nuclear heat storage development

- **Korean Government Energy Policy – "The 8th Basic Plan for Long-term Electricity Supply and Demand (2017 - 2031)"**

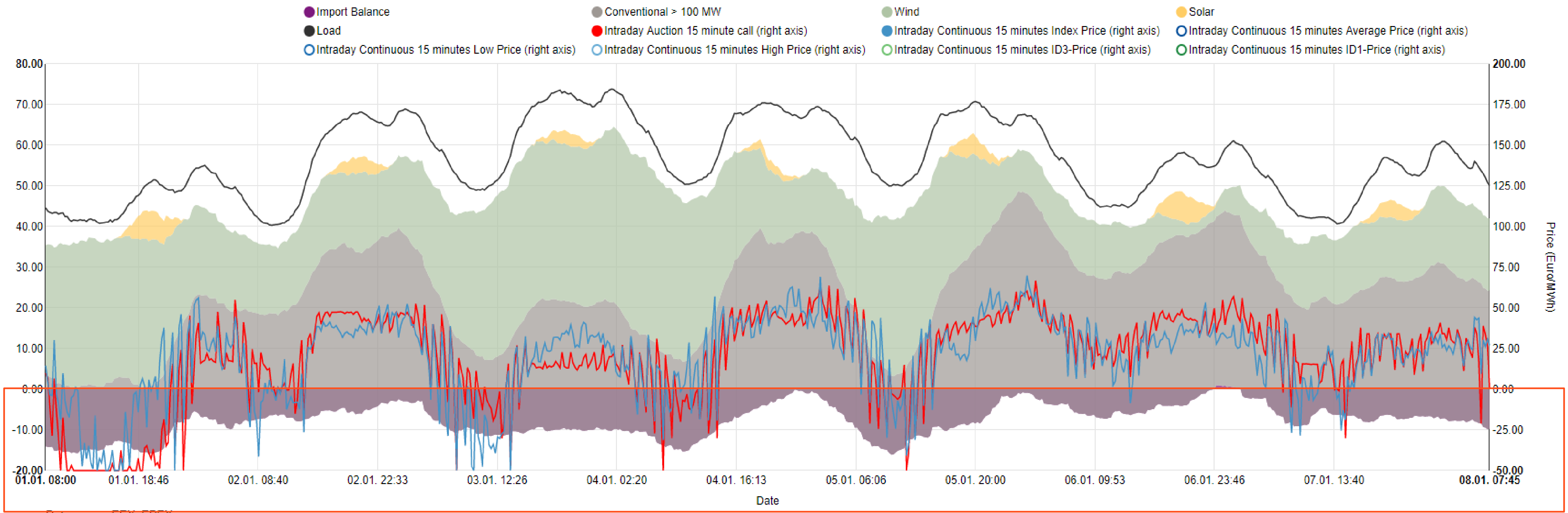
Electricity Generation Mix – Nominal Capacity [1]



Changes of Energy Market

- New energy market paradigms

Electricity production and spot prices in Germany in week 1 2018 [2]



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Variable Power Generation in NPPs

Primary System Cycling

- Load following operation of Nuclear Power Plants results in:
  - technical issues,
  - large equipment aging acceleration,
  - increased operational risk,
  - reduced plant production [3].

Secondary System Cycling

- Nuclear Heat Storage and Recovery enables plant to operate at full reactor power with variable plant power output
- The advantages of heat storage technology:
  - large scale storage,
  - cost competitive.

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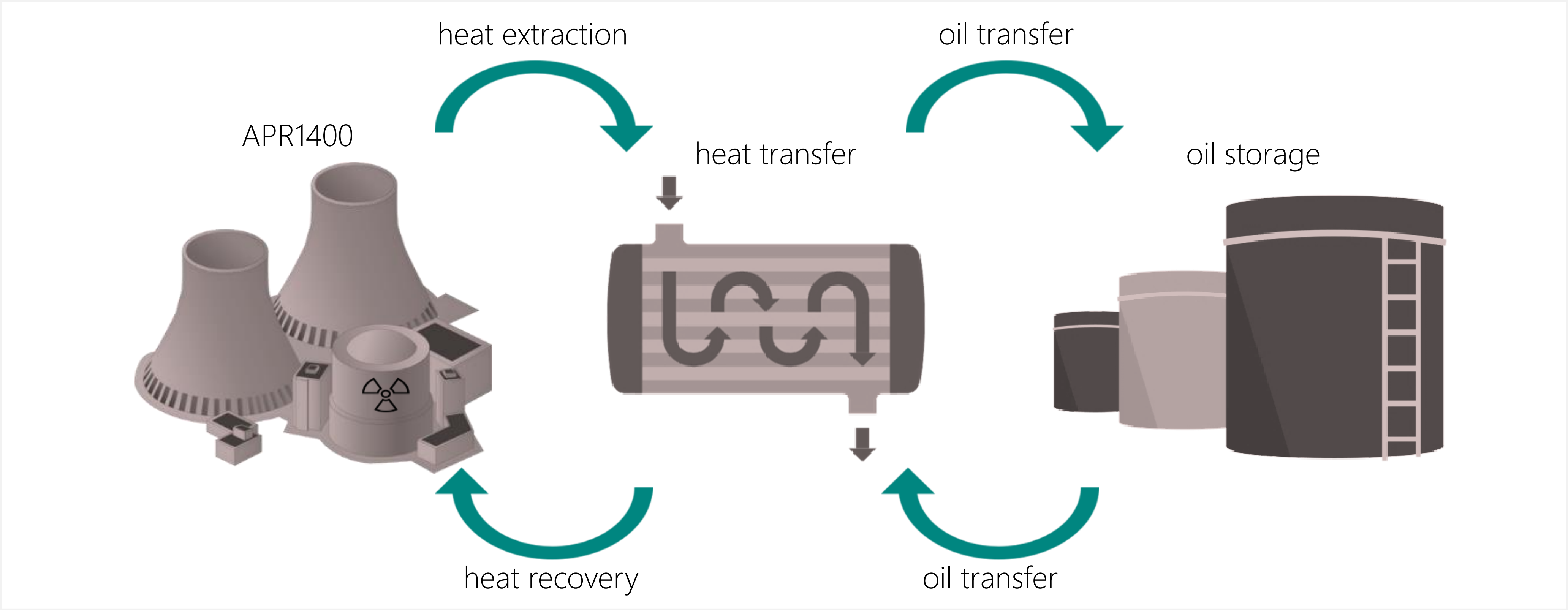
Concept of APR1400 NHS&R



