Utah Sustainable Transportation and Energy Plan (STEP)

Clean Coal Research Projects

CarbonSAFE, Biomass Co-Firing & Cryogenic Carbon Capture

ROCKY MOUNTAIN POWER

Let's turn the answers on.

STEP Clean Coal Technology Research Plan

- Mission
  - SB115-54-20-104: "…**a program to investigate, analyze, and research clean coal technology"**
- 54-2-1 Definitions: **"Clean coal technology" means a technology that may be researched, developed or used for reducing emissions or the rate of emissions from a thermal electric generation plant that uses coal as a fuel source.**
- Budget
  - An average of $1 million per year over a five year period for the clean coal technology program ($5 million total)

STEP Process to Engage Stakeholders

- Compiled Clean Coal Research team consisting of: Huntington & Hunter plant personnel, Technical Services, Utah university academia: Chem. Eng./Mech. Eng. (BYU, USU, UofU), Utah Office of Energy Development, USTAR, UofU, Energy & Geoscience Institute, Reaction Engineering International and Sustainable Energy Solutions
- Multiple workshops/locations
- Identified key *Areas of Research* in the areas of CO_2 capture and sequestration (projects presented today)

Preferences, Objectives and Requirements – Message to Clean Coal Team

- Preferences:
  - Technology demonstrations (hardware)
  - Advance existing technology
  - Utah centric
  - Leverage other funding sources (US DOE, state, local)
- Objectives:
  - Benefits customers, technology/commercialization advancement and emissions improvements
- Commission review to determine if the expenditures were prudently incurred in accordance with the purposes of the program

Utah STEP Clean Coal Research Technical Conference #2 Areas of Interest

1. CarbonSAFE

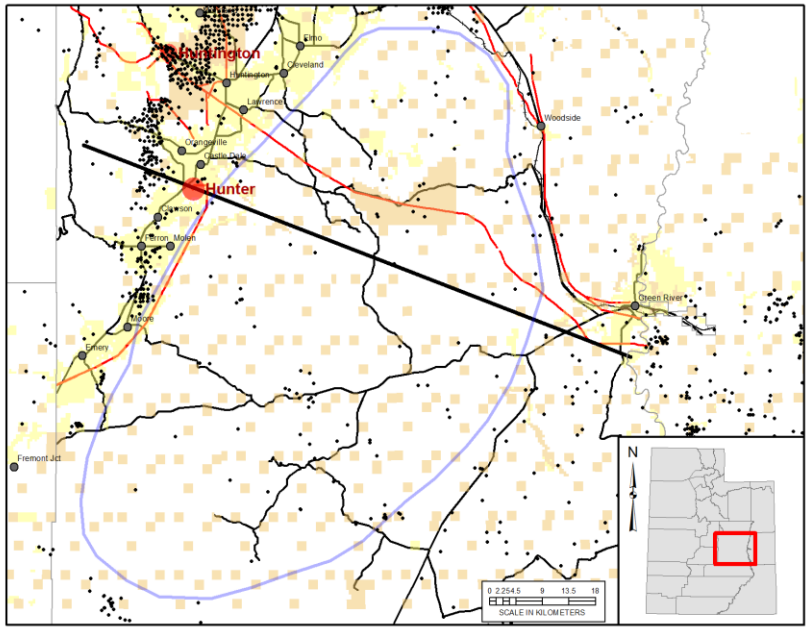
2. Biomass Co-Firing – Hunter Unit 3

3. Cryogenic Carbon Capture (Sustainable Energy Solutions)

CO_2 Capture

1. Sequestration: CarbonSAFE - Co-Funding towards Pre-Feasibility Assessment of a commercial scale CO_2 capture site (study)

- Co-funding towards USTAR's pre-feasibility assessment in response to US Department of Energy's Funding Opportunity Announcement (DE-FOA-0001584) – Phase 1
- Purpose of FOA:
  - To conduct a pre-feasibility for a commercial scale CO_2 geological storage complex (>50 m metric tons). The proposed Utah storage site: San Rafael Swell
  - Identify reliable large-scale anthropogenic CO_2 sources: Hunter Plant
- Leverages up to $1.2 m in US DOE funding
- University of Utah submitted a proposal to the US DOE on August 30, 2016. Lead: Dr. BJ McPherson

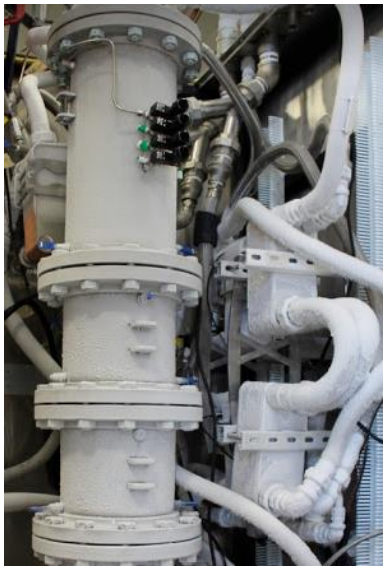


CO_2 Capture
2. Utah Woody Waste Co-Firing

- Apply Utah-based technology that processes woody waste
  - Amaron Energy (torrefaction)
  - AEG Coal Switch (steam expansion)
- Perform single ~18 hour 10% woody waste co-firing test at Hunter 3 using both processed materials. Additional testing based on economic assessment of woody-waste firing.
- Objective: no adverse plugging/fouling; handles like coal with existing handling facilities.
- Benefit: assess feasibility of potential periodic removal of Utah's woody waste
- Coal milling study with University of Utah includes testing material from Amaron Energy and Coal Switch process.
- Team: UofU, Amaron Energy, AEG Coalswitch, USU, PacifiCorp, BYU
- Proposal received from UofU; lead: Dr. Eric Eddings

CO_2 Capture
3. Cryogenic Carbon Capture (CCC) Demonstration

- Leverage existing equipment and $4.7 million in outside funding to prepare and demonstrate promising Utah technology for scale-up
  - Research and modification of some key aspects of process
  - Long term test of CCC technology at Hunter or Huntington
  - Techno-economic & EH&S Assessments
  - Team SES, RMP, Tri-State, EPRI, NRECA



- Sustainable Energy Solutions has submitted a draft proposal; lead: Dr. Larry Baxter

CO_2 Capture

1. Sequestration: CarbonSAFE - Co-fund Utah's proposal to US Dept of Energy to perform Integrated CCS Pre-feasibility studies - Phase 1 (study)

