UKy-CAER Heat-integrated Transformative CO_2 Capture Process in Pulverized Coal Power Plants (DE-FE00031583)

Kunlei Liu, Heather Nikolic and Jesse Thompson

University of Kentucky

Center for Applied Energy Research

Lexington, KY

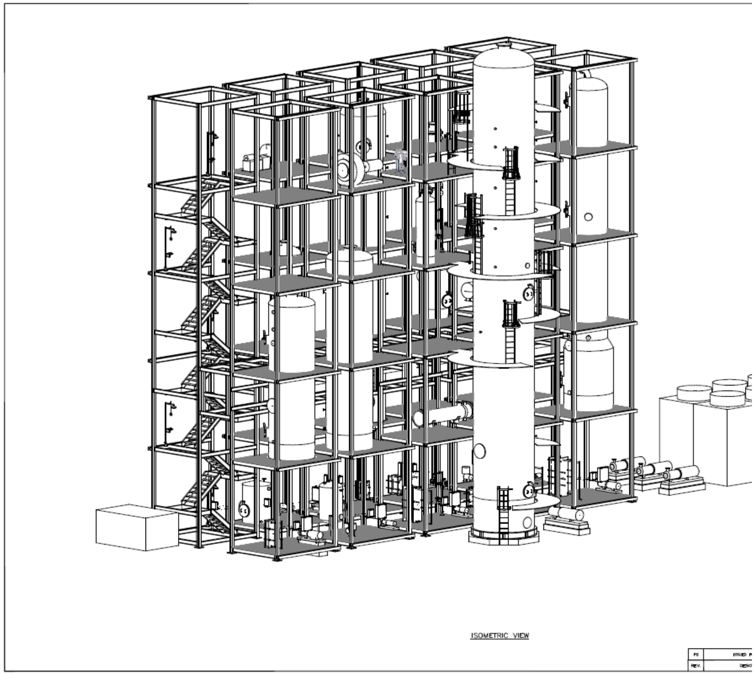
http://www.caer.uky.edu/powergen/home.shtml

DOE-NETL's Integrated Project Review Meeting-- CCUS

August 18-19, 2020

Executive Summary

- Process oriented technology, applicable with any 2nd generation solvent with short columns and low operating cost, proven at bench and small-pilot
- Host site at WY ITC, minor source air permits for construction approved
- All engineering-related activities complete, fixed cost estimate in progress
- TEA in progress
- EIV revision complete
- Team in place with expertise covering all aspects – chemistry, engineering, fabrication, installation, operation, control, environment, health and safety, permit and waste management
- Cost share arrangements in progress

