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

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TEAM

SOUTHERN RESEARCH

Advanced Resources International, Inc.

DiFilippo Consulting

HEARTLAND TECHNOLOGY PARTNERS, LLC

NEW LOGIC RESEARCH, INC.

SOUTHERN COMPANY

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

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- Larry Stowell – Eastern Regional Sales Manager, New Logic Research, Inc.
- Michael N. DiFilippo – Owner, DiFilippo Consulting
- Jay E. Renew, P.E. - Senior Environmental Engineer, Southern Research

GOALS

- Select four candidate CO_2 sequestration reservoirs based on water chemistry and geologic properties
- Develop an integrated and adaptable concentration system
- Develop solidification & stabilization mixtures to immobilize residual contaminants
- Evaluate opportunities to recover strategic and rare earth minerals (SREMs), efficiently utilize CO_2 and beneficially use the produced water
- Complete a technical readiness review, economic feasibility analysis and an environmental risk assessment

TASK LIST & TECHNICAL LEAD

Task #	Description	Lead
1	Project Management	SR
2	Design Basis	ARI
3	Evaporation System	Heartland Technology & New Logic Research
4	Mineral Recovery System	SR
5	Solidification & Stabilization	SR
6	Water Condensation	SR
7	Byproduct Reuse	SR
8	Techno Economic Assessment	DiFilippo Consulting
9	Environmental Risk Assessment	SR

DESIGN BASIS

- Define the CO_2 injection rate as 3.5 million tonnes per year
- Select four representative saline aquifer reservoirs with distinct geologic and/or geochemical characteristics
- Evaluate geologic properties and estimate the number of injection and withdrawal wells required per reservoir
- Estimate pre-injection water withdrawal volume to enable efficient CO_2 plume directional control
- Estimate long term water withdrawal requirements to manage and sustain reservoir pressure

FORMATION CHARACTERISTICS

Formation	Description or Test Site	TDS (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Organic Carbon (mg/L)
Tuscaloosa	Mississippi	180,000	13,000	1,200	46,900	800	78
	Formation Avg.	138,927	10,108	1,081	40,733	359	450
Mount Simon	Decatur	190,000	19,000	1,800	50,000	1,700	-
	Formation Avg.	127,482	8,514	1,428	22,545	758	-
Sulphur Point & Keg River	Sulphur Point	35,000	200*	50*	98,000 (Na + K)*		-
	Keg River	35,000	942	123	4,851	586	-
Wasson Field San Andres	Formation Avg.	188,320	5,578	3,482	63,014	519	-
	Formation Min.	66,887	1,100	293	6,318	510	-

* Chemical Analyses from Sulphur Point Analyses estimated from graph in Crockford, 2008

SOURCE: Advanced Resources International, 2015. *Estimated Produced Water Volumes with Objectives of Controlling Reservoir Pressure and/or Plume Dispersion During CO2 Injection for Storage*. DE-FE0024084 Project Deliverable #3. October 2015

HIGHEST CONCENTRATION VALUES

Formation	Description or Test Site	TDS (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Organic Carbon (mg/L)
Tuscaloosa	Mississippi	180,000	13,000	1,200	46,900	800	78
	Formation Avg.	138,927	10,108	1,081	40,733	359	450
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LOWEST CONCENTRATION VALUES

Formation	Description or Test Site	TDS (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Organic Carbon (mg/L)
Tuscaloosa	Mississippi	180,000	13,000	1,200	46,900	800	78
	Formation Avg.	138,927	10,108	1,081	40,733	359	450
Mount Simon	Decatur	190,000	19,000	1,800	50,000	1,700	-
	Formation Avg.	127,482	8,514	1,428	22,545	758	-
Sulphur Point & Keg River	Sulphur Point	35,000	200*	50*	98,000 (Na + K)*		-
	Keg River	35,000	942	123	4,851	586	-
Wasson Field San Andres	Formation Avg.	188,320	5,578	3,482	63,014	519	-
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LARGEST FORMATION DEVIATION

Formation	Description or Test Site	TDS (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Organic Carbon (mg/L)
Tuscaloosa	Mississippi	180,000	13,000	1,200	46,900	800	78
	Formation Avg.	138,927	10,108	1,081	40,733	359	450
Mount Simon	Decatur	190,000	19,000	1,800	50,000	1,700	-
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CO_2 INJECTION RATES

Storage Reservoir Setting	CO_2 Injection Rate per Well (Mscf/day)	Number of CO_2 Injection Wells *
Tuscaloosa	9,242	21
Mount Simon	14,447	14
Keg River	1,259	145
San Andres	119	1,531

* Estimated to achieve 3.5 million tonnes per year of CO_2 injection per reservoir

SOURCE: Advanced Resources International, 2015. *Estimated Produced Water Volumes with Objectives of Controlling Reservoir Pressure and/or Plume Dispersion During CO2 Injection for Storage*. DE-FE0024084 Project Deliverable #3. October 2015

