Treatment of Produced Water from Carbon Sequestration Sites for Water Reuse, Mineral Recovery and Carbon Utilization

Performer: Southern Research

PI: Jay Renew, P.E.

2017 Crosscutting Research Portfolio Review
March 23, 2017

DE-FE0024084

Period of Performance: October 1, 2014 to September 30, 2017

PROJECT GOALS AND OBJECTIVES

- Select candidate CO_2 sequestration reservoirs based on water chemistry and geologic properties
- Develop an integrated and adaptable concentration system
- Evaluate solidification & stabilization mixtures to immobilize residual contaminants
- Evaluate opportunities to recover valuable minerals, efficiently utilize CO_2, and recover water
- Complete a technical readiness review and economic feasibility analysis

TOPICS

- Team
- Formation Characteristics
- Integrated Concentration System
- Solidification/Stabilization
- Remaining Work

DISCLAIMER

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TEAM

SOUTHERN RESEARCH

Advanced Resources International, Inc.

HEARTLAND TECHNOLOGY PARTNERS, LLC

DiFilippo Consulting

NEW LOGIC RESEARCH, INC.

SOUTHERN COMPANY

FORMATION CHARACTERISTICS

Component (mg/L)	Keg Mountain	Mount Simon	San Andres
TDS	18,419	88,900	190,459
Ca^{2+}	940	8,514	5,578
Na^{+}	5,019	22,545	63,014
Mg^{2+}	123	1,428	3,482
K^{+}	587	758	519
Cl^{-}	9,212	53,700	116,600
SO_4^{2-}	499	1,219	1,166
HCO_3^{-}	1,501	100	100