- USDOE issued two Funding Opportunity Announcements (FOA)
  - Phase I: Integrated CCS Pre-Feasibility Studies
    - Up to 12 funding awards (~$1.2 million each)
  - Phase II: Storage Complex Feasibility (more detailed evaluation)
    - Up to 6 funding awards (~$9 million each)
  - Phase III and IV: Site Characterization and Construction
- Purpose: Identify commercial CO_2 sequestration sites (capacity >50 million metric tons)
- Conceptual CO_2 site: San Rafael Swell; CO_2 source: Hunter plant
- Proposal lead: University of Utah

CO_2 Capture

1. Sequestration: CarbonSAFE - Co-fund Utah's proposal to US Dept of Energy to perform Integrated CCS Pre-feasibility studies - Phase 1 (study)

Objectives:

- Team formation to address technical / non-technical challenges (regulatory, legislative, technical, policy, commercial, financial)
- Plan development –economic feasibility & public acceptance
- High level technical evaluation of sub-basin (geology)

Key Risks:

- Economic viability
- Subsequent phases requiring additional co-funding

CarbonSAFE Rocky Mountains Phase I - Concept Diagram

Establish and Formalize CCS Coordination Team

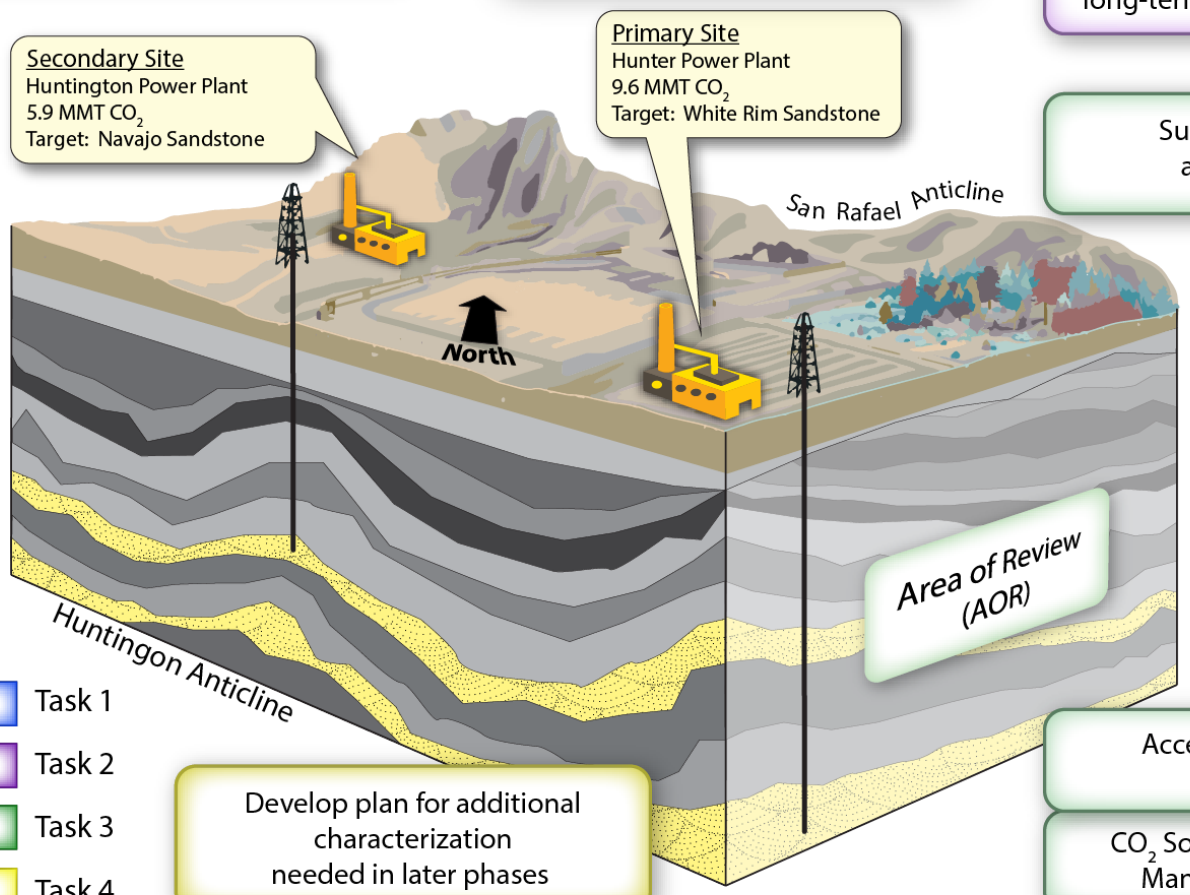
Assemble Catalog of Technical and Non-Technical Challenges

Assemble Plan to Address Integrated CCS Project Challenges

External Challenges:
- Including Legal, Regulatory, Contractual, Economic

Public and Economic Acceptability (Aspects within Direct Control of Project)

