



# Technical Reference

## Capstone MicroTurbine Fuel Requirements

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This document presents the Gaseous and the Liquid Fuel Requirements necessary for satisfactory operation of the Capstone Turbine Corporation® MicroTurbine™.

### Introduction

This Technical Reference outlines all the approved fuels for use with Capstone MicroTurbines. Compliance with the requirements detailed in this document is essential and necessary in order to avoid problems that may affect the performance, life, reliability, warranty, and in some cases, the safe operation of the Capstone MicroTurbine.

Many fuels that are not yet approved may be acceptable, either conditionally or unconditionally. Those considering the use of unapproved fuel are encouraged to check the new fuel against the specific fuel requirements detailed herein, and to review acceptance criteria in this document. It is also requested that any newly proposed fuel specification and any associated technical data be submitted to Capstone Applications Engineering for review and consideration.

For additional information and guidance regarding different fuels and fuel usage, please refer to the Referenced Specifications, including ASTM D2880 and the Approved Fuels portion of this document.

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## Definitions

The following four tables contain definitions of the various terms as used within this document. Table 1 presents general terms and definitions for the Capstone MicroTurbine.

**Table 1. Capstone MicroTurbine General Terms and Definitions**

General Terms	Definitions
abs	Absolute.
ASTM	American Society for Testing and Materials.
°C	Degree Celsius. A commonly used unit of temperature in the metric units.
°F	Degree Fahrenheit. A commonly used unit of temperature in the English units. ( $^{\circ}\text{F} = 1.8 \times ^{\circ}\text{C} + 32$ ).
BB	Ball Bearing (as in Ball Bearing Rotary Flow Compressor, or BB – RFC).
Btu	British Thermal Unit. A commonly used unit of energy in the English units.
Btu/ft <sup>3</sup>	British Thermal Units per cubic foot. A commonly used unit of fuel heating or calorific value in the English units. (Volume basis – Gases).
Btu/lbm	British Thermal Units per pound (mass). A commonly used unit of fuel heating or calorific value in the English units. (Mass basis – Liquids).
C1	Abbreviation for all hydrocarbon species, usually measured by gas chromatography, containing 1 carbon atom (e.g. methane) bonded to multiple hydrogen atoms
C2	Abbreviation for all hydrocarbon species, usually measured by gas chromatography, containing 2 carbon atoms (e.g. ethane) bonded to multiple hydrogen atoms
C3	Abbreviation for all hydrocarbon species, usually measured by gas chromatography, containing 3 carbon atoms (e.g. propane) bonded to multiple hydrogen atoms
C4	Abbreviation for all hydrocarbon species, usually measured by gas chromatography, containing 4 carbon atoms (e.g. butane) bonded to multiple hydrogen atoms
C5+	Abbreviation for all hydrocarbon species, usually measured by gas chromatography, containing 5 carbon atoms or more (e.g. pentane, hexane, etc.) bonded to multiple hydrogen atoms
Capstone	Capstone Turbine Corporation.
Centipoise	A commonly used unit of absolute (dynamic) viscosity. 1 Centipoise = 0.01 poise = 0.001 Pa.s. (Also see Poise).
Centistoke	A commonly used unit of kinematic viscosity. 1 cSt = 0.01 stoke = $10^{-6}$ m <sup>2</sup> /s. (Also see Stoke).
Cloud Point	Petroleum fluids (when cooled) may become plastic solids, either from wax formation or from the fluid congealing. The initial wax crystal formation becomes visible at temperatures slightly above the solidification point. When the temperature is reached at specific test conditions, it is known as the Cloud Point (ASTM 2500). The Cloud Point indicates the temperature below which clogging of filters may be expected in service.

CO	Carbon Monoxide (Gas)
CO <sub>2</sub>	Abbreviation for carbon dioxide, usually measured by gas chromatography
Contaminant	Any material or substance, which is unwanted or adversely affects the fluid power system or components, or both.
Energy	The capacity for doing work. (Also see [J] Joule).
FB	Foil Bearing (as in Foil Bearing Rotary Flow Compressor, or FB – RFC).
Flash Point	The lowest temperature at which a liquid fuel can form an ignitable mixture in the air near the surface of a liquid. The lower the Flash Point, the easier it is to ignite the liquid fuel.
Fluid	A liquid, gas, or a mixture thereof.
ft <sup>3</sup>	Standard cubic feet of gas @ 15 °C and 101.33 kPa (59 °F and 14.696 psia)
Gauge	An instrument or device for measuring, indicating, or comparing a physical property.
Gauge, Pressure	A gauge, which indicates the pressure in the system to which it is connected.
H <sub>2</sub> S	Abbreviation for hydrogen sulfide, usually measured by gas chromatography
HHV	Higher Heating Value (Gross Heating Value). It is the sum of the heat released when a known quantity of fuel is burned, and the heat recovered when the water produced by combustion is re-condensed to a liquid. (Also see Btu/ft <sup>3</sup> or kJ/kg or Btu/lbm).
HP	High Pressure (Gaseous Fuel System)
ISO	International Standards Organization
JIS	Japanese Industrial Standards
Joule	Joule. The unit of work, energy, or heat in the metric (S.I.) units. 1J = 1N·m.
kg	Kilogram. The unit of mass in the metric (S.I.) units. 1 kg = 2.205 lbm (pound-mass).
kJ/kg	Kilojoules per kilogram. A commonly used unit of fuel heating or calorific value in the metric (S.I.) units. (Mass basis – Liquids).
kPa	Kilopascals. A commonly used unit of absolute pressure. 1 kPa = 1/6.895 psia. (Also see Pa).
kPa Gauge	Kilopascals gauge. A measure of gauge pressure. (Also see kPa).
L/DG	Landfill/Digester Gas
LF	Liquid Fuel
LFC	Liquid Fuel Controller
LHV	Lower Heating Value (Net Heating Value). It is the heat released when a known quantity of fuel is burned. Since engines exhaust water from combustion in a gaseous state, the LHV is the appropriate value for comparing fuels. (Also see Btu/ft <sup>3</sup> or kJ/kg or Btu/lbm).
LP	Low Pressure (Gaseous Fuel System)
LP-F	Low Pressure (Gaseous Fuel System) with FB – RFC
LPG	Liquefied Petroleum Gas
LSL	Lower Spec Limit
m	Meter. The unit of length in metric (S.I.) units. 1 m = 39.37 inches
m <sup>3</sup>	Normalized cubic meter of gas @ 15 °C and 101.33 kPa (59 °F and 14.696 psia).

