Natural Resources Canada | Ressources naturelles Canada

Entrained Flow Gasifier R&D at CanmetENERGY

CLEAN ENERGY TECHNOLOGIES

May 6, 2010

Robin Hughes

Canada

CanmetENERGY

- Canadian Federal energy R&D organization
- All aspects of energy production excluding nuclear
- Employs over 450 scientists, engineers, and technicians
- Laboratories:
  - Ottawa, ON – fossil fuel and hydro power generation, industrial, commercial, residential, catalysis, explosives
  - Varennes, QC – wind, solar, system integration and optimization, smart grid
  - Devon, AB – oil and gas
- Project arrangements
  - Fee for service
  - Cost shared
  - Task shared

Clean Electrical Power Generation

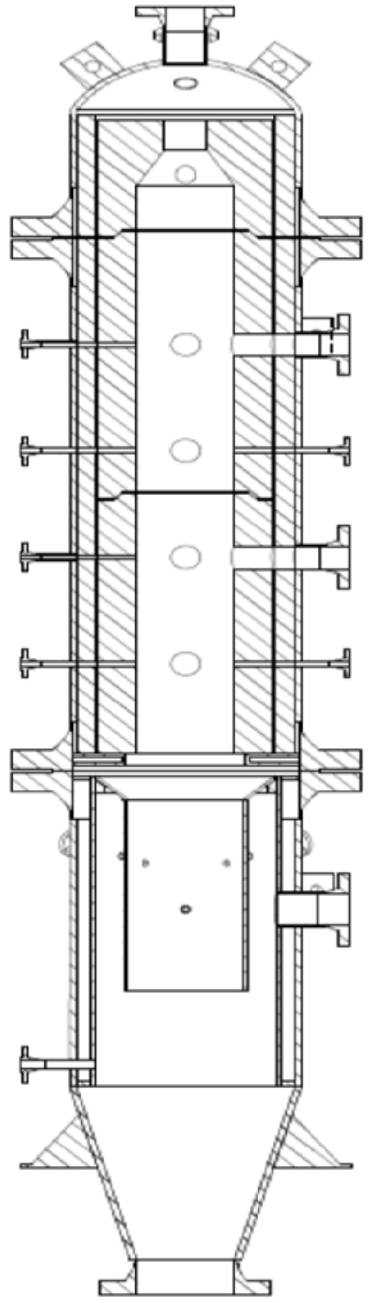
- Focus areas – fossil fuel power generation
  - Carbon capture and storage
  - High efficiency
  - Emissions reduction
- Groups
  - Fluidized Bed Combustion & Gasification
    - Entrained flow gasification
    - Air and **oxygen** fired circulating fluidized bed combustion
    - Solid looping cycles for carbon capture (pre & post combustion)
  - Zero Emissions Technologies
    - Oxygen fired pulverized coal combustion
  - Combustion Optimization
  - Combustion Kinetics
  - Emissions
  - CO_2 Storage

EF Coal Gasification R&D Scope

Active 2010

- Near Zero Emissions Coal Gasification Development in Canada 1.0.0
  - Project Administration 1.1.0
    - Supporting Project Management 1.1.1
    - Systems Engineering Management 1.1.2
    - Safety & Training 1.1.3
  - Gasification Characteristics 1.2.0
    - Fuel Properties 1.2.1
    - *In Situ* Sampling 1.2.2
    - Slagging Properties 1.3.3
    - Reactivity 1.3.4
    - Trace Elements 1.3.5
    - Optical Systems 1.3.5
  - Materials 1.3.0
    - Heat Transfer 1.3.1
    - Slag Adhesion 1.3.2
    - Corrosion 1.3.3
    - Refractory 1.3.4
    - Metals 1.3.5
    - Advanced Materials 1.3.6
  - Process Efficiency 1.4.0
    - Feed System 1.4.1
    - Injector 1.4.2
    - Multiple Stages 1.4.3
    - High Mass Flux 1.4.4
    - Partial Quench 1.4.5
    - Hot Gas Cleaning 1.4.6
  - Modelling 1.5.0
    - Process Simulation 1.5.1
    - Mixing 1.5.2
    - Rate of Reaction 1.5.3
    - Deposition 1.5.4
    - CFD 1.5.5
  - Performance Evaluation 1.6.0
    - Efficiency 1.6.1
    - Air Emissions 1.6.2
    - Solids 1.6.3
    - Waste Water 1.6.4
    - Byproducts 1.6.5
    - Reporting 1.6.6

