Fuel Cell Systems Analysis

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Objective

Develop a validated system model and periodically update it to assess the technology status.

Technical Barriers Addressed

A. Compressors/Expanders
B. Thermal Management
C. Fuel Cell Power System Benchmarking
D. Heat Utilization
H. Start-up Time
I. Fuel Processor Start-up/Transient Operation
K. H_2 Purification/CO Cleanup
M. Fuel Processor System Integration and Efficiency
R. Thermal and Water Management

Approach

Develop, document & make available versatile system design and analysis tool.

- GCtool: Stand-alone code on PC platform
- GCtool_ENG: Coupled to PSAT (MATLAB/SIMULINK)

Validate the models against data obtained in laboratory and at Argonne's Fuel Cell Test Facility.

Apply models to issues of current interest.

- Work with FreedomCAR Technical Teams.
- Assist DOE contractors as requested by DOE.

Project Milestones

Milestone	*Date*	
Support setting of CEMM targets.	Oct. 2002	✓
Support setting of H_2 storage targets.	Jan. 2003	✓
Build models for components and systems.	Apr. 2003	✓
Propose and analyze FC systems for hybrid vehicles.	May 2003	✓
Analyze Nuvera data.	Jul. 2003	
Evaluate FC systems for combined heat and power.	Sep 2003	

Reviewers’ Comments

Focus on dynamic model development and issues of transients, turndown ratio, start-up.

- Will present results on transient response & cold-start of H_2 FC systems
- Assisted project on fast start of gasoline fuel processors
- Filed a patent on load-following fuel processors

More interactions with FreedomCAR Fuel Cell, Systems Analysis, and Energy Storage Tech Teams.

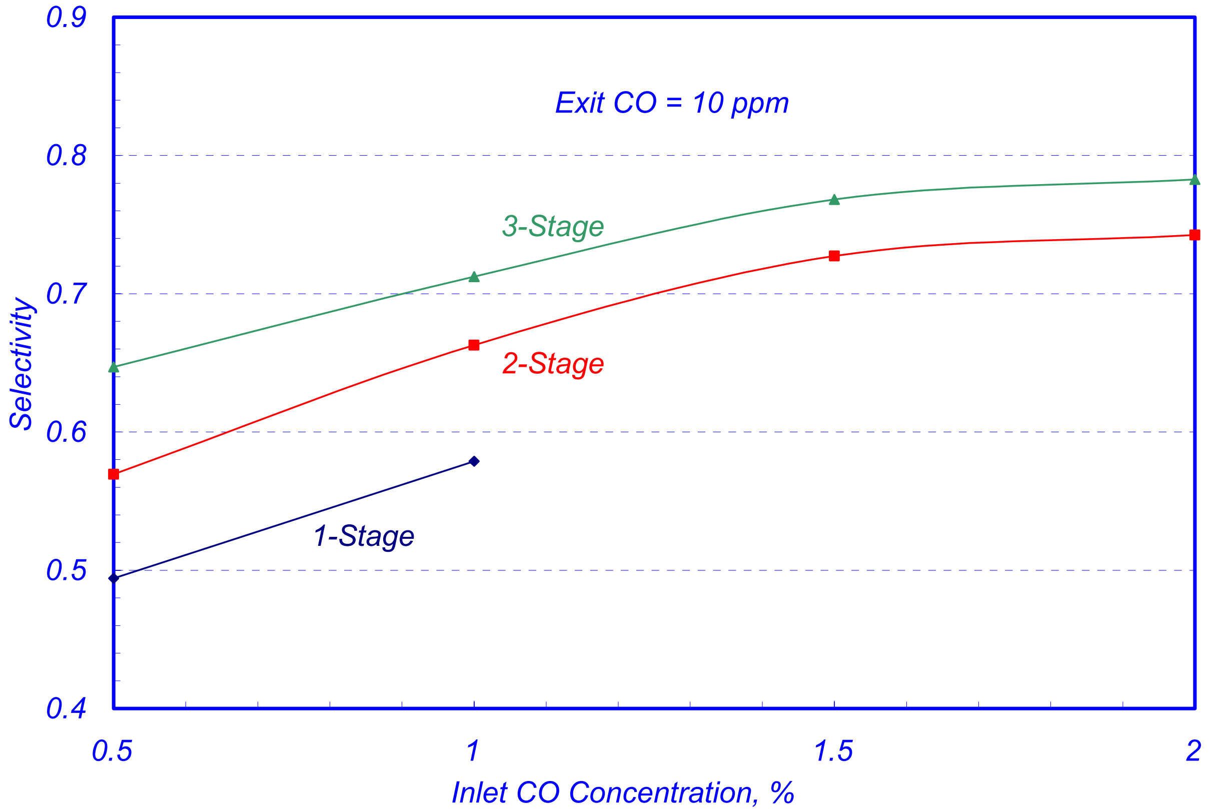
- Supported setting of targets for air management system.
- Supported setting of H_2 storage targets
- Participating in hybridization study.

Emphasize code development.

- Developed dynamic models of catalytic reactors, CEMM, heat rejection system, water management system …….

