Sixth Annual Conference on Carbon Capture & Sequestration

Technical Session: Capacity Building

Carbon Dioxide Recovery from Power Plant Flue Gas Using Supported Carbonate Sorbents in a Thermal-swing Process

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Outline

- Project Background and Past Research
- Process Design
- Bench-scale Testing of Integrated Process Unit
- Slipstream Testing at Combustion Research Facility
- Path Forward

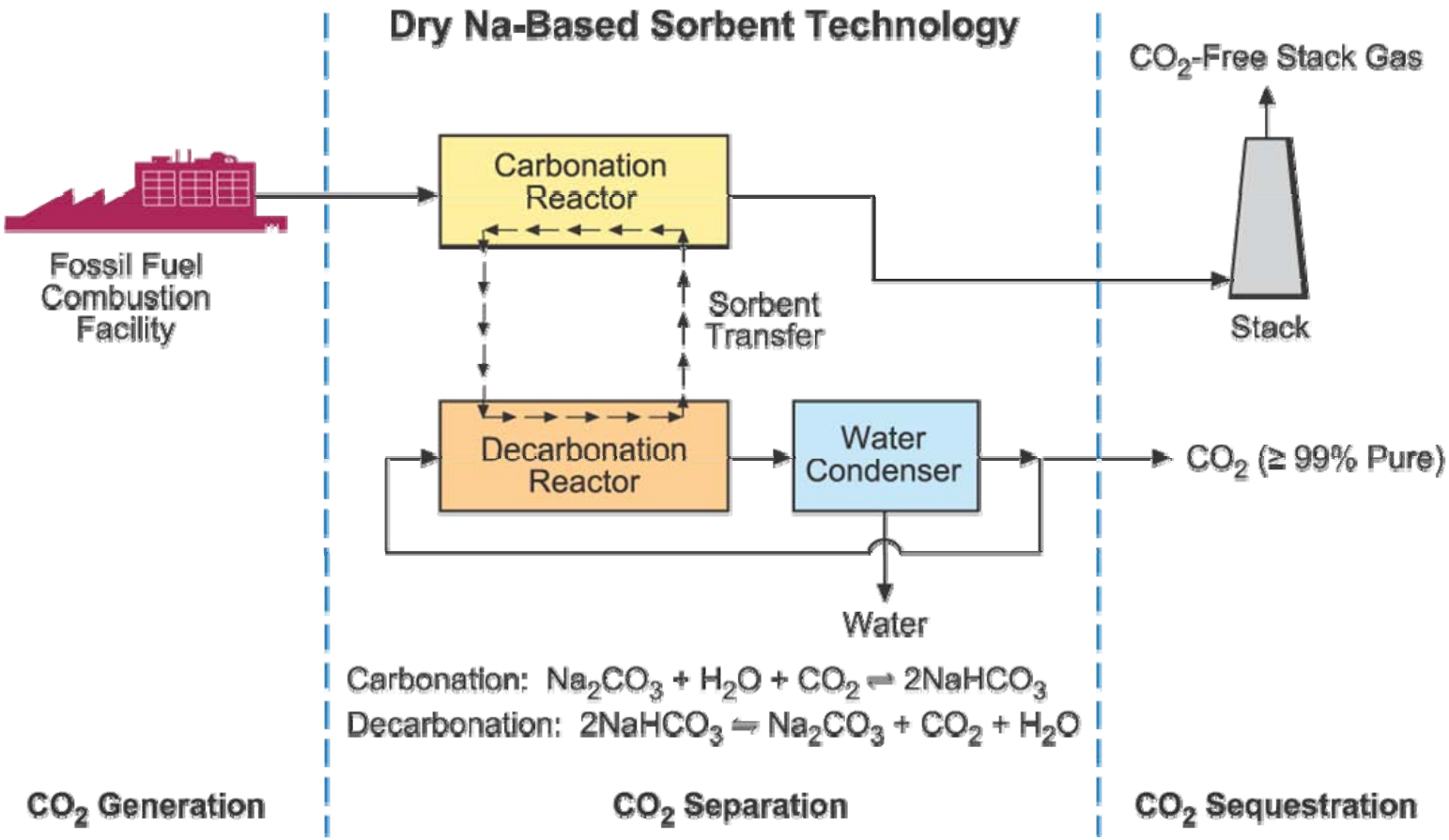
Project Objectives

To develop a carbon dioxide capture technology that is

- Based on a solid, regenerable, carbonate sorbent
- Applicable to flue gases of coal and natural gas-fired power plants
- Intended for retrofit in existing plants
- Less expensive and less energy intensive than current technologies (MEA)
- Of relatively simple process design

Concept of "Dry Carbonate" Process

CO_2 Capture from Flue Gas



Reaction Chemistry

- CO_2 absorption (carbonation):

$$Na_2CO_3\,(s) + CO_2(g) + H_2O(g) \leftrightarrow 2NaHCO_3(s)$$

- Sorbent regeneration (decarbonation):

$$2NaHCO_3(s) \leftrightarrow Na_2CO_3(s) + CO_2(g) + H_2O(g)$$

- Wegscheider's Salt:

$$5/3\ Na_2CO_3\,(s) + CO_2(g) + H_2O(g) \leftrightarrow 2/3\ Na_2CO_3{\cdot}3NaHCO_3(s)$$