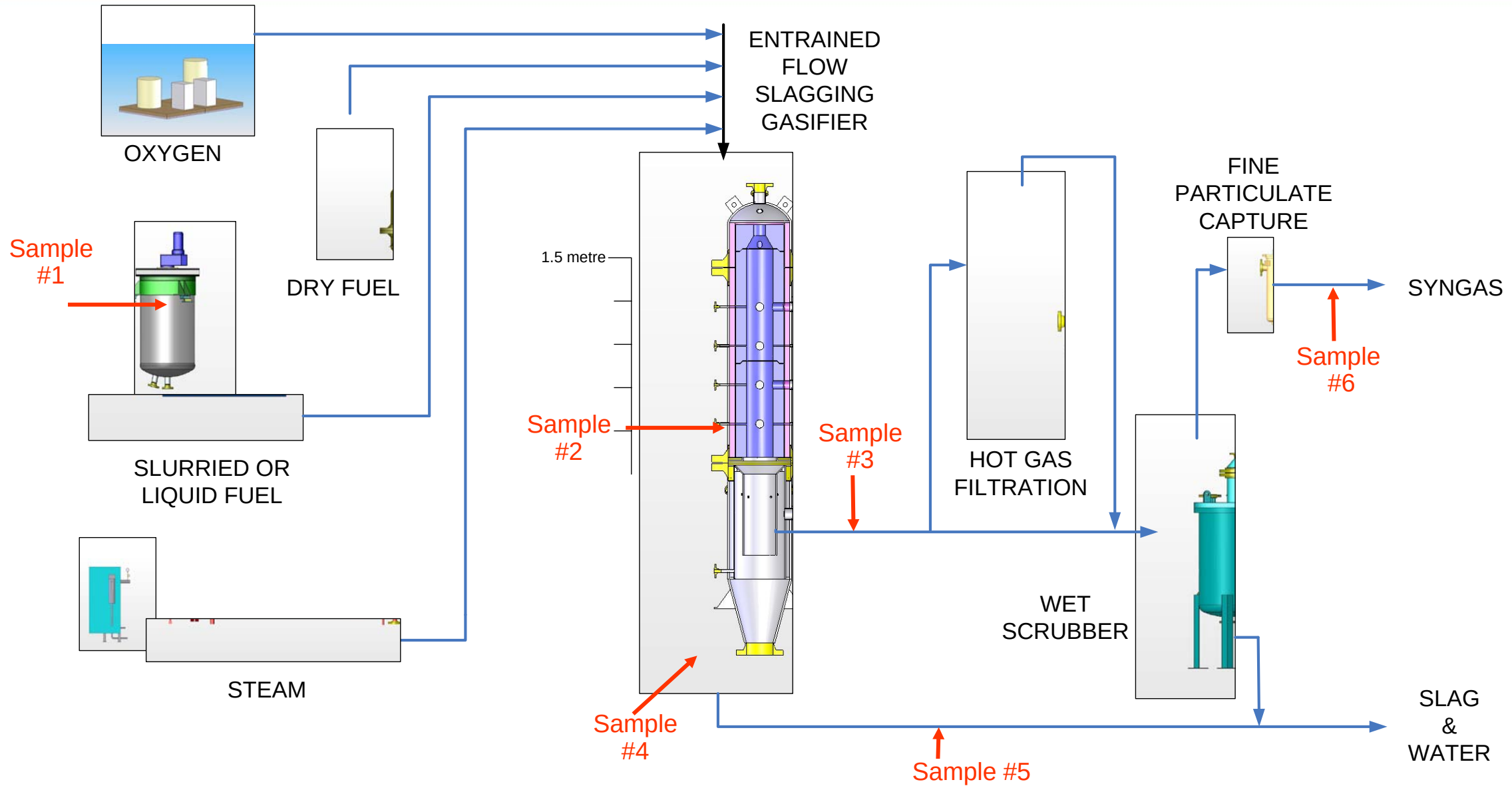
Pressurized Entrained Flow Gasifier



Operating Parameters

- P_{max} = 1500 kPa
- T_{max} = 1700 ^{o}C
- Capable of gasifying pulverized fuel, fuel-water slurry, or liquids
- Dry coal feed rate: 10-20 kg/h
- Slurry or liquid feed rate: 100 kg/h
- 1 or 2 stage operation
- Full or partial quench
- Tie ins for syngas treating and optical access available

Canmet EF Gasification Facility



FUELS

COAL
ASPHALT
HEAVY OIL
PETROLUEMCOKE
BIOMASS
WASTES

APPLICATIONS

IGCC
HYDROGEN
HIGH VALUE CHEMICALS
CLEAN LIQUID FUELS
OIL SANDS

NEAR ZERO EMISSIONS

CARBON CAPTURE & STORAGE

Gasification Applications Research

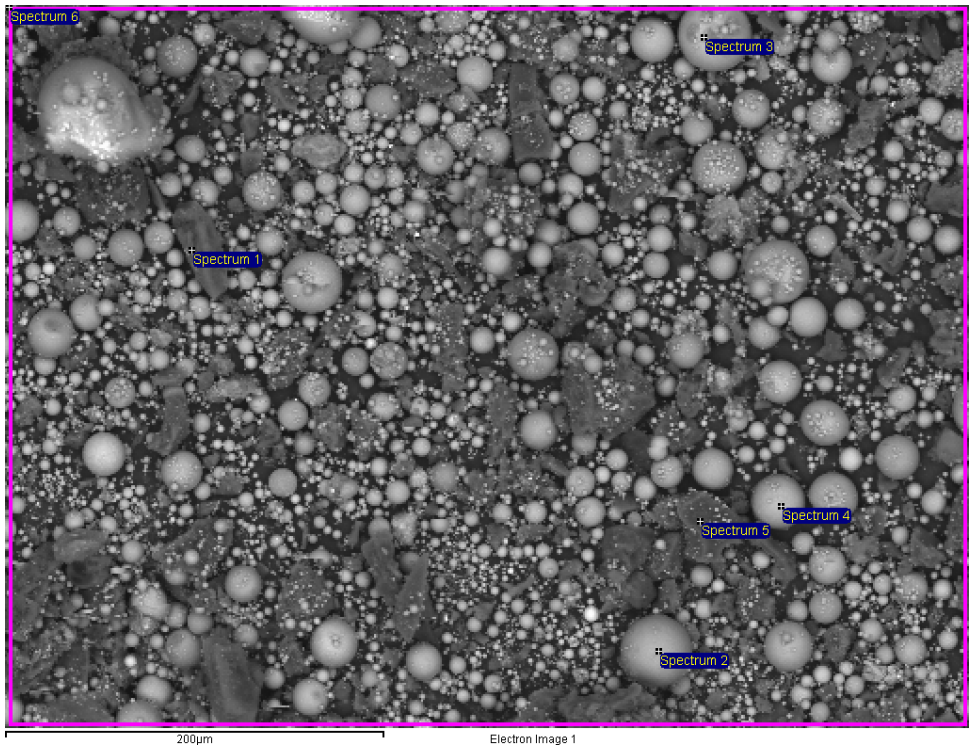
- CO_2 separation
  - Solid looping cycles
- Hot gas clean-up
  - Hg
  - Alkali
- IGCC and oil sands upgrader modelling
  - With and without CO_2 capture
  - With Advanced technologies
- Integration of slurry hydrocracking technology with gasification and CO_2 capture for oil sands upgrading

Gasification Characteristics

- Working with the Canadian Clean Power Coalition to characterize both raw and beneficiated Canadian & US fuels
  - Bituminous, sub-bituminous, lignite coals
  - Petroleum coke
- CCPC includes Canadian and US organizations
  - Members: Basin Electric, Capital Power , Nova Scotia Power, SaskPower, TransAlta, and Sherritt (metallurgical and thermal coal)
  - Associate member : Electric Power Research Institute
  - Additional research and funding NRCan, Alberta, Saskatchewan, Nova Scotia
- Fuel Properties
  - Proximate, ultimate, major oxides, trace elements, Hg, halides
  - Reactivity via thermogravimetric analysis
  - Surface area and pore size determination
    - Nitrogen porosymmetry and Hg pycnometry
  - Density
  - Slurryability