- <u>Storage mode</u>: **heat extraction** from secondary cycle , **heat transfer** to tertiary cycle and hot **oil transfer** to storage facility
- <u>Recovery mode</u>: **heat return** to secondary system by **transferring** stored heat energy to secondary cycle media (feedwater)

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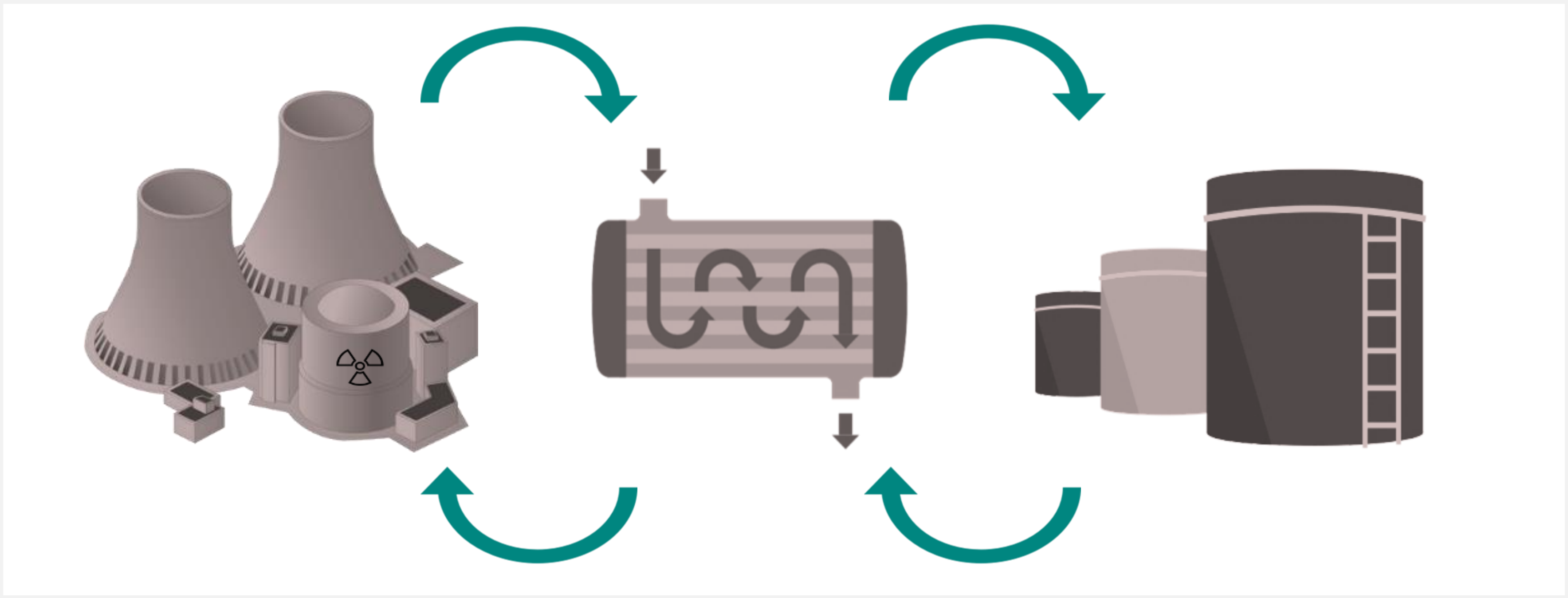
Optimization Considerations



I. Heat Storage Capacity
II. Steam Extraction Location
III. Steam-Oil Heat Transfer
IV. Condensate Return Location
V. Recovery System Configuration

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I. Optimization – Heat Storage Capacity

