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World Leader in Ultra-Clean Power

# ***Carbonate Fuel Cell Power Plant Using Renewable Fuels***

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**Danbury, CT**

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# Carbonate Fuel Cell Power Plant Using Renewable Fuels

## Topics

FCE Company Background

Products and Technology

Liquid Renewable Fuels for Fuel Cells

Processing of Commercial Biodiesel for DFC

DFC System Utilizing Biodiesel

Conclusions



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## FuelCell Energy Profile

- Delivering products to commercial/industrial customers with advanced carbonate Direct FuelCell® technology
- Established strong commercial relationships with major distributors in the U.S., Canada, Germany, Japan and Korea
- Premier high temperature stationary fuel cell manufacturer and developer including carbonate and solid oxide applications
- A leading fuel cell technology developer for over 30 years – over \$530 million invested
- Headquarters in Danbury, CT with 70 MW manufacturing capacity in Torrington, CT





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## *Fuel cell power plants enable broad distributed generation*

- Distributed generation puts power where it's needed
- Increases power reliability
- Near zero emissions allow units to be sited almost anywhere – even polluted urban areas
- Reduces need for central generation plants
- Reduces grid congestion and need for new transmission lines
- Distributed generation enables smart grid
- Balances the grid with 24/7 power
- Meets requirements for low carbon technology
- Smaller projects enable faster permitting, financing, and execution



**600 kW at M&L Commodities**

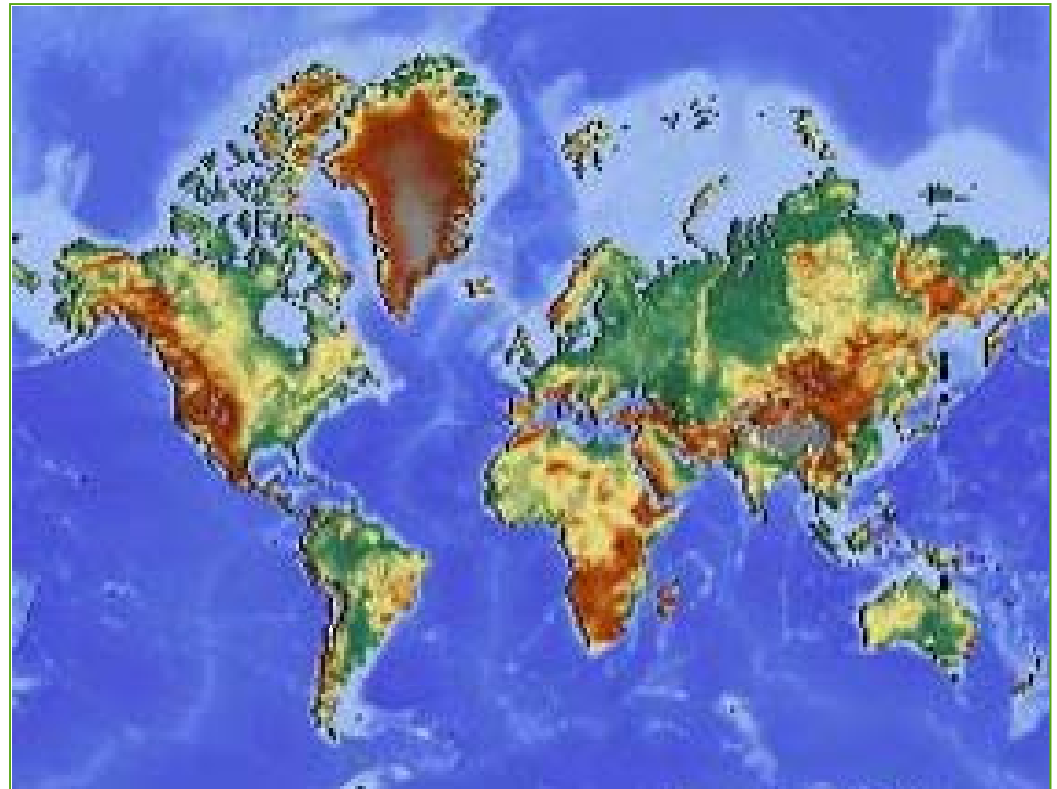


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## Markets

- 95 MW installed/backlog
  - Japan/Korea: 72 MW
  - California/West Coast: 15 MW
  - Northeast/Canada: 5 MW
  - Europe: 2 MW
- Targeted applications
  - Grid Support: 69 MW
  - Renewable/Wastewater: 9 MW
  - Manufacturing: 7 MW
  - Hotels: 3 MW
  - University & Hospitals: 2 MW
  - Government: 3 MW
  - DFC-ERG: 2 MW