MJ/m <sup>3</sup>	Mega joules per cubic meter. A commonly used unit of fuel heating or calorific value in the metric (S.I.) units. (Volume basis – Gases).
Micron	1 x 10 <sup>-6</sup> m. The commonly used unit of particle size.
N	Newton. The unit of force in the metric (S.I.) units. 1 N = kg·m/s <sup>2</sup>
N2	Abbreviation for nitrogen, usually measured by gas chromatography
N/A	Not Applicable
NO <sub>x</sub>	Oxides of Nitrogen (Gases). Usually measured as parts per million (ppm)
Pa	Pascal. The unit of pressure in the metric (S.I.) system. 1 Pa = 1 N/m <sup>2</sup>
Poise	The unit of absolute viscosity in the c.g.s. (Centimeter-Gram-Second) system.
Pour Point	The absolute lowest temperature at which a liquid will flow under specified conditions. (See ASTM D97).
ppb	Parts per Billion
ppm	Parts per Million
Pressure	Force per unit area, usually expressed in pounds per square inch. (See Pa or psi).
Pressure, Absolute	Pressure above absolute zero (sum of atmospheric and gauge pressure). (Also see kPa or psia).
Pressure, Atmospheric	Pressure exerted by the atmosphere at any specific location. At sea level, atmospheric pressure = 101.33 kPa (14.696 psia).
Pressure, Gauge	Pressure above atmospheric. (Also see kPa gauge or psig).
Pressure, Vapor	The pressure, at a given fluid temperature, in which the liquid and gaseous phases of the fluid are at equilibrium.
psi	Pound force per square inch. The unit of pressure in the English units.
psia	Pound force per square inch absolute. A unit of absolute pressure. (Also see psi).
psig	Pound force per square inch gauge. A unit of gauge pressure. (Also see psi).
RFC	Rotary Flow Compressor. (Gas boost compressor within a MicroTurbine package).
SC	Simple Cycle (Non-Recuperated)
SG	Sour Gas: A gaseous fuel with H <sub>2</sub> S >5 and <70,000 ppm V (7.0%)
SG-SPV	Sour Gas Smart Proportional Valve (Flow Control Valve).
Specific Gravity of Gas	Ratio of the weight of a given volume of gas to the weight of an equal volume of air at the same pressure and temperature (Dimensionless).
Specific Gravity of Liquid	Ratio of the weight of a given volume of liquid to the weight of an equal volume of water at the same pressure and temperature (Dimensionless).
SPV	Smart Proportional Valve. (A Gaseous Flow Control Valve).
Stoke	Unit of kinematic viscosity in the c.g.s. (Centimeter-Gram-Second) system.
TBD	To Be Determined.
Temperature	See °C and °F.
TET	Turbine Exit Temperature
THC	Total Hydrocarbons.
USL	Upper Spec Limit
Viscosity	A measure of the internal friction or the resistance of a fluid to flow.
Viscosity, Absolute	Ratio of the shearing stress to the shear rate of a fluid. Also called dynamic viscosity. It is usually expressed in centipoise.

Viscosity, Kinematic	Absolute viscosity divided by the density of the fluid. Usually expressed in centistoke.
Wobbe Index	Calorific Value (HHV) divided by (Specific Gravity) <sup>0.5</sup>

## Gaseous Fuel Requirements

Gaseous fuel requirements, including the composition, physical and gaseous fuel supply conditions requirements are detailed in the paragraphs that follow.

### Definitions

Table 2 presents gaseous fuel definitions for the Capstone MicroTurbine.

**Table 2. Capstone MicroTurbine Gaseous Fuel Definitions**

<b>Model Type</b>	<b>Fuel Definitions</b>
C30 HP	Capstone 30 [High Pressure Gaseous Fuels]
C30 LP	Capstone 30 [Low Pressure Gaseous Fuels]
C30 SG	Capstone 30 [High Pressure (Sour Gas Compatible) Gaseous Fuels]
C30 L/DG	Capstone 30 [Landfill and/or Digester (Sour Gas Compatible) Gaseous Fuels]
C30 LF	Capstone 30 [Liquid Fuels]
C60 HP	Capstone 60 [High Pressure Gaseous Fuels]
C60 HP/ICHP	Capstone 60 Gaseous Fuels [High Pressure (ICHP)]
C60 LP <sup>(1)</sup>	Capstone 60 [Low Pressure Gaseous Fuels]
C60 LP/ICHP <sup>(1)</sup>	Capstone 60 Gaseous Fuels [Low Pressure (ICHP)]

Note (1): Low pressure gas can be used when C60 HP, C60 HP ICHP is integrated with Capstone Integrated Fuel System Optional Accessory

## Fuel Parameters

Tables 3 and 4 present allowable gaseous fuel parameters for the Capstone MicroTurbine.