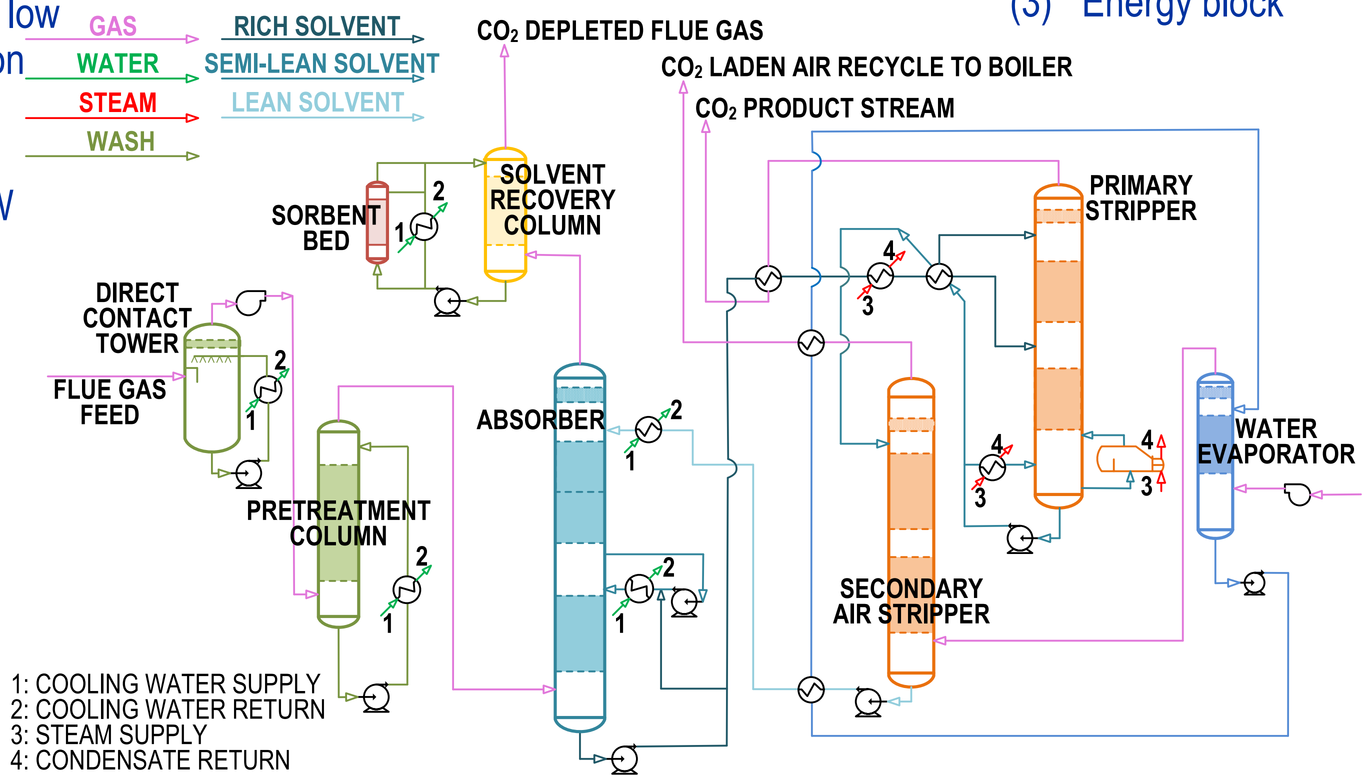


Project Team Member	Working Together Since	Significant Accomplishments Together
CCSUS	2016	Solvent campaigns conducted at large bench and small pilot scales
CMU	2018	New collaborator on advance process control
EPRI	2008	CCS TEAs since 2012; 0.7 MWe small pilot CCS independent testing and calculation verification
ITC	2018	10 MWe large pilot CCS host site for design basis
KMPS	2009	0.7 MWe small pilot CCS ISBL process and equipment design and supply
Parsons	2011	CCS TEA cost estimation and large-pilot OSBL
SMG	2009	EH&S assessments, NEPA and EIVs of CO_2 capture
Trimeric	2015	Cost estimation of CCS and gasification processes
UTA	2013	Aspen model and simulation development 0.7 MWe small pilot CCS emissions monitoring

UKy-CAER CO_2 Capture Technology
Self-adaptive (Operating Conditions and Solvents)

Heat recovered internally for:
(1) Relatively stable steam extraction
(2) Partial CO_2 cycling for low ST and low degradation
(3) DI water
(4) Amine direct cooling
(5) Desuperheating by FW

Advanced Control:
(1) In-line C, N signal
(2) Forward feed
(3) Energy block



Process Intensification:
(1) Discretized packing
(2) In-situ gas/liquid distributor
(3) Split rich feed
(4) Enhanced WWC

CAPx and OPEx Balanced:
(1) Solvent chemical and physical properties
(2) Undersized equipment

From Bench to Small-pilot and Large-pilot

UKy-CAER CCS Transformative Technologies (Scale Verified)

- Heat Integration, Two-stage Stripping with Low Primary Stripper Temperature (CAER Small Pilot)
- Discretized Packing and Load-robust Liquid/Gas Distribution (CAER Large Bench and Industrial-scale)
- Solvent Recovery System (CAER Large Bench and Small Pilot)
- Undersized L/R Exchanger and Pressurized Stripper (CAER Small Pilot and Industrial practice)
- Carbon Steel Material of Construction (Industrial common practice)
- Undersized Thermal Reclaimer with Continuous Operation (CAER Small Pilot)
- Advanced Solvent (CAER Small Pilot and CCSL Large Pilot)
- Short Packing Column (CAER Small Pilot)
- Advanced Control with Energy Computing Block (CAER Small Pilot and CCSI)
- Split Rich Solvent Feed to Primary Stripper (UT Small Pilot at NCCC)
- Exergy Loss Minimization using FW Heater (CAER Aspen simulation)

UKy-CAER 0.7 MWe Small Pilot CCS Findings

- Net 8 MWe gain from the steam superheat recovery prior to reboiler
- Minimum energy consumption obtained at max temperature drop inside stripper
- 30-40 minutes response time to load changes
- Absorber oversized and near-equilibrium solvent absorption with 40 ft packing
- 36% lower regeneration energy compared to RC 10 achieved with advanced solvents
- Se levels in the solvent after 1000 hours run exceed the RCRA hazardous waste limit
- Additive/inhibitor effective for multi-function as reducing corrosivity and degradation
- Thermal compression benefits realized only when L/R exchanger approach T <20 °F
- 4.9-1385 ppmv amine solvent emissions due to entrainment and aerosol formation
- Column channel flow observed by 20 °F shift under same conditions
- 90% CO_2 capture with 99.9+% purity easily achieved
- Air stripper regenerates >10% of CO_2 captured
- Insignificant corrosion on amine contacted wet surface except stripper
- Impact of secondary air stripper on solvent oxidative degradation is negligible
- 13% lower regeneration energy compared to RC 10 achieved with MEA

UKy-CAER 0.7 MWe Small Pilot CCS >4500 operational hours logged

2015	2016	2017	2018	2019 - 2024
MEA	H3-1 CAER	6M MEA	UK A2 CDRMax	CDRMax, UK Solvent