- Constrains on the heat storage capacity

Minimum impact on NSSS operation – eliminated safety related considerations

Minimum impact on secondary cycle hardware modification – simple system design

Maximum storage capacity – economic benefit due to scale effect

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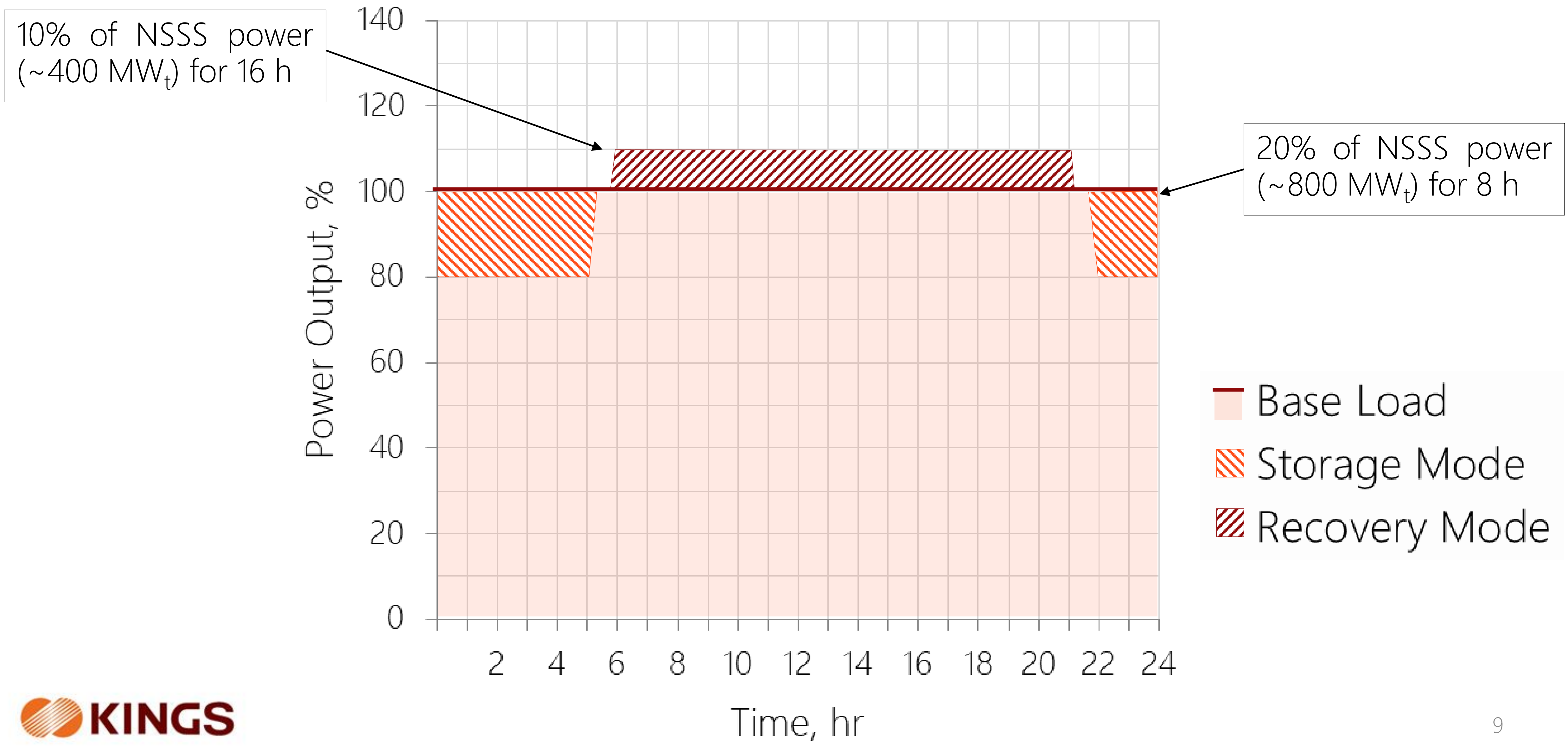
I. Optimization – Heat Storage Capacity



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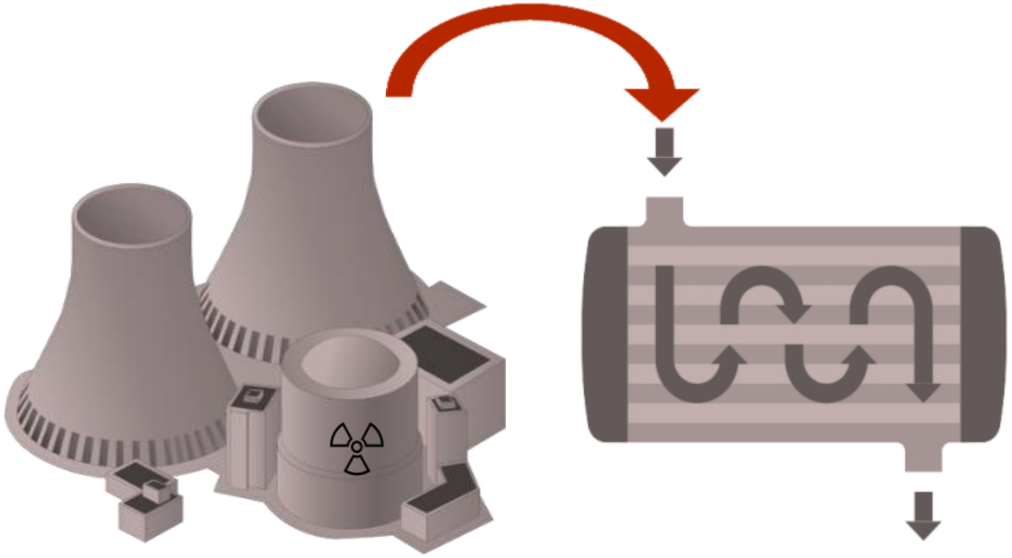
II. Optimization – Steam Extraction