- Effect of HCl and SO_2:

$$Na_2CO_3\,(s) + 2HCl(g) \rightarrow 2NaCl\,(s) + CO_2\,(g) + H_2O\,(g)$$
$$Na_2CO_3\,(s) + SO_2\,(g) + \tfrac{1}{2}O_2\,(g) \rightarrow Na_2SO_4\,(s) + CO_2\,(g)$$

- No Effect of O_2 and NO_x

Reaction Chemistry

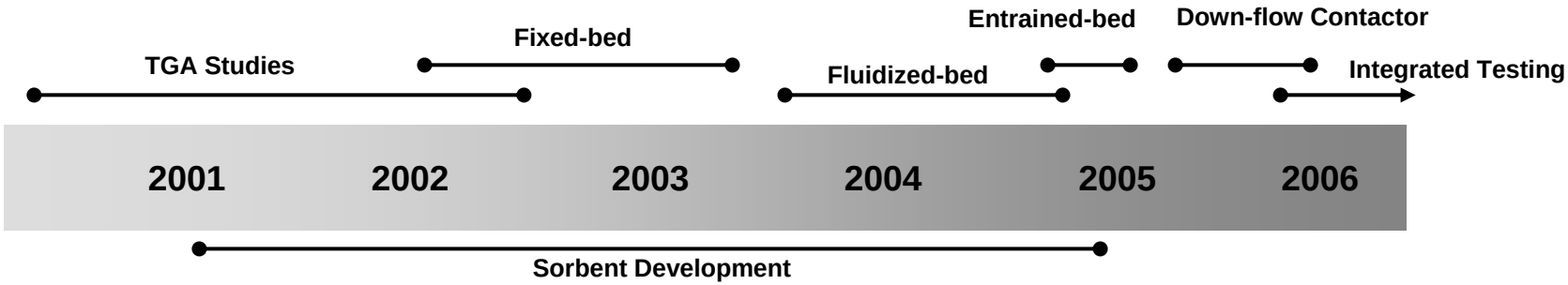
Reaction	Δ H Kcal/gmol CO_2
$2/3\ Na_2CO_3 \cdot 3NaHCO_3 \leftrightarrow 5/3\ Na_2CO_3 + CO_2 + H_2O$	32.8
$5\ NaHCO_3 \leftrightarrow Na_2CO_3 \cdot 3NaHCO_3 + CO_2 + H_2O$	32.1
$2NaHCO_3 \leftrightarrow Na_2CO_3 + CO_2 + H_2O$	30.8

- CO_2 absorption is *exothermic*; absorption temperature < 80ºC
- Sorbent regeneration is *endothermic*; regeneration T ≥ 120ºC
- Sorbent is fully regenerable in pure CO_2 (TGA studies)

“Dry Carbonate” Advantages

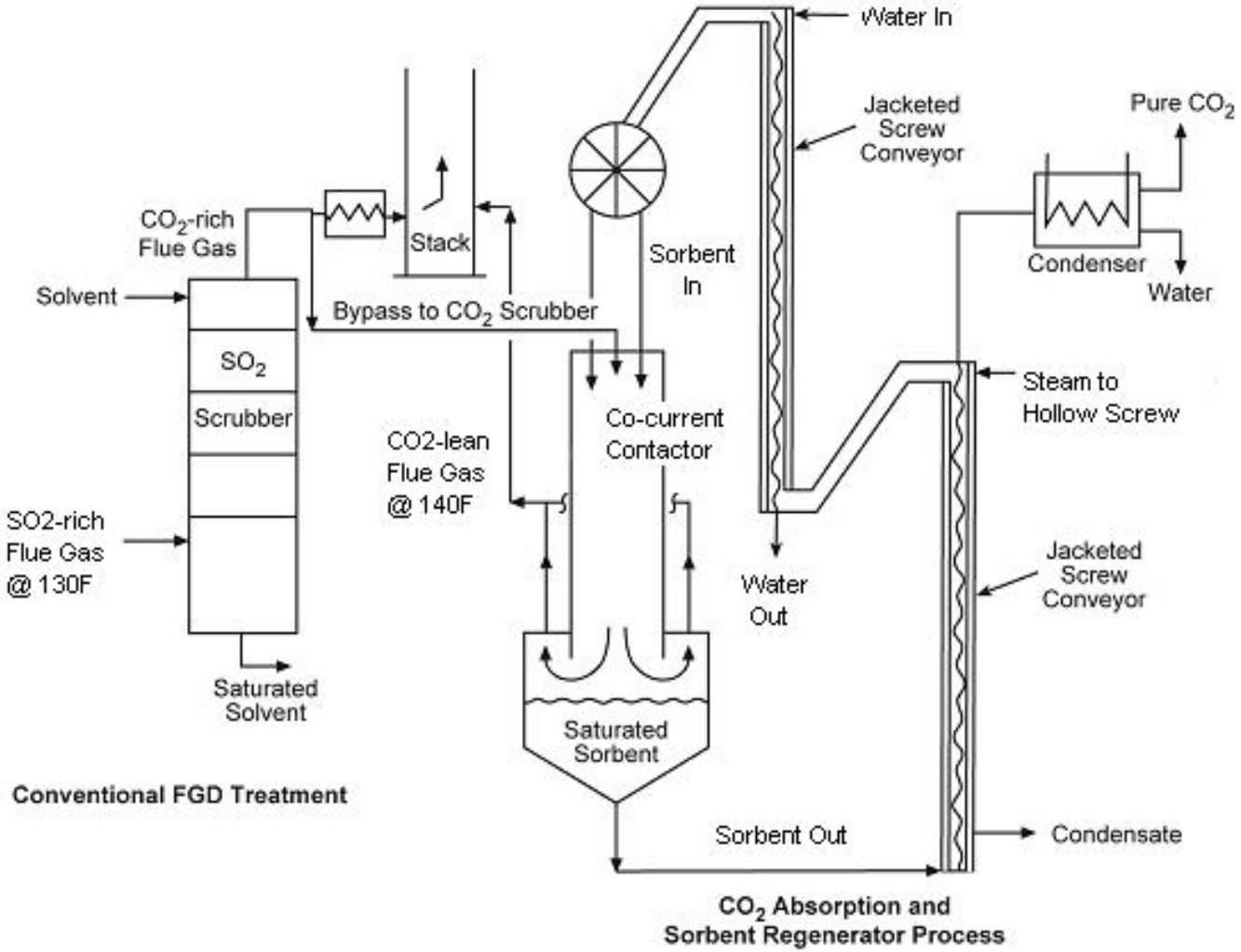
- Simple, known chemistry
- Non-hazardous materials
- Modest temperatures of operation
  - Ideal for flue gas from WFGD system (~60ºC absorption temperature)
- Potential for lower CO_2 capture cost than existing (MEA) processes
  - Low regeneration energy and regeneration temperature (~120ºC)
  - Low raw material costs; sorbent preparation costs are low