WATER PRODUCTION RATES

Storage Reservoir Setting	Total Reservoir Production (BPD)	Total Reservoir Production (GPD)	Number of Production Wells *	Well Production (GPM)
Tuscaloosa	58,926	2,478,000	6	287
Mount Simon	73,063	3,066,000	7	304
Keg River	92,492	3,864,000	9	298
San Andres	72,687	3,066,000	7	304

* Assumes maximum water production rate of 10,000 barrels per day per well to achieve 3.5 million tonnes per year CO_2 injection

SOURCE: Advanced Resources International, 2015. *Estimated Produced Water Volumes with Objectives of Controlling Reservoir Pressure and/or Plume Dispersion During CO2 Injection for Storage*. DE-FE0024084 Project Deliverable #3. October 2015

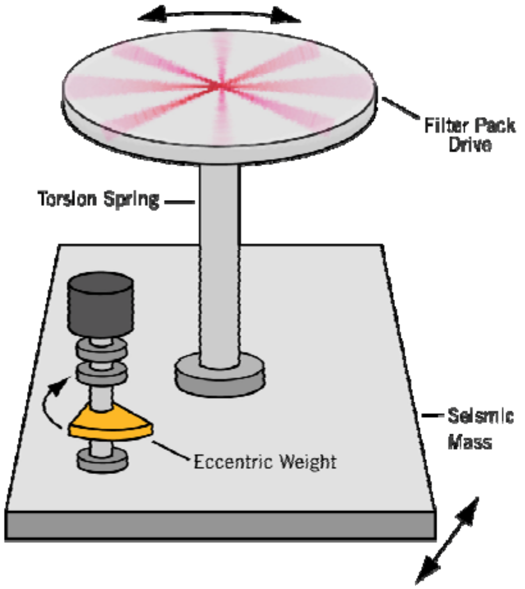
EVAPORATION SYSTEM

- Develop a conceptual high efficiency thermal evaporation system to treat high TDS streams
- Develop a integrated conceptual system with non-thermal pre-concentration and final stage thermal concentration
- Create process flow diagrams for promising concepts
- Calculate mass and energy balances for the selected systems
- Estimate solids production rates and concentrate properties
- Evaluate reuse opportunities

VIBRATORY SHEER ENHANCED PROCESSING (VSEP)

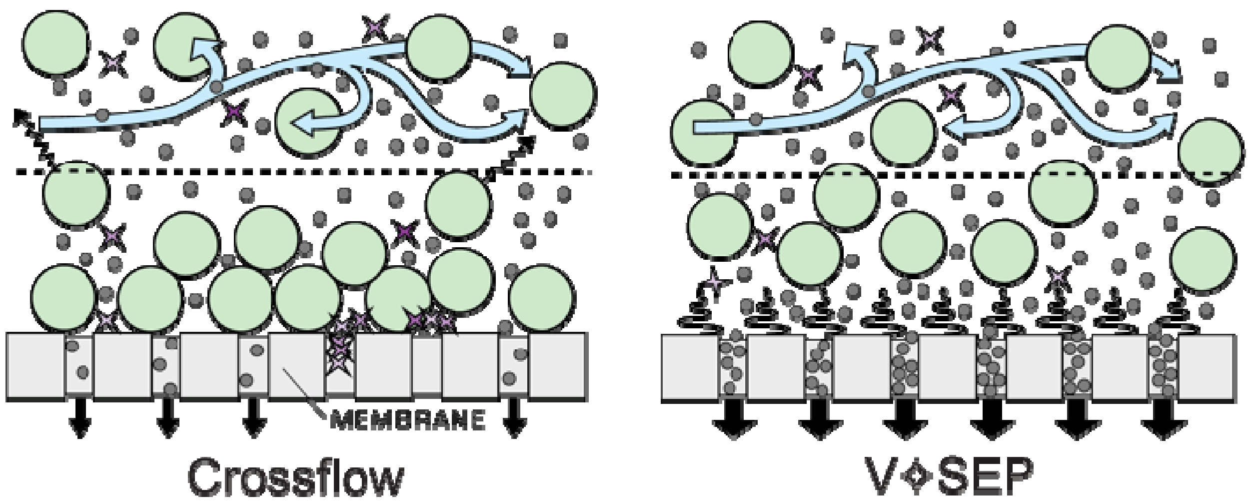
Patented Membrane filtration system by New Logic Research:

- Decreased membrane fouling
- Processes difficult high solids feed waters
- Produces intense shear waves on the face of membranes
- Non-Thermal operation for reduced CO_2 impact



