

# Advancements in Military Logistic Fuel Processing

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# Overview

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## Logistic fuel processing challenges

- Desulfurization Systems

- Desulfurization of diesel, Jet-A and JP-8
- Desulfurizer for 3kW Tactical Fuel Cell Generator

- Fuel Processors and Reformers

- Regenerative Desulfurization/Reformer Systems

- 5 kW<sub>e</sub> SOFC logistic fuel processor

- Sulfur Tolerant Reformer with reformat desulfurization

- <2 kW<sub>e</sub> SOFC logistic fuel processor

- Dry and wet partial oxidation of sulfur containing fuels

- Waterless Reformer System

- System choices to match mission needs



# Logistic Fuel Desulfurization

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## Challenges

- High sulfur concentrations pose catalyst poisoning concern
  - Up to 3000 ppm<sub>w</sub> in liquid fuels
    - Potentially ~300 ppm<sub>v</sub> in reformat
- High molecular weight aromatic species difficult to treat
  - benzothiophenes, dibenzothiophenes, etc.

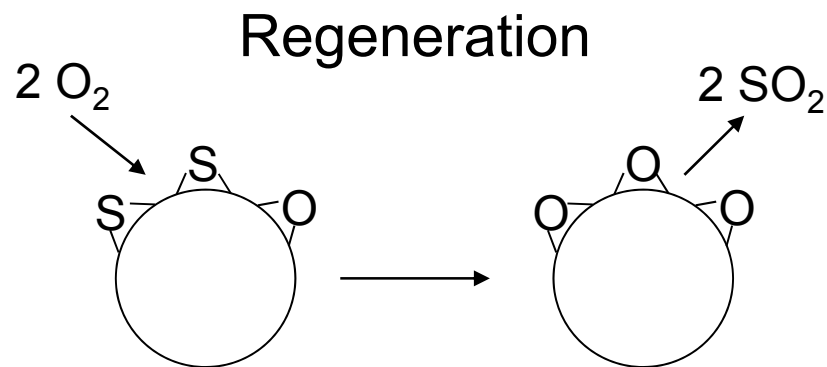
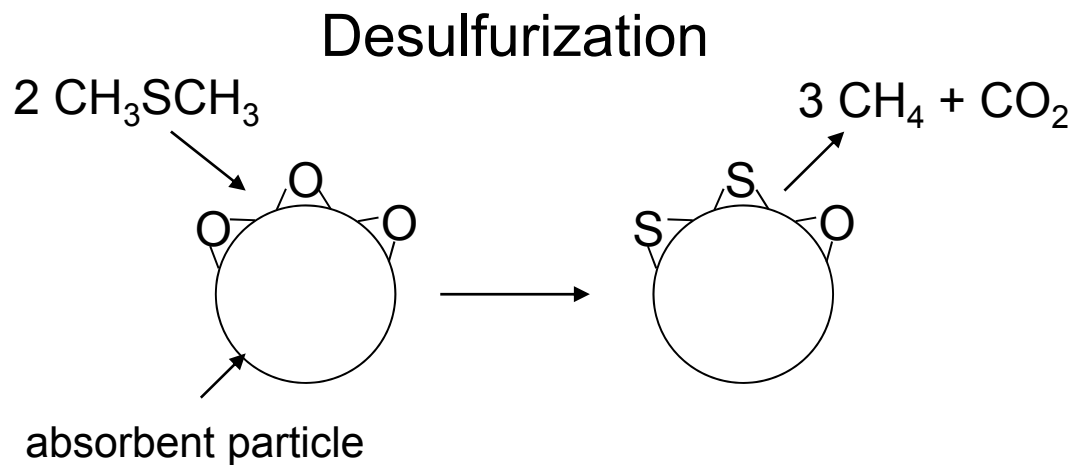
## Absorbent requirements dictate approach for sulfur removal

- High absorption activity,
- High capacity, and/or
- Simple and effective regeneration process



# APG's Desulfurization Concept

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# Logistic Fuel Desulfurization Prototypes