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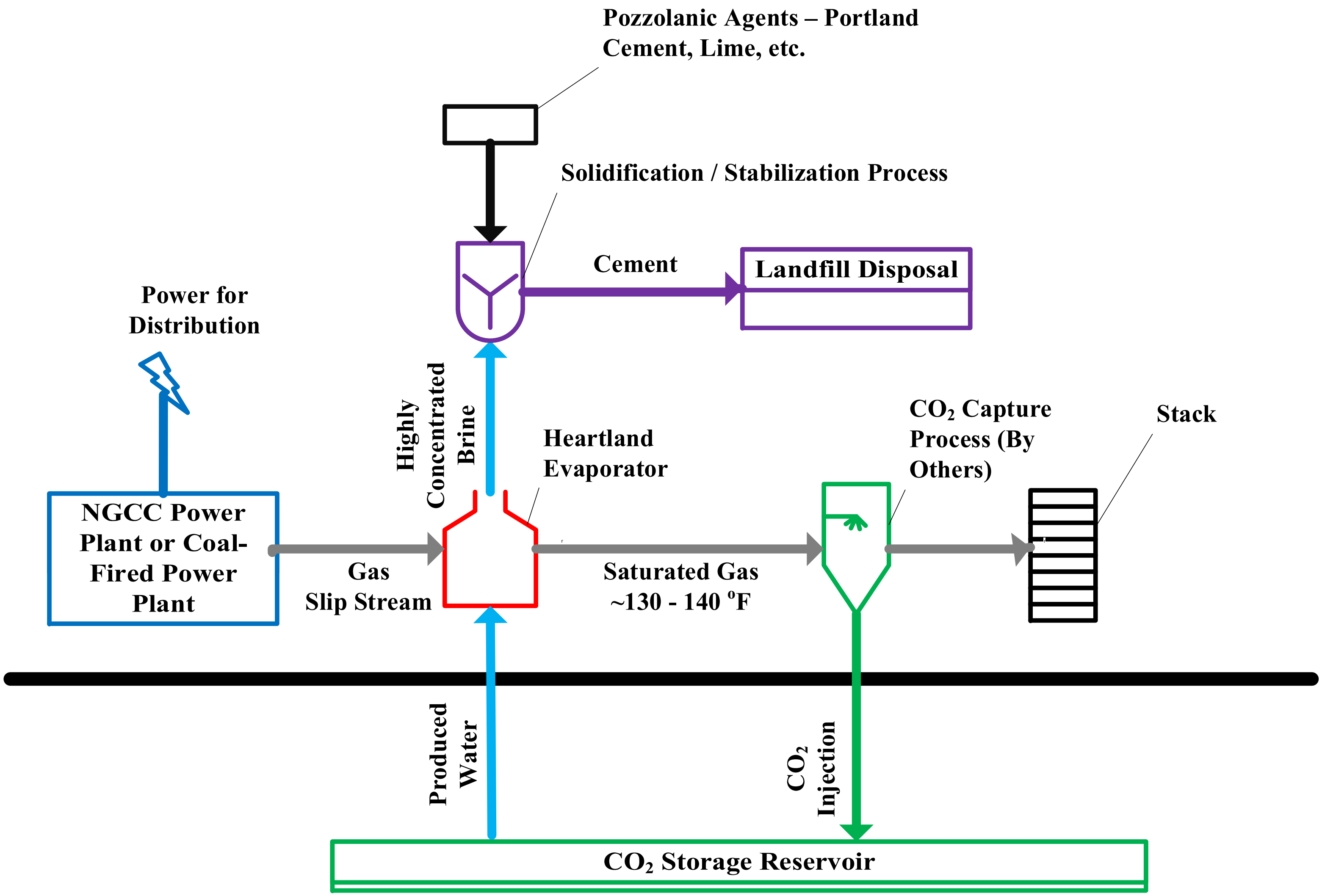
