Capstone Turbine Corporation • 21211 Nordhoff Street • Chatsworth • CA 91311 • USA
Telephone: (818) 734-5300 • Facsimile: (818) 734-5320 • Website: www.microturbine.com

Technical Reference

Capstone MicroTurbine Fuel Requirements

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 a not yet approved fuel are encouraged to check the new fuel against the specific fuel requirements detailed herein, and to review the New Fuel Acceptance Criteria, section of this document. It is also requested that any newly proposed fuel specification and any associated technical data be submitted to Capstone for review and consideration.

For additional information and guidance regarding different fuels and fuel usage, please refer to the Referenced Specifications, including ASTM D2880 (Sections X1 and X2) and the Approved Fuels portion of this document.

The major areas of this document are detailed as follows:

- Capstone MicroTurbine Fuel System Terms and Definitions
- Capstone MicroTurbine Approved Fuels
- Capstone MicroTurbine Fuel Requirements
- Capstone MicroTurbine New Fuel Acceptance Criteria
- Reference Documents Listing
- Gaseous Fuel and Liquid Fuel Questionnaires

This document supersedes and replaces the Capstone MicroTurbine Fuel Requirements Application Guide 512420-001, dated May 2001.

Capstone Turbine Corporation

21211 Nordhoff Street • Chatsworth • CA 91311 • USA

Telephone: (818) 734-5300

Facsimile: (818) 734-5320

Website: www.microturbine.com

Capstone Technical Support

Telephone: (818) 407-3600

Facsimile: (818) 734-1080

Toll Free Telephone: (877) 282-8966

E-mail: service@capstoneturbine.com

Table of Contents

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. (°F = 1.8 x °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^3	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).
Capstone	Capstone Turbine Corporation.
Centipoise	A commonly used unit of absolute (dynamic) viscosity. 1 Centipoise = 0.01 poise = 0.001Pa.s. (Also see Poise).
Centistoke	A commonly used unit of kinematic viscosity. 1 cSt = 0.01 stoke = 10^{-6} m^2/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)
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^3	Standard cubic feet of gas @ 15 °C and 101.33 kPa (59 °F and 14.696 psia)

Table 1. Capstone MicroTurbine General Terms and Definitions (Continued)

General Terms	Definitions
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.
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^3 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^3 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
m	Meter. The unit of length in metric (S.I.) units. 1 m = 39.37 inches
m^3	Normalized cubic meter of gas @ 15 °C and 101.33 kPa (59 °F and 14.696 psia).
MJ/m^3	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^{-6} 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^2
N/A	Not Applicable
NO_x	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^2
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).

Table 1. Capstone MicroTurbine General Terms and Definitions (Continued)

General Terms	Definitions
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_2S >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.
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. It is usually expressed in centistoke.
Wobbe Index	Calorific Value (HHV) divided by (Specific Gravity) $^{0.5}$

Table 2 presents gaseous fuel definitions for the Capstone MicroTurbine.

Table 2. Capstone MicroTurbine Gaseous Fuel Definitions

Fuels	Calorific Value (HHV) (Note 1) MJ/m^3 (Btu/ft^3)	Specific Gravity Relative to Air (Note 1)	Wobbe Index (HHV) (Note 1) MJ/m^3 (Btu/ft^3)	Composition
Methane	37.63 (1,010)	0.55	50.56 (1,357)	100% Methane (CH_4).
Natural Gas A Range	28.32 to 42.10 (760 to 1,130)	0.55 to 0.80	31.65 to 55.01 (849 to 1,477)	Mixture containing over 75% methane (CH_4). The rest consists of ethane (C_2H_6), propane (C_3H_8), butanes (C_4H_{10}), carbon dioxide (CO_2), nitrogen (N_2), and H_2S @ < 5 ppm V.
Natural Gas B Range (Note 2)	36.14 to 42.10 (970 to 1,130)	0.55 to 0.70	41.99 to 55.01 (1,127 to 1,477)	Mixture containing over 90% methane (CH_4). The rest consists of ethane (C_2H_6), propane (C_3H_8), butanes (C_4H_{10}), carbon dioxide (CO_2), nitrogen (N_2), and H_2S @ < 5 ppm V.
High Btu Fuel	42.10 to 93.74 (1,130 to 2,516)	0.70 to 1.52	55.01 to 75.97 (1,477 to 2,039)	Mixture containing methane (CH_4), ethane (C_2H_6), propane (C_3H_8), butanes (C_4H_{10}), carbon dioxide (CO_2), nitrogen (N_2) and H_2S @ < 5 ppm V. More ethane, propane, and butanes than Natural Gas).
Commercial Propane	92.03 to 94.41 (2,470 to 2,534)	1.50 to 1.54	75.11 to 76.05 (2,016 to 2,041)	Mixture containing over 87.5% propane (C_3H_8), less than 2.5% butanes (C_4H_{10}), less than 5% ethane (C_2H_6), less than 5% propylene (C_3H_6), less than 50 ppm ethyl Mercaptan, and H_2S @ < 5 ppm V. (Note 3).
LPG	93.74 to 121.35 (2,516 to 3,257)	1.52 to 2.01	75.97 to 85.66 (2,039 to 2,299)	Mixture consisting mainly of propane and butanes in varying amounts, with the butanes content between 2.5% and 100%, plus H_2S @ < 5 ppm V.
Landfill/ Digester Gas (Medium Btu)	13.04 to 28.32 (350 to 760)	0.80 to 1.10	12.45 to 31.65 (334 to 849)	Mixture consisting mainly of methane, carbon dioxide, and nitrogen, with trace quantities of higher hydrocarbons, plus hydrogen sulfide (H_2S) in quantities >5 ppm V, but <70,000 ppm V. (Note 4).
Sour Natural Gas A Range (Note 2)	28.32 to 42.10 (760 to 1,130)	0.55 to 0.80	31.65 to 55.01 (849 to 1,477)	Same properties as Natural Gas (A Range), but also contains hydrogen sulfide (H_2S) in quantities >5 ppm V, but <70,000 ppm V (Note 4).