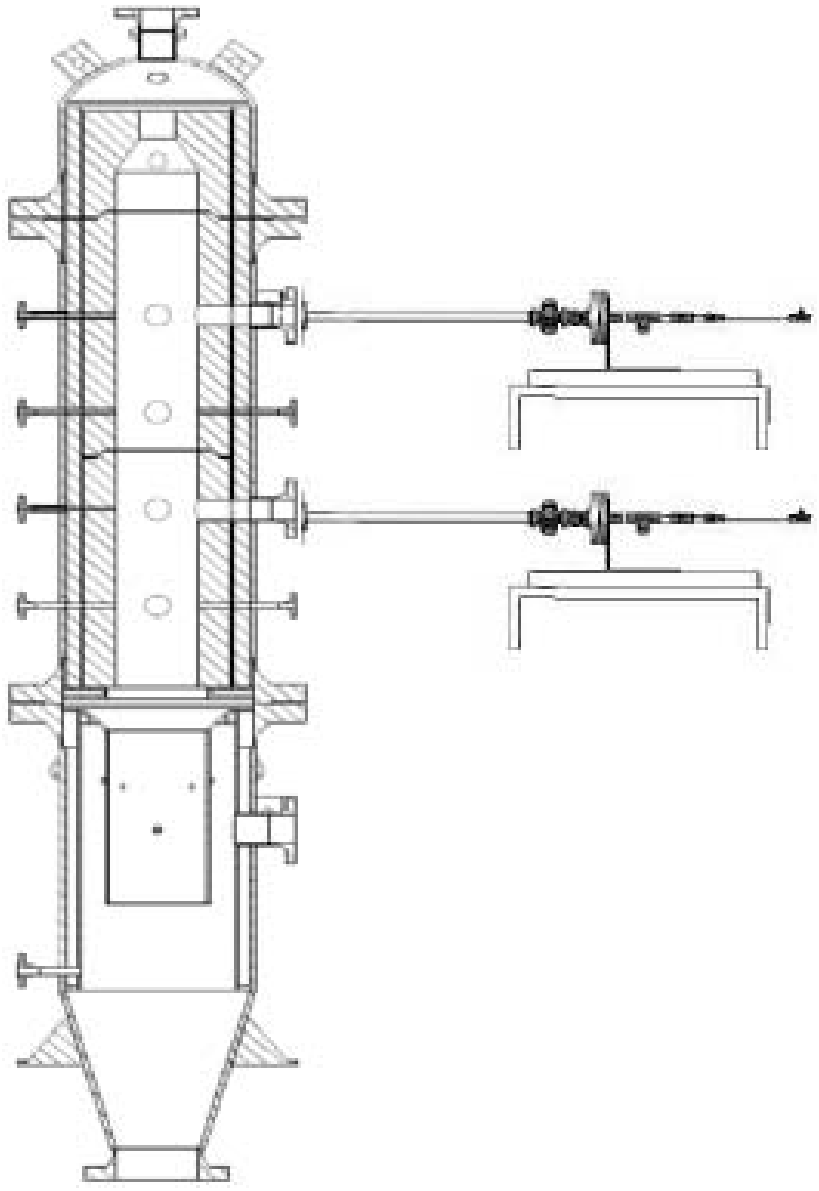
Gasification Characteristics

- *In Situ* Sampling
  - Provide validation data for computational fluid dynamics task shared project to create advanced modelling tools and code for slagging gasification
  - Characterize gasification products
    - Syngas majors (H_2, CO, CO_2, N_2, CH_4, H_2S)
    - Minors (COS, NH_3)
    - Trace
    - Characterization of coarse and fine fractions
      - >10 micron
      - 8 size fractions between 0.2 and 10 micron
      - Toxics leachability (TCLP), micro XRD to determine local composition



Slag and char from liquids bag filter

Sample Probes



- Sample Probes are used for extracting gases, tar, slag and char from the gasifier
- Fixed point testing winter 2010
- Radial traversing using servo motors fall 2010
- Axial traversing under design
- Servo motors have been successfully used in the past to position actively cooled test samples for materials testing and heat transfer analysis

Fixed Point Sampling System

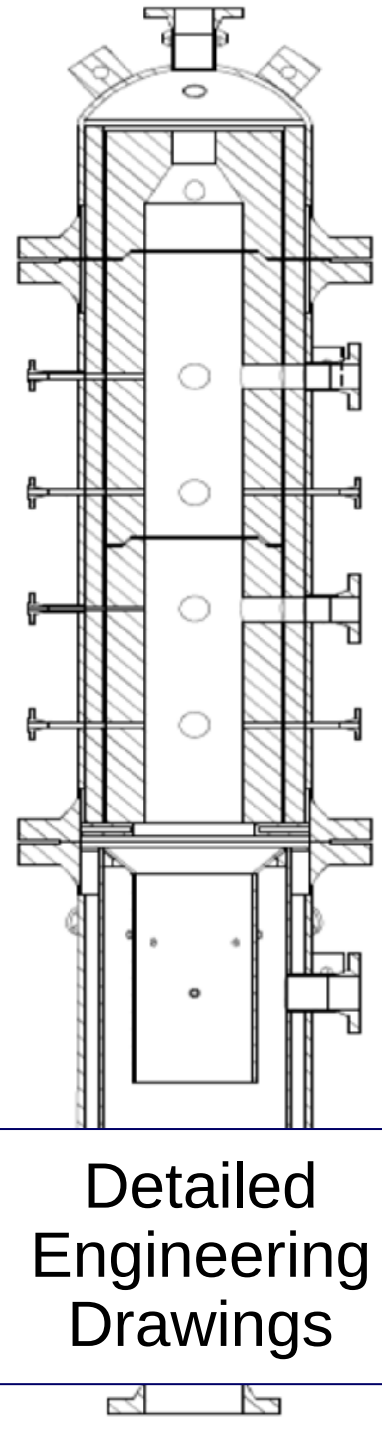
Impingers for Wet Chemistry

- Used winter 2010 for Hg speciation and fate
  - Oxidized via KCl solution
  - Elemental via activated carbon
  - Results being analyzed now
  - Results will be reported at IPCC in Turkey
- Test method for NH_3 developed and tested winter 2010
  - Dilute sulphuric acid
  - Test campaign fall 2010
- Other minors to follow

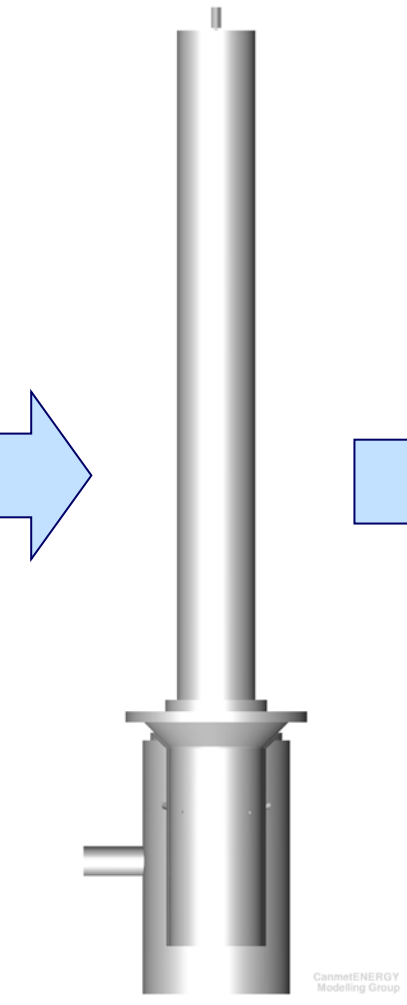
Gasifier CFD Modelling

Entrained flow slagging gasifier computational fluid dynamics (CFD)

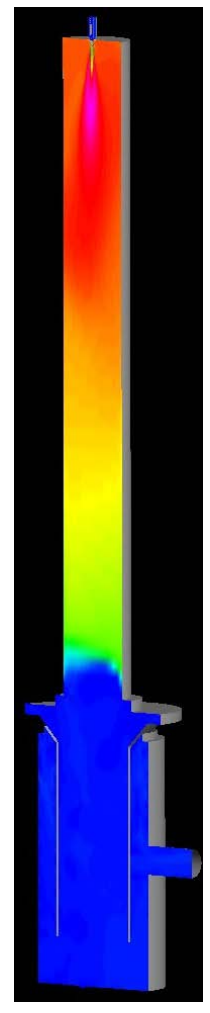
- Models are being validated using pilot plant data
- Our models include the gasifier and the quench section
- Working with National Research Council to characterize slurry sprays at high pressure
- Task shared agreement expected shortly to develop next generation gasification CFD code