Code Development in FY2003

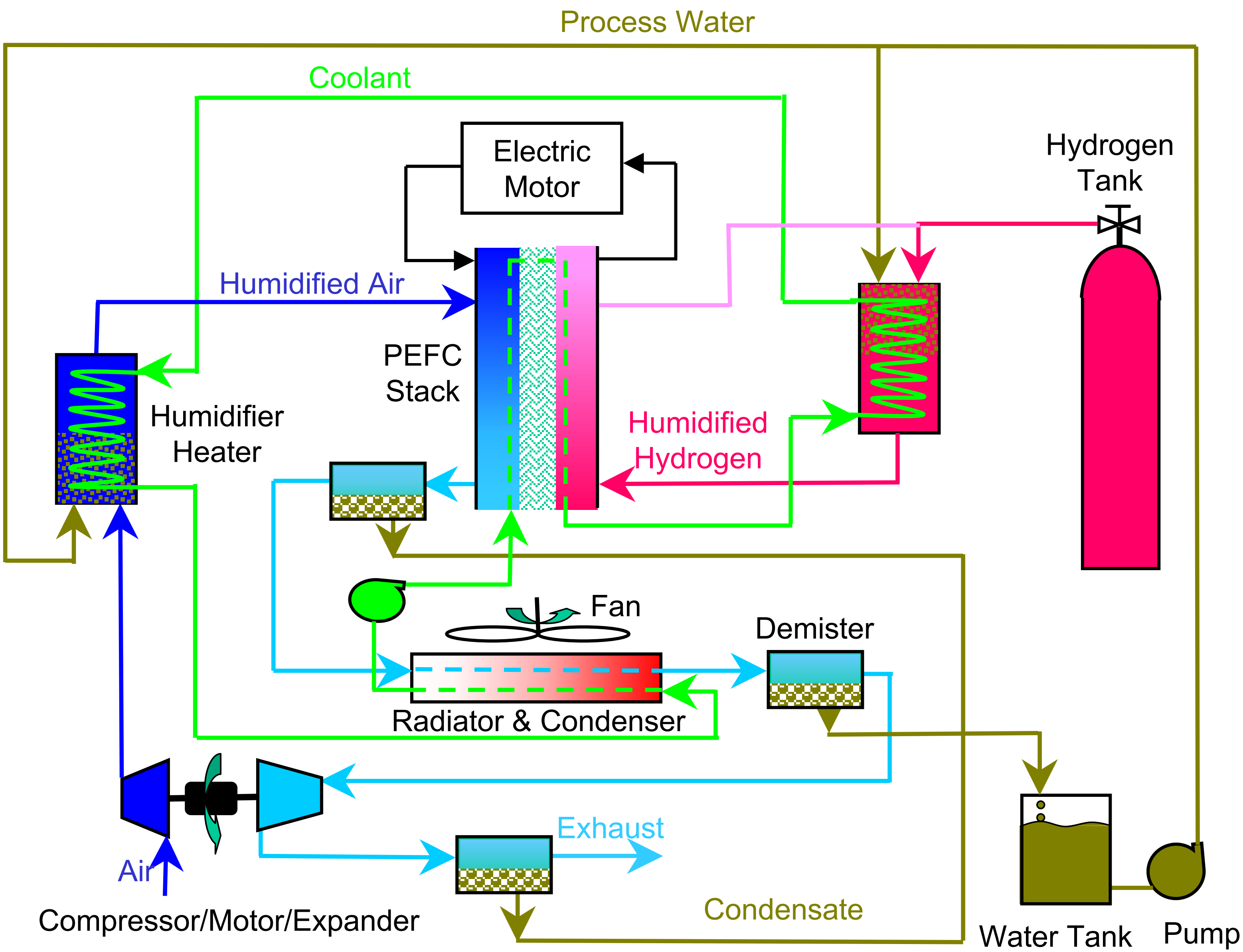
- Dynamic model of compressor, expander & motor on single shaft.
- Ram-air cooled condenser and radiator.
- Catalytic WGS and ATR on microlith supports
- Monolith – supported PROx (data from LANL)



Hydrogen Storage Targets
Fuel Economy of H_2 Fuel-Cell Vehicles

		Cavalier		Taurus		Explorer	
		ICE	H_2-FC	ICE	H_2-FC	ICE	H_2-FC
Weight (kg)		1214	1400	1693	1850	2055	2320
Drag Coefficient		0.38		0.32		0.41	
Frontal Area (m^2)		1.8		2.2		2.46	
Coeff. Roll. Friction		0.009		0.009		0.0084	
Engine Power (kW)		86	90	116	120	160	160
TIM (kW)			**58/90**		**78/120**		**100/160**
Fuel Economy (mpgge)	FUDS	25	73	20	58	18	47
	FHDS	32	75	29	69	23	54
	Comb	27.6	73.8	23.2	62.4	19.8	49.7
H_2 / ICE mpgge		1.0	2.7	1.0	2.7	1.0	2.5
EPA Fuel Economy Combined (mpgge)		26.0		23.7		18.4	

