Simplified modeling of thermo-chemical energy storage system (TCES) for solar power tower using the System Advisor Model (SAM)

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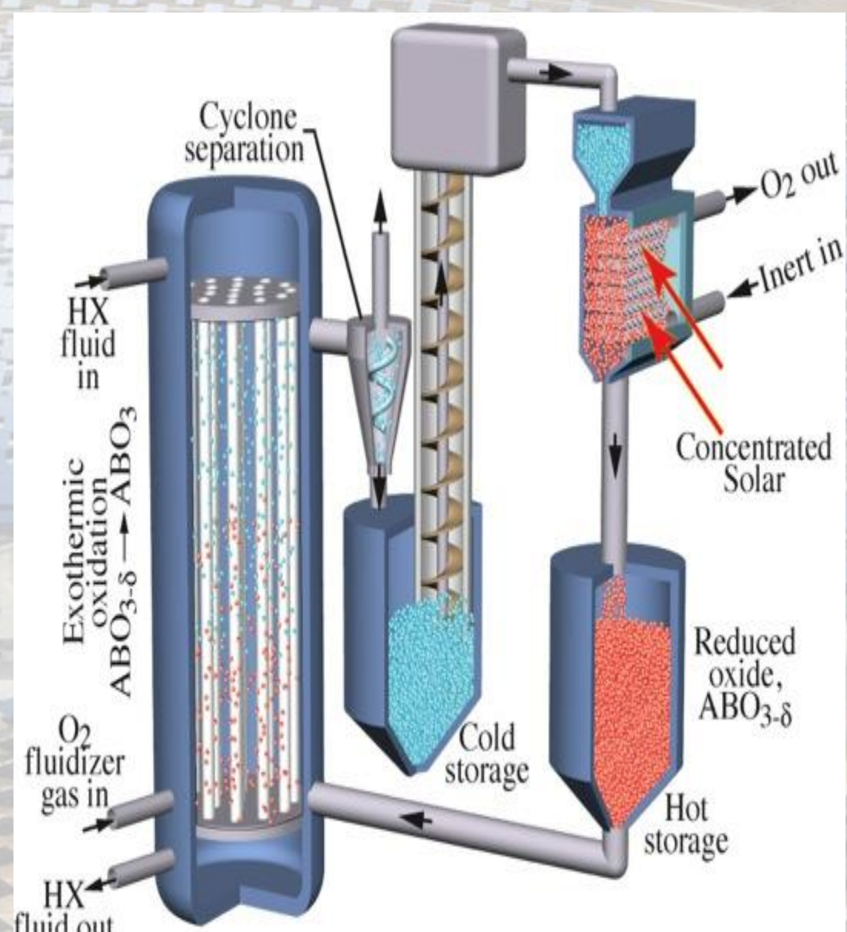
Background

- Presenter background
- Project background
  - Make CSP viable with technological advancements in thermal energy storage (TES)
  - DOE target $15/kWh$_{th}$
  - Colorado School of Mines (CSM), NREL and Abengoa –CSP Elements project
    - Principal Investigator: Greg Jackson, CSM
    - Other Contributors: Robert Braun, CSM; Christina Lopez, Abengoa Solar; Zhiwen Ma, NREL; Ryan O’Hayre, CSM
  - This work – Part of M.S Thesis project titled – “**Thermodynamics of Doped Calcium Manganite for Thermochemical Energy Storage in Concentrated Solar Power Plants**”

Thermochemical Energy Storage (TCES) for CSP plants

- TES and TCES
  - Utilizes chemical energy stored in bonds
  - Stores energy during endothermic reduction
  - Releases energy during exothermic oxidation
- SAM allows modeling of CSP tower system with TES
- **This presentation attempts design of CSP tower system with TCES**



Courtesy: Dr. Kee (CSM)