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## FuelCell Energy Core Products – 300kW-10MW



**DFC300MA**



**DFC1500**



**DFC3000**

### Product Characteristics

- High temperature, high efficiency, carbonate fuel cell power plants for base load commercial and industrial applications
- High value waste heat by-product for cogeneration
- Internal reforming of readily available fuels such as natural gas and digester gas - *at customer sites today*
- Certifications for product safety, interconnection, performance and installation



**Multi-MW Grid Support**



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## FCE Commercial Product Status

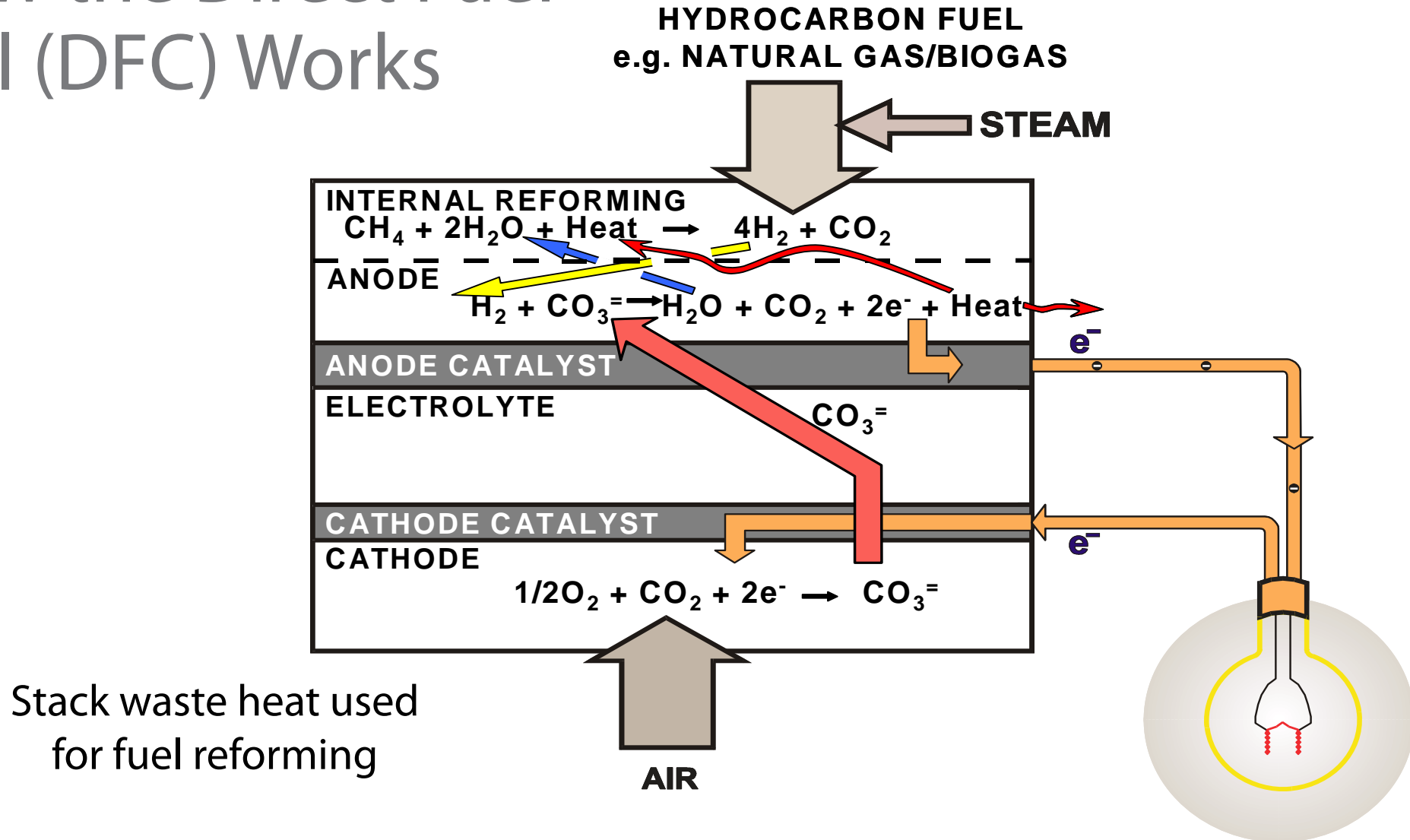
(September 2009)