- Constrains on steam extraction selection

Maximized system thermal efficiency – high energy potential maximizes Carnot considerations

Physical aspects – high energy steam require minimized line size

Main Steam Export to Storage System



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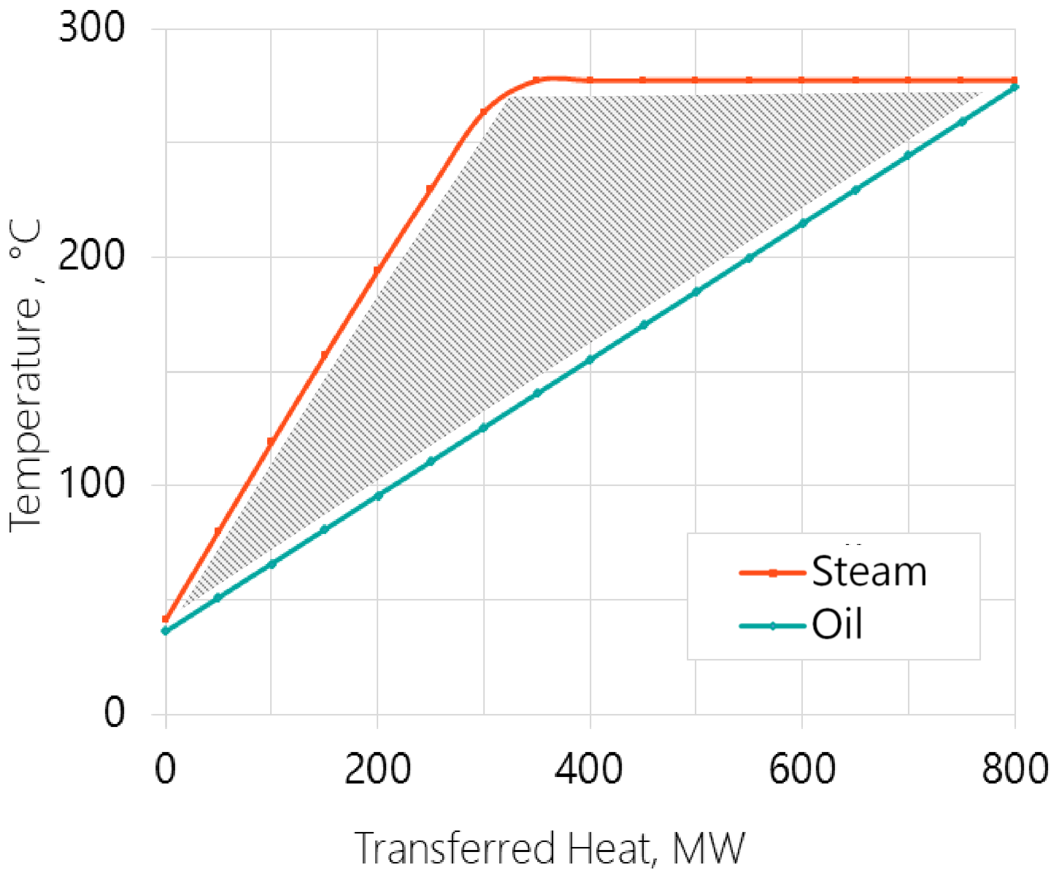
III. Optimization – Steam-Oil Heat Transfer

- Constrains on heat transfer

Oil mass flow rate – determines oil pipe size, tanks size and required pumping power