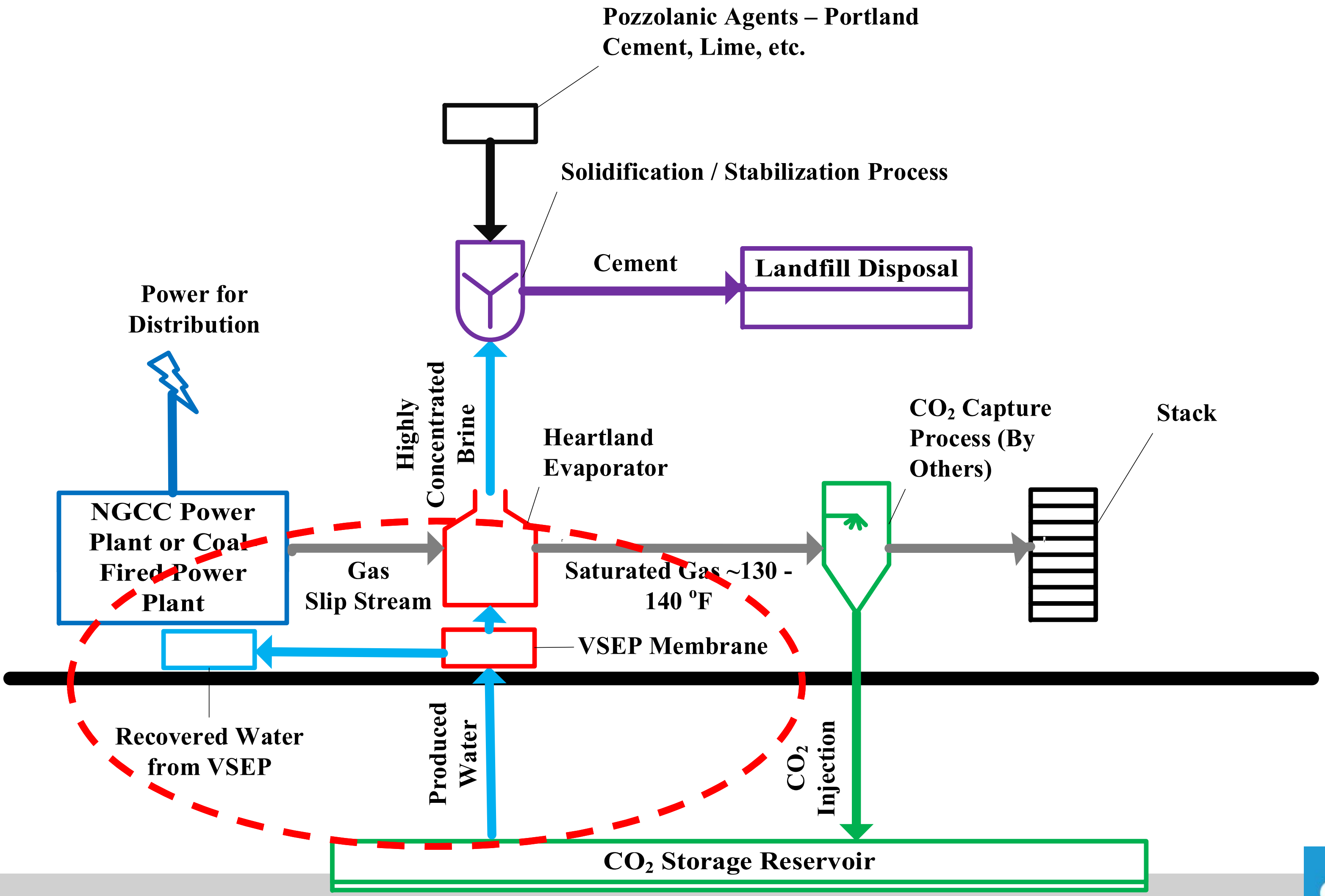
Process Overview



