ALLAM CYCLE COAL – A NEW CLEAN COAL POWER CYCLE

Presentation at 2017 U.S.-China Clean Coal Industry Forum
Changes-Challenges-Collaboration in the Coal Industry

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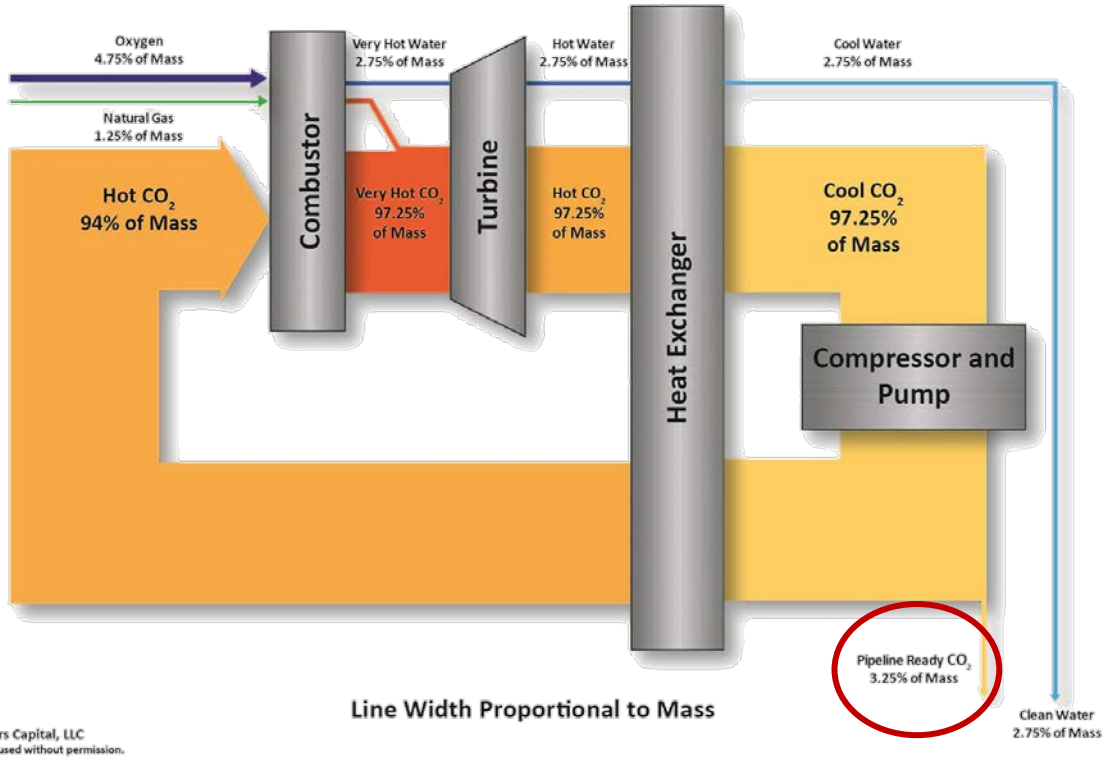
What is the Allam Cycle?

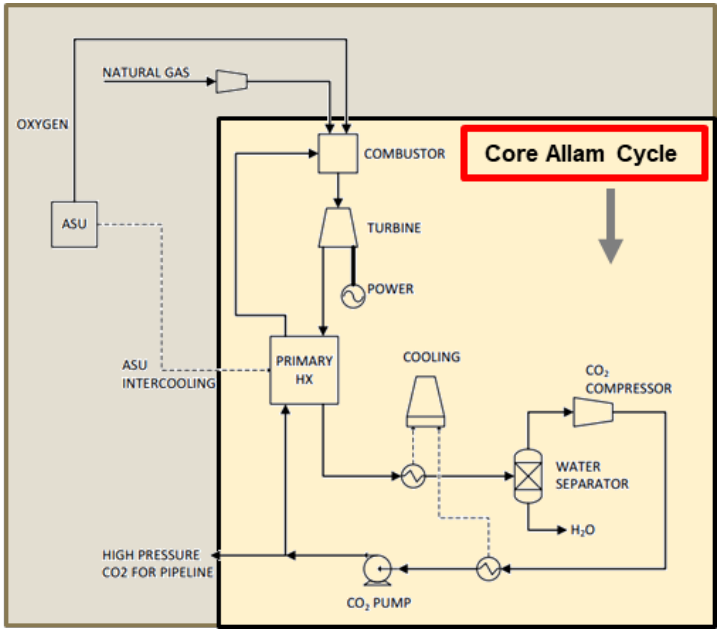
- **The Allam Cycle is**
  - A semi-closed, supercritical CO_2 Brayton cycle,
  - That uses oxy-combustion with natural gas, coal syngas, or other carbonaceous fuels.
- **Historically, CO_2 capture has been expensive, whether using air to combust or oxy-combustion.**
- **The Allam Cycle makes oxy-combustion economic by:**
  - Relying on a more efficient core power cycle.
  - Recycling heat within the system to reduce O_2 and CH_4 consumption, and associated costs of the ASU.