Pressurized Direct H_2 Fuel Cell System



FC Systems for Hybrid Vehicles

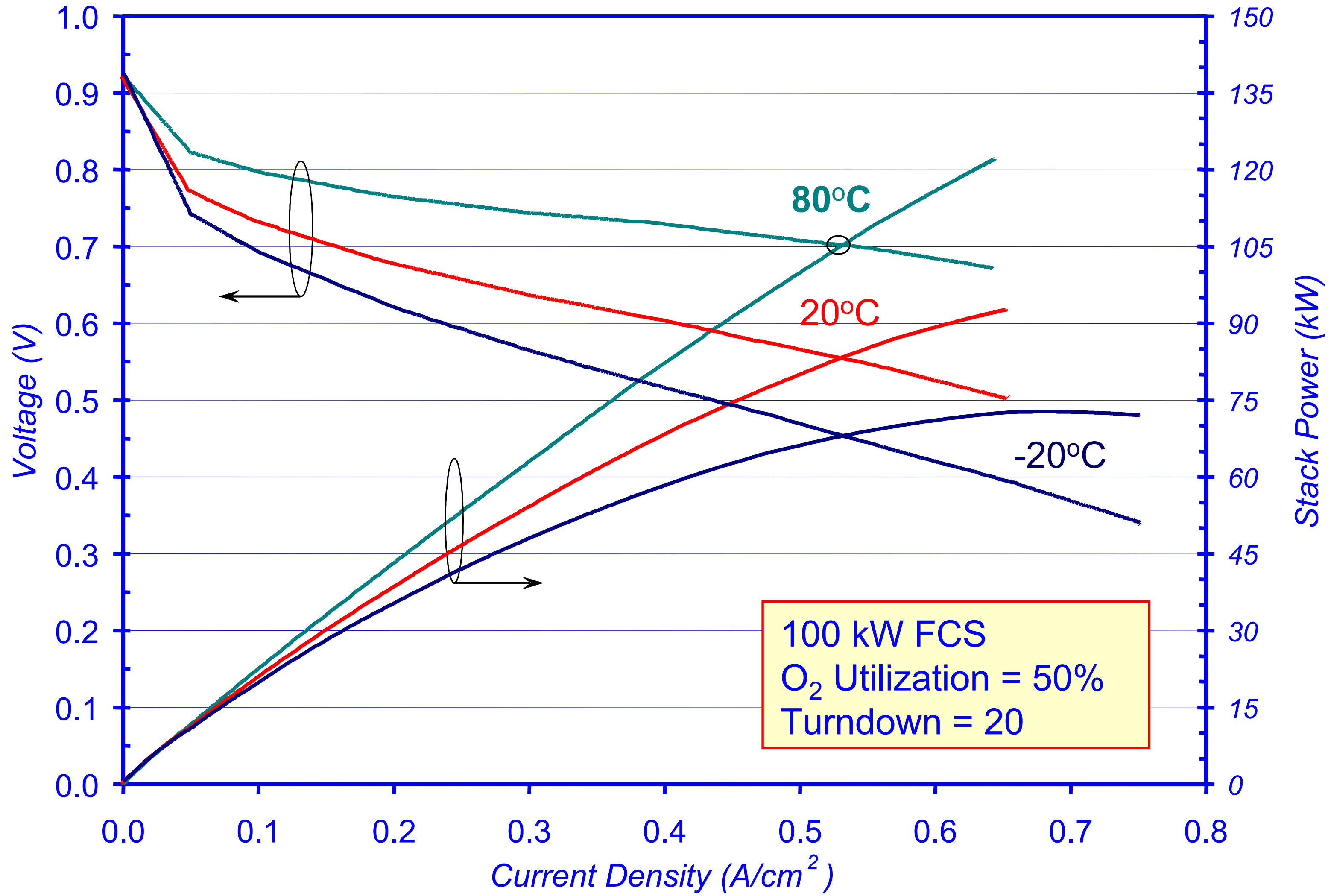
Requirement	Approach
FCS alone meets vehicle power demand at top sustained speed.	Defines mimimum FCS rating.
FCS alone maintains the vehicle at 55 mph at 6.5% grade for 20 min.	Heat rejection system sized for top speed or gradeability at $T_{amb} = 42^oC$.
0 to 60 mph in 10 s with battery assist.	Defines the size of energy storage system.
50% FCS efficiency at rated power.	0.7 V cell voltage at rated power.
15-s cold start time at $T_{amb} = 20^oC$.	Oversize the air management system.
30-s cold start time at $T_{amb} = -20^oC$.	
1-s transient response time for 10 to 90% power.	Overload motor & let O_2 utilization exceed 50% during fast acceleration.
FCS is self sufficient in water.	Balance water management system for all loads at 50% O_2 utilization and $T_{amb}<42^oC$.