Process Overview – VSEP Pre-Concentration



VSEP SYSTEMS

- Create high shear rate at membrane surface to prevent fouling (Luo, Ding, Wan, & Jaffrin, 2012; Luo et al., 2013).
- Fouling prevention very important for treatment of high TDS waters.
- High shear rate can be achieved through vibrating the membrane (Luo, Zhu et al. 2013).

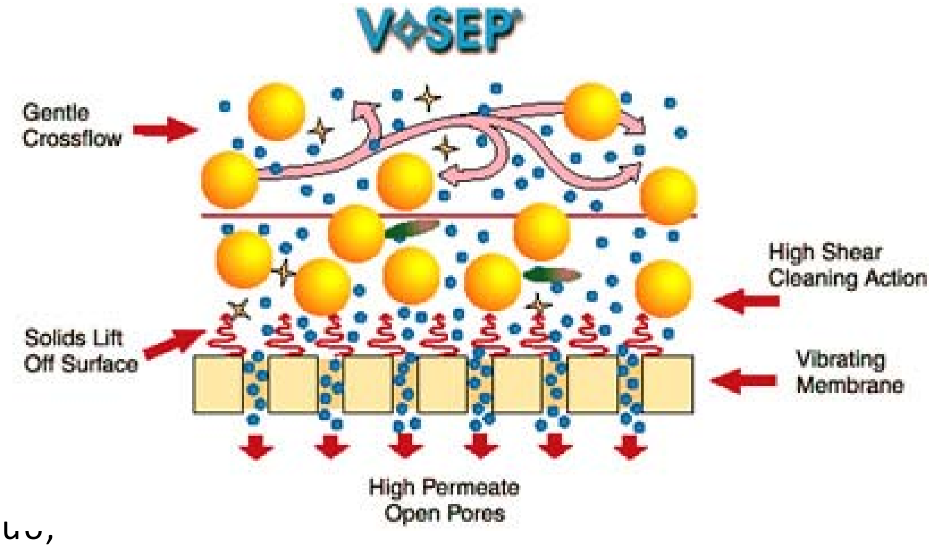
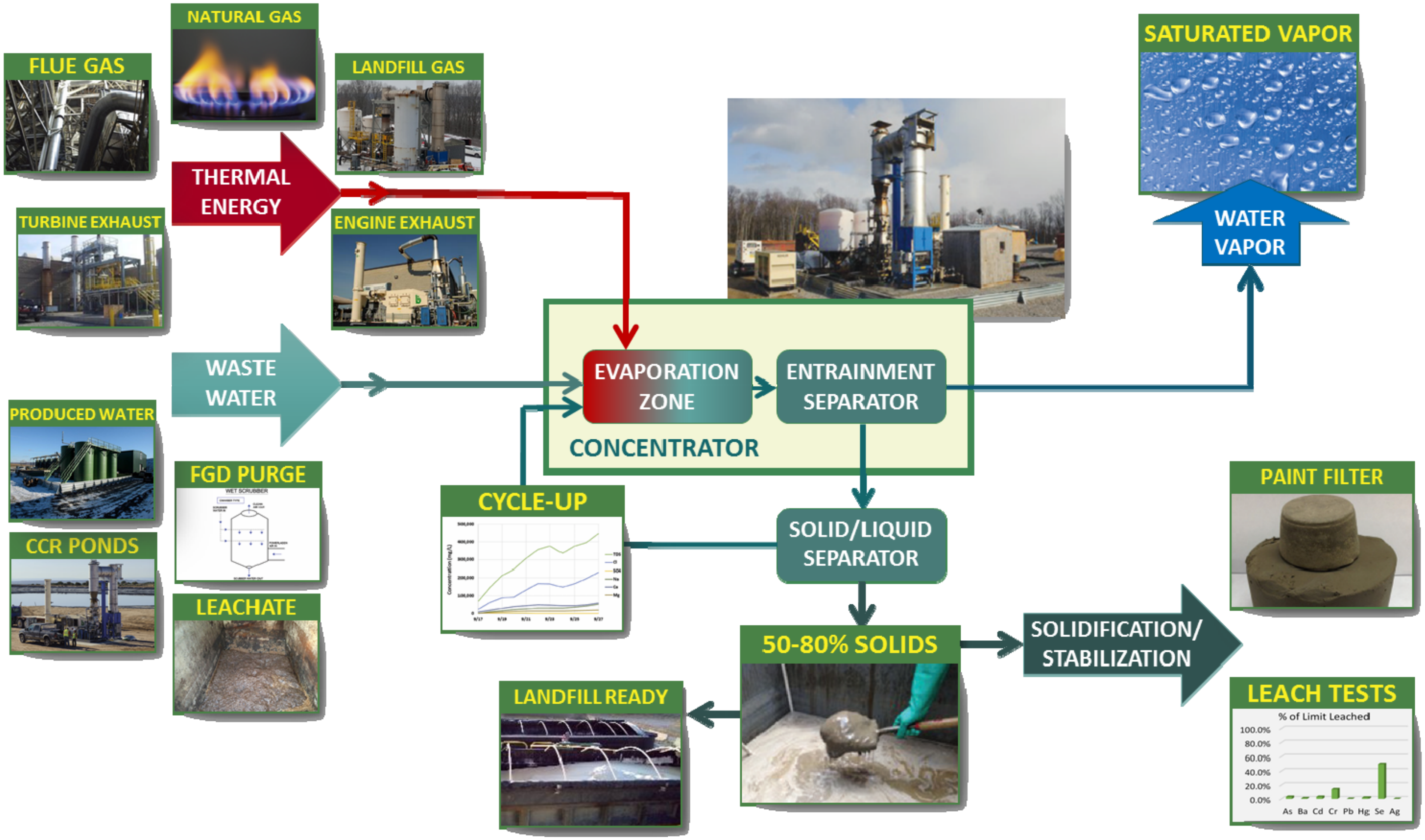