Note 1: Calorific Values/Specific Gravity/Wobbe Index values taken considering 15 °C and 101.33 kPa (59 °F and 14.696 psia).

Note 2: Higher Heating Value (HHV) range is per Table 2-I of the Gas Research Institute report (entitled *Variability of Natural Gas Composition in Select Major Metropolitan areas of the United States*), dated March 1992.

Note 3: If the fuel is supplied from the storage tank as a vapor, then it is important not to allow the tank to empty or to operate below 20% full capacity before replenishing to prevent excessive butane content. Excessive butane content results in a higher dew point temperature and formation of liquid hydrocarbons that cause MicroTurbine (engine) damage.

Note 4: Refer to Capstone Technical Reference 512531, for information relating to Landfill/Digester Gas Usage.

Table 2. Capstone MicroTurbine Gaseous Fuel Definitions (Continued)

Fuels	Calorific Value (HHV) (Note 1) MJ/m^3 (Btu/ft^3)	Specific Gravity Relative to Air (Note1)	Wobbe Index (HHV) (Note 1) MJ/m^3 (Btu/ft^3)	Composition
Sour Natural Gas B Range	36.14 to 42.10 (970 to 1,130)	0.55 to 0.70	41.99 to 55.01 (1,127 to 1,477)	Same properties as Natural Gas (B Range), but also contains hydrogen sulfide (H_2S) in quantities >5 ppm V, but <70,000 ppm V.
Sour High Btu Gas	42.10 to 93.74 (1,130 to 2,516)	0.70 to 1.52	55.01 to 75.97 (1,477 to 2,039)	Same properties as high Btu fuel, but also contains hydrogen sulfide (H_2S) in quantities >5 ppm V, but <70,000 ppm V.

Table 3 presents liquid fuel definitions for the Capstone MicroTurbine.

Table 3. Capstone MicroTurbine Liquid Fuel Definitions

Fuels	Calorific Value (HHV) kJ/kg (Btu/lbm)	Viscosity @ 40 °C (104 °F) (Centistokes)	Composition
Diesel Fuel	46,050 to 46,520 (19,800 to 20,000)	1.3 to 4.1	ASTM D975 No. 1-D, 2-D Grade Low Sulfur No. 1-D and No. 2-D
Kerosene	46,050 to 46,520 (19,800 to 20,000)	1.0 to 1.9	ASTM D3699 1-K JIS K2209

Table 4 presents system definitions for the Capstone MicroTurbine.

Table 4. Capstone MicroTurbine System Definitions

Model Type	Engine Type	Recuperator	Fuel Type
C30 HP	Model C30	Recuperated	High Pressure Gaseous Fuels
C30 LP	Model C30	Recuperated	Low Pressure Gaseous Fuels (Includes an Internal BB – RFC as Fuel Gas Compressor)
C30 LP-F	Model C30	Recuperated	Low Pressure Gaseous Fuels (Includes an Internal FB – RFC as Fuel Gas Compressor, plus a Smart Proportional Valve as a Gaseous Flow Control Valve)
C30 SC	Model C30	Non-Recuperated (Simple Cycle)	High Pressure Gaseous Fuels (Sour Gas Compatible)
C30 SG	Model C30	Recuperated	High Pressure Sour Gas Fuels
C30 L/DG	Model C30	Recuperated	Landfill and/or Digester Gaseous Fuels (Sour Gas Compatible)
C30 LF	Model C30	Recuperated	Liquid Fuels
C30 ELF	Model C30	Recuperated	Liquid Fuels (using the Enhanced Liquid Fuel System)
C60 HP	Model C60	Recuperated	High Pressure Gaseous Fuels (Not Sour Gas Compatible)
C60 LP	Model C60	Recuperated	Low Pressure Gaseous Fuels (Requires an External Fuel Gas Compressor)

Approved Fuels – MicroTurbine System Combinations

Capstone approved and validated gaseous and liquid fuel systems are detailed in the paragraphs that follow.