Preliminary Economic Analysis

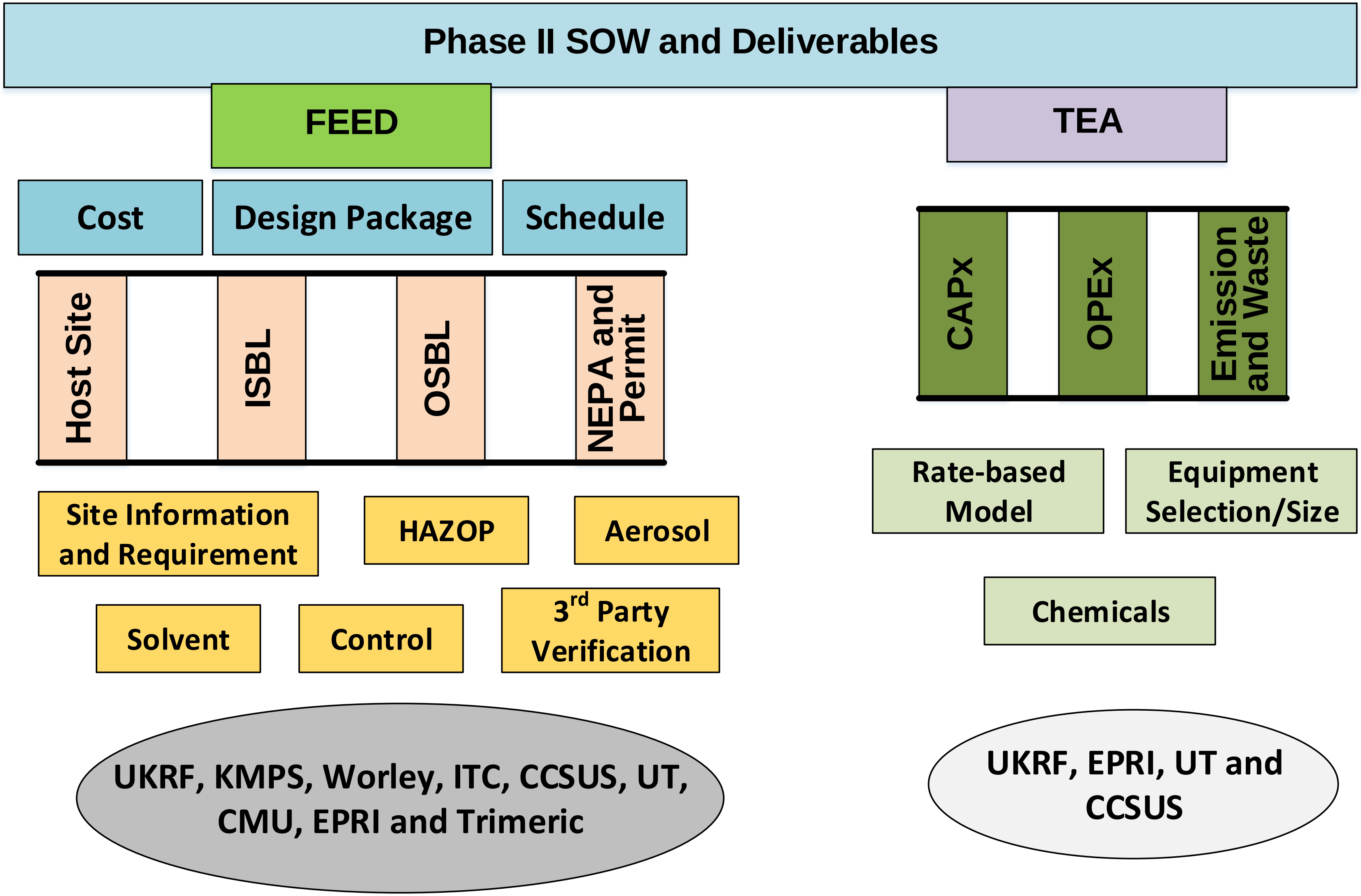
Economics of Integrated UKy-CAER CCS.

UKy-CAER CCS Cost Estimate	RC B12B[11]	UKy-CAER CCS	Percent Difference
Net Power, MWe	550	550	0%
Total Plant Cost (2011 $/kW)	3524	2977	-16%
Total Overnight Cost (2011$/kW)	4333	3660	-16%
Total As-Spent Cost (2011$/kW)	4940	4173	-16%
COE ($/MWh, 2011$) (including T&S)	142.8	125.2	-12%
COE ($/MWh, 2011$) (excluding T&S)	133.2	116.9	-12%
CO_2 T&S Costs	9.6	8.3	-13%
Fuel Costs	30.9	29.5	-5%
Variable Costs	12.3	12.4	1%
Fixed Costs	15.4	13.0	-16%
Capital Costs	72.2	61.9	-14%
Cost of CO_2 Captured ($/tonne CO_2) (including T&S)	67.8	51.4	-24%
Cost of CO_2 Captured ($/tonne CO_2) (excluding T&S)	58.2	41.4	-29%
Cost of CO_2 Avoided ($/tonne CO_2)	89.4	61.6	-31%

Goals and Objectives

- Phase II
  - Complete all necessary preparation and be ready to begin fabrication design and construction immediately in Phase III
    - Complete the FEED
    - Detailed cost and schedule for Phase III (ISBL is fixed cost, OSBL is Class 2)
    - Completing the permitting process with WY ITC as host site
  - Securing cost share for Phase III
  - Updating the TEA
- Phase III
  - Complete detailed engineering design, procurement, fabrication, assembly, and construction
  - 2000 hours of testing and demonstration
  - Technology transfer