- Power Plant Installations Worldwide: 84
- Total Fleet Operating Hours: >1,500,000
- Total Fleet Megawatt Hours: >360,000
- Availability Approaching 95%
- Longest Plant Operation, Hours: 51,400





## How the Direct Fuel Cell (DFC) Works





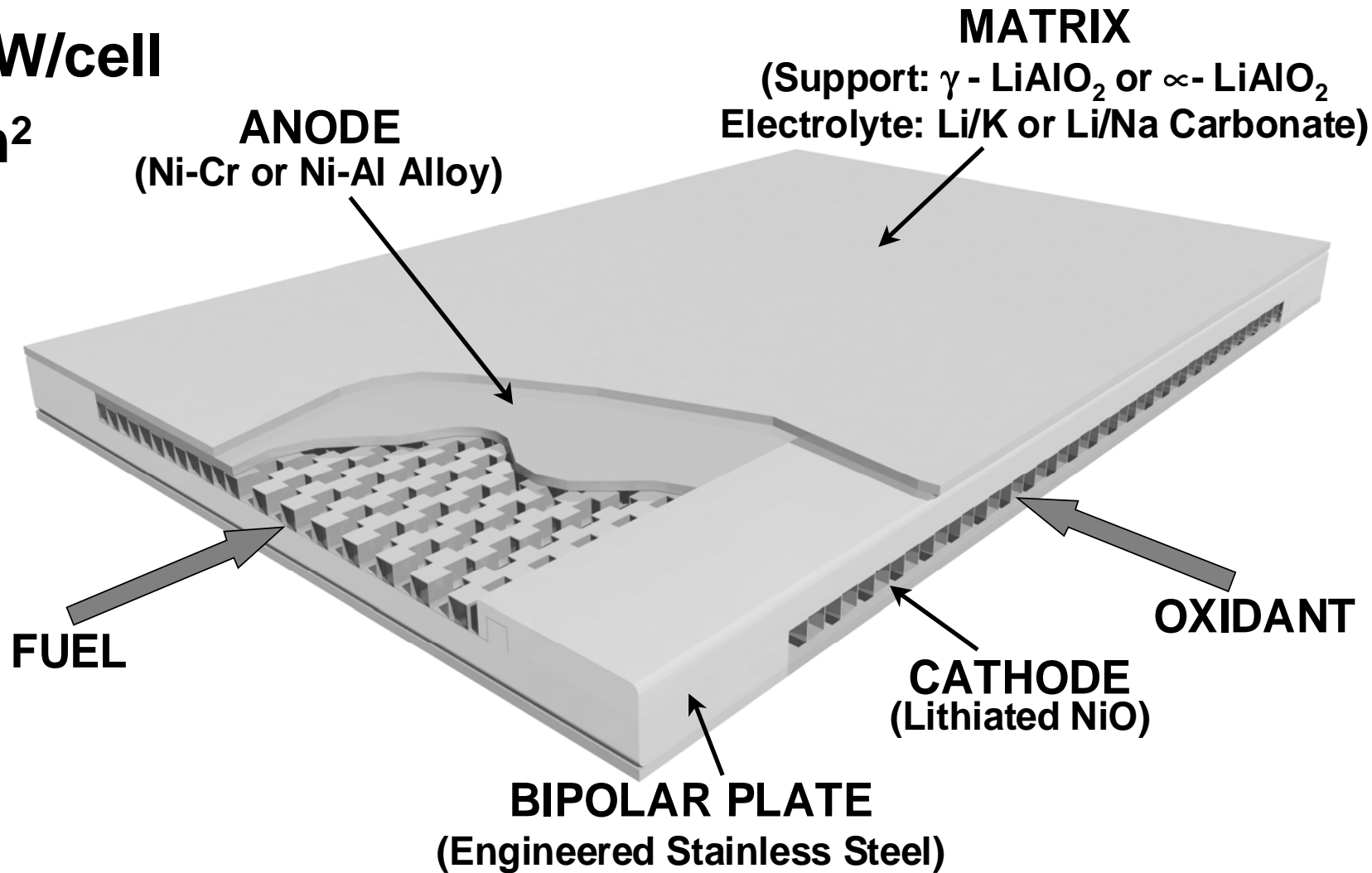
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## DFC Single Cell Assembly