Detailed Engineering Drawings



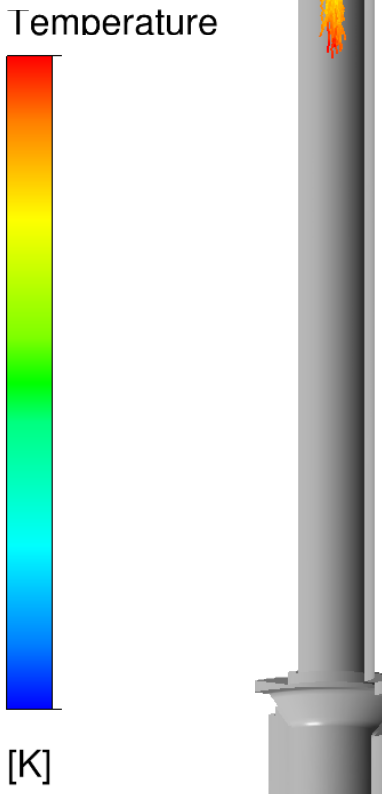
3D Solid Model

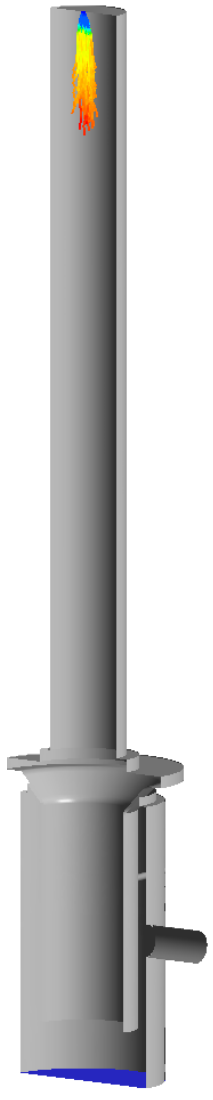


CFD Model

Gasifier CFD Model Validation

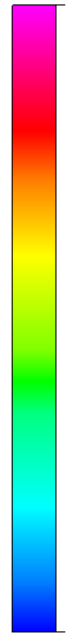
Coal slurry droplets coloured by temperature





Winter 2010 experimental data set

Cross-section coloured by CO molar fraction (wet)