Assemble detailed plan for long-term liability for stored CO_2



Sub-Basinal Storage and CO_2 Sources

Site Screening & Selection of Sites in Storage Complex

Model Simulation - reservoir simulators, NRAP & EDX

Risk Assessment - Develop risk mitigation plan

Task 1

Task 2

Task 3

Task 4

Develop plan for additional characterization needed in later phases

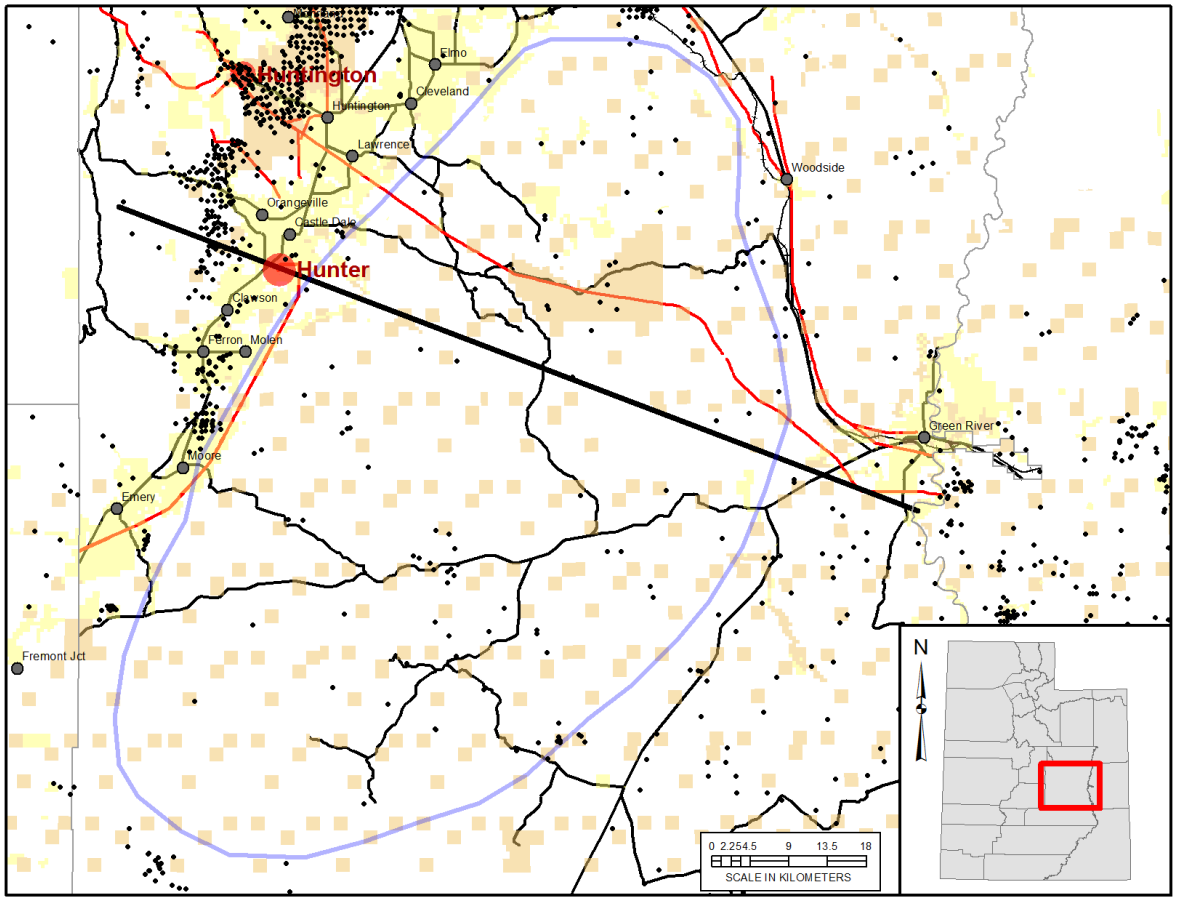
Accessible Information and Resources

CO_2 Source Assessment and Management Strategy

