Thermal Management in a Coal-Based SOFC Hybrid Through Numerical Simulation

7th Annual SECA Workshop and Peer Review

Philadelphia, PA September 12-14, 2006

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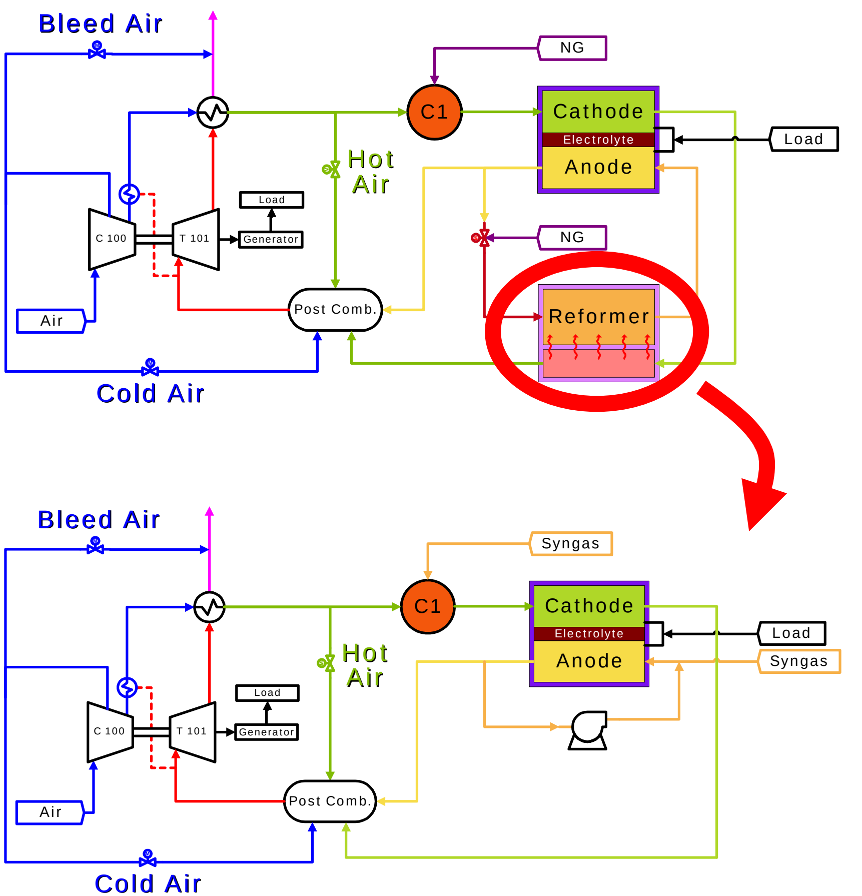
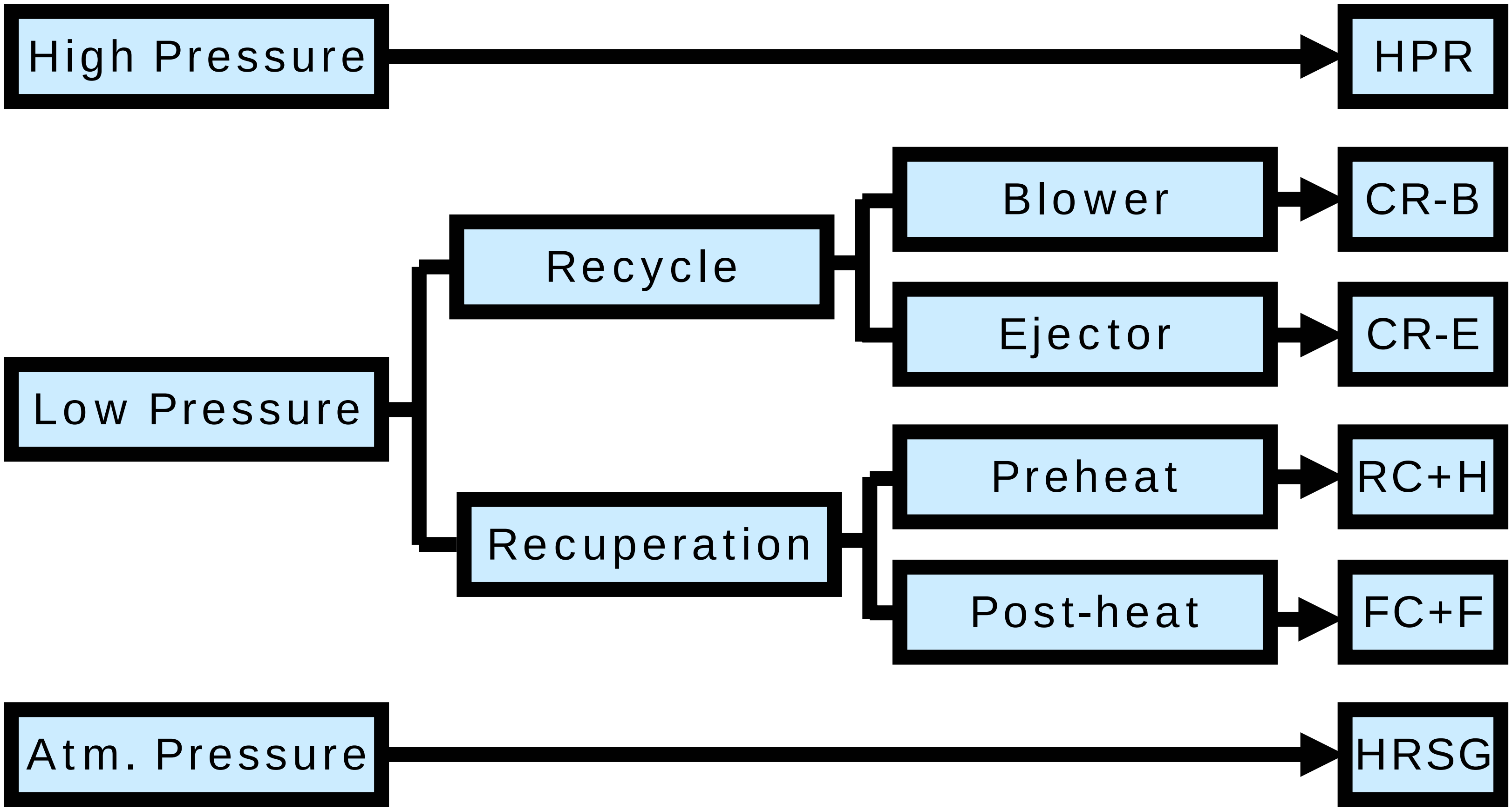
Objective

Provide a relative comparison of methods commonly considered for thermal management in coal-based fuel cell turbine systems