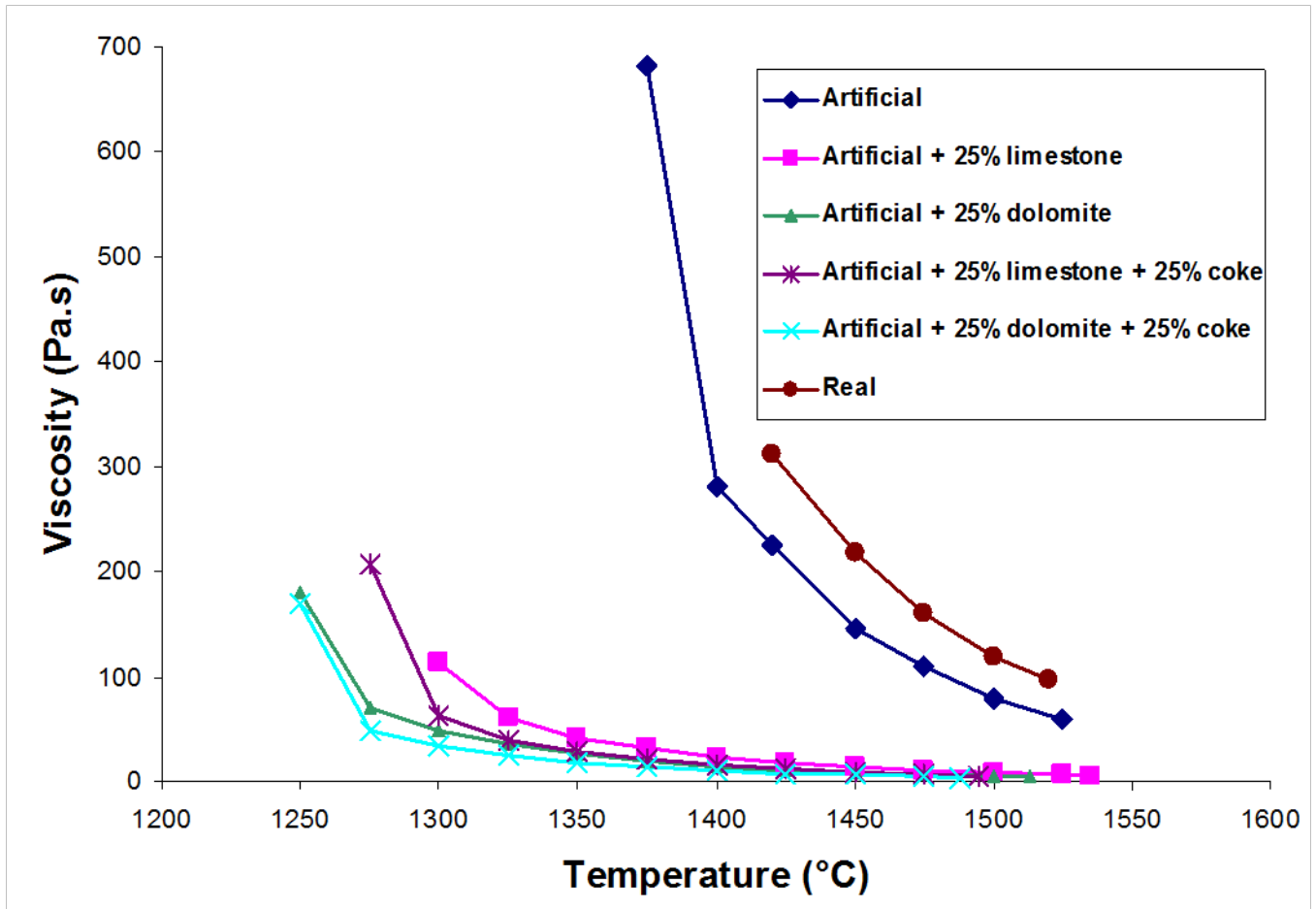
Traversing points to be added fall 2010

Winter 2010 experimental data set

Selected raw plant data available to aid validation

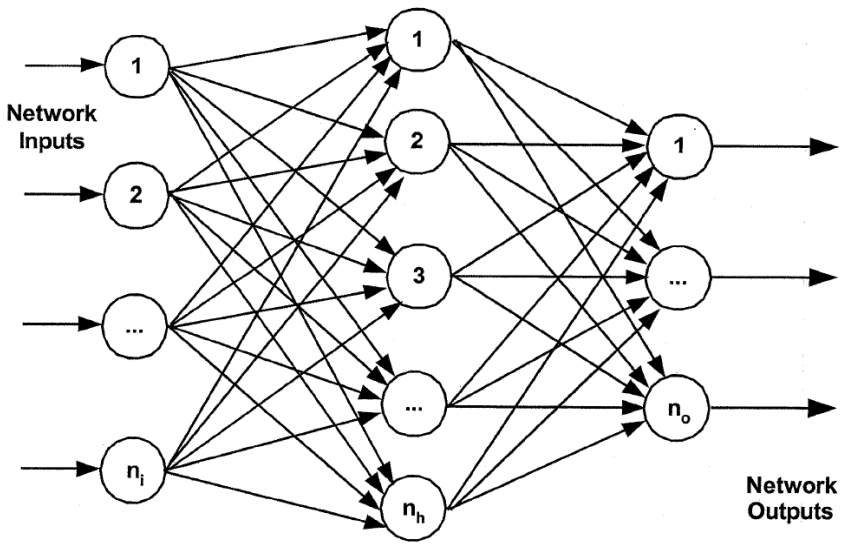
Slag Viscosity Measurements

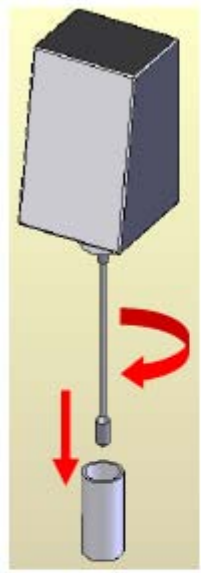
- Measure the viscosity of slags derived from Canadian coal, petroleum coke and hydrocracker residue
- Study blending and fluxing, effect of vanadium
- Compare neutral and reducing atmospheres

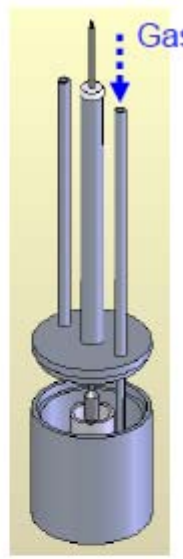


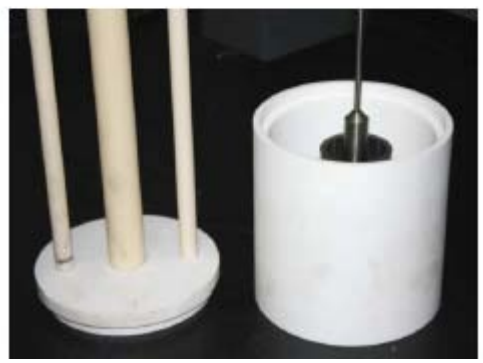
Slag Viscosity Modelling

- Apply artificial neural networks to model viscosity
- Compare with other available models
- Apply FactSage thermodynamic equilibrium predictions
- Combine models with process simulation and computational fluid dynamics models









- Rotational viscometer
- Mo spindle and crucibles
- Alumina chamber for gas containment (Ar or Ar/H2)
- 1700 C Furnace
- Method standardized with CSIRO, Australia

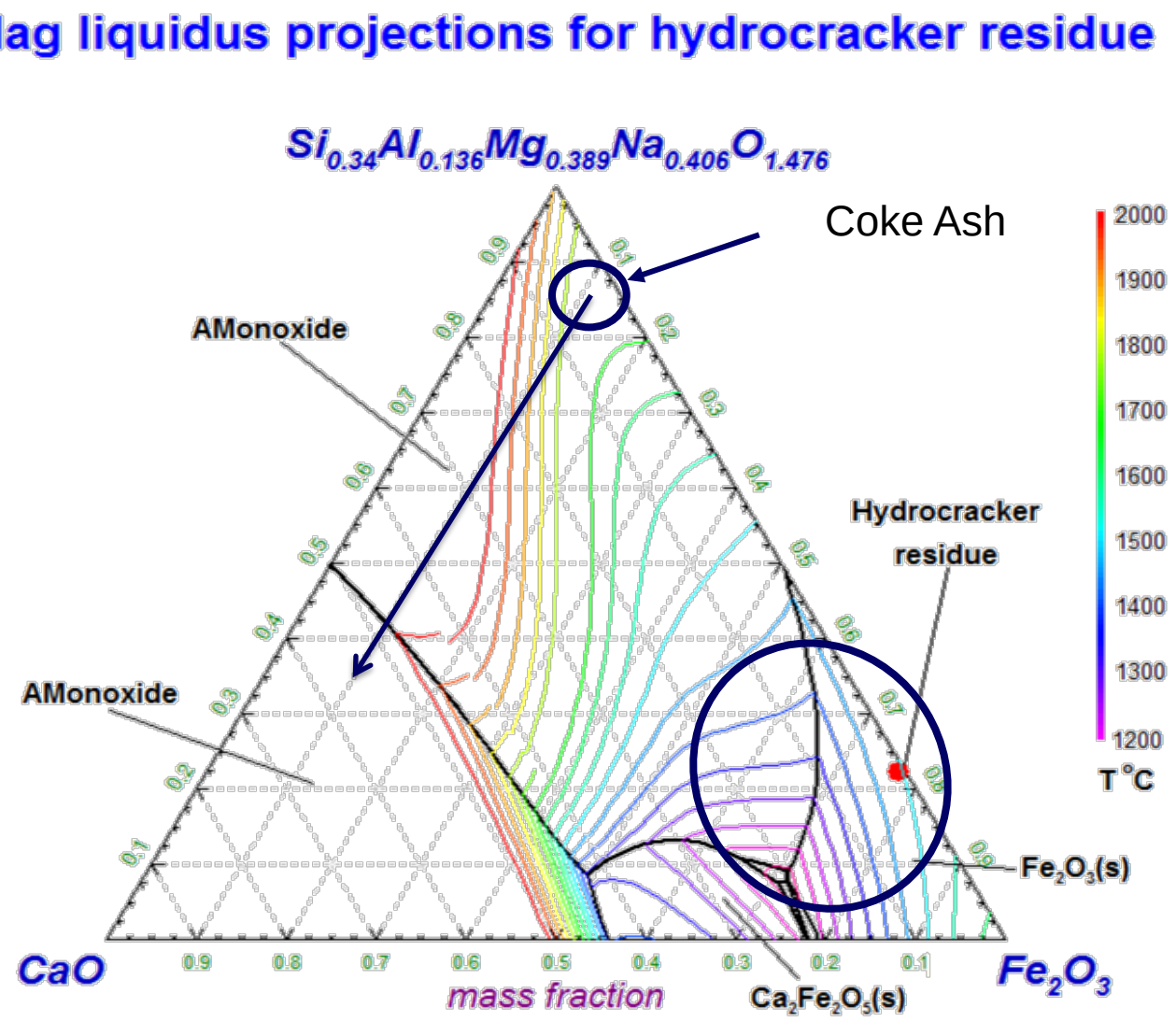
Pilot Plant Slag Tests

- Generate gasifier slags from a variety of sources
- Removable samples
  - Slag thickness
  - Slag - component bonding mechanisms
  - Viscosity
  - Rate of slag build-up at various locations
- Varying fuel, fluxant, O2:fuel ratio and wall heat flux