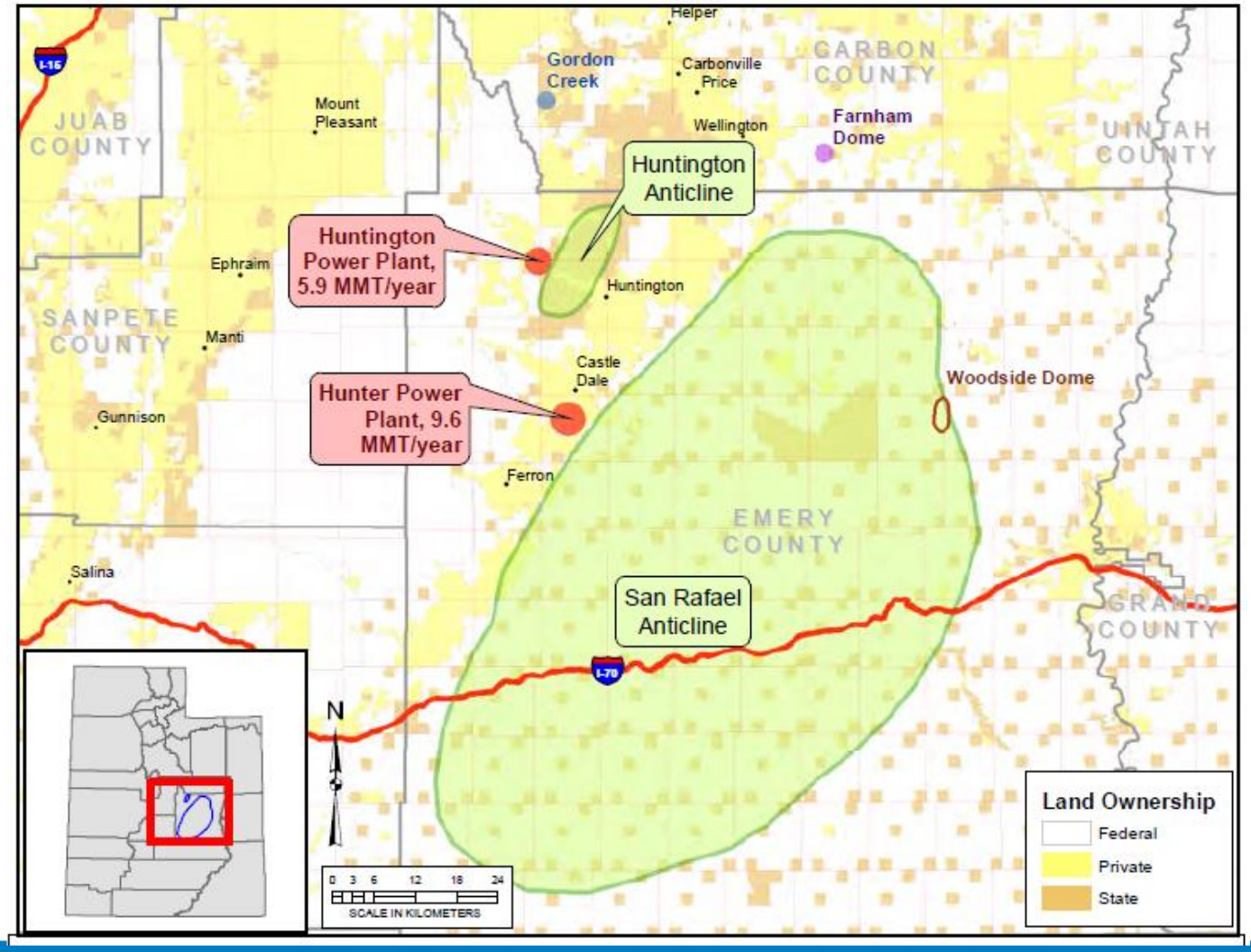
US DOE CCS Pre-Feasibility

San Rafael Swell

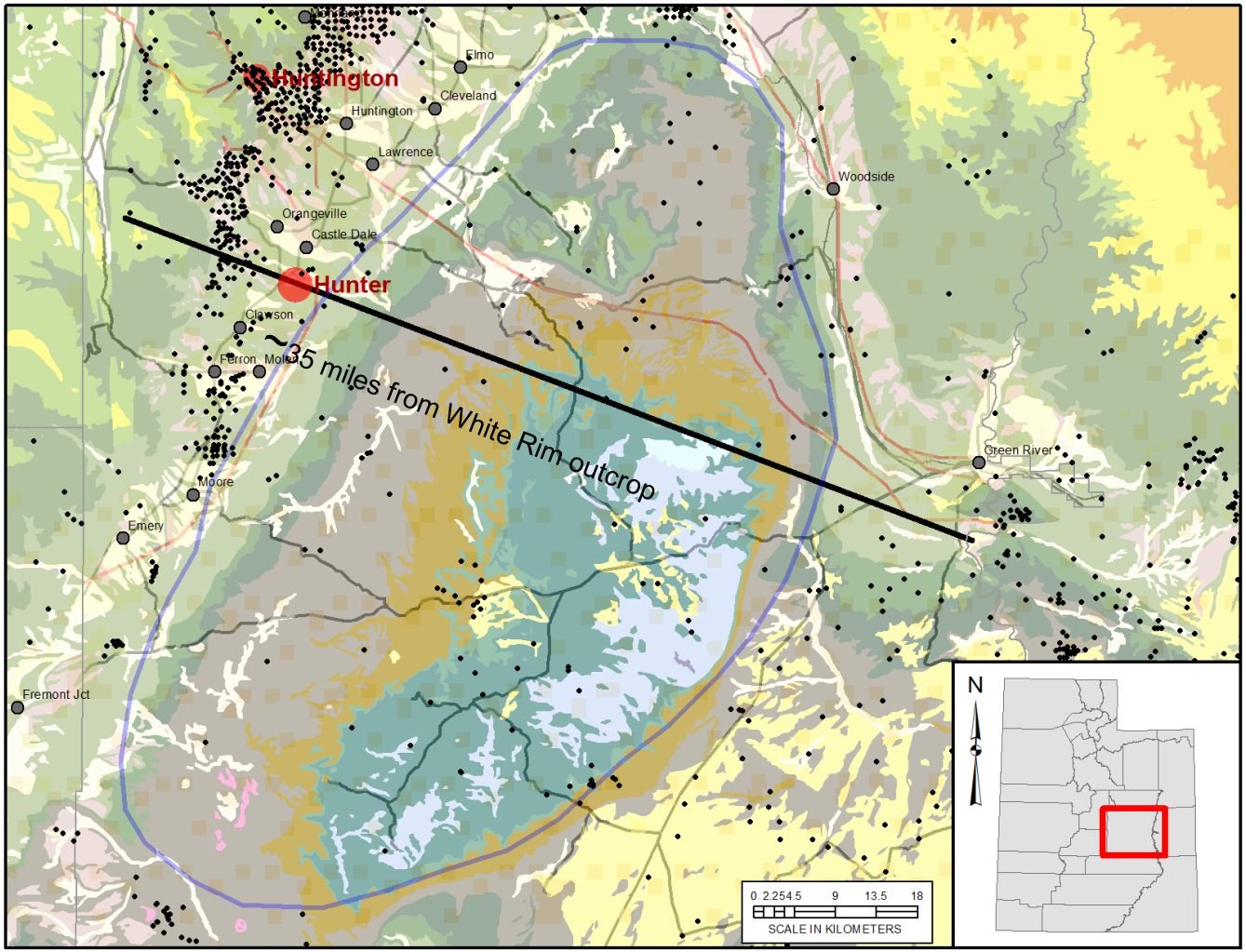
- Proximity to Hunter
- Federal and SITLA (orange squares) land ownership
- Geologic structural anticline
- Forms hydrostratigraphic trap with multiple sealing layers above injection horizon(s)
- White Rim Sandstone is excellent reservoir
  - Sufficiently deep
  - Thick overlying seal
  - High porosity
  - High permeability
  - >160 million metric tons CO_2 storage capacity