Phase II Scope of Work

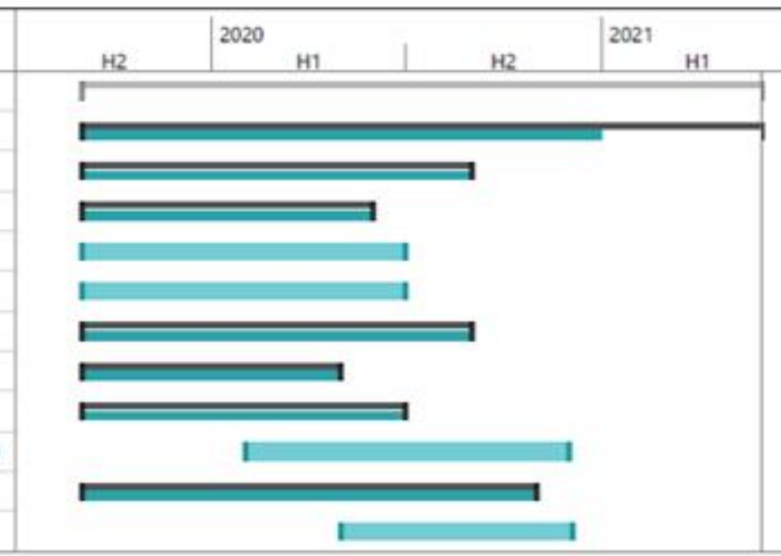


Center for Applied Energy Research

Project Funding and Gantt Chart

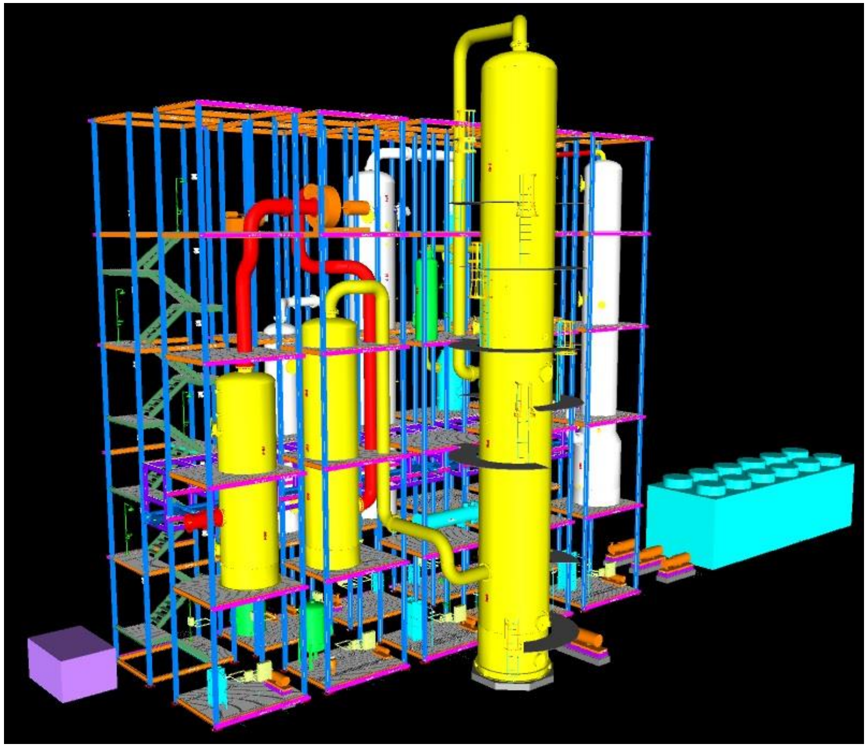
Funding	Funding	Performance Dates
Phase I	$1,177,550	04/01/18 to 08/31/19
Phase II	$2,786,841	09/01/19 to 5/31/21

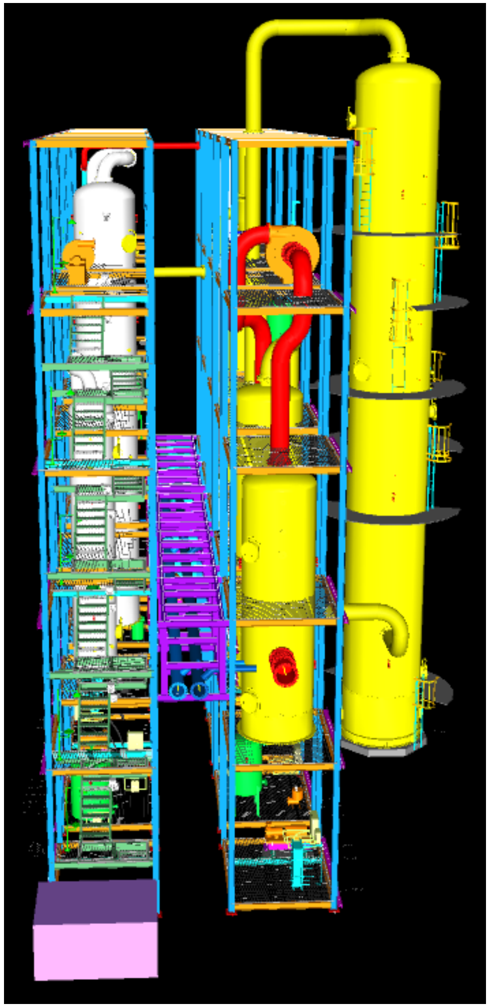
Task Name	Start	Finish
Phase II Schedule	Sun 9/1/19	Mon 5/31/21
1 Project Management and Planning	Sun 9/1/19	Mon 5/31/21
2 FEED Study	Sun 9/1/19	Mon 8/31/20
2.1 ISBL Feed Study	Sun 9/1/19	Sun 5/31/20
2.2 CCS Process Control Scheme	Sun 9/1/19	Tue 6/30/20
2.3 Aerosol Emissions Model Development	Sun 9/1/19	Tue 6/30/20
2.4 OSBL FEED Study	Sun 9/1/19	Mon 8/31/20
2.5 Process HAZOP	Sun 9/1/19	Thu 4/30/20
3 NEPA/Permitting at Host Site	Sun 9/1/19	Tue 6/30/20
4 Team and Cost Share Commitments	Sat 2/1/20	Mon 11/30/20
5 Techno-Economic Analysis	Sun 9/1/19	Sat 10/31/20
6 Project Schedule and Cost Estimate	Fri 5/1/20	Fri 12/4/20



caer.uky.edu

ISBL Completed





KMPS issued: solution volumes, IA datasheet, equipment list, pump, blower and filter specifications, and foundation loads.