- Previous work based on NG
- Higher air mass flows required
- Fix fuel cell load in each case
- Fuel varied to get target fuel cell power
- Turbine load based on available heat
- Compressor airflow to target ΔT=150ºC
- Efficiency based on HHV syngas
- Power density evaluated for each case
- Lumped fuel cell model for ASPEN
- 1D fuel cell model for performance



Configurations Studied



Fuel Cell Parameters

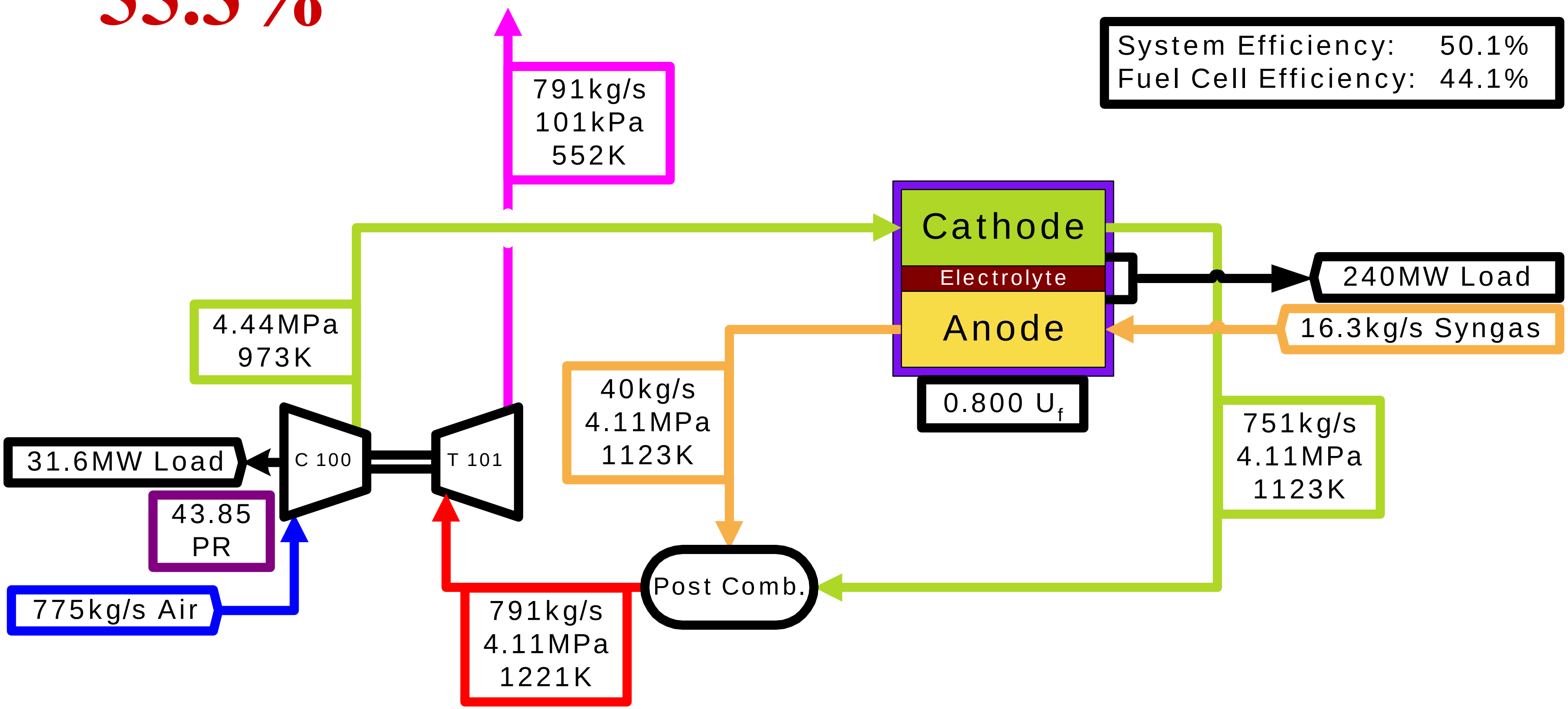
Parameter	**Value**
Initial Cell Voltage at 101.325kPa	0.7V
Initial Current Density at 101.325kPa	$500mA/cm^2$
Stack Power	240MW
Stack Fuel Utilization	80%
Cell Temperature	1123K
Fuel Cell Inlet Temperature	973K
Fuel Cell ΔT	150K

Turbine Parameters

Parameter	Value
Compressor Isentropic Efficiency	80%
Turbine Isentropic Efficiency	90%
Gas Turbine Mechanical Efficiency	98%
Generator Efficiency	97%
Inverter Efficiency	98%
Fuel Cell Pressure Drop	2.5%
Combustor and Manifolds Pressure Drop	5.0%
Recuperator Pressure Drop	2.5%
Recuperator Effectiveness	89%