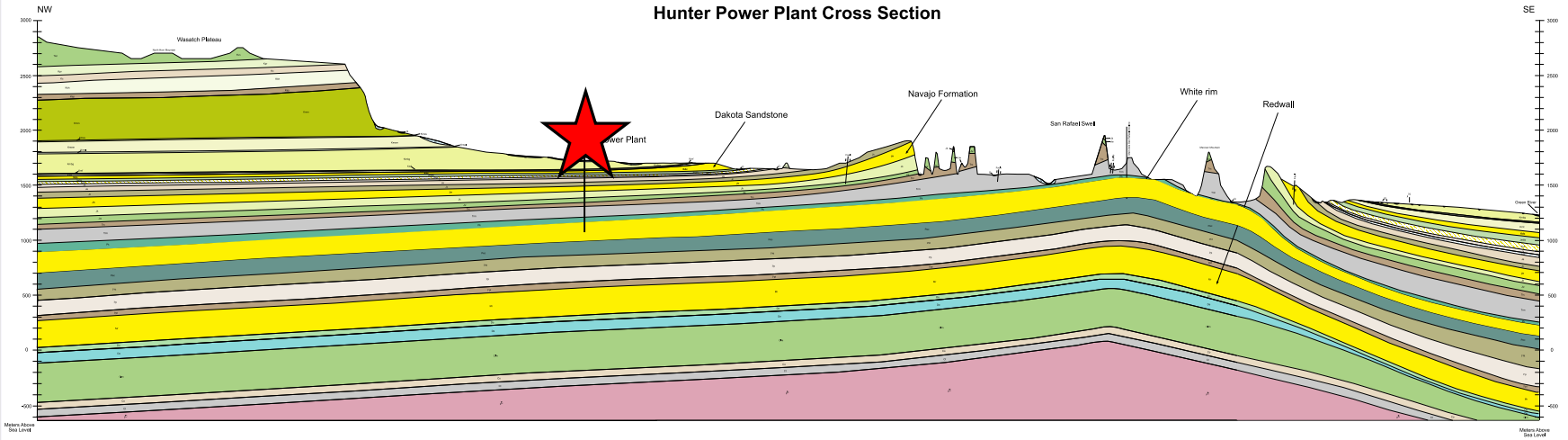
US DOE CCS Pre-Feasibility



US DOE CCS Pre-Feasibility



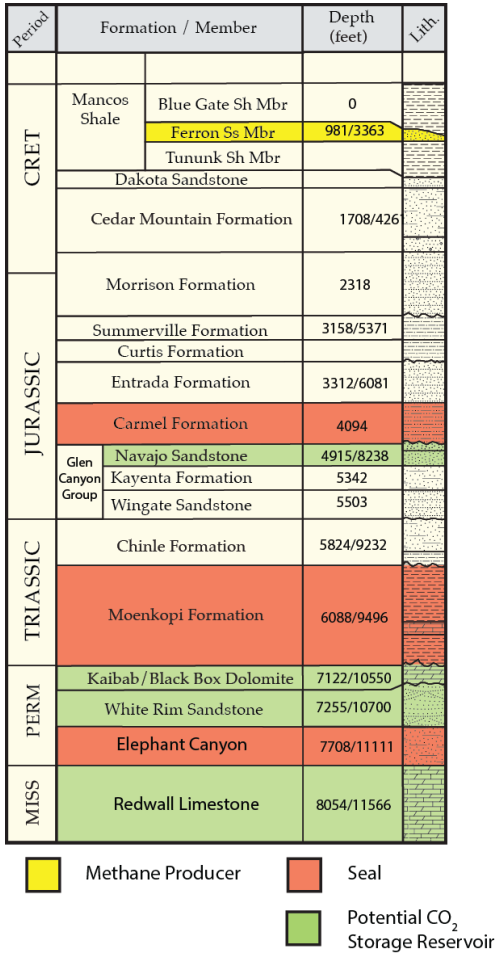
US DOE CCS Pre-Feasibility



US DOE CCS Pre-Feasibility

Colorado Plateau Geology

- Multiple basins characterized by “layer cake” of alternating reservoirs and seals
- Abundant saline aquifers
  - Often sandstones
  - High porosity
  - High permeability
  - Large cumulative CO_2 storage capacity (>250 *billion* metric tons within SWP region)

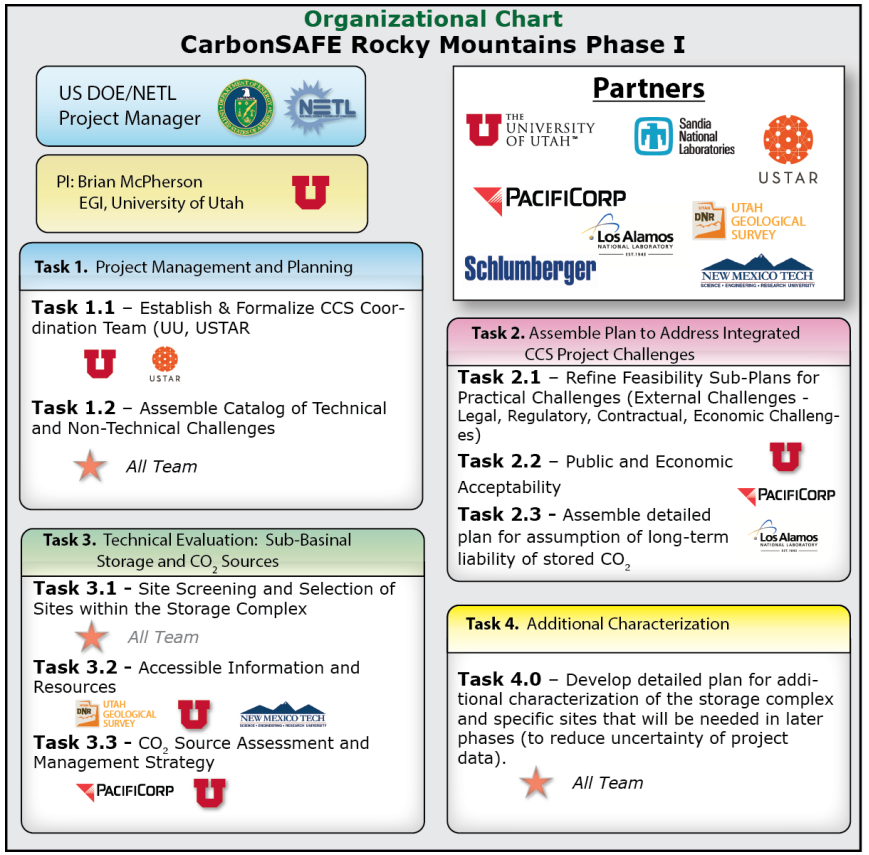


CarbonSAFE

- Application to Phase I submitted to US DOE on August 30, 2016.
- Objective is to secure $1.3 million in US DOE funds which is leveraged from $333k in non-federal funds (including STEP contribution from Rocky Mountain Power)

CarbonSAFE Partners

- University of Utah/Energy & Geoscience Institute
- USTAR
- Utah Geological Survey
- Sandia National Laboratory
- Los Alamos National Laboratory
- Schlumberger Carbon Services
- Utah Division of Environmental Quality
- New Mexico Institute of Mining & Technology
- University of Utah Law School
- Rocky Mountain Power (PacifiCorp)
- Advisory Board (OED, Tri-State, SES, Utah DOGM)



CarbonSAFE - Rocky Mountain Power

- Rocky Mountain Power participation:
  - Co-funding source
  - Providing input on technical, commercial, regulatory and public issues
  - Economics of carbon dioxide capture (future phases)
  - Input on above-ground facilities, access for well siting
- More detail on proposed roles of each partner can be found in the application CarbonSAFE Rocky Mountains Phase I: Ensuring Safe Subsurface Storage of CO_2 in the Intermountain West, DE-FOA-0001584

CarbonSAFE- Budget

- $150,000 to University of Utah
- University of Utah will be monitoring and reporting expenditures to the United States DOE

Recipient Organization	DOE Funds	Non- Federal Cost Share	Total
University of Utah/EGI	$557,495	$121,706	$679,201
UGS	$187,401	$43,642	$231,042
New Mexico Tech	$147,835	$67,501	$215,335
Schlumberger Carbon Services	$112,834	$100,000	$212,834
Sandia National Lab	$112,834	$-	$112,834
Los Alamos	$212,833	$-	$212,833
Total ($)	$1,331,229	$332,849	$1,664,078