- 10 kW<sub>th</sub> Fuel Processor
  - Units delivered to AFRL and CERDEC
  - Demonstrated with fuels containing 2000 ppm<sub>w</sub> S\*; cleaned to < 5 ppm<sub>v</sub> H<sub>2</sub>S

\*(total sulfur limited by fuel availability)



- 14 kW<sub>th</sub> JP-8 Desulfurizer for Army TFCG
  - To be integrated with IdaTech PEM fuel cell
  - Prototype delivered to CERDEC
  - 2<sup>nd</sup> prototype delivered this summer



# TFCG Logistic Fuel Desulfurizer

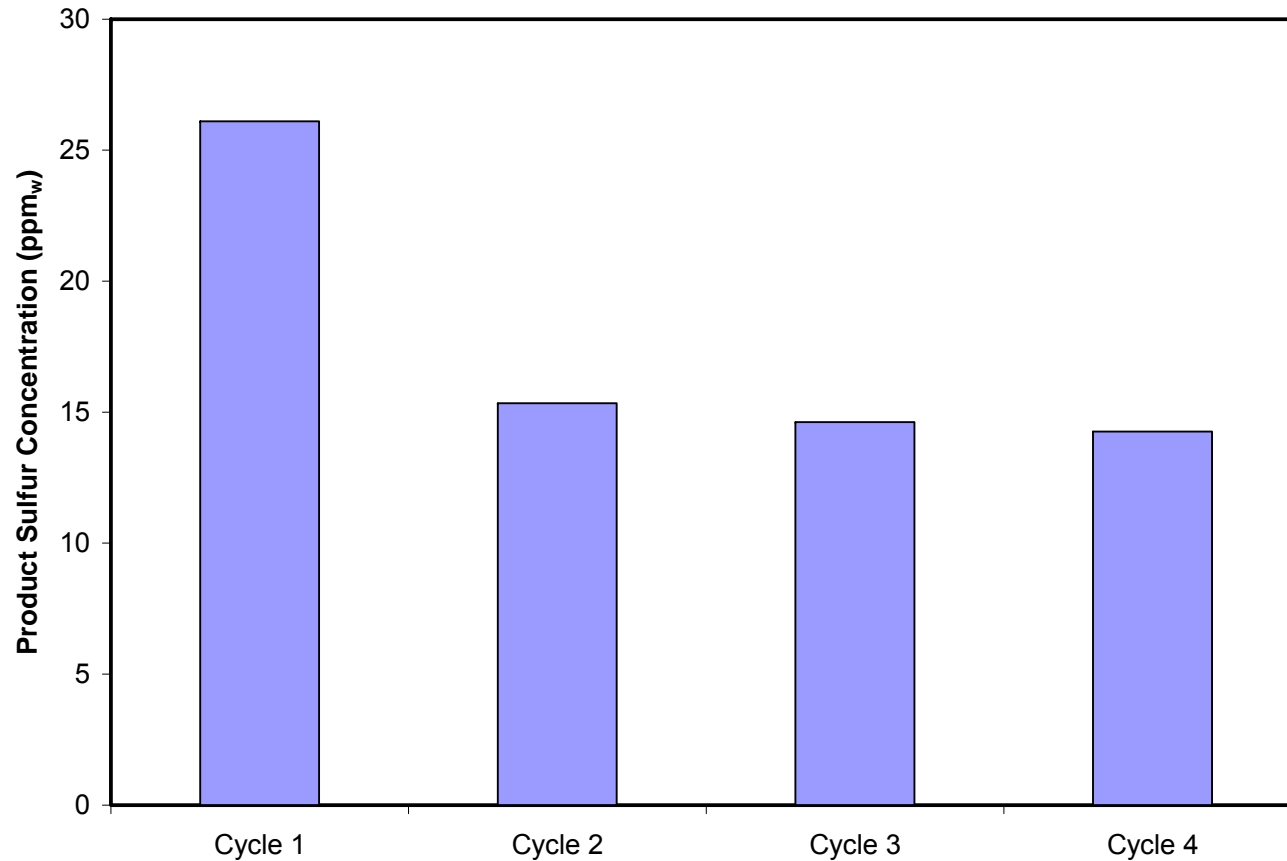
- IdaTech LLC PEM tactical fuel cell generator system
  - JP-8 desulfurizer ( $\leq 1000$  ppm<sub>w</sub> sulfur)
  - Rated up to 14 kW<sub>th</sub>
  - Deliver liquid fuel with  $< 15$  ppm<sub>w</sub> sulfur
- Regenerable desulfurization beds
  - Automatic control
  - $< 100$  W<sub>e</sub> parasite power
  - Adaptable to other fuels with higher sulfur & aromatic levels
- 3<sup>rd</sup> prototype to be delivered this fall
  - Weight/volume 60 kg / 144 L
  - Startup time  $< 40$  minutes
  - Improved operability, durability, reliability