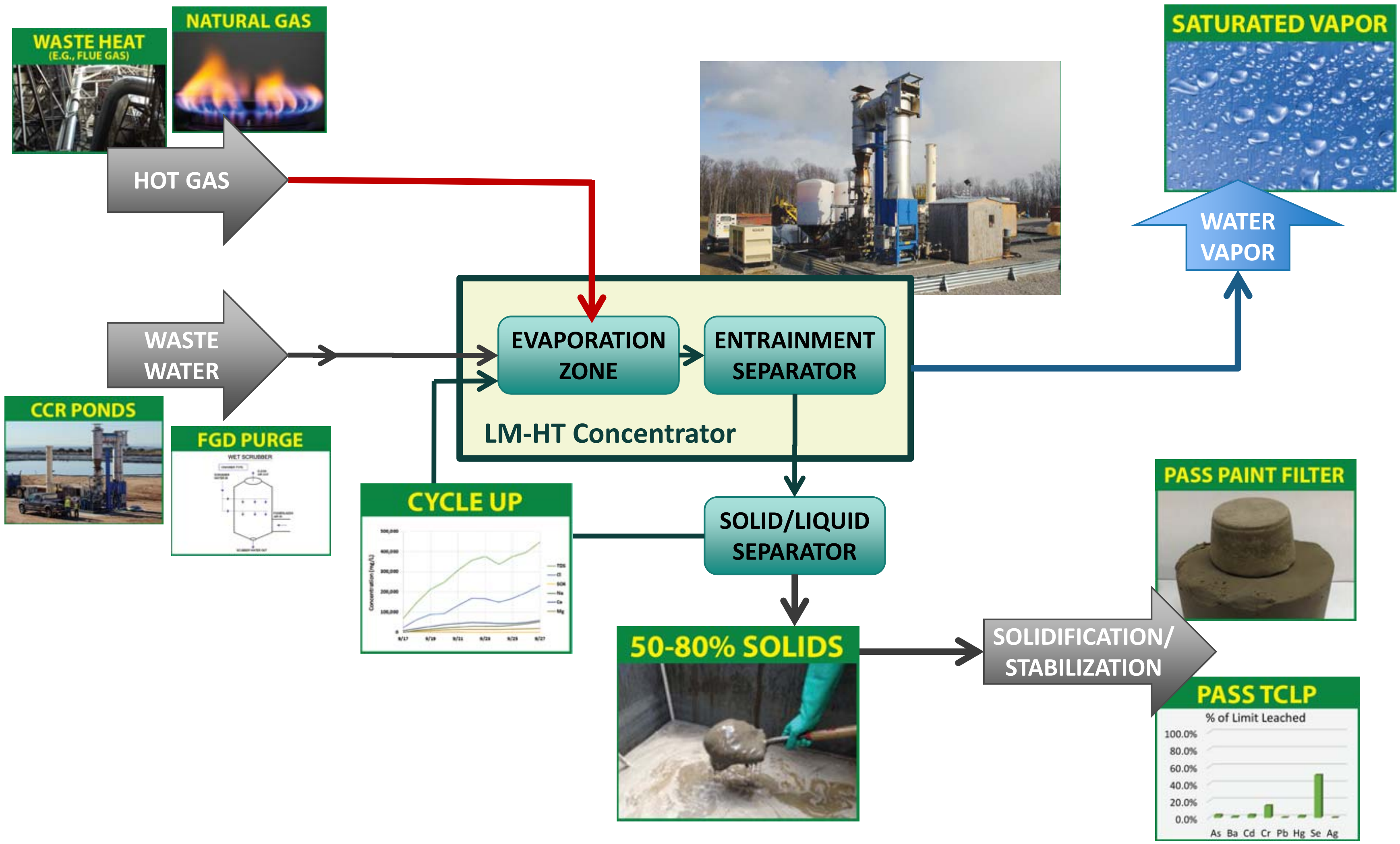
Oscillating motion generates 200 G's of force

VSEP TECHNOLOGY



- Oscillating resonant motion
- Travels up to 1/2” 50x/sec
- Causes solids to hover above membrane
- Wide feed channel allows processing of high solids & difficult brines