1 kW/cell

1 m<sup>2</sup>



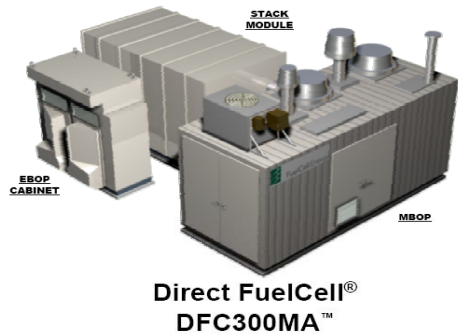


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## DFC<sup>®</sup> Product Assembly

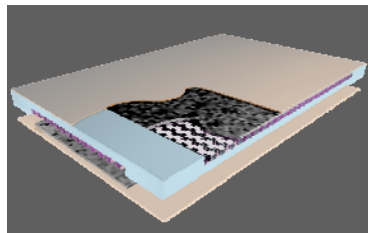
**Building block approach provides scalability and a standardized product to manufacture**



**Sub-MW Power Plant**



**Sub-MW Module**



**Fuel Cell**



**Fuel Cell Stack**



**MW Module**



**2 MW Power Plant**



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## Opportunities for Green DFC Power with Liquid Renewable Fuels

*Military installations - 2005 Energy Policy Act mandates power generation using renewable energy sources*

- Army and USMC bases
- Naval bases
- Navy port facilities
- Pier - side power for ships
- Back up fuel at critical installations
- Alternate fuel for dual - fuel power plants



## Selected Properties of Liquid Fuels for DFC

Property	JP-8	DF-2	Biodiesel	ULSD	Ethanol
Molecular formula (avg)	$C_{11.5}H_{22.8}$	$C_{14.6}H_{26.3}$	$C_{19}H_{36}O_2$	$C_{13.5}H_{26.4}$	$C_2H_5OH$
Molecular weight	161	202	292	188	46
H/C Ratio (molar)	1.98	1.80	1.9	1.95	3.0
Sulfur (mass %)	0.3 (max)	0.5 (max)	0.0015 (max)	0.0015 (max)	0.003 (max)
Specific gravity	0.809	0.849	0.88	0.84	0.794
Net heating value, Btu/lb	18,570	18,442	16,217	18,452	11,500



## Biodiesel Properties Summary

- Virtually sulfur-free (15 ppm max ASTM D6751)
- Boiling point range: 360 – 640°F
- Flash Point: >300°F vs 145° F for diesel
- No nitrogen or aromatics
- Biodegradable
- Non-toxic



## Sulfur in Biodiesel

- ASTM D 6751 permits up to 15 ppm max. sulfur
- Soydiesel BD-100 analyzed by FCE showed less than 0.3 ppm sulfur (ASTM D5453)
- Low sulfur biodiesel from certain plants may be processed directly into DFC<sup>®</sup> anode fuel gas



## Adiabatic Preconversion

### Key Fuel Conditioning Reactions:

Reforming:  $C_nH_m + nH_2O \rightarrow nCO + (n+m/2)H_2$  Endothermic

Methanation:  $CO + 3H_2 \rightarrow CH_4 + H_2O$  Exothermic  $\Delta H = -206$  kJ/mole

Shift:  $CO + H_2O \rightarrow CO_2 + H_2$  Exothermic  $\Delta H = -41$  kJ/mole