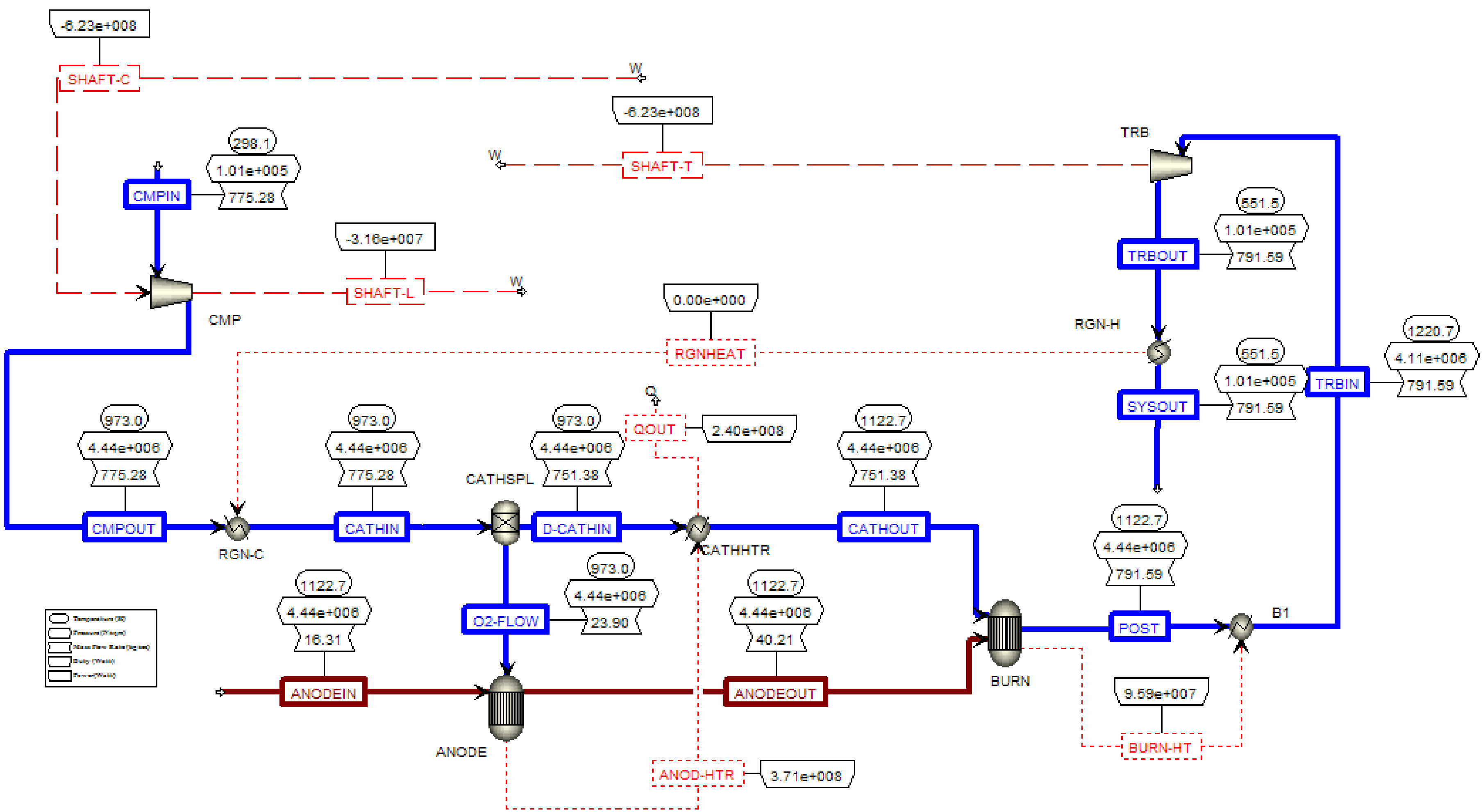
Heat of Compression Configuration

HPR
55.3%

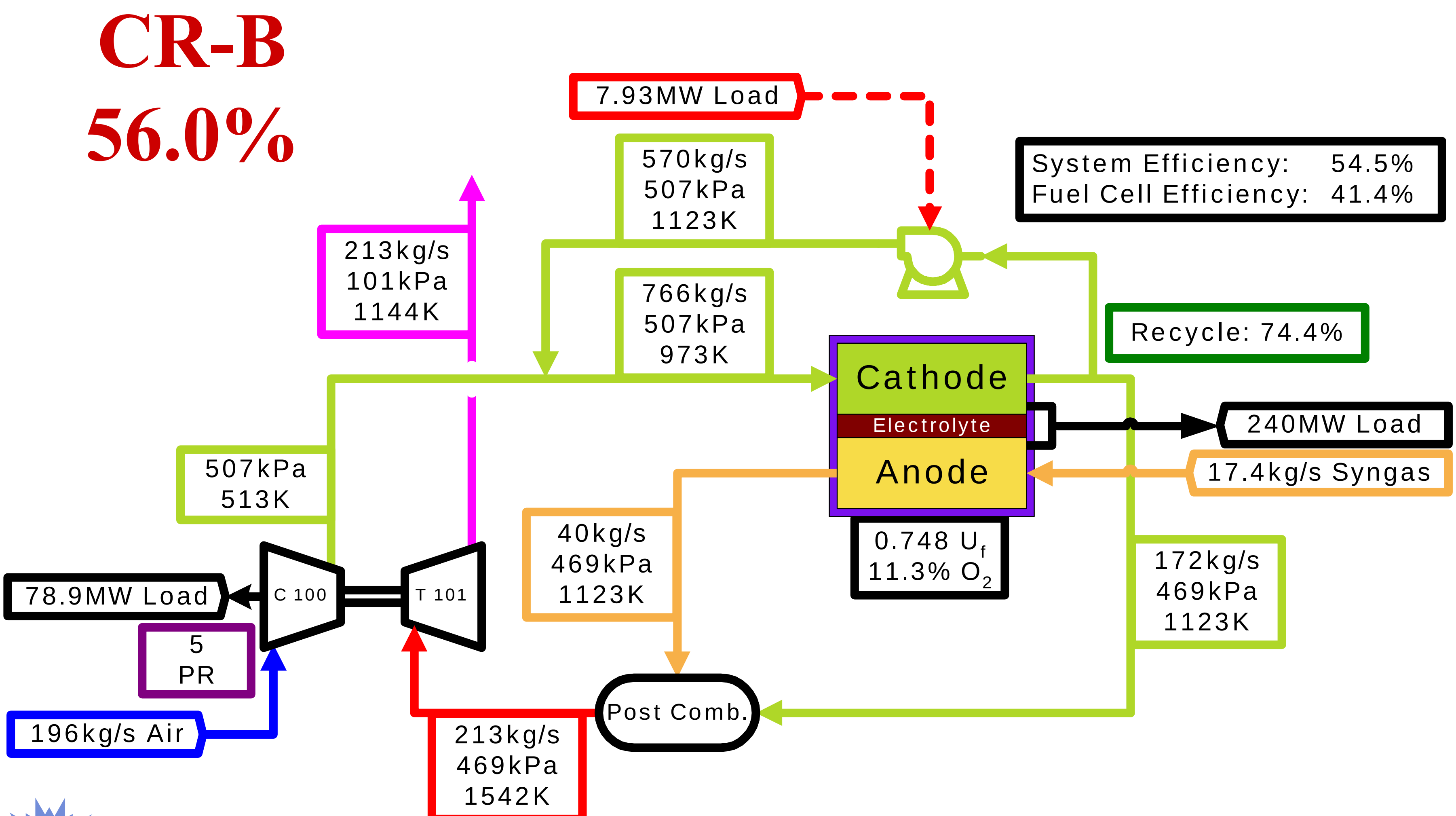


Heat of Compression Configuration

- PR = 43.85 used to get target cathode Tin of 700°C (973K)
- Fuel flow used to get a FC power of 240MW
- Compressor Flow used to get 150°C ΔT across FC
- 44.1% FC Eff. (HHV)
- 50.0% System Eff (HHV)
- ΔP = 7.5%