Approved Gaseous Fuels – MicroTurbine System Combinations

A matrix of approved and validated Capstone MicroTurbine systems along with their relevant gaseous fuel types is listed in Table 5. The gaseous fuels are defined in Table 2. Combinations marked with ♦ are approved and are subject to the limitations noted in the Gaseous Fuel Requirements paragraph of this document.

Table 5. Approved Gaseous Fuels – MicroTurbine System Combinations

System	Methane	Natural Gas A Range	Natural Gas B Range	High Btu Fuel	Commercial Propane	LPG	Landfill/ Digester Gas	Sour Natural Gas A Range	Sour Natural Gas B Range	Sour High Btu Fuel
C30 HP	♦	♦	♦	♦	♦	-----	-----	-----	-----	-----
C30 LP	♦	-----	♦	-----	-----	-----	-----	-----	-----	-----
C30 LP-F	♦	-----	♦	-----	-----	-----	-----	-----	-----	-----
C30 SC	♦	-----	♦	-----	-----	-----	-----	-----	♦	-----
C30 SG	♦	♦	♦	♦	♦	-----	-----	♦	♦	♦
C30 L/DG	♦	♦	♦	-----	-----	-----	♦	♦	♦	-----
C60 HP	♦	-----	♦	-----	-----	-----	-----	-----	-----	-----
C60 LP	♦	-----	♦	-----	-----	-----	-----	-----	-----	-----

Approved Liquid Fuels – MicroTurbine System Combinations

A matrix of approved and validated Capstone MicroTurbine systems along with their relevant liquid fuel types is listed in Table 6. The liquid fuels are defined in Table 3. Combinations marked with ♦ are approved and are subject to the limitations noted in the Liquid Fuel Requirements paragraph of this document.

Table 6. Approved Liquid Fuels – MicroTurbine System Combinations

System	Diesel Fuel No. 2-D ASTM D975	Diesel Fuel No. 2-D ASTM D975 (Low Sulfur)	Diesel Fuel No. 1-D ASTM D975	Diesel Fuel No. 1-D ASTM D975 (Low Sulfur)	Kerosene ASTM D3699 No. 1-K	Kerosene JIS K2209
C30 LF	♦	♦	♦	♦	♦	♦
C30 ELF	♦	♦	♦	♦	♦	♦

Approved Fuel Supply Pressure/Temperature Requirements

A matrix of approved and validated Capstone MicroTurbine fuel supply pressure and temperature requirements is presented in Table 7.

Table 7. Approved Fuel Supply Pressure and Temperature Requirements

System	Supply Press Max kPa Gauge (psig)	Supply Press Min kPa Gauge (psig)	Supply Temp Max °C (°F)	Supply Temp Min °C (°F)	Fuel Flow Control Device
C30 HP	414 (60) (Notes 2 and 5)	379 (55) (Note 2)	50 (122)	(Notes 4 and 5)	SPV
C30 LP	103 (15)	34 (5)	50 (122)	(Note 4)	BB – RFC
C30 LP-F	103 (15)	1.4 (0.20)	50 (122)	(Note 4)	FB – RFC and SPV 25
C30 SC	414 (60)	379 (55)	50 (122)	(Note 4)	SPV 25
C30 SG	414 (60) (Note 2)	379 (55) (Note 2)	50 (122)	(Note 4)	SG-SPV
C30 L/DG	(Note 3)	(Note 3)	50 (122)	(Note 4)	SPV 25
C30 LF	69 (10)	34 (5)	50 (122)	-20 (-4) (Note 7)	LFC, Fuel pump and BB – RFC (for air assist)
C30 ELF	34 (5)	-34 (-5)	50 (122)	-20 (-4) (Note 7)	LFC, Fuel pump and BB – RFC (for air assist)
C60 HP	552 (80)	517 (75)	50 (122)	(Note 4)	SPV 25
C60 LP (Note 1)	103 (15)	1.72 (0.25) (Note 6)	50 (122)	(Note 4)	SPV 25

Note 1: This item uses an External Fuel Gas Compressor.

Note 2: Fuels with volumetric heating value greater than Natural Gas (A or B Range) or Sour Natural Gas (A or B Range) may require lower inlet pressures, down to 310 kPa gauge (45 psig).

Note 3: This item is dependent upon the fuel Calorific Value as noted in Table 8.

Note 4: This value must be the highest of -20 °C (-4 °F), or 10 °C (18 °F) above the fuel dew point temperature at the Fuel Supply Pressure Maximum noted in this table (Table 7). Also, refer to the Fuels Requirements portion of this document.

Note 5: For Commercial Propane fuel, the minimum temperature is 8 °C (47 °F), and the maximum supply pressure is 310 kPa gauge (45 psig), whereas the minimum supply pressure is 276 kPa gauge (40 psig).