Project History



- Sorbent Development
  - Evaluated pure sodium bicarbonate, Trona, supported sorbents
  - Supported sorbent advantages: better initial reactivity, physical strength
  - Supported sorbent manufactured by Süd-Chemie, Inc. (~500 lbs to date)
- Process Development
  - Evaluated fixed-bed, fluidized-bed, and entrained-bed reactor systems
  - >90% CO_2 capture achieved and maintained over multiple cycles
  - Temperature rise = major issue for fixed-bed and fluidized-bed
  - Problems avoided in entrained-bed system (dispersed solids in gas)

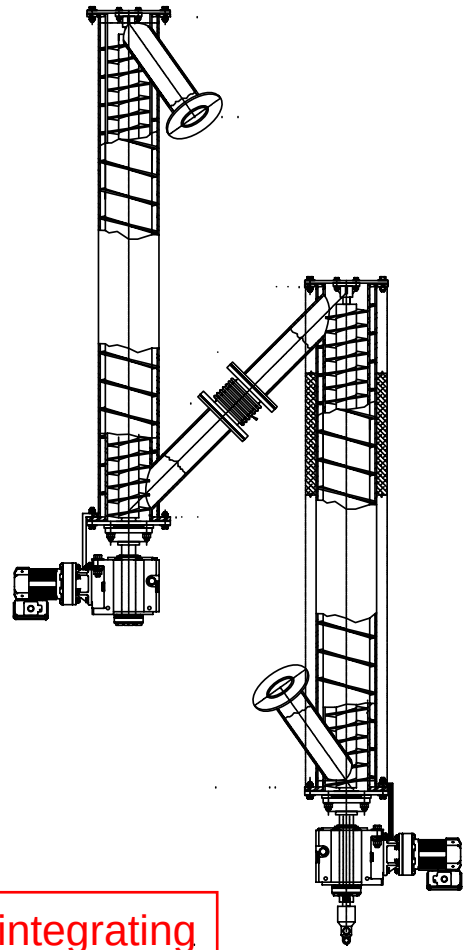
Process Concept



Process Development
Down-Flow Contactor and Screw Conveyors

Why a Down-flow Contactor?

- Minimizes pressure drop of flue gas
  - Commercial consideration: limits ID fan power requirements
- All the benefits of an entrained-bed system
  - short residence time, dispersed solids in flue gas, limits temp rise
- Very simple design



Why Screw Conveyors?

- Proven design for moving, heating, and cooling solids
- Effective heat integration
  - Commercial consideration: uses low pressure steam for indirect sorbent heating and cooling water for indirect sorbent cooling
- Low power consumption
- Note: Identified to be commercially feasible up to a certain scale