Cathode Recycle Configuration with Blower

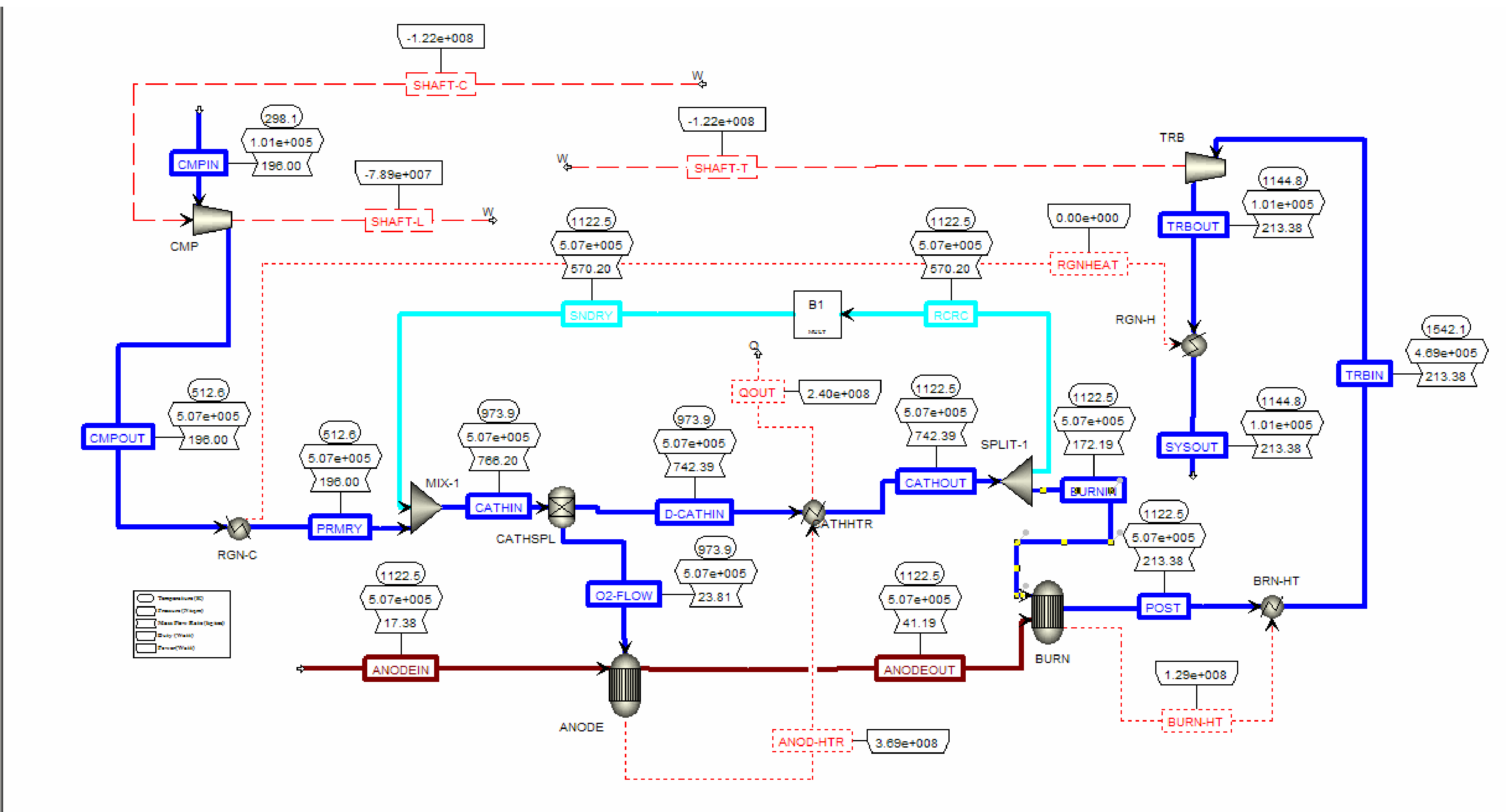


NETL

Cathode Recycle Configuration with Blower

- Recycle ratio of 74.4% to get cathode Tin of 700°C (973K)
- Fuel flow used to get a FC power of 240MW
- Compressor Flow used to get 150°C ΔT across FC

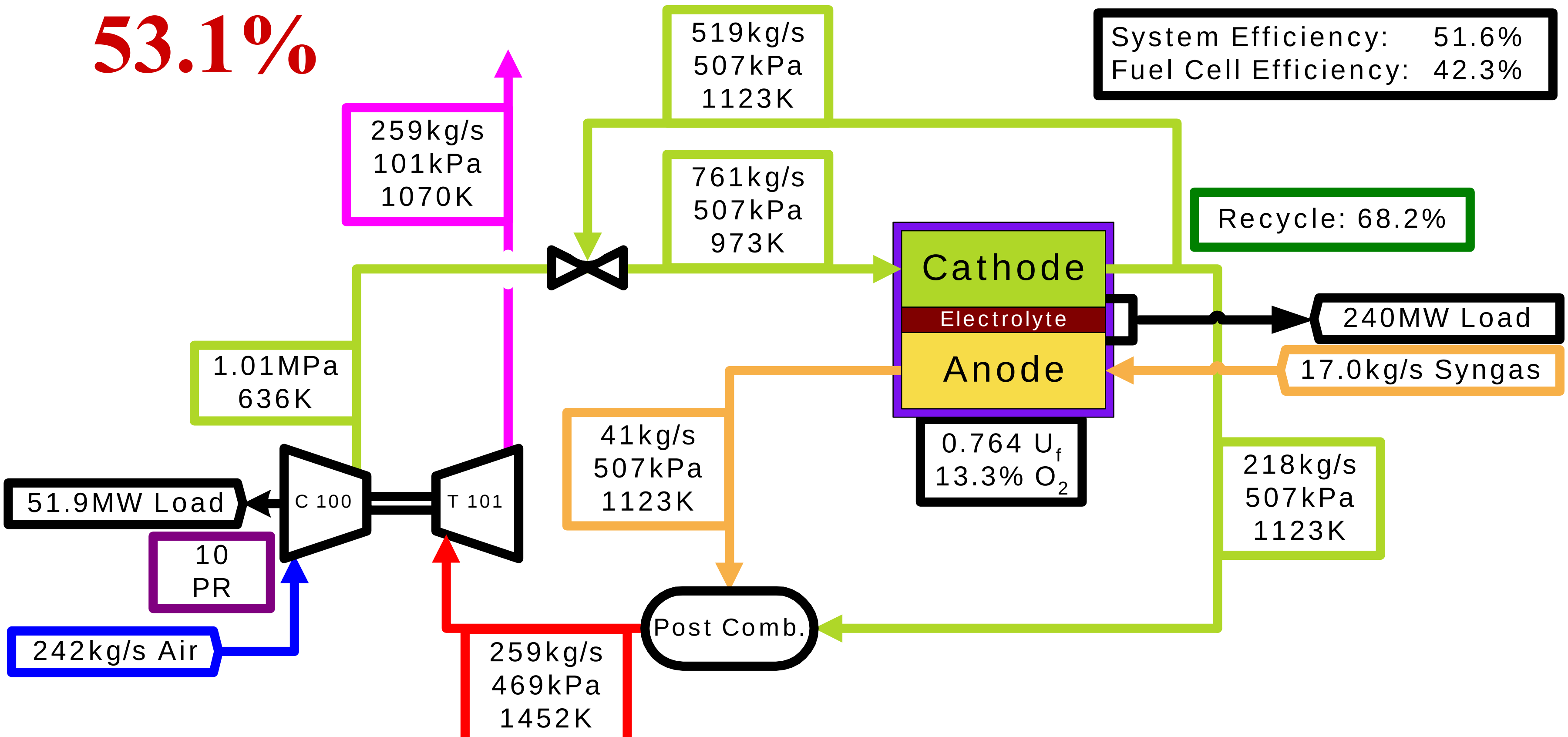
- 41.4% FC Eff.
- 54.5% System Eff.
- ΔP = 7.5%