Note 6: An external (Copeland) fuel gas compressor can be used in applications with inlet pressures up to 103 kPa (15 psig) (minimum discharge pressure of 482 kPa gauge (70 psig) from the fuel gas compressor). These pressure values are based upon an external (Copeland) fuel gas compressor system. Please refer to the Copeland documentation for additional information. Typically, for a single Model C60 MicroTurbine used with a single (Copeland) fuel gas compressor system, the ideal pressure is 1.72 to 6.89 kPa gauge (0.25 to 1.0 psig).

Note 7: When operating on diesel fuel, the minimum temperature is 0 °C (32 °F).

The fuel supply pressure requirements for the Model C30 MicroTurbine Landfill/Digester (C30 L/DG) gas systems are dependent upon the Fuel Calorific Value, and are listed in Table 8.

Table 8. C30 L/DG Fuel Supply Pressure Requirements

Calorific Value (HHV) Max MJ/m^3 (Btu/ft^3)	Calorific Value (HHV) Min MJ/m^3 (Btu/ft^3)	Supply Pressure Max kPa Gauge (psig)	Supply Pressure Min kPa Gauge (psig)
42 (1,130)	26 (700)	379 (55)	345 (50)
26 (700)	22 (600)	414 (60)	345 (50)
22 (600)	19 (500)	448 (65)	379 (55)
19 (500)	17 (450)	483 (70)	414 (60)
17 (450)	15 (400)	517 (75)	448 (65)
15 (400)	13 (350)	552 (80)	483 (70)

Fuel Requirements

The Capstone MicroTurbine fuel requirements are comprised of the essential items detailed in Tables 9 through 12.

The fact that a fuel may meet all of the requirements detailed in Tables 9 through 12, does not necessarily mean that fuels within the range of limits tabulated can be interchanged for one given system. If a user wishes to change from the fuel originally specified for a given system, he must contact Capstone to see whether the change may be permissible, and just what hardware and/or software changes may be required or what consequences may ensue.

Refer to Tables 5 and 6 in this document for the approved Capstone MicroTurbine systems versus the various fuel types. A Fuel Questionnaire (Attachment 1A or 1B) must be completed for Capstone review/approval for each newly proposed fuel type.

The fuel specifications and the fuel requirements listed are those necessary for satisfactory operation of the Capstone MicroTurbine. The total contaminants and/or content of the fuels may also be governed by any relevant exhaust emissions requirements.

The Test Methods are as identified, or other equivalent authority test methods, such as those specifically defined by ASTM D2880, and agreed to by Capstone.

Gaseous Fuel Requirements

The gaseous fuel requirements including the composition, physical/chemical properties, and gaseous fuel supply conditions requirements are detailed in the paragraphs that follow.

Gaseous Fuel Composition and Properties Requirements

The Gaseous Fuels being evaluated **must be** in accordance with the specifications and parameters listed in Table 9, in addition to the referenced Notes.

Table 9. Gaseous Fuel Composition and Properties Requirements

Component or Property	Units	Max	Min	Test Method	Notes
Combustible Gases	% Volume	100	30	-----	-----
Condensable Combustible Gases	% Mass instantaneous	0	0	-----	(Note 1)
Acetylene	% Volume	5	0	-----	-----
Nitrogen	% Volume	50	0	ASTM D1945	-----
Carbon Dioxide	% Volume	50	0	ASTM D1945	-----
Carbon Monoxide	% Volume	5	0	ASTM D1945	-----
Hydrogen	% Volume	5	0	ASTM D1945	-----
Oxygen	% Volume	10	0	ASTM D1945	-----
Water Vapor	% Volume	5	0	-----	(Note 2)
Specific Gravity @ 59 °F, 14.7 psia	Relative to air	1.54	0.55	ASTM D1070	(Note 3)
Wobbe Index @ 15 °C (59 °F)	MJ/m^3 (Btu/ft^3)	76.05 (2,041)	12.45 (334)	-----	HHV Based (Note 3)
Calorific Value Average (HHV)	MJ/m^3 (Btu/ft^3)	94.41 (2,534)	13.04 (350)	ASTM D4891	(Note 3)
Calorific Value Variation	Percent of average	(+/- 10)	0	ASTM D4891	-----

Note 1: At minimum gas temperature -10 °C (18 °F) above the dew point (as system cannot operate below the temperature at which gas can condense), and maximum supply pressure as noted in Table 7. 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.

Note 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.

Note 3: With appropriate MicroTurbine model selection and control system setting for the particular fuel that falls within this range. The supply pressures are tabulated in Table 7 and in Table 8.

Gaseous Fuel Contaminants Limitations

The Gaseous Fuels being evaluated **must be** in accordance with the specifications and parameters listed in Table 10, in addition to the referenced Notes.