**Table 3. Allowable Gaseous Fuel Parameters**

Allowable Fuels	Calorific Value, HHV Btu/ft <sup>3</sup> (MJ/m <sup>3</sup> ) Note (1)		Major Gas Component Limits [vol%] <sup>(NOTE 3)</sup>															
			C1		C2		C3		C4		C5+		N <sub>2</sub>		CO <sub>2</sub>		H <sub>2</sub> S (ppm)	
	LSL	USL	LSL	USL	LSL	USL	LSL	USL	LSL	USL	LSL	USL	LSL	USL	LSL	USL	LSL	USL
Low Btu Gas	325 (12.1)	875 (32.6)	24%	75%	0.3%	14%	0.2%	7.0%	0.3%	6.0%	0.0%	Note (2)	0.5%	64%	0.3%	58%	0	400
Natural Gas	825 (30.7)	1275 (47.5)	75%	100%	0.1%	13%	0.0%	10%	0.0%	10%	0.0%	Note (2)	0.1%	23%	0.0%	10%	0	5
High Btu Gas	1252 (46.6)	2131 (79.4)	22%	75%	5.0%	18%	10%	43%	6.0%	15%	0.0%	Note (2)	0.0%	8.0%	0.0%	4.0%	0	5
LPG (Note 4)	2516 (93.7)	2962 (110)					40%	99%	0.0%	60%	0.0%	Note (2)					0	5
Sour Low Btu Gas	325 (12.1)	875 (32.6)	24%	75%	0.3%	14%	0.2%	7.0%	0.3%	6.0%	0.0%	Note (2)	0.5%	64%	0.3%	58%	400	3.5%
Sour Natural Gas	825 (30.7)	1275 (47.5)	75%	100%	0.1%	13%	0.0%	10%	0.0%	10%	0.0%	Note (2)	0.1%	35%	0.0%	10%	5	7%
Sour High Btu Gas	1252 (46.6)	2131 (79.4)	22%	75%	5.0%	18%	10%	43%	6.0%	15%	0.0%	Note (2)	0.0%	8.0%	0.0%	4.0%	5	7%

Notes:

- (1): Wobbe index is equal to Calorific Value (HHV)/(Specific Gravity)<sup>0.5</sup>. For Btu/ft<sup>3</sup>, HHV and Wobbe Index are taken at a ref. pressure of 14.696 psia and temp. of 60°F. For MJ/m<sup>3</sup>, HHV and Wobbe Index are taken at a ref. pressure of 101325 Pa and temp. of 0°C.
- (2): Feed gas may contain concentrations of C5+ hydrocarbon components, but liquid components must be knocked out prior to entering the MicroTurbine fuel system to ensure the fuel remains a vapor.
- (3): Gas may be composed of other components in small percentages. See Table 5 for limits on other constituents.
- (4): Fuel supplied from the storage tank must be drawn of the bottom of the tank as a liquid and vaporized in a Capstone Engineering approved fuel delivery system to guarantee fuel is maintained as a vapor throughout the MicroTurbine fuel system. Excessive butane content results in a higher dew point temperature. Care must be taken so that the fuel system operates at least 18°F (10°C) higher than the dew point temperature to prevent condensation of liquid hydrocarbons that cause engine damage. See Figure 1 for LPG dew point curves.

Table 4 presents Wobbe Index values for the allowable gaseous fuels.

**Table 4. Wobbe Index Values - Allowable Gaseous Fuels**

Allowable Fuels	Wobbe Index <sup>(Note 1)</sup> Btu/ft <sup>3</sup> (MJ/m <sup>3</sup> )	
	LSL	USL
Low Btu Gas	348 (12.9)	1023 (38.1)
Natural Gas	1002 (37.3)	1488 (55.4)
High Btu Gas	1384 (51.6)	1887 (70.3)
LPG	2039 (76.0)	2200 (82.0)
Sour Low Btu Gas	348 (12.9)	1023 (38.1)
Sour Natural Gas	1002 (37.3)	1488 (55.4)
Sour High Btu Gas	1384 (51.6)	1887 (70.3)

Note (1): Wobbe index is equal to Calorific Value (HHV)/(Specific Gravity)<sup>0.5</sup>. For Btu/ft<sup>3</sup>, HHV and Wobbe Index are taken at a ref. pressure of 14.696 psia and temp. of 60°F. For MJ/m<sup>3</sup>, HHV and Wobbe Index are taken at a ref. pressure of 101325 Pa and temp. of 0°C.

## Composition/Physical Properties Requirements

Approved gaseous fuels must be in accordance with the physical properties listed below, in addition to the referenced notes. Table 5 presents Fuel Composition/Physical Property Requirements and test method for allowable fuels.