# Logistic Fuel Desulfurizer Performance

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Desulfurized fuel produced from 1000 ppm<sub>w</sub> sulfur JP-8



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# Logistic Fuel Desulfurizer Requirements

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## Target Specifications

Net Rated Power ( $\text{kW}_{\text{th}}$ )	14
Fuel	Diesel/JP-8/Jet-A
sulfur max. ( $\text{ppm}_w$ )	3000
aromatics max. (vol%)	30
Product	Vaporized fuel
sulfur max. ( $\text{ppm}_w$ )	15
Efficiency (%)	99
Startup (min.)	10
Volume (L)	8
Weight (kg)	8
Power Consumption (W)	30
Durability (h)	6000

Long-term plan to integrate desulfurizer into fuel cell system

# Logistic Fuel Reforming Challenges

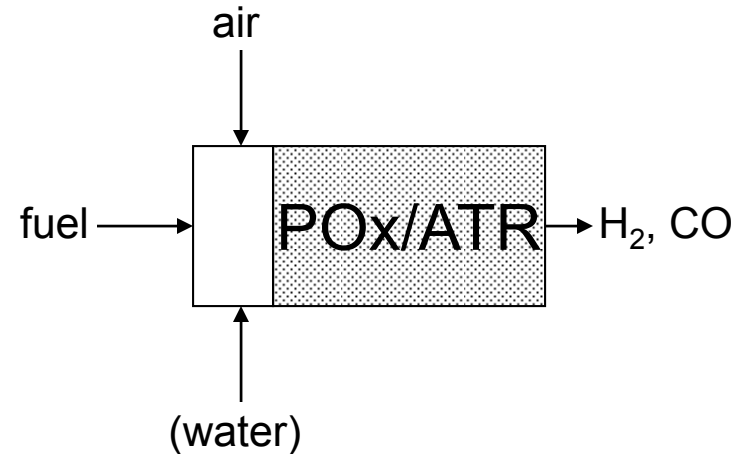
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## Catalyst

- Sulfur tolerance
- High-temperature durability
- High thermal conductivity
- Coking resistance
- Low pressure drop

## Reactor

- Uniform fuel-air mixture
- Prevention of non-selective reactions
- Materials durability & compatibility
- Low pressure drop