CarbonSAFE- Budget

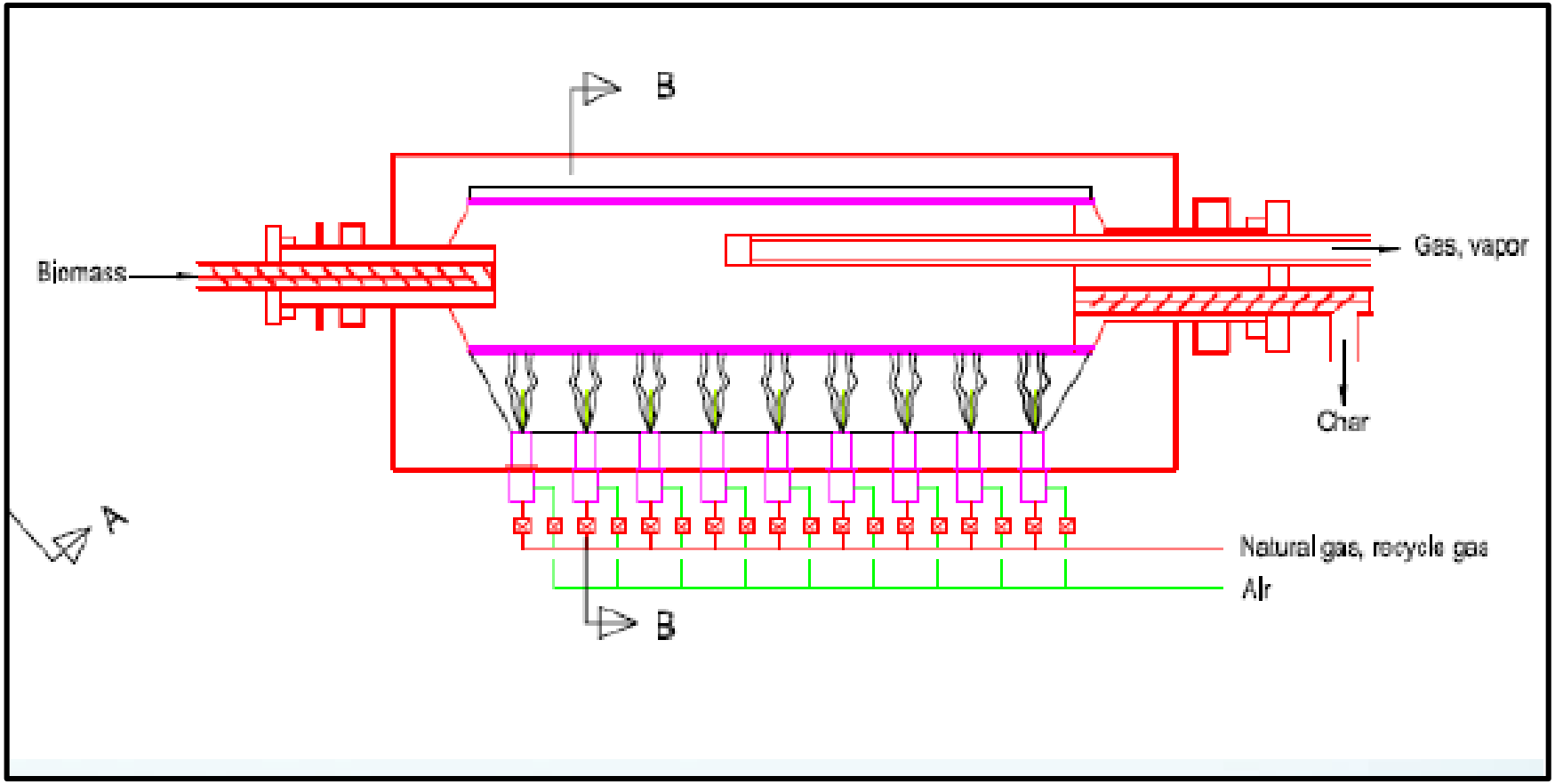
- US DOE – rigorous reporting
  - Tasks and subtasks thoroughly planned
  - Project milestones mapped
  - Project deliverables well defined
  - Regular updates, briefings/reports, review sessions, technical presentations
  - Detailed budgeting and justification
    - By task
    - By fiscal quarter
    - By funded organization

CO_2 Capture
2. Utah Woody Waste Co-Firing

- Apply Utah-based technology that processes “homegrown” woody waste: a) Amaron Energy (torrefaction process) & b) AEG Coal Switch (rapid steam expansion process)
- Perform two single 18-hour 10% woody waste co-firing tests at Hunter 3 using both processes. Additional testing based on economic assessment of woody-waste firing.
- Objective: no adverse plugging/fouling; handle like coal with existing handling facilities. Benefit: assess feasibility of potential periodic removal of Utah’s woody waste
- Coal milling study (2016) with UofU currently in process; includes material from both Amaron and Coal Switch
- Proposal received from University of Utah

Hunter Plant, Castle Dale UT

Overview of Amaron Energy Technology



US Patent 8,298,498,B2

US Patent Application US2012/0063965 A1

Conversion of Prototype to Mobile Platform

Retrofitted to a shipping container, which was then mounted on a trailer for remote deployment

Shipping container approach will also be useful for remote international deployment