Table 10. Gaseous Fuel Contaminants Limitations

Contaminant	Units	Max	Min	Test Method	Notes
Water (Liquid)	% Mass	0	0	ASTM D5454	-----
Lubricating Oil	ppm mass	2	0	-----	(Note 1)
Particulate Size	Microns	10	0	-----	-----
Particulate Quantity (<10 Micron)	ppm mass	20	0	-----	-----
Hydrogen Sulfide	ppm volume	5 or 70,000	0	ASTM D3588	(Notes 2 and 3)
Sulfur, other	TBD	TBD	0	-----	-----
Siloxanes	ppb volume	5	0	TBD	-----
Sodium plus Potassium	ppm mass	0.51	0	ASTM D3605	-----
Vanadium	ppm mass	0.5	0	ASTM D3605	-----
Calcium	ppm mass	0.5	0	ASTM D3605	-----
Lead	ppm mass	0.5	0	ASTM D3605	-----
Chlorine	ppm mass	1,500	0	TBD	-----
Fluorine	ppm mass	TBD	0	TBD	-----
Ammonia	ppm volume	TBD	0	TBD	-----
All Other Contaminants	ppm mass	0.5	0	-----	(Note 4)

Note 1: Oil contamination may emanate from the following 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, (2) compressed bottled gas, or (3) various other sources.

Note 2: Sulfur limitations may be lower depending on the exhaust emission requirements.

Note 3: Values above 5 and up to 70,000 ppm Volume are permissible on Capstone MicroTurbine Models C30 SG, C30 SC, and C30 L/DG.

Note 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.

Gaseous Fuel Supply Conditions Requirements

The gaseous fuel supply conditions must be in accordance with Table 7.

Liquid Fuel Requirements

The various liquid fuel requirements including the physical/chemical properties, contaminants, and liquid fuel supply conditions requirements are detailed in the paragraphs that follow.

Liquid Fuel Properties Requirements

The Liquid Fuels being evaluated **must be** in accordance with the specifications and parameters listed in Table 11, in addition to the referenced Notes.

Table 11. Liquid Fuel Properties Requirements

Property	Units	Max	Min	Test Method (Note 4)	Notes
Kinematic Viscosity	Centistokes	5	1	ASTM D445	(Note 1)
Specific Gravity @ 20 °C (68 °F)	Relative to H_2O	0.95	0.75	ASTM D1298	-----
Cloud Point	°C (°F)	T_{min} –10 (-18)	-----	ASTM D2500	(Note 1)
Pour Point	°C (°F)	T_{min} –10 (-18)	-----	ASTM D97	(Note 1)
Flash Point	°C (°F)	66 (150)	38 (100)	ASTM D93	-----
Calorific Value	MJ/kg (Btu/lbm)	46.5 (20,000)	34.9 (15,000)	ASTM D240	-----
Calorific Value Variation	Percent of nominal	(+/- 10)	0	ASTM D240	(Note 2)
Vapor Pressure	kPa absolute (psia) @ T_{max}	20.67 (3)	0	ASTM D323	(Note 3)
Initial Distillation Point	°C (°F)	175 (350)	120 (250)	ASTM D86	-----
Final Distillation Point	°C (°F)	370 (700)	-----	ASTM D86	-----

Note 1: The minimum temperature requirement (T_{min}) may be higher than the minimum supply temperature shown in Table 7. This is because it is limited by the Pour point, Cloud point, Viscosity, or other property listed in the applicable table.

Note 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 may lead to decreased system reliability due to flame-outs, fail-to-light conditions, or unsteady MicroTurbine operation.

Note 3: The maximum temperature requirement (T_{max}) may be lower than the maximum supply temperature shown in Table 7. This is because it is limited by the Vapor pressure, or some other property listed in Table 7.

Note 4: Or other equivalent test method as permitted by ASTM Standards for Industrial Fuel Applications, including Burners, Diesel Engines, Gas Turbines, and Marine Applications.

Liquid Fuel Contaminants Limitations

The liquid fuels must be in accordance with the specifications and parameters listed in Table 12, in addition to the referenced Notes.

Table 12. Liquid Fuel Contaminants Limitations

Contaminant	Units	Max	Min	Test Method (Note 3)	Notes
Water (free) @ 20 °C (68 °F)	% Mass	0.05	0	ASTM D2709	-----
Particulate Size	Micron	2	0	ASTM D2276	-----
Particulate Quantity (<2 Micron)	ppm mass	5	0	ASTM D2276	-----
Sulfur	ppm mass	10,000	0	ASTM D129	(Note 1)
Chlorine	ppm mass	1,500	0	-----	-----
Fluorine	ppm mass	150	0	-----	-----
Ash	ppm mass	100	0	ASTM D482	-----
Sodium plus Potassium	ppm mass	0.5	0	ASTM D3605	-----
Vanadium	ppm mass	0.5	0	ASTM D3605	-----
Calcium	ppm mass	0.5	0	ASTM D3605	-----
Lead	ppm mass	0.5	0	ASTM D3605	-----
All Other Contaminants	ppm mass	0.5	0	-----	(Note 2)
Copper Strip	% Weight loss	0.005	0	-----	-----
PH	-----	TBD	TBD	-----	-----

Note 1: Sulfur limitations may be lower depending on the exhaust emission requirements.