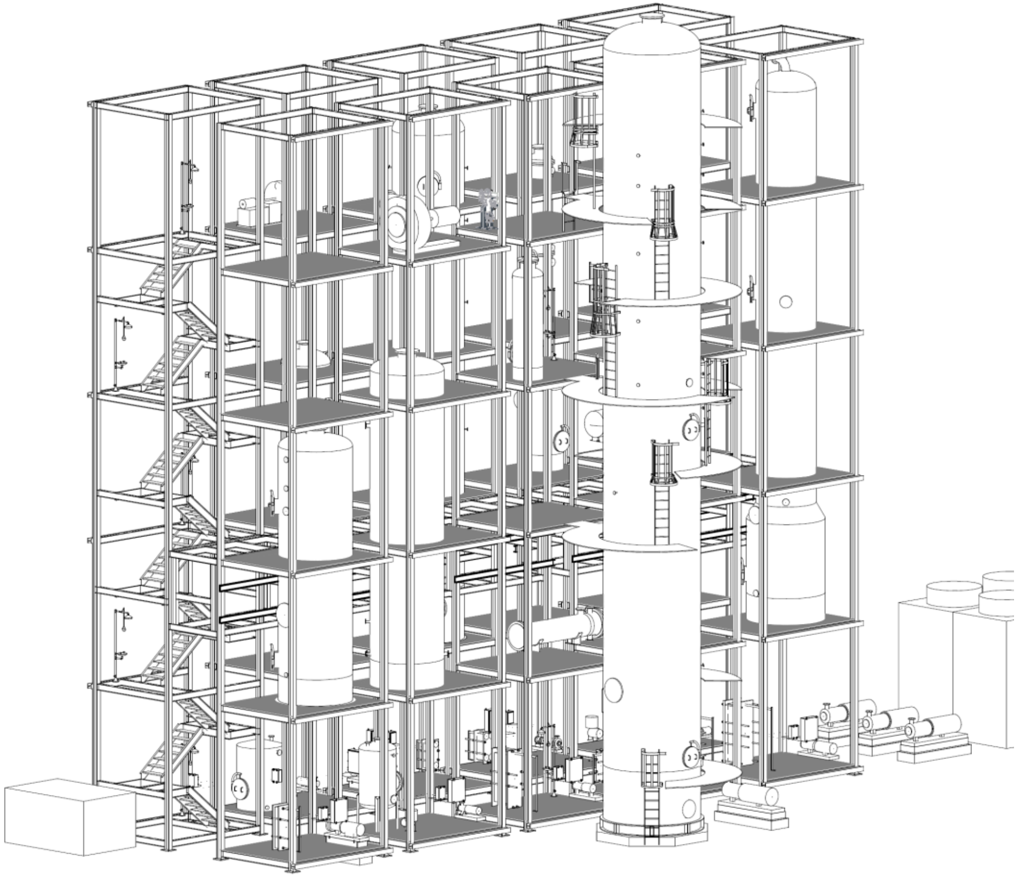
Facilities

0.7 MWe

2x3 (total 6 modules) with stand-alone integrated cooling tower

Footprint of CCS modules: 28’ x 44’
Highest: 75’

10 MWe



2x5 (total 10 modules) with stand-alone absorber and conventional cooling tower

Footprint of CCS modules: 34’ x 76’
Highest: 88’