Demonstration of Amaron RK240 Unit

Eureka, Nevada July-August 2014

Sunnyside, Utah August 2015

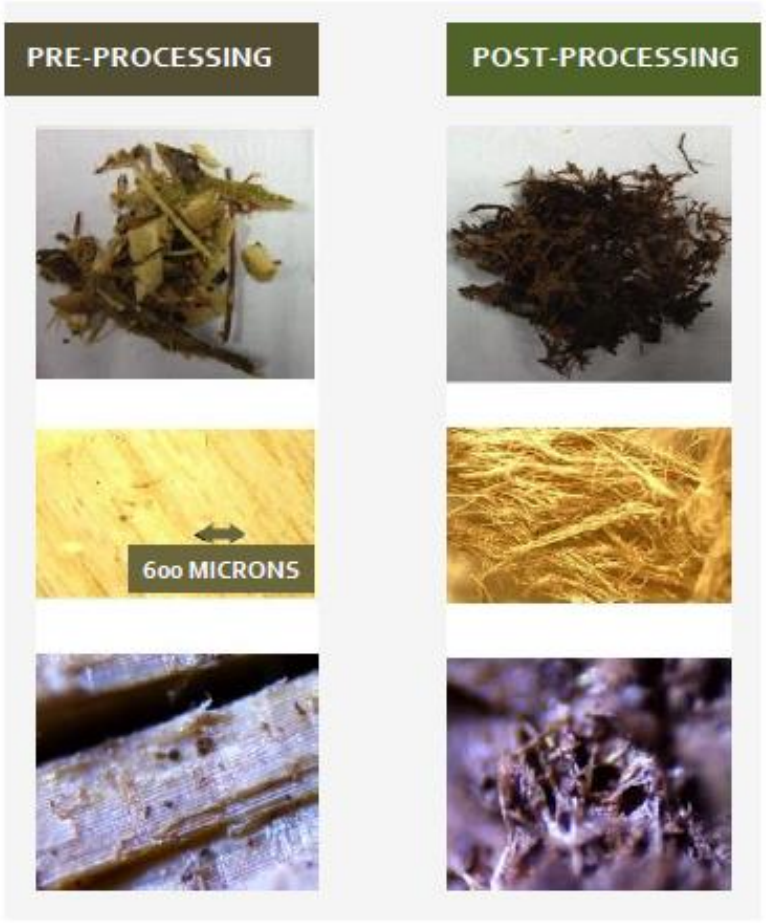
Demonstration of Amaron RK240 Unit

Feed Stock

Char Product

PROCESS OVERVIEW

- 5-Stage Process, utilizes no chemicals and leaves no harmful residues
- Cleanses and optimizes raw Biomass feedstock to:
  - Increase energy density by 50%-300%
  - Increase bulk density to levels comparable to coal
  - Reduce moisture content to less than 15%
  - Reduce salt content (which fouls power plant boilers) by more than 90%
  - Reduce volatility and improve friability of Biomass feedstock to enable co-firing
  - Increase bioavailability to facilitate biological/chemical digestion
- Creates CO_2 offsets and Carbon Tax savings



AEG CoalSwitch

Woody Waste Processing

CoalSwitch – Processed Fuel

CoalSwitch Demonstration Unit Reactor

Hog Fuel	As Rec'd	Beneficiated	Δ (%)
LHV (BTU/lb.)	4200	9018	115%
M/C	50%	12%	(76%)
Sodium (ppm)	4552	426	(91%)
Chloride (ppm)	5053	406	(92%)
[illegible]fate (ppm)	3928	481	(88%)

0.45 Tons @ 12% Moisture content

0.38 Tons of Clean Water

0.17 Tons of Volatiles, Ash, and Salts

AEG CoalSwitch

1 Ton @ 50% Moisture content

Energy Content of Beneficiated Biomass:
9018 BTU/lb. x 2000 lb./Ton x 0.45 Tons
= 8.12 MMBTU (HHV 10248 BTU/lb.)

Energy Content of Volatiles Removed
8.40 MMBTU – 8.12 MMBTU
= 0.28 MMBTU

Energy Required to Beneficiate Biomass:
391 BTU/lb. x 2000 lb./Ton x 1 Ton
= 0.78 MMBTU (from boiler)

Energy Stored in As Rec'd Biomass:
4200 BTU/lb. x 2000 lb./Ton x 1 Ton
= 8.40 MMBTU (HHV = 8400 BTU/lb.)

22% Increase in HHV

Biomass Co-Firing Study
Project Team

- PacifiCorp (Hunter Plant, Corporate Technical Services, Resource Development)
  - Project management & fuel procurement
  - Fuel handling
  - Test management and data gathering
  - Permitting approval
  - Monitoring
- University of Utah & Brigham Young University
  - Test design
  - Specialized instrumentation installation and data gathering
  - Assessment, monitoring and reporting
  - Air quality assessment
- Amaron and AEG CoalSwitch
  - Fuel processing and delivery

Biomass Co-Firing - Budget

	2017	2018	2019	2020	2021	Total
Univesity of Utah						$ -
Task 1 - Biomass Fuel Handling & Stability	$ 19,243					$ 19,243
Task 2 - On-site Measurements	$ 79,585					$ 79,585
Task 3 - Analysis	$ 25,100	$ 25,100				$ 50,200
Task 4 - Combustion Performance Evaluation	$ 36,932	$ 36,932				$ 73,864
Task 5 - Air Quality Assessment		$ 25,000				$ 25,000
Biomass Fuel & Processing	$ 396,981					$ 396,981
Test Design	$ 20,000					$ 20,000
Instrumentation	$ 10,000					$ 10,000
Travel	$ 5,000	$ 5,000				$ 10,000
Biomass Market Study		$ 35,000				$ 35,000
External Consulting	$ 20,000	$ 50,000				$ 70,000
Total	**$ 612,841**	**$ 177,032**	**$ -**	**$ -**	**$ -**	**$ 789,873**

CO_2 Capture
3. Cryogenic Carbon Capture (CCC) Demo

- Leverage existing equipment and $4.7 million in outside funding to prepare and demonstrate promising Utah technology for scale-up
  - Research and modify some key aspects of process
  - Long term test of CCC technology at Hunter or Huntington
  - Techno-economic & Environmental, health & safety assessments
  - Team SES, RMP, Tri-State, EPRI, NRECA

Cryogenic Carbon Capture Research Objectives

Research and modify key aspects of technology

- Process reliability for long-term demonstrations
- Multi-pollutant capture (SOx, NOx, Mercury in addition to CO_2)

Long-term testing (6-9 months) at Hunter or Huntington

- Key to securing $20+ million from outside funders for scale-up

Independently validated techno-economic analysis

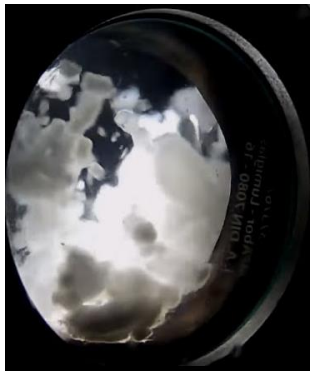
- Independent work done by EPRI, input from RMP and Tri-State