FCS For Hybrid Mid-Size SUV

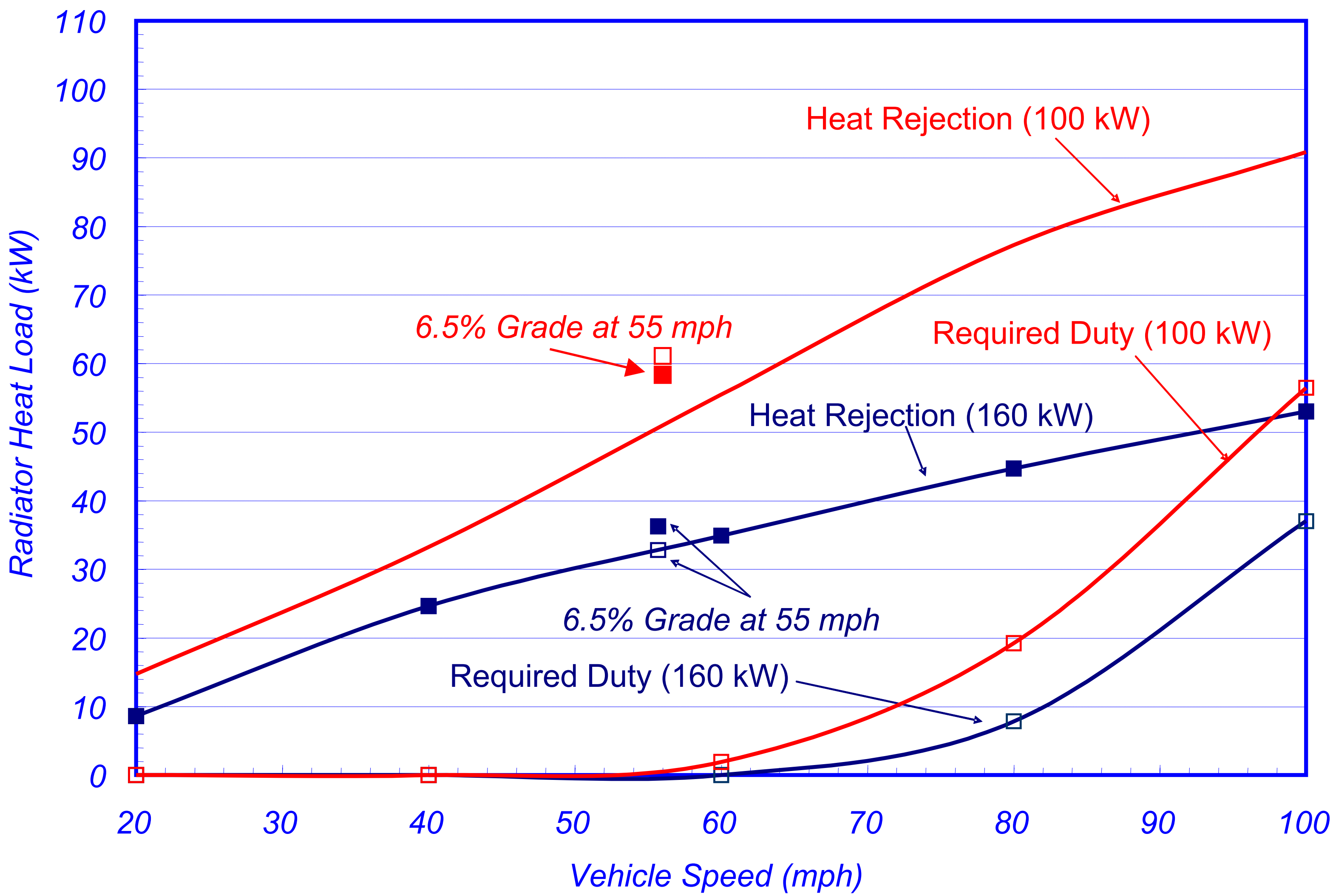
	Mid-Size AWD SUV		
GVW with FCS	2400 kg	Frontal Area	2.46 m^2
Coefficient Rolling Fraction	0.0084	Drag Coefficient	0.41
	Traction Power Requirement		
Z-60	160 kWe		
Top Speed (110 mph)	80 kWe		
6.5% Grade (55 mph)	60 kWe		
	FCS - 1	FCS - 2	FCS - 3
Rated Power at 0.7 V	100 kWe	100 kWe	160 kWe
Air Management System	CMM	CEMM	CEMM
CEMM / CEM M/C Power	27.3 kW	9.5 kW	15.1 kW
FCS Efficiency			
@ Rated Power	47.2%	53.6%	53.6%
@ 25% of Rated Power	61.3%	62.3%	62.8%
@ 80 kWe	52.0%	55.7%	59.2%
@ 20 kWe	61.6%	63.0%	63.9%

Stack Behavior with Oversized CEMM

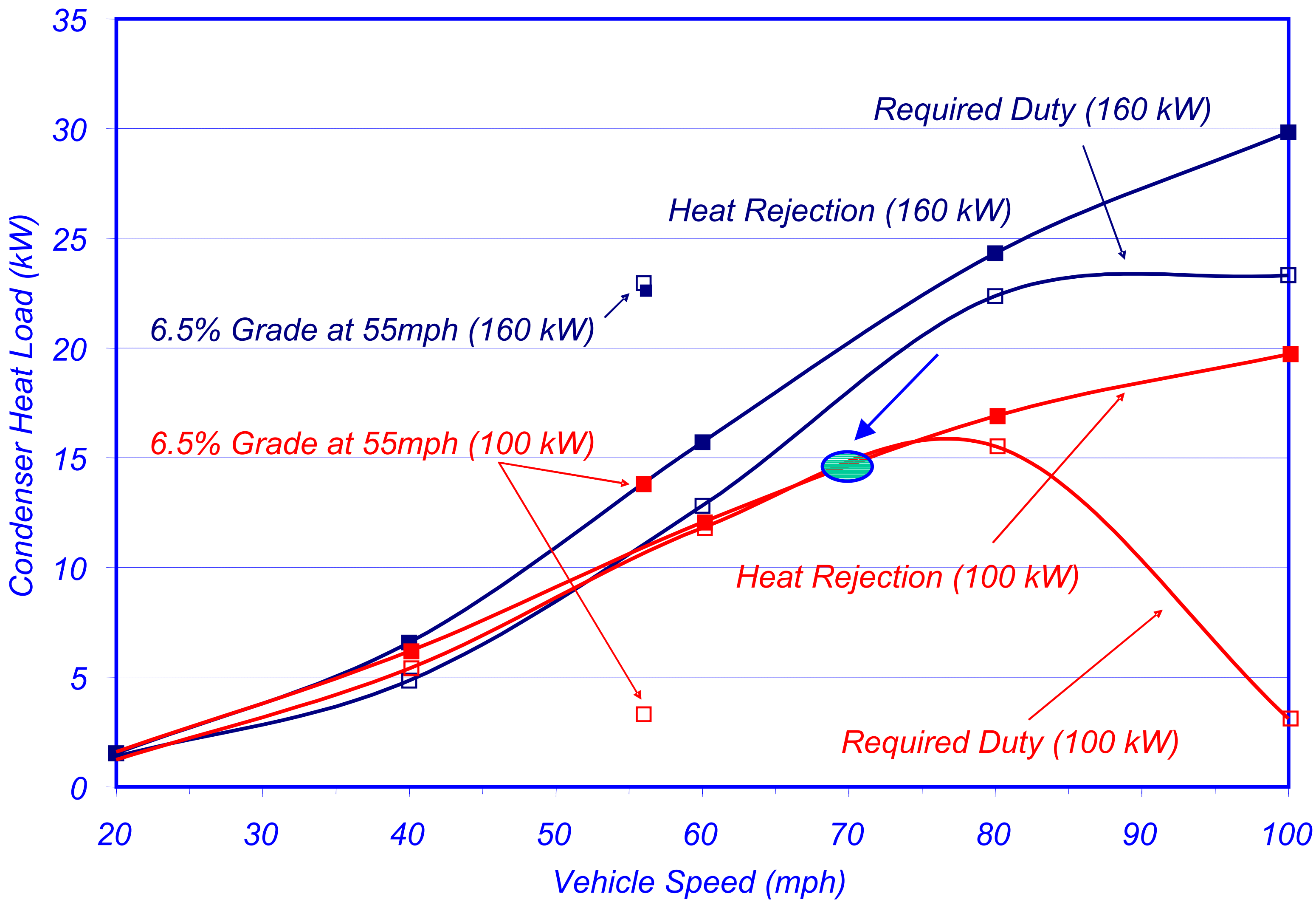
- At 80°C, stack can produce 20% more than rated power.
- Stack derated by 20% at 20°C and 35% at -20°C.