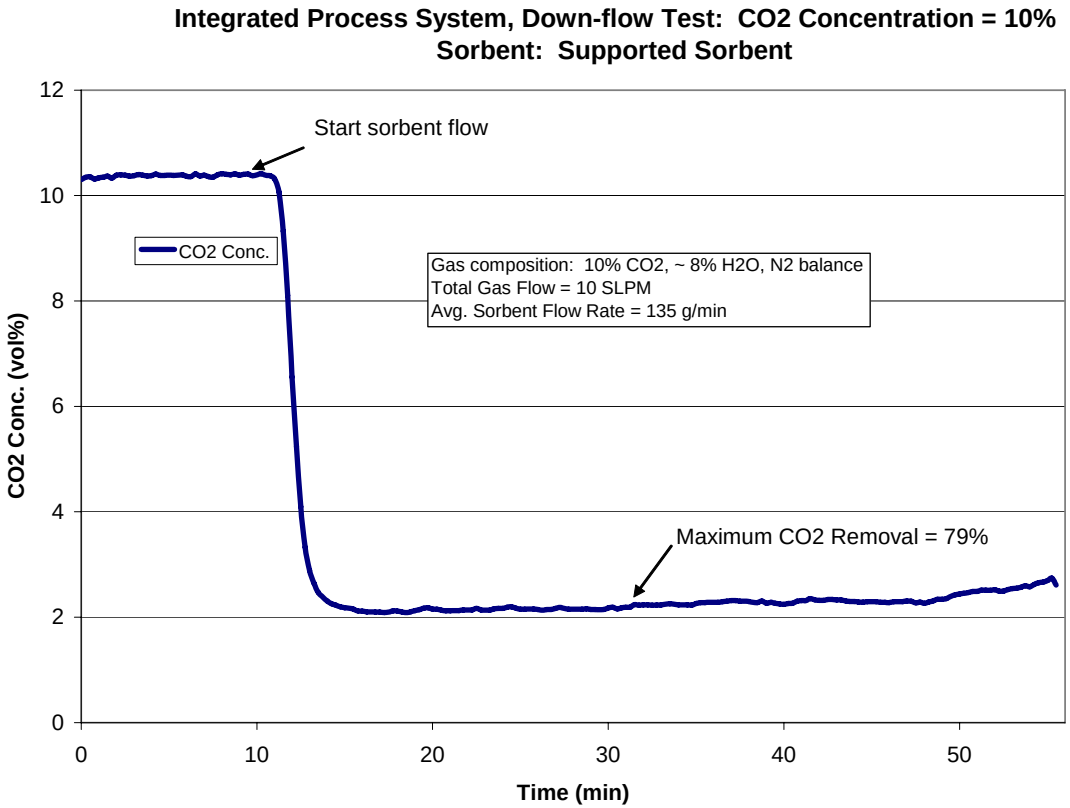
RTI verified performance of each component independently before integrating

Integrated Process System Built at RTI

Integrated Process System Built at RTI

- Bench-scale screw conveyor system
  - Fabricated by Therma-flite, Inc. (Benicia, CA)
  - Steam-heated screw conveyor with hollow shaft and hollow jacketing
  - Water-cooled screw conveyor with hollow jacketing
- Down-flow contactor fabricated and installed by RTI
- System Specifications
  - Screw conveyors: 8” diameter and 6’ length
  - Sorbent circulation rate: 25 – 250 lb/hr
  - Designed to “treat” up to 200 SLPM of flue gas
  - Heated screw conveyor is rated to 80 psi (315ºF saturated steam)
  - Steam generated by small laboratory boiler
  - City water used for cooling

Integrated Process System
Results from Simulated Flue Gas Testing



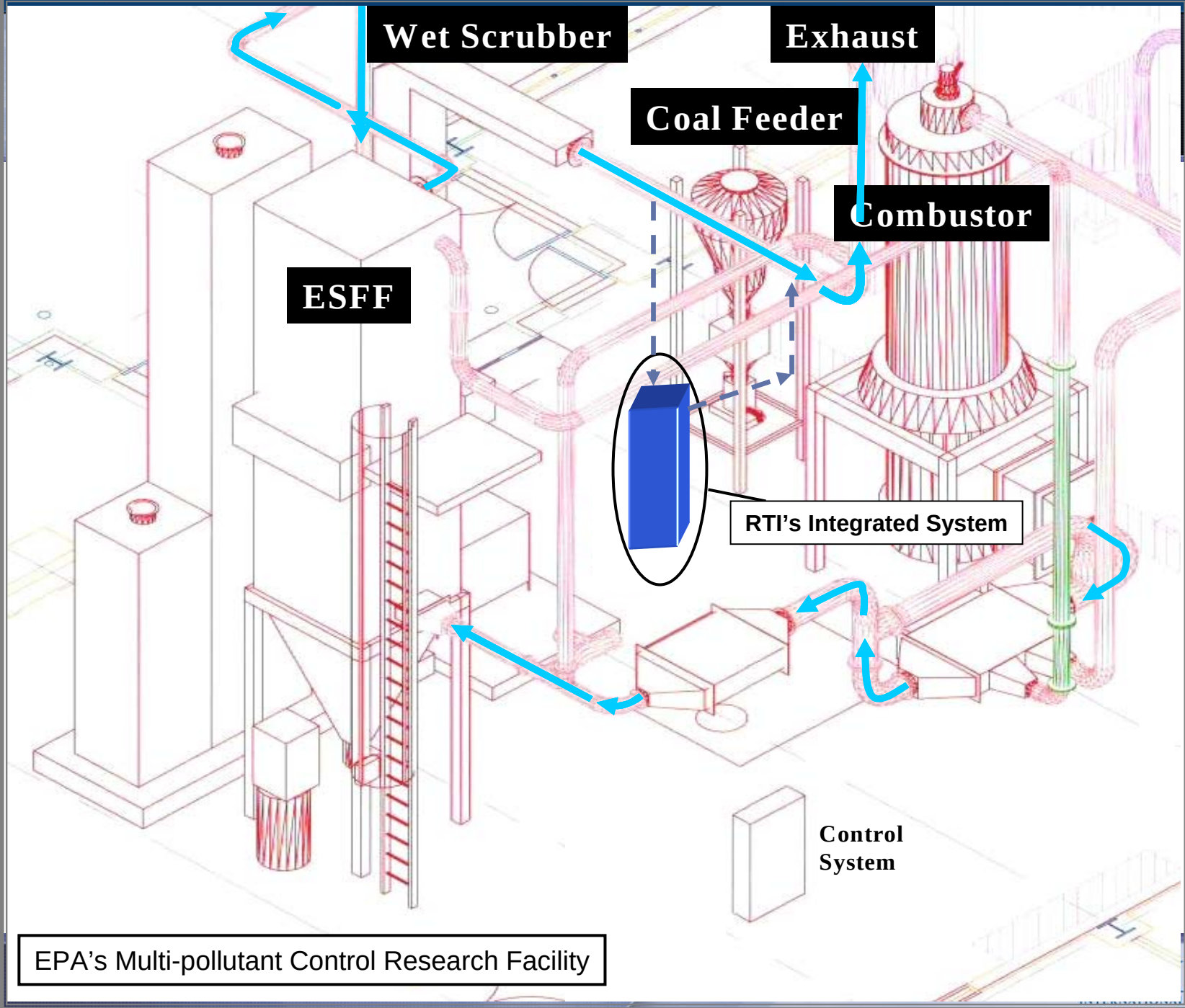
- Objectives:
  - Sorbent circulation
  - Sorbent heating with steam
  - Sorbent cooling
  - Sorbent attrition (measure)
  - CO_2 capture performance
  - Prove system reliability for field test
- ~80% CO_2 removal was achieved in flue gas with 10% and 15% CO_2 using RTI supported sorbent
- Possible limitation: not enough steam (volume), regeneration temperature not reached