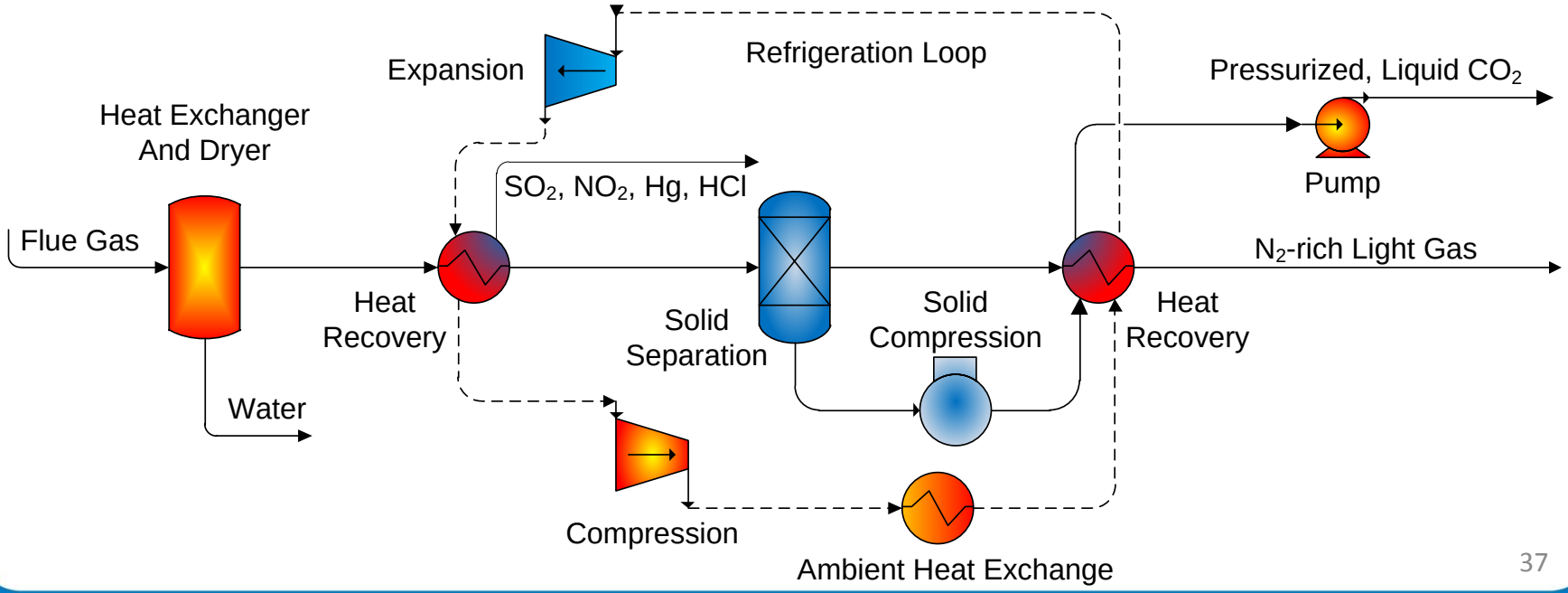
Specific case studies for RMP and Tri-State plants

- Site specific evaluation of cost and energy requirements
- Environmental, Health, and Safety evaluation

Sustainable Energy Solutions (SES) – Cryogenic Carbon Capture

Process removes CO_2 and other pollutants using heat recovery to cool the flue gas stream and separate components in solid or liquid form.





CCC Process Potential Benefits

Half the cost and energy of existing alternatives

Retrofit technology to existing plants

Robustly handles criteria pollutants such as SOx, NOx, mercury and particulates

Cryogenic Carbon Capture – Project Team

- PacifiCorp (Huntington / Hunter plants, Corporate Technical Services, Resource Development)
  - Funding
  - Project management & procurement
  - Installation of tie-in facilities
  - Operations data collection
  - Permitting assistance
  - Summary reporting
  - Scale-up cost estimate
- NRECA
  - Advising
- Sustainable Energy Solutions
  - R&D work
  - Equipment installation, operation and testing
  - Permitting approval
  - Monitoring and reporting
- Tri-State
  - Environmental, health, and safety assessment
  - Advising
- EPRI
  - Independent techno-economic analysis

Cryogenic Carbon Capture - Budget

	2017	2018	2019	2020	2021	Total
Pre-Run Budget	$ 356,557	$ 159,144				$ 515,701
Field Test Run						
Lodging, M&I Expenses		$ 76,190				$ 76,190
Transportation		$ 17,100				$ 17,100
Salaries		$ 255,487				$ 255,487
Loading & Transportation		$ 7,000				$ 7,000
Liability Insurance		$ 45,000				$ 45,000
Supplies & Consumables		$ -				$ -
Temporary on-site work space		$ 20,000				$ 20,000
Water Treatment & Disposal		$ 10,000				$ 10,000
Overhead for Supplies and Travel		$ 53,380				$ 53,380
Consulting	$ 25,000	$ 25,000	$ 25,000			$ 75,000
Capital Cost Assessment (Scale Up)			$ 100,000			$ 100,000
	$ 381,557	$ 668,301	$ 125,000	$ -	$ -	$ 1,174,858

Utah DPU Questions

Regarding the co-funding of University of Utah Phase 1 Pre-feasibility Study of Commercial CO_2 Sequestration sites in Utah:

- Please explain in detail Rocky Mountains participation in the study.
- How will the $150,000 be spent? If it is added to other co-participants funding, how will Rocky Mountains contribution be monitored or verified?

Utah DPU Questions – Carbon Capture

Regarding the co-funding of Sustainable Energy Solutions' Cryogenic Capture Technology -

- What is the total anticipated cost of the project?
  - The total project cost is estimated to be $6,059,206; RMP's portion, if awarded, is $1.174 million.

Utah DPU Questions – Carbon Capture

- Who has committed funds and how much has been committed by each entity (also timeline)?
  - US DOE has conditionally approved funds of $3,743,249. Other entities including SES, EPRI and Tri-State have committed in-kind and cash cost share of $1,141,100. RMP's participation would be $1,174,857.

Org.	Contribution	Start Date	End Date
DOE/NETL	$3,743,249	10/1/16	3/31/19
Rocky Mountain Power	$1,174,857	1/1/17	3/31/19
SES	996,100	10/1/16	3/31/19
Tri-State	$70,000	10/1/16	3/31/19
EPRI	$75,000	10/1/16	3/31/19

Utah DPU Questions – Carbon Capture

- How much will PacifiCorp pay in total?
  - $1,174,858
- What portion of PacifiCorp's fund commitment is allocated to STEP?
  - PacifiCorp’s commitment is contingent on STEP funding
- When was the company first approached by Sustainable Energy Solutions regarding the project?
  - RMP approached SES; RMP has been following the technology since 2008. RMP hosted a short duration demonstration at the Dave Johnston Plant (2014)

Questions?