Note 2: 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.

Note 3: Or other equivalent test method as permitted by ASTM Standards for Industrial Fuel Applications, including Burners, Diesel Engines, Gas Turbines, and Marine Applications.

Liquid Fuel Supply Conditions Requirements

The liquid fuels supply conditions **must be** in accordance with Table 7, and as detailed in the following paragraphs.

Supply Pressure Stability

The supply pressure must be stable within (+/- 2%) of the nominal pressure (within the specified minimum-to-maximum pressure range) for the entire load range operation of the MicroTurbine system.

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 7. 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 7. This is because it is limited by the Vapor Pressure, or some other property listed in Table 11.

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 (Sections X1 and X2).

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_x levels than natural gas systems. Landfill and digester fuels may have lower NO_x 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_x 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. Additional information may be found in the Fuel Gas Compressor documentation (Capstone 512000 and 512001).

Liquid Fuel Density and Viscosity

Deviation of the liquid fuel density from the parameters noted within this document may result 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.

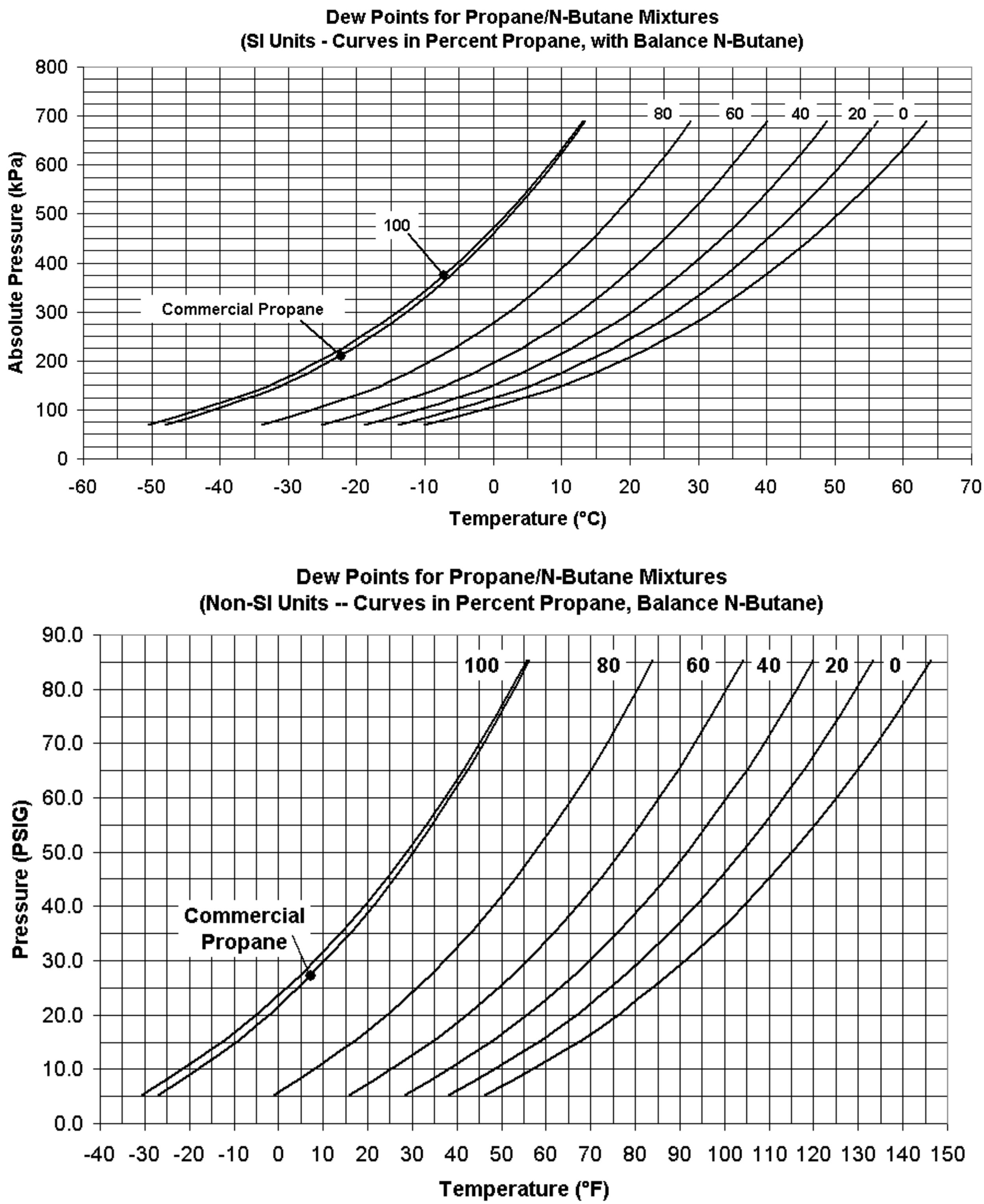

Figure 1. Effect of Propane/N-Butane Percent Variation on Dew Point for LPG Fuel

Reference Documents

The documents listed in Table 13 form a part of this document to the extent specified herein. Use the latest revision applicable for the date of each reference document.