Cathode Recycle Configuration with Ejector

CR-E

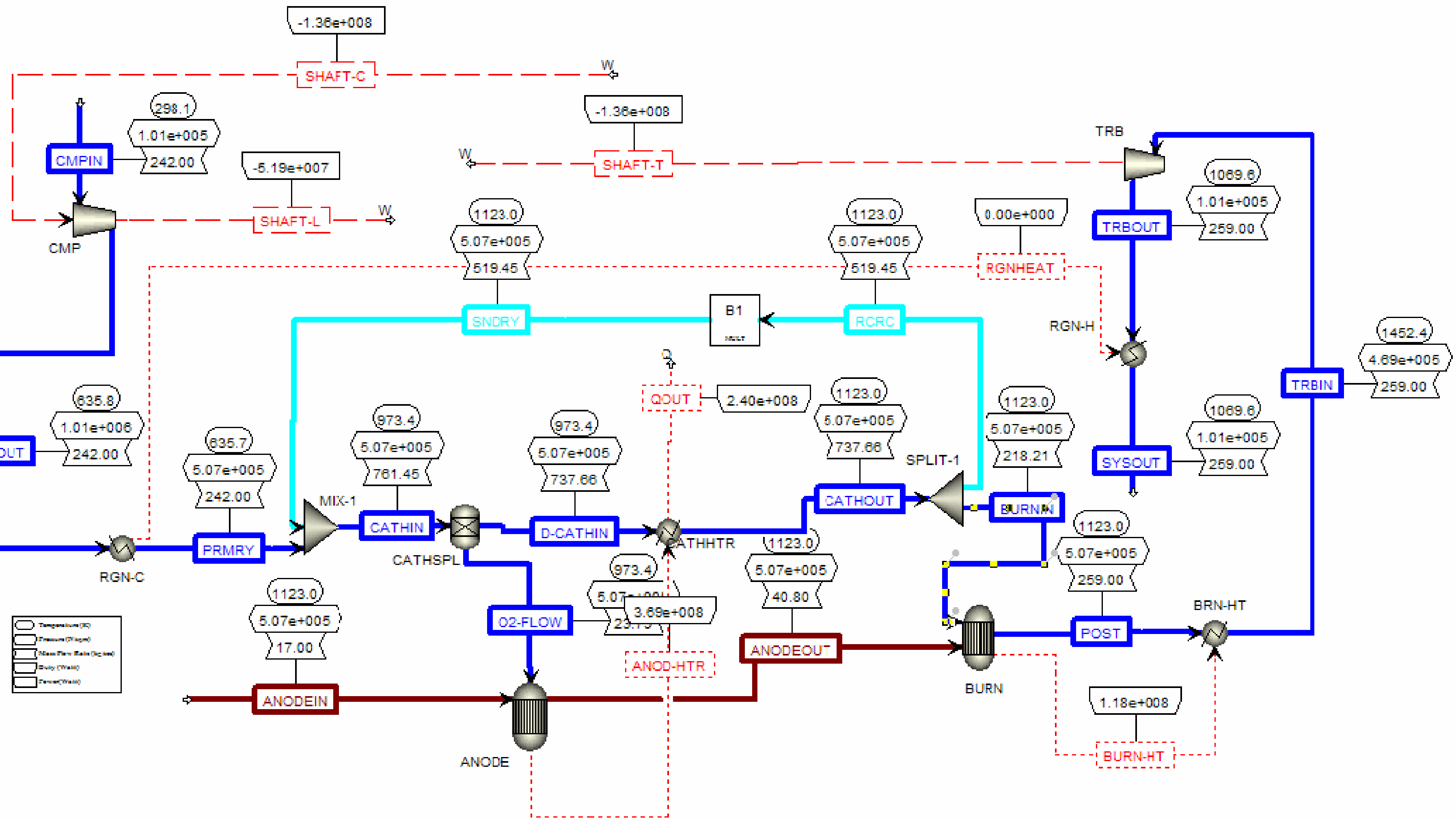
53.1%



Cathode Recycle Configuration with Ejector

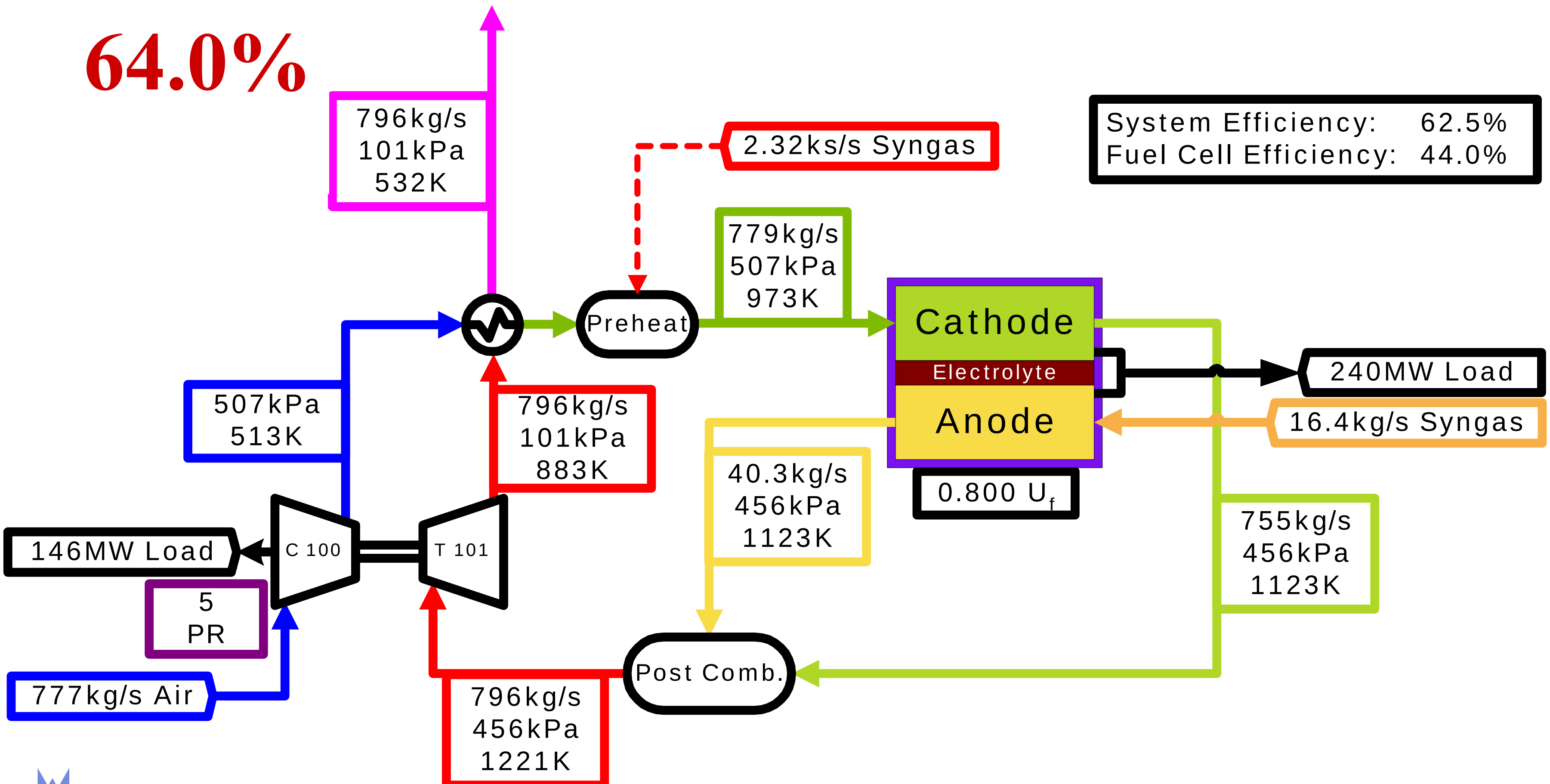
- Recycle ratio of 70.3% to get cathode Tin of 700ºC (973K)
- Fuel flow used to get a FC power of 240MW
- Compressor Flow used to get 150ºC ΔT across FC