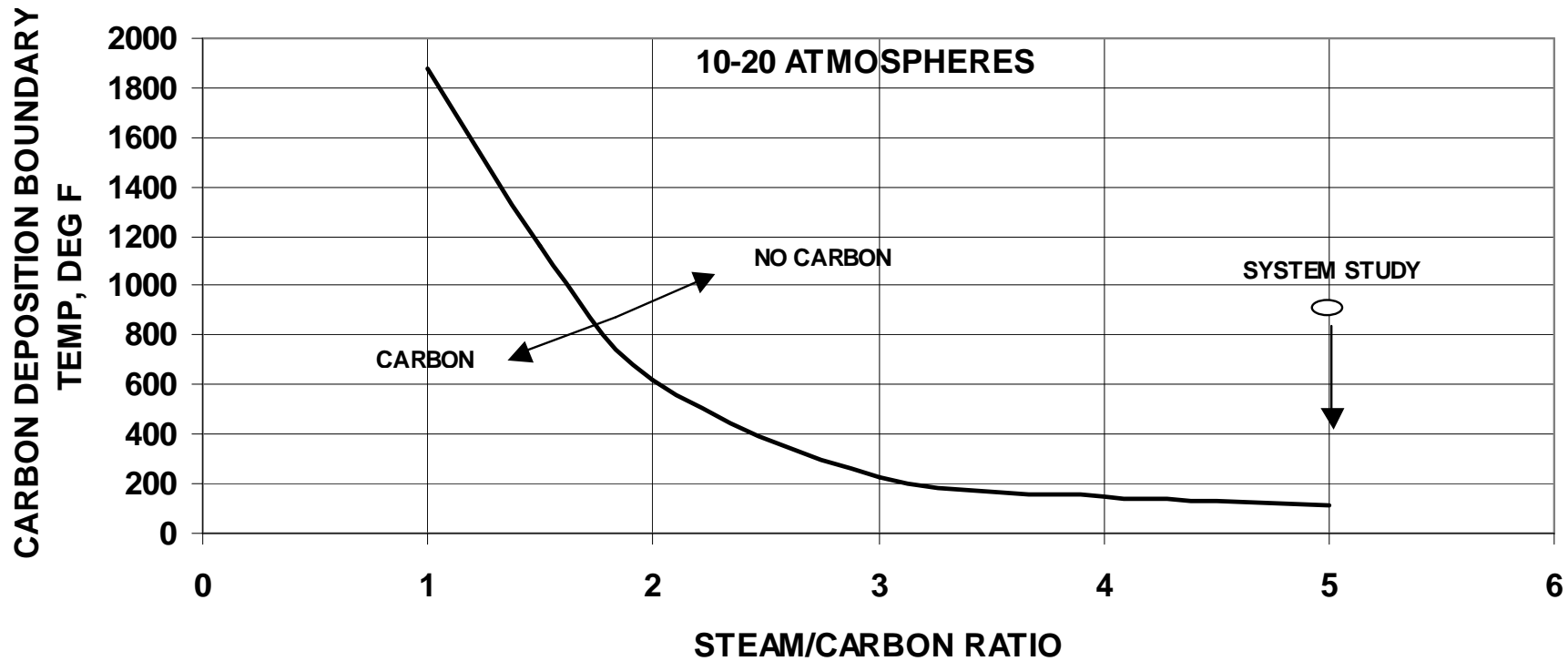
### **Advantages of Adiabatic Preconversion:**

- Provides high methane content for internal reforming DFC stack
- No external heat source needed
- Simple reactor construction