**Table 5. Physical Property Requirements/Test Method – Gaseous Fuels**

Physical Property	Units	LSL	USL	Test Method	Notes
Condensable Combustible Gases	% Mass instantaneous	0	0	----	(1)
Acetylene	% Volume	0	0	----	----
Carbon Monoxide	% Volume	0	5	ASTM D1945	----
Hydrogen	% Volume	0	0	ASTM D1945	----
Oxygen	% Volume	0	10	ASTM D1945	----
Water Vapor	% Volume	0	5	----	(2)
Calorific Value Variation	% of average	0	(±10)	ASTM D4891	95% Confidence Interval

Notes:

- (1): At minimum gas temperature minus 10° C (18° F), and maximum supply pressure (as noted in Tables 7 and 8). If the fuel and/or the fuel system must be heated to a temperature above the ambient temperature in order to meet this requirement, then precautions must be taken to prevent the condensation of the fuel when the MicroTurbine is shutdown so that no combustible liquid may enter the MicroTurbine control system when started or run.
- (2): Any water vapor content must be at a minimum of 10° C (18° F) above its dew point anywhere within the fuel connections and the system between the MicroTurbine fuel inlet and the MicroTurbine fuel manifold block. If the fuel or fuel system must be heated to a temperature above the ambient temperature in order to meet this requirement, or to prevent condensed water from freezing, precautions must be taken to prevent the condensation of the water vapor or freezing, when the MicroTurbine is shutdown so that freezing of control valves does not occur and no liquid may enter the MicroTurbine control system when started or run.

## Contaminant Limitations

The approved gaseous fuels must be in accordance with the contaminant limitations listed in Table 6 below.

**Table 6. Gaseous Fuel Contaminant Limitations**

Contaminant	Units	LSL	USL	Test Method	Notes
Lubricating Oil	ppm mass	0	2	-----	Note (2)
Particulate	Size Microns	0	10	-----	-----
Particulate	Qty ppm mass < 10 micron	0	20	-----	-----
Water	% Mass liquid	0	0	ASTM D5454	-----
Fluorine	ppm mass	0	Note (1)	Note (1)	-----
Chlorine	ppm mass	0	1,500	Note (1)	-----
Sodium plus Potassium	ppm mass	0	0.51	ASTM D3605	-----
Vanadium	ppm mass	0	0.5	ASTM D3605	-----
Calcium	ppm mass	0	0.5	ASTM D3605	-----
Lead	ppm mass	0	0.5	ASTM D3605	-----
Sulfur, other than Hydrogen Sulfide	Note (1)	0	Note (1)	Note (1)	Note (3)
Siloxanes	ppb volume	0	5	Note (1)	-----
Ammonia	ppm volume	0	Note (1)	Note (1)	-----
Other	ppm mass	0	0.5	-----	Note (4)

**Notes:**

- (1): Consult Capstone Applications Engineering.
- (2): Oil contamination may emanate from the following two areas: 1) a fuel gas compressor, if used to compress the fuel supply pressure from a low-pressure supply to the pressure required by the MicroTurbine, or 2) any other source.
- (3): Sulfur limitations may vary depending on the exhaust emission requirements.
- (4): If other contaminants are present at more than 0.5 ppm by mass, they may need treatment, precautions, and/or modifications. These items must be detailed to Capstone for additional consideration.

## Fuel Supply Conditions and Temperature Requirements

The approved gaseous fuel supply conditions and temperature requirements must be in accordance with Table 7 below.

**Table 7. Gaseous Fuel Supply Conditions and Temperature Requirements**

System	Supply Pressure kPa Gage (psig)		Supply Temperature °C (°F)		Fuel Flow Control Device
	LSL	USL	LSL	USL	
C30 HP	379 (55) (Note 2)	414 (60) (Notes 2,3)	(Note 4)	50 (122)	SPV25
C30 LP	1.4 (0.20)	103 (15)	(Note 4)	50 (122)	FB-RFC & SPV25
C30 SG	379 (55) (Note 2)	414 (60) (Note 2)	(Note 4)	50 (122)	SPV25
C30 L/DG	(Note 3)	(Note 3)	(Note 4)	50 (122)	SPV25
C60 HP	517 (75)	552 (80)	(Note 4)	50 (122)	SPV25
C60 HP/ ICHP	517 (75)	552 (80)	(Note 4)	50 (122)	SPV25
C60 LP (Note 1)	3.4 (0.50)	103 (10)	(Note 4)	50 (122)	SPV25
C60 LP/ ICHP (Note 1)	3.4 (0.50)	103 (10)	(Note 4)	50 (122)	SPV25

Notes:

- (1) Low pressure gas can be used when C60 HP, C60 HP ICHP is integrated with Capstone Integrated Fuel System Optional Accessory.
- (2) Fuels with Calorific Value greater than Natural Gas Range or Sour Natural Gas Range may require lower inlet pressures, down to 310 kPa (45 psig).
- (3) This item is dependent upon the fuel Calorific Value as noted in Table 8.
- (4) This value must be the highest of 0 °C (32 °F), or 10 °C (18 °F) above the fuel dew point temperature at the Fuel Supply Pressure Maximum noted in this table.

The fuel supply pressure requirements for the Capstone 30 MicroTurbine Landfill/Digester (C30 L/DG) Gas Systems are dependent upon the Fuel Calorific Value, and are presented in Table 8.