HEARTLAND CONCENTRATOR PROCESS



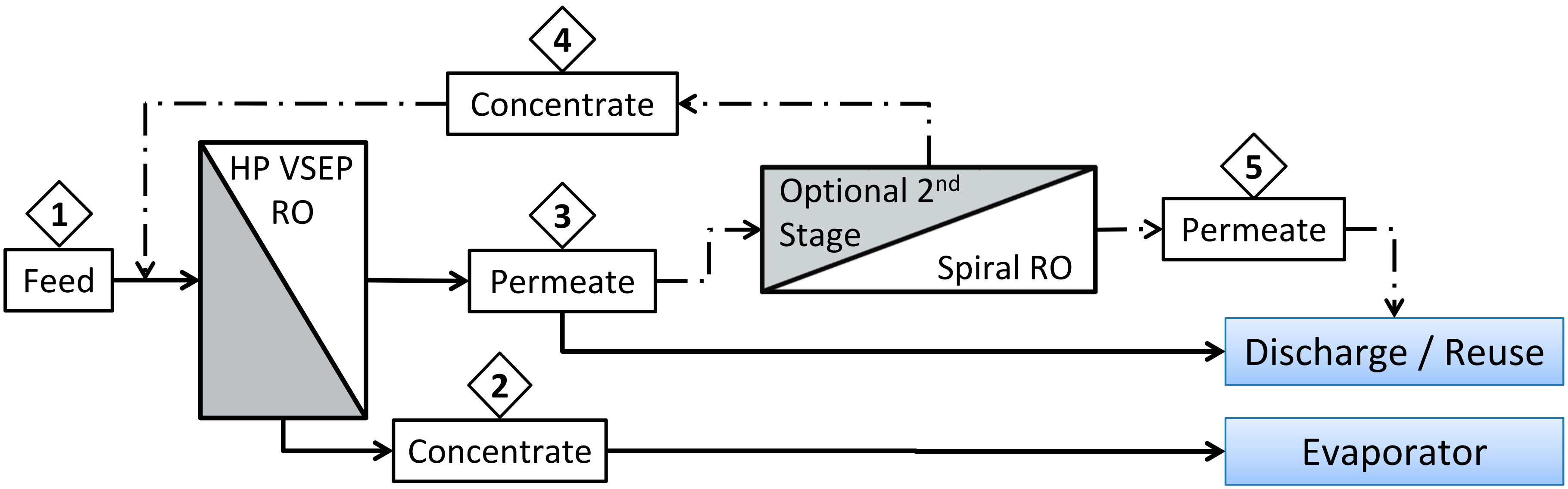
HEARTLAND TECHNOLOGY OVERVIEW

- Demonstrated ZLD process
- Direct contact evaporation
  - No heat exchangers mitigates scaling
  - Operates on waste heat or direct fire
  - Two moving parts
  - Saturated gas stream precludes drying and scaling
- Manages heavy scaling brines in continuous mode

SYSTEM DESIGN CONSIDERATIONS

- 10,000 bbl/day ≈ (292 GPM) per well for all four formations
- VSEP pre-concentration at Keg River with further consideration for Wasson Field formation minimum
- Utilize three parallel 100 GPM Heartland LM-HT® concentrators
- Volume Reduction:
  - 5:1 volume reduction
  - 5:1 cycle-up of TDS/TSS
- Slurry effluent concentration up to 65% total solids (TDS+TSS)