## Carbon Boundary for Biodiesel Prereforming





## Subscale Prereformer with B-100 Biodiesel



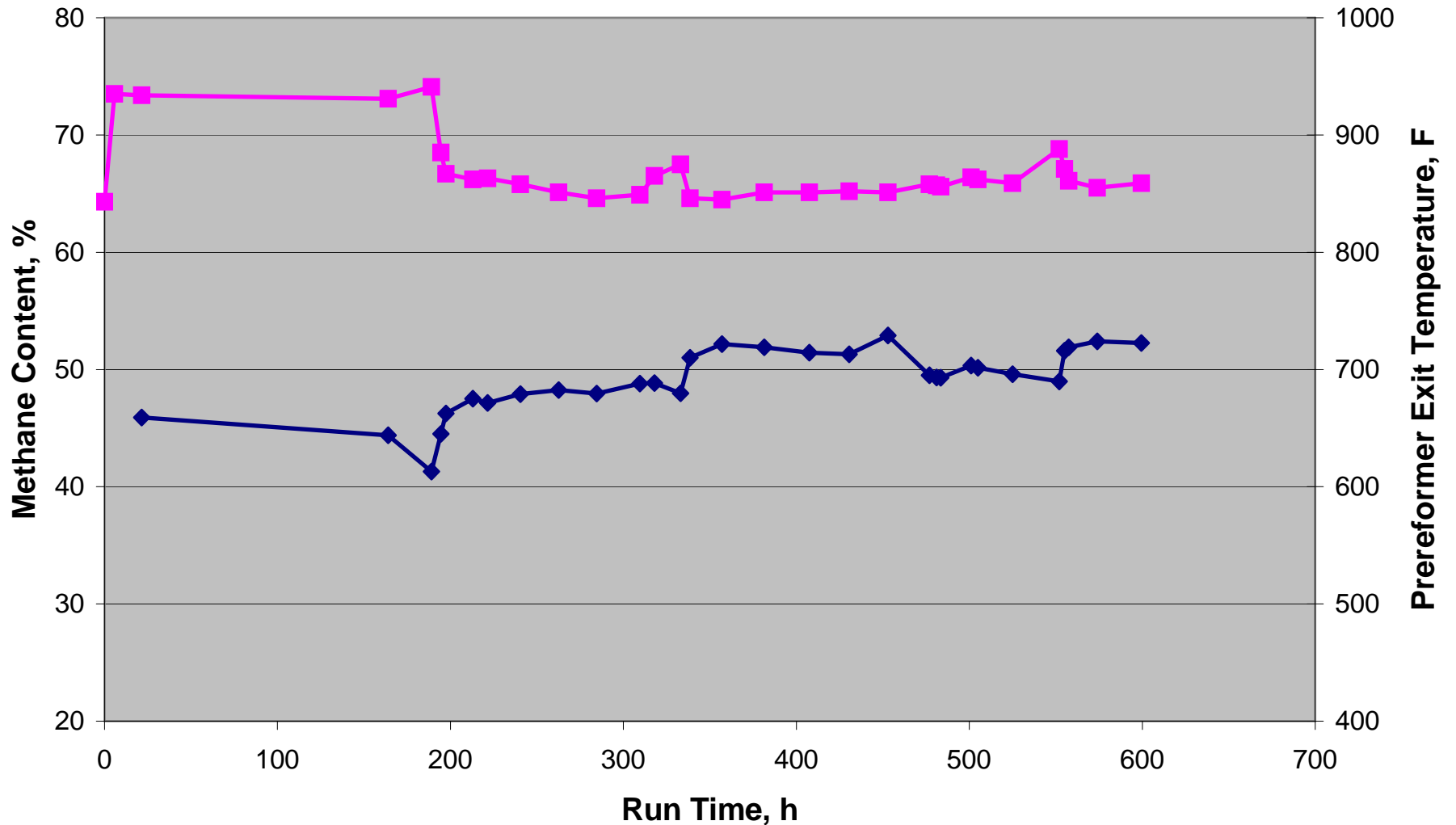
### Reformate Gas Composition (% dry basis)

	<u>Measured</u>	<u>Equilibrium</u>
CH <sub>4</sub>	51.4	52.0
H <sub>2</sub>	21.2	18.9
CO <sub>2</sub>	27.1	28.6
CO	0.4	0.5

No detectable unconverted biodiesel



## Effect of Prereformer Temperature on Methane Content





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## Direct Fuel Cell with Biodiesel Fuel

Net AC Power, kW	300	Steam to Carbon, S/C	5.0
DC Power, kW	332	Plant Efficiency, LHV%	50.6