Integrated Process System
Highlights from Simulated Flue Gas Testing

- Total hours of stable sorbent circulation, heating, cooling: *~600 hrs*
- Longest continuous sorbent circulation run: *96 hrs*
- Sorbent transfer between system components is smooth and efficient
- Sorbent regeneration temperature achieved: *115ºC*
- Lowest temperature achieved in sorbent cooler: *25ºC*
- Total hours of sorbent exposure to CO_2: *~80 hrs*
- Maximum CO_2 removal in laboratory: *~80%*
- System reliability confirmed and ready for field testing with actual coal-derived flue gas

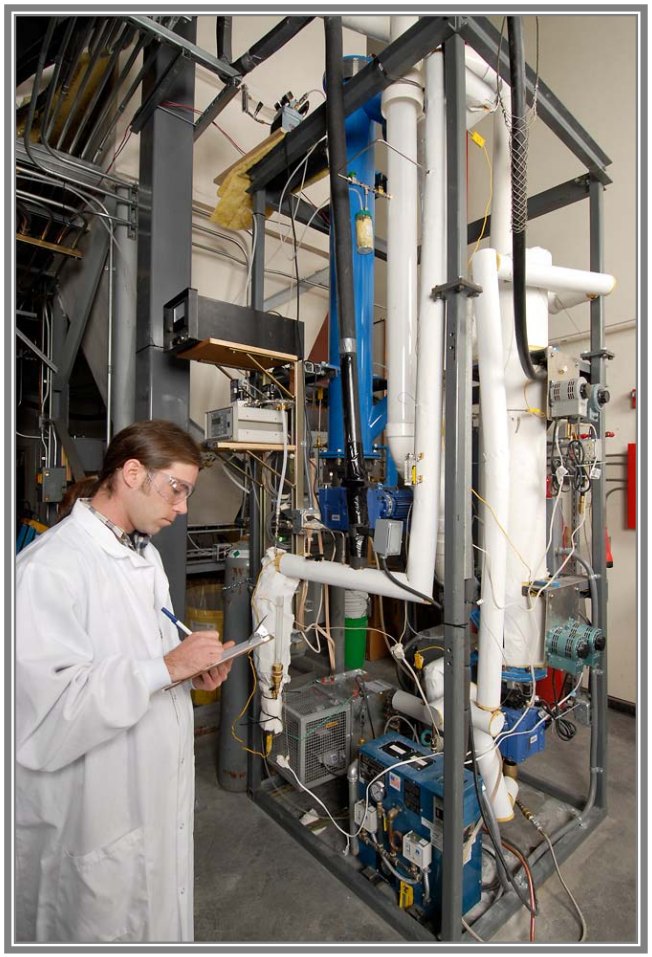
Slipstream Testing at the U.S. EPA

- EPA's Combustion Research Facility
  - 4 Million Btu/hr (1.2 MW_t) multi-fuel fired facility
    - 330 lb/hr bituminous coal (dedicated pulverizer)
    - 120 m^3/hr natural gas
  - Designed for evaluation of different control technologies
  - Location: Research Triangle Park, NC (2 mi from RTI)
- Multi-pollutant control technologies installed at EPA:
  - Selective Catalytic Reduction (SCR): NOx and Hg Oxidation
  - Lime Flue Gas Desulfurization (FGD): SO_2 and Hg Capture
  - Fabric Filter: Fine PM and Hg Capture
- RTI's Integrated System moved to EPA site in January '07
  - Testing is being coordinated with ARCADIS, Inc, (EPA's on-site contractor)
  - Re-commissioning complete (~3-5% slipstream of EPA's flue gas)
  - Testing of system is currently being performed