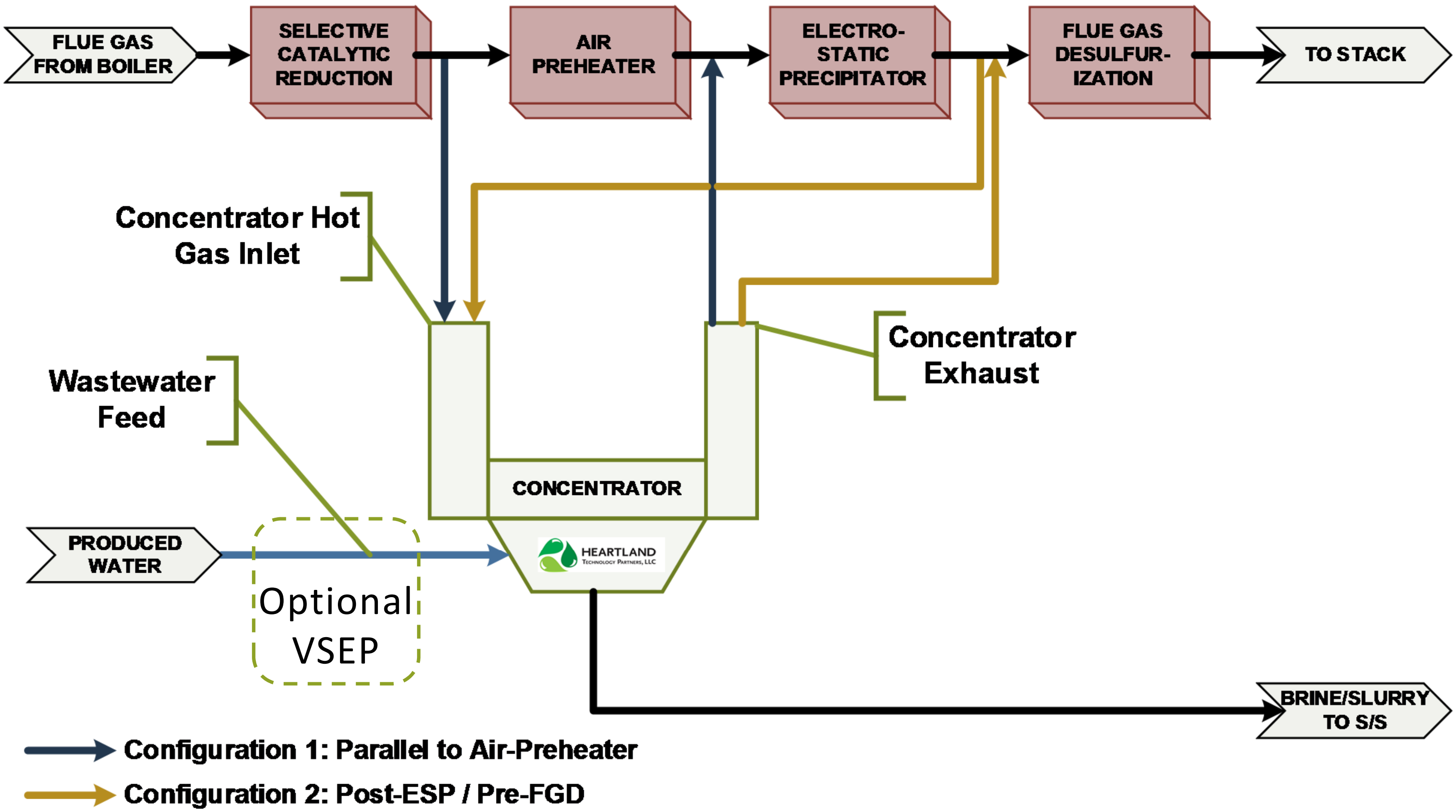
VSEP PROCESS FLOW



	1	2	3	4	5
Flow (GPM)	292	102	190	29	162
TDS (mg/L)	35,000	92,247	4,175	25,009	497
Ca (mg/L)	942	2,582	59	371	3.6
Mg (mg/L)	123	340	6	38	0.3
Na (mg/L)	4,851	12,666	642	3,802	85
K (mg/L)	586	1,456	117	648	23

SOURCE: New Logic Research, 2016. *Created for Task 3 of award DE-FE0024084.*

HEARTLAND PROCESS FLOW – FLUE GAS



SOURCE: Heartland Technology Partners, 2016. *Created for Task 3 of award DE-FE0024084.*

PRELIMINARY HEARTLAND MASS BALANCE RESULTS

Energy Source	Location	Infeed Flow (GPM)	Evaporation Rate (GPM)	Slurry Rate (GPM)	Volume Reduction
Turbine Waste Heat	Tuscaloosa	292	236	58	80%
	Mount Simon	292	232	61	79%
	Keg River	58	47	11	81%
	San Andres	292	233	61	79%
Flue Gas (Before APH)	Tuscaloosa	292	232	65	78%
	Mount Simon	292	229	68	77%
	Keg River	58	47	13	78%
	San Andres	292	230	67	77%
Flue Gas (After APH)	Tuscaloosa	292	236	58	80%
	Mount Simon	292	232	61	79%
	Keg River	58	47	11	81%
	San Andres	292	233	61	79%

SOURCE: Heartland Technology Partners, 2016. *Created for Task 3 of award DE-FE0024084.*

PROCESS INTEGRATION BENEFITS

- TDS concentration up to ≈ 80% solids for combined systems
- Brine volume reduction ≈ 65%: 1- Stage System (HP VSEP)
- Brine volume reduction ≈ 61%: 2 -Stage System (HP VSEP/SRO)
- Evaporation energy requirements reduced by up to 65%
- High TDS slurry easily mixes with stabilizing admixtures
- Permeate, concentrate and evaporated streams allow multiple opportunities for beneficial reuse
- Significant opportunity for targeted strategic rare earth mineral recovery

MINERAL RECOVERY SYSTEM

- Determine elements of interest for recovery based on reservoir geochemistry (e.g. Li, Zn, Mn, Ga, Ge, In, Te, Y, and La)
- Conduct a literature survey to determine the most economically viable manner in which to recover valuable minerals
- Develop high level process flow diagrams with budgetary cost estimates for the mineral recovery system
- Estimate the recovery rate for minerals with commercially relevant value