Host Site and PC Unit

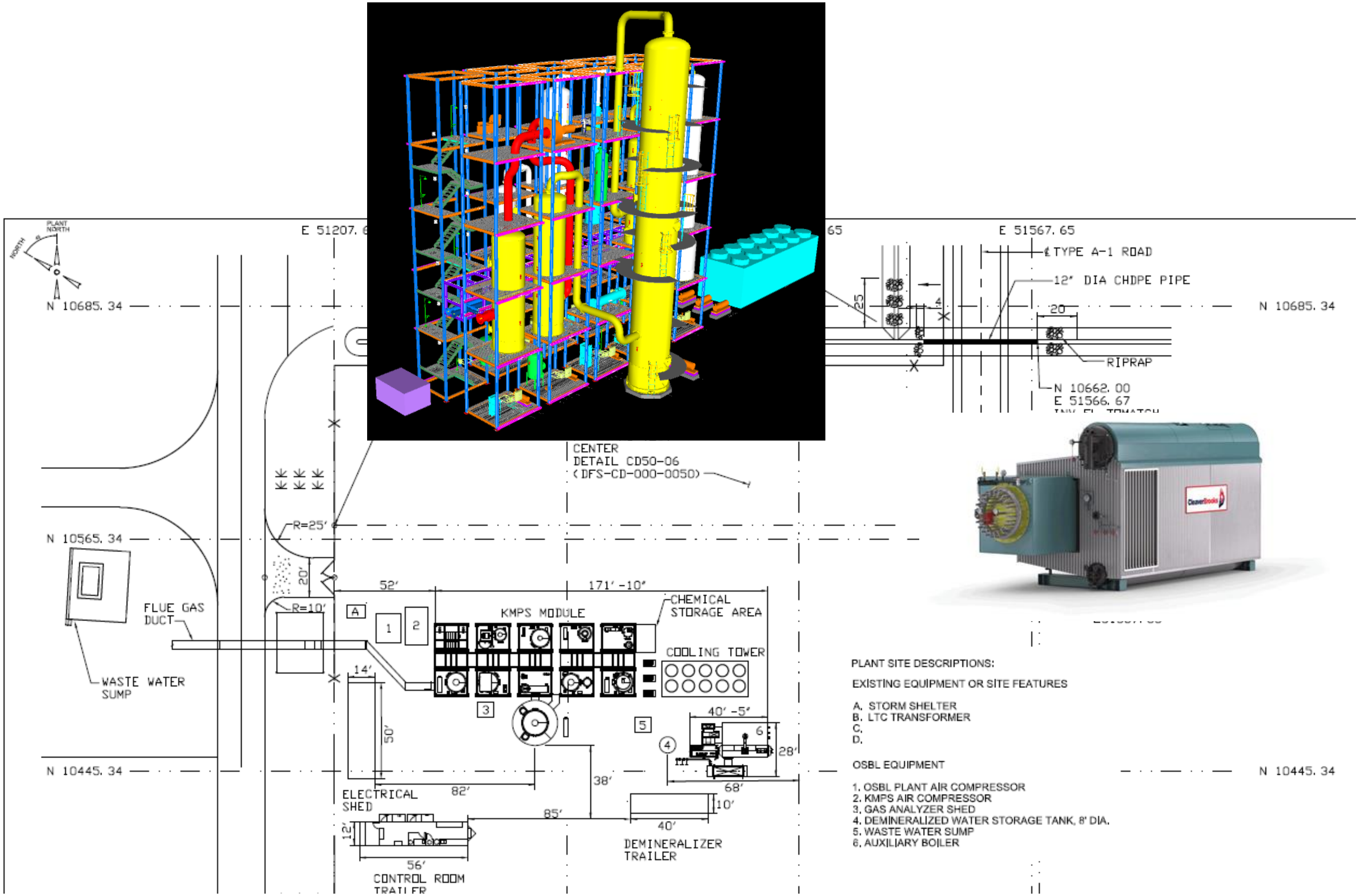
0.7 MWe

KU's EW Brown Generating Station	
Elevation	850 ft
Temperature	27 - 87 °F
Unit 3	
Boiler	Wall-fired PC
APCD	Low NOx Burner, SCR, ESP, PAC+Baghouse, WFGD
Steam Cycle	Subcritical, 457 MWe (net)
Coal	Eastern bituminous coal

10 MWe

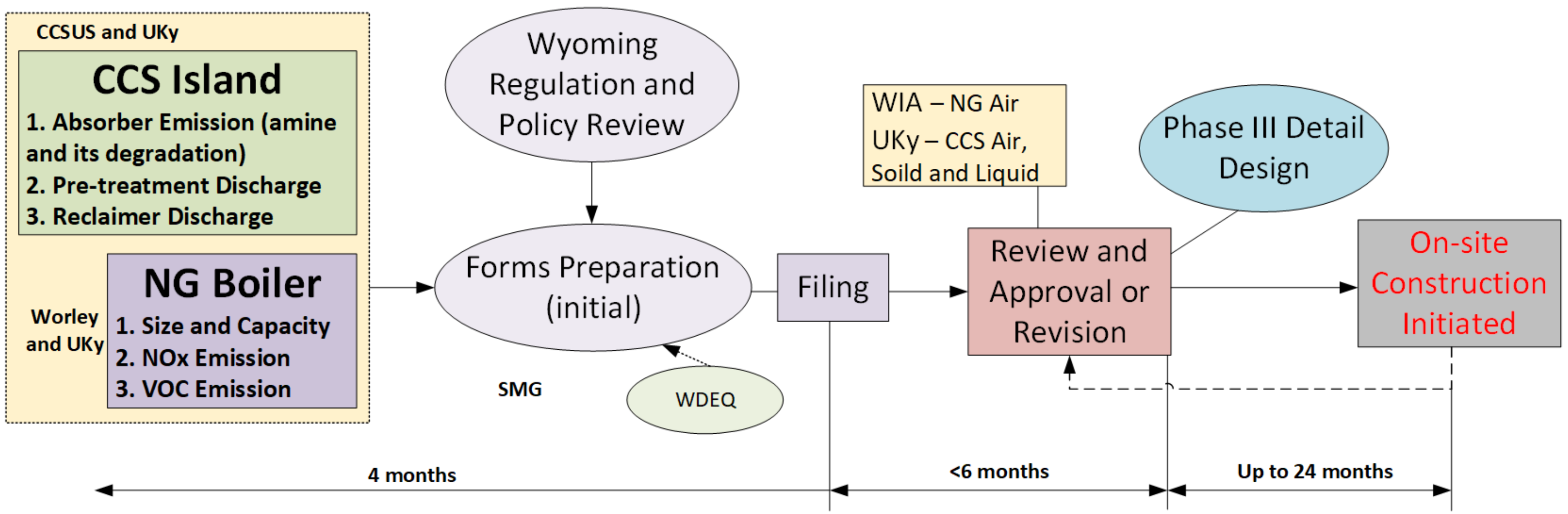
ITC in conjunction with BEPC Dry Fork Station	
Elevation	4250 ft
Temperature	-40 - 37 °F
Unit 1	
Boiler	Wall-fired PC
APCD	Low NOx Burner, SCR, Spray-dry FGD
Steam Cycle	Subcritical, 385 MWe (net)
Coal	PRB