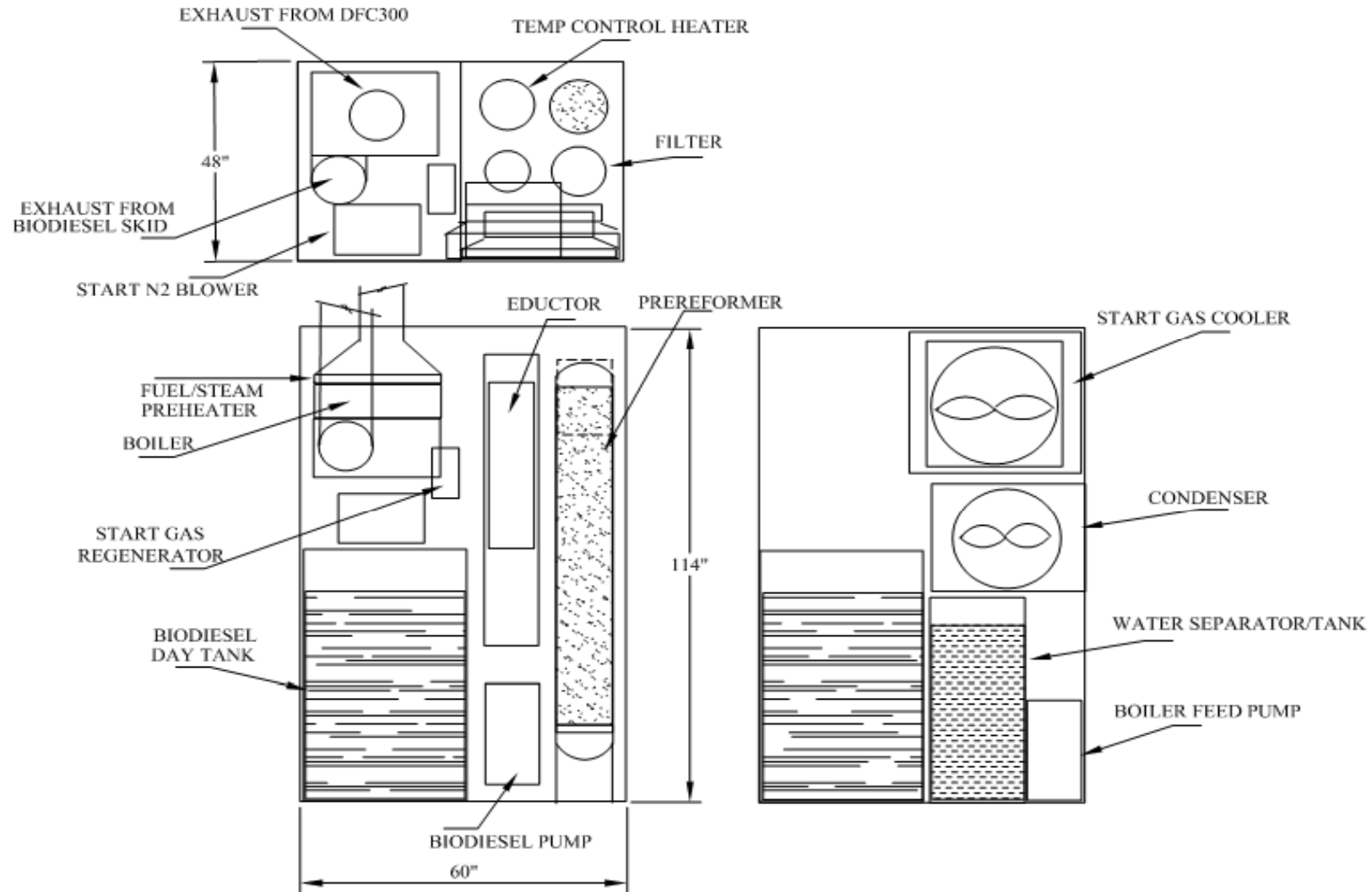
	<b>Temp., °F</b>	<b>Pressure, psia</b>	<b>Flow, lb/hr</b>
Fuel to system	70	400	130
Water to system	70	400	419
Prereformer exit	937	375	549
Anode outlet	1170	16	1524
Air to system	70	16	3297
Oxidizer exit	1080	15.5	4821
Cathode exit	1180	15.3	3846
System exhaust	500	14.7	3846