The Allam Cycle is Being Commercialized in Two Pathways

NETPOWER

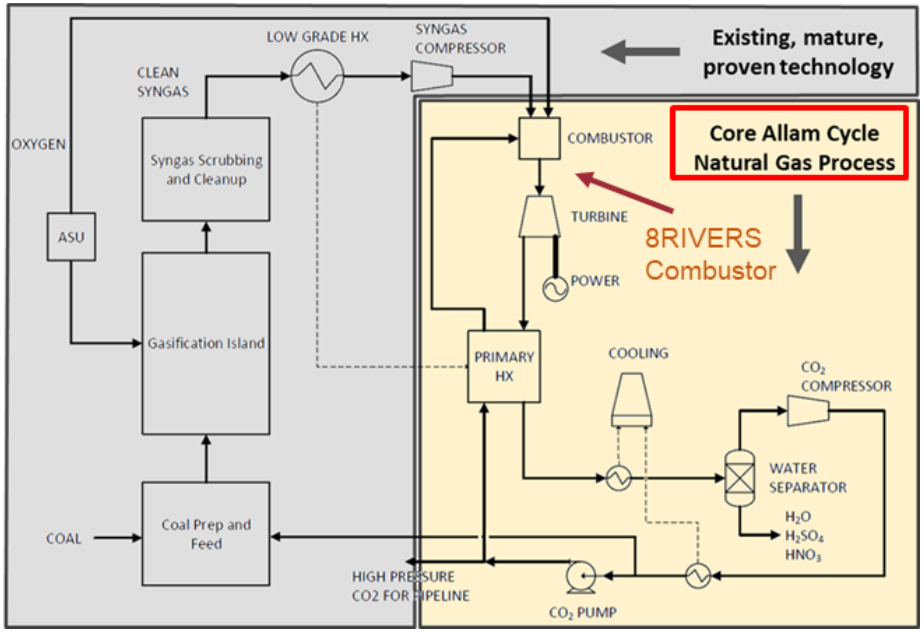
Efficiency Breakdown	
Gross Turbine Output	82.7%
CO_2 Comp+Pump Power	-11.6%
Other Plant Auxiliary Power	-12.2%
Net Efficiency	58.9%



8RIVERS ENERGY

(coal+)

Efficiency Breakdown	
Gross Turbine Output	76.3%
CO_2 Comp+Pump Power	-15.6%
Other Plant Auxiliary Power	-10.4%
Net Efficiency	50.3%



8 RIVERS

NET Power Is Demonstrating the Core Allam Cycle

50MWth gas plant in La Porte, TX

- Scaled down from 500MWth design
- Construction nearing completion; commissioning in progress.