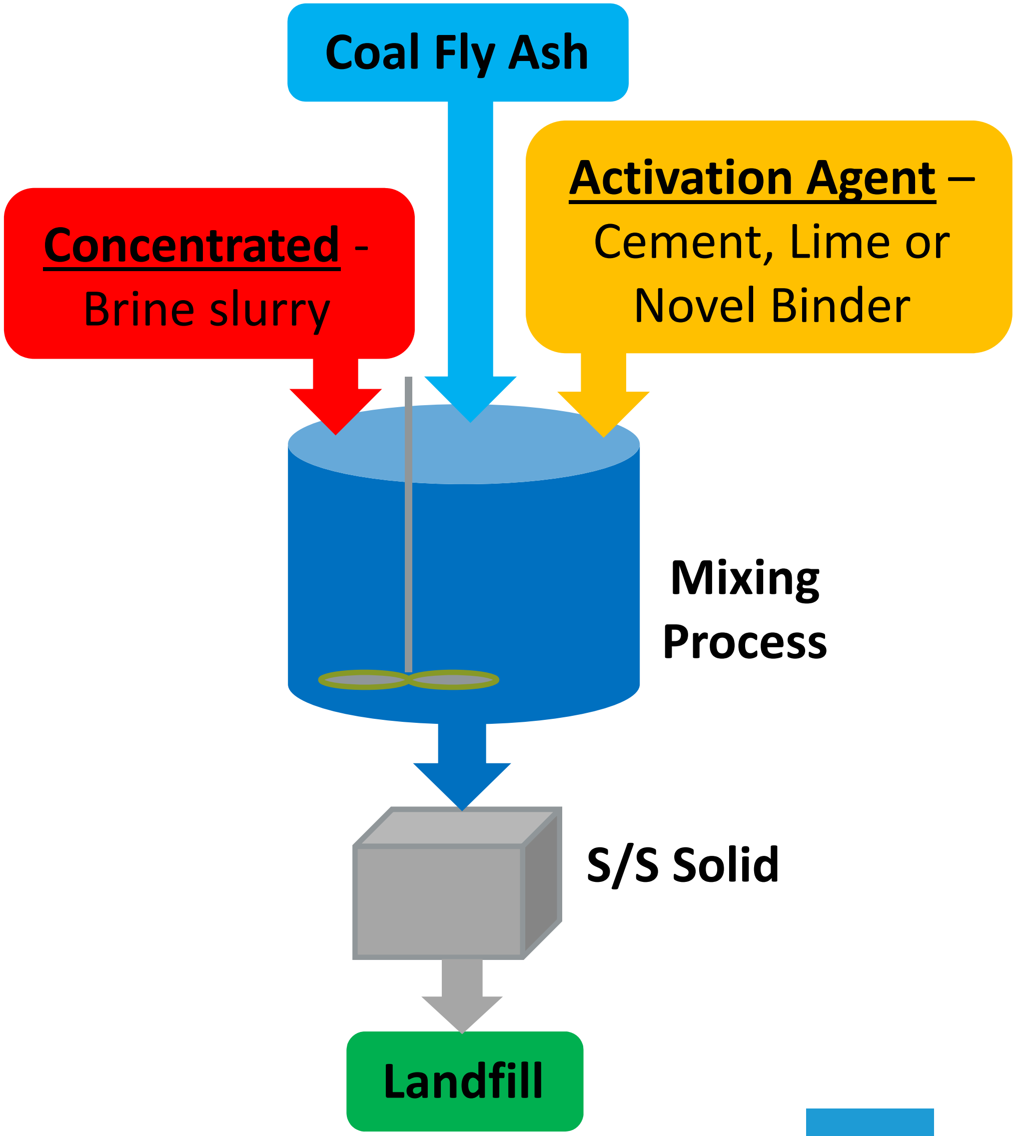
SOLIDIFICATION / STABILIZATION

- Conduct bench scale studies to optimize mix formulations required for solidifying and stabilizing (S/S) solids
- Utilize leaching environmental assessment framework (LEAF) and toxicity characteristic leaching procedure (TCLP) testing to determine leachability of constituents of concern
- Develop high level process flow diagrams using suitable formulations for each of the distinct water types
- Estimate capital and O&M costs for annual treatment