Figure Courtesy of New Logic, Inc.

HEARTLAND CONCENTRATOR PROCESS



FLUE GAS

NATURAL GAS

LANDFILL GAS

TURBINE EXHAUST

ENGINE EXHAUST

THERMAL ENERGY

WASTE WATER

PRODUCED WATER

FGD PURGE

CCR PONDS

LEACHATE

CONCENTRATOR

EVAPORATION ZONE

ENTRAINMENT SEPARATOR

WATER VAPOR

SATURATED VAPOR

CYCLE-UP

SOLID/LIQUID SEPARATOR

50-80% SOLIDS

LANDFILL READY

SOLIDIFICATION/ STABILIZATION

PAINT FILTER

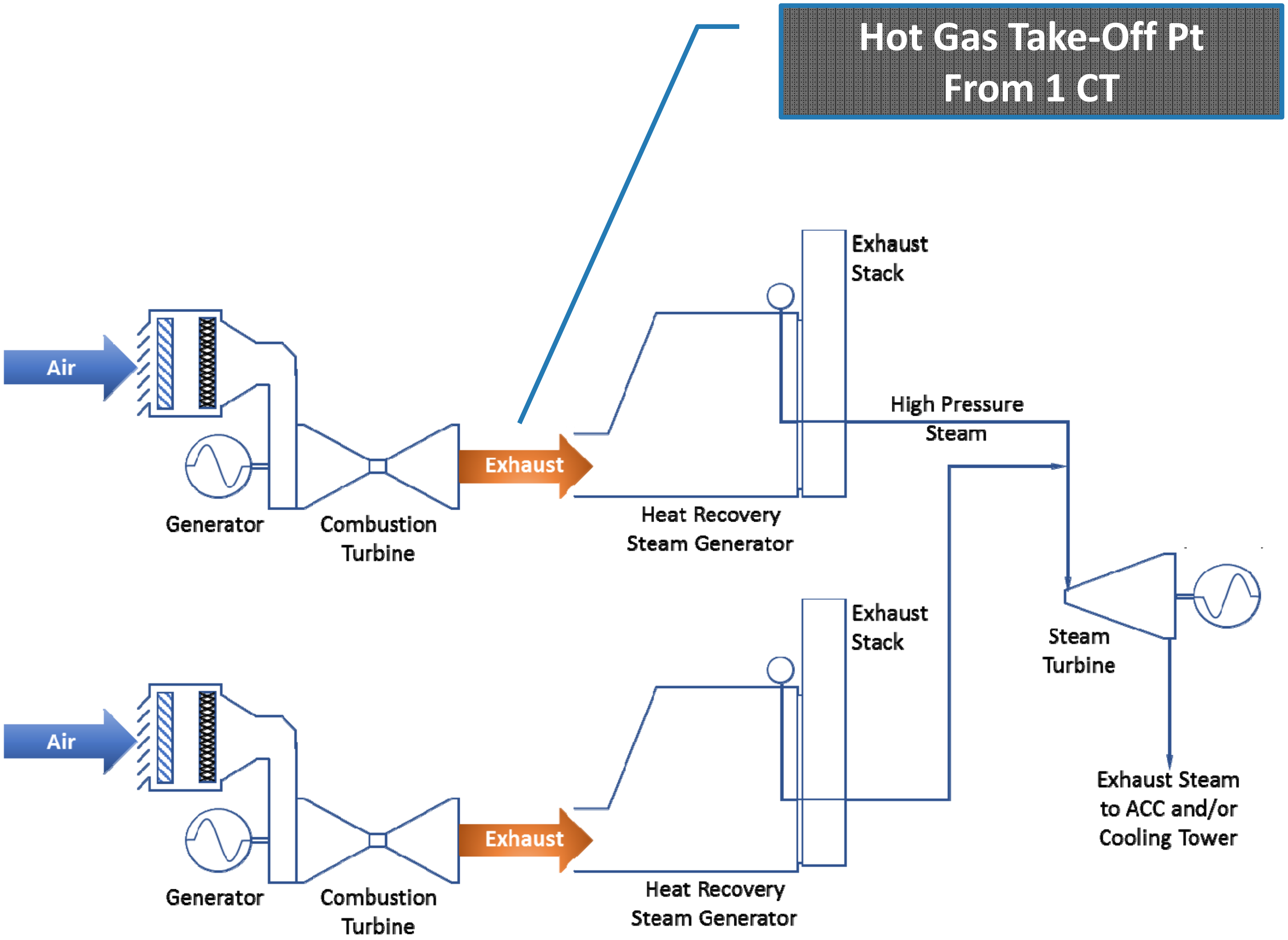
LEACH TESTS

Scenario Evaluations

- Natural Gas Combined Cycle (NGCC) Scenario
  - 500 MW (317 MW output from natural gas turbine / 183 MW supplemental HRSG turbine)
  - 90% CO_2 capture
  - Waste heat from downstream of gas turbine / upstream of HRSG utilized
  - Gas temperature = 1,149 °F
  - Concentrate produced water to 65% total solids
  - Assume 80% annual system capacity factor

- Coal Scenario
  - 500 MW Illinois basin coal-fired power plant
  - 90% CO_2 capture
  - Waste heat flue gas upstream of air pre-heater utilized
  - Gas temperature = 650 °F with plant heat rate of 10,000 BTU/kWh
  - Concentrate produced water to 65% total solids
  - Assume 80% annual system capacity factor

NGCC Hot Gas Take-Off Point



Calculation Assumptions

Parameter	NGCC	Coal	Unit
Gross Electrical Output	500 (317)	500	MW
Plant Capacity Factor	80%	80%	
Plant Heat Rate (HHV)	6,715	9,800	BTU/kWh
Gas Energy Content	1,029	--	BTU/SCF
Coal Energy Content	--	11,666	BTU/lb (wet)
Plant Fuel Input	54,401	210	SCFM (gas) / Ton/Hr (Coal)
	3,358	4,900	MMBTU/hr
Plant CO_2 Emissions	6,611	16,386	lb/min
	1,389,973	3,444,961	Ton/Yr
	793	1,966	lb/mWh
CO_2 Capture Rate	90%	90%	%
Concentrator Hot Gas Temp	1,149	650	°F
Maximum Evap Rate	4,331,549	1,555,803	GPD
	3,008	1,080	GPM

Notes

1 - Max evap rate based on 100% of ‘hot’ flue gas going to Heartland concentrator.