Includes all core components

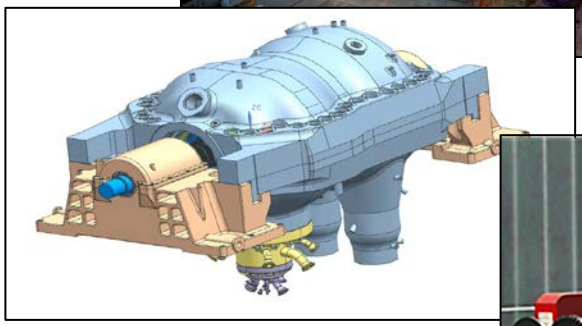
- Combustor/turbine, heat exchangers, pumps/compressors, controls, etc.
- Grid connected and fully operable

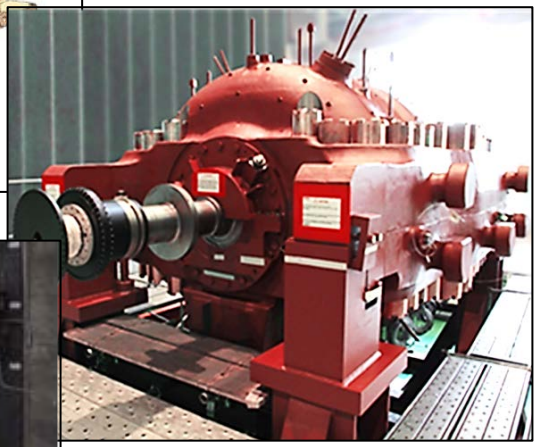
$140 million (USD) program

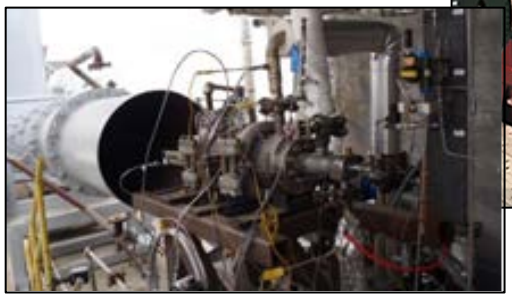
- Includes first of a kind engineering, all construction, and testing period
- Partners include Exelon Corpration, CB&I, 8 Rivers and Toshiba

The coal cycle can utilize the turbine already under development

- Operating conditions, performance and efficiency can be maintained across fuels