Table 13. Listing of Reference Documents

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 Propene 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

Attachment 1A: Gaseous Fuel Questionnaire

The Gaseous Fuel Questionnaire should be completed whenever a possible new gaseous fuel may be used with the Capstone MicroTurbine. The Gaseous Fuel Questionnaire is detailed in the following tables.

- ❑ Table A: Fuel Questionnaire – Gaseous – General Customer Information
- ❑ Table B: Fuel Questionnaire – Gaseous – Fuel Composition
- ❑ Table C: Fuel Questionnaire – Gaseous – Fuel Properties
- ❑ Table D: Fuel Questionnaire – Gaseous – Fuel Combustibles
- ❑ Table E: Fuel Questionnaire – Gaseous – Fuel Contaminants
- ❑ Table F: Fuel Questionnaire – Gaseous – Fuel Supply Inlet Conditions

Table A presents a gaseous fuel questionnaire detailing the general customer information.

Table A. Fuel Questionnaire – Gaseous – General Customer Information

Item	Customer Information
Customer Name	
Street Address	
State and Country	
Phone Number	
Facsimile Number	
E-Mail Address	
Engineering Contact	
Engineering Contact	
Other Data	
Other Data	
Other Data	
Date	

Table B presents a gaseous fuel questionnaire detailing the fuel composition.

Table B: Fuel Questionnaire – Gaseous – Fuel Composition

Component	Formula	Nominal (Vol/Mol %)	Maximum (Vol/Mol %)	Minimum (Vol/Mol %)	Test Method (or Equivalent)
Methane	CH_4				ASTM D1945
Ethane	C_2H_6				ASTM D1945
Ethylene	C_2H_4				ASTM D1945
Acetylene	C_2H_2				ASTM D1945
Propane	C_3H_8				ASTM D2163
Propylene	C_3H_6				ASTM D2163
Total Butane	C_4H_{10}				ASTM D2163
I-Butane	I-C_4H_{10}				ASTM D2163
N-Butane	N-C_4H_{10}				ASTM D2163
Total Pentane	C_5H_{12}				ASTM D2163
I-Pentane	I-C_5H_{12}				
N-Pentane	N-C_5H_{12}				
Hexane	C_6H_{14}				
Heptane	C_7H_{16}				
Octane +	C_8H_{18}+				
Carbon Monoxide	CO				
Carbon Dioxide	CO_2				ASTM D1945
Nitrogen	N_2				ASTM D1945
Hydrogen	H_2				ASTM D1945
Oxygen	O_2				ASTM D1945
Water	H_2O				
Helium	He				ASTM D1945
Hydrogen Sulfide	H_2S				
Other Components (>0.5%)	(Identify)				
Other	(Identify)				
Sum	%				

Table C presents a gaseous fuel questionnaire detailing the fuel's physical and chemical properties.

Table C: Fuel Questionnaire – Gaseous – Fuel Calculations

Property	Units	Nominal	Maximum	Minimum	Test Method (or Equivalent)
Molecular Weight	G/mol				ASTM D3588
Density @ 15 °C (59 °F)	kg/m^3				ASTM D3588
Specific Gravity Relative to Air					ASTM D3588
LHV Dry	Btu/ft^3				ASTM D3588
	MJ/m^3				ASTM D3588
	Btu/lbm				ASTM D3588
	MJ/kg				ASTM D3588
HHV Dry	Btu/ft^3				ASTM D3588
	MJ/m^3				ASTM D3588
	Btu/lbm				ASTM D3588
	MJ/kg				ASTM D3588
Wobbe Index (HHV)	Btu/ft^3				ASTM D3588
	MJ/m^3				ASTM D3588

Table D presents a gaseous fuel questionnaire detailing the fuel combustibles.

Table D: Fuel Questionnaire – Gaseous – Fuel Combustibles

Property	Value	Nominal	Maximum	Minimum	Test Method (or Equivalent)
Combustible Gases	%				ASTM D3588
Unsaturated Gases	%				ASTM D3588
Condensable Hydrocarbons (>C3)	%				ASTM D3588
Fuel Mixture Dew Point @ 101.3 kPa absolute (14.7 psia)	°C (°F)				----
Fuel Mixture Dew Point @ 241.2 kPa absolute (35 psia)	°C (°F)				
Fuel Mixture Dew Point @ 447.9 kPa absolute (65 psia)	°C (°F)				
Fuel Mixture Dew Point @ 654.6 kPa absolute (95 psia)	°C (°F)				

Table E presents a gaseous fuel questionnaire detailing the fuel contaminants.