Probes inserted
- Metal and ceramic
- Ambient and actively cooled

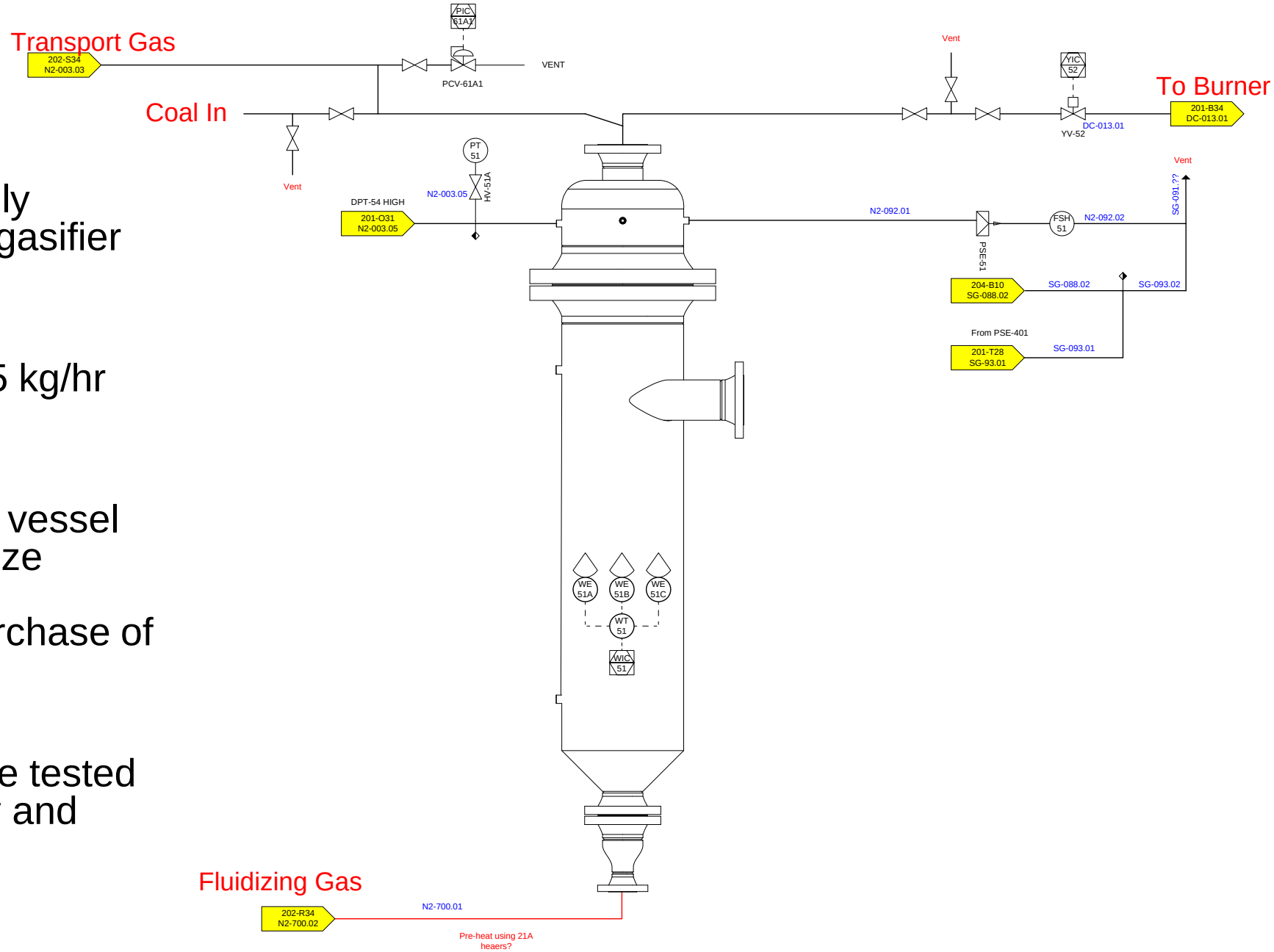
Slurry Hydrocracker and Gasification

- Slurry hydrocracker technology uses an Fe additive to produce high yields and high quality oil from bitumen
- Removing the Fe additive can be problematic in many applications, but when combined with gasification the additive greatly reduces the temperature required for slagging operation
- Combination of technologies:
  - Low operating temperature for gasifier while allowing slagging operation
  - Inert slag produced rather than soot
  - High oil yield technology enabled
  - Gasifier can meet hydrogen, power, and steam needs of hydrocracker
  - Carbon dioxide capture easily performed



Dense Phase Conveying

- Allow us to more closely approach commercial gasifier gas:solid ratio
- Design feed rate 25-75 kg/hr fuel
- Using hot gas filtration vessel as coal hopper to finalize design and operating procedures prior to purchase of final feed vessel
- A variety of fuels will be tested to determine variability and operating limitations