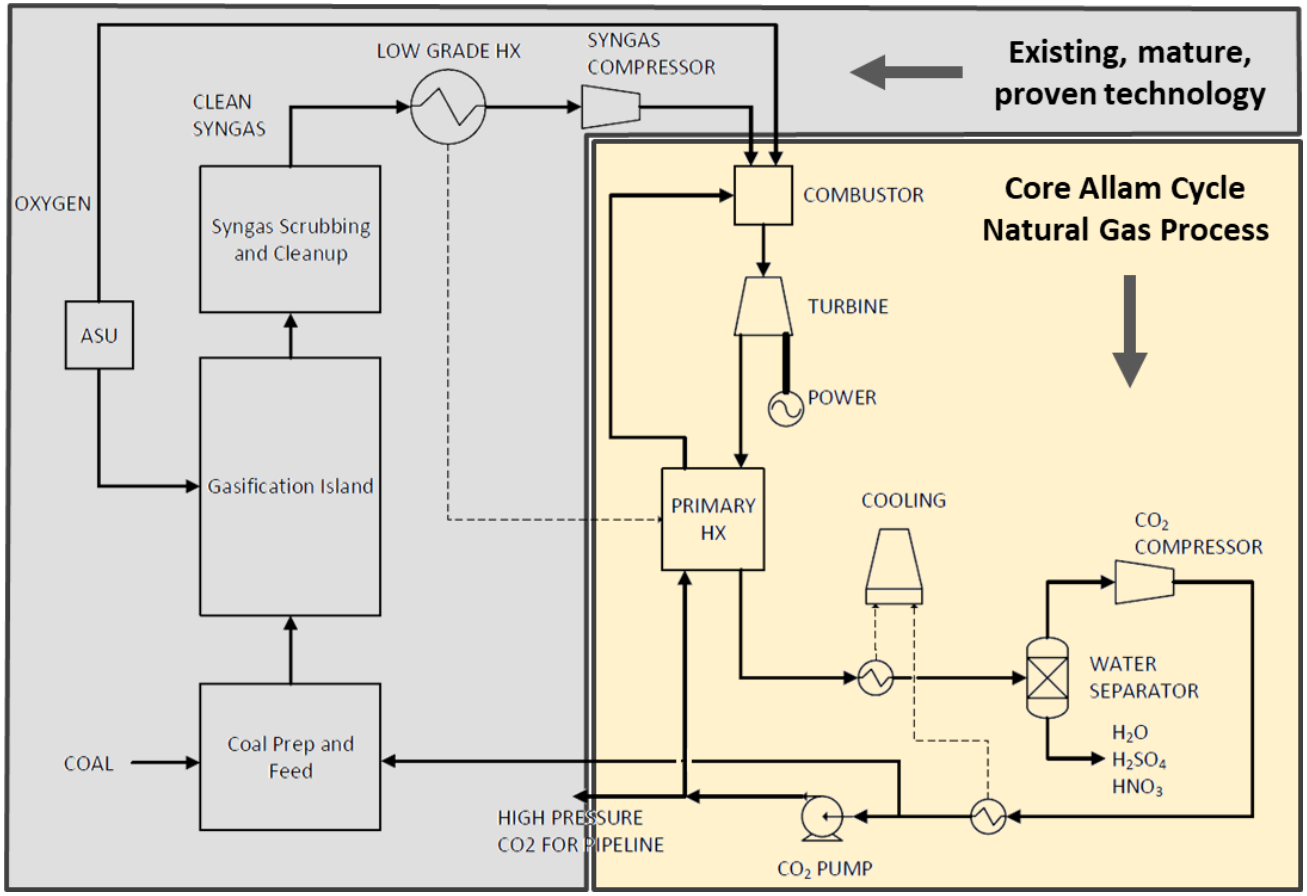






The Core Allam Cycle Platform Is Being Extended to Coal

The Allam Cycle can be used with solid fuels while maintaining all the benefits of the core Allam Cycle.



Efficiency	LHV	HHV
Gross Turbine Output	76.3%	72.5%
Coal prep & feed	-0.2%	-0.2%
ASU	-10.2%	-9.7%
CO_2, Syngas Comp.	-9.1%	-8.7%
Other Auxiliaries	-6.5%	-6.1%
Net Efficiency	**50.3%**	**47.8%**

- **High efficiency** with existing gasifiers.
- **Significant process simplification** vs. IGCC.
- Can use **unique impurity removal methods.**
- Special material considerations to **prevent corrosion.**
- **Zero emissions,** including CO_2, SOx, NOx, Hg, particulates.