- 51.6% FC Eff.
- 42.3% System Eff.
- ΔP = 53.8%



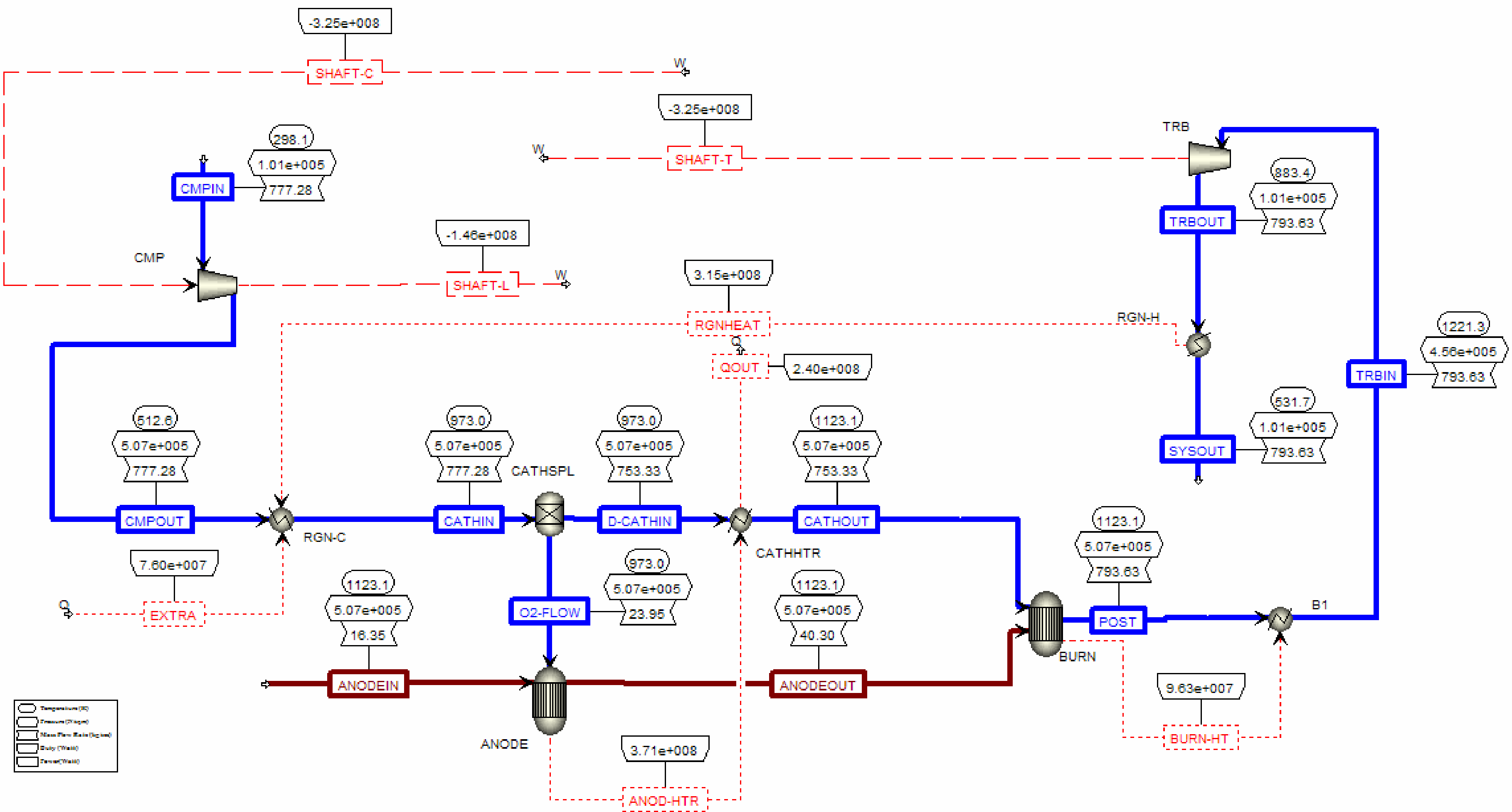
Recuperated Configuration with Pre-Heat

RC+H
64.0%



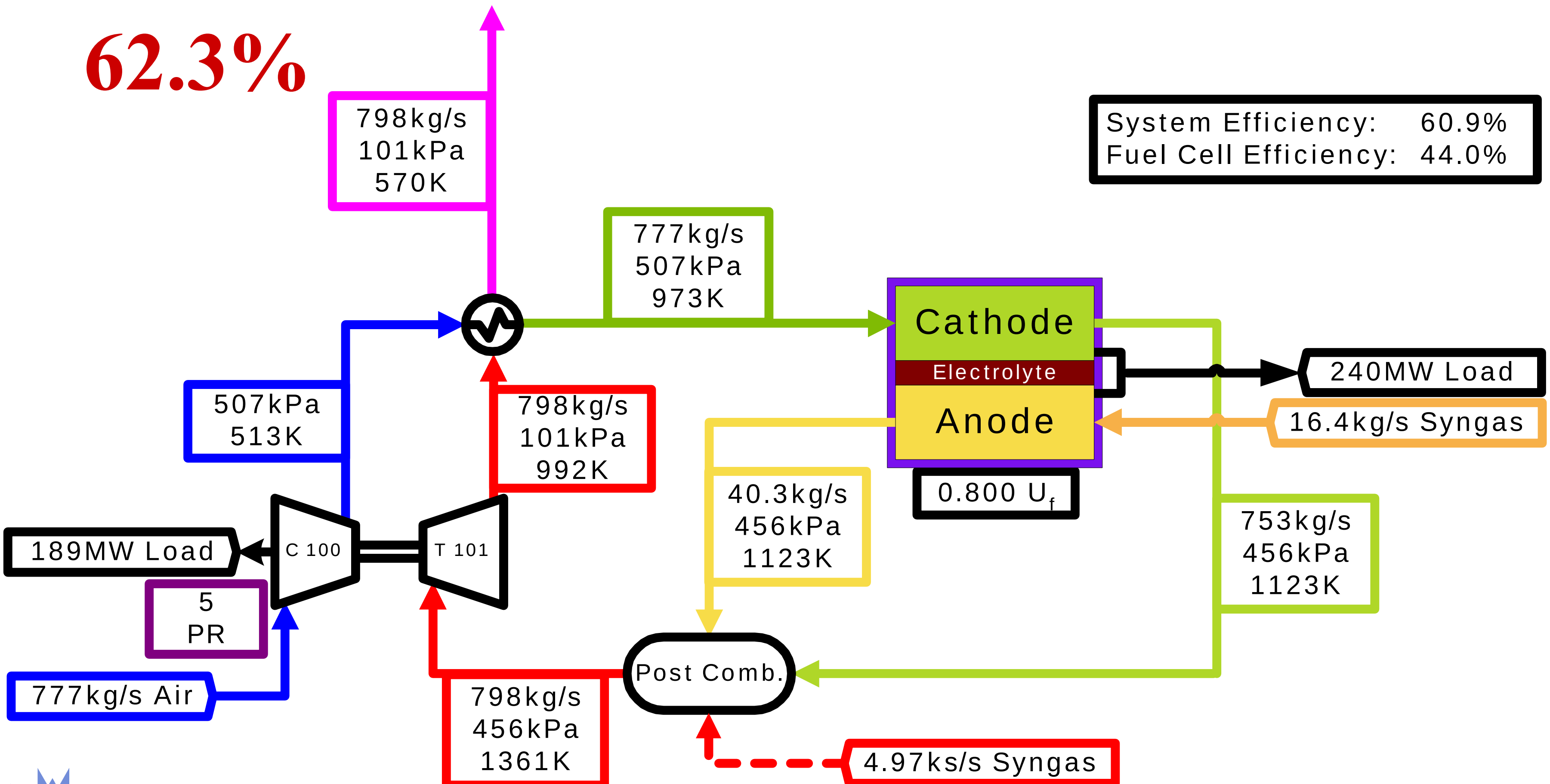
Recuperated Configuration with Pre-Heat

- Pre-heat used to get target cathode Tin of 700ºC (973K)
- Fuel flow used to get a FC power of 240MW
- Compressor Flow used to get 150ºC ΔT across FC