## System

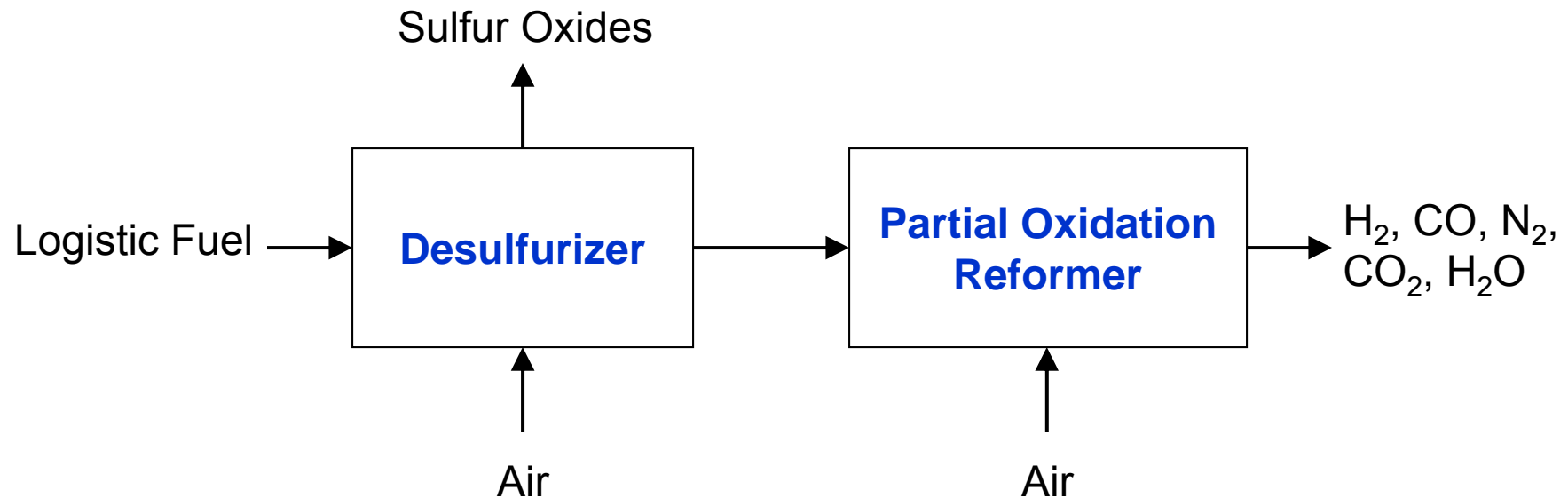
- Mission duration
  - Efficiency
- Power density
  - Weight/Volume limits



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# 5 kW<sub>e</sub> SOFC Logistic Fuel Processor

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- *In-situ* regenerable sulfur absorbent enables long-term operation on high sulfur fuels
- Absence of water simplifies logistics and cold weather operation
- Thermal integration of desulfurizer and reformer minimizes volume and maximizes efficiency
  - Desulfurization component acts as vaporizer



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# Logistic Fuel Processor



- Contains thermally integrated desulfurizer, CPOx and startup combustor
- Diesel & jet fuel compatible (up to 1000 ppm<sub>w</sub> sulfur)
- Fully automated
- 15" diameter by 24" high (excluding BOP)

# Reformate from Jet Fuel

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SOFC reforming successfully demonstrated

- Partial oxidation reformer
- >9 kW<sub>th</sub> output
- JP-8, Diesel, & Jet A
  - 850-2000 ppm<sub>w</sub> sulfur
- Tested at multiple labs
  - CERDEC, AFRL, General Dynamics & APG
- Automatic system controls; simple interfaces

Reformate Composition	
H <sub>2</sub> (vol%)	22
CO (vol%)	24
CO <sub>2</sub> (vol%)	1
H <sub>2</sub> O (vol%)	2
CH <sub>4</sub> (vol%)	0.2
C <sub>2</sub> H <sub>x</sub> (vol%)	<0.1
H <sub>2</sub> S (ppm <sub>v</sub> )	3
Thermal Efficiency	0.76
Power (kW <sub>th</sub> LHV)	10