Table E: Fuel Questionnaire – Gaseous – Fuel Contaminants

Contaminant	Units	Nominal	Maximum	Minimum	Test Method (or Equivalent)
Water (Liquid)	Vol / Mol %				ASTM D5454
Lubricating Oil	ppm mass				-----
Particulate Size	Micron				-----
Particulate Quantity	ppm mass				-----
Sulfur – H_2S	Vol / Mol %				ASTM D3588
Sulfur - Other	(Identify)				-----
Siloxanes	ppm V				-----
Sodium plus Potassium	ppm mass				ASTM D3605
Vanadium	ppm mass				ASTM D3605
Calcium	ppm mass				ASTM D3605
Lead	ppm mass				ASTM D3605
Chlorine	ppm mass				-----
Fluorine	ppm mass				-----
NH_3	ppm V				-----
All Other Contaminants	(Identify)				-----

Table F presents a gaseous fuel questionnaire detailing the inlet fuel supply conditions.

Table F: Fuel Questionnaire – Gaseous – Fuel Supply Inlet Conditions

Condition	Units	Nominal	Maximum	Minimum	Test Method (or Equivalent)
Fuel Inlet Pressure	kPa Gauge (psig)				
Fuel Inlet Temperature	°C (°F)				

Attachment 1B: Liquid Fuel Questionnaire

The Liquid Fuel Questionnaire should be completed whenever a possible new liquid fuel may be used with the Capstone MicroTurbine. The Liquid Fuel Questionnaire is detailed in the following tables.

- ❑ Table A: Fuel Questionnaire – Liquid – General Customer Information
- ❑ Table B: Fuel Questionnaire – Liquid – Fuel Composition
- ❑ Table C: Fuel Questionnaire – Liquid – Fuel Properties
- ❑ Table D: Fuel Questionnaire – Liquid – Fuel Contaminants
- ❑ Table E: Fuel Questionnaire – Liquid – Fuel Supply Inlet Conditions

Table A presents a liquid fuel questionnaire detailing the general customer information.

Table A. Fuel Questionnaire – Liquid – Customer Information

Item	Customer Information
Customer Name	
Street Address	
State and Country	
Phone Number	
Facsimile Number	
E-Mail Address	
Engineering Contact	
Engineering Contact	
Other Data	
Other Data	
Other Data	
Date	

Table B presents a liquid fuel questionnaire detailing fuel composition.

Table B: Fuel Questionnaire – Liquid – Fuel Composition

Component	Quantity	Nominal	Maximum	Minimum	Test Method (or Equivalent)
	%				
	%				
	%				
	%				
	%				
	%				
	%				

Table C presents a liquid fuel questionnaire detailing the fuel's physical and chemical properties.

Table C: Fuel Questionnaire – Liquid – Fuel Properties

Property	Units	Nominal	Maximum	Minimum	Test Method (or Equivalent)
Kinematic Viscosity @ 0 °C (32 °F)	Centistokes				ASTM D445
Kinematic Viscosity @ 40 °C (104 °F)	Centistokes				ASTM D445
Specific Gravity	@ 20 °C (68 °F)				ASTM D1298
Cloud Point	°C (°F)				ASTM D2500
Pour Point	°C (°F)				ASTM D97
Flash Point	°C (°F)				ASTM D93
Calorific Value	MJ/kg (Btu/lbm)				ASTM D240
Calorific Value Variation	%				ASTM D240
Vapor Pressure	kPa absolute				ASTM D323
Distillation, Initial	°C (°F)				ASTM D86
Distillation, 10%	°C (°F)				ASTM D86
Distillation, 50%	°C (°F)				ASTM D86
Distillation, 90%	°C (°F)				ASTM D86
Distillation, Final	°C (°F)				ASTM D86
Other	(Identify)				-----
Other	(Identify)				-----

Table D presents a liquid fuel questionnaire detailing the fuel contaminants.

Table D: Fuel Questionnaire – Liquid – Fuel Contaminants

Contaminant	Units	Nominal	Maximum	Minimum	Test Method (or Equivalent)
Water (free) @ 20 °C (68 °F)	% Mass				ASTM D2709
Particulate Size	Micron				ASTM D2276
Particulate Quantity	ppm mass				ASTM D2276
Sulfur	ppm mass				ASTM D129
Chlorine	ppm mass				TBD
Fluorine	ppm mass				TBD
Ash	ppm mass				ASTM D482
Sodium plus Potassium	ppm mass				ASTM D3605
Vanadium	ppm mass				ASTM D3605
Calcium	ppm mass				ASTM D3605
Lead	ppm mass				ASTM D3605
All Other Contaminants					
Copper Strip	ppm mass				-----
pH	(Identify)				TBD

Table E presents a liquid fuel questionnaire detailing the inlet fuel supply conditions.

Table E: Fuel Questionnaire – Liquid – Fuel Supply Inlet Conditions

Condition	Units	Nominal	Maximum	Minimum	Test Method (or Equivalent)
Fuel Inlet Pressure	kPa Gauge (psig)				
Fuel Inlet Temperature	°C (°F)				

Notes and Related Information