**Table 8. C30 L/DG Fuel Supply Pressure Requirements**

Calorific Value (HHV) [MJ/m <sup>3</sup> (Btu/ft <sup>3</sup> )]		Supply Pressure [kPa Gage (psig)]	
LSL	USL	LSL	USL
26.1 (700)	38.4 (1,030)	345 (50)	379 (55)
22.4 (600)	26.1 (700)	345 (50)	414 (60)
18.6 (500)	22.4 (600)	379 (55)	448 (65)
16.8 (450)	18.6 (500)	414 (60)	483 (70)
14.9 (400)	16.8 (450)	448 (65)	517 (75)
12.1 (325)	14.9 (400)	483 (70)	552 (80)

## Approved and Validated Fuel Applications

### Gaseous Fuels

A matrix of approved and validated Capstone MicroTurbine systems along with their relevant gaseous fuel types is listed in Table 9. Combinations marked with ✓ are approved and are subject to the limitations noted.

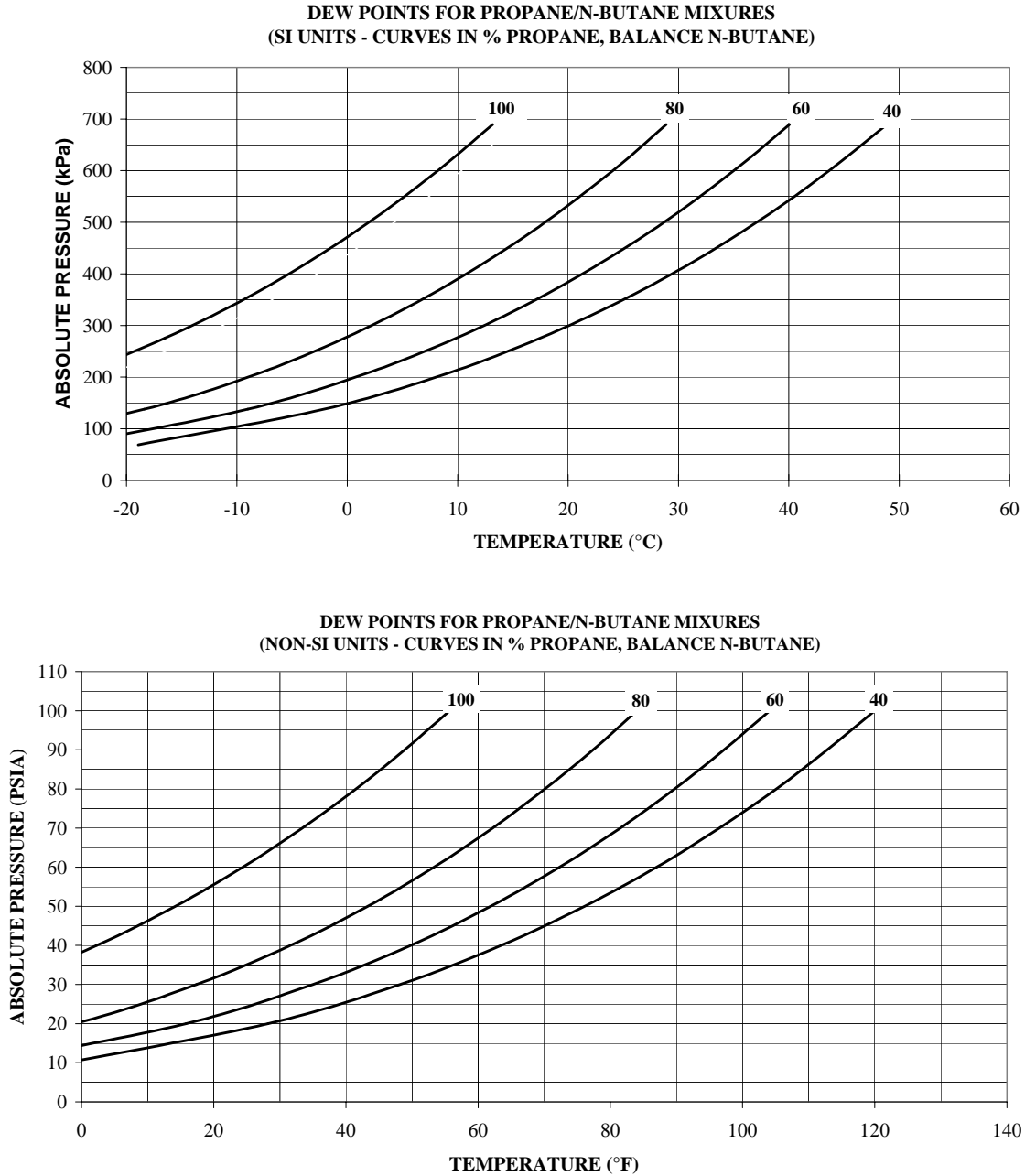
**Table 9. MicroTurbine System Combinations - Approved and Validated Gaseous Fuels**

System	Low Btu Gas	Natural Gas (Note 4)	High Btu Gas	LPG	Sour Low Btu Gas	Sour Natural Gas	Sour High Btu Fuel
C30 HP	----	✓	✓ Note (2)	✓ Notes (2,3)	----	----	----
C30 LP	----	✓	----	----	----	----	----
C30 SG	----	✓	✓ Note (2)	----	----	✓	✓ Note (2)
C30 L/DG	✓	----	----	----	✓	----	----
C60 HP	----	✓	✓	✓ Note (3)	----	----	----
C60 HP ICHP	----	✓	✓	✓ Note (3)	----	----	----
C60 LP [Note (1)]	----	✓	----	----	----	----	----
C60 LP ICHP [Note (1)]	----	✓	----	----	----	----	----