2 - NGCC scenario assumes 317 MW of electric generation from natural gas combustion turbine followed by HRSG that produces up to 183 MW of additional electric power.

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Calculation Assumptions – Water Chemistry

Parameter	Mount Simon	Keg Mountain	San Andres	Unit
Water Production	320	403	320	Gallons per Ton CO_2 Injected
Raw Water TDS	88,900	18,419	190,459	mg/L
Raw Water to Concentrator TDS	88,900	73,676	190,459	mg/L
VSEP Volume Reduction	N/A	75%	N/A	
Raw Water SG	1.04	1.05	1.09	SG
Concentrated Slurry %TS	65%	65%	65%	TS
Concentrated Slurry % Fly Ash (Coal Scenarios)	24%	22%	13%	wt% Fly Ash
Concentrated Slurry SG	1.4	1.4	1.4	SG
Feed : Evap Ratio - Turbine Exhaust	1.1	1.12	1.26	Gal Infeed / Gal Evap
Feed : Evap Ratio - Flue Gas	1.14	1.15	1.3	Gal Infeed / Gal Evap
Slurry : Evap Ratio - Turbine Exhaust	0.11	0.12	0.26	Gal Slurry / Gal Evap
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Notes

1 - For Keg Mountain scenario, it is assumed the water will first be pre-concentrated through a VSEP membrane with 4 cycles of concentration

2 - For flue gas scenarios, this analysis does not account for the SO_2 mass balance; i.e., the side effect of capturing of SO_2 from the flue gas into the Heartland Concentrator and impact on system pH and solids balance.

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Raw Water TDS	88,900	18,419	190,459	mg/L
Raw Water to Concentrator TDS	88,900	73,676	190,459	mg/L
VSEP Volume Reduction	N/A	75%	N/A	
Raw Water SG	1.04	1.05	1.09	SG
Concentrated Slurry %TS	65%	65%	65%	TS
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Results – NGCC Scenario

NGCC Scenario	Mount Simon	Keg Mountain	San Andres	Unit
Produced Water Processed	400	400	400	MMGPY
	1,370,932	1,370,932	1,370,932	GPD
	952	952	952	GPM
Heartland Feed	400	100	400	MMGPY
	1,370,932	342,733	1,370,932	GPD
	952	238	952	GPM
% of Turbine Exhaust Required	29	7	25	%
Steam Turbine Electrical Derate	55	14.6	48	MW
Slurry Produced	94	26	201	GPM

Notes

Derate includes lost thermal energy to HRSG + Heartland parasitic electric load.

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Slurry Produced	94	26	201	GPM

Notes

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Results – Coal Scenario

Coal Scenario A	Mount Simon	Keg Mountain	San Andres	Unit
Produced Water Processed	992	1,249	992	MMGPY
	3,397,769	4,279,066	3,397,769	GPD
	2,360	2,972	2,360	GPM
Heartland Feed	992	312	992	MMGPY
	3,397,769	1,069,766	3,397,769	GPD
	2,360	743	2,360	GPM
% of Flue Gas Required	192	60	168	%
Plant Derate	99	32.7	86	MW
Slurry Produced	370	125	618	GPM