- 44.0% FC Eff. (HHV)
- 62.5% System Eff. (HHV)
- ΔP = 10%



Recuperated Configuration with Post-Heat

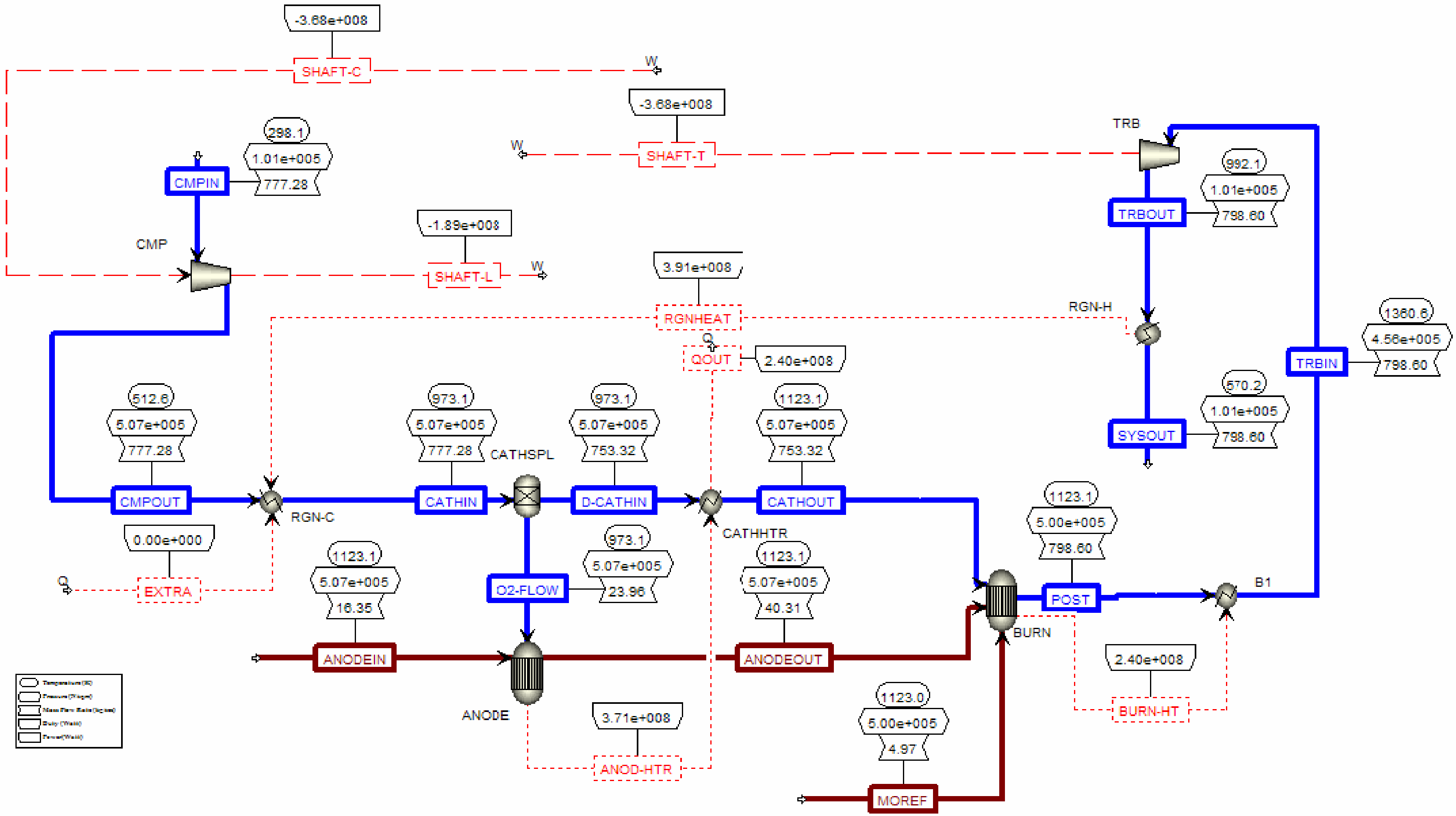
RC+F
62.3%



Recuperated Configuration

- Extra fuel used to get turbine exhaust T to target cathode Tin of 700ºC (973K)
- Fuel flow used to get a FC power of 240MW
- Compressor Flow used to get 150ºC ΔT across FC