Radiator sized for 6.5% grade at 55 mph can reject heat at all operating conditions.



Condenser is challenged most at 6.5% grade in FCV and at intermediate speed in hybrid FCV.



CEMM Idle Speed

Minimum idle speed is the rpm at which the CEMM can provide sufficient cathode air to enable FCS to generate the power needed by the overloaded CEMM/CMM.

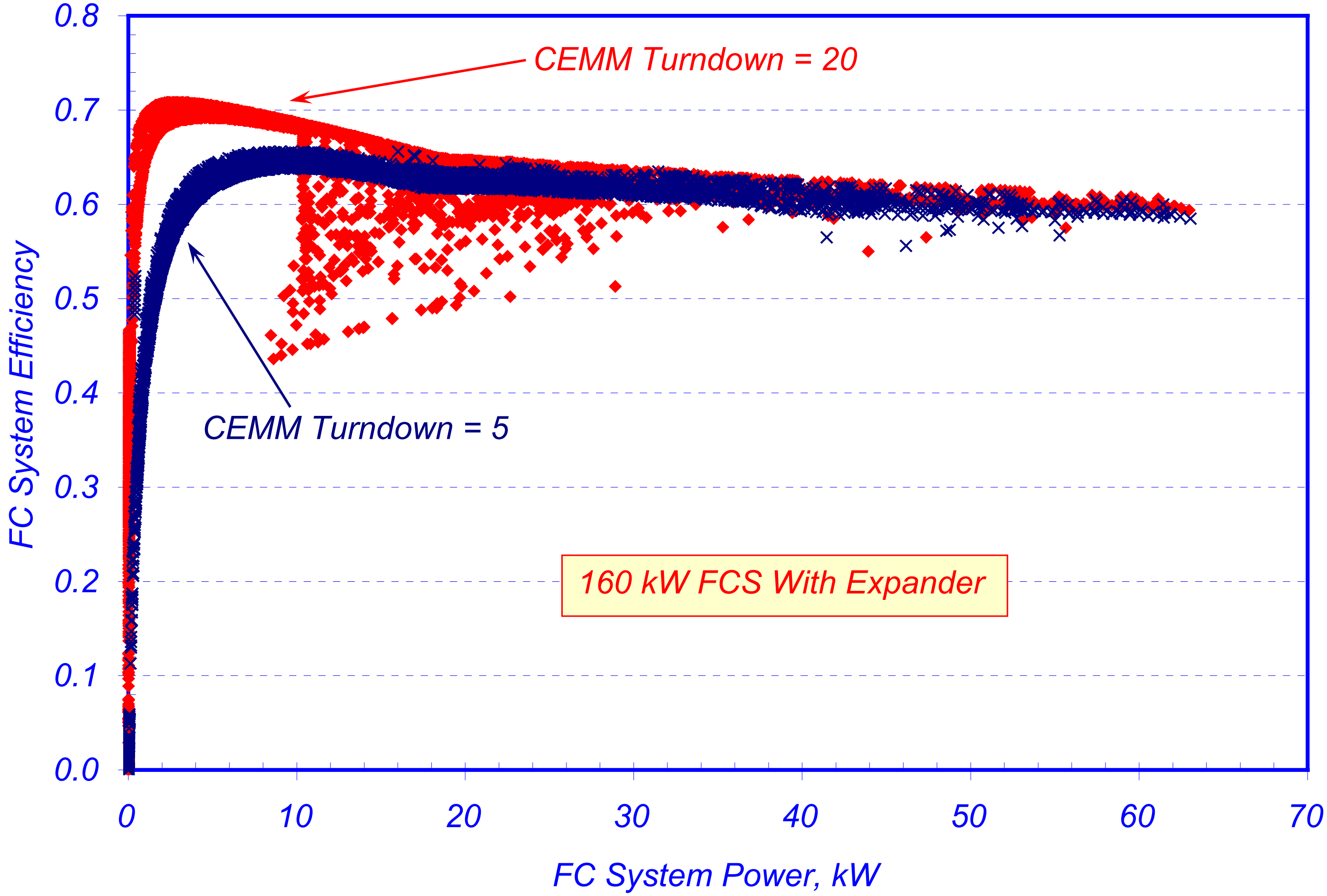
Idle speed may be determined by
- Motor power and M/C.
- Maximum turndown available with a given CEMM configuration.