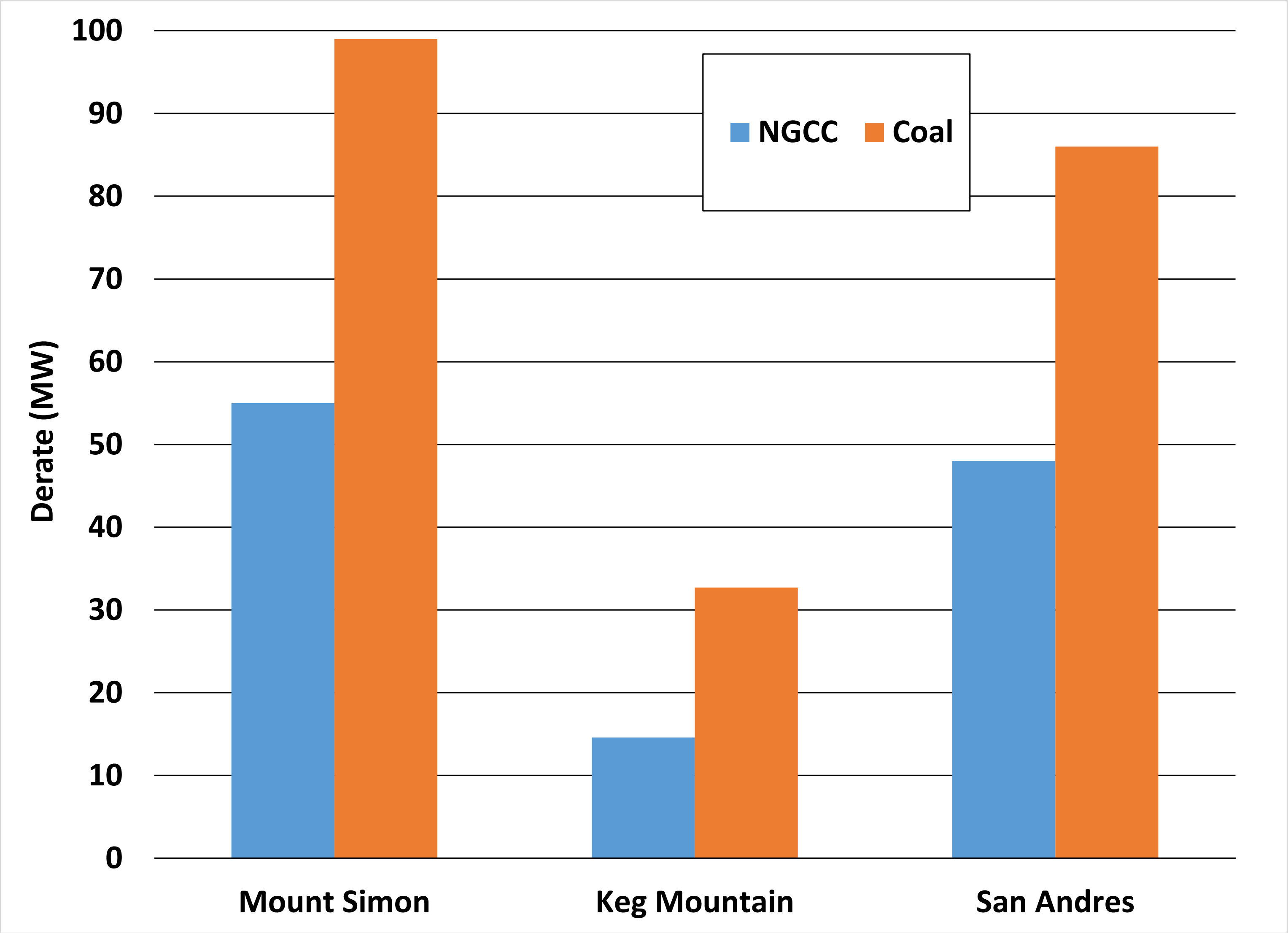
Notes

1 - Derate includes lost thermal energy to APH + Heartland parasitic electric load.