Allam Cycle Coal Achieves High Performance with Various Gasifiers and Feedstocks

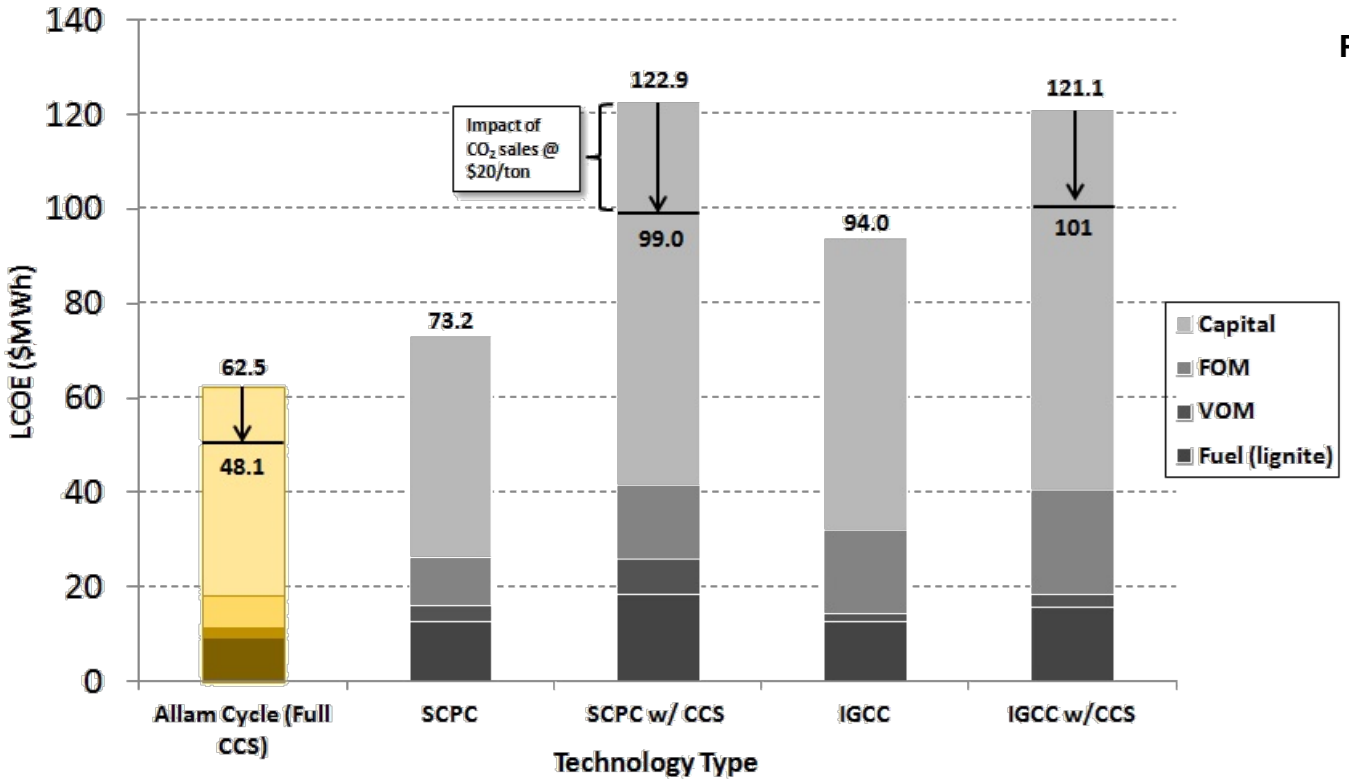
Allam Cycle Cases

Coal Type	Gasifier Type		Heat Recovery	CCS	Efficiency (%HHV)
Bituminous	Entrained flow, dry-feed	Slagging	Syngas cooler	Y	49.7
Lignite	Moving bed	Slagging	Full water quench	Y	48.2
Bituminous	Entrained flow, dry-feed	Slagging	Full water quench	Y	47.8
Lignite	Entrained flow, dry-feed	Slagging	Full water quench	Y	47.4
Bituminous	Entrained flow, slurry	Slagging	Syngas cooler	Y	46.8
Lignite	Fluidized bed	Non-slagging	Syngas cooler	Y	43.3

NETL Coal Benchmark Cases

Coal Type	Gasifier Type		Heat Recovery	CCS	Efficiency (%HHV)
Bituminous	Entrained flow, dry-feed	Slagging	Syngas cooler	N	42.1
Lignite	Entrained flow, dry-feed	Slagging	Syngas cooler	N	37.6
Bituminous	SCPC	N/A	N/A	N	39.3
Lignite	SCPC	N/A	N/A	N	38.7

Increased Performance, Lower Capex, Reduced Complexity Lead to Much Lower LCOE Projections for Allam Cycle Coal



Reduction in costs from removal of:

~~Steam turbine~~

~~HRSG~~

~~Steam piping/equipment~~

~~Water-gas shift reactor~~

~~High Temp syngas cooler~~

~~NO_X control unit/SCR unit~~

Potential removal of:

AGR/sulfur recovery unit

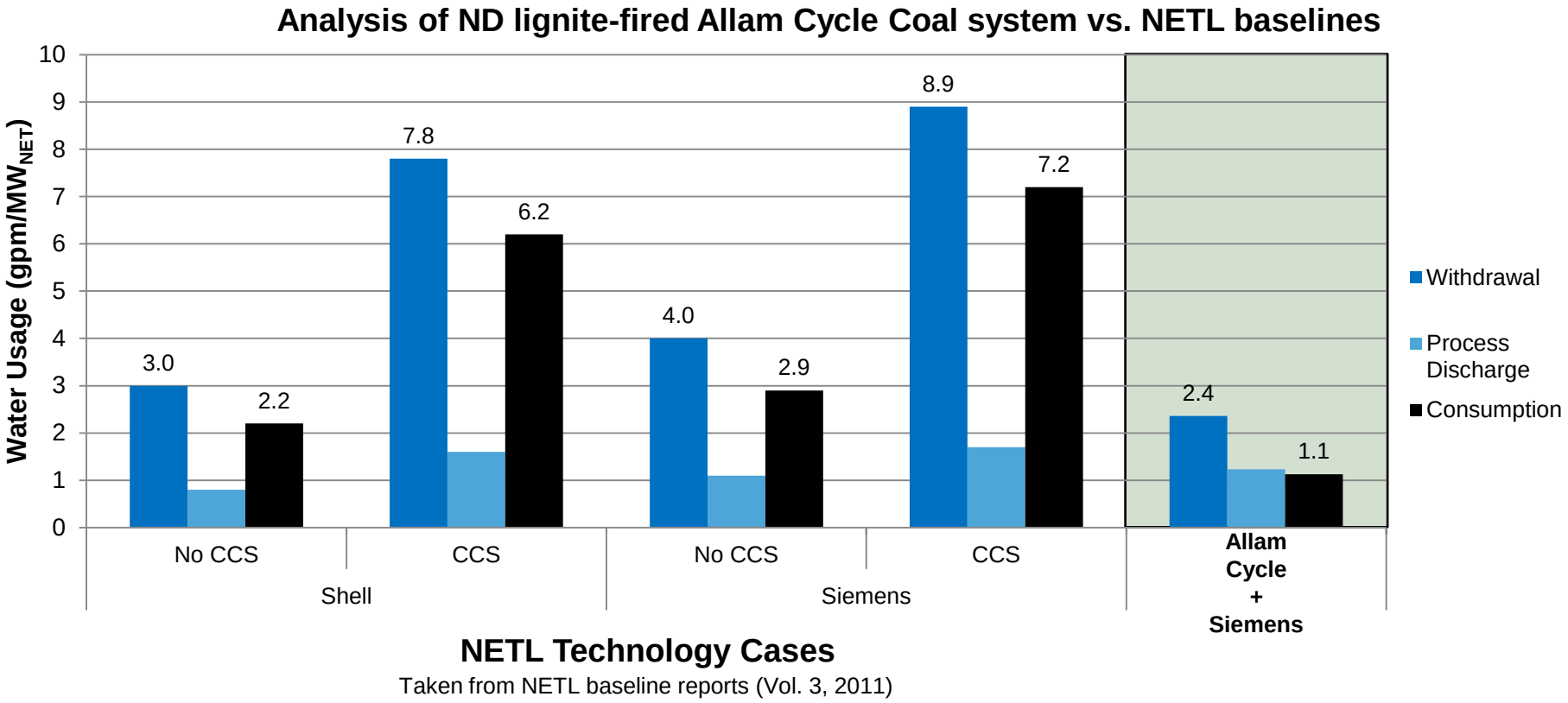
COS hydrolysis

Solvents/catalysts

Notes

- Lu et al. Oxy-Lignite Syngas Fueled Semi-Closed Brayton Cycle Process Evaluation (2014)
- Total Plant Cost and O&M costs were estimated for lignite-fired system in conjunction with EPRI; AACE Class 5 estimate
- Cost data for other technologies is taken from NETL baseline reports (Vol. 3, 2011)

Significant Water Savings Compared to IGCC



50-60% reduction in water consumption vs. IGCC non CCS using ND Lignite; Major reductions come from:
(1) elimination of steam cycle; (2) reduced cooling duty (higher efficiency, utilization of low-grade heat); (3) semi-closed cycle captures and condenses combustion derived water.