Idle Speed for a Turbocompressor/Expander Module

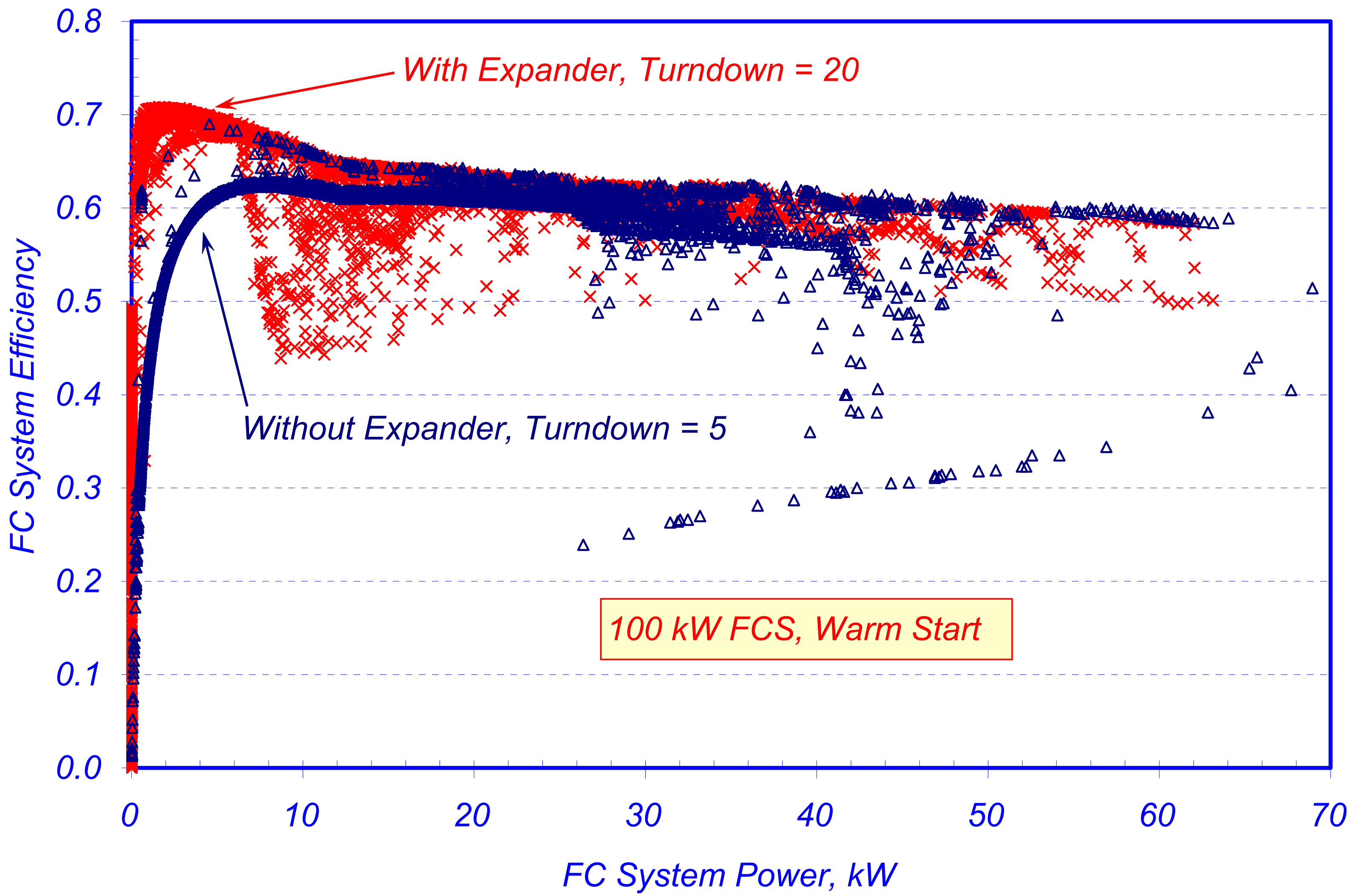
	Idle rpm	Maximum Turndown
CEMM: System with Expander	42,500	20
CEM: System without Expander	46,000	12

CEMM turndown affects FCS efficiency at low loads.