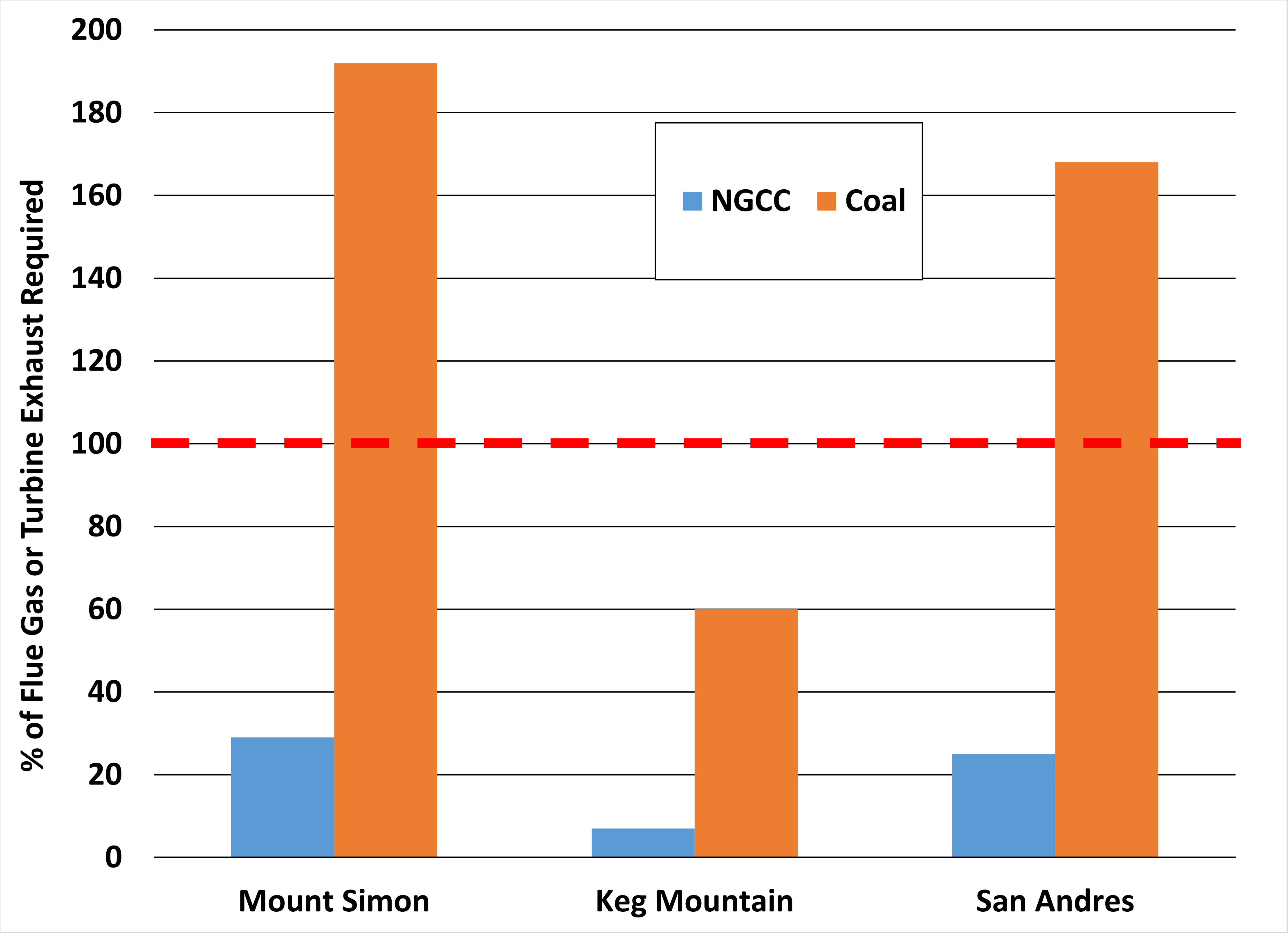
2 - Red highlight = Impossible scenario given flue gas requirement

3 - Yellow highlight = thermodynamically possible, but likely presents significant integration challenges with AQCS equipment and performance.

Derate Comparison



% of Flue Gas or Turbine Exhaust Required



SOLIDIFICATION / STABILIZATION

- Conduct bench scale studies to optimize mix formulations required for solidifying and stabilizing (S/S) solids
  - Based on simulated brine with high concentrations
- Utilize leaching environmental assessment framework (LEAF) testing to determine leachability of constituents of concern.

REMAINING WORK

- Conduct an economic feasibility study for the selected reservoirs
- In addition to VSEP/Heartland, evaluate
  - Forward Osmosis
  - Vapor Compression Evaporation
  - Crystallization
- Conduct a technical readiness review
- Complete solidification/stabilization study
- Evaluate opportunities to recover valuable minerals, efficiently utilize CO_2, and recover water
- Evaluate deep well injection for disposal

ACKNOWLEDGMENTS

USDOE for funding and Project Officer Maria Reidpath.

REFERENCES

Luo, J., L. Ding, Y. Wan and M. Y. Jaffrin (2012). "Threshold flux for shear-enhanced nanofiltration: Experimental observation in dairy wastewater treatment." Journal of Membrane Science **409–410**(0): 276-284.

Luo, J., Z. Zhu, L. Ding, O. Bals, Y. Wan, M. Y. Jaffrin and E. Vorobiev (2013). "Flux behavior in clarification of chicory juice by high-shear membrane filtration: Evidence for threshold flux." Journal of Membrane Science **435**(0): 120-129.

SOUTHERN
RESEARCH

75
YEARS

1941 - 2016