10 MWe Facility General Layout

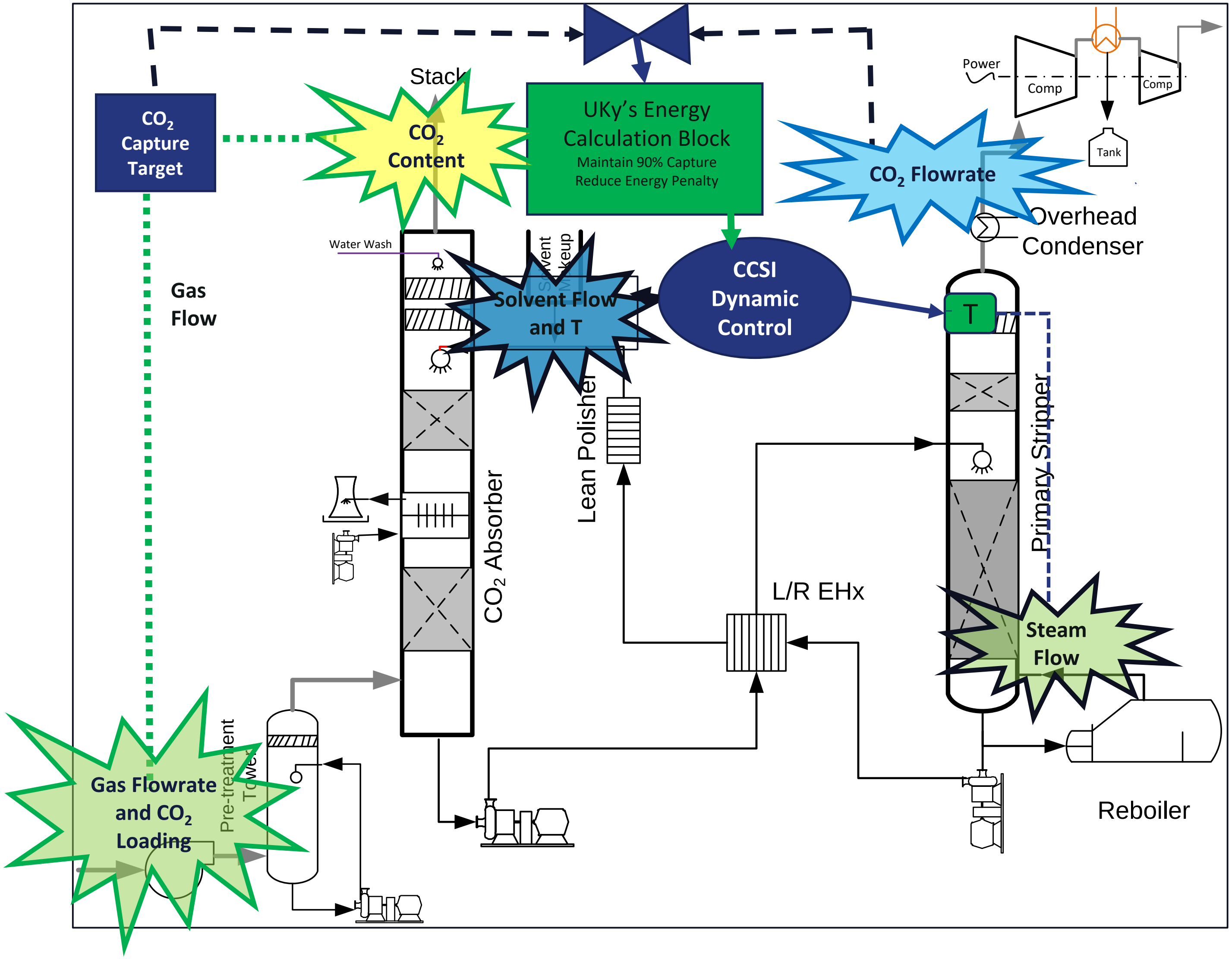


Permitting Process and Permits Approved

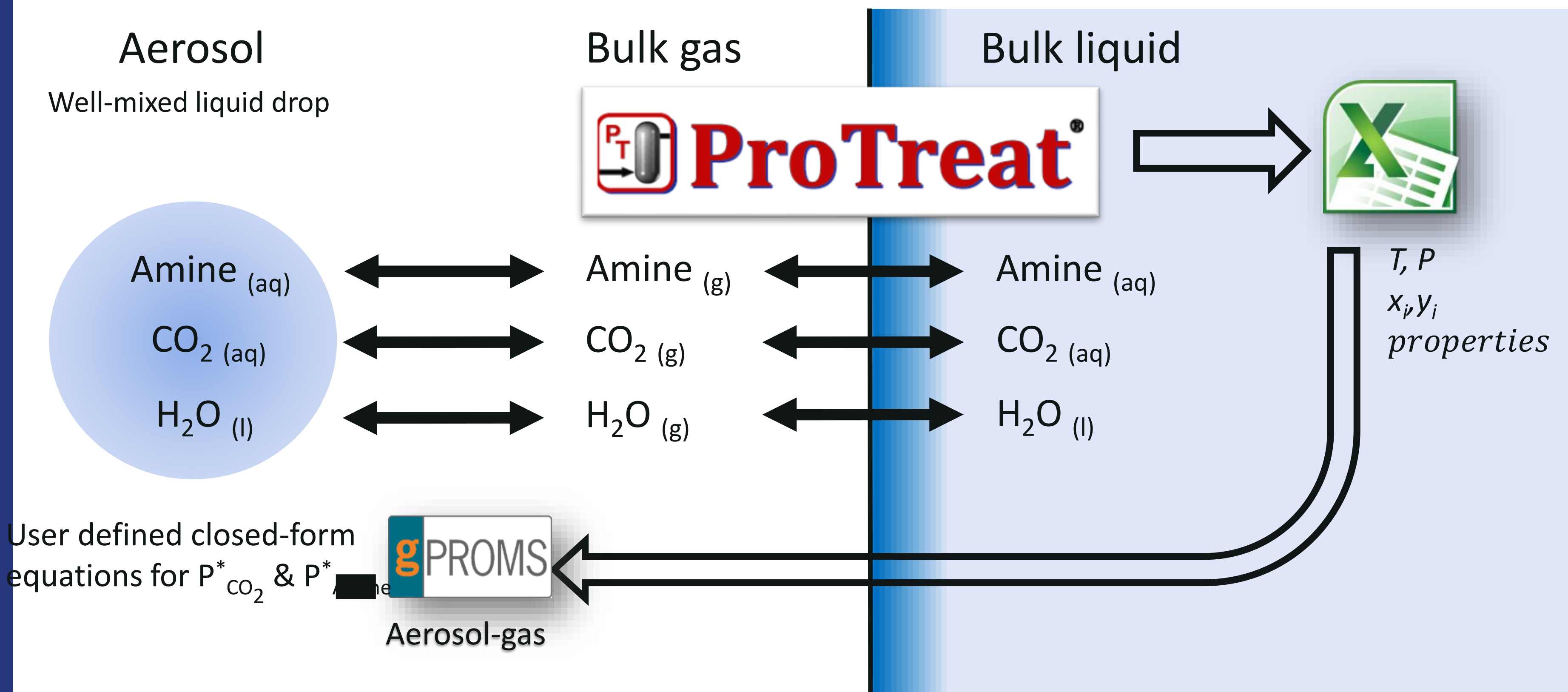
- Minor source construction permits are required under WDEQ's NSR program prior to commencing construction: NG boiler and CCS processed flue gas