Differential temperature – determines heat losses due to process irreversibility

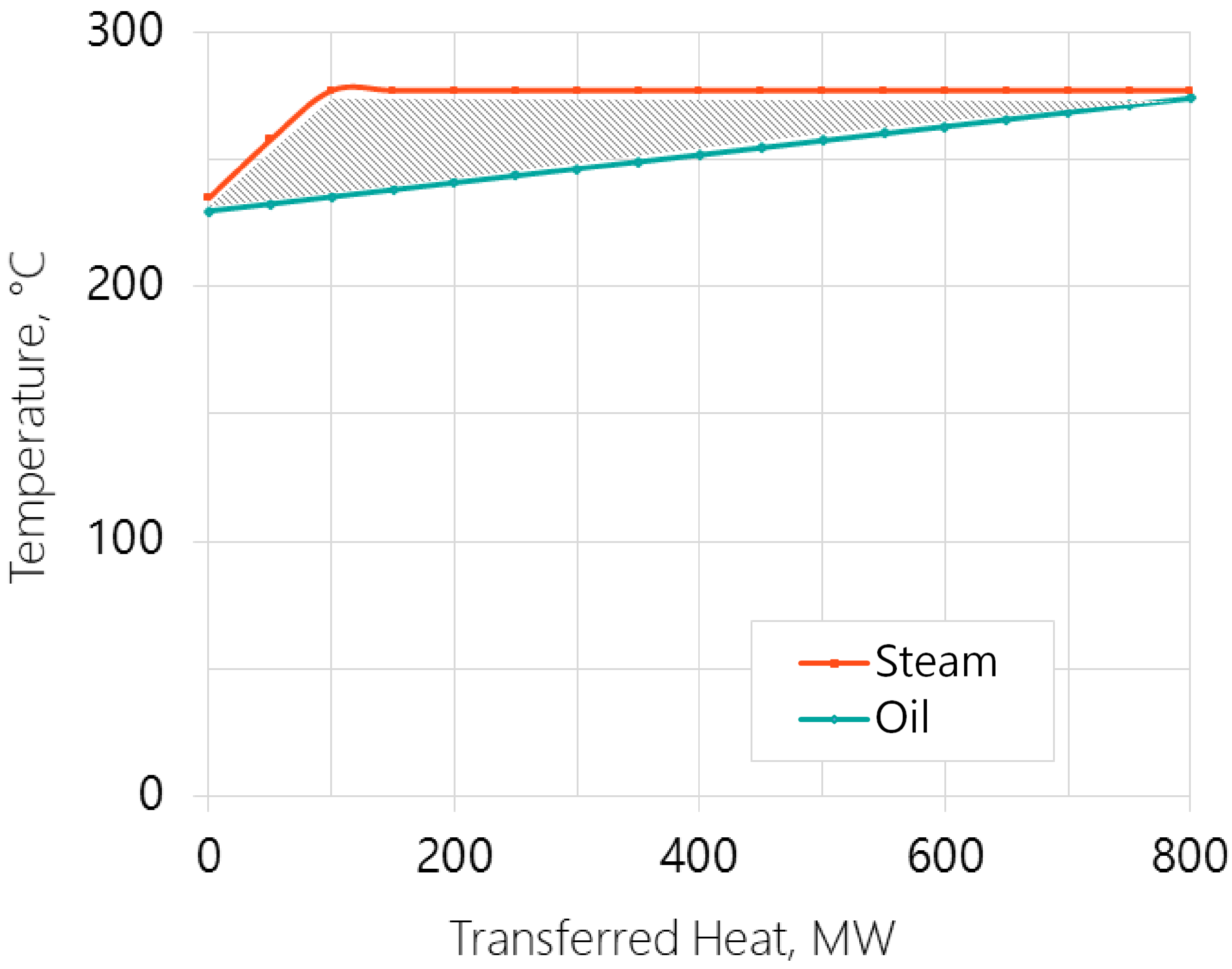


III. Optimization – Steam-Oil Heat Transfer

- Proposed solution

Minimized ΔT

- The **benefit of reduced irreversibility** is higher than the penalty of higher pumping power for the increased oil mass flow rate
- The temperature range depends on the **selected condensate return point**

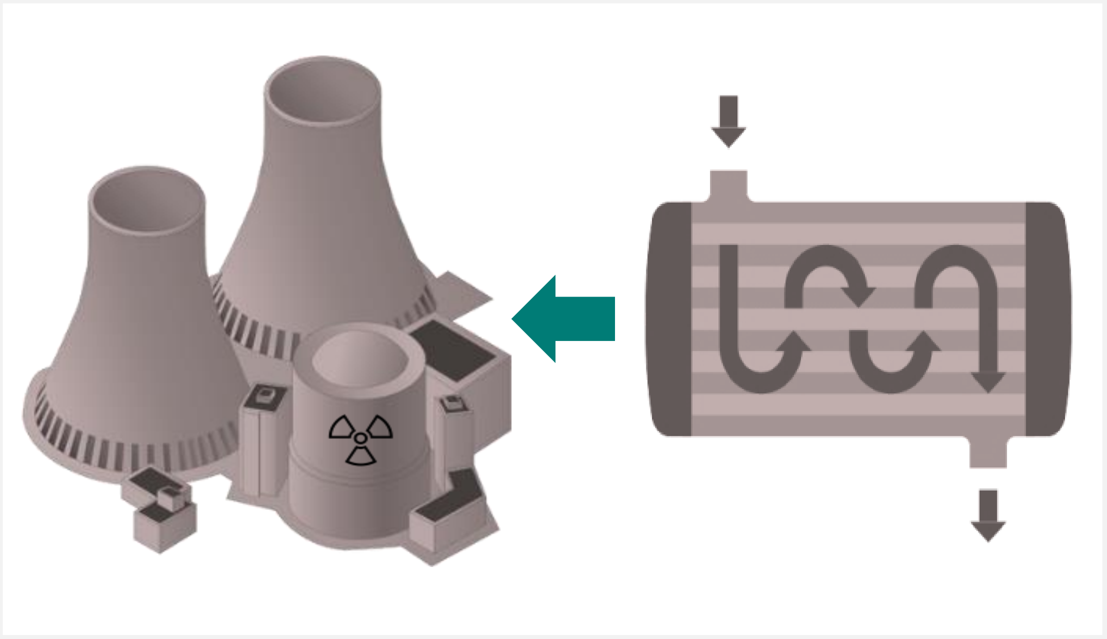


IV. Optimization – Condensate Return

- Constrains on condensate return point location

Return point parameters close to the condensate parameters – improved heat balance of the system

Minimum impact on secondary cycle hardware modification – simple system design



Return location

- **High pressure** of the condensate and its relatively **high temperature** determines return point in a cycle
- Preferable locations are either **deaerator** or **downstream of FWBPs** (Feedwater Booster Pump)