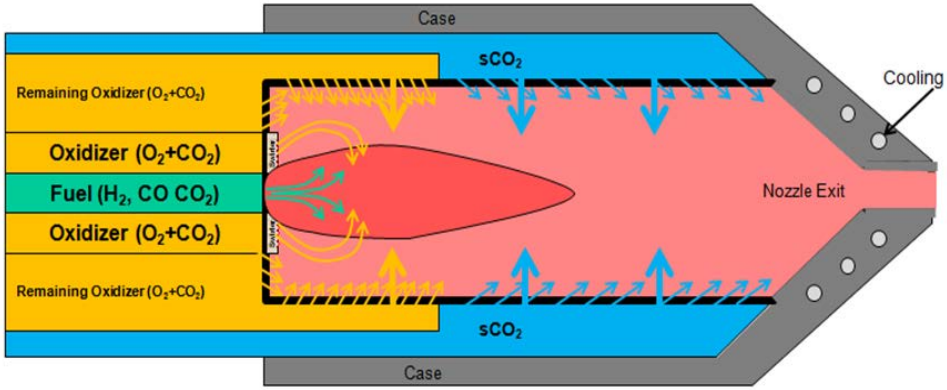
Development Program Underway

	2016	2017	2018	2019
Task 1 Corrosion	Static tests	Dynamic tests		
Task 2 Gasifier Selection	Down-select	Model with vendor data		
Task 3 Impurity Removal	Feasibility testing	Detailed testing		Additional partners needed
Task 4 Syngas Combustion	Feasibility design	Reaction kinetics	Small scale testing	

Syngas Combustor Development is a Key Step

Development status:

- Conceptual commercial syngas combustor design
- Detailed design and CFD modeling for a 5MW$_{th}$ test combustor
- Test program and rig development
- Work supported by US DOE.

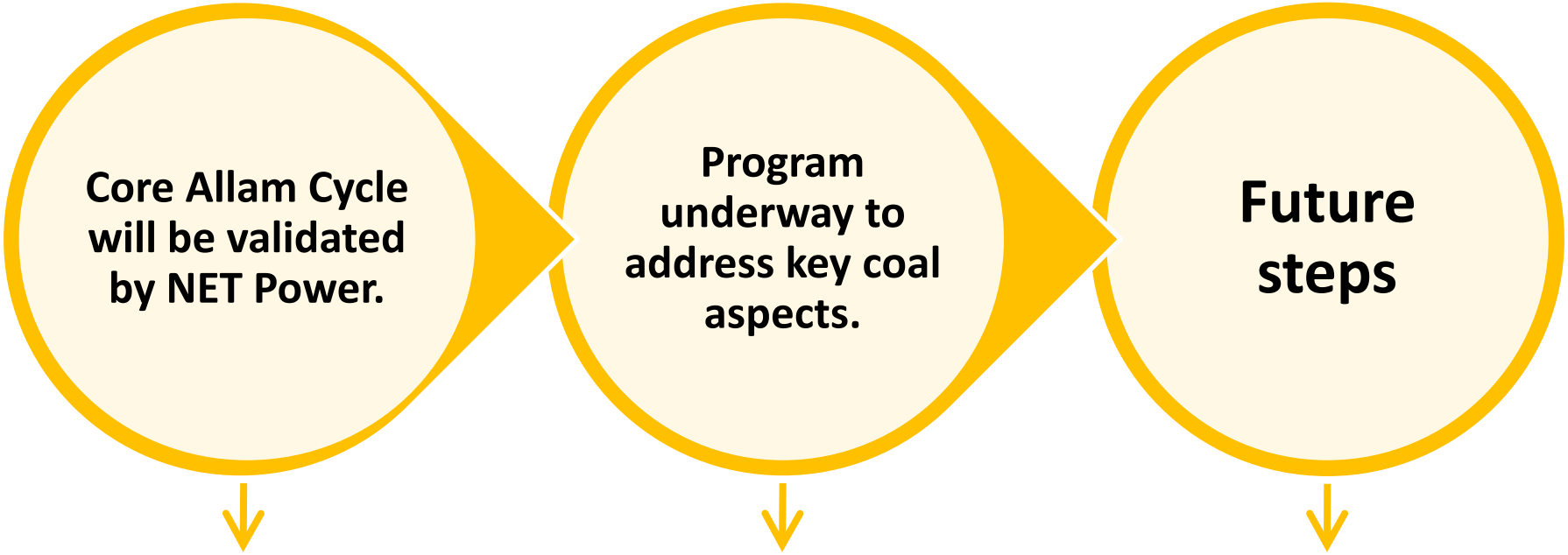


Work to date indicates a highly promising design:

- Good mixing and negligible pressure oscillations with uniform exit temperatures
- Consistent performance across a wide range of syngas fuels
- No mechanical or liner cooling issues identified

Program is ready to move to test article developing and operation.

Coal Cycle Development Process



Thank you.

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