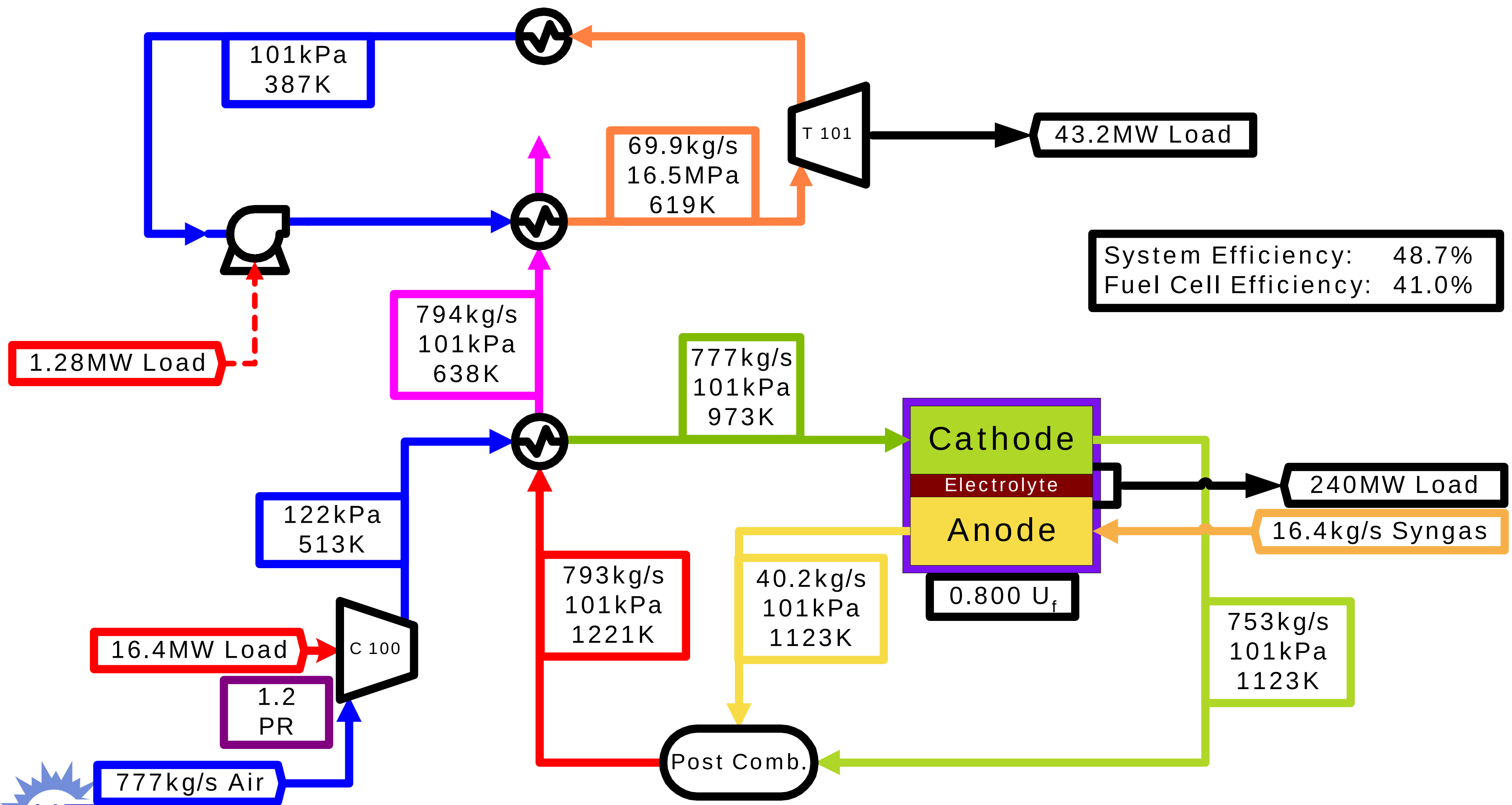
- 44.0% FC Eff. (HHV)
- 60.9% System Eff. (HHV)
- ΔP = 10%



Atmospheric Fuel Cell with Steam Bottom

HRSG

48.7%



Summary of Results

Parameter	HPR	CR-B	CR-E	RC+H	RC+F	HRSG
Highest System Efficiency	55.3%	56.0%	53.1%	64.0%	62.3%	48.7%
Highest Fuel Cell Efficiency	47.2%	43.4%	44.3%	46.1%	46.1%	41.0%
Total Syngas (kg/s)	16.3	17.4	17.0	18.7	21.3	16.4
Pressure Ratio	43.85	5	10	5	5	1.2
Comp. Mass Flow (kg/s)	775	196	242	777	777	777
Turbine Power (MW)	32	79	52	148	189	43.2
Turbine Inlet Temp. (K)	1220	1542	1452	1220	1360	619
System Exhaust Temp. (K)	552	1144	1070	532	570	387
Total Pressure Drop	7.5%	7.5%	53.8%	10%	10%	20%
Cathode Mass Flow (kg/s)	775	766	761	777	777	777
Recycle Ratio	N/A	74.4%	68.2%	N/A	N/A	N/A

Conclusions

Heat of Compression

- Mechanically simple
- Higher power density
- Lower fuel cell material cost
- Fuel cell integration issues
- Lower efficiency

Steam Bottom

- Mechanically simple
- Available Technology
- Integration with Other Steam
- Lowest efficiency

Recuperation

- Highly efficient
- Complex

Cathode Recycle

- No recuperator
- Reasonable performance at lower pressure
- Higher grade heat from exhaust
- Reduced control options for air flow management
- Methods of recycle require further study

Acknowledgements

- **DOE Fuel Cell Program**
  - This work was funded by the DOE Fuel Cells Program at NETL administered by Wayne Surdoval.
- **Woodward Industrial Controls**
  - This work was done in collaboration with Woodward Industrial Controls through a Cooperative Research and Development Agreement.
- **Dave Ruehl**
  - Dave is the Hyper project facility operator assigned to the project by Parsons Power, Inc.