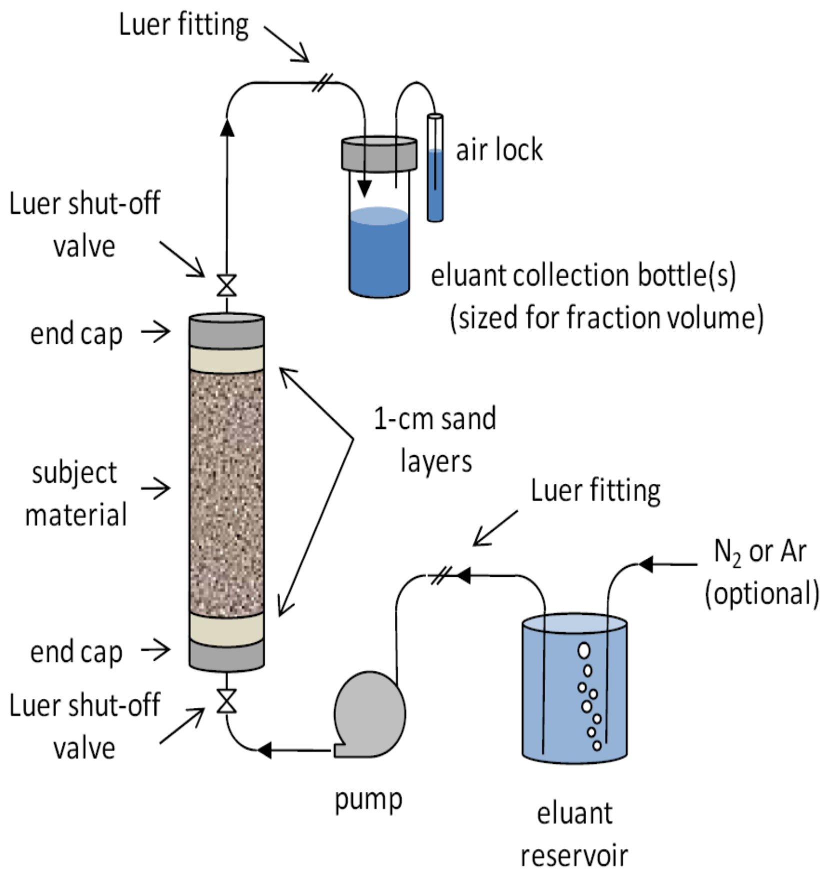
CONCENTRATE STABILIZATION

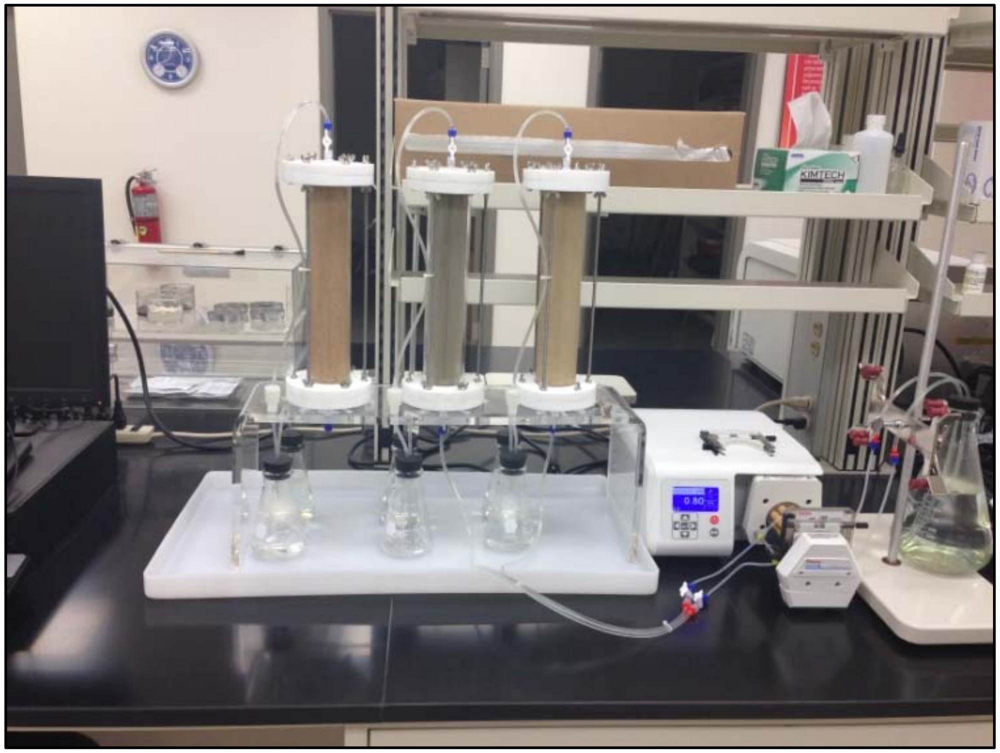
S/S consists of two processes:

- Solidification – Physically encapsulating and improving physical properties
- Stabilization – Converting contaminants to a less mobile and less toxic form



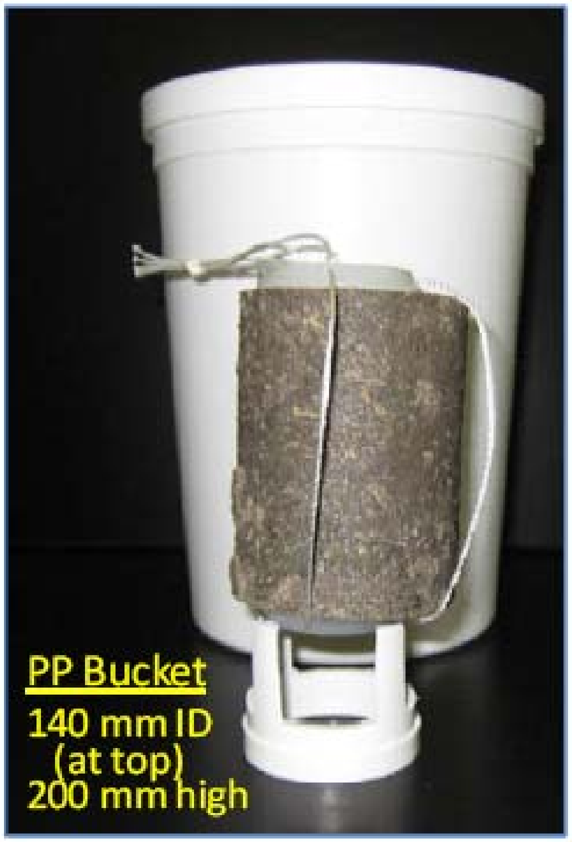
PERCOLATION COLUMN





Source – USEPA Method 1314

MONOLITH TEST



3-D Leaching Setup

Sample Centered in Eluant (top view)