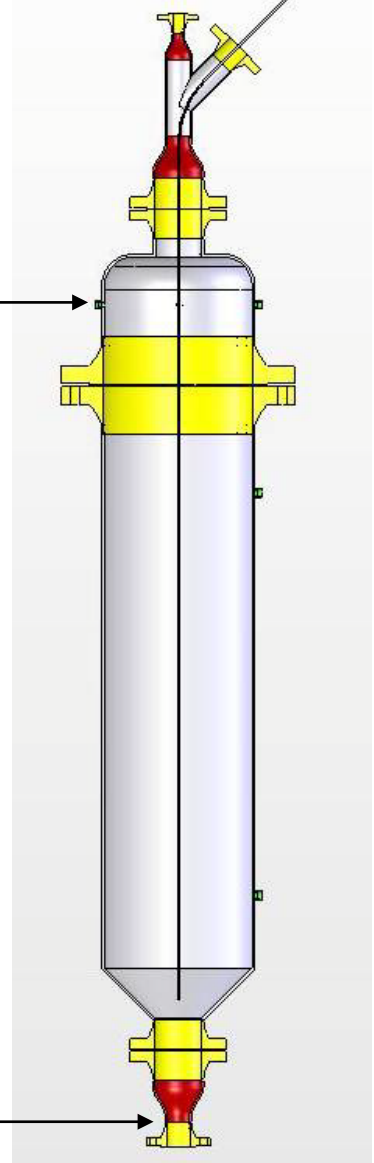
Dense Phase Conveying

Transport Gas

Coal Out

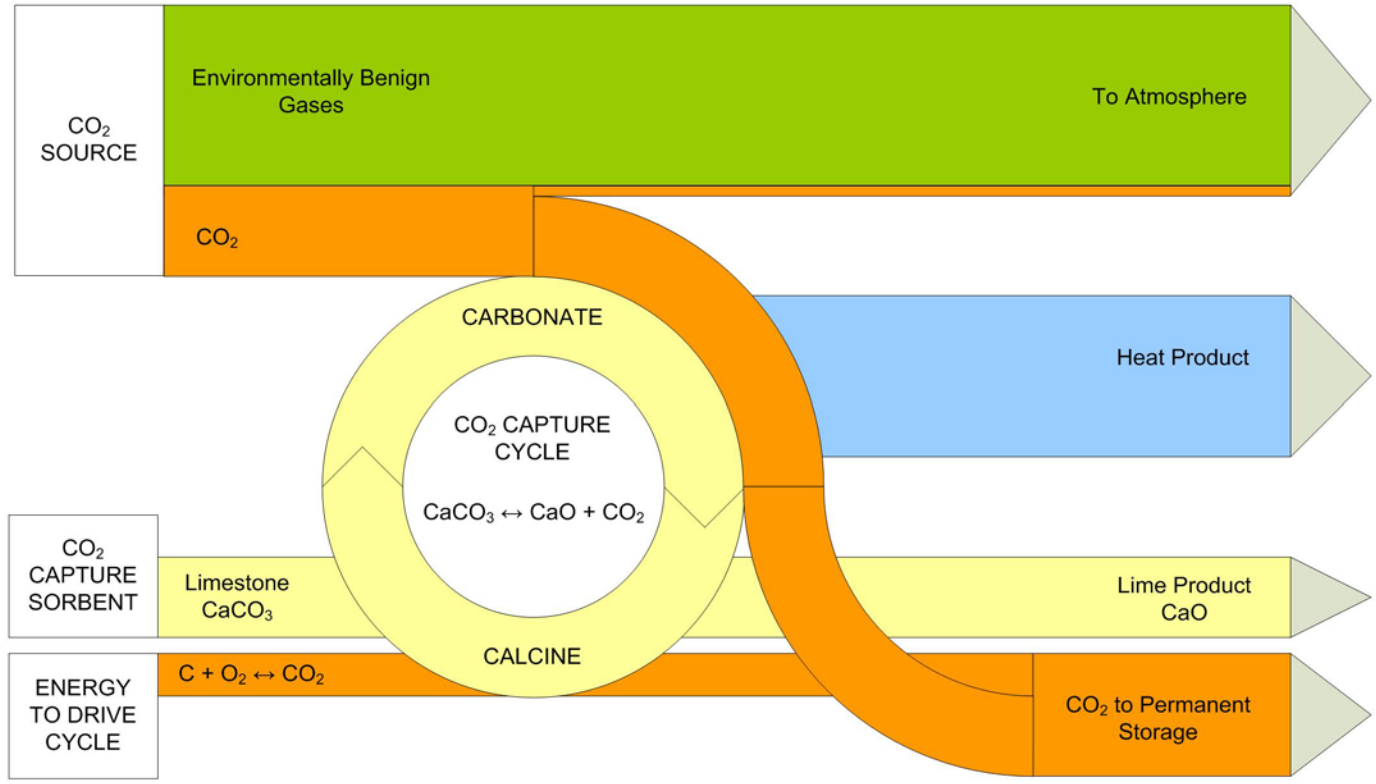
Pressurizing Gas

Fluidizing Gas



CO_2 Capture with Solid Looping Cycles

- Solid looping cycles can be used to remove C and S species at high temperature
- Allow process simplification for H_2 production by combining removal of multiple contaminants and WGS
- Reduce capital cost
- Improve efficiency
- Working with many partners worldwide

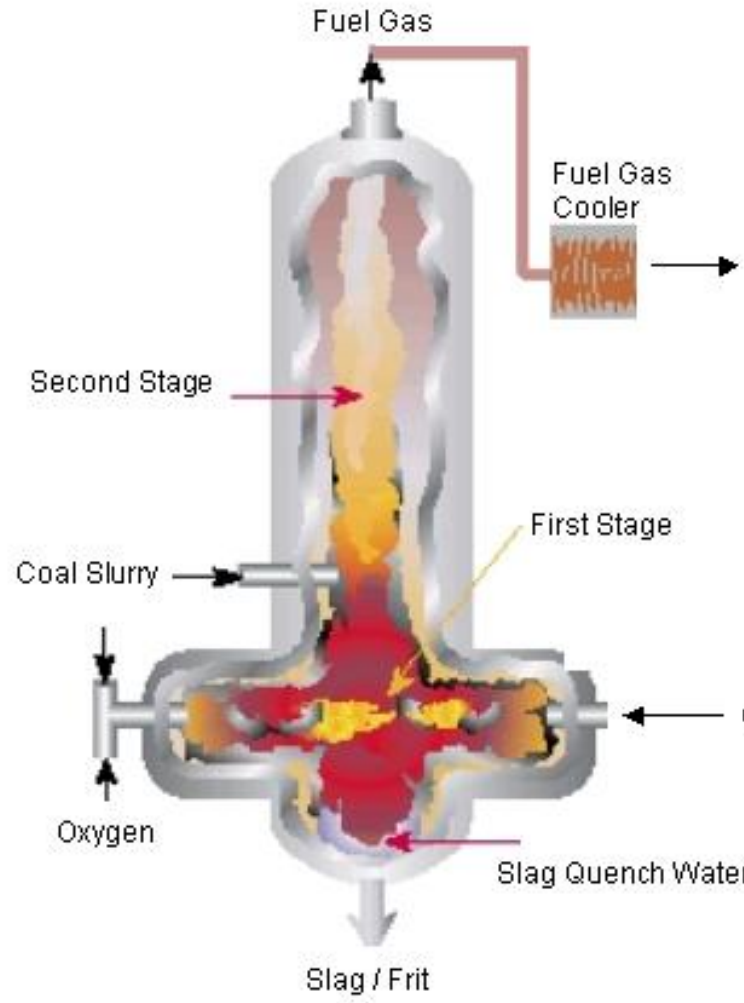


Other cycles under study:
- Fe looping
- $CaS/CaSO_4$ looping

Multi Stage Gasification

ConocoPhillips

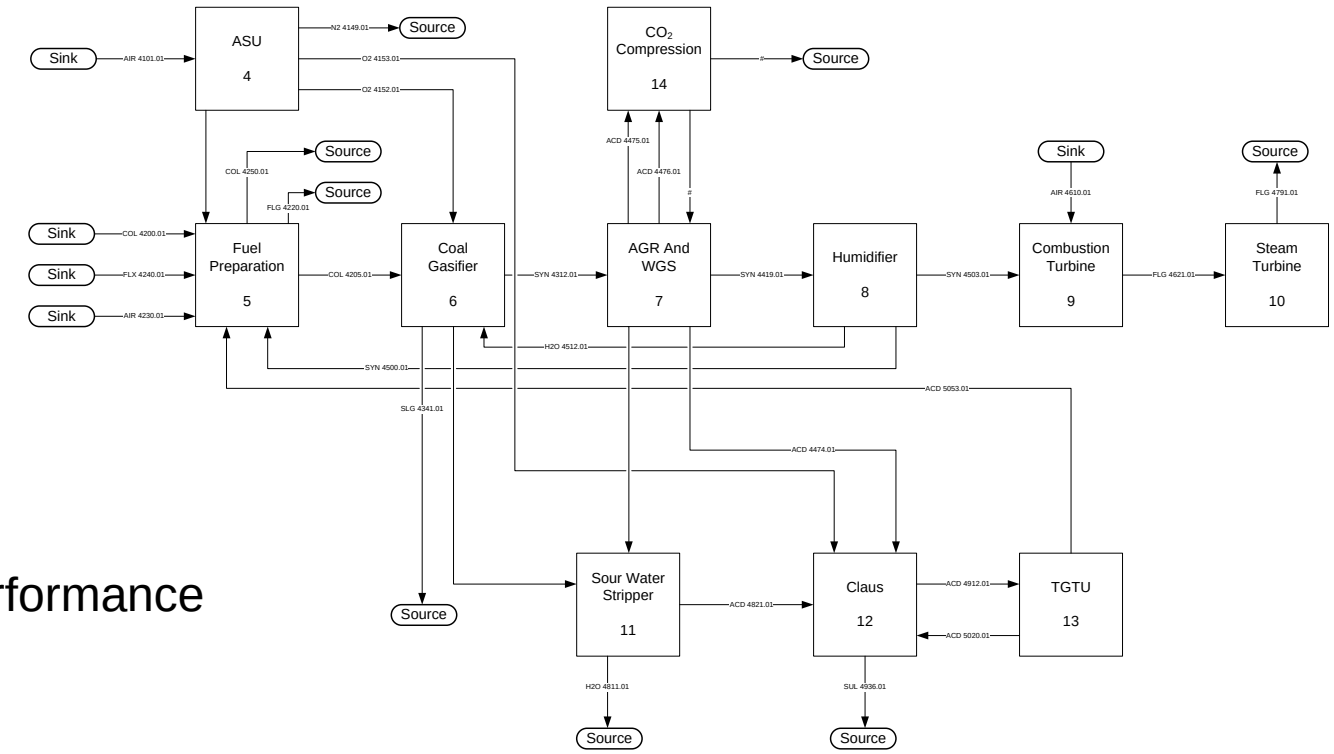
- Objective: Tar formation and control in 2nd stage of CoP gasifier
- Fee for service work
- CanmetENERGY gasifier can operate with 2 stages
  - Stage 1
    - Additional 6 ft reactor section
    - Oxy-fuel burner
  - Stage 2
    - Slurry atomization
    - *In situ* sampling and analysis of gas, tars, and solids