Notes:

- (1): Low-pressure gas can be used when C60 HP, C60 HP ICHP is integrated with Capstone Integrated Fuel System Optional Accessory.
- (2): Only in 3-Pilot Lock Mode.
- (3): Fuel supplied from the storage tank must be drawn off the bottom of the tank as a liquid and vaporized in a Capstone Engineering approved fuel delivery system to guarantee fuel is maintained as a vapor throughout the MicroTurbine fuel system. Excessive butane content results in a higher dew point temperature. Care must be taken so that the fuel system operates at least 18°F (10°C) higher than the dew point temperature to prevent condensation of liquid hydrocarbons that cause engine damage. See Figure 1 for LPG dew point curves.
- (4): Engine is ATP tested within lower level of this fuel range (Calorific Value).

Figure 1 shows the effects of Propane/N-Butane mixtures on LPG dew points.



**Figure 1. Effect of Propane/N-Butane % Variation for LPG Fuel on the Dew Point**

## Liquid Fuels

### Definitions

Table 10 provides definitions of the types of approved liquid fuels.

**Table 10. Liquid Fuels Definitions**

Fuels	Specifications
Diesel Fuel	ASTM D975 No. 1-D, 2-D Grade Low Sulfur No. 1-D and No. 2-D
Aviation Fuels	ASTM D1655 (Jet-A), MIL-DTL-83133E (JP-8), and MIL-DTL-5624U (JP-5)
Kerosene	ASTM D3699 1-K JIS K2203

### System Combinations

Table 11 lists approved and allowable MicroTurbine system combinations, along with their relevant liquid fuel types. Combinations marked with a ✓ are approved.

**Table 11. MicroTurbine Liquid Fuels System Combinations**

System	Kerosene		Diesel				Aviation		
	K2203	1-K	No. 1-D	No. 2-D	No. 1-D Low Sulfur	No. 2-D Low Sulfur	Jet-A	JP-5	JP-8
C30 LF	✓	✓	✓	✓	✓	✓	✓	✓	✓

### Supply Pressure and Temperature Requirements

Table 12 lists the required supply pressure and temperature requirements for liquid fuels. Supply pressure must be stable (within ±2% of the nominal pressure)

**Table 12. Liquid Fuels Supply Pressure and Temperature Requirements**

System	Supply Pressure kPa Gage (psig)		Supply Temperature °C (°F)		Fuel Flow Control Device
	LSL	USL	LSL	USL	
C30 LF	-34.5 (-5)	34.5 (5)	0 (32)	50 (122)	LFC Pump

## Physical Properties Requirements

Approved liquid fuels must be in accordance with the physical properties requirements listed in Table 13, in addition to the referenced notes. Table 13 presents the liquid fuels physical properties.

**Table 13. Liquid Fuels Physical Properties Requirements**

Physical Property	Units	LSL	USL	Test Method (Note 4)	Notes
Viscosity	Centistokes	1	14	ASTM D445	(1)
Specific Gravity	@ 20 °C (68 °F)	0.75	0.95	ASTM D1298	-----
Cloud Point	°C (°F)	-----	T <sub>min</sub> -10 (-18)	ASTM D2500	(1)
Pour Point	°C (°F)	-----	T <sub>min</sub> -10 (-18)	ASTM D97	(1)
Flash Point	°C (°F)	38 (100)	66 (150)	ASTM D93	-----
Calorific Value	MJ/kg (Btu/lbm)	34.9 (15,000)	46.5 (20,000)	ASTM D240	-----
Calorific Value Variation	% Of nominal	0	(+/- 10)	ASTM D240	(2)
Vapor Pressure	kPa absolute (psia) @ T <sub>max</sub>	0	20.67 (3)	ASTM D323	(3)
Initial Distillation Point	°C (°F)	120 (250)	175 (350)	ASTM D86	-----
Final Distillation Point	°C (°F)	-----	370 (700)	ASTM D86	-----

Notes:

- (1): The minimum temperature requirement (T<sub>min</sub>) may be higher than the minimum supply temperature shown in Table 12. This is because it is limited by the Pour point, Cloud point, Viscosity, or other property listed in the applicable table.
- (2): The variation from nominal is that occurring without any adjustment to the control system or other applicable MicroTurbine (engine) feature. Variations outside this range may be permissible but are subject to any necessary adjustments or changes to MicroTurbine (engine) features and approval by Capstone.
- (3): The maximum temperature requirement (T<sub>max</sub>) may be lower than the maximum supply temperature shown in Table 12. This is because it is limited by the Vapor pressure, or some other property listed in Table 13.
- (4): Or other equivalent test method as permitted by "ASTM Standards For Industrial Fuel Applications Including Burners, Diesel Engines, Gas Turbines, and Marine Applications"

## Contaminants Limitations

Approved liquid fuels must be in accordance with the contaminants limitations listed in Table 14, in addition to the referenced notes.