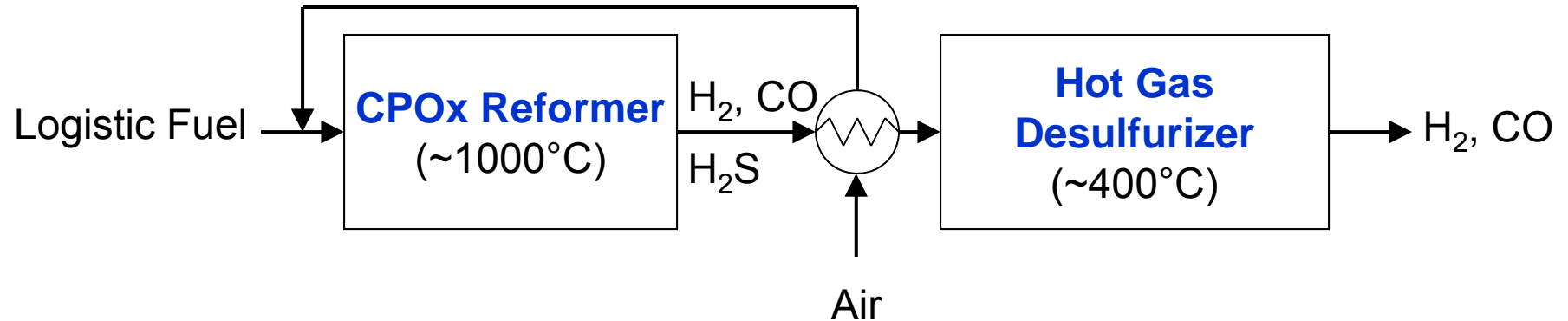
1000 ppm<sub>w</sub> sulfur JP-8



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# 2 kW<sub>e</sub> SOFC Logistic Fuel Processor

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## Attributes

- Internally heated & fast starting
- No water storage or recycle
- High degree of sulfur removal
- Simple & compact
- Low cost
- Well-suited for ULSD

# Direct Reforming System for JP 8

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## Fuel Processor Concept

- SOFC system compatible
- Compact and lightweight

## Direct JP-8 reforming

- Sulfur tolerant CPOx catalyst
  - $\leq 3000$  ppm<sub>w</sub> design

## Replaceable sulfur cartridge

- $< 0.5$  ppm<sub>v</sub> in reformat

## Automatic controls with simple interfaces



## 2 kW<sub>e</sub> prototype delivered to ARL

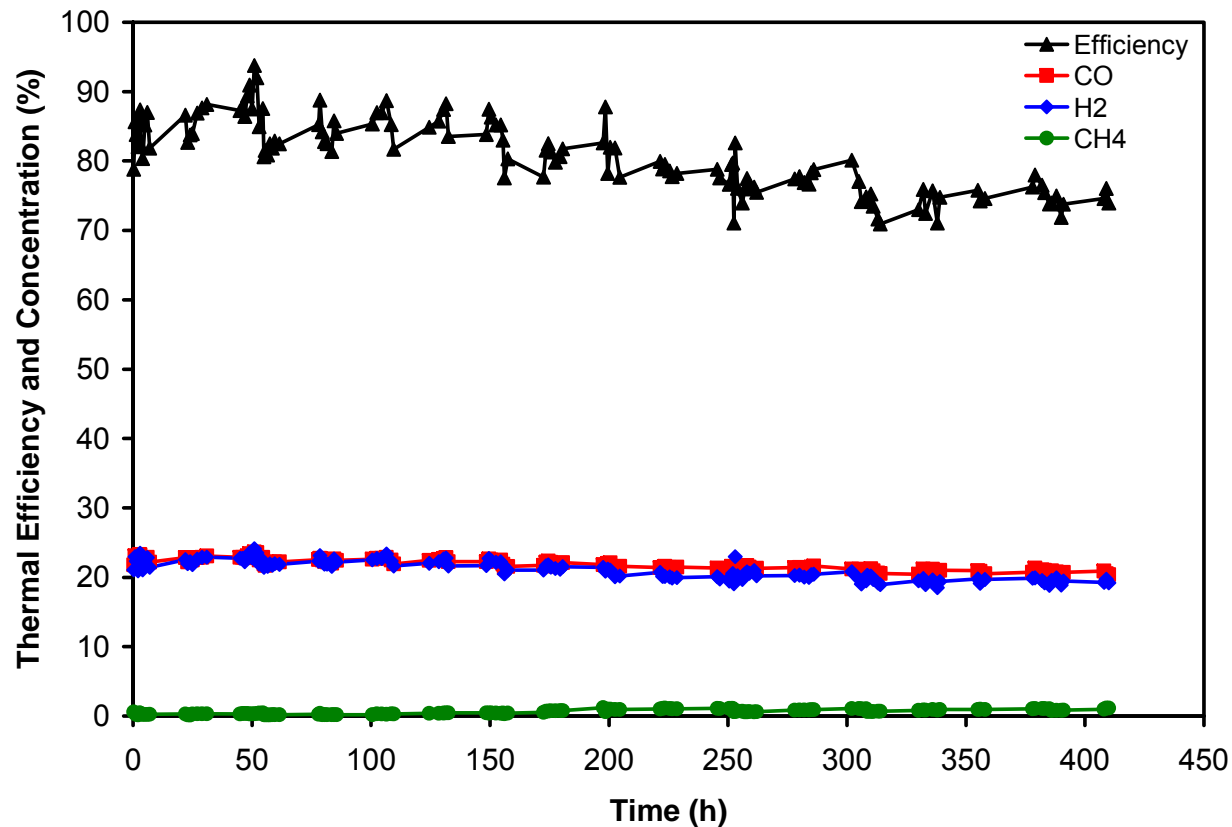
- 30 kg (66lbs)
- 96 L (16"x16"x23")
- $< 100$  W power consumption
- 55 dBA at 3m