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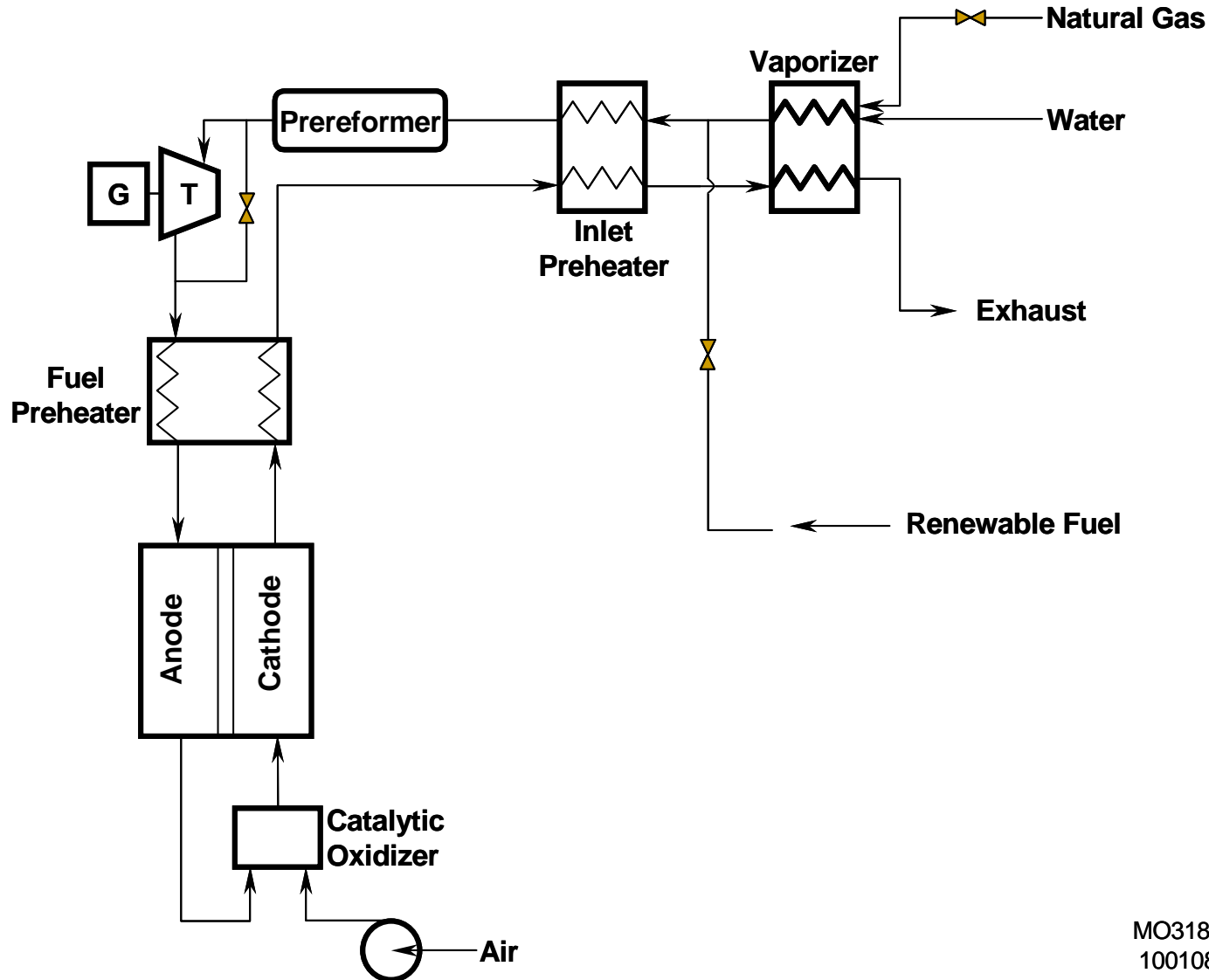
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## 300 kW Bio Diesel Equipment Skid





## Dual Fuel DFC Power Plant Schematic



MO3189  
100108



## Conclusions

- Commercial source Bio diesel can be pre-reformed to a methane-rich fuel gas for use with internal reforming carbonate fuel cells
- DFC power plants operating with biodiesel can provide efficiencies comparable to natural gas fuel cell power plants
- Commercial design DFC<sup>®</sup> power plants can operate in dual fuel mode when equipped with auxiliary fuel processor skid



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