**Table 14. Liquid Fuels Contaminants Limitations**

Contaminant	Units	LSL	USL	Test Method (Note 2)	Notes
Water (free)	% Mass	0	0.05	ASTM D2709	----
Particulate	Size Micron	0	2	ASTM D2276	----
Particulate	Qty ppm mass	0	5	ASTM D2276	----
Ash	ppm mass	0	100	ASTM D482	----
Fluorine	ppm mass	0	150	----	----
Chlorine	ppm mass	0	1,500	----	----
Sulfur	ppm mass	0	10,000	ASTM D129	Note (3)
Sodium plus Potassium	ppm mass	0	0.5	ASTM D3605	----
Vanadium	ppm mass	0	0.5	ASTM D3605	----
Calcium	ppm mass	0	0.5	ASTM D3605	----
Lead	ppm mass	0	0.5	ASTM D3605	----
Other	ppm mass	0	0.5	----	Note (4)
Copper Strip	% Weight loss	0	0.005	----	----
Ph	Note (1)	0	Note (1)	----	----

**Notes:**

- (1): Consult Capstone Applications Engineering.
- (2): Or other equivalent test method as permitted by “ASTM Standards For Industrial Fuel Applications Including Burners, Diesel Engines, Gas Turbines, and Marine Applications”
- (3): Sulfur limitations may be lower depending on the exhaust emission requirements.
- (4): If other contaminants are present at more than 0.5 ppm by mass, they may need treatment, precautions, and/or system modifications. These contaminants must be detailed to Capstone for additional consideration.

## Pour Point

Pour Point is the lowest temperature at which a liquid will flow under specified conditions. The minimum temperature requirement ( $T_{min}$ ) is the lowest operational temperature for the Capstone MicroTurbine system. Based upon specific fuel properties, the minimum temperature requirement ( $T_{min}$ ) may be higher than the minimum supply temperature shown in Table 12. This is because it is limited by the Pour Point, Cloud point, Viscosity, or some other property listed in the applicable table.

## Vapor Pressure

Vapor Pressure is the pressure at a given fluid temperature in which the liquid and gaseous phases of the liquid are at equilibrium. The maximum temperature ( $T_{max}$ ) is the highest operational temperature for the Capstone MicroTurbine system. Based upon specific fuel properties, the maximum temperature requirement ( $T_{max}$ ) may be lower than the maximum supply temperature shown in Table 12. This is because it is limited by the Vapor Pressure, or some other property listed in Table 13.

## New Fuel Acceptance Criteria

Capstone evaluates three MicroTurbine system components when considering possible new fuels. These areas are identified as noted below, and as detailed in the paragraphs on the following pages.

- Combustion System Evaluation Concerns
- Fuel System Evaluation Concerns
- MicroTurbine (Engine) Evaluation Concerns

Additional information may be obtained from within the detail Specification ASTM D2880.

## Combustion System Evaluation Concerns

The combustion system evaluation concerns include the items presented in the following paragraphs.

### Stability Limits

The fuel type may affect the stability of the combustion system. Fuels highly diluted with inert items (as well as different liquid fuels), may have degraded stability at low power levels. For liquid fuels, atomization, which is highly dependent on fuel physical properties, has a significant effect on stability.

### Flashback

Fuels containing significant amounts of hydrogen and acetylene may result in flashback and combustion system damage.

### Combustor Life

Operating on fuels containing significant amounts of carbon monoxide and acetylene will result in reduced combustor life due to high combustor temperatures. Liquid fuels with poor atomization qualities will also result in reduced combustor life.

### Emissions

Some fuels will have inherently higher emissions levels. Liquid fuel systems will generally have higher NO<sub>x</sub> levels than natural gas systems. Landfill and digester fuels may have lower NO<sub>x</sub> levels, as well as higher CO and THC levels at full power. Fuels containing significant amounts of carbon monoxide and acetylene will also result in higher NO<sub>x</sub> emissions. For liquid fuels, atomization, which is highly dependent on fuel physical properties, also has a significant effect on emissions.

### Vapor Lock

Liquid fuels with sufficiently high vapor pressures will cause vapor lock in the fuel injectors, resulting in decreased system reliability due to flame-outs, fail-to-light conditions, or unsteady MicroTurbine operation.

## Fuel System Evaluation Concerns

The fuel system evaluation concerns include the items presented in the following paragraphs.

### Gaseous Fuel Temperature

High or low temperature limits of the MicroTurbine raise concerns regarding liquid formation, high vapor pressure, high density, and high viscosity. High or low temperature extremes may also cause damage to the materials of construction of the fuel system component parts.

### Degradation of Fuel System Components, Metals, and Elastomers

Fuel contaminants, additives, as well as some hydrocarbons may corrode or attack critical fuel system components. Combinations of contaminants such as water with hydrogen sulfide may lead to even more severe corrosion effects. Temperature may also accelerate the corrosive effects of some fuels.

### Water Condensation and Freezing in a Gaseous Fuel System

The presence of condensed water or ice will result in fuel system malfunction and eventual system shut down. Provisions must be taken to maintain the gaseous fuel 10 °C (18 °F) above the water dew point temperature (freezing point), throughout the fuel system. This includes up to and including the fuel manifold.

### Liquids in a Gaseous Fuel System

The presence of liquids in a gaseous fuel, either from the fuel, or from the fuel gas compressor lubricating oil, may result in fuel system malfunction. It is important to maintain the gaseous fuel at 10 °C (18 °F) above the dew point temperature throughout the fuel system. This includes up to and including the fuel manifold. In addition, provisions must be made for purging the fuel system upon shutdown, and/or prior to startup.