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# Long Term CPOx Performance

5 kW<sub>th</sub> reformat from 1000 ppm<sub>w</sub> sulfur JP-8



Concentration (vol%)	
H <sub>2</sub>	20
CO	21
CH <sub>4</sub>	1
H <sub>2</sub> O	4
CO <sub>2</sub>	2
N <sub>2</sub>	52
H <sub>2</sub> S	0.01
Thermal Efficiency (%)	75



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# 2 kW<sub>e</sub> Fuel Processor Specifications

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## Target Specifications

Net Rated Power (kW <sub>th</sub> )	1.5-6.0
Fuel	Diesel/JP-8/Jet-A
sulfur max. (ppm <sub>w</sub> )	3000
aromatics max. (vol%)	30
Product	H <sub>2</sub> , CO
sulfur max. (ppm <sub>v</sub> )	0.1
Efficiency (%)	82
Startup (min.)	3
Turndown	4:1
Volume (L)	40
Weight (kg)	10
Durability (h)	5000
Cartridge Replacement (h)	320



# 5 kW<sub>e</sub> Waterless JP 8 Reformer

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Newly Awarded SBIR Project: Funded by the USMC

Objective: Develop low-cost waterless JP-8 reformer for SOFC

Approach:

- Pre and post reformer sulfur removal
- Hybrid reformer
  - CPOx for start up
  - Transition to ATR for operation
- Passive water recovery
  - Fuel cell exhaust