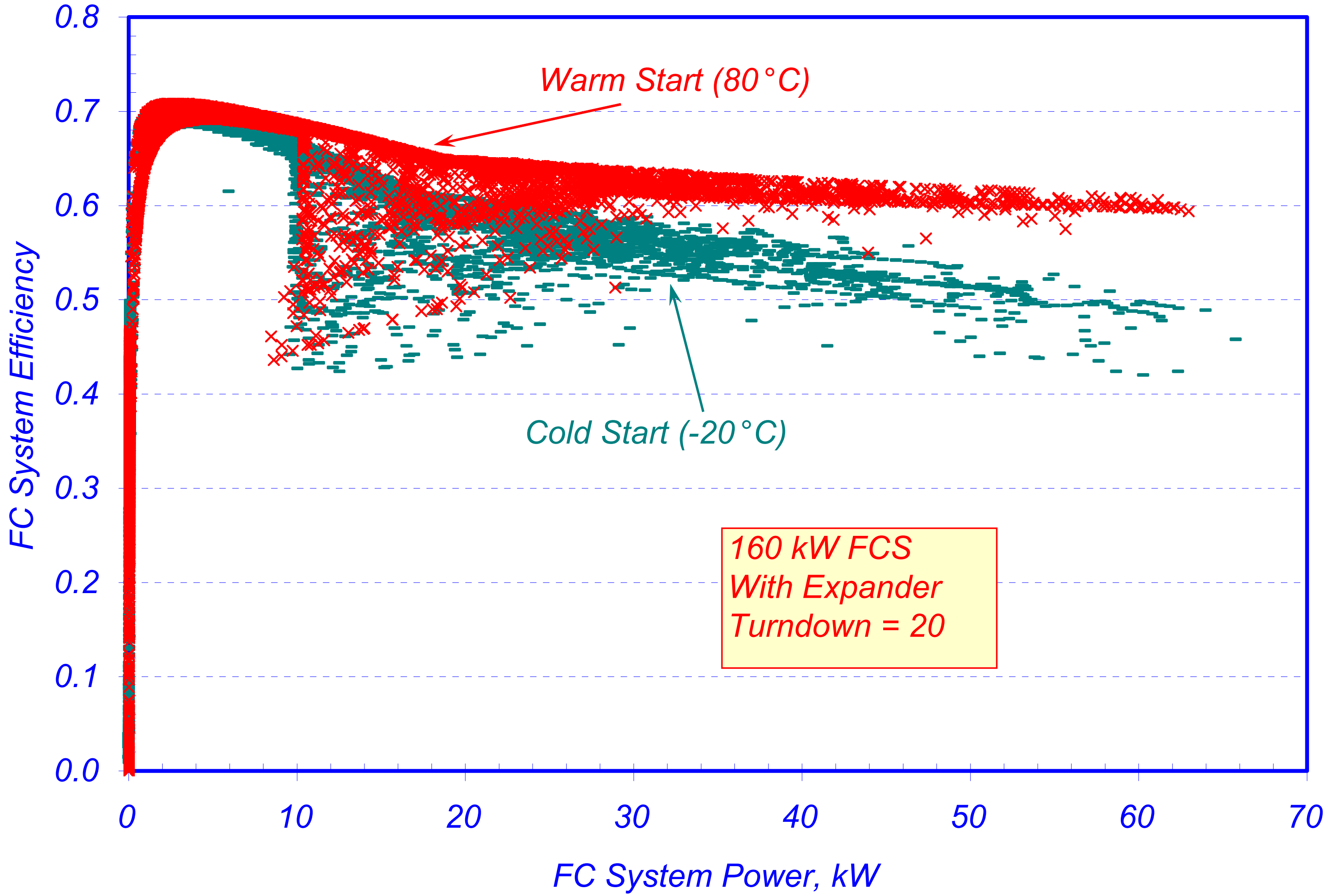
- Efficiency depends on power demand, dynamic variation in load, and maximum CEMM turndown.



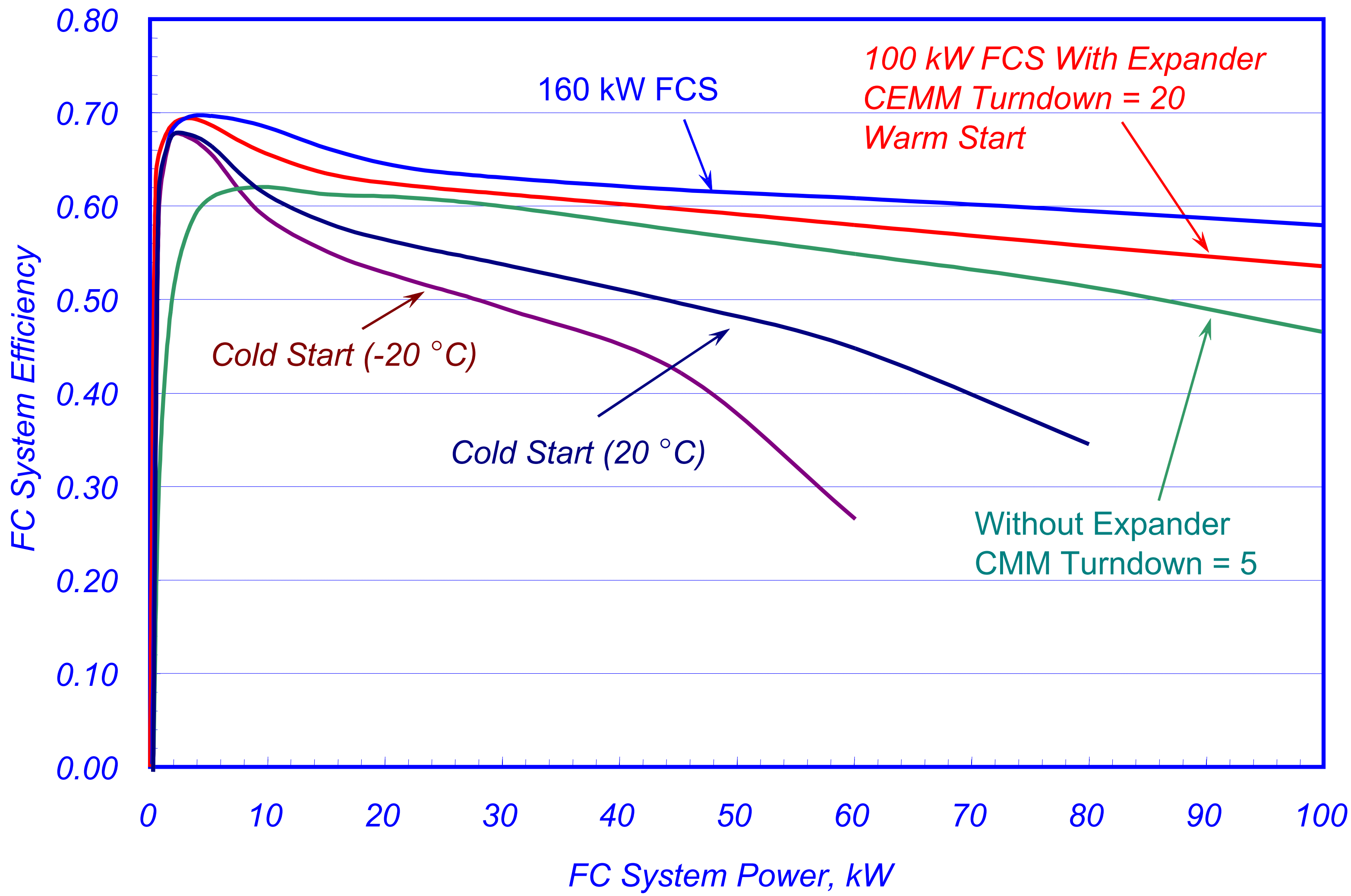
Effect of Expander on FCS Efficiency (FUDS)