CSP modeling in SAM

Generic

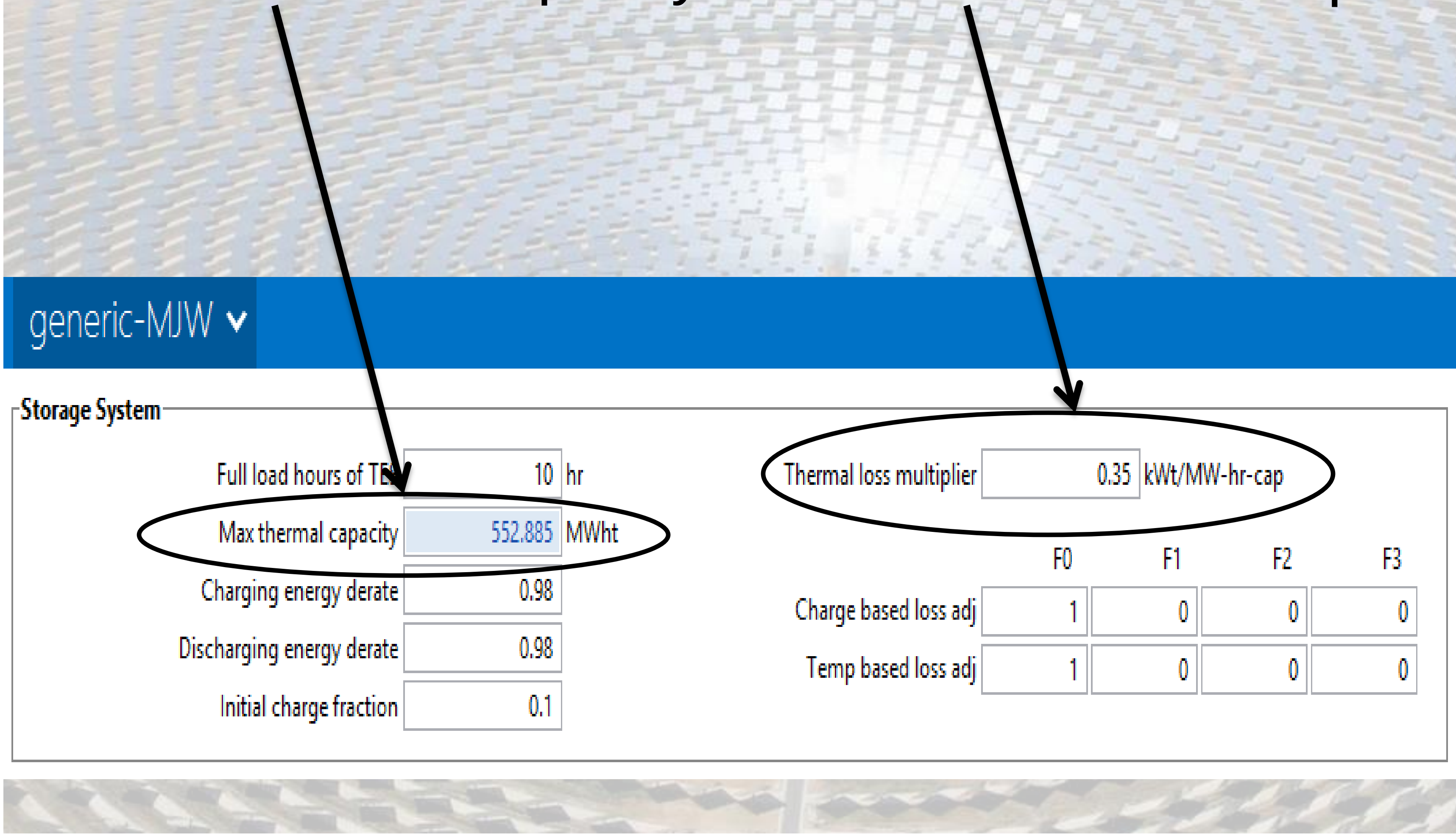
- No ‘fluid’ selected
- Properties defined by ‘MWh’
- TCES based system has less “$/MWh” than TES based system

Specific

- Heat transfer fluid (HTF) selected
- Properties defined by Cp, density, kinematic viscosity etc.
- Cost calculations are considered separately
- Defined 2 types of salts as HTF
- Allows ‘user defined fluid’ as HTF