EPA's Multi-pollutant Control Research Facility

Slipstream Testing at the U.S. EPA



Slipstream Testing at the U.S. EPA
Objectives

- System integration within a fossil fuel combustion facility
- Determine optimal operating conditions to achieve set goals for CO_2 capture
- Determine effect of long-term flue gas testing on sorbent performance and system reliability
  - Sorbent attrition
  - Sorbent deactivation
  - System's ability to maintain steady state operation
- Operate system under various "upset" and "trip" conditions to determine effect of unexpected operational difficulties

Slipstream Testing at EPA
Highlights of Fossil Fuel-Derived Flue Gas Testing

- Sorbent regeneration temperature achieved: *145ºC (EPA system steam)*

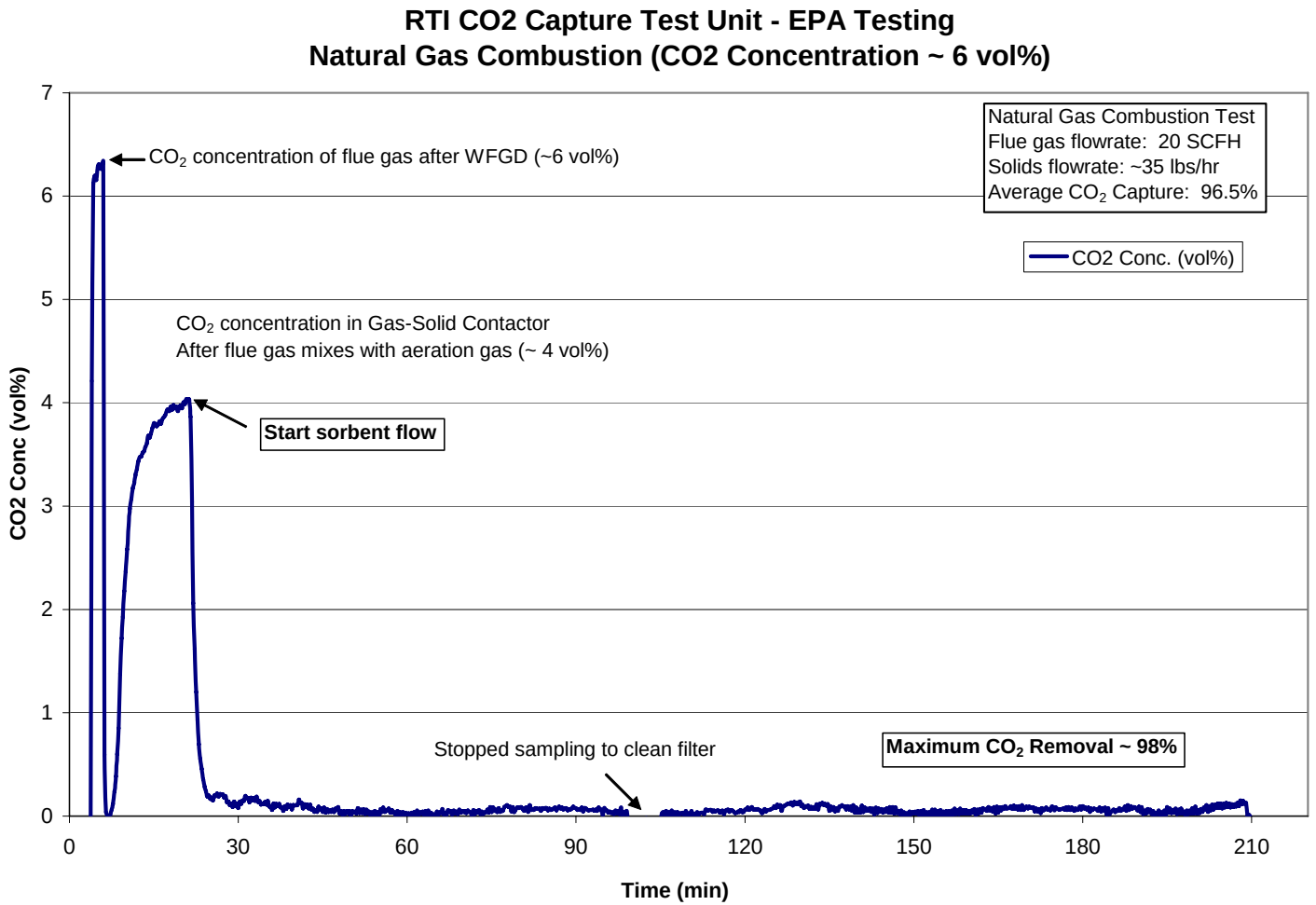
Natural Gas Combustion

- Total hours of exposure to natural gas derived flue gas: *~90 hrs.*
- CO_2 concentration in flue gas: *~6 vol% (before dilution)*
- Maximum CO_2 removal achieved: *~99%*

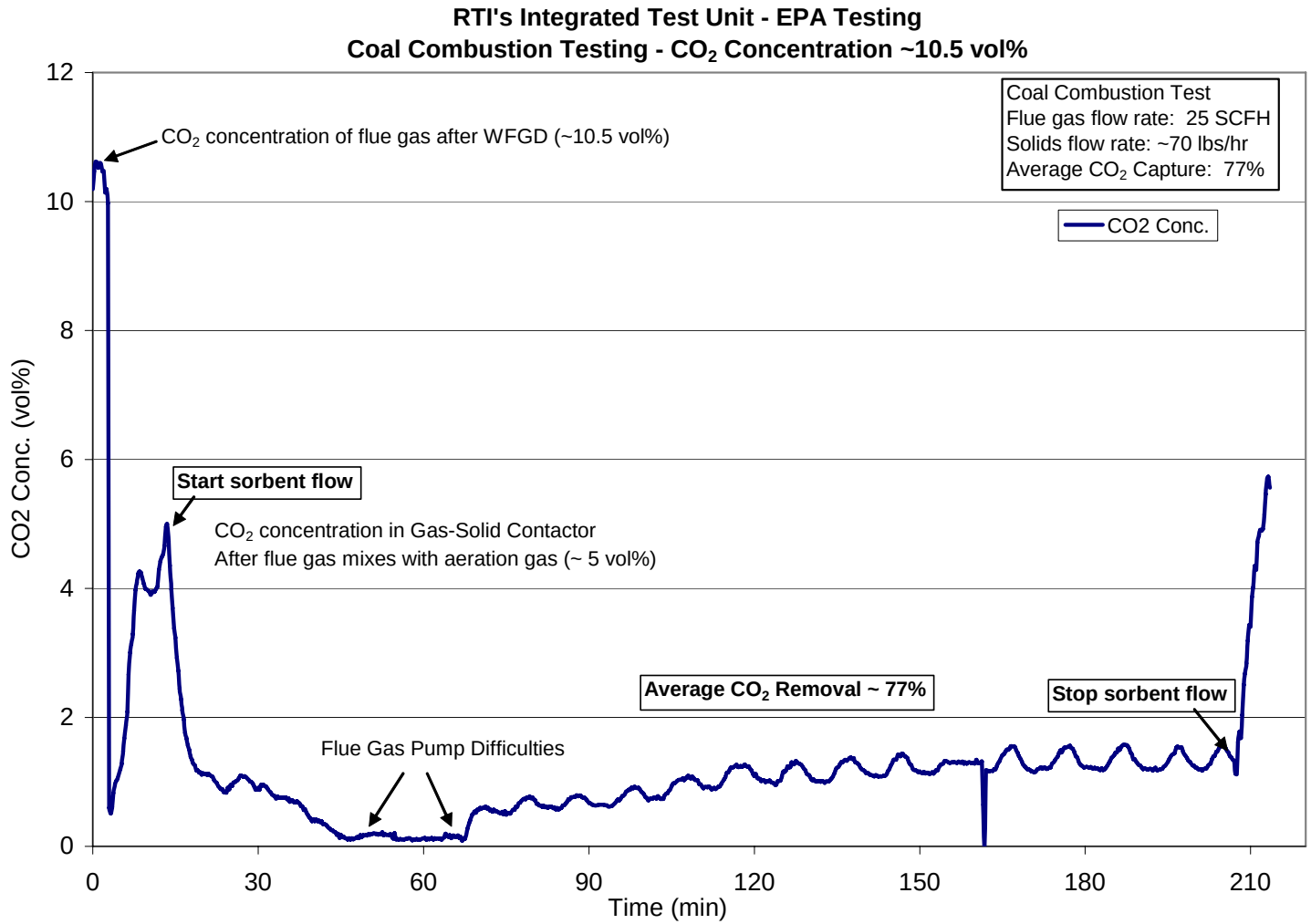
Coal Combustion

- Total hours of exposure to coal-derived flue gas: *~70 hrs.*
- CO_2 concentration in flue gas: *~10.5 vol% (before dilution)*
- SO_2 concentration in flue gas: *~20 ppm (following FGD scrubber)*
- Maximum CO_2 removal achieved: *~92%*
- Coal supply: mixture of Eastern Bituminous and PRB

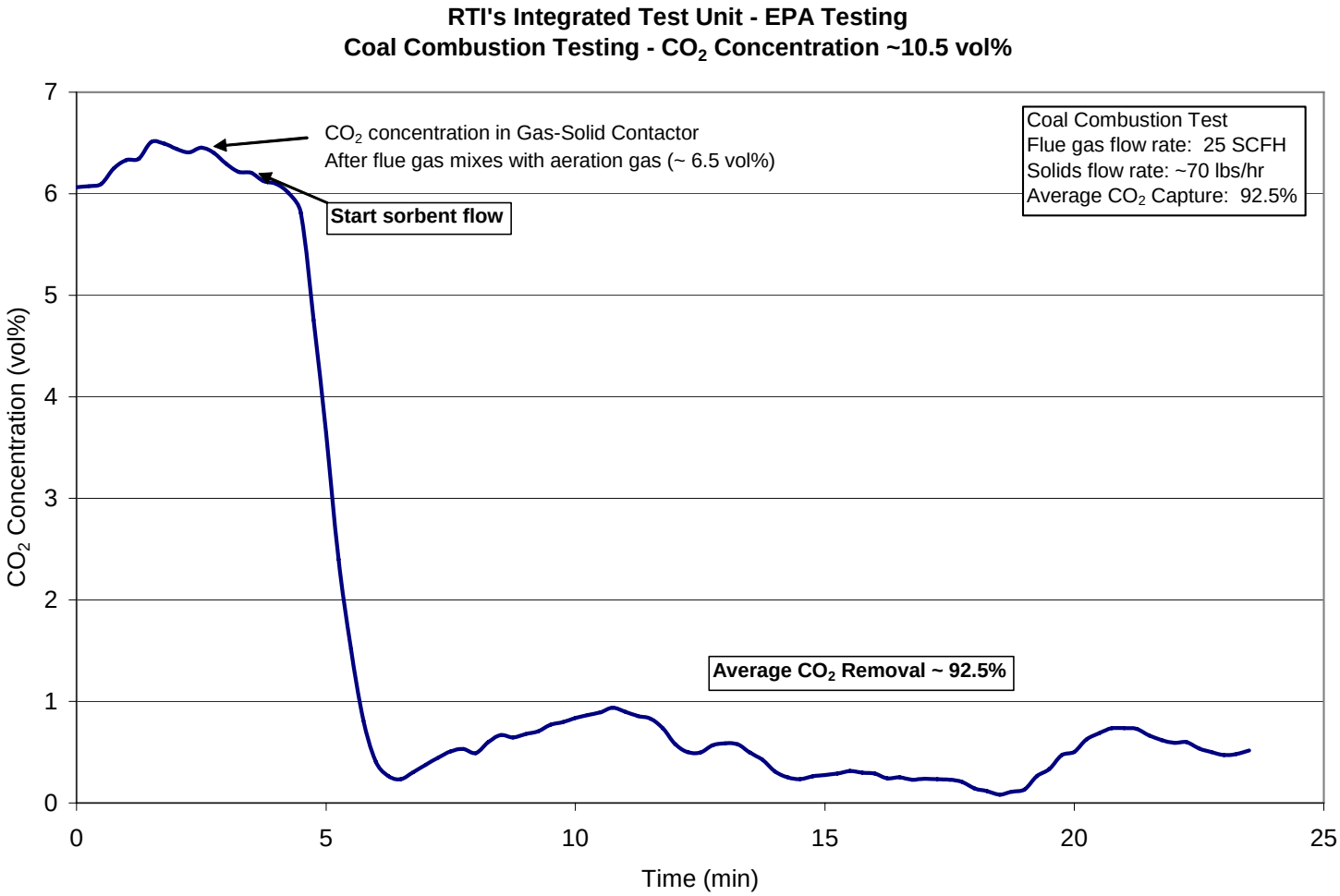
Slipstream Testing at EPA
Natural Gas Combustion



Slipstream Testing at EPA
Coal Combustion



Slipstream Testing at EPA
Coal Combustion



Path Forward

- Additional testing at U.S. EPA facility
  - Extended coal-fired testing, system reliability testing
  - Sorbent attrition: sorbent mass, particle size analysis, SEM
  - Sorbent deactivation: Na_2CO_3 analysis, SO_2 analysis, trace metals
  - "Trip" tests: sorbent flow failure, power failure, erratic flue gas flow
- Engineering evaluation of regenerator process design
- Finalize process design
- Scale-up to pilot-scale (1 ton CO_2 captured per day)
  - Evaluate at coal combustion facility

Commercialization Timeline

Present Status: 2007

Bench-Scale Technology Demonstration:

2-10 lbs/hr CO_2 capture (15 vol% CO_2)

Sorbent usage: 50 lbs

Phase I: 2007-2009

Pre-Pilot technology demonstration:

~ 1 ton/day CO_2 capture

Sorbent usage: 8,000 lbs

Phase II: 2010-2011

Slipstream testing at utility site:

~ 50 ton/day CO_2 capture

Sorbent usage: 70,000 lbs

Phase III: 2012-2013

Demonstration at commercial utility:

~ 1000 ton/day CO_2 capture

Sorbent usage: 300,000 lbs

Commercially Available: 2014

90% CO_2 capture at <20% increased C.O.E.

Summary

- RTI has developed a supported sorbent which is produced by a commercial catalyst/sorbent manufacturer
- RTI has developed a novel process design that is suited for retrofit in a power plant and is of relatively simple process design
- > 90% CO_2 removal has been demonstrated at all stages of the research program
- RTI has built and thoroughly tested a bench-scale, integrated system to evaluate process performance and operation
- RTI process unit has been tested with natural gas- and coal-derived flue gas and is capable of >90% capture of CO_2 from these gas streams
- Preliminary indication is that sorbent performance is constant over long-term exposure to fossil fuel derived flue gas – attrition and reaction with contaminants show little to no effect to date
- Past reporting: economic analyses show RTI process has lower capital cost, similar operating cost, and less plant power de-rating than MEA system. Cost of electricity impact is <20% increase overall.

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