FCS Efficiency on FUDS
Warm vs. Cold Start

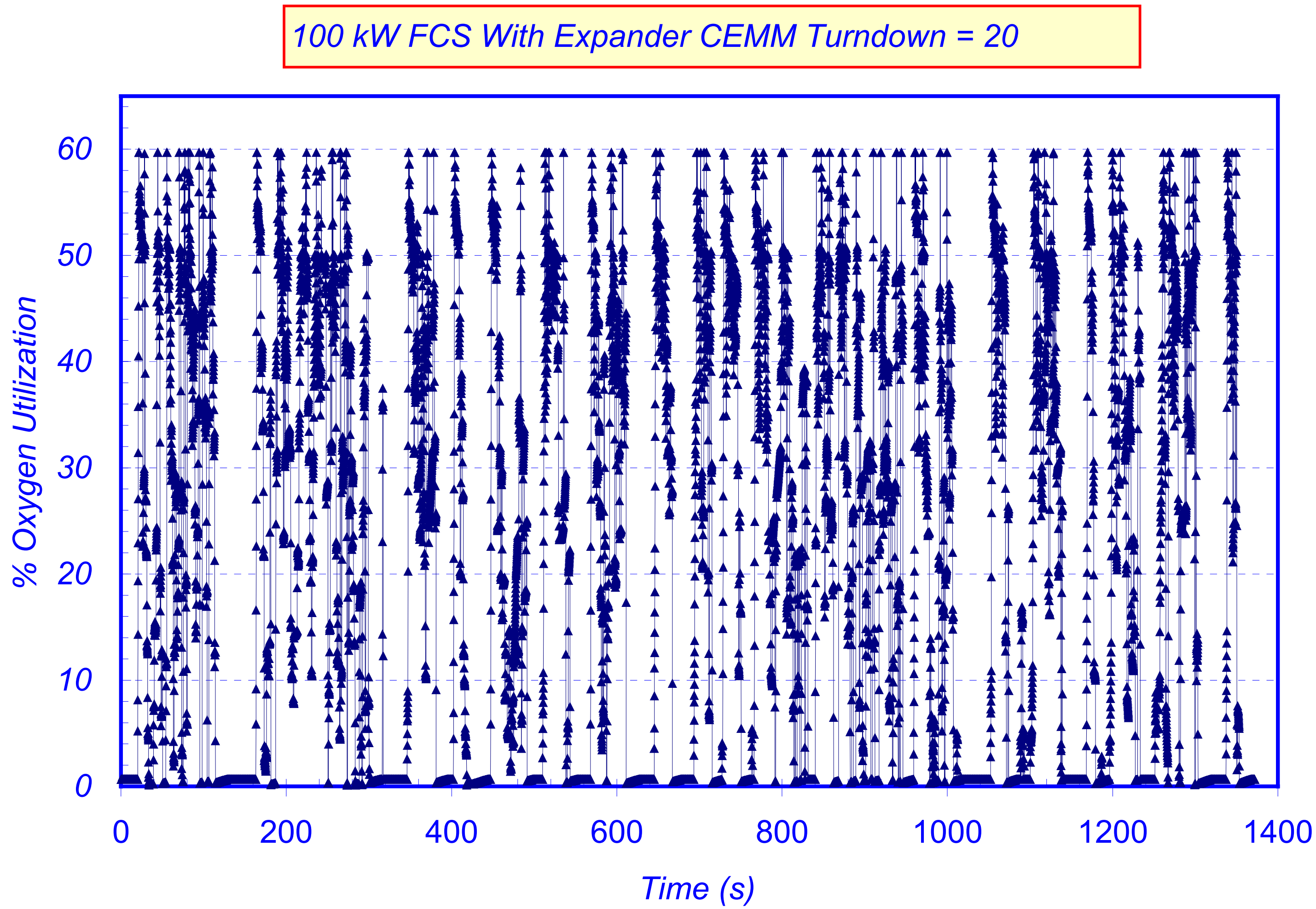


FCS Efficiency at Constant Load



Oxygen Utilization over Urban Cycle

- O_2 utilization cannot be held constant over drive cycle.
- Low utilization during idling conditions and deceleration.



Technology Transfer and Collaborations

Licensed GCtool to >50 domestic and international private enterprises, universities, national labs, and government affiliated organizations.

Collaborations and Interactions

- Joint IEA Annex XV Tank-to-Wheel Study (Canada, Germany, Italy, Korea, Netherlands, Sweden, and U.S.)
- FreedomCAR Fuel Cell Tech Team
- Joint Battery, Fuel Cell and SEAT Tech Team
- FASTER Program: LANL, PNNL, ORNL, PCI
- Nuvera Fuel Cells: Fuel Reforming and HiQ
- Mechanology, LLC: Flow Leakage in TIVM

Proposed Future Work

- Fuel Cell – Battery Hybridization study with Joint Tech Team
- Drive cycle analysis of direct hydrogen and reformed liquid fuel systems
- International Tank-to-Wheel Study (IEA Annex XV)
- Fuel cell systems for combined heat and power
- Support fuel processor engineering projects at ANL
- Continue to support DOE/FreedomCAR development efforts