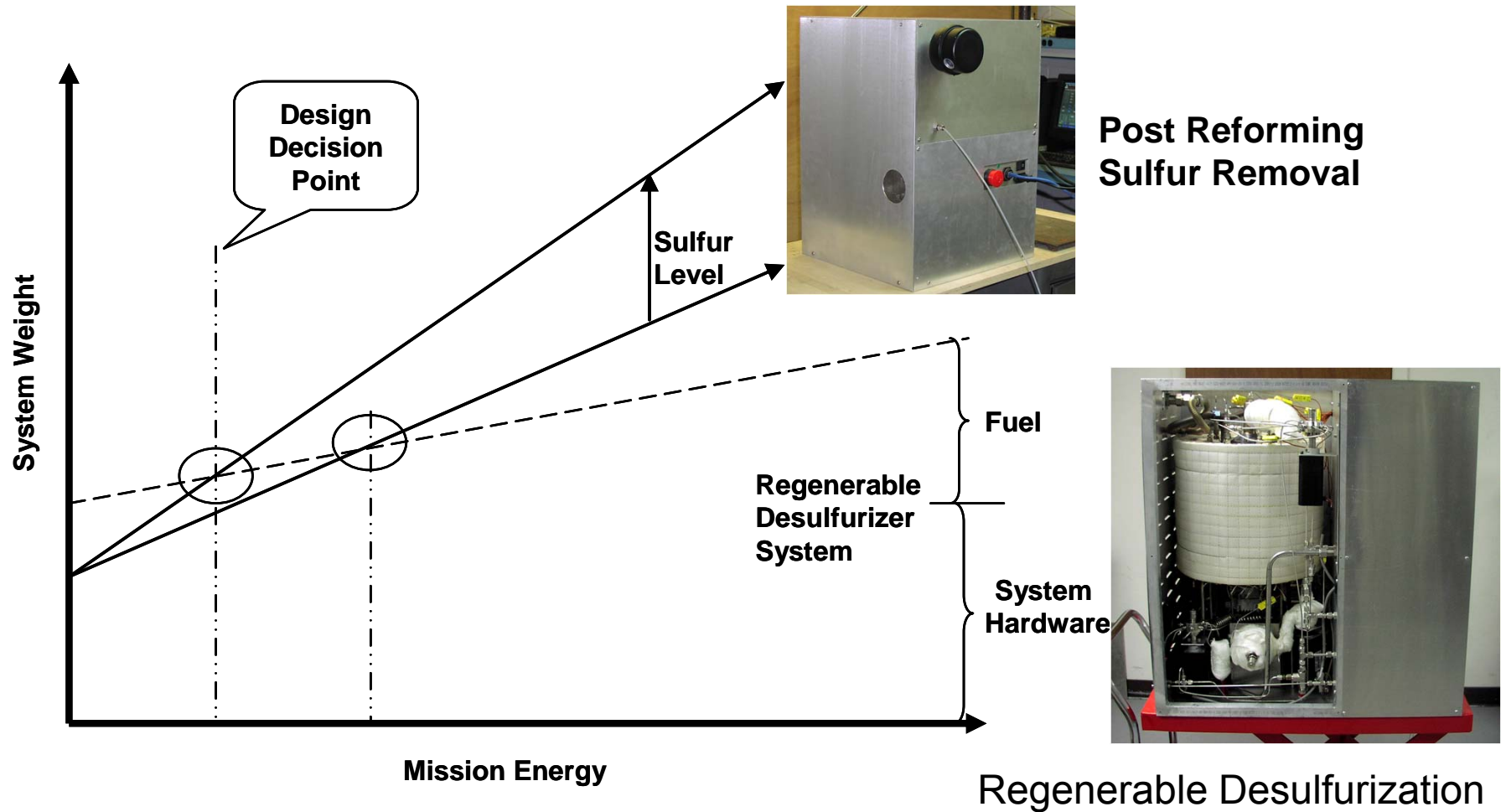
Target Specifications:

Fuel	JP-8
Fuel S Content (ppm <sub>w</sub> )	<3000
Thermal Efficiency (%)	>84
Fuel Conversion (%)	>99
Reformate S Content (ppm <sub>v</sub> )	<2
Start-Up Time (min.)	<30
System Life (h)	>2,000
Parasitic Power Consumption (W)	<200
Volume (L)	<60
Weight (kg)	<40



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# System Approach Determined by Mission Needs



# Conclusions

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## Effective desulfurization of logistic fuels demonstrated

- Depot fuels containing  $>2000$  ppm<sub>w</sub> sulfur successfully processed
- Good durability;  $>1400$  hrs
- Regenerable pre-reforming, cartridge post-reforming, or both
  - $<15$  ppm<sub>w</sub> S in liquid/vaporized fuel
  - $<0.5$  ppm<sub>v</sub> S in reformat with cartridge polishing

## Compact fuel processing systems developed for SOFC integration

- Reformat demonstrated on SOFC stacks
- Direct reforming of high-sulfur fuels demonstrated
  - CPOx to ATR transition for increased efficiency and durability
- Waterless system concept in development
- System approach based on mission requirements minimizes weight/volume



# Acknowledgments

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- US Marine Corps, Quantico VA



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