Source – USEPA Method 1315

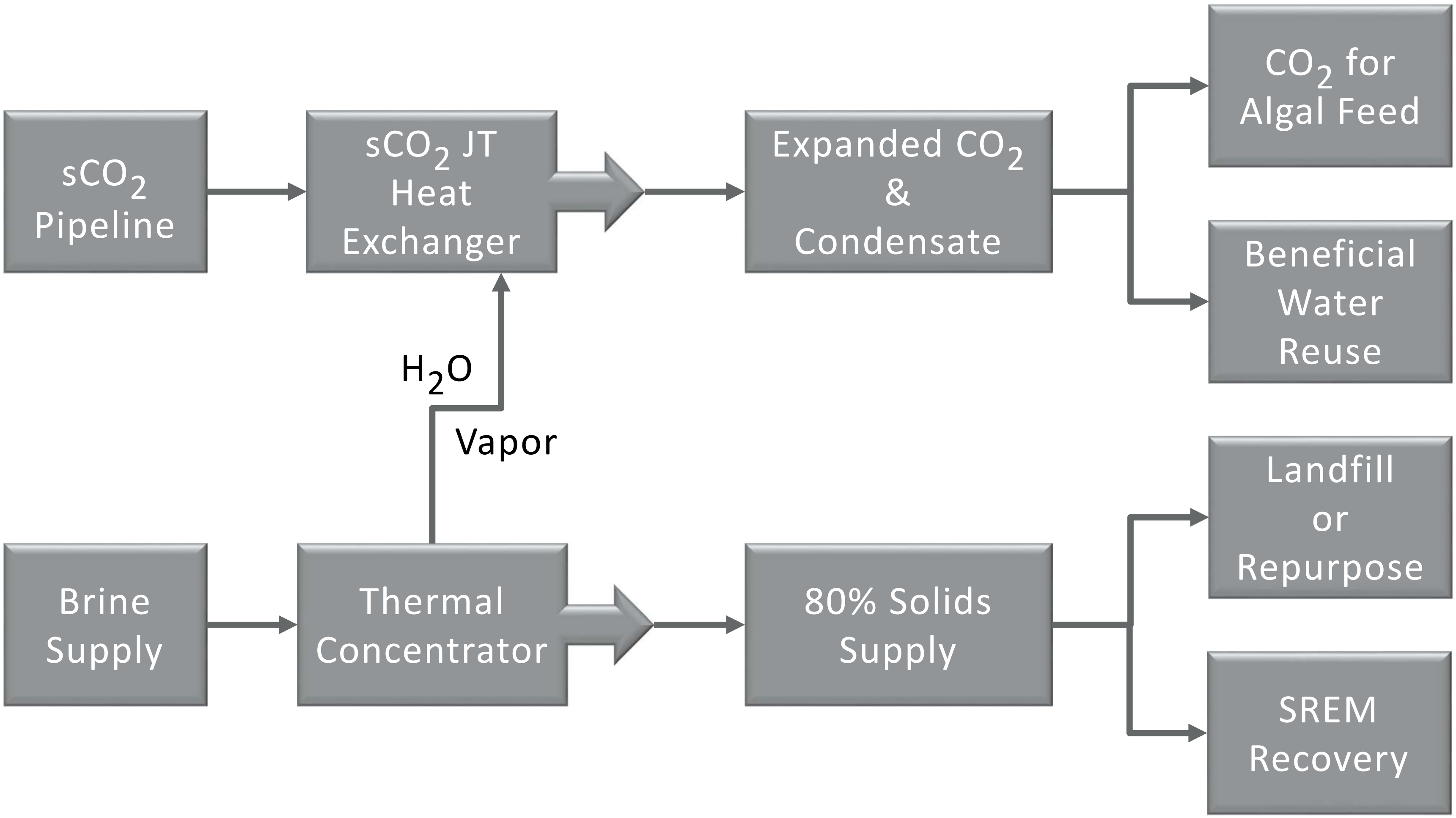
WATER CONDENSATION

- Investigate use of waste heat recovery to increase efficiency
- Investigate Joules-Thompson (JT) style heat exchanger utilizing supercritical CO_2 as cooling fluid
- Develop a high level design and process flow diagram for the heat exchanger used to condense the evaporated produced water and evaporator combustion byproducts
- Determine relative efficiency of a JT style heat exchanger to a standard refrigeration based design

BYPRODUCT REUSE

- Estimate condensate production rates and water quality for:
  - Reuse within the concentration or other plant processes
  - Surface discharge to engineered wetland
- Evaluate beneficial reuse options for expanded supercritical CO_2
- Investigate repurposing expanded supercritical CO_2 for use as a feedstock for an onsite engineered algae conversion system

BENEFICIAL REUSE & VALUE ADDED



TECHNO ECONOMIC ASSESSMENT

- Conduct a technical readiness review
- Conduct an economic feasibility study for the selected reservoirs
- Develop cost comparisons for each of the four systems on a dollar per gallon of water basis
- Develop a list of primary treatment costs drivers to enable identification of barrier technologies

ENVIRONMENTAL RISK ASSESSMENT

- Evaluate the potential environmental risk to air, water and land
- Example considerations include:
  - Identified hazard pathways
  - Estimated magnitude of potential consequences
  - Spatial and temporal scale of consequences
  - The probabilistic likelihood of each event

CONTINUING CHALLENGES

- Highly variable geochemistry will likely limit the development of a universal treatment technology
- Development of a strategic plan that aligns local natural resource utilization, regional energy demand and global emissions reduction requirements
- Designing an economically feasible process for long term CO_2 capture, sequestration and treatment of produced water byproducts

SOUTHERN
RESEARCH

75
YEARS

1941 - 2016