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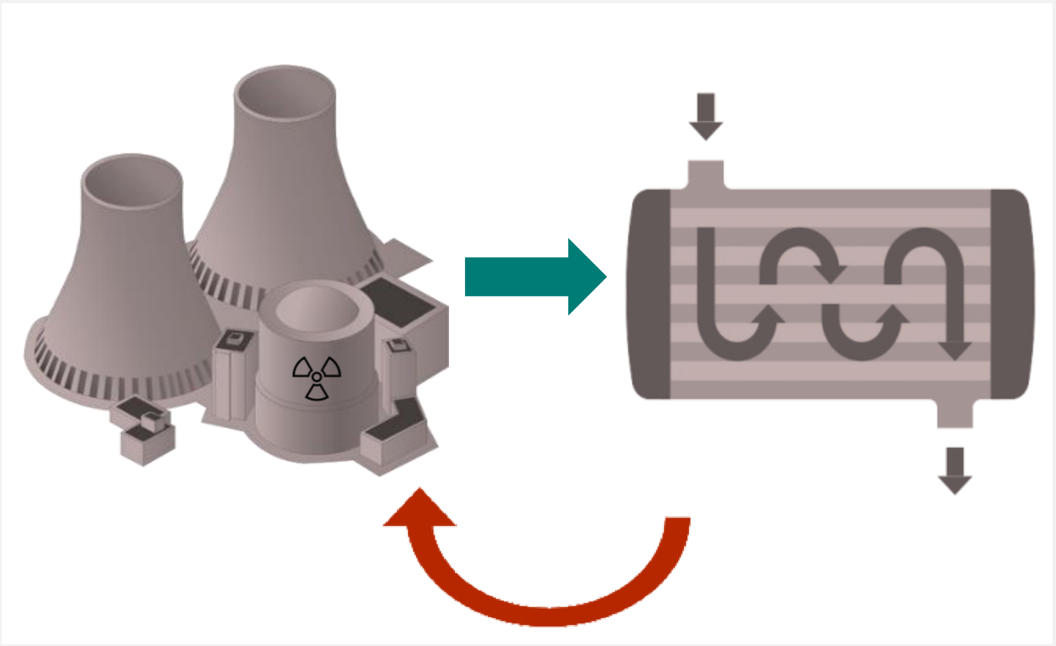
V. Optimization – Recovery system

- Constrains on recovery system configuration

Extracted water pressure – the pressure shall be sufficient to overcome return location backpressure

Reduced irreversibility of heat transfer – multistage approach improves efficiency of the system

Minimum impact on secondary cycle hardware modification – simple system design



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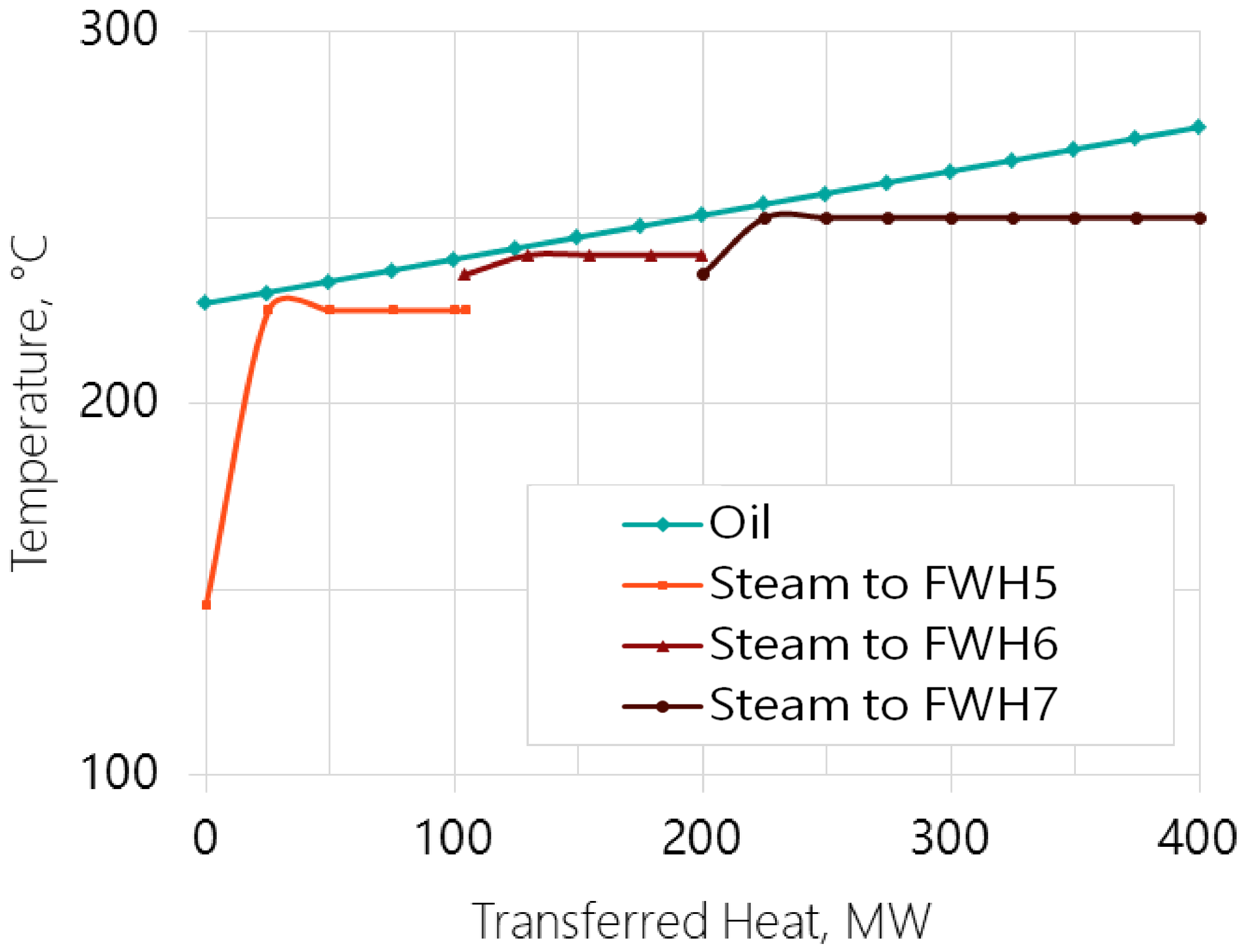
V. Optimization – Recovery system