### Rotary Flow Compressor Life (BB – RFC)

Excessive gaseous fuel temperatures or corrosive contaminants will cause early failure. Sub-atmospheric inlet pressure to the compressor can also result in air leaking into the gas fuel supply and the consequent risk of an explosive mixture. Sub-atmospheric inlet pressure will result in reduced Ball Bearing Rotary Flow Compressor (BB-RFC) life.

### Rotary Flow Compressor Life (FB – RFC)

Excessive gaseous fuel temperatures or corrosive contaminants will cause early failure. Sub-atmospheric inlet pressure to the compressor can also result in air leaking into the gas fuel supply and the consequent risk of an explosive mixture.

### External Fuel Gas Compressor Life

Excessive gaseous fuel temperatures or corrosive contaminants will cause early component failure. Sub-atmospheric inlet pressure to the compressor can also result in air leaking into the gas-fuel supply and the consequent risk of an explosive mixture.

## Liquid Fuel Density and Viscosity

Deviation of the liquid fuel density from the parameters noted within this document may result in incorrect metering of the liquid fuel, and/or other fuel control issues. High fuel viscosity may result in increased heating of the fuel pump internal components, which may affect the fuel pump performance. High fuel viscosity may result in cold start problems due to its effect on fuel atomization, and may also increase emissions. Lower than specified fuel viscosity may result in increased internal leakage of the fuel pump, which may adversely affect the fuel metering accuracy, especially under low flow conditions.

## Liquid Fuel Pump Life

Liquid fuel pump life may be adversely affected by the fuel viscosity, fuel lubricity, and fuel temperature, in addition to any contaminants in the fuel that are outside of the requirements detailed within this document.

## Water in Liquid Fuels

Excessive water present in liquid fuels may result in freezing at cold temperatures that may result in fuel system malfunction and system shutdown. Excessive water may also result in biological growth in fuel system components, especially within the fuel filter.

## MicroTurbine (Engine) Evaluation Concerns

The MicroTurbine (Engine) evaluation areas include the following items:

### Damage of MicroTurbine Hot End Components

Due to their chemistry, some fuel contaminants (sulfur, for example) may lead to hot end component damage (combustor, and/or other components).

### Combustible Liquids in a Gaseous Fuel System

The presence of liquids in a gaseous fuel, either from the fuel or from the fuel gas compressor lubricating oil, may result in MicroTurbine (engine) hardware damage. It is important to maintain the gaseous fuel at 10 °C (18 °F) above the dew point temperature throughout the fuel system. This includes up to and including the manifold. In addition, provisions must be made for purging the fuel system upon shutdown, and/or prior to startup, to prevent liquid ingress to the MicroTurbine.

You may also refer to Figure 1, which shows the effect of Propane/N-Butane percent variation on the dew point for LPG fuel. Notice that a margin of 10 °C (18 °F) must be added to the dew point temperature noted in Figure 1.

### Surge

Fuels with reduced volumetric heating values will reduce surge margin of the engine. This may result in unsteady operation of the MicroTurbine.

## Listing of Reference Documents

The following documents form a part of this Engineering Specification to the extent specified herein. Use the latest revision applicable for the date of each referenced document.

Document	Document Title
ASTM D1070	Standard Test Methods for Relative Density of Gaseous Fuels
ASTM D129	Standard Test Method for Sulfur in Petroleum Products
ASTM D1298	Standard Practice for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method
ASTM D1945	Standard Test Method for Analysis of Natural Gas by Gas Chromatography
ASTM D2163	Standard Test Method for Analysis of Liquefied Petroleum (LP) Gases and Propane Concentrates by Gas Chromatography
ASTM D2276	Standard Test Method for Particulate Contaminant in Aviation Fuel by Line Sampling
ASTM D240	Standard Test Method for Heat Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter
ASTM D2500	Standard Test Method for Cloud Point of Petroleum Products
ASTM D2709	Standard Test Method for Water and Sediment in Middle Distillate Fuels by Centrifuge
ASTM D2880	Standard Specification for Gas Turbine Fuel Oils
ASTM D323	Standard Test Method for Vapor Pressure of Petroleum Products (Reid Method)
ASTM D3588	Standard Practice for Calculating Heat Value, Compressibility Factor, and Relative Density of Gaseous Fuels
ASTM D3605	Standard Test Method for Trace Metals in Gas Turbine Fuels by Atomic Absorption and Flame Emission Spectroscopy
ASTM D3699	Standard Specification for Kerosene
ASTM D445	Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (the Calculation of Dynamic Viscosity)
ASTM D482	Standard Test Method for Ash from Petroleum Products
ASTM D4891	Standard Test Method for Heating Value of Gases in Natural Gas Range by Stoichiometric Combustion
ASTM D5454	Standard Test Method for Water Vapor Content of Gaseous Fuels Using Electronic Moisture Analyzers

ASTM D86	Standard Test Method for Distillation of Petroleum Products at Atmospheric Pressure
ASTM D93	Standard Test Methods for Flash-Point by Pensky-Martens Closed Cup Tester
ASTM D97	Standard Test Method for Pour Point of Petroleum Products
ASTM D975	Standard Specification for Diesel Fuel Oils
JIS K2209	Standard Test Method for Kerosene
ASTM D1655	Standard Specification for Aviation Turbine Fuels
MIL-DTL-5624T	Turbine Fuel, Aviation, Grades JP-4, JP-5
MIL-DTL-83133E	Turbine Fuels, Aviation, Kerosene Types, NATO F-34(JP-8), NATO F-35, and JP-8+100

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