CSP with TCES using generic model

- Total thermal capacity
- Thermal loss multiplier

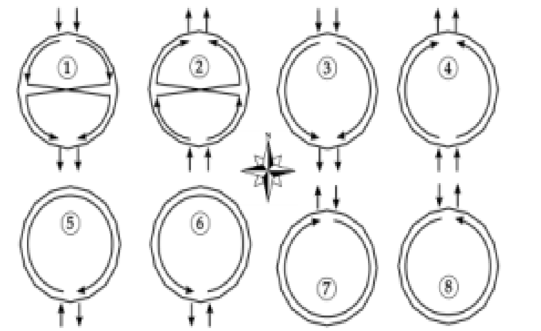


CSP with TCES using specific model

- CSP with TCES
  - Two tank/ One Tank
  - Type of HTF – Molten Salt / User defined
  - HTF inlet/outlet conditions

Materials and Flow

HTF Type	User-defined...
Property table for user-defined HTF	Edit...
Material Type	Stainless AISI316
Flow Pattern	3



Power Block Design Point

Rated Cycle Conversion Efficiency	0.49	
Design Thermal Power	55.2885	MWt
Design HTF Inlet Temp.	900	'C
Design HTF Outlet Temp.	500	'C
Fossil Backup Boiler LHV Efficiency	0.9	
Aux heater outlet set temp	900	'C
Fossil Dispatch Mode	Minimum backup level	

SAM model for tower based TES system

Location	Mojave, CA
Gross plant output	23 MW_e
Power cycle	Rankine superheat steam cycle
Pressure and temperature	100 bar, 470 °C
Turbine net output	20 MW_e
Auxiliary BOP	Air cooled condenser, deaeartor
HTF inlet [T_{hot}]	565 °C
HTF outlet [T_{cool}]	290 °C
No of hours of storage	10 h
Type of HTF	Molten salt 60% NaNO3 and 40% KNO3

SAM model for tower based TCES system

Location	Mojave, CA
Gross plant output	23 MW_e
Power cycle	Supercritical CO_2 Brayton cycle
Pressure and temperature	100 bar, 640 °C
Turbine net output	20 MW_e
Auxiliary BOP	Compressor, Recuperator
HTF inlet [T_{hot}]	900 °C
HTF outlet [T_{cool}]	500 °C
No of hours of storage	10 h
Type of HTF	TCES material

Model set up and results

- User defined values
- SAM does not have ability to define TCES, so define Cp_{eff}

User –defined input values for TCES material

Temperature (°C)	890	940	990
k_g ($W\ m^{-1}\ K^{-1}$)	0.17	0.22	0.30
Δh_{total} ($kJ\ kg^{-1}$)	533	645	766
ρ_{bulk} ($kg\ m^{-3}$)	1113	1097	1081
k_{eff} ($W\ m^{-1}\ K^{-1}$)	0.12	0.13	0.14
ν (m^2 s)	2.70E-06	2.74E-06	2.78E-06
Cp_{eff} ($kJ\ kg^{-1}K^{-1}$)	1.33	1.42	1.53

$$[\text{Energy produced}]_{TCES} \approx 0.91\ [\text{Energy produced}]_{TES}$$

Challenges in TCES design

- System flow diagram different – Particle flow Vs HTF flow
  - Difference in flow types
  - Difference in heat transfer mechanisms
  - SAM uses HTF fluid flow
- Integration of higher efficiency power cycle
  - SAM utilizes superheat Rankine cycle
- Parasitic load

Solutions in TCES design

- System flow diagram different – Particle flow Vs HTF flow
  - Difference in flow types – Implement/Allow particle flow selection
  - Difference in heat transfer mechanisms
  - SAM uses HTF fluid flow
- Integration of higher efficiency power cycle
  - SAM utilizes superheat Rankine cycle
    - To implement TCES based storage, need to implement supercritical CO_2 cycle
    - Includes replacement of BOP system like deaerator, condenser etc
- Parasitic load determination
    - Efficiency of bucket elevators and PSA auxiliary load requirement already implemented in parasitic load efficiency
- Writing of own script file to be inputted into SAM??