Recovery System Configuration

- **Feedwater extraction** locations: downstream of **FWBP**, downstream of **MFWP** (Main Feedwater Pump) and/or downstream of **FWH No. 7** (Feedwater Heater No. 7)
- **Steam return** locations: **FWHs No. 5, 6 and 7** and/or cross-around steam line (**hot reheat)**



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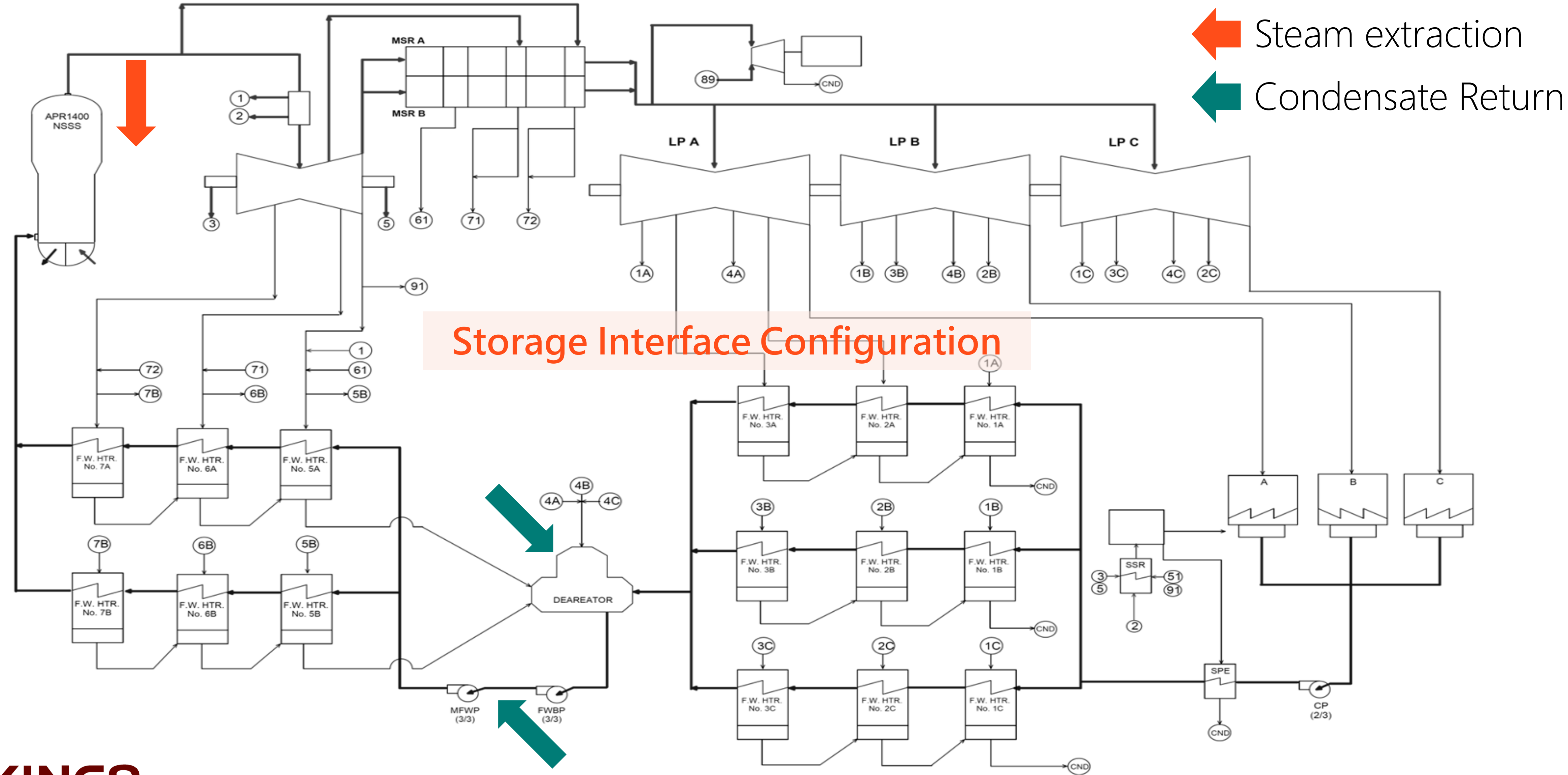
Optimization Considerations - Summary