Forward-feed and Energy Computational Control



Aerosol Modeling and Verification



UK CAER CO_2 Capture Research TRL Advancement

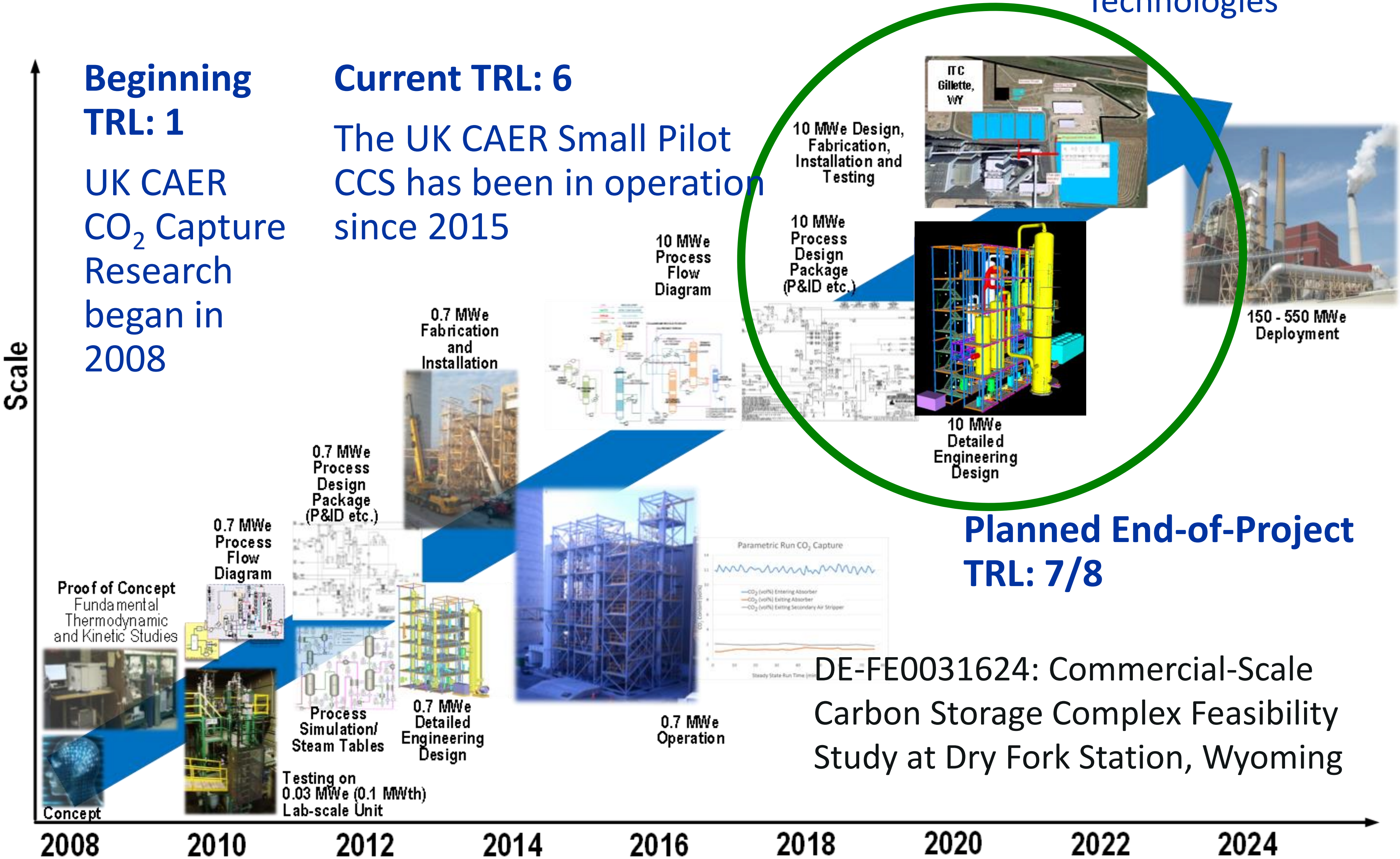
KMPS
Worley
CO_2 Management Technologies

Beginning TRL: 1

UK CAER CO_2 Capture Research began in 2008

Current TRL: 6

The UK CAER Small Pilot CCS has been in operation since 2015



Planned End-of-Project TRL: 7/8

DE-FE0031624: Commercial-Scale Carbon Storage Complex Feasibility Study at Dry Fork Station, Wyoming

Wrap-Up

- UK CAER has a demonstrated CO_2 capture technology ready for the large-pilot with minimal risk
- All engineering aspects of the ISBL SOW complete
- Fixed cost for ISBL and Class 2 for OSBL in process
- Cost share is identified and being finalized
- Plan for technology transfer in Phase III

Acknowledgements

U.S. DOE NETL: Andy Aurelio, José Figueroa, Greg O'Neil, Lynn Brickett and John Litynski

ITC: Ray DeStefano, Jim Ford, Will Morris and Jason Begger

CCSUS: Will Shimer, Dave Bahr and Gopi Kiran

EPRI: Abhoyjit Bhown and Yang Du

KMPS: Stan Lam and Terence Nish

Worley: Keith McKenrick, Gary Von Bargen, and Sandeep Jain

SMG: Clay Whitney and Stewart McCollam

Trimeric: Rosalind Jones and Andrew Sexton

UTA: Korede Akinpelumi and Gary Rochelle

CUM: David Thierry and Lorenz Biegler

UKy: Don Challman