Conclusion & Future Work

- Attempt was made to design power tower with TCES based system using SAM
- Design Parameters in SAM
  - Effective specific heat Cp_{eff} was defined for ‘user-defined HTF’
  - Parasitic load efficiency changed
  - Power conversion efficiency
- Ideally, design parameters in SAM should allow
  - Selection of particle based fluid flow
  - Implementation of other power conversion cycles

Acknowledgment

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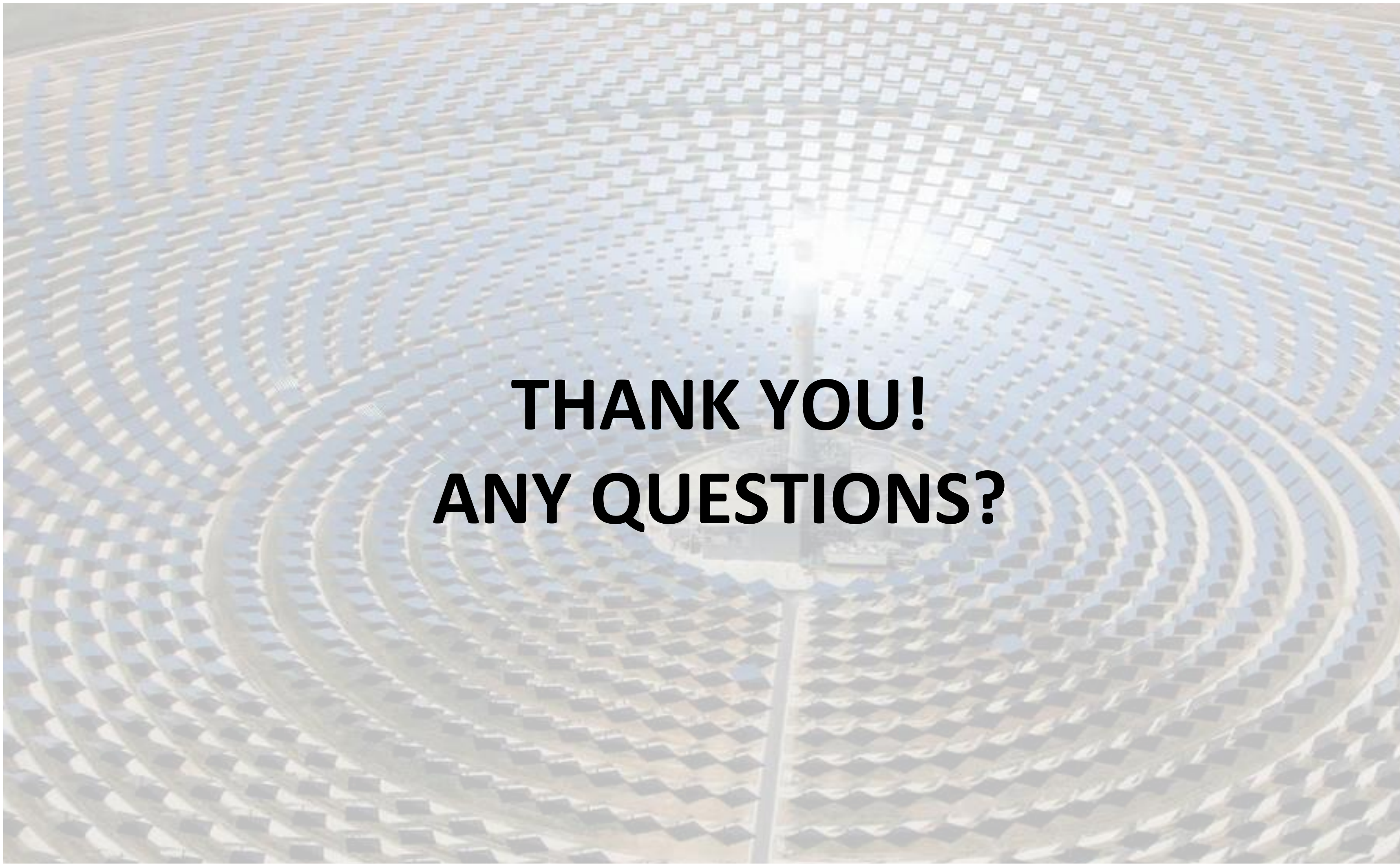

THANK YOU!
ANY QUESTIONS?

Supplementary slides