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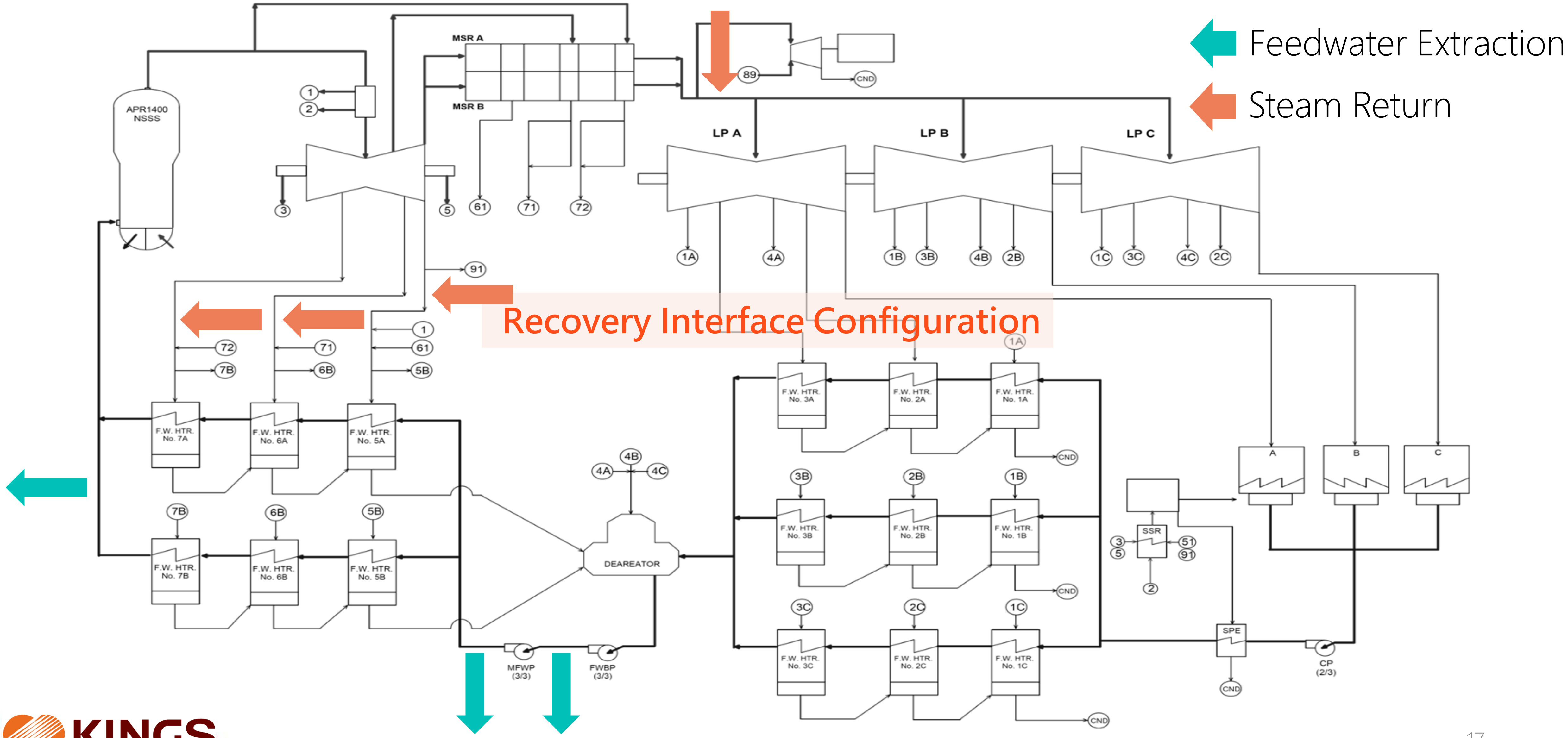
Optimization Considerations - Summary



Conclusions

- Changing energy markets result in **demand for variable power output** of Nuclear Power Plants
- The optimized Nuclear Heat Storage and Recovery represents **opportunity for NPP to adapt** to future energy market
- To optimize NHS&R a detailed **analysis of the system thermodynamic performance** needs to be performed
- The evaluation of proposed design configurations needs to be performed by **thermodynamic model simulation**

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References

[1] Ministry of Trade, Industry and Energy The 8th Basic Plan for Long-term Electricity Supply and Demand (2017-2031), December 29, 2017

[2] Fraunhofer ISE, Energy Chatrs, Electricity production and spot prices in Germany in week 1 2018, [Online], Available: https://www.energy-charts.de/price.htm?auction=15m&year=2018&week=1

[3] R.D. Varrin, A Case Study for Load Following with Heat Storage at an Existing LWR, Light Water Reactor Heat Storage for Peak Power and Increased Revenue: Focused Workshop on Near-Term Options, Cambridge, June 27-28, 2017, [online], Available: https://energy.mit.edu/wp-content/uploads/2017/12/Light-Water-Reactor-Heat-Storage-for-Peak-Power-and-Increased-Revenue.pdf

Acknowledgments

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Thank you!

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