Process Simulation

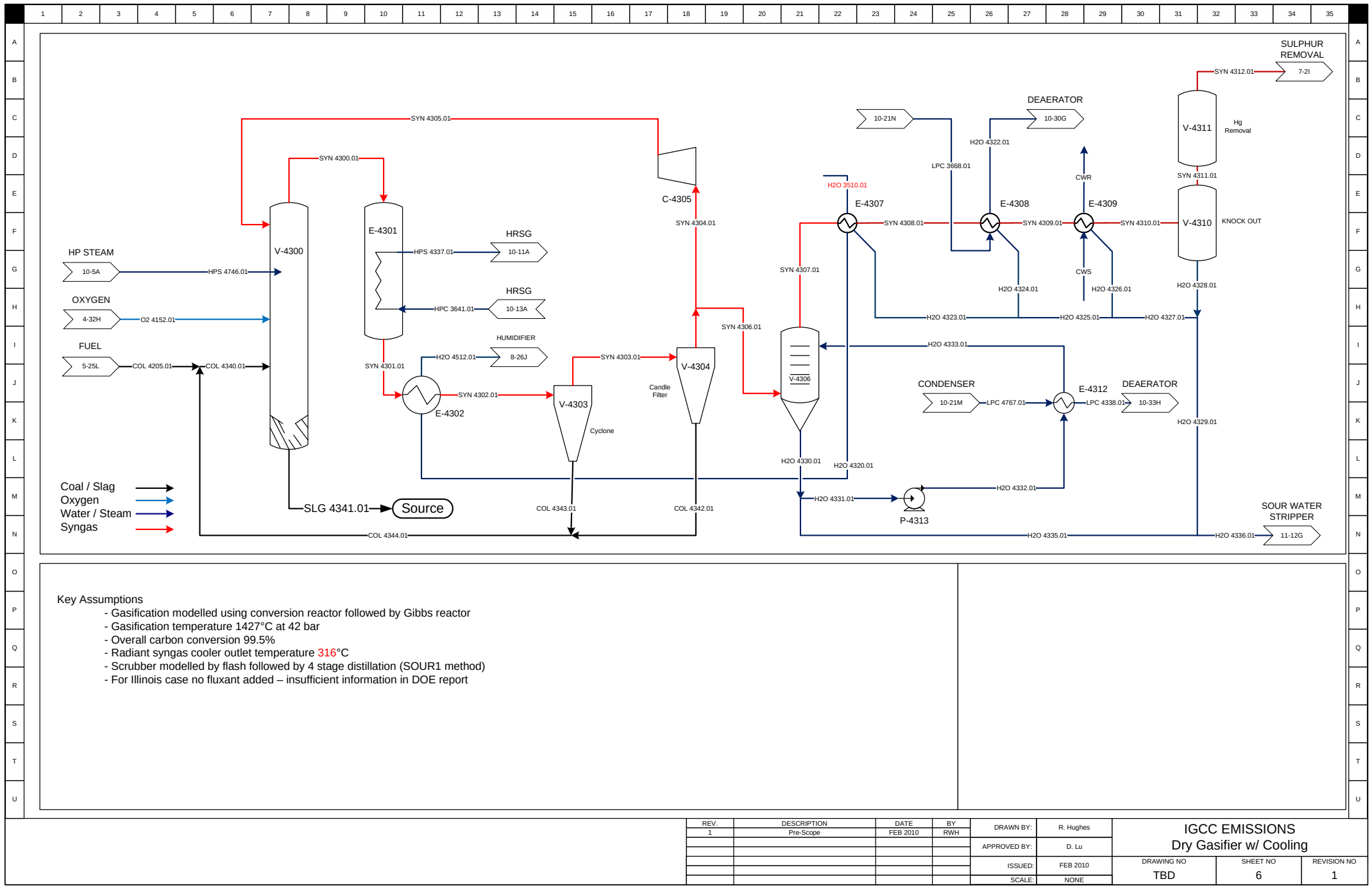
- Process simulations
  - Power, oil sands, polygen
  - Built-in fluxant optimization routines
  - Integration of advanced technologies
  - Carbon dioxide capture technologies

- Objectives
  - Compare efficiency and environmental performance
  - Technology screening
  - Pilot facility planning and analysis



- Recently completed simulation for typical IGCC with Canadian fuels
  - Sub-bit, lignite, pet coke
- Typical IGCC with CO_2 capture to be completed this spring
- Advanced CO_2 capture technologies
  - In-house
  - In conjunction with CCPC and Electric Power Research Institute (EPRI)

Process Flow Diagrams for Simulation



Key Assumptions

- Gasification modelled using conversion reactor followed by Gibbs reactor
- Gasification temperature 1427°C at 42 bar
- Overall carbon conversion 99.5%
- Radiant syngas cooler outlet temperature 316°C
- Scrubber modelled by flash followed by 4 stage distillation (SOUR1 method)
- For Illinois case no fluxant added – insufficient information in DOE report

REV.	DESCRIPTION	DATE	BY
1	Pre-Scope	FEB 2010	RWH

DRAWN BY:	R. Hughes	IGCC EMISSIONS Dry Gasifier w/ Cooling	
APPROVED BY:	D. Lu		
ISSUED:	FEB 2010	DRAWING NO: TBD	SHEET NO: 6
SCALE:	NONE		REVISION NO: 1

Topics of Interest

- Gasification databank of feedstocks
- Mechanisms of entrained flow gasification
- Process efficiency improvement of high ash feedstocks
  - Feedstock beneficiation
  - Partial quench
  - Multi-stage gasification
- High temperature syngas treating
- Synthesis gas conversion
- Gasifier materials testing
- Gasification by-products
- Hydrogen production technologies for gasification systems
- High pressure